Discussion Papers on Forest Carbon in Maine and Northeast

Lloyd C. Irland

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Introduction

Growing Carbon on Our Woodlot – a good idea for us?

Lloyd C. Irland

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Woodlot owners know their woods are yielding environmental and social benefits every day just by being there. The list is long. With rising taxes and expenses, and occasional vandalism and trespass, could we get paid a little something for these "co-benefits"? This question has been around for a long time. Now we know it's not your Grampa's climate anymore: it's changing. So, Carbon credits are the big new thing. Could I sell carbon credits from my woodlot? At first glance, this seems a fine idea. What might my carbon be worth?

Irland's Iron Laws of Forest Carbon:

You get paid for wood when you cut it.

You get paid for carbon when you don't.

You don't get Paid for what would be profitable anyway.

You don't get paid much for temporarily storing carbon.

You don't get paid for good intentions.

Anytime you manage a woodlot for a single goal, you give up something else

I have been trying to cook up a simple calculation worksheet that a woodlot owner can use to answer this question. So far, the complexities, goofy measurement units, and many assumptions needed have baffled me. And I know from experience the more complicated I make it, the more errors creep in. I recalled the old saying by my friend Hank Webster, onetime state forester for Michigan: "When you're digging yourself deeper into a hole, stop digging!" I will follow this advice, and continue the quest for a calculating engine another day. I'll need help from some people more clever with numbers than I am. As a woodlot owner you need to think through a few things before you pick up the calculator and the carbon offset rulebook.

Today, let's talk about what you should do before you try reading lots of rules and running numbers. This may save you some time. First, read Alison Truesdale's article in the last issue of MW. Carbon credit sales are difficult even for very large owners. How could it be easy for you? Well, some smart people are trying to devise ways to make carbon markets accessible to small owners. We don't know what will emerge or how long it will take. But before looking further, you can take the following steps:

1. Then, how would Carbon credits work for us? Think about Irland's Iron Laws of Forest Carbon (see box), and consider the following:
    a. A sale of a carbon credit is a sale of cutting rights to someone else. The carbon buyer plans to do no cutting, but you have given up the right to do so to the extent of the rights sold.
    b. To really offset fossil fuel C emissions, Carbon offsets should last a century or more. Efforts to devise offsets of

only 20 to 30 years duration may succeed, but they cannot pay prices similar to the 100 year ones.

c. Think of a carbon offset sale as a conservation easement. Like an easement, it takes upfront planning and expense and ongoing monitoring.
d. Alternatively, recognize it as a partial liquidation of your timber value – its effect on your land's value is the same as if you had cut the wood.
e. Recognize that if your plans change, buying your way out of a Carbon Credit sale might be costly and inconvenient.
f. So, do I understand the above points?
   Then look over these questions and think about them.
   Chat with family about them.

2. Are we in Tree Growth?
   a. Do we have a current inventory and management plan? Are we following it?
   b. If TGT is too complex, too long term for us, why would we do a Carbon credit sale?
3. What are our larger goals for this land?
   a. Is it important that it remain in one piece?
   b. Estate tax liability? (more than a few woodlots have been swallowed by this black hole)
4. How important is future income from the property?
5. If income is not important, are there other financial sideboards?
   a. Do we need to cover the taxes from income?
   b. Is it important to supply our household firewood or other materials from the lot?

  c. Can we imagine a situation where an emergency might trigger a compelling need to sell some timber?
6. Is a carbon commitment for 20 or 30 years realistic for us?
   a. What will it mean for the next generation or a later owner?
7. Would an outright donation of the land, or an easement, to a conservation group serve (2) above, and have a more favorable tax result for us than keeping title and selling carbon?

Think of these as *screening questions*; the answers taken together will tell you if it's worth spending more time on the details of carbon credits.

