EXEMPLARY FORESTRY FOR THE ACADIAN FOREST

NEW ENGLAND FORESTRY FOUNDATION

32 Foster Street | P.O. Box 1346 | Littleton, MA 01460
T 978.952.6856 | newenglandforestry.org

Exemplary Forestry for the 21st Century: Managing the Acadian Forest for Bird's Feet and Board Feet at a Landscape Scale

Prepared by R. Alec Giffen and Robert Perschel
For New England Forestry Foundation | May 2021

Table of Contents

I. Introduction / Context / Overview

The New England Forestry Foundation (NEFF) has worked for more than 75 years to conserve New England's forests and to promote the highest standards of forest sustainability. In this paper, we take a step further and define the characteristics and outcomes of the forestry we strive to practice. We believe these practices will help our forests make their strongest possible contributions to New England's regional economy, wildlife, and climate mitigation and resilience. We call this approach to forestry "Exemplary Forestry." NEFF is committed to practicing forestry in line with the standards herein and is open and welcoming to helping other forest owners who wish to adopt practices and standards that can influence the contributions of New England's forests.

The specifics of what constitutes Exemplary Forestry will vary by forest region. The Acadian Forest of northern New England served as our laboratory to develop this approach, both because of the depth of experience of the lead authors in that region and because it is the largest contiguous area devoted almost entirely to commercial forest harvesting in the northeastern U.S. Because our goals include increasing forest productivity and ensuring that forest products are used in long-lived applications that displace materials with greater greenhouse gas emissions (e.g. steel and concrete), it follows that influencing the wood basket of commercial forestry is vitally important. NEFF has already conserved more than a million acres of this region through conservation easements and its network of more than 150 Community Forests, and is now focusing on conserving large private lands through ownership so NEFF's foresters can put Exemplary Forestry to work at scale.

In December 2020, NEFF completed a campaign to protect and acquire Downeast Maine forestlands of ecological significance; NEFF protected approximately 3,300 acres along the Denny's River, an important river in Downeast Maine for the survival of Atlantic Salmon, as well as two Downeast forestlands near or on the coastline, a 2,690-acre parcel along Holmes Bay and 3,100-acre parcel near Egypt Bay.

NEFF aims to own and manage additional large parcels in the Acadian Forest. We intend to hold ourselves to the standards laid out herein as we expand our ownership in the Acadian Forest region. A one-page summary of the substance of these standards can be found in Section VI of this paper. The rest of this paper provides the scientific grounding that supports our expectations that this approach will provide the wildlife habitats and climate mitigation, as well as timber production called for in the 21st century.

By implementing Exemplary Forestry, NEFF is fundamentally looking to maintain or enhance the public values that its forests provide, while also supplying materials—wood in its many forms—that are environmentally preferable to non-wood alternatives from several perspectives, including climate change. Realizing financial returns is also important as achieving reliable financial returns ensures NEFF is able to practice good forestry in the long term. Demonstrating financial viability will also support its efforts to reach other landowners, as well as educate the public about the benefits of long-term forest management for multiple purposes.

NEFF's Exemplary Forestry standards are intended to build on and supplement the good programs already in place to advance beneficial forest practices such as third-party forest management certification. Our objective is to concisely define the concept of Exemplary Forestry with a few of the most powerful metrics indicative of good stewardship at the landscape scale in a commercial forestry setting. Beyond protecting the forest environment and the many "ecosystem" services it provides, Exemplary Forestry is targeted to:

1) Enhance wildlife habitat for the full range of species present;
2) Increase the quality and quantity of both the wood produced and retained in forest stands over time; and

3) Enhance the role forests can play to mitigate climate change—this involves increasing resilience, facilitating adaptation to future climate conditions, and managing forests to sequester more carbon in the forest and in forest products—and to use the other influences of forests on climate change in positive ways as well (e.g., the production of biogenic chemical compounds that can increase the reflectivity of the atmosphere and hence cool the earth).

The intent of this paper is to distill the essence of Exemplary Forestry from the thousands of studies and dozens of guidelines written on what constitutes responsible and productive forestry. This paper summarizes the scientific support for the approaches Exemplary Forestry takes and the results we expect to achieve, presented in a way that is as easy to understand as possible—hopefully even for non-foresters.

NEFF's Exemplary Forestry starts from a **landscape perspective**. To achieve ecological and particularly wildlife habitat goals, the management of any lands must be viewed in the context of the landscape where they occur; therefore, Exemplary Forestry starts from **this broad perspective.** We view these goals in the context of at least a township in settled portions of New England and several townships in areas of big woods. When forestry is practiced on smaller parcels, such as most of the approximately 150 community forests NEFF owns, we do not expect those parcels to be able to incorporate the full set of specifications identified for Exemplary Forestry on a single parcel (e.g., small parcels cannot include wildlife habitats that must be at least a square mile in area). Instead, NEFF's forestry on individual parcels will consider how these lands can maximize their contribution to the landscapes where they occur and help provide as close to the full suite of forest values as possible, by filling in elements missing in the landscape. Sometimes it may require multiple management actions and many years to provide those missing elements, particularly when starting with a parcel with depleted forest stocking or other deficits.

To be clear, these standards are for actively managed forest lands, but NEFF is nevertheless mindful of the important role played by ecological reserves, which a number of organizations, including NEFF, are pursuing. NEFF supports strategically expanding the existing regional system of ecological reserves to meet other habitat needs not met on managed forest lands. As part of this system, NEFF contributes forested parcels it already owns that are designated "forever wild" and not subject to active management.

As alluded to earlier, the specifics of what constitutes Exemplary Forestry will of course vary from one forest region to another. However, across all forest types in New England, Exemplary Forestry aims to manage for landscape scale objectives, including **improving the quality of the forest, enhancing wildlife habitat, and mitigating climate change** over time by:

1) Growing the tree species best suited to each site;
2) Maintaining or restoring stocking that fully occupies sites;
3) Growing and harvesting more of the wood our forests are capable of providing;
4) Achieving a diverse stand size class distribution from seedlings to large diameter trees in multi-storied stands;
5) Creating stand conditions that are well suited to the great majority of native wildlife species;
6) Employing best management practices to protect soils, riparian habitats and aquatic habitats, as well as aesthetics;
7) Protecting special habitats including wildlife trees (e.g., snags and trees for cavity nesting species), habitats of species identified as having special needs not entirely met

by the management outlined above, and habitats which are critically important to more common species such as deer wintering areas; and

8) Employing a mix of management styles to simultaneously achieve the three goals outlined earlier.

In this regard, NEFF sees Exemplary Forestry as a journey rather than just an end point—that is, practicing Exemplary Forestry means that management puts a parcel on the path to reaching the conditions specified. This approach recognizes that practicing Exemplary Forestry will, in many cases, require decades to achieve the results desired and that disturbances such as windstorms or insects and disease will require finding new paths to the goals.

II. Improving Wildlife Habitat and Protecting Biodiversity

NEFF's definition of Exemplary Forestry incorporates elements from two dominant schools of thought regarding the best silvicultural practice to both grow wood for harvest and provide habitat for wildlife.

One school of thought holds that forest harvesting should mimic historic natural disturbance patterns. For example, in the Acadian Forest, such disturbances are largely the death of single mature trees or small groups of trees—affecting approximately 1% of the landscape in any given year—with long periods between stand-replacing events like large-scale fires or massive windthrow events. In some cases, these long periods can be 1,000 or more years in duration (Lorimer and White 2003, Seymour, et al. 2002). Pre-settlement forests also contained considerable numbers of snags and downed logs, which are important habitat features for a number of species.

This disturbance pattern leads to a landscape consisting of a mosaic of small patches of different ages and are considered "multi-aged" stands; while perhaps not entirely consistent with the older definitions in classic silviculture (Smith 1962), such stands have more in common with uneven-age stands than large even-age blocks,[1] and they favor some but not all species of wildlife; for example, the American Marten, forest interior species and species that thrive in small patch openings—see Pounch, Giffen and Fenner (2019) for more on this topic. Even though they are actively managed, such forests can have complex forest stand structures—irregular patches with trees of different diameters and heights—that to some extent mimic "late-successional" (LS) characteristics[2] and have other benefits (e.g., storing more carbon) beyond providing superior habitat for certain wildlife[3] (see also Ten Broeck 2018). They can also serve as a reservoir of genetic diversity when compared to stands where only what are seen as "superior" trees are retained (see Kenefic 2018 for more on this topic). Despite these several benefits, other species that require larger forest openings—bigger blocks of early successional habitat for nesting, feeding or raising

---

[1] Smith defines an uneven-aged stand as one containing "at least three age classes intermingled intimately on the same area" and has graphics which might or might not be interpreted as including this forest condition as "uneven-aged" because the different age classes are largely in small patches rather than "intermingled intimately." More recently such management has been referred to as irregular shelterwood and is considered "multi-aged" rather than the older concept of "uneven managed." In any case, as contemplated here, when implemented fully it includes patches regenerated at 20-year intervals—thus 6 age classes on any given area.

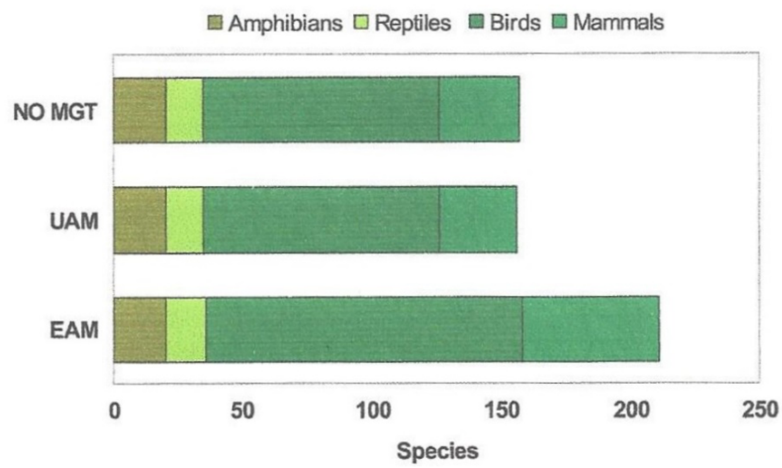
[2] True "late successional" conditions require very old trees; some studies say 150 years old and more (Whitman and Hagan 2009). Providing such stands, needed for at least some mosses, lichens and liverworts, is one of the purposes for having system of ecological reserves to complement Exemplary Forestry in the forests around them. Similarly, but more broadly, they provide benchmarks for how more intensive management affects forest ecosystems. In addition, they can serve as a source of inspiration.

[3] Ecological reserves should be strategically located to maximize their benefit, e.g., maintain a particular habitat or provide connectivity, etc. The report on Wildlands and Woodlands calls for them to occupy 10% of the forested landscape.

their young—do not thrive in such forests. These latter species may have only been present in pre-settlement forests at very low numbers or may have been entirely absent, but now make up a large portion of the region's wildlife.

Another school of thought is that harvesting should provide habitat for robust populations of all the species that use the Acadian Forest region today. Adherents to this perspective argue that in addition to meeting the needs of forest interior species by providing a forest with only small gaps in the canopy, larger openings (15 acres or more) are needed to maximize habitat benefits for species like Canada Lynx, Chestnut-sided Warbler, Eastern Kingbird, Meadow Voles, Snowshoe Hare, Ruffed Grouse and even post-fledgling chicks of some species of birds that breed in more mature forests. These patches are called "even-aged" because the trees all regenerated at one time. Figure 1 below shows the number of species[4] favored by these different styles of management.

Figure 1. Potential number of wildlife species by silvicultural system and cover type group



NO MGT = no management (largely intact forest with small gaps)

UAM = uneven-aged management (largely intact forest with small gaps)

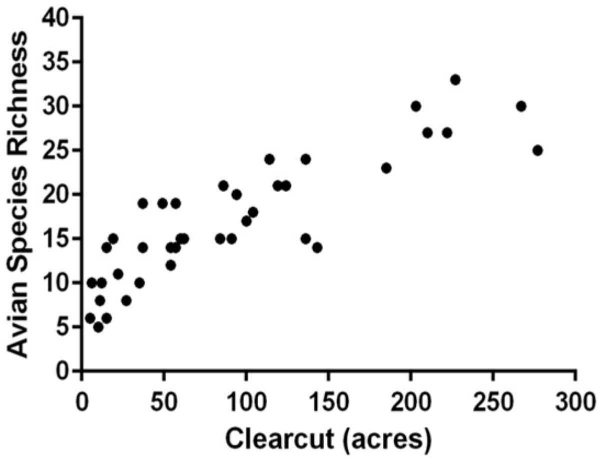
EAM = even-aged management (forest managed in patches of a single size)

Source: DeGraaf, et al. 2006

Studies show that the number of species using forest openings (even-aged patches) in spruce-fir forests increases dramatically as the size of the opening approaches 20 acres and then climbs slowly up to perhaps 50 acres.

