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Managing Mixed Stands: Reassessing a Forgotten Stand Type in the Southeastern United States

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Abstract: Forestry in the Southeastern United States has long focused on converting natural stands into pine plantations or managing exclusively for hardwoods. Little consideration has been given to managing stands containing pine and hardwood mixtures, as these stands were considered inferior in terms of productivity and/or quality. Recent declines in small-diameter softwood markets and logging workforce have, however, begun to stress the traditional pine production model in some locations, raising interest in management alternatives. Here, we provide biological, economic, and sociocultural rationale for pine-hardwood mixtures as an alternative strategy for landowners with multiple management objectives. To support this idea, an illustration compares a mixed-species plantation to pine and hardwood monocultures under a variety of simulated scenarios to demonstrate growth potential and economic and biological resilience. Moreover, to identify scenarios where managing pine-hardwood mixtures would be most appropriate, and to help conceptualize landowner interest in mixed stands, we present a guide combining biological, economic, and sociocultural factors that we anticipate influencing the adoption of mixed-stand management. The aim of this conceptual paper is not to suggest that mixed-species stand management should become the dominant management paradigm; rather, we seek to encourage researchers and land managers to consider it as part of the broader silvicultural toolbox.

Keywords: pine–hardwood mixtures; mixed-stand management; economic risk; pine silviculture; forest management

1. Introduction

Increasing the productivity of economically valued species is often an objective in managed forest ecosystems throughout the world. In the Southeastern United States, pine plantations have become one of the most recognizable symbols of forest management [1]. Much of the success of pine plantations can be attributed to their logistical simplicity, silvicultural advancements, and the existence of a vibrant pulp industry [2]. While plantation management continues to be an attractive management strategy to many landowners, changing social, biological, and economic conditions are making pine plantations more difficult to implement or maintain in some locations. This paper advances mixed-stand management (stands regenerated naturally or artificially containing pine and hardwood components) (MSM) as an alternative strategy for land managers to consider when pine plantation management is no longer economically feasible or when broader sets of ecosystem services are desired [3]. As a conceptual article, we propose a variety of interdisciplinary justifications and an economic illustration to encourage land managers to consider MSM as a management option in the Southeastern United States. We acknowledge that MSM will not be the optimal strategy in all scenarios, and that few studies have explored mixed-stand dynamics in the Southeastern United States. As such, a second objective is to encourage future research into this overlooked stand type.

2. Biological Rationale

2.1. Benefits of Mixed Stands

Choosing a management strategy creates trade-offs in ecosystem services and functional responses. Innovations in seedling production, competition control, and fertilization, combined with genetic improvements, have increased the productive capacity of pine plantations in the Southeast, representing a silvicultural success story [1,4]. However, due to a reliance on a single species, pine plantations are susceptible to damage from genera-specific pests, such as southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) or volatility in softwood markets [3,5,6]. Concomitantly, ongoing weakness in small-diameter softwood markets in some locations may indirectly magnify the risk of insect outbreaks in the future if a reduction in stumpage prices or logging capacity makes silvicultural practices economically unattractive or logistically infeasible [7–9]. In addition, projected increases in frequency and intensity of drought and precipitation events (IPCC 2014) may further increase the risk of insect outbreaks at local scales [10,11].

Implementing MSM would help reduce risk to SPB and other native insects and diseases that affect pine by reducing pine continuity within stands and at the landscape scale. Depending on the species mixture, MSM could also present a more resilient stand to wind events as a result of increasing canopy structural diversity and decreasing the density of loblolly pine (*Pinus taeda* L.), which have relatively shallow rooting depth [12–17]. Thus, MSM could be an attractive strategy for risk mitigation.

The advantages of practicing MSM may also extend to productivity [18–21]. Increases in productivity can occur if the presence of one species facilitates growth of another through increasing availability of a limiting resource [22,23], decreasing environmental stress [24], or reducing pest attacks [25]. Productivity within mixtures can also benefit from complimentary resource use via differences in crown architecture, phenology, shade tolerance, rooting zone utilization, or mycorrhizal associations [25–32]. Finally, productivity can increase when intra-specific competition for resources is greater than inter-specific competition, resulting in improved growth of the dominant species [21,33]. Although studies examining these relationships among southeastern United States species are not currently available, there is little reason to believe that mixtures could not be designed to improve productivity in a region where nitrogen and phosphorous deficiencies, harsh climatic conditions, and cyclic insect outbreaks are common.

2.2. Managing Mixed Stands

Mixed stands are commonly found on upland sites as an intermediate successional stage between pine and hardwood dominance. However, operational knowledge of how to manage mixed-stand dynamics in the Southeastern United States has been neglected because of the expectation of lower economic returns [34]. Considerably more effort has been given to expediting succession of mixed stands to hardwood dominance on productive sites or resetting succession and establishing pine plantations using herbicides and other cultural methods [35,36].

Despite the lack of directed studies, knowledge gains in herbicide application in monocultures, combined with knowledge of species life history traits, can help inform MSM. Silvicultural capacity to selectively alter species composition through herbicide applications exists. Chemical site preparation is often considered necessary to establish pine plantations, but regeneration attempts involving hardwood species typically do not require herbicide applications unless noxious woody or broadleaf weed species are present [37]. Some research has indicated that carefully applied herbaceous weed control using sulfometuron methyl is beneficial regarding both pine and hardwood seedling survival and growth [38,39]. In addition, various herbicides have been used to perform individual stem treatments for removal of undesirable species, resulting in very little non-target impact and growth of residual trees [40–42]. The challenge of stem injection arises in the economic feasibility of high stem density conditions when large numbers of undesired stems are present.

Gains in our understanding of forest fuels and trees' strategies to survive within a fire regime can help with implementing prescribed fire within MSM [43–46]. Bark thickness has long-been recognized as an important trait for resisting cambial death during prescribed fire [47,48]. For example, studies exploring prescribed fire within mixed stands demonstrated that prescribed fire can help regenerate pine-oak mixtures [49], inhibit small hardwood competition on pine seedlings [50], and accelerate self-thinning among small pines (>10 cm Diameter at Breast Height (DBH) [51]. A number of studies examining oak (*Quercus* spp.) regeneration have shown fire sensitivity decreases with increasing stem size [52–54]. Strong sprouting responses to prescribed fire can be expected from species that store large amounts of carbohydrates in their roots such as oak, hickory (*Carya* spp.), and red maple (*Acer rubrum* L.), or that sucker, such as sweetgum (*Liquidambar styraciflua* L.) [55–57]. Sprouting also tends to be promoted more consistently in dormant-season burns [55,58]. Alternatively, prescribed fire has not been shown to be effective at controlling larger advanced regeneration of mesophytic species [54,57,59] In short, while questions regarding the use of prescribed fire in mixed stands remain, research demonstrates that prescribed fire is capable of altering species composition early in stand development, prior to sprouting species gaining sufficient size to escape the effective range of prescribed fire [60].

Although an increase in management complexity is a concern associated with MSM [34], maintenance of complex stand structures, multiple-age classes, or a broad range of species may not be necessary. Even-aged, mixed-species plantations (consisting of at least one pine and one hardwood) may provide a compromise between minimizing management complexity, maintaining productivity, and achieving resilience to SPB. An example of such a mixture may be achieved with loblolly pine (*Pinus taeda* L.) and sweetgum. Each species has a similar intolerance of shade, relatively high growth potential [61], but opposing degrees of susceptibility to SPB.