If the answer is yes, or a strong "maybe", take out a pad of scratch paper and pencil (you won't need a computer) and rough out some numbers like this:

	Mockup for simple screening table --			lci Apr 22
1	current inventory in cords/A			from inventory or even "windshield cruise"
2	Baseline for this type/area			Go to lookup table A
3	Subtract line 2 from line 1			gives you excess over baseline -- you can sell this
	If (3) exceeds (2) by more than 2 cds, got to (4)			
	If not, read a book or take a walk.			
4	Get rough estimate of value/cd			See lookup table for regions
5	Take (3) multiply by			factor for tonnes MTCo2e per cord -- see lookup table
6	Multiply by	$10 per tonne		Or other price if seems defensible
7	Multiply (1) by (4) then by .25			Theoretical yield of a 25% cut of the acre.
8	Compare (7) to (6)			If (7) far exceeds (6), think about just continuing to manage for timber.
				If the opposite, look more deeply into a C credit sale.
				but first, see if prices being paid for carbon on the terms you can agree with are less than $10.00.
				And what the front end costs are.

A few of us are working on putting the meat on the bones of this little outline to make it very easy for you. Stay tuned.

If it looks good to you, read these: they won't take much time.

Catanzaro, Paul, and Anthony d'Amato. Forest Carbon: essential natural solution for climate change. No facts of publication given. Assume Univ of Massachusetts. 2019.

Excellent well illustrated introduction with good reading list

Beane, Julie. 2012. Selling forest carbon: practical guide to developing forest carbon offsets for Northeast forest owners. Manomet Center for Conservation Sciences.

> *Excellent summary and checklist on going through the process of selling carbon credits.*

<u>Then, and only then, call your consultant and any financial advisers who need to be consulted.</u>

Lenses for Forest Carbon

LCI May 31

I think in our group we are making some progress in trying to keep our discussions focused. What makes this hard is the number of distinct lenses or frames involved. I offer this view of the various lenses involved to emphasize how important this is. What may not be so clear is that a proposal or management prescription that seems really attractive by analysis through one of these lenses can actually be neutral or even harmful when viewed through the other lenses.

"The only way to see the Big Picture is to step out of the Frame" -- Salman Rushdie

LENSE	TOOLS	APPLICATION	REMARKS
1. TREE	VOLUME TABLES	Tree vol/value; prescr.	In Maine we are a little weak here, esp. for longterm analysis
2. STAND	GROWTH/YIELD TABLES	Prescr. & prediction	Same
2aTOTAL BIOMASS	INVENTORY	assessment	Info base is good, I think
2b. TOTAL ECOSYSTEM CARBON	C INVENTORIES; CONV FACTORS	same	We're trying to affect 2a and 2b by manipulating 2c.

2c. MERCHANTABLE WOOD	CONV. TO PRODUCTS	Product yield & valuation	Use patterns changing
3. MANAGED FOREST UNIT	AAC CALCS ETC Longterm modelling	Operational plans /sustainability eval.	Additionality, leakage
4. REGION/TIMBERSHED	same	Impact on manufacturing, local economies	Trying to extrapolate 30 yr or so of data for 100 yr. **Goal:** nondeclining timber flows
5. Economics	Accounting, financial analysis	Tree/stand/property decisions	Assumptions critical; $$$ influence differently situated decisionmakers differently
6. Wood in Use	Calculation protocols; engineering, evaluation substitution for other fuels, constr. materials	Est. total C footprint of forest mgt and industry	High sensitivity to assumptions
7. **Global CO2 Balance**	Models as above	Assess effects of changed practices/policies	Net contribution to reducing CO2 in atmosphere
8. Policy	Above plus policy analysis; IPCC & Other rules	Design/eval. Of existing/proposed programs & policies	Will be ineffective – or worse -- if above 7 lenses are way out of focus!!!

9. Time	Models enable us to see longrun effects of today's choices	Comparing time paths of choices at above levels	'We can buy a lot of things – but we can't buy Time'. -- Gordon Baskerville.