[4] The number of species is only one measure of the importance of habitat to wildlife—diversity, or the combination of number of species and relative abundance is often used in addition to species richness, and tree age class becomes important for different species as well.

Figure 2. Avian richness across patch sizes



- Adapted from work by Rudnicky and Hunter (1993) in regenerating spruce-fir patches.
- The relationship of avian species richness to increasing regeneration patch size is strongest in this dataset up to 50 acres.
- King, et al. (2001) found similarly high nest survival rates for bird species using both clearcuts and group cuts in heavily forested landscapes.
- Costello, et al. (2000) detected 8 bird species that used clearcuts ($\bar{x}$ = 20 ac) but not smaller group selection cuts ($\bar{x}$ = 0.5 ac).
- Bird species that use larger forest gaps may be habitat-limited in locales solely practicing single-tree and small group selection management.

A number of species use different forest successional stages. Of Maine's vertebrate species, 71% benefit from management for species like marten (more "mature" and unbroken forests), and 48% are benefited by early successional habitats like those for lynx, though there is obviously considerable overlap (McCollough 2007). Thus, the proposed standards for Exemplary Forestry honors both points of view by calling for significant portions of the landscape to be managed under even- and uneven-age management regimes. Even though some large patches will be created to provide early successional habitats, they will only occupy 5-15% of the landscape at any point in time to meet the stand size class objectives specified as a desired result; the management approaches specified will result in the great majority of a landscape managed to Exemplary Forestry standards being in relatively closed canopy conditions.

It can be argued that the graphics included herein are weighted toward larger forms of "wildlife" and that if all species down to the very small (e.g., fungi, bacteria and insects) were included, the results could be shifted with more species tallied as benefitting from uneven-aged management, but regardless of the division of species numbers between the two forms of management, the point remains that different species need different habitats or need them at different times in their lives.

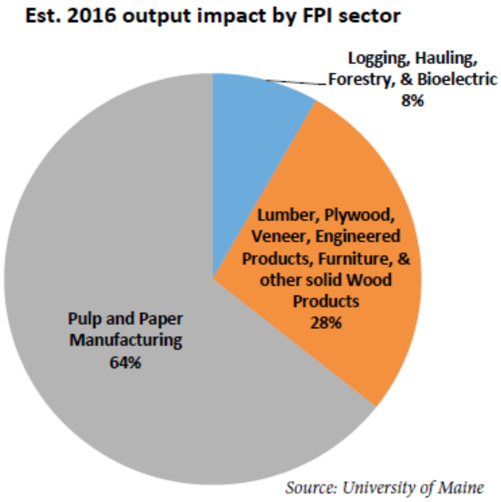
III. Growing More and Better-Quality Wood

As stated earlier, the second goal of Exemplary Forestry is to increase the quality and quantity of wood produced. This goal is important from both ecological and economic perspectives.

From an economic perspective, harvesting wood provides a financial return that enables NEFF to fund its programs to advance good forestry and provide other landowners with a reliable, modest return on investment and a reason to keep forests as forests. An analysis of data from several sources conducted as part of the work on Exemplary Forestry shows that on average, actively managed lands in the Acadian Forest yield a net return of $5-10/acre a year after expenses, with significantly more possible over time with improved management (Giffen 2018).

Of course, timber supplies are also important to rural economies. For example, the Maine Forest Products Council (2016) reports that the forest products industry in Maine is responsible for generating $8.5 billion in economic activity and 33,538 jobs.

Figure 3. Maine's forest economy



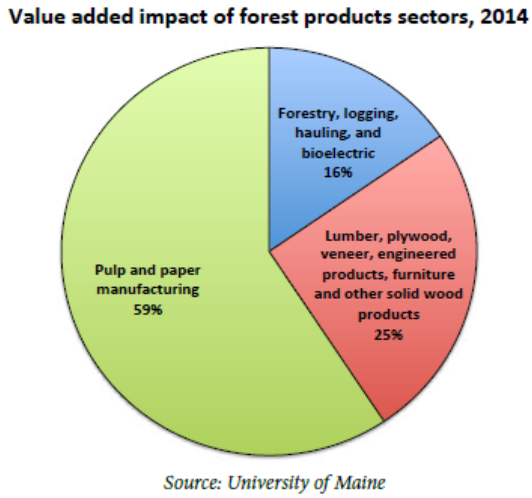
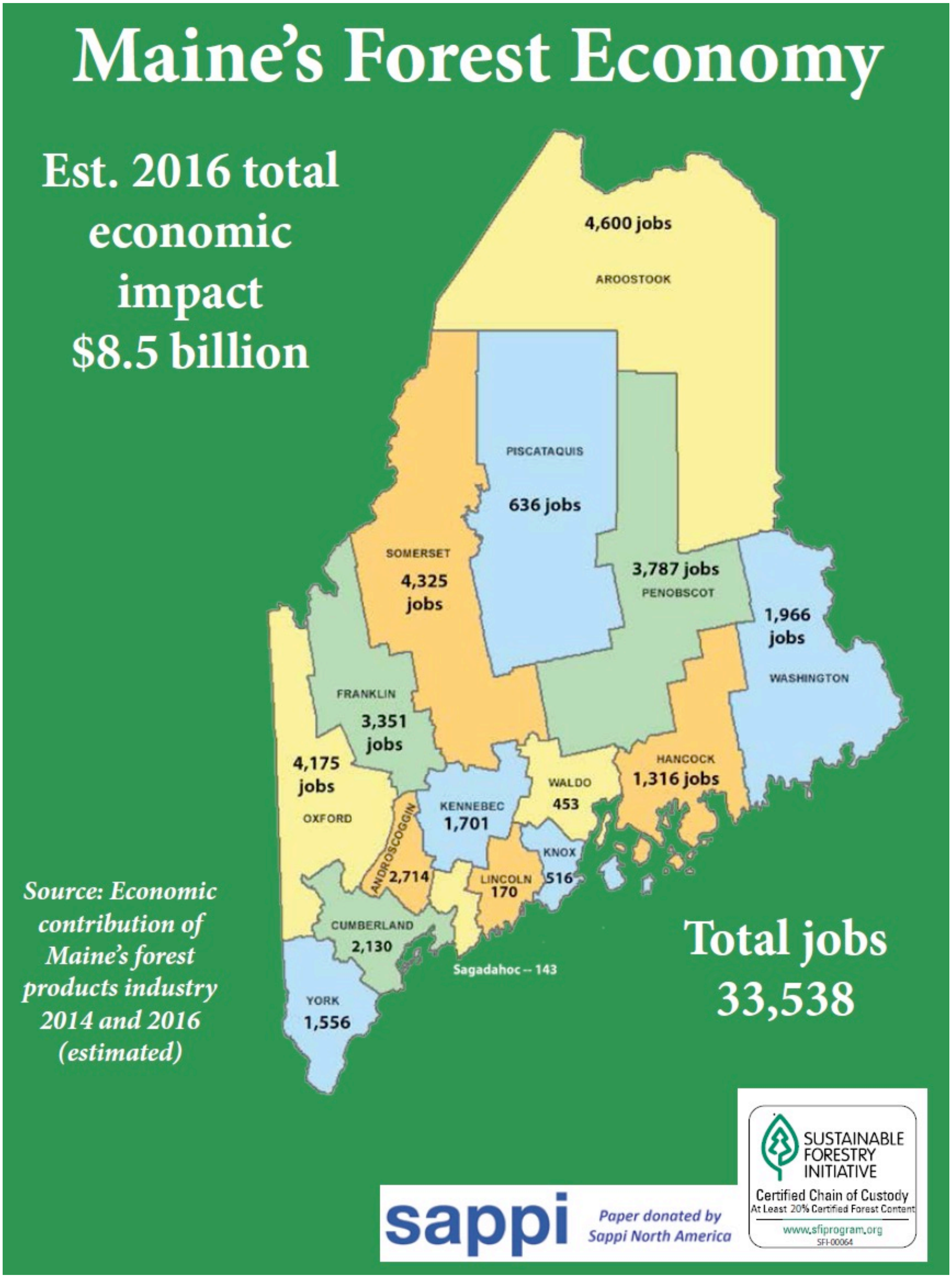


Table 3. Estimated annual economic impact of the forest products industry (FPI) in Maine, 2016

Est. 2016 *(in 2016 U.S. dollars)*	Direct and indirect contribution	Total multiplier effects (indirect and induced)		Total impact
	FPI	FPI support	Non-FPI	Total
Output	$5,506,841,557	$414,408,861	$2,620,051,284	$8,541,301,702
Employment	14,562.5	1,040.1	17,935.4	33,538
Labor income	$904,980,706	$83,910,010	$844,146,645	$1,833,037,361



Source: Maine's Forest Products Council (2016).

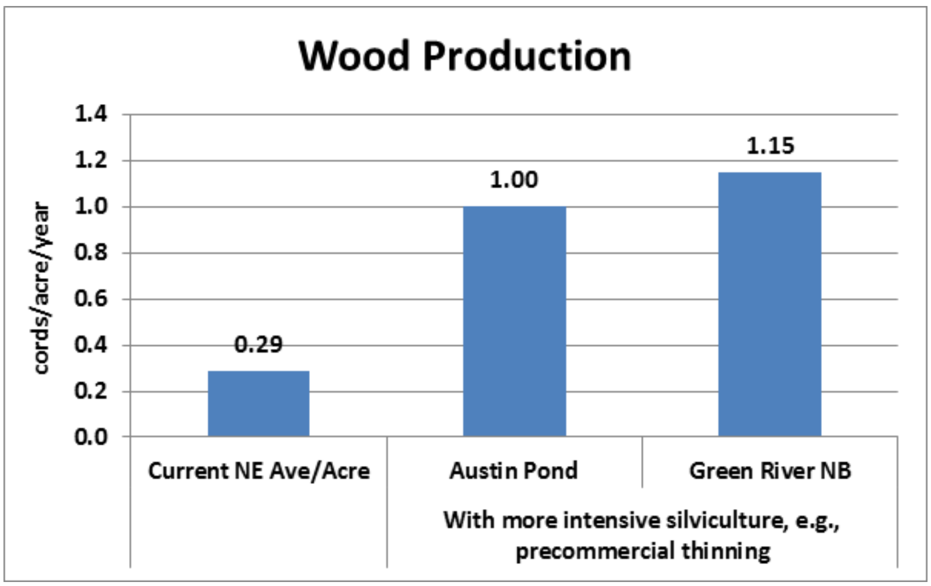
Thus, increasing wood production is important to:

- Keeping forests as forests;
- Rural economies; and
- Financial returns to landowners.

As described later, growing and harvesting more wood is also important to reduce climate change, as wood can substitute for more energy-intensive building materials. See Section III for more on this topic.

But, can we grow more wood and simultaneously improve the environment? The answer is yes. A study conducted for NEFF as part of its work on its Path to Sustainability report concluded that the harvest of wood in New England could be doubled with more intensive management. Figure 4 compares current levels of harvests in New England forests (0.29 cords/acre/year) with what has been shown to be possible on typical sites (over 1 cord/acre/year) with more intensive management. Some landowners who practice very intensive management (e.g., Bob Chadbourne) report yields of up to two cords/acre/year on their best sites (Bob Chadbourne, pers. comm.).

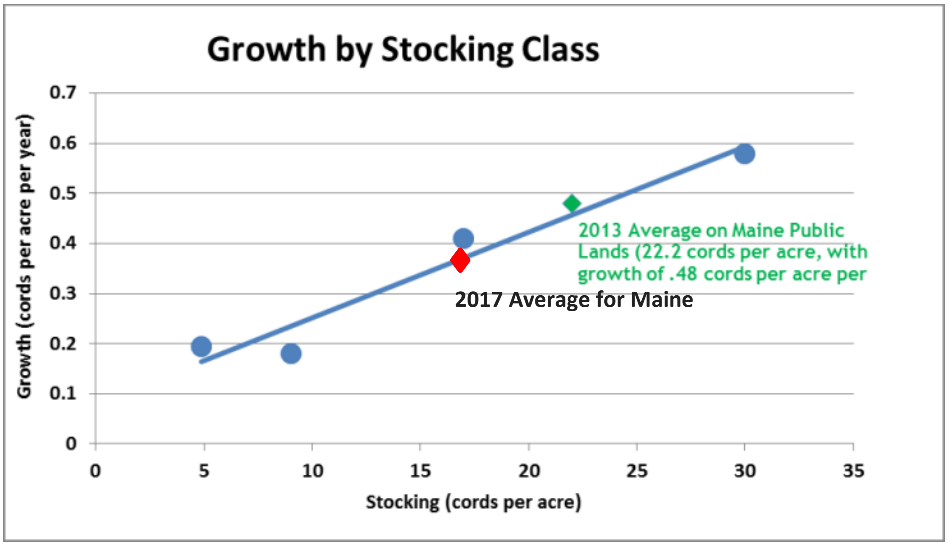
Figure 4. Wood production



As context for considering this issue, a recent study of forest harvesting in New England and New York concluded that “37% of all harvests in Maine” were “harvest types fitting the characteristics of exploitive harvests” (Belair and Ducey 2018). These practices can reduce growth rates.