3. Economic Rationale

A key reason MSM has been ignored as a management option in the Southeastern United States is because land managers have expressed concern over the economic feasibility of such practices when compared to monocultures [62,63], although this may be due in part to a dearth of experimental trials comparing monoculture plantations with mixed species alternatives [64]. To our knowledge, there is little published research pertaining to economic considerations of choosing MSM in the Southeastern United States [65–68], although research for European forests is more abundant, as are those in other parts of the world [68–76]. Reference [64] reports that several studies found increased yields from mixed-species plantings. However, caution should be taken as these studies only examined mixing Eucalyptus (*Eucalyptus* spp.) with a nitrogen fixing species. The increased yields of those studies are promising but may not be representative of results from admixing other combinations. Two studies, [77] and [78], discussed findings related to stumpage prices; however, there was little economic justification for the discussion because financial analysis was beyond the scope of the research. Reference [36] suggested that small, non-industrial landowners may be willing to sacrifice yields if other values are desired. These non-timber values may be particularly attractive if site conditions are not conducive to producing yields necessary to make pine planting a superior option. Further, [62,63] noted that although yield benefits will likely be reduced under a mixed regime, comparing biological and financial risks of mixed versus monocultures (as discussed above) may put the two approaches on more equal financial footing.

Reflecting this, [63,69,74] argue that risk-averse individuals would prefer mixed-stand management, despite lower profitability. [69] used a bioeconomic modelling approach to simultaneously optimize tree species mixture in a two-species forest stand and a distribution of harvest activities over time. [62,63] used techniques often found in the finance literature, viewing mixed stands from the perspective of portfolio diversification, finding in all cases pure forests did not outperform mixed forests under various risk scenarios. In our conceptual rationale for MSM, we think of forest management in terms of a portfolio of benefits and risks may show effects of risk compensation similar to diversified portfolios of stocks. Thus, investing only in pine would increase investment volatility compared to a mixed-stand approach if prices are unstable or if prices at harvest are different from those assumed at stand establishment. Even if such variables are accounted for in an economic analysis, they still lack risk preferences of the timberland owner. In other words, while the risks of a particular decision are taken into account, that individual's tolerance for different levels of risk would still be missing in modeling assumptions [23,68,79]. Reference [80] provides a thorough treatment on the economics of mixed forests.

4. Illustration: Mixed-Plantation Stand Resilience Compared to Monocultures

To reinforce a conceptual justification for the advancement of MSM, we provide an economic illustration comparing monocultures to mixed plantations. Specifically, to highlight the risk-aversion rationale, the illustration incorporates a severe insect outbreak. We report two scenarios that consistently show smaller losses, both in terms of volumes and financial losses, when the stands suffer heavy mortality losses (Table 1). These scenarios are intended to provide a conceptual demonstration of mixed stands response to common management practices compared to pure stands; more comprehensive analyses of stand density management conducted across a wider array of site conditions will be necessary to provide a more robust comparison between mixed and pure stands affected by thinning decisions and insect damage. Data for this illustration consisted of modeled yields (using forest vegetation simulator, USDA Forest 161 Service) of loblolly pine and sweetgum measured at age 9 in monoculture or mixed plantations [81]. A detailed description of the site, silvicultural practices utilized, and underlying assumptions and cash flow activities can be found in supplemental methods and Table S1.

Table 1. Net present value (NPV), land expectation value (LEV), and internal rate of return (IRR) at a 8% interest rate for a 30-year rotation in response to species selection treatments at a site in north central Louisiana.

Treatment	NPV	LEV	IRR
If Sweetgum CNS is Sold for Small Sawtimber			
Sweetgum Only	–$114.97	–127.65	5.41%
Pine Only	$321.84	357.35	14.06%
Both, No preference for thin	$85.37	94.79	9.67%
Pine+sweetgum with pine thinned completely	$121.24	134.62	10.94%
Pine+sweetgum with sweetgum thinned completely	$102.35	113.65	9.98%
If 30% mortality is included for bug kill			
Sweetgum Only	–$135.83	–150.81	4.64%
Pine Only	$256.89	285.24	13.50%
Both, No Preference for Thin (30% for Pine)	$54.36	60.36	9.16%
Both, No Preference for Thin (30% for Gum)	$71.05	78.89	9.44%

In the first scenario, we assumed that no atypical mortality occurs in any of the stands. These stands included pine only, sweetgum only, and mixed plantations of pine and sweetgum; tree dimension and site data from plots from three stands of each type were used as inputs in forest vegetation simulator. The simulations included a 50% mix of pine and gum with no preference at thinning, a 50% mix with all of the pine harvested at age 15, and a 50% mix with all of the gum harvested at age 15. The final harvest age was 30 years for all stand types. The sweetgum treatment resulted in a negative net present value (NPV), while all the others met the hurdle rate of 8% (nominal). The pine treatment outperformed all other mixed-plantations as well, with the mixed-plantation with pine thinned completely at age 15 showing the best financial performance amongst the alternatives (internal rate of return (IRR) of 14.06% and 10.94%, respectively). Among the thinning scenarios tested for mixed plantations (thinning for spacing irrespective of species, removing all sweetgum in thinning, removing all pine in thinning), thinning pine completely at age 15 had superior financial performance. Thinning all pine in the mixed plantations had the highest NPV, land expectation value (LEV), and IRR among the mixed-plantation scenarios because there was a substantial proportion of higher-valued chip-and-saw (CNS) within the thinning not observed for the other thinning techniques.

In the second scenario, we modeled 30% mortality (occurring at age 25) to simulate the consequences of insect damage occurring in clusters of the stand and the recovery capacity of loblolly pine and sweetgum as pure and mixed stands. This delayed mortality event was simulated because by this stage of stand development, tree stress increases from competition as canopy closure re-occurs, leaving stands more vulnerable to insect damage. The delayed timing of the mortality event would also affect larger, more valuable trees. The insect damage simulations consisted of 30% mortality occurring within sweetgum-only, pine-only, and sweetgum–pine mixture that had been thinned with no species preference. We selected the sweetgum-pine mixture with no species preference at thinning because it was the only mixed-stand scenario that would have both species present by age 25. To best simulate insect-related mortality, we chose clusters and simulated the mortality event occurring in the stand at 25 years of age, with mortality occurring within clusters of the stand preferentially affecting smaller-diameter (suppressed) trees.

While pine monocultures still outperformed mixed-plantations and sweetgum monocultures, the financial loss in mixed-plantations was smaller in percentage terms, indicating a reduction in risk exposure in mixed plantations regardless of scenario. While financial losses to pine monocultures were 20% (using LEV), losses of mixed plantations ranged from 17% to 36% using the same financial metric. Further, the volume losses in the mixed plantations were lower than either monoculture (10–16% for mixed plantations and 20% for both pine and sweetgum monocultures). A caveat in these results was the absence of sweetgum sawtimber in the scenarios at 30 years, as only CNS-sized product was available for harvest according to the forest vegetation simulator. This yield trend gave stands with pine sawtimber at 30 years a distinct advantage, and it is possible the gap between the mixed-plantation (as well as sweetgum monoculture) and the pine monoculture would be smaller on a longer rotation This, however, will be tempered by the establishment costs for sweetgum, which are approximately twice that of pine establishment in our simulations.