Accounting Stances

The key issue for us and for policy is how to design forest practices and programs that can be held accountable qualitatively for their contribution to a goal that is also defined quantitatively.

The concept of accounting stances emerged from the practice of benefit cost analysis for federal water resource projects. In a way they are analogous to the issues in assessing how forest management practices and polices can change the contribution of forests to the global carbon balance. Since a tremendous amount of academic, bureaucratic, and political literature deals with these questions, I think they are worth noting here.

Project Level Economics - Costs and benefits as perceived by project builders/owners/beneficiaries

(Project financials statements)

Local economic development - Effects of project on local /regional economies

(local economic impact/multiplier analysis)

National Economic Development - Net effects on the national economy

(Net project effect on allocation of resources in national economy, in "real " terms, meaning not just financial transfers)

Environmental Quality - Effect of the project on the environment (EIS)

This system emerged because many federal water projects were being built that looked good to locals by the first criterion, but were flawed by the other measures. Damming the Grand Canyon looked like a great idea by that measure. Flunked the 4th one.

An economist once calculated that instead of building all the Corps of Engineers dams in the South, the country (third measure) would have been better off to just send them money – the dams were reducing the national wealth by being highly inefficient, wasting resources. (Now, Lake of the Ozarks, one of these lakes, is made famous by the partiers spreading the virus.)

Obviously all of four of these “measures” are measured in practice with uncertainty and often intense debate about how to evaluate various issues. All are defended by powerful vested interests and political iron triangles – except the third one.

I guess we would say that the proper objective of the Governor’s Climate goals refers to Lense No. 7 above.

Tensions in Managing for Carbon and Timber

Notes using a default dataset

I offer a few charts to illustrate the tensions we face in managing for carbon, whether as a sole objective, or as a way to enhance returns to growing wood for conversion to long lived products so as to support landowner returns and the local economy. Default yields are from USFS GTR-343 for spruce fir (for source, see last page of this note). Later we can list issues and uncertainties with this data –and we should. For now, let's accept this as "the maintained hypothesis", used "for training purposes only". The growth curves we learned in silviculture are a good way to build this up from first principles. Plainly details will matter – a lot—in application.

To apply all this, however, what will matter is **the lens** we are using:

> Merchantable wood vs total ecosystem carbon,
>
> The timeline: to 2050? 100 yr? 300 yr?
>
> Individual tree (grow logs faster)
>
> Individual stand
>
>> A sub-question is, are we starting at age zero, or with what we have now?
>
> Managed property (Leakage)
>
> Timbersheds or timber baskets
>
> National carbon accounting (now we include wood stored in use)
>
> Global Ecosystem, Atmospheric and Ocean C Balance
>
> Then, we have to consider the financial side and landowner behavior.

Right now I propose to look just at the individual stand. Unless we get this straight, the rest of this is a house built on sand. But there is an aggregation problem. To end up with the right policy for Carbon we have to apply **all the lenses** noted above. If we are to develop guidance for programs to support particular carbon friendly practices, we have to be able to identify them clearly and show accountability for what they accomplish in storage. There is no avoiding this.