In contrast, as shown in Figure 5 below, more intensive management that increases stocking levels can increase growth and sustainable levels of harvest. Average stocking in Maine is now approximately 17 cords/acre, but could be increased, thereby growing more wood. As noted earlier this also can have ecological benefits. As also noted in the figure, the Maine Bureau of Parks and Lands has approximately 22 cords per acre of stocking and hence higher growth rates.

Figure 5



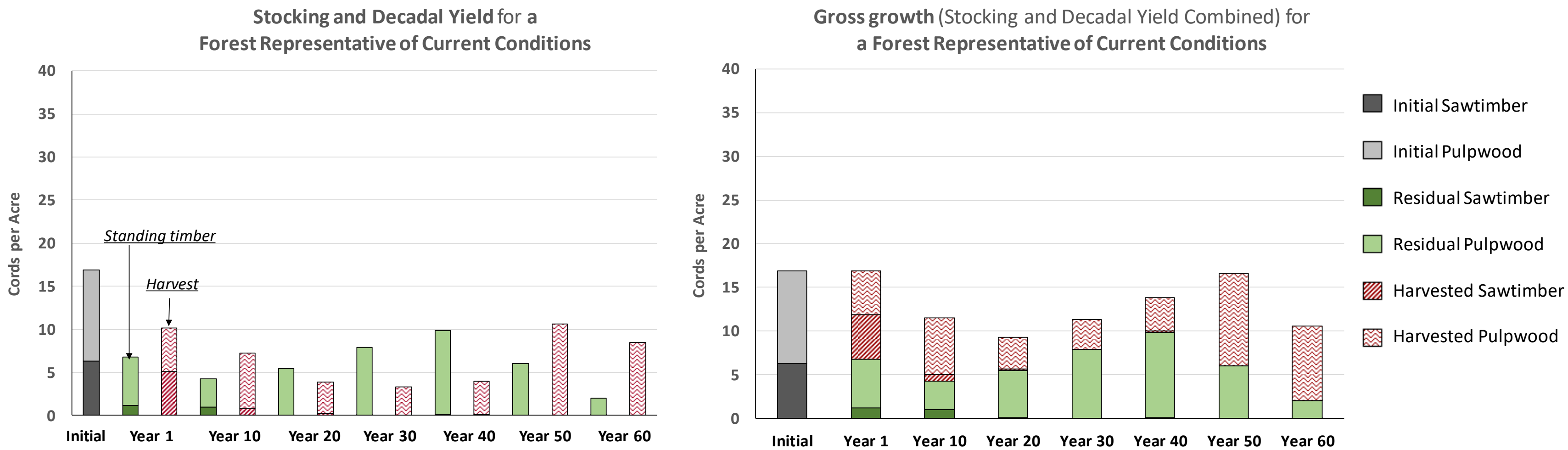
An analysis of how the growth of timber under Exemplary Forestry's dominant form of management (irregular shelterwood silviculture) compares to management oriented to maximize short term cash flows shows that while Exemplary Forestry will not result in the highest return in the short term (discounted cash flows are lower), patient management can, over time, increase timber stocking, timber value, harvest volumes (particularly of higher value products) and annual returns. Figures 6 and 7 show how these two forms of management compare, in the first case for a forest representative of average conditions in the area of the Mountains of the Dawn (a portion of the Acadian Forest in the mountains of western Maine), and in the second case, for a pole-sized spruce/fir stand with good stocking. Analyses comparing Exemplary Forestry management with management to maximize cash flows start with the same initial condition. Silvicultural prescriptions for Exemplary Forestry were developed in consultation with the region's preeminent silviculturalists. These were applied to over 46 stand condition classes (a combination of forest type, stand size class, and level of stocking) present in the Acadian Forest. The model Forest Vegetation Simulator was then used to analyze how the growth and harvest of timber compared with management to maximize short term cash flows (harvesting when a sufficient volume of trees per acre reach a merchantable size).[5]

This analysis indicates that after restocking, Exemplary Forestry management produces stands with higher residual volumes—particularly in the sawtimber classes—and more higher-value sawtimber is harvested than pulp. What this means is Exemplary Forestry can, over time, produce higher-value stands with greater annual returns while they also retain the ecological values and carbon sequestration benefits related to older and more fully stocked stands.

[5] This analysis was conducted for irregular shelterwood silviculture that will be practiced on the great majority of the landscapes managed to Exemplary Forestry standards. The shelterwood management intended to regenerate spruce/fir early successional habitat was not modeled but other studies have shown that such management can provide yields of over one cord per acre per year (Bataineh, Wagner and Weiskittel 2013, and Pitt, et al. 2013).

Figure 6. The results of management to maximize short-term cash flows versus Exemplary Forestry for a forest of average condition

Projections for Management to Maximize Net Present Value (Short Term Cash Flow)



Projections for Exemplary Forestry Management

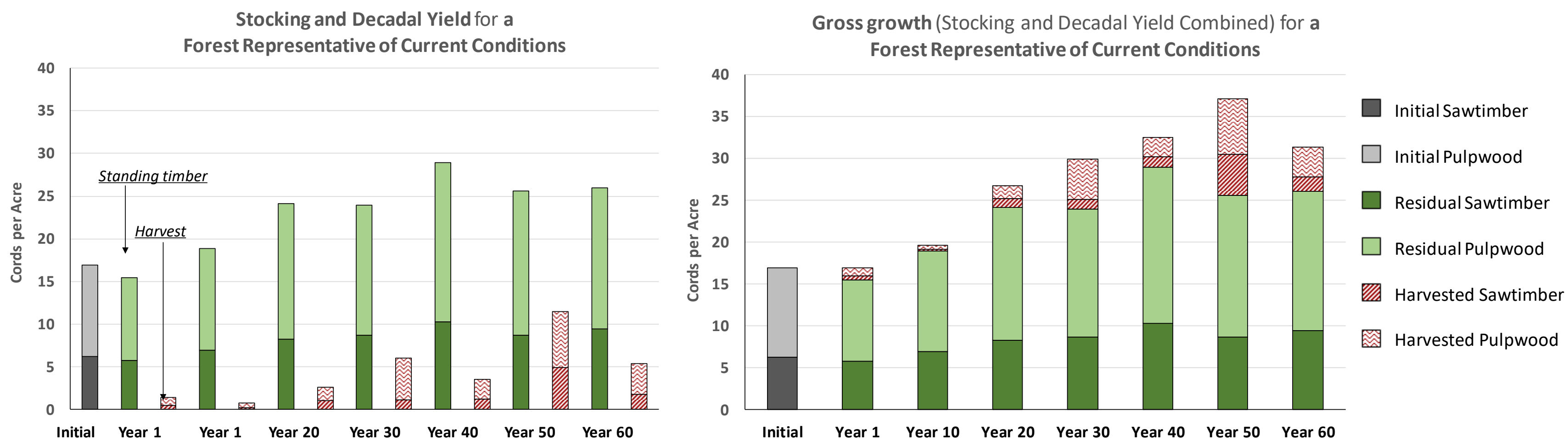
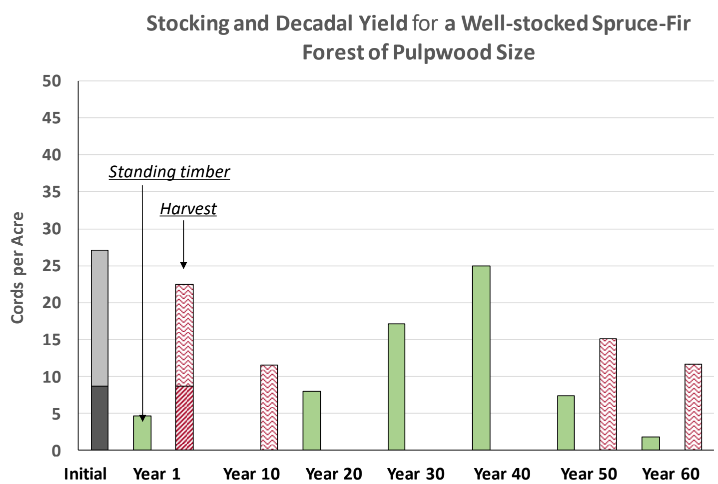
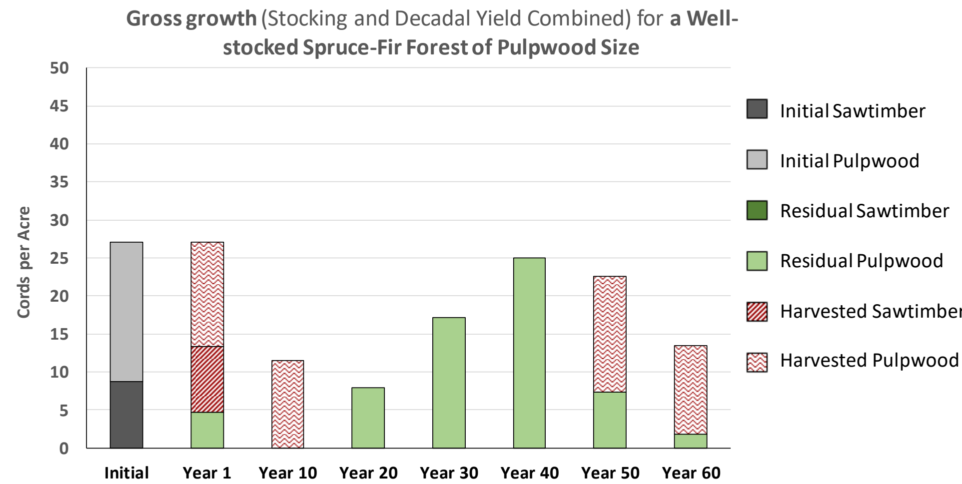


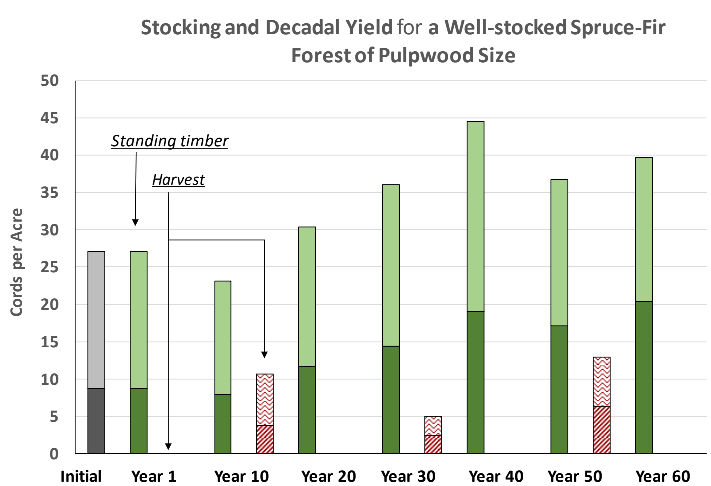
Figure 7. The results of management to maximize short-term cash flows versus Exemplary Forestry for a poletimber-size spruce/fir stand with good stocking

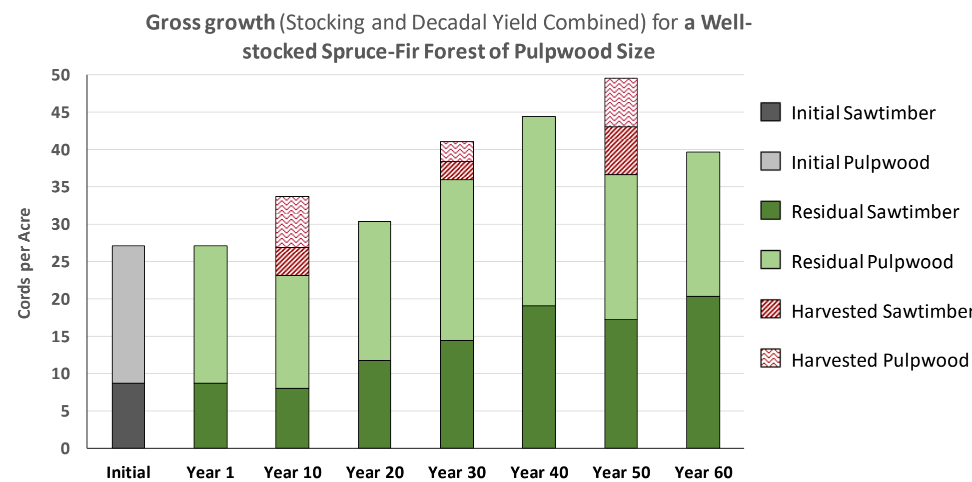
Projections for Management to Maximize Net Present Value (Short Term Cash Flow)





Projections for Exemplary Forestry Management





The conclusions from this analysis of the growth and yield expectations under Exemplary Forestry are corroborated by the empirical evidence from the long-term management of woodlots like Wicopy Woods (Figure 8) and with the results from the Demeritt Forest at the University of Maine.