This case study illustrates several facets of MSM. The mixed plantation was comprised of an even proportion of loblolly pine and sweetgum at establishment. If there were no markets for larger diameter trees for either species and each was removed (pine in one case and sweetgum in the other) entirely during thinning at mid-rotation, financial performance was higher than the mixed plantations with no preference at thinning. This trend was due to larger revenues at thinning age, which, once compounded to year 30, gave higher financial returns despite the smallest amounts of sawtimber among the mixed treatments. This trend allows the landowner response flexibility to market conditions at thinning age and allows for reduced competition and lower mortality loss from insect-induced mortality as individual-tree stress is reduced, despite sacrifices in volume. In regions where markets may incentivize removal of a species during thinning, the proportion of each species planted and planting density should be adjusted to favor a sufficient number of trees of the species that will be carried longer into the rotation.

Although these results do not favor mixed stands over monocultures, in terms of pure financial returns, losses sustained (due to introduced mortality) in the MSM stands were lower than in the monocultures (both pine and sweetgum). The reader should keep in mind that we are merely attempting to show that mixed stands, in some cases, can be more resilient than monocultures. However, this is only an illustration and is not meant to be an exhaustive examination of alternative scenarios and levels of variable sophistication.

5. Sociocultural Rationale

Besides biological and economic considerations, demographic and ownership factors may indicate whether landowners prefer MSM to pine plantation management. Preferences may be linked to changing values, attitudes, and behaviors of forest landowners as forestland is transferred to new generations and as the United States population continues to move from rural to urban areas [82]. For example, research has shown that urban residents have different values and attitudes towards forests than rural residents, with place attachment, early life experiences, and extent of outdoor activity as major influences [83–85]. Urban populations tend to have more concerns about ecological qualities, while rural populations are expected to be more concerned with production values [86]. However, in general, rural populations are more likely to act according to their attitudes about forests than urban populations [87].

Forest landowner characteristics have remained stable through the last several decades. According to the 2013 national woodland owner survey (NWOS), most southeasternforest landowners have graduated high school, while nearly a quarter have a bachelor's degree. Notably, southeastern forest landowners tend to be older than the general population. The average age of Americans 25 or older is 49 years, compared to 60 years for forest landowners [88]. In addition, the vast majority of southeastern forest landowners are male—only 32 percent are female—1 and have a household income between $50,000 and $100,000. Most NWOS survey participants were white with only five percent African American, the next largest group by race. They have owned their land between 10 and 50 years; the majority (57%) acquired their land through purchase, while 38% inherited the land. Around 47% had joint ownership between spouses and 34%, the next largest group, have individual ownership. Only 12% own their land as a family partnership.

According to the NWOS, forest landowners own land to pass it on to heirs, to enjoy beauty, and to protect wildlife. This and other research over several decades dispel the myth that forest landowners are motivated solely by economic returns through timber harvesting [89–91]. In fact, managing land for timber was the fifth most likely reason for owning forest land in the Southeastern United States according to the latest NWOS. Regarding future activities, almost 17% of respondents said they intended to improve wildlife habitat. The next highest percentage (10%) NWOS intended to reduce fire risks, followed by 10% planning to cut/remove trees for personal use. The lowest percentage (6%) said they intended to harvest trees for sale and only 13% had a management plan. Finally, most (almost 10%) landowners were concerned about trespassing or poaching on their land, while wildfire, unwanted insects/diseases, extreme weather, development, animal damage, and climate change were concerns expressed by less than 8.5% of respondents.

Landowners' decisions about management approaches are influenced by site limitations, including parcel size and site quality characteristics. Most southeastern forest landowners owned between 20 and 50 acres. Over the past 30 years, forest landowners have typically owned smaller parcels of land and have become less likely to engage in forest management practices [91,92]. Shrinking parcel sizes caused by forest parcelization (driven by gifting, selling, or urbanizing landscapes) is a major limitation to traditional forest management because as tract sizes shrink, so do the economies of scale [88,93]. The economic viability of forest operations like site preparation, planting, and harvesting become increasingly difficult, unavailable, or costly. This trend is made worse as small logging operations have been pushed out of the market and replaced by increasingly larger operations unsuited for working smaller acreages [94].

The 2013 NWOS found that only about 11% of landowners harvested trees to sell. Even fewer landowners were engaged in other harvesting practices (e.g., nontimber forest products, wood chips). Besides economies of scale, the association between parcel size and management intensity is influenced by available capital with greater accumulated capital more likely among landowners with large tracts than those with small tracts [95,96]. Capital impacts traditional forest management activities (e.g., site preparation, planting, prescribed fire), which are costly and provide economic benefits that may not be realized for decades. Access to federally funded programs, which are aimed at offsetting management expenses, are also related to parcel size with recipients of most cost share programs tending to be traditional timber-oriented owners with higher incomes and larger acreages [97]. By contrast, MSM may appeal to landowners with smaller tracts who are less willing to invest in capital-intensive management and less interested in growing timber solely for profit.

MSM does not represent the optimal management approach for all forest landowners. A variety of decision factors influence forest landowners' planning for the future of their forestland. For example, besides the biological and economic considerations discussed above, the landowner may want to avoid risks associated with activities such as prescribed fire. Limited knowledge is also a constraint among management professionals as well as landowners; therefore, stakeholders will have to become more familiar with MSM before adoption. Certain types of forest landowners' will employ MSM while others will determine the approach as unsuitable to their management objectives, land management values, attitudes, and knowledge, risk perceptions, economic constraints, and site limitations. However, MSM may engage some landowners who would otherwise exclude themselves from forest management. The challenge for natural resource managers and educators is to identify forest landowners receptive to learning about MSM as one option among many management approaches that they can choose.

6. Conceptual Guide Illustrating MSM Suitability

We present a conceptual guide to illustrate the interplay between landowner characteristics and biological and economic conditions that may contribute to MSM suitability for landowners. This guide is intended to help organize attributes discussed in our conceptual rational into groups with similar characteristics [98]. Thus, the guide allows identification of several types of landowners that contain similar characteristics such as parcel size, ownership objectives, site conditions, and risk/profit orientation. Biological, economic, and landowner factors are considered together to develop a continuum of landowners at varying levels of likelihood to participate in MSM. Again, it is important to note that the ideas in this guide are derived from information presented in previous sections of this article outlining a broad literature base for MSM, not on primary data, which is beyond the scope of this article. Table 2 is a non-exhaustive summary of potential factors associated with MSM landowner types.

Table 2. Possible factors* associated with adoption of mixed-stand management (MSM).

Factors	Biological	Economic	Landowner
	Site quality	*Mill diversity*	*Ownership objectives*
	Stand age	*Mill proximity*	*Production orientation*
	Prescribed fire	*Market diversity*	*Parcel size*
	Invasive species	Leasing opportunities	Absenteeism
			Urban-rural values
			Ownership tenure
			Education
			Race
			Age
			Gender

* Key factors considered in the conceptual guide and illustrated in the following figures are denoted by italics.