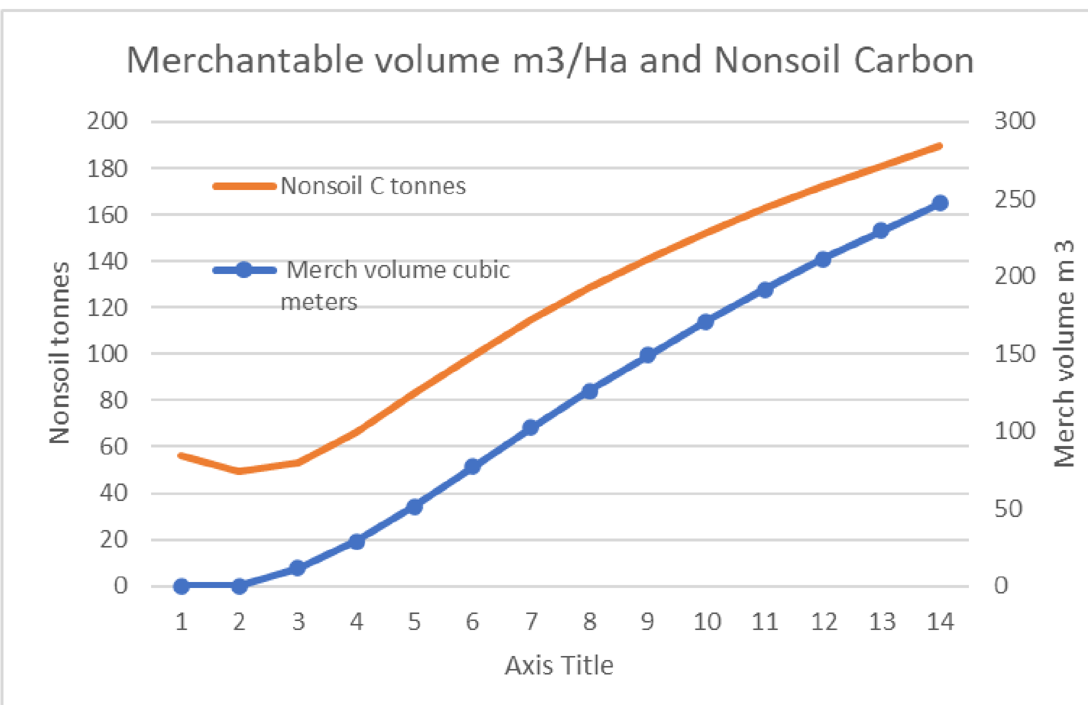
We plan to put the companion spreadsheet up on this site so anyone can work with these numbers themselves, examine other ways to look at this problem, perhaps even spot errors in my arithmetic…. Maybe even – add a plausible financial module to see how that looks, along with C prices.

Here is a series of charts to lay out some issues --

First point:

Carbon yield curves look different from merchantable timber curves in important ways. Units are different so you need to look at patterns not levels. Carbon curve basically takes 20 yr + to recover initial tonnage of C due to decomposition in forest floor and DWD. This reinforces what Bob and Si were saying about the period lost to sequestration when you clearcut.

(Excel won't let me put in the years here – 0 to 125.)



The first time I ran MAI’s and PAI’s on these numbers, results came out strange – this is because with the nonsoil tons starting at about 50 tons, the MAI is always sloping downward.   If we cared to do this again the correct procedure would be to subtract the nonlive tree aboveground carbon from this value and use that. But the nonsoil C line does tell us somethings.

My slipup on this is a reminder of how you have to keep the books on different things when doing this and keep track carefully.

Second point, I doubt that there is anything merchantable (or operable) in a 15 yr stand as suggested by these numbers. But that’s not material for present purposes.

Third, the jump from current harvest practice on most private land to unmanaged 125 year rotations seems like Evel Knievel jumping the Grand Canyon on a motorcycle.

Again, for a private owner, all you have to do is think about annual taxed/admin, and the capital cost of holding high volumes.   Keeping *unmanaged stand* for decades past “normal” rotations is not a cheap strategy for storing C.

Further, I dithered about using spruce fir because of the issue of risk – few of us in FCDG need to be remind of that.