Figure 8. Wicopy Woods Tree Farm

Wicopy Woods Tree Farm: A Rare 50-year Record of Forest Productivity and Stewardship

Bob Seymour and Jessica Leahy

Co-owners, SocioSilv LLC

Ownership History

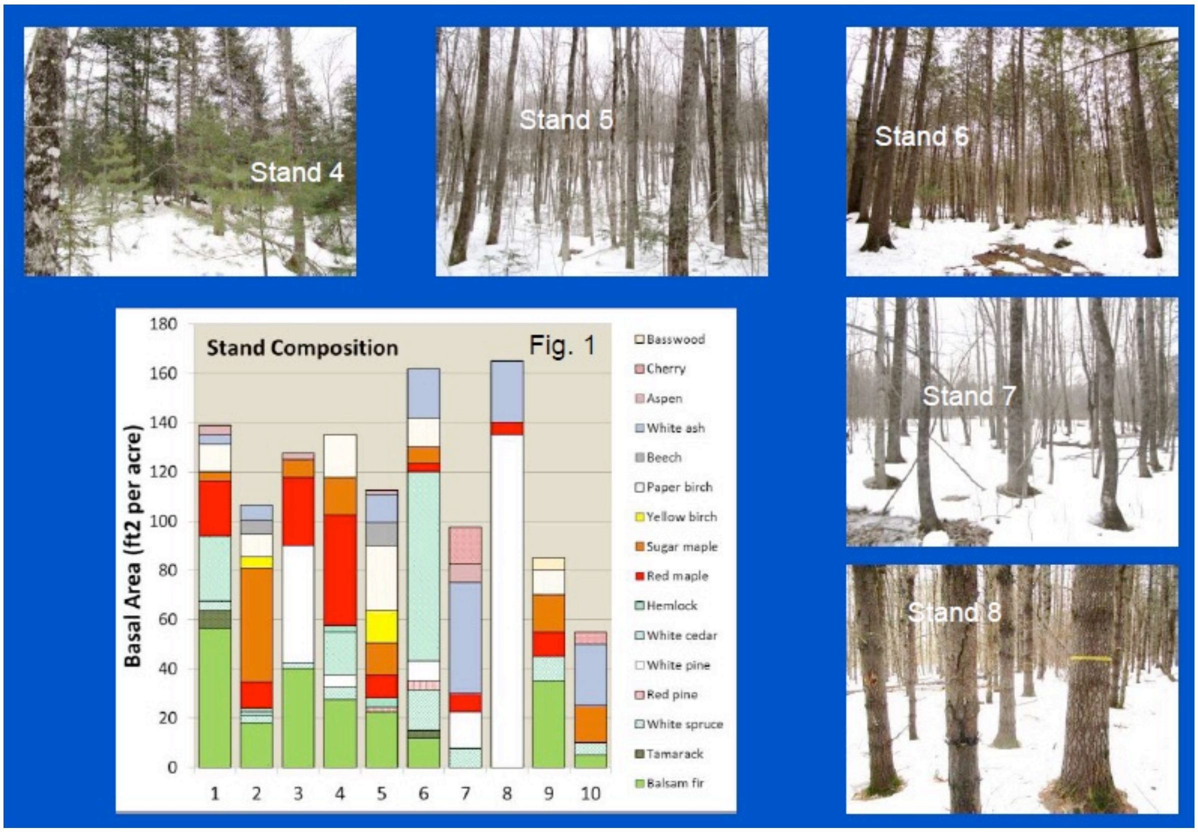
In 1968, Ron and Stephanie Locke purchased a run-down farm and woodlot in Sebec, Maine. Over the course of his active career as a forester, which included the Maine Forest Service, Columbia Plywood, the Dover-Foxcroft Forestry Cooperative, and a self-employed consultant, Ron worked the land himself, cutting 1,500 cords of various products and selling another 500 cords of stumpage.

Wicopy Woods - named after the rare leatherwood shrub (*Dirca palustris*) - has been a certified Tree Farm for over 40 years, winning Maine Outstanding Tree Farm of the Year in 1984. The property was also a Forest Guild Model Forest, and has been featured in countless tours during Ron's tenure. Ron retired and moved to New York in 2006. After leaving Maine, Ron entrusted consulting forester Bill Mahan, NESAF 2014 Austin Cary award winner, with the on-site stewardship responsibilities.

Figure 8 (cont.)

Current Stand Composition

The forest is quite diverse overall, with 16 species (Fig. 1). Sugar maple ranks first in total cubic volume (17%), followed closely by red maple (14%), northern white-cedar (13%) , paper birch (13%) and white pine (12%). Pine dominates sawtimber stocking (32%), with sugar maple and cedar tied for second at 14% each. Red spruce and hemlock are rare; white ash dominates old-field stands 7 and 10.



Growth

From 1978 to 2011, stocking increased from 2,137 to 2,570 cords; sawtimber stocking rose from 195 to 329 MBF. Over 32 years, these 90 acres produced 2,270 cords of wood (1,837 harvested plus 433 increase in stocking), equal to 71 cords per year or 0.79 cords per acre. Figure 2 shows the breakdown by 3 decadal periods. Additional volumes on 24 acres purchased in 1996, along with ingrowth on reverting fields, gives a total stocking of 3,547 cords (27.3 per acre) in 2011. Sawtimber comprises 34% of the total volume.

Figure 8 (cont.)

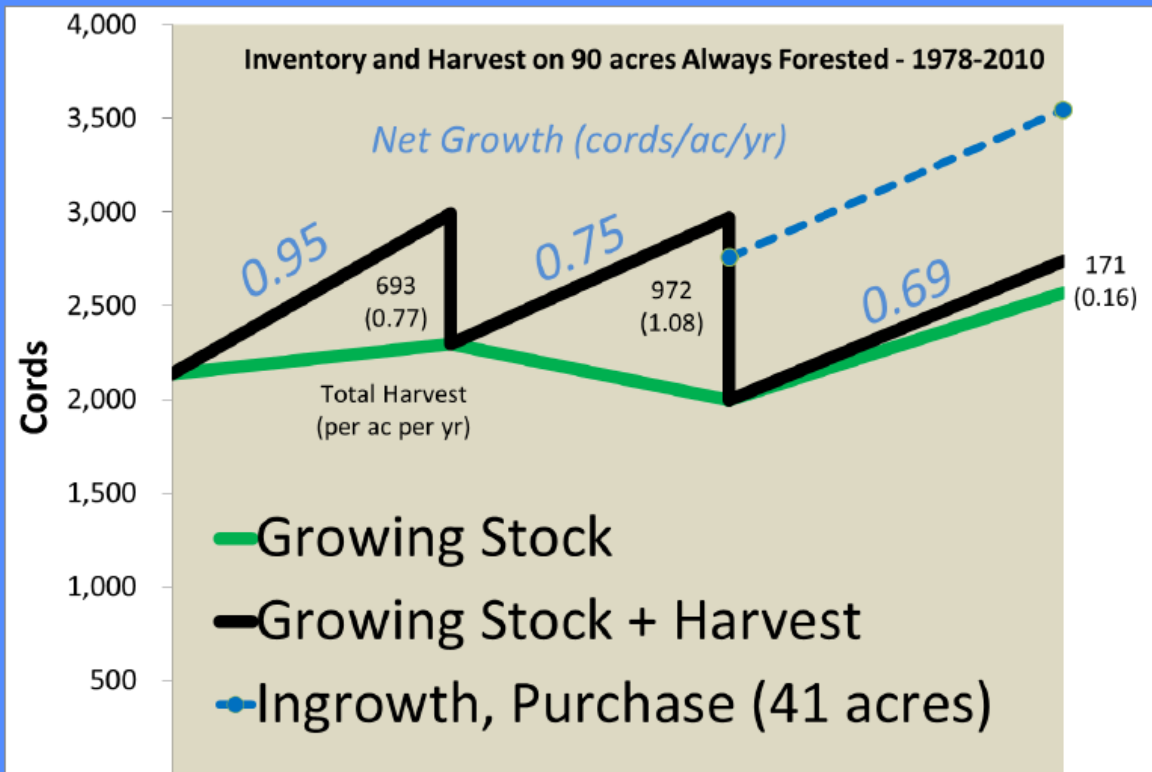


Fig. 2

Financial Performance

In 1967, consulting forester Jim LaCasce appraised the original 100 acres for $5,820; $10/acre bare land and $48.20/acre in timber. Using current stumpage prices of the 2011 growing stock, adjusted downward for recent decline in softwood pulp prices, the standing timber on 131 acres in 2015 is worth $87,965. This yields a nominal rate of return of 6.2% compounded annually over 48 years. This does not include the income from over 2,000 cords harvested that would in today's prices bring over $50,000 – more than 10 times the original value of all the standing timber.

From a financial perspective, the empirical data also suggests that, over the long term, net annual returns could be doubled by better management. This is not to say that financial returns considered as normally calculated (net present value using discount rates for future returns) will be better for Exemplary Forestry, as it is virtually always better in financial terms to liquidate anything of value when it gets to merchantable size. Sixty years of experiments at the Penobscot Experimental Forest demonstrate this dispositively.

Figure 9. Results of 50 years on the Penobscot Experimental Forest

The results of 50 years of selection management on the Penobscot Experimental Forest

This stand was managed selectively with light harvests every 20 years. The financial return from this management (measured as the net present value of all income and costs) is approximately $534. **(Photo: John Brissette, Northeastern Research Station)**

The results of 50 years of diameter limit cutting on the Penobscot Experimental Forest

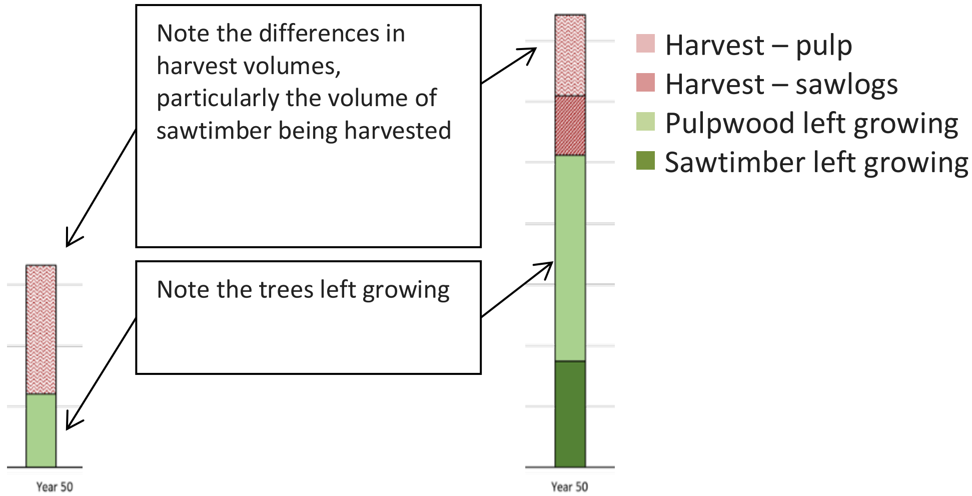
This stand was managed using a diameter limit (all trees above a given diameter were harvested). The financial return from this management was $976 (net present value). **(Photo: John Brissette, Northeastern Research Station)**

Note: The financial returns from diameter limit cutting calculated in conventional terms are almost twice as good from those of careful management.

However, as shown earlier, it is also true a patient forest landowner practicing good silviculture can increase periodic “nominal” (undiscounted) cash flows over the long term and, with prudent management, perpetuate them indefinitely.

To illustrate this point, reflect on what was shown earlier in Figure 6. Starting with the same initial condition (average stocking and species mix for the area in question), after 50 years the comparison of Exemplary Forestry management and management to maximize short-term cash flows is shown below in terms of residual stocking (trees still growing) and harvesting during that decade.