7. Biological Factors

As primary biological influences impacting participation in MSM, we present site quality, stand age, and the ability to apply prescribed fire (Figure 1). Stands featuring a lower site index represent better opportunities to practice MSM due to potential for enhanced productivity on lower-quality sites [99]. Conversely, higher-quality sites are likely ill-suited for MSM, due to loss of productivity that could otherwise be achieved with a pine plantation. Stand age will influence the types of species mixtures that can be achieved with minimal management investment. Stands that are in early-to-mid successional stages of development are more likely to contain a pine component and an early successional hardwood species, from which a rapidly growing species mixture can be developed through natural regeneration. In contrast, at the other end of the gradient, late successional, hardwood-dominated stands will require time and extensive silvicultural intervention to reintroduce pine into the species mixture. Limitations on silvicultural options will also influence the applicability of MSM. Stands that have few limitations on prescribed burning will be most favorable for MSM, as prescribed fire can be used to prepare a seedbed for conifer regeneration and altering species composition. Alternatively, maintaining desirable species mixtures without the use of prescribed fire will likely require herbicide applications. Established populations of stress-tolerant, frequently seeding invasive species, such as Chinese tallow (*Triadica sebifera* L. (Small)), may also make MSM challenging, as species mixtures will become increasingly dominated by undesirable species [100].

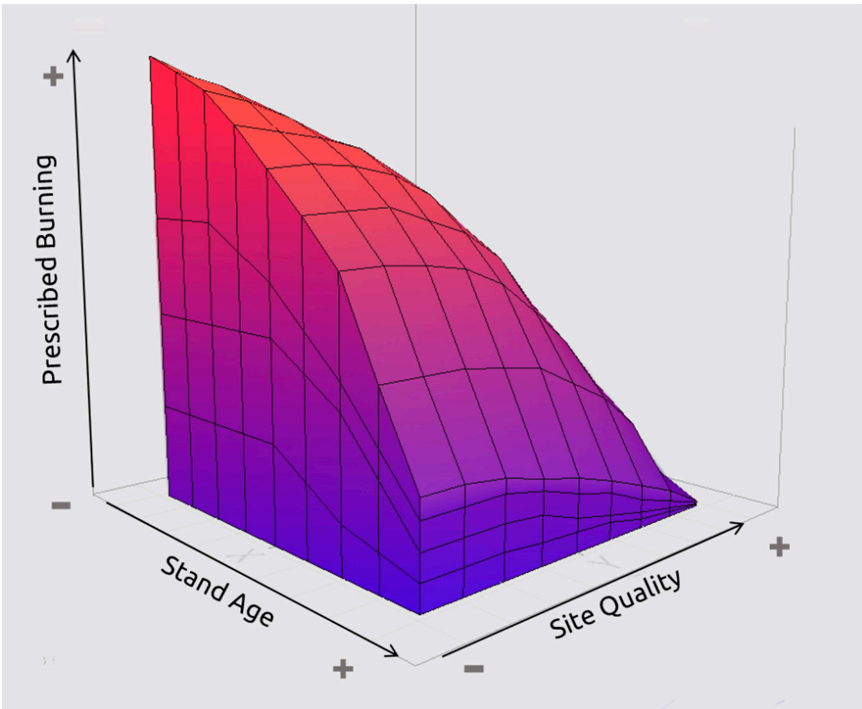

Figure 1. Illustration of biological factors influencing landowner participation in MSM. Areas on the diagram in red represent biological conditions where MSM could provide a viable management alternative, while areas in purple represent areas where adopting MSM is less favorable. Plus signs indicate an increase in site quality, stand age, and the ability to apply prescribed fire as a silvicultural tool. Minus signs indicate a decrease in site quality, stand age, and ability to apply prescribed fire as a silvicultural tool.

In most situations, the applicability of MSM will be determined by more than just the effects of a single factor. For example, a stand that has mid-successional, pine–hardwood mixture on a lower quality site may be unsuitable for MSM if the use of prescribed fire is limited (Figure 1), as maintaining the mixture may be unsustainable. Conversely, a stand with the same species mixture on a moderate site index with few burning restrictions may be conducive for practicing MSM (Figure 1).

8. Economic Factors

Figure 2 represents favorable economic conditions driving landowner adoption of MSM. Mill diversity is important, as some mills within proximity of the property may accept only pine sawtimber, which would constrain the economically minded landowner from growing hardwood forest products. A greater diversity of mills helps ensure that product demand exists. Even if the mill is appropriate, it must be within an economically viable distance for transportation. Further, where mill options are sufficient, there tend to be loggers who can harvest and transport the trees. In some cases, neither mills nor loggers may be within reasonable proximity. Local and extra-local markets are an important influence as well. Local markets include nearby mills as well as regional housing markets and other outlets for products. Forestry is influenced by global market fluctuations, including competition from South America, Russia, and Asia. Price fluctuations associated with local and global markets will influence whether or not a landowner decides to take risks associated with investment in management of MSM stand or pine plantations.

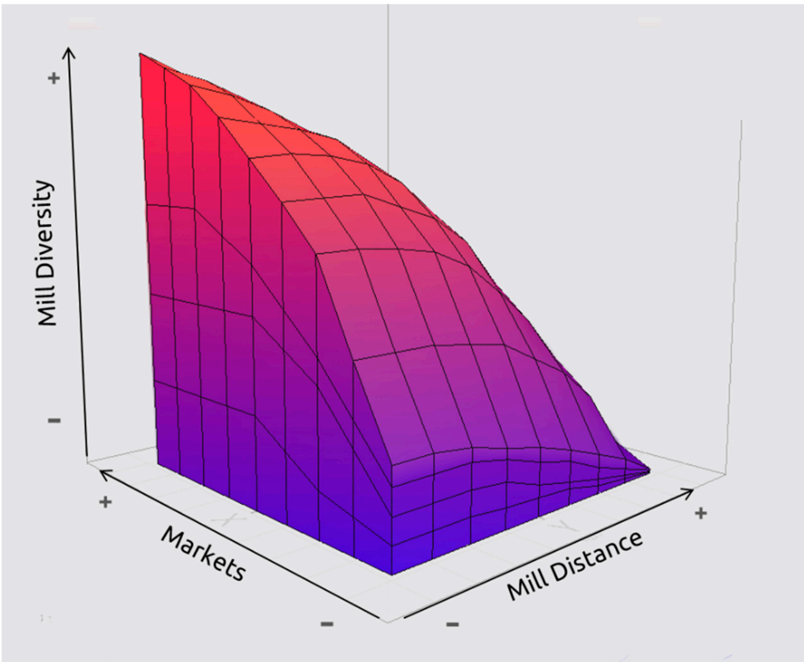

Figure 2. Illustration of economic factors influencing landowner participation in MSM. Areas on the diagram in red represent a combination of economic conditions conducive for MSM, while areas in purple represent a combination of factors where MSM is unlikely to be a viable management option. Plus signs indicate an increase in distance to nearest mill, number of local markets, and diversity of products sought by local mills. Minus signs indicate a decrease in distance to nearest mill, number of local markets, and diversity of products sought by local mills.

Interactions occur among these three economic conditions. For example, a strong global demand for structural timbers will drive local mill consumption for softwood and hardwood products. Meanwhile, mill diversity within economically feasible transportation distances to timber supply will address the demand by processing local products. Together, these conditions represent an economy conducive to landowners adopting MSM if they have pine and hardwoods on their property.