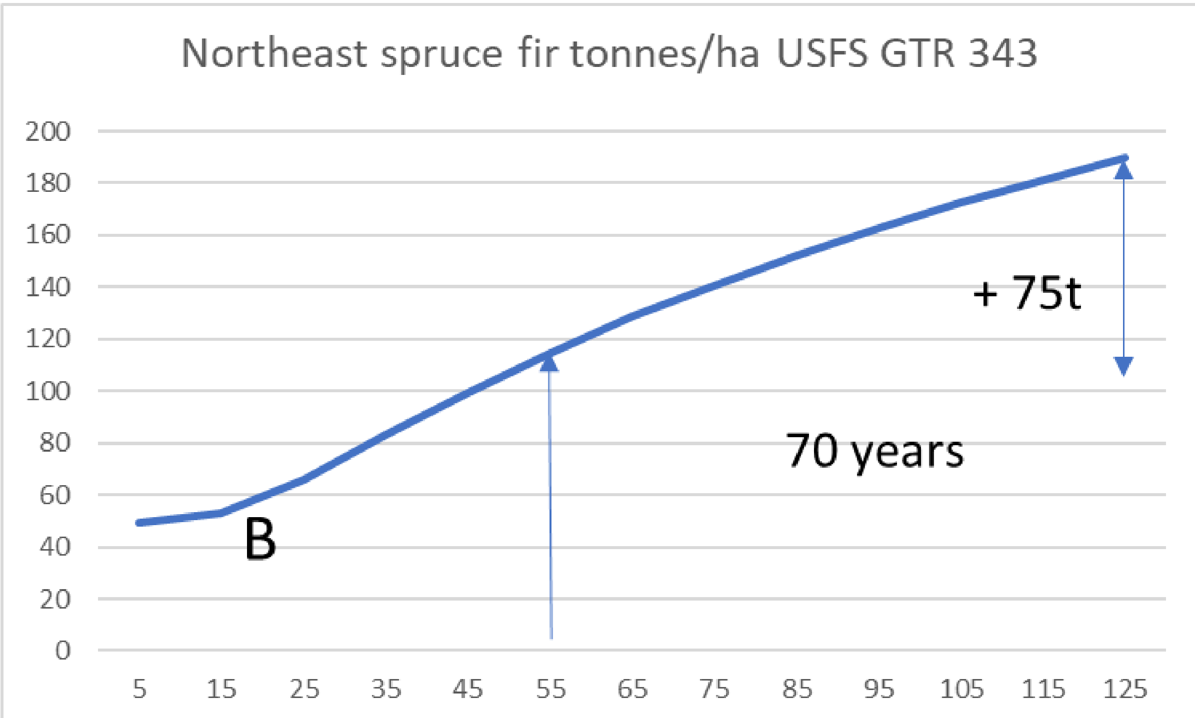
Analyzing unmanaged long rotations does give you a gateway into the conundrums. To me, it makes a good case for trying to find ways to re-imagine the management of mid-aged stands so as to move toward Bob and Si’s thoughts on “making sure no sun reached the ground”.

Whatever these practices turn out to be, we don’t need to know the future price of C. What we can do is calculate what C prices would need to be to make them work.   Adam Daigneault is on the case. When he’s got his stuff ready we will want to hear from him.

Here is the Carbon yield curve by itself (not CO2). Well, as usual Excel won't copy my beautiful artwork, B marks the young cultch stands Bob S. speaks of.