Figure 10. Comparison of the results of practicing Exemplary Forestry versus management to maximize net present value (short term cash flows)



Maximizing net present value (short term cash flows) | Exemplary Forestry

Which outcome is better for the landowner, society and rural economies, wildlife, and the environment? How many more wood products could be produced to offset carbon-intensive products like steel and concrete, thus mitigating climate change? We think the answer is self-evident. The Swedes figured this out in the beginning of the 20th century and restored their forests. Now their landowners make several times what New England landowners make per acre, and their forest products economy is thriving. They face challenges with biodiversity, but they are working on it (Giffen 2018).

IV. Adaptation to and Mitigation of Climate Change

Adapting to climate change is another important aspect of Exemplary Forestry, and it involves increasing "resistance" and "resilience" of forests to climate change and facilitating their "transition" to forest types better suited to future climate conditions.

Mitigation of climate change involves measures that reduce the future level of warming, including but not limited to reducing greenhouse gas levels by cutting emissions and removing greenhouse gases from the atmosphere.

Forests can and should be managed to both adapt to and mitigate climate change.

Regarding adaptation, resistance to climate change is as the name implies, the ability of the forest to remain unchanged in the face of climate chance. A variety of forest management techniques can be applied to increase resistance (e.g., favoring tree species most able to "resist" adverse effects of climate change such as increased damage from ice storms). These and other techniques for adapting forests to climate change are explained in Swanston and Janowiak (2016).

Resilience is the ability of the forest to rebound from adverse effects of climate change—for example, to recover from the damage from ice storms. Again, techniques for increasing resilience are explained in Swanston and Janowiak (2016).

"Transitioning" forests involves activities like changing species composition to those which are better suited to future climates (e.g., reportedly oak/pine on much of the Acadian Forest).

A single forest management activity can serve more than one adaptation purpose, and indeed mitigation purposes as well.

Mitigation typically involves activities like increasing the carbon stored in forests. However, on the carbon side of the ledger, it can also include increasing growth and harvest rates to increase the carbon stored in wood products. New thinking regarding the carbon consequences of forest management includes recognition of the fact that substituting wood for other construction materials can significantly reduce greenhouse gas emissions. These other materials can require far more energy to produce than wood.

Thus, using wood rather than other materials can help achieve the third goal of Exemplary Forestry: using forest management approaches that make our forests more resilient and better adapted to climate change, while concurrently mitigating climate change. Exemplary Forestry leads to older, more diverse forests with a mix of age classes, which is likely to make them more resilient[6] to, as well as facilitate adaptation[7] to, climate change. However, it is through its potential impact on climate mitigation[8] that Exemplary Forestry offers its most important, but largely unrecognized, contribution.

As was agreed by all the nations of the world in the Paris Accords, it is critically important that we keep global temperature rise below 1.5 degrees Celsius. However, it is predicted we will surpass that level in a few decades unless we take immediate action to reduce carbon emissions. Because a great deal of carbon is stored in the world's forests, and more could reside there if forests are allowed to grow, they have become a focal point for thinking about how to reduce atmospheric carbon dioxide levels. There is currently a great deal of attention in the scientific and policy arenas paid to in-forest carbon stocks. While this attention is important, the full effect of forests and forest management on climate requires a more holistic approach. We need to account for the carbon emissions that are offset when we use wood products instead of other carbon intensive products such as steel, concrete and plastic. These are called "equilibrium economic effects"—that is, understanding how affecting one segment of the economy affects others and creates a new balance or equilibrium.

In contrast to some other forest influences on climate (e.g., how biogenic volatile organic compounds influence the formation and life of clouds), we understand how changes in forest carbon stocking and the production of forest products can help mitigate climate change as regards carbon dioxide levels in the atmosphere. Our goal with management is to keep as much carbon in the forest as possible while producing wood products that both store carbon and maximize substitution benefits. This will maximize climate mitigation. Simply put, it requires far more energy to produce materials other than wood. For example, it takes approximately 10 times as much energy to produce a steel stud for construction as a wooden stud. So, the more wood we can direct to replacing carbon-intensive building alternatives, the greater the effect on climate mitigation.

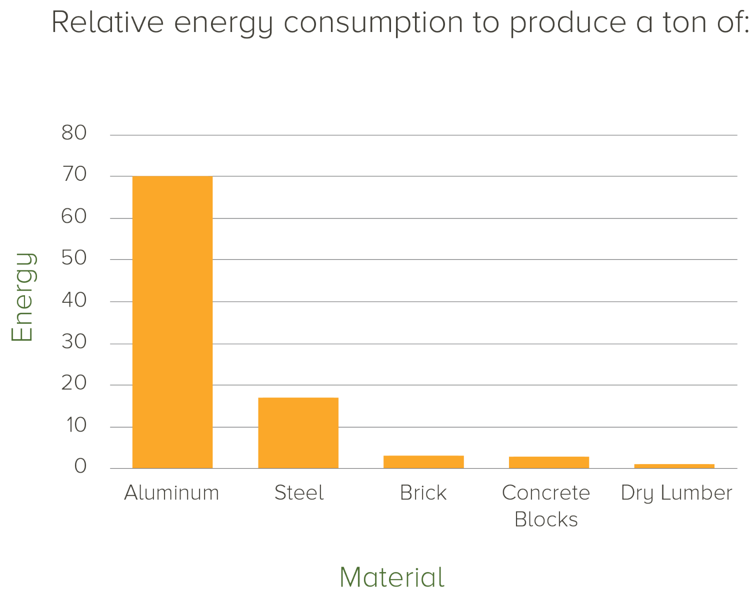
---

[6] Resilience is the ability to withstand the stresses brought about by climate change.

[7] Adaptation is the ability to change over time in response to climate change.

[8] The ability to reduce climate change.

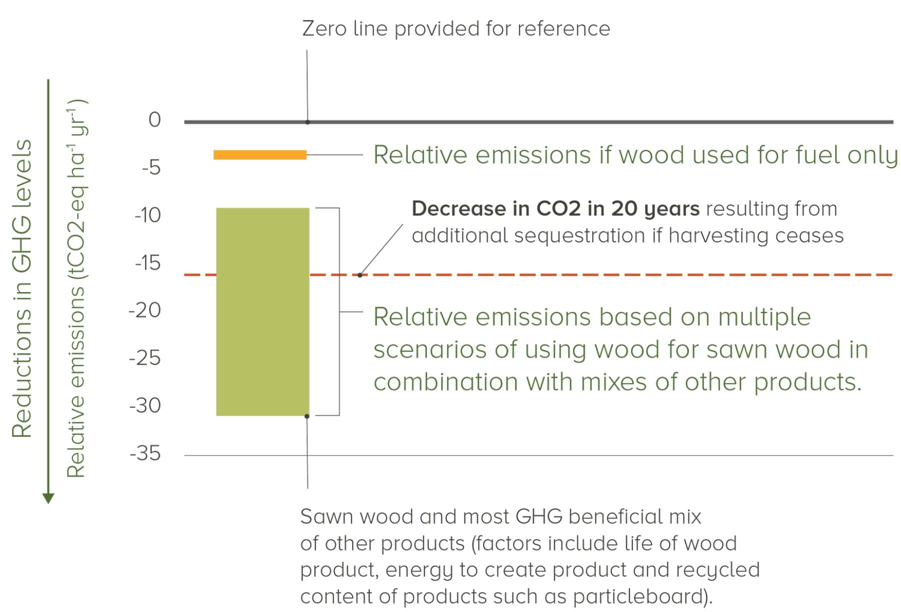
Figure 11. Relative energy consumption



Source: Committee on Renewable Resources for Industrial Materials (1976).

Matthews, et al. (2014) analyzed how using wood in the United Kingdom when compared to the most reasonable alternatives reduces greenhouse gas emissions. The authors concluded that increasing the use of wood could significantly reduce greenhouse gas emissions when considered over timeframes as short as 20 years (wood should have even greater benefits when considered over longer timeframes as the forests regrow).

Figure 12. Relative greenhouse gas emissions over 20 years comparing use of wood to use of non-wood substitutes (based on UK conifer forests with a history of sustained yield management).



Source: Simplified by R. A. Giffen but based on Figure 5.12 and Table 5.2 from Matthews (2014).

From a global perspective, Oliver, et al. (2014) analyzed how much the increased use of wood could decrease global CO_2 emissions. They concluded that global emissions could be reduced by 14-31% by substituting wood in construction for other materials (primarily steel and concrete).

Figure 13. Carbon consequences over time when forest regrowth and wood use are considered

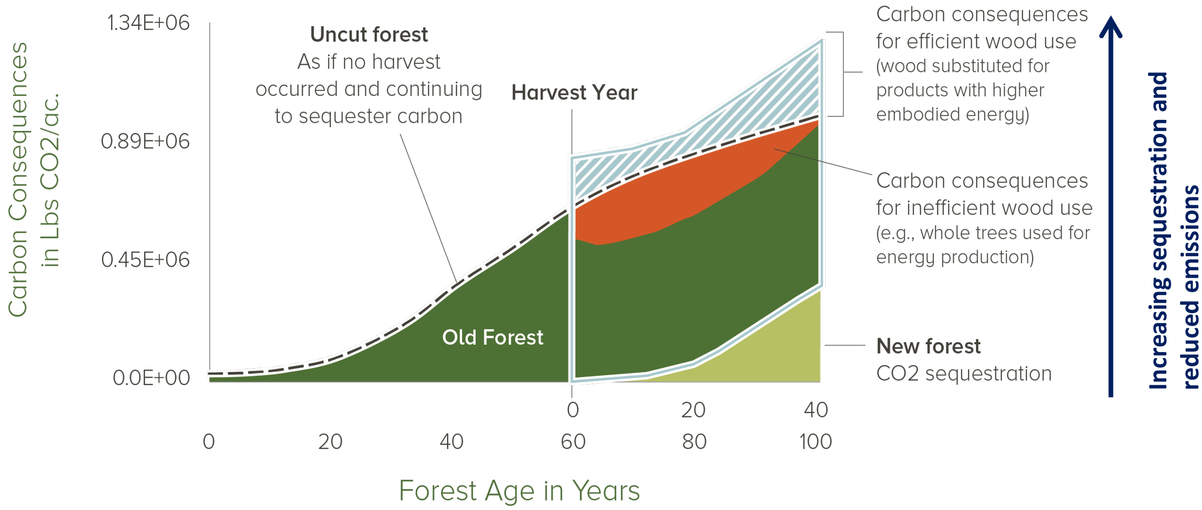
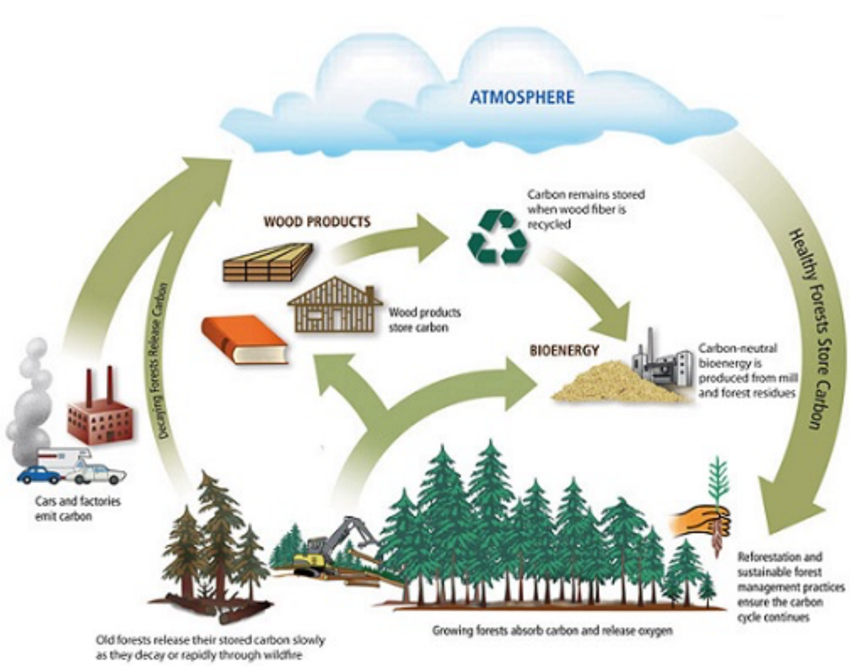


Figure adapted by R. A. Giffen from Oliver (2014) with permission of the author.

Further, because forests regrow after sustainable harvesting, the use of wood from New England forests to replace steel and concrete is not a once-and-done proposition. Forests can be used sustainably to "pump" CO_2 out of the atmosphere and store it in wood products for centuries.