9. Landowner Characteristics

The literature describes demographic factors such as age and gender as well as landowner objectives as important factors in management decisions. For example, an owner most interested in protecting nature may be more inclined to MSM than an owner who focuses on regular revenue generation. Production orientation, or profit-seeking motive, is a landowner characteristic that interacts with ownership objectives to manage pine, hardwoods, wildlife, and the many other reasons landowners own forests. Parcel size is a key factor, as small parcels are less appropriate for extensive timber management activities and investments. The landowner's frequency of visitation to their property influences their involvement in management activities. Absentee owners are often less likely to manage intensively. Similarly, landowners who live in urban and suburban places may be less hands-on in management activities than those who live on their property. Urban-based owners, with corresponding values and interests, may be more willing to attempt MSM than rural landowners. MSM might also be more attractive to owners who are just beginning their involvement in forest management.

We expect the primary landowner factors influencing participation in MSM to be parcel size, production orientation, and ownership objectives (Figure 3). For example, an owner has their primary objective of passing forestland to heirs, while selling timber is the least important objective. In addition, the property is less than 40 acres, making it difficult to market a pine plantation. Finally, the landowner is not interested in investing in forest productivity such as purchasing improved seedlings and paying for site preparation. This individual may be more likely to adopt MSM.

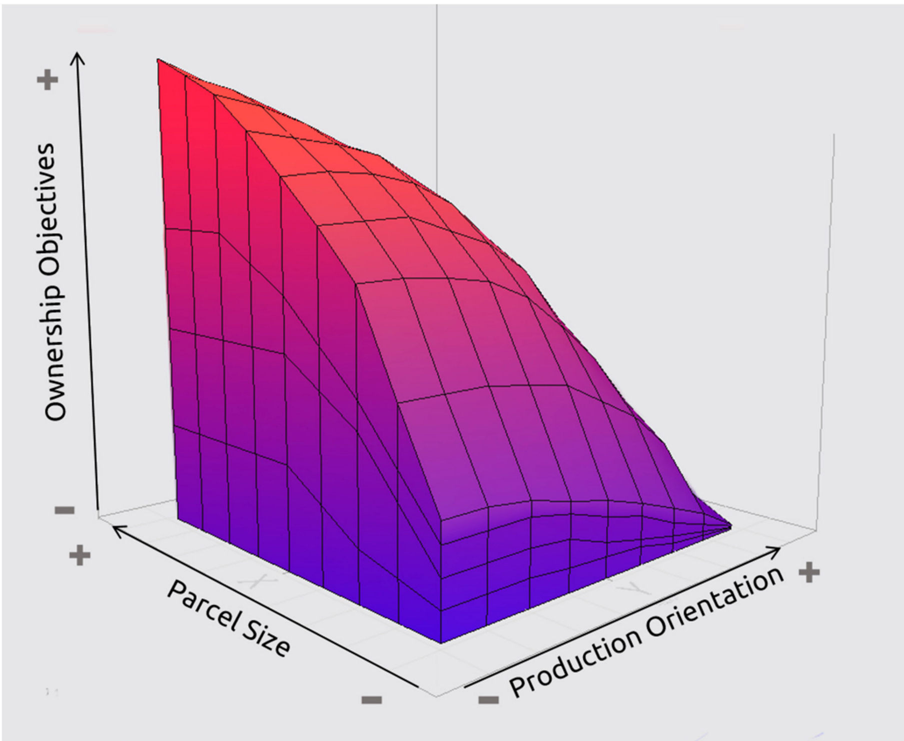

Figure 3. Illustration of landowner characteristics influencing landowner participation in MSM. Areas on the diagram in red represent a combination of characteristics conducive for adopting MSM, while areas in purple represent a combination of characteristics that dissuade practicing MSM. Plus signs indicate an increase in a landowners production orientation, parcel size, and number of ownership objectives. Minus signs indicate a decrease in landowner production orientation, parcel size, and number of ownership objectives.

10. Conclusions

The rationale and illustrations advanced in this manuscript were developed to illustrate the potential of practicing mixed-stand management in the Southeastern United States. However, the underlying rationale likely applies to other locations where species-diverse stands have been replaced by monocultures. The traditional pine production model in the Southeastern United States has been an effective management strategy for decades. However, changes in market conditions landowner attitudes, and a greater appreciation for ecosystem resilience has raised concerns about plantation management. Based on the biological, economic, and sociocultural rationale advanced in this manuscript, we believe that MSM may provide an attractive alternative management strategy for landowners that have a broader suite of ownership objectives. Moreover, as demonstrated by our mixed-plantation illustration, increasing species diversity even by one species can be an effective strategy for reducing risk to genera-specific disturbance agents. We acknowledge that MSM will not be appropriate in all situations, and that our silvicultural understanding of mixed-stand dynamics lags behind our knowledge of pine plantations. Nevertheless, we do not think these limitations should stop land managers from considering MSM as part of a broader silvicultural strategy when managing for a broad set of ecosystem services is the goal.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/10/9/751/s1; Table S1: Cash Flow Assumptions and Cash Flow Activities.

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References

1. Fox, T.R.; Jokela, E.J.; Allen, H.L. The development of pine plantation silviculture in the southern United States. *J. For.* **2007**, *105*, 337–347.
2. Carter, M.C.; Kellison, R.C.; Wallinger, R.S. *Forestry in the U.S. South: A History*; LSU Press: Baton Rouge, LA, USA, 2015; p. 386.
3. Kelty, M.J. The role of species mixtures in plantation forestry. *For. Ecol. Manag.* **2006**, *233*, 195–204. [CrossRef]
4. Allen, H.L.; Fox, T.R.; Campbell, R.G. What is Ahead for Intensive Pine Plantation Silviculture in the South? *South. J. Appl. For.* **2005**, *29*, 62–69. [CrossRef]
5. Jactel, H.; Brockerhoff, E.G. Tree diversity reduces herbivory by forest insects. *Ecol. Lett.* **2007**, *10*, 835–848. [CrossRef] [PubMed]
6. Asaro, C.; Nowak, J.T.; Elledge, A. Why have southern pine beetle outbreaks declined in the southeastern U.S. with the expansion of intensive pine silviculture? A brief review of hypotheses. *For. Ecol. Manag.* **2017**, *391*, 338–348. [CrossRef]
7. Guldin, J.M. Silvicultural considerations in managing southern pine stands in the context of southern pine beetle. In *Southern Pine Beetle II*; General Technical Report SRS-140; Coulson, R.N., Klepzig, K.D., Eds.; US Department of Agriculture, Forest Service, Southern Research Station: Asheville, NC, USA, 2011; pp. 317–352.
8. Clarke, S.R.; Riggins, J.J.; Stephen, F.M. Forest Management and Southern Pine Beetle Outbreaks: A Historical Perspective. *For. Sci.* **2016**, *62*, 166–180.
9. Field, C.B.; Barros, V.R.; Mastrandrea, M.D.; Mach, K.J.; Abdrabo, M.K.; Adger, N.; Anokhin, Y.; Anisimov, O.; Arent, D.; Barnett, J. Summary for policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*; Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2014; pp. 1–32.