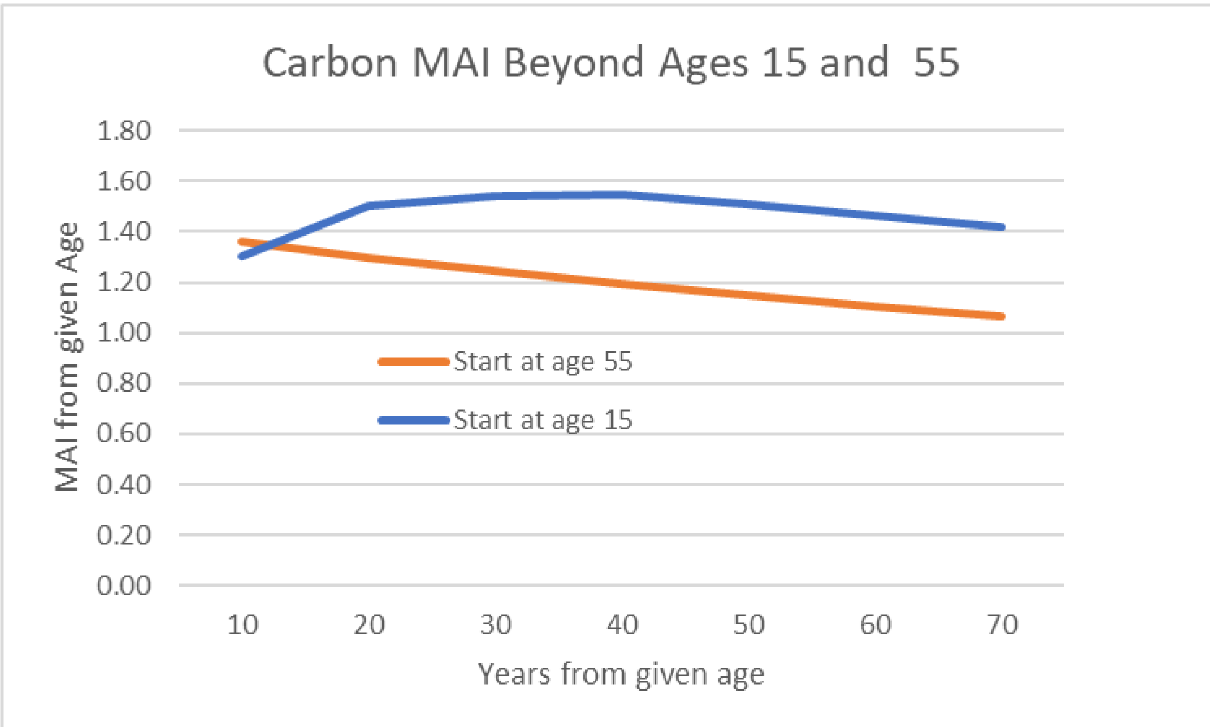
The arrow points to age 55 – we'll see why in a moment.

According to GTE-343, if we hold the stand from age 55 to 125, a mere 70 years, we'll sequester an incremental 75 tons. Why wouldn't we do this???



We understand that if we managed the stand at all, at age 125 it will hold less carbon. In a way, that's one reason we are managing it!

I'm not always clear whether what matters most is annual sequestration, or the total stock. This chart applies the notion of MAI, which we usually associate with age zero, to let it start at the ages noted above. This is really what's relevant for management anyway.



I suspect in Maine we have more area in young stands gaining C at high rates, then we do in 100 yr + stands gaining C at lower rates. If true, this has implications for sustaining the recent statewide sequestration rates.

Significance of this? The stock-flow problem. Obviously we'd wish to avoid cutting the high volume stands and losing that C stock…

Is this something of a Zen double bind?

Which leads to analyses of this form:

Which is Better? 3 - 125 yr rotations, or 7 -55 year ones?				
Series of 55 yr rotations			**Series of 125 yr rotations**	
		tons/ha		
1	115.5	1	187.5	
2	115.5	2	187.5	
3	115.5	3	187.5	
4	115.5			
5	115.5			
6	115.5			
7	115.5			
cum total				
385 yr	**808.5**	**375 yr**	**562.5**	
memo: think of use paths; keep last rotation forever?				

Would be cool to extrapolate the GTR 343 data out to age 300. Pretty speculative, I guess; examples I've seen contain about one data point beyond 150. Less than compelling to me. Is there a better way?

Ince did some work with Leak's white pine yield table which I think went out to age 200 or so.

PI is current growth. Usually approximated by an average over a 5 or 10 yr period (in a continuous curve, think slope of curve, or first derivative if you're mathematically inclined). We were told in forestry school to cut stands when PAI falls below MAI.