Figure 14. Sustainable forestry carbon cycle

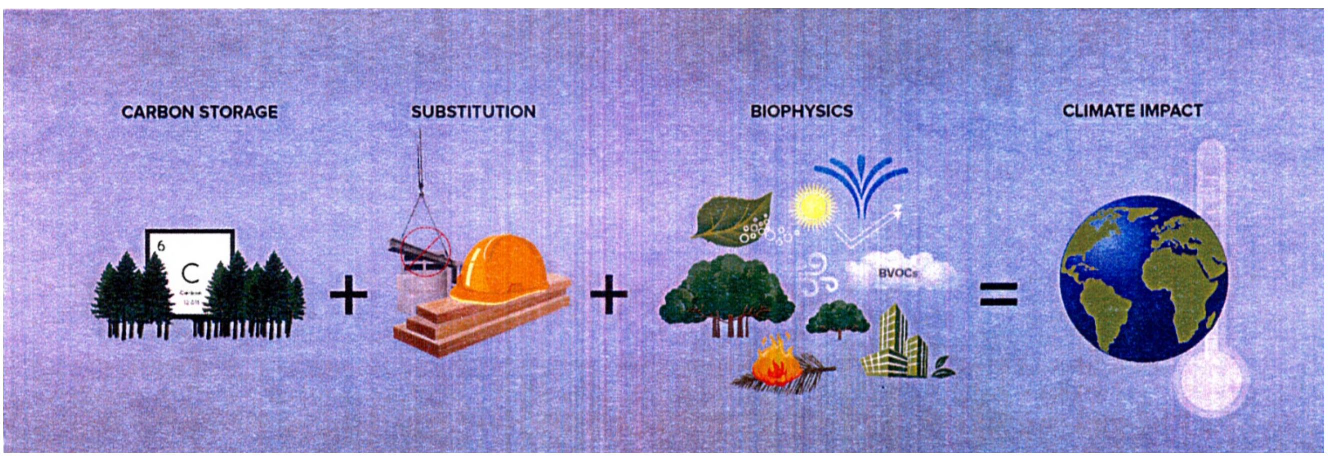


Source: Washington Forest Protection Association (n.d.)

Thus, the use of Exemplary Forestry practices to increase the use of wood and regrowth of forests could provide a low-risk approach to “geoengineering” to reduce excess CO_2 levels. We are working at many levels to present this opportunity to climate scientists and policy makers. We welcome other landowners to join us in practicing the forestry approaches that help mitigate climate change while producing valuable wood products and creating important wildlife habitat. As stated earlier, practicing Exemplary Forestry is a journey not just a destination, thus even landowners with depleted parcels can practice Exemplary Forestry by getting on the path to restoration. For more on the topic of substituting wood for other construction materials, please see NEFF’s website at newenglandforestry.org and NEFF’s Build It With Wood website at builditwithwood.org. In the Publications section of NEFF’s website, the Path to Sustainability report chapters “Grow As Much As We Use,” “Grow More Wood,” and “Protect Us From Climate Change” will prove particularly helpful, and can be found at newenglandforestry.org/connect/publications/path-to-sustainability.

In addition to reducing carbon emissions, there are a host of other ways that forests influence climate that we must understand and account for, if we are to take full advantage of the opportunities forests offer. These include forest effects on cloud formation or the reflectivity of different forest cover types (Figure 15). Forest management affects both the carbon stored in the forest, the availability of forest products to substitute for other materials, and the full range of forest effects on climate. Ultimately, Exemplary Forestry must address all the ways that forest management affects climate. Future research will improve our understanding of these non-carbon effects on climate, and thereby allow us to calculate how Exemplary Forestry can contribute to supporting a stable climate.

Figure 15



Source: New England Forestry Foundation.

Both adapting to and mitigating climate change are important to the future of forests and our climate.

See Janowiak, et al. (2018) on documenting the impacts of climate change in the region.

V. Continuous Improvement

Finally, NEFF does not expect its definition of Exemplary Forestry to remain static. As our knowledge increases, we instead expect the definition to be refined and improved—but not changed in fundamental ways. We do indeed know enough to act now.

NEFF has chosen to call this forest management approach Exemplary Forestry because the name connotes that the concept is aspirational, and that practicing Exemplary Forestry is a journey, not just a destination: landowners can rightly say they are practicing Exemplary Forestry even if their lands have not yet reached their full potential. NEFF is working to add new parcels to our ownership, and these additions may affect the metrics for the overall condition of our forests (e.g., average stocking) before we bring them up to Exemplary Forestry standards. And, nature is unpredictable—any landowner's properties may be affected by wind, pests or drought. In essence, our Exemplary Forestry standards and metrics are what we aspire to achieve. If outside factors affect our efforts, we will re-commit ourselves to our approach and the achievement of our metrics over time. We invite others to join us in the effort to practice Exemplary Forestry.

VI. Thanks to Those Who Helped

While assuming full responsibility for the content of this document, NEFF thanks the following for their thoughtful contributions to this and a related analysis of habitat conditions in the forests of northwestern Maine (Pounch, Giffen and Fenner 2019):

- Bill Leak, Research Forester, US Forest Service, Northern Research Station – for his expertise on northern hardwood silviculture to improve long-term productivity.
- Mariko Yamasaki, Research Wildlife Biologist, US Forest Service, Northern Research Station – for her expertise in meeting habitat/biodiversity objectives.
- Sally Stockwell, Conservation Director, Maine Audubon – for her wildlife management expertise, particularly as regards avian species.
- Rob Bryan, Consulting Forester – for his wildlife management expertise, particularly as regards avian species.
- Gary Donovan, Certified Wildlife Biologist, Wildlife Management Institute – for his wildlife management expertise, particularly for species that need early successional habitats.
- Bob Seymour, Professor of Forest Resources, University of Maine – for his silviculture expertise to improve long-term productivity, particularly for pine and spruce/fir.
- Andy Cutko, Ecologist/Licensed Forester, Maine Natural Areas Program and now with The Nature Conservancy – for his forest ecology expertise.
- Dave Publicover, Senior Staff Scientist and Assistant Director of Research, Appalachian Mountain Club – for his forest ecology expertise.
- Jensen Bissell, former Director, Baxter State Park – for his forest management expertise in the Acadian Forest.
- Dr. Daniel Harrison, Professor of Wildlife Ecology at the University of Maine in Orono, who contributed his thoughts on management for umbrella species.
- Craig Ten Broeck, environmental consultant – for his heroic assistance in researching various topics.
- Matt Tarr, Wildlife State Specialist, University of New Hampshire Cooperative Extension
- Jeff Reardon, Maine Brook Trout Project Director, Trout Unlimited

Thanks to all!

VII. Defining Exemplary Forest Management[A] in the Acadian Forest

As stated earlier, these guidelines are for actively managed lands rather than ecological reserves (also an important part of the landscape) and are intended to be implemented in the context of the landscapes where NEFF's lands occur. Thus, for example, one kind of habitat may be missing in a particular landscape and quite a different habitat in another landscape. Likewise, maintaining connectivity between habitats across the landscape is also important and will influence implementation on any given parcel. In addition to implementing these standards, NEFF intends to maintain dual third-party certification of its lands. With these understandings, Exemplary Forestry includes:

1. **Implementing Best Management Practices to protect and improve forest conditions**. Employing accepted "Best Management Practices" to protect soils, riparian and aquatic habitat, special habitats, wildlife trees, etc. (see the section which follows on this topic).
2. **Implementing advanced silviculture**. Practicing forestry which results in:
   a. **Continuously improving forest stands** over time in terms of both quality and quantity.
   b. **Conditions which are well suited to the umbrella wildlife species** known to be representative of the habitat needs of more than 75% of native species.[B]

Umbrella Wildlife Species	Percent of Landscape	Forest Stand Condition Described
American Marten[C]	16%	Blocks of at least 640 acres that are at least 80% stocked at over 80 ft^2 of basal area (approximately 16 cords/acre)
Canada Lynx[c]	27%	Even-aged blocks $\geq$15 acres in size which are regenerated to spruce and fir on a revolving schedule.[D]

   c. A **diverse size class distribution** of 5-15% of stands in seedlings, 30-40% in saplings and poles, 40-50% sawtimber (DeGraaf, et al. 2005) (including 10% of the total area in large diameter multi-storied stands [see also Ten Broeck 2018]—note 9% of NEFF's existing lands are, or will become, such stands over time).
   d. **Growing tree species**[E] well-suited to each site[F], (e.g., matched to soil and physiographic conditions as well as expected changes in climatic conditions).
   e. **Stocking that fully occupies the sites**; this is an average at least "B" line stocking for stands not currently being regenerated.[G] For example, in 8-10" diameter stands of mixed wood this would be approximately 20 cords/acre.
   f. **Growing and harvesting quality timber** at an average of 0.5 cords/acre/year,[H] and targeting increasing the stocking of high-quality products.
3. **Addressing climate change** as the knowledge base becomes available, and increasing the resistance and resilience to, adaptation for, and mitigation of, climate change.[I] This includes but is not limited to using forests and forest products to sequester more carbon and substitute for steel and concrete, thereby reducing greenhouse gas emissions.
4. **Diversifying management approaches**. To the extent that site conditions and the landscape context allow, NEFF intends to manage significant portions of its properties using both the even- and uneven-aged management approaches described earlier.[J]
5. **Aesthetics**. Public support for forest management depends in many cases on how forests look. In this regard, NEFF intents to manage its lands to maximize aesthetic benefits particularly in key areas (e.g., attractive roadsides, trails and shorelines) and minimize adverse effects (e.g., careless looking harvests).[K]

Notes for Section VII above

[A] For actively managed properties or portions thereof, this is specifically not intended to obviate the need for strategically located ecological reserves and withhold portions of otherwise actively managed parcels from harvesting, e.g., steep slopes, wetlands, rare plant sites, legacy patches, etc.

[B] The US Fish & Wildlife Service, as well as state wildlife management agencies, can provide recommendations on the best species to select. These species too may change over time.

[C] Management suggestions from the work of Dr. Dan Harrison. Note the fact that only 16% of the landscape is to be specifically managed for marten does not mean that is the proportion of the landscape that will be in relatively closed canopy forests. Indeed, most of it will be including the patches created for early successional habitat as they mature.

[D] Harvest blocks being regenerated are intended to include legacy trees and patches (see Bennett 2010, Tubbs, et al. 1987).

[E] Decisions of what tree species are “best suited” to each site can be guided by the recommendations contained in soil surveys prepared by the Natural Resources Conservation Service with site conditions verified by a qualified forester or soil scientist. The selection of species should also take into account the changes expected in climatic conditions and their impact on tree growth (Anderson and Palik 2011, USDA NRCS n.d.).

[F] This requires matching the silvicultural system to the site and may require controlling invasive species and/or excessive browsing (see Leak 2014, Leak, et al. 2014, Bennett 2010, Rawinski 2014).

[G] 20 cords/acre (see Leak et al. 2014). NEFF’s lands, mostly south of the Acadian Forest, average >30 cords per acre.

[H] This will not be possible on some properties when they are acquired, e.g., if they have been depleted, also over time the value of the timber should be enhanced (more and better quality sawlogs). Overall, NEFF’s properties are currently estimated to grow approximately 2% per year, or 1.25 tons/acre/year (Chris Pryor, pers. comm., 03/26/18). This is approximately 0.5 cords/acre/year depending on species.

[I] USFS guidance on how to increase forest resistance and resilience and facilitate adaptation will be followed.

[J] Achieving the several objectives outlined here may in the future require management using the “triad” approach. That is, setting aside a modest portion of the property for passive or light-handed management, while dedicating another modest portion for intensive management to produce the desired volume of wood, and yet the majority to forest management that mimics patterns of natural disturbances—with a specific objective of addressing the challenges presented by climate change. For more on this topic see Seymour, et al. (1992).

[K] USDA Forest Service. 1995. Landscape aesthetics: A handbook for scenery management. Agriculture Handbook No. 701. 104 p.

VIII. Best Management Practices

In addition to adhering to the standards of the Forest Stewardship Council and the Sustainable Forestry Initiative, NEFF will employ Best Management Practices (BMPs) to:

a. **Provide wildlife trees** by retaining all snags if possible and at least 3-5 live but decaying trees > 18" in diameter per acre (Maine Audubon 2017). For marten habitat, maintaining more snags is reported to be desirable (Chapin, et al. 1998, Fuller and Harrison 2005, Payer & Harrison 2003, Simons 2009).

b. **Protect soils, riparian and aquatic habitats**, including maintaining upstream as well as downstream passage for aquatic life.[9]

c. **Maintain soil productivity** by, among other measures, retaining adequate amounts of slash onsite consistent with BMPs developed by the Forest Guild (Forest Guild Biomass Working Group 2010) and guidelines for the timing of operations and types of logging equipment to avoid soil composition and rutting.

d. **Protect special habitats** including habitats of species identified as having special needs[10] not entirely met by the management outlined above and habitats which are critically important to more common species, including by way of example, deer wintering areas.

e. **Control invasive exotics** so they do not limit biodiversity or interfere with regeneration of trees, shrubs, and native ground plants.

f. **Reduce animal damage** by taking action to reduce over-browsing where it is a problem, e.g., leave patches of dense slash to protect regeneration, and support efforts to keep wildlife populations below destructive levels, e.g., special seasons to reduce excessive populations of some species.

g. Strictly **limit damage to the residual stand**.