10. Kalkstein, L.S. An improved technique to evaluate climate-southern pine beetle relationships. *For. Sci.* **1981**, *27*, 579–589.
11. Duehl, A.J.; Koch, F.H.; Hain, F.P. Southern pine beetle regional outbreaks modeled on landscape, climate and infestation history. *For. Ecol. Manag.* **2011**, *261*, 473–479. [CrossRef]
12. Needham, T.; Kershaw, J.A., Jr.; MacLean, D.A.; Su, Q. Effects of mixed stand management to reduce impacts of spruce budworm defoliation on balsam fir stand-level growth and yield. *North. J. Appl. For.* **1999**, *16*, 19–24. [CrossRef]
13. Pautasso, M.; Holdenrieder, O.; Stenlid, J. Susceptibility to Fungal Pathogens of Forests Differing in Tree Diversity. In *Forest Diversity and Function*; Springer Science and Business Media LLC: Berlin, Germany, 2005; Volume 176, pp. 263–289.
14. Jactel, H.; Nicoll, B.C.; Branco, M.; González-Olabarria, J.R.; Grodzki, W.; Långström, B.; Moreira, F.; Netherer, S.; Orazio, C.; Piou, D.; et al. The influences of forest stand management on biotic and abiotic risks of damage. *Ann. For. Sci.* **2009**, *66*, 701. [CrossRef]
15. Griess, V.C.; Knoke, T. Growth performance, windthrow, and insects: Meta-analyses of parameters influencing performance of mixed-species stands in boreal and northern temperate biomes. *Can. J. For. Res.* **2011**, *41*, 1141–1159.
16. Forrester, D.I. Transpiration and water-use efficiency in mixed-species forests versus monocultures: Effects of tree size, stand density and season. *Tree Physiol.* **2015**, *35*, 289–304. [CrossRef] [PubMed]
17. Jactel, H.; Bauhus, J.; Boberg, J.; Bonal, D.; Castagneyrol, B.; Gardiner, B.; Gonzalez-Olabarria, J.R.; Koricheva, J.; Meurisse, N.; Brockerhoff, E.G. Tree Diversity Drives Forest Stand Resistance to Natural Disturbances. *Curr. For. Rep.* **2017**, *3*, 223–243.
18. Légaré, S.; Paré, D.; Bergeron, Y. The responses of black spruce growth to an increased proportion of aspen in mixed stands. *Can. J. For. Res.* **2004**, *34*, 405–416.
19. Pretzsch, H.; Schütze, G. Transgressive overyielding in mixed compared with pure stands of Norway spruce and European beech in Central Europe: Evidence on stand level and explanation on individual tree level. *Eur. J. For.* **2009**, *128*, 183–204.
20. Zhang, Y.; Chen, H.Y.H.; Reich, P.B. Forest productivity increases with evenness, species richness and trait variation: A global meta-analysis. *J. Ecol.* **2012**, *100*, 742–749. [CrossRef]
21. Tobner, C.M.; Paquette, A.; Gravel, D.; Reich, P.B.; Williams, L.J.; Messier, C. Functional identity is the main driver of diversity effects in young tree communities. *Ecol. Lett.* **2016**, *19*, 638–647. [PubMed]
22. Richards, A.E.; Forrester, D.I.; Bauhus, J.; Scherer-Lorenzen, M. The influence of mixed tree plantations on the nutrition of individual species: A review. *Tree Physiol.* **2010**, *30*, 1192–1208. [CrossRef]
23. Forrester, D.I. The spatial and temporal dynamics of species interactions in mixed-species forests: From pattern to process. *For. Ecol. Manag.* **2014**, *312*, 282–292. [CrossRef]
24. Pretzsch, H.; Bielak, K.; Block, J.; Bruchwald, A.; Dieler, J.; Ehrhart, H.P.; Zingg, A. Productivity of mixed versus pure stands of oak (Quercus petraea (M att.) L iebl. and (Quercus robur L.) and European beech (Fagus sylvatica L.) along an ecological gradient. *Eur. J. For. Res.* **2013**, *132*, 263–280.
25. Man, R.; Lieffers, V.J. Are mixtures of aspen and white spruce more productive than single species stands? *For. Chron.* **1999**, *75*, 505–513. [CrossRef]
26. Perry, D.A.; Bell, T.L.; Amaranthus, M.P.; Cannell, M.G.R.; Malcolm, D.C.; Robertson, P.A. Mycorrhizal fungi in mixed-species forests and other tales of positive feedback, redundancy and stability. In *The Ecology of Mixed-Species Stands of Trees*; England Blackwell Scientific Publications: Oxford, UK, 1992; pp. 151–179.
27. Morin, X.; Fahse, L.; Scherer-Lorenzen, M.; Bugmann, H. Tree species richness promotes productivity in temperate forests through strong complementarity between species. *Ecol. Lett.* **2011**, *14*, 1211–1219. [PubMed]
28. Brassard, B.W.; Chen, H.Y.; Bergeron, Y.; Paré, D. Differences in fine root productivity between mixed-and single-species stands. *Funct. Ecol.* **2011**, *25*, 238–246. [CrossRef]
29. Jucker, T.; Bouriaud, O.; Avacaritei, D.; Coomes, D.A. Stabilizing effects of diversity on aboveground wood production in forest ecosystems: Linking patterns and processes. *Ecol. Lett.* **2014**, *17*, 1560–1569. [CrossRef] [PubMed]
30. Jucker, T.; Bouriaud, O.; Coomes, D.A. Crown plasticity enables trees to optimize canopy packing in mixed-species forests. *Funct. Ecol.* **2015**, *29*, 1078–1086. [CrossRef]