---

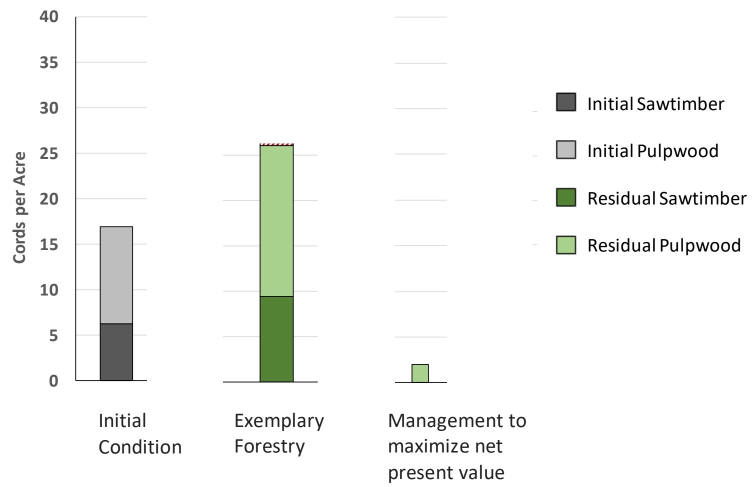
[9] Soils, riparian and aquatic resources to be managed consistent with management guidelines from the Natural Resource Conservation Service and other sources, e.g. 1) Maine Forest Service (2004) is the standard forestry BMP erosion and sediment water quality protection guide for road construction, skidding, and landings, and this document also includes recommendations for allowing fish passage. Does not include riparian habitat guidelines not associated with soils or aquatic habitats; 2) Bryan (2007), the Riparian and Wetland Forest guidelines on pages 30-31 include wildlife-focused riparian zone management recommendations and includes by reference to Maine BMPs to address water quality concerns; 3) Forest Guild Biomass Working Group (2010) addresses concerns related to soil depletion due to biomass harvesting and retention of woody material that provides habitat benefits; and 4) Abbot (2016). deMaynadier et al. (2007).

[10] As identified by state natural heritage and wildlife management agencies, as well as archaeological sites, heritage sites, unique geologic/hydrologic sites, and significant historic/cultural sites as identified by the State Historic Preservation office.

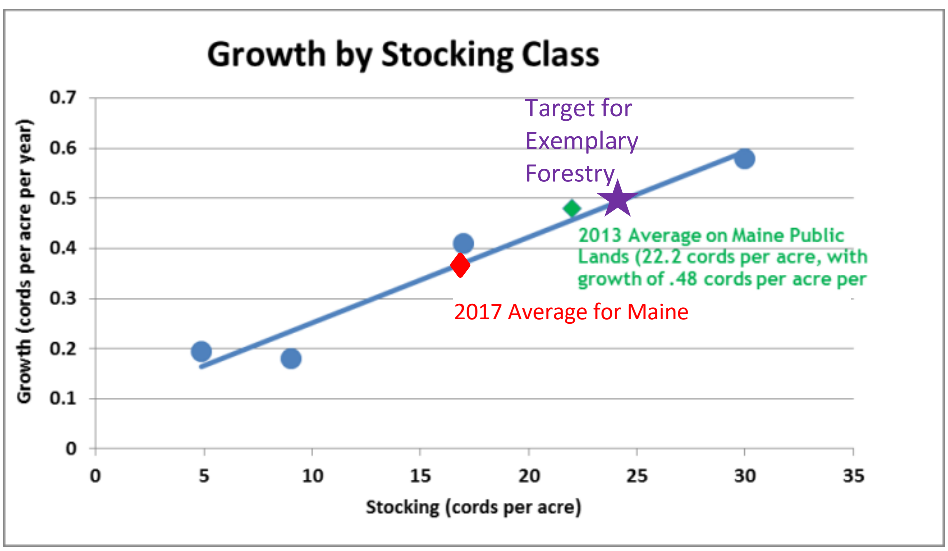
IX. Overview of Results from Exemplary Forestry

To reiterate some of the key points from earlier, the results from 60 years of applying the silvicultural prescriptions for Exemplary Forestry developed in consultation with the region's leading silviculturalists to a forest in average condition for northwestern Maine are:

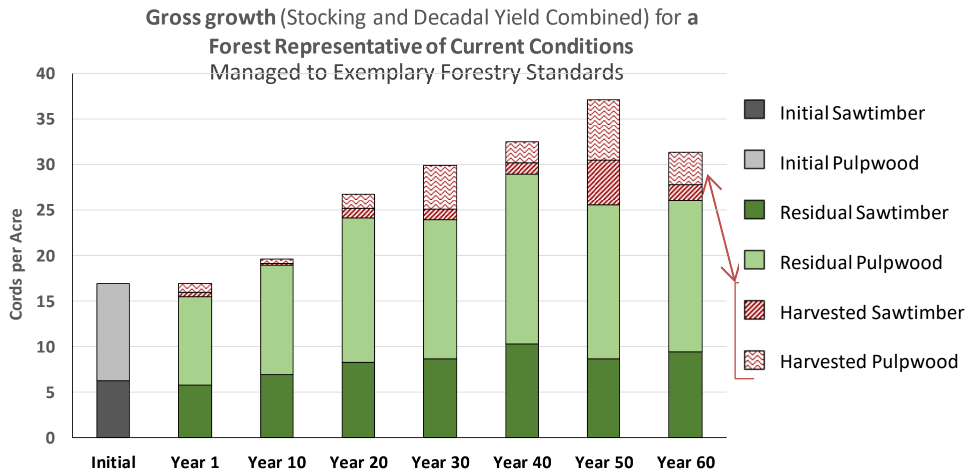
- A well-stocked forest with approximately 25 cords per acre and higher value timber than either the initial condition or management to maximize net present value.



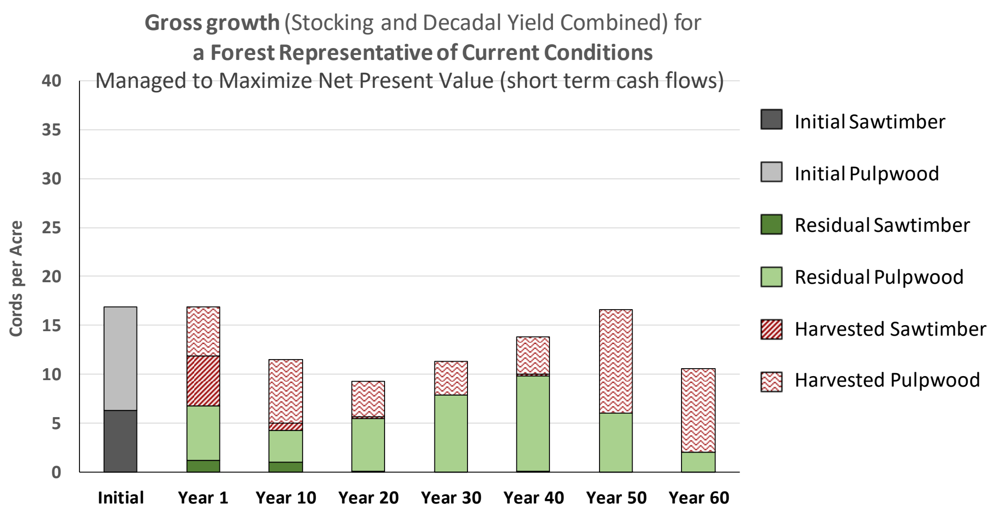
- The ability to grow and sustainably harvest almost half again as much timber as current stocking levels or levels resulting from management to maximize net present value allow.



And, over time, sawlogs will make up a greater proportion of the timber both left in the forest and in what is harvested.



In contrast, the same forest managed to maximize net present value has the following results:

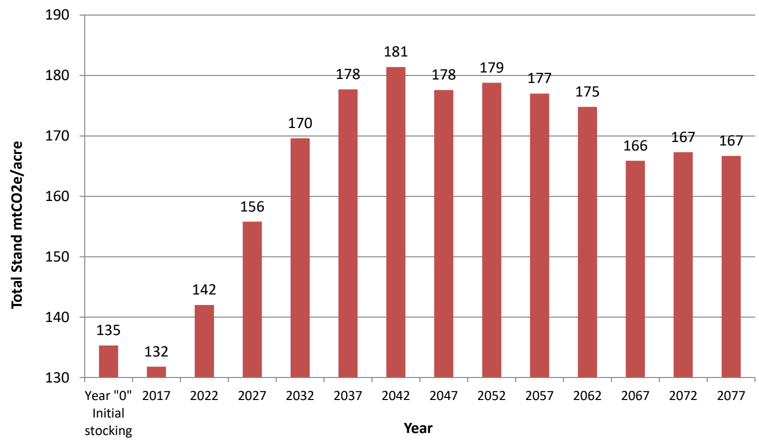


- A stand size class distribution and habitat conditions that are moving in the right direction to meet the recommendations of ecologists to benefit wildlife with more larger-diameter stands. So, for example, the figure above shows that in addition to increased stocking, the volume of sawtimber grows over time under Exemplary Forestry management.

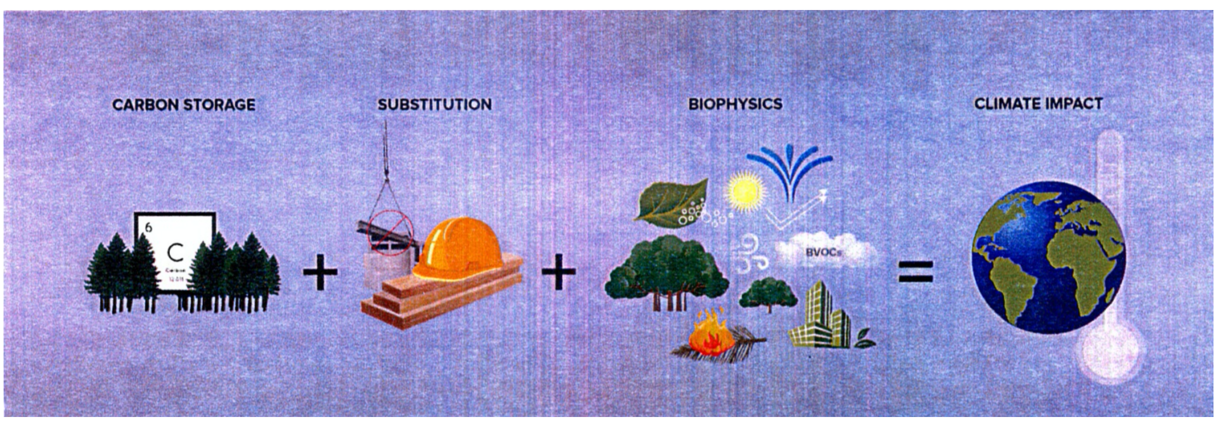
Further in this regard, while only 16% of the landscape is targeted specifically for management to meet the habitat needs of American Marten (at least square mile blocks of relatively closed canopy conditions in forest of at least mid-height), in practice, most of the forest (>70%) should be in relatively closed canopy conditions with small gaps as a result of the silvicultural prescriptions to be employed. The specifications for meeting the habitat needs of umbrella species call for managing another 27% of the landscape for Canada Lynx (even-aged management using shelterwood techniques with patches of spruce/fir regeneration at least 20 acres in size), and the balance of the area will be managed by creating small irregular gaps expanding over time to regenerate the stands to a mix of shade-tolerant to -intolerant species on a 100-year rotation. Harvesting to create and expand the small gaps would include thinning in the intervening forests to remove lower quality trees and trees that may die before the next harvest, and would free up the highest quality trees in the stand to grow more rapidly (Anon. 2018, Miller 1997, Miller et al. 2007, Ward 2011, Ward 2019), and as shown by an analysis of FIA data (Pounch 2018). These studies show that the growth of residual trees can be increased by roughly 50% to 200%.

- In addition to timber products to substitute for other materials, storage of an additional 30 MtCO2e per acre of carbon

Figure 1. In-forest carbon storage from practicing Exemplary Forestry in a forest representative of current condition in northwestern Maine*



* Representative of current conditions in terms of forest types, stocking, and size class



References

Abbot, A. 2016. Maine stream crossing survey manual. Falmouth: US Fish and Wildlife Service. (Pending recommendation from NRCS per Rob Bryan email to Ben Naumann 1/12/2017).