31. Lu, H.; Mohren, G.M.; Ouden, J.D.; Goudiaby, V.; Sterck, F.J. Overyielding of temperate mixed forests occurs in evergreen–deciduous but not in deciduous–deciduous species mixtures over time in the Netherlands. *For. Ecol. Manag.* **2016**, *376*, 321–332. [CrossRef]
32. Williams, L.J.; Paquette, A.; Cavender-Bares, J.; Messier, C.; Reich, P.B. Spatial complementarity in tree crowns explains overyielding in species mixtures. *Nat. Ecol. Evol.* **2017**, *1*, 0063. [CrossRef] [PubMed]
33. Roscher, C.; Schumacher, J.; Gubsch, M.; Lipowsky, A.; Weigelt, A.; Buchmann, N.; Schmid, B.; Schulze, E.-D. Using Plant Functional Traits to Explain Diversity–Productivity Relationships. *PLoS ONE* **2012**, *7*, e36760. [CrossRef]
34. Sheffield, R.M.; Birch, T.W.; Leatherberry, E.C.; McWilliams, W.H. The pine-hardwood resource in the Eastern United States. In *Proceedings of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type, Atlanta, GA, USA, 18–19 April 1989*; General Technical Report SE-58; Waldrop, T.A., Ed.; US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: Asheville, NC, USA, 1989; pp. 9–19.
35. Grandy, D.L.; Kitchens, R.N. Oak-Pine. In *Silvicultural Systems of the Major Forest Types of the United States*; Agriculture Handbook 445; Burns, R.M., Ed.; US Department of Agriculture, Forest Service: Washington, DC, USA, 1983; pp. 172–173.
36. Leopold, B.D.; Weaver, G.H.; Cutler, J.D.; Warren, R.C. Pine-hardwood forests in north-central Mississippi: An ecological and economic perspective. In *Proceedings of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type, Atlanta, GA, USA, 18–19 April 1989*; General Technical Report SE-58; Waldrop, T.A., Ed.; US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: Asheville, NC, USA, 1989; pp. 211–222.
37. Self, A.B.; Ezell, A.W.; Londo, A.J.; Hodges, J.D.; Alkire, D.K. Effects of chemical site preparation on herbaceous vegetation prior to hardwood plantation establishment. In *Proceedings of 16th Biennial Southern Silviculture Research Conference, Charleston, SC, USA, 15–18 February, 2011*; General Technical Report SRS-156; Butnor, J.R., Ed.; US Department of Agriculture, Forest Service, Southern Research Station: Asheville, NC, USA, 2012; pp. 302–307.
38. Ezell, A.W.; Yeiser, J.L.; Nelson, L.R. Survival of Planted Oak Seedlings is Improved by Herbaceous Weed Control. *Weed Technol.* **2007**, *21*, 175–178. [CrossRef]
39. Self, A.; Ezell, A.; Rowe, D. Performance of Oak Seedlings Grown under Different Oust® XP Regimes. *Forests* **2014**, *5*, 1331–1340. [CrossRef]
40. Lockhard, B.R.; Hodges, J.D.; Gardiner, E.S. Response of Advance Cherrybark Oak Reproduction to Midstory Removal and Shoot Clipping. *South. J. Appl. For.* **2000**, *24*, 45–50. [CrossRef]
41. Peairs, S.E.; Ezell, A.W.; Belli, K.L.; Hodges, J.D. A comparison of oak regeneration conditions following midstory injection and partial overstory removal in a Tombigbee River terrace. In *Proceedings of 12th Biennial Southern Silviculture Research Conference, Biloxi, MS, USA, 24–28 February, 2003*; General Technical Report SRS-71; Connor, K., Ed.; US Department of Agriculture, Forest Service, Southern Research Station: Asheville, NC, USA, 2004; pp. 499–501.
42. Alkire, D.K.; Ezell, A.W.; Self, A.B.; Demarais, S.; Strickland, B.K. Efficacy of non-target impact of midstory injection in bottomland hardwoods. In *Proceedings of 16th Biennial Southern Silviculture Research Conference, Charleston, SC, USA, 15–18 February, 2011*; General Technical Report SRS-156; Butnor, J.R., Ed.; US Department of Agriculture, Forest Service, Southern Research Station: Asheville, NC, USA, 2012; pp. 3–6.
43. Kane, J.M.; Varner, J.M.; Hiers, J.K. The burning characteristics of southeastern oaks: Discriminating fire facilitators from fire impeders. *For. Ecol. Manag.* **2008**, *256*, 2039–2045.
44. Kreye, J.K.; Brewer, N.W.; Morgan, P.; Varner, J.M.; Smith, A.M.; Hoffman, C.M.; Ottmar, R.D. Fire behavior in masticated fuels: A review. *For. Ecol. Manag.* **2014**, *314*, 193–207. [CrossRef]
45. Varner, J.M.; Kane, J.M.; Kreye, J.K.; Engber, E. The Flammability of Forest and Woodland Litter: A Synthesis. *Curr. For. Rep.* **2015**, *1*, 91–99.
46. Schweitzer, C.J. Fire in Eastern North American Oak Ecosystems: Filling the Gaps. *Fire Ecol.* **2016**, *12*, 1–6.
47. Hare, R.C. Contribution of bark to fire resistance of southern trees. *J. For.* **1965**, *63*, 248–251.
48. Schafer, J.L.; Breslow, B.P.; Hohmann, M.G.; Hoffmann, W.A. Relative Bark Thickness is Correlated with Tree Species Distributions Along a Fire Frequency Gradient. *Fire Ecol.* **2015**, *11*, 74–87.
49. Phillips, D.R.; Abercrombie, J.A. Pine-Hardwood Mixtures—A New Concept in Regeneration. *South. J. Appl. For.* **1987**, *11*, 192–197. [CrossRef]

50. Clabo, D.C.; Clatterbuck, W.K. Site Preparation Techniques for the Establishment of Mixed Pine-Hardwood Stands: 22-Year Results. *For. Sci.* **2015**, *61*, 790–799.
51. Hammond, D.H.; Varner, J.M.; Fan, Z.; Kush, J.S. Long-term stand dynamics of old-growth mountain longleaf pine (Pinus palustris L.) woodlands. *For. Ecol. Manag.* **2016**, *364*, 154–164. [CrossRef]
52. Harmon, M.E. Survival of Trees After Low-Intensity Surface Fires In Great Smoky Mountains National Park. *Ecology* **1984**, *65*, 796–802. [CrossRef]
53. Hengst, G.E.; Dawson, J.O. Bark properties and fire resistance of selected tree species from the central hardwood region of North America. *Can. J. For. Res.* **1994**, *24*, 688–696. [CrossRef]
54. Keyser, T.L.; McDaniel, V.L.; Klein, R.N.; Drees, D.G.; Burton, J.A.; Forder, M.M. Short-term stem mortality of 10 deciduous broadleaved species following prescribed burning in upland forests of the Southern US. *Int. J. Wildland Fire* **2018**, *27*, 42. [CrossRef]
55. Brose, P.; Van Lear, D.; Cooper, R. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. *For. Ecol. Manag.* **1999**, *113*, 125–141. [CrossRef]
56. Simon, D.M. Repeated Application of Fuel Reduction Treatments in the Southern Appalachian Mountains, USA: Implications for Achieving Management Goals. *Fire Ecol.* **2016**, *12*, 28–47.
57. Wang, Y. Hardwood-Pine Mixedwoods Stand Dynamics Following Thinning and Prescribed Burning. *Fire Ecol.* **2016**, *12*, 85–104.
58. Robertson, K.M.; Hmielowski, T.L. Effects of fire frequency and season on resprouting of woody plants in southeastern US pine-grassland communities. *Oecologia* **2014**, *174*, 765–776. [CrossRef]
59. Reilly, M.J.; Outcalt, K.; O'Brien, J.J.; Wade, D. Effects of Repeated Growing Season Prescribed Fire on the Structure and Composition of Pine–Hardwood Forests in the Southeastern Piedmont, USA. *Forests* **2016**, *8*, 8. [CrossRef]
60. Grady, J.M.; Hoffmann, W.A. Caught in a fire trap: Recurring fire creates stable size equilibria in woody resprouters. *Ecology* **2012**, *93*, 2052–2060. [CrossRef]
61. Kormanik, P.P. Sweetgum. In *Silvics of North America 2, Agriculture Handbook 654*; Burns, R.M., Honkala, B.H., Eds.; US Department of Agriculture: Washington, DC, USA, 1990; Volume 2, pp. 400–405.
62. Knoke, T.; Stimm, B.; Ammer, C.; Moog, M. Mixed forests reconsidered: A forest economics contribution on an ecological concept. *For. Ecol. Manag.* **2005**, *213*, 102–116.
63. Knoke, T. Mixed forests and finance—Methodological approaches. *Ecol. Econ.* **2008**, *65*, 590–601.
64. Nichols, J.D.; Bristow, M.; Vanclay, J.K. Mixed-species plantations: Prospects and challenges. *For. Ecol. Manag.* **2006**, *233*, 383–390. [CrossRef]
65. Zhou, M.; Buongiorno, J. Forest landscape management in a stochastic environment, with an application to mixed loblolly pine–hardwood forests. *For. Ecol. Manag.* **2006**, *223*, 170–182. [CrossRef]
66. Zhou, M.; Buongiorno, J. Effects of stochastic interest rates in decision making under risk: A Markov decision process model for forest management. *For. Policy Econ.* **2011**, *13*, 402–410.
67. Buongiorno, J.; Zhou, M. Multi-criteria forest decision making under risk with goal-programming Markov decision process models. *For.Sci.* **2017**, *63*, 474–484.
68. Buongiorno, J.; Zhou, M.; Johnston, C. Risk aversion and risk seeking in multi-criteria forest management: A MDP approach. *Can. J. For. Res.* **2017**, *47*, 800–807. [CrossRef]
69. Roessiger, J.; Griess, V.C.; Härtl, F.; Clasen, C.; Knoke, T. How economic performance of a stand increases due to decreased failure risk associated with the admixing of species. *Ecol. Model.* **2013**, *255*, 58–69. [CrossRef]
70. Whitesell, C.; Debell, D.S.; Schubert, T.; Strand, R.; Crabb, T. *Short-Rotation Management of Eucalyptus: Guidelines for Plantations in Hawaii*; General Technical Report PSW-GTR-137; U.S. Department of Agriculture Forest Service: Washington, DC, USA, 1992.
71. Bristow, M.; Vanclay, J.K.; Brooks, L.; Hunt, M. Growth and species interactions of Eucalyptus pellita in a mixed and monoculture plantation in the humid tropics of north Queensland. *For. Ecol. Manag.* **2006**, *233*, 285–294. [CrossRef]
72. Agestam, E.; Karlsson, M.; Nilsson, U. Mixed forests as a part of sustainable forestry in southern Sweden. *J. Sustain. For.* **2005**, *21*, 101–117. [CrossRef]
73. Hyytiäinen, K.; Penttinen, M. Applying portfolio optimisation to the harvesting decisions of non-industrial private forest owners. *For. Policy Econ.* **2008**, *10*, 151–160. [CrossRef]