Anderson, P., and B. Palik. 2011. Silviculture for climate change. (October 2011) USDA Forest Service, Climate Change Resource Center. www.fs.usda.gov/ccrc/topics/silviculture (accessed 06/18/18). Belair, E. P., and M. J. Ducey. 2018. Patterns in forest harvesting in New England and New York: Using FIA data to evaluate silvicultural outcomes. *Journal of Forestry*, 116(3):273-282.

Anon. 2018. Commercial thinning in spruce-fir forests. Orono: University of Maine, Cooperative Forestry Research Unit Research Bulletin 2018(1).

Bataineh, M.M., R.G. Wagner, and A.R. Weiskittel. 2013. Long-term response of spruce–fir stands to herbicide and precommercial thinning: observed and projected growth, yield, and financial returns in central Maine, USA. Canadian Journal of Forest Research, 43:385-395.

Bennett, K. P. (ed). 2010. Good forestry in the Granite State: Recommended voluntary forest management practices for New Hampshire (2d ed). Durham, NH: Univ. of NH Coop. Ext. p. 119., http://extension.unh.edu/goodforestry/assets/docs/GoodForestry2010FINALreducedsizeSECURE.pdf (accessed 03/30/17)

Bryan, R. B. 2007. Focus species forestry: A guide to integrating timber and biodiversity management in Maine. Falmouth: Maine Audubon. 92 p. http://www.forestsynthesis.com/files/FocusSpeciesForestryMaine.pdf (accessed 03/30/17).

Chapin, T.G., D.J., Harrison & D.D. Katnik. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. Conservation Biology 12: 1327-1337

Committee on Renewable Resources for Industrial Materials — National Research Council. 1976. Wood for structural and architectural purposes. *Wood and Fiber*, 8(1):1-72

DeGraaf, R. M., M. Yamasaki, W. B. Leak, and A. M. Lester. 2005. Landowner's guide to wildlife habitat: Forest management for the New England region. Vermont: University of Vermont Press. 128 p.

DeGraaf, R., M. Yamasaki, W. Leak, and A. Lester. 2006. A technical guide to forest wildlife habitat management in New England. Burlington, VT: University of Vermont Press. 305 p.

deMaynadier, P., T. Hodgman, and B. Vickery. 2007. Forest management recommendations for Maine's riparian ecosystems. Technical report submitted to the Maine Department of Inland Fisheries and Wildlife, Bangor, ME.

Forest Guild Biomass Working Group. 2010. Forest biomass retention and biomass guidelines for the northeast. Santa Fe: Forest Guild. 17 p. https://www.forestguild.org/publications/research/2010/FG_Biomass_Guidelines_NE.pdf (accessed 03/30/17).

Fuller, A.K. & D.J. Harrison. 2005. Influence of partial timber harvesting on American martens in north-central Maine. Journal of Wildlife Management 69: 710-722.

Giffen, R. A. 2018. A synopsis on timber yields, management costs, and financial returns from Exemplary Forestry management over the long term in the Acadian Forest. Draft paper in the author's files available upon request.

Guangsheng, C., S. Pan, D. J. Hayes, and H. Tian. 2017. Spatial and temporal patterns of plantation forests in the United States since the 1930s: An annual and gridded data set for regional Earth system modeling. *Earth Syst. Sci. Data*, 9:545–556.

Janowiak, M. K., A. W. D'Amato, C. W. Swanston, L. Iverson, F. R. Thompson, III, W. D. Dijak, S. Matthews, M. P. Peters, A. Prasad, J. S. Fraser, L. A. Brandt, P. Butler-Leopold, S. D. Handler, P. D. Shannon, D. Burbank, J. Campbell, C. Cogbill, M. J. Duveneck, M. R. Emery, N. Fisichelli, J. Foster, J. Hushaw, L. Kenefic, A. Mahaffey, T. L. Morelli, N. J. Reo, P. G. Schaberg, K. R. Simmons, A. Weiskittel, S. Wilmot, D. Hollinger, E. Lane, L. Rustad, and P. H. Templer. 2018. New England and northern New York forest ecosystem vulnerability assessment and synthesis: a report from the New England Climate Change Response Framework project. Gen. Tech. Rep. NRS-173. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 234 p. https://www.nrs.fs.fed.us/pubs/55635 (accessed 04/09/19).Kenefic, L. 2018. Long-term U.S. Forest Service research at the Penobscot Experimental Forest. June 18, 2018 field tour handout. Available from the author's files.

Leak, W. B. 2014. Forestry field note: Effects of nuisance/invasive species on regeneration in New Hampshire. https://extension.unh.edu/blog/effects-nuisanceinvasive-species-regeneration-new-hampshire (accessed 03/30/17)

Leak, W. B., M. Yamasaki, and R. Holleran,.2014. Silvicultural guide for northern hardwoods in the northeast. Newtown Square, PA: US Forest Service. p. 31. http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs132.pdf (accessed 03/30/17).

Lorimer, C. G., and A. S. White. 2003. Scale and frequency of natural disturbances in the northeastern US: implications for early successional forest habitats and regional age distributions. *Forest Ecology and Management*, 185:41-64.

Maass, D. I., L. C. Irland, B. E. Roth, and K. M. Laustsen. 2016. Maine exotic larch plantations exceed expectations. Poster prepared for the 2016 New England Society of American Foresters meeting. https://larchresearch.com/wp-content/uploads/2016/03/LarchPoster_NESAF-2016_Final.pdf (accessed 03/14/18).

Maine Audubon. 2017. Forestry for Maine birds: A guidebook for foresters managing woodlots "with birds in mind". http://www.maineaudubon.org/wp-content/uploads/2017/03/FFMB-2017-1.pdf (accessed 01/29/18).

Maine Forest Service. 2004. Best management practices for forestry: Protecting Maine's water quality.

Maine's Forest Products Council. 2016. Maine's forest economy. Augusta. 32 p. http://maineforest.org/wp-content/uploads/2016/09/Maines-Forest-Economy-10-12-2016.pdf (accessed 01/29/18).

Matthews, R., N. Mortimer, E. Mackie, C. Hatto, A. Evans, O. Mwabonje, T. Randle, W. Rolls, M. Sayce, and I. Tubby. 2014. Carbon impacts of using biomass in bioenergy and other sectors: forests. DECC project TRN 242/08/2011 Final report: Parts a and b.

McCollough, M. 2007 (draft). Canada lynx habitat management guidelines for Maine. Old Town, ME: US Fish & Wildlife Service, Maine Field Office. 44 pp.

Miller, G. W. 1997. Effect of crown growing space and age on the growth of northern red oak. In: Spiecker, H, R. Rogers, and Z. Somogyi, (comps.) IUFRO Proceedings: Advances in Research in Intermediate Oak Stands; July 27-30. Freiburg, Germany: University of Freiburg: 140-159. https://www.nrs.fs.fed.us/pubs/jrnl/1997/ne_1997_miller_007.pdf (accessed 01/13/20).

Miller, G. W., J. W. Stringer, D. C. Mercker. 2007. Technical guide to crop tree release in hardwood forests. Publication PB1774. Knoxville, TN: University of Tennessee Extension. 24 p. https://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_miller_001.pdf (accessed 01/13/20).

Oliver, C. D., N. T. Nassar, B.R. Lippke, and J. B. McCarter. 2014. Carbon, fossil fuel, and biodiversity mitigation with wood and forests. *Journal of Sustainable Forestry*. 33(3):248-275.

Ontl, T.A., Swanston, C.W., Janowiak, M.K., Daley, J. A practitioner's menu of adaptation strategies and approaches for forest carbon management. Northern Institute of Applied Climate Science White Paper, in review.

Payer, D.C. & D.J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management, 179: 145-156

Payn, T., J. Carnus, P. Freer-Smith, M. Kimberley, W. Kollert, S. Liu, C. Orazio, L. Rodriguez, L. Neves Silva, M. J. Wingfield. 2015. Changes in planted forests and future global implications. *Forest Ecology and Management*, 352: 57-67.

Pitt, D.G., L. Lanteigne, M.K. Hoepting, and J. Plamandon. 2013. The Forestry Chronicle, 89(4):446-457.

Pounch, M. A. 2018. Exemplary forestry growth and yield modeling project synopsis. Unpublished. In author's files available upon request.

Pounch, M. A., C. A. Fenner, and R. A. Giffen. 2019. Landscape scale habitat needs in the Mountains of the Dawn. Draft paper in the author's files available upon request.

Rawinski, T. J. 2014. White-tailed deer in northeastern forests: Understanding and assessing impacts. Newtown Square, PA: US Forest Service. p. 9. http://www.na.fs.fed.us/pubs/2014/NA-IN-02-14_WhitetailedDeerNEForestsWEB.pdf (accessed 03/30/17).

Rudnicky, T. C., and M. L. Hunter. 1993. Reversing the fragmentation perspective: Effects of clearcut size on bird species richness in Maine. *Ecological Applications* 3:357-366.

Sedjo, R. A., and D. Botkin. 1997. Using forest plantations to spare natural forests. *Environment,* 39(10):15-20, 30.

Sedjo, R. A. 2001. The role of forest plantations in the world's future timber supply. *The Forestry Chronicle*, 77(2).

Seymour, R., and J. Leahy. 2016. Wicopy Woods Tree Farm: A rare 50-year record of forest productivity and stewardship. Poster prepared for 2016 New England Society of American Foresters meeting.

Seymour, R. S., A. S. White, and P. G. deMaynadier. 2002. Natural disturbance regimes in northeastern North America – Evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management*, 155:357-367.

Seymour, R. S., and M. L. Hunter. 1992. New forestry in eastern spruce-fir forests. Maine Agricultural Experiment Station Miscellaneous Publication 716. 36 p.

Shuman, J. K., H. H. Shugart, and T. L. O'Halloran. 2011. Sensitivity of Siberian larch forests to climate change. *Global Change Biology,* 17(7):2370-2384.

Simons, E. 2009. Influences of past and future forest management on the spatiotemporal dynamics of habitat supply for Canada lynx and American martens in northern Maine. Ph.D. Dissertation, University of Maine, Orono, Maine, USA.

Smith, D. 1962. The practice of silviculture. 7th Ed. Horizon Pubs & Distributors Inc. 578 pp.

Swanston, C., and M. Janowiak (eds.) 2016. Forest Adaptation Resources: Climate change tools and approaches for land managers, 2nd Edition. Gen. Tech. Rep. NRS-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.161 p. (see also supplemental "Menu of Adaptation Strategies and Approaches: Developed for forest carbon management at https://forestadaptation.org/sites/default/files/Carbon%20Adaptation%20and%20Mitigation%20Menu_draft1pg_%20NIACS%20Climate%20Change%20Response%20Framework.pdf)

Ten Broeck, C. 2018. The importance of late-successional and old-growth forests. TBO

Tubbs, C. H., R. M. DeGraaf, M. Yamasaki, W. M. Healy. 1987. Guide to wildlife tree management in New England northern hardwoods. Broomall, PA: US Forest Service, NE For. Exp. Sta., GTR NE-118. 30 p.

UN Food and Agriculture Organization. 2005. Global forest resources assessment. Rome, Italy. http://www.fao.org/forestry/fra/fra2005/en/ (accessed 07/26/17).

USDA Forest Service. 2011. National report on sustainable forests – 2010. FS-979Washington, DC.

USDA Natural Resources Conservation Service. n.d. National agricultural land evaluation and site assessment (LESA) handbook. DRAFT. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052600.pdf (accessed 06/18/18). 95 p.

Ward, J. S. 2011. Stand and individual tree growth of mature red oak after crop tree management in southern New England: 5-year results. In: Fei, S, J. M. Lhotka, J. W. Stringer, K. W. Gottschalk, and G. W. Miller (eds.) Proceedings, 17th central hardwood forest conference; April 5-7. Lexington, KY; Gen. Tech. Rep. NRS-P-78. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 502-513. https://www.nrs.fs.fed.us/pubs/gtr/gtr-p-78papers/51wardp78.pdf (accessed 01/13/20)

Ward, J. S., and J. Wikle. 2019. Increased individual tree growth maintains stand volume growth after B-level thinning and crop-tree management in mature oak stands. *Forest Science*, 65(6):784-795.

Washington Forest Protection Association. n.d. The forest industry is a part of the climate change solution. http://www.wfpa.org/our-forest-today/climate-change/ (accessed 01/29/18).

Whitman, A. A., and J. M. Hagan. 2009. A revised rapid-assessment late-successional index for common northeastern forest types. Forest Mosaic Science Notes 2009-1. Manomet Center for Conservation Sciences, Brunswick, ME. 4 p.