74. Hahn, W.A.; Härtl, F.; Irland, L.C.; Köhler, C.; Moshammer, R.; Knoke, T. Financially optimized management planning under risk aversion results in even-flow sustained timber yield. *For. Policy Econ.* **2014**, *42*, 30–41. [CrossRef]
75. Hildebrandt, P.; Kirchlechner, P.; Hahn, A.; Knoke, T.; Mujica, H. Mixed species plantations in Southern Chile and the risk of timber price fluctuation. *Eur J. For. Res.* **2010**, *129*, 935–946. [CrossRef]
76. Lu, F.; Gong, P. Adaptive thinning strategies for mixed-species stand management with stochastic prices. *J. For. Econ.* **2005**, *11*, 53–71. [CrossRef]
77. Farrar, R.M.; Murphy, P.A.; Leduc, D.J. Volume growth of pine and hardwood in uneven-aged loblolly pine-upland hardwood mixtures. In *Proceedings of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type, Atlanta, GA, USA, 18–19 April 1989*; General Technical Report SE-58; Waldrop, T.A., Ed.; US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: Asheville, NC, USA, 1989; pp. 173–189.
78. Schultz, R.P. Loblolly—The pine for the twenty-first century. *New For.* **1999**, *17*, 71–88. [CrossRef]
79. Hildebrandt, P.; Knoke, T. Investment decisions under uncertainty—A methodological review on forest science studies. *For. Policy Econ.* **2011**, *13*, 1–15. [CrossRef]
80. Knoke, T. Economics of Mixed Forests. In *Mixed-Species Forests*; Pretzsch, H., Forrester, D., Bauhus, J., Eds.; Springer: Berlin, Germany, 2017.
81. Dixon, G.E. *Essential FVS: A User's Guide to the Forest Vegetation Simulator*; USDA Forest Service; Forest Management Service Center: Fort Collins, CO, USA, 2018. Available online: https://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/EssentialFVS.pdf (accessed on 11 June 2019).
82. Nowak, D.J.; Walton, J.T. Projected urban growth (2000–2050) and its estimated impact on the US forest resource. *J. For.* **2005**, *103*, 383–389.
83. Smith, M.D.; Krannich, R.S. Culture clash revisited: Newcomers and longer-term residents' attitudes toward land use, development, and environmental issues in rural communities in the Rocky Mountain West. *Rural Sociol.* **2000**, *65*, 396–421. [CrossRef]
84. Ewert, A.; Place, G.; Sibthorp, J. Early-Life Outdoor Experiences and an Individual's Environmental Attitudes. *Leis. Sci.* **2005**, *27*, 225–239. [CrossRef]
85. Berns, G.N.; Simpson, S. Outdoor Recreation Participation and Environmental Concern: A Research Summary. *J. Exp. Educ.* **2009**, *32*, 79–91.
86. Gordon, J.S.; Stedman, R.C.; Matarrita-Cascante, D.; Luloff, A. Wildfire perception in rapid growth communities. *Rural Sociol.* **2010**, *75*, 455–477. [CrossRef]
87. Berenguer, J.; Corraliza, J.A.; Martín, R. Rural-Urban Differences in Environmental Concern, Attitudes, and Actions. *Eur. J. Psychol. Assess.* **2005**, *21*, 128–138. [CrossRef]
88. Butler, B.J.; Leatherberry, E.C. America's family forest owners. *J. For.* **2004**, *102*, 4–14.
89. Ticknor, W.D. *A Survey of Selected Forestland owners in Southcentral Indiana*; Forestry Consultants Inc.: Orient, OH, USA, 1993.
90. Metcalf, A.L. Human Dimensions of Private Forestland Ownership: Sampling, Estimation, Decision Making Processes, and Implications. Ph.D. Dissertation, School of Forest Resources, The Pennsylvania State University, State College, PA, USA, 2010.
91. Godar-Chhetri, S.; Gordon, J.S.; Henderson, J.; Munn, I. Factors influencing the use of consulting foresters by non-industrial private forest landowners in Mississippi. *For. Chron.* **2018**, *94*, 254–259.
92. Bliss, J.C.; Martin, A.J. Identifying NIPF management motivations with qualitative methods. *For. Sci.* **1989**, *35*, 601–622.
93. DeCoster, L.A. The Boom in Forest Owners—A bust for forestry? *J. For.* **1998**, *96*, 5–25.
94. Greene, W.D.; Harris, T.G.; Deforest, C.E.; Wang, J. Harvesting Cost Implications of Changes in the Size of Timber Sales in Georgia. *South. J. Appl. For.* **1997**, *21*, 193–198. [CrossRef]
95. Straka, T.J.; Wisdom, H.W.; Moak, J.E. Size of forest holding and investment behavior of nonindustrial private owners. *J. For.* **1984**, *82*, 495–496.
96. Birch, T.W. *Private Forest-Land Owners of the United States*; Northeastern Forest Experiment Station Resource Bulletin. NE-134; USDA Forest Service: Washington, DC, USA, 1996.
97. Hyberg, B.T.; Holthausen, D.M. The behavior of nonindustrial private forest landowners. *Can. J. For. Res.* **1989**, *19*, 1014–1023.
98. Aldenderfer, M.S.; Blashfield, R.K. *Cluster Analysis*; Sage: Beverly Hills, CA, USA, 1984.

99. Toïgo, M.; Vallet, P.; Pérot, T.; Bontemps, J.-D.; Piedallu, C.; Courbaud, B. Overyielding in mixed forests decreases with site productivity. *J. Ecol.* **2015**, *103*, 502–512. [CrossRef]
100. Pile, L.S.; Wang, G.G.; Stovall, J.P.; Siemann, E.; Wheeler, G.S.; Gabler, C.A. Mechanisms of Chinese tallow (Triadica sebifera) invasion and their management implications—A review. *For. Ecol. Manag.* **2017**, *404*, 1–13. [CrossRef]