This maximizes volume.   (Silviculture profs and foresters like this decision rule. The Germans too)   Later, when we studied economics we were told to maximize returns, not volume, leading to shorter rotations. (The MBA's and TIMOs look at this chart and all they see is the bars shown)

Our thinking needs to adjust to an important Carbon reality – at least for this example, PAI never does fall below MAI! (well, 125 years is "the hereafter" for most practical purposes)

I picked 55 yrs as an illustrative rotation because beyond that the merchantable volume PAI falls below MAI. (See the excel for details)

The principal reason for management is to make the transition to logs happen sooner and proceed faster than it will in this unmanaged stand.

A thorough analysis would account rigorously for increases in unit value with age. Today, so much wood is sold in tons that we'd have to estimate log value vs size relationships the old fashioned way by looking at mill data and not market data. But even a rough take on value MAI's and PAI's would suggest longer rotations, even in unmanaged stands. The purpose of management would be to extend the period of high percent growth rates so as to hold the carbon inventory on the land. And also to pay the owner's expenses and supply an industry.

As Si noted, a cord of maple logs and a cord of spruce pulp have very different market values, but a ton of carbon is worth the same no matter what wood it's in. (I think this has implications I have not fully explored yet -- thoughts?)

Famous example: from Irving. Illustrates that in timber volume terms these stands are sustaining annual growth rates while boosting tree sizes and unit values. I bet they have done this into C terms…

JD IRVING LTD BLACK BROOK THINNINGS

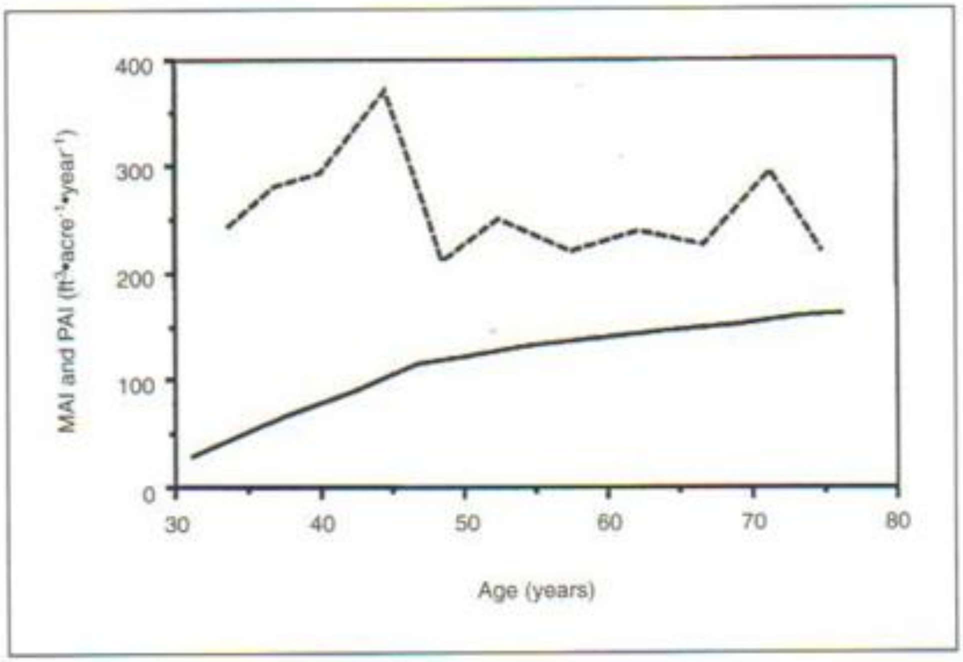
White spruce now age 40

	Mean tree cm	MAI m3/ha/yr
No thin	17.7	8.7
Thin once	20.3	8.3
Thin late	21.9	8.5
Thin twice	22.1	8.5

- Parker & Peltier, n.d.

Example from British Columbia --

Thinning can defer peak of PAI   Cowichan L, BC



Curtis et al, PNW- GTR 435, p. 50

Detailed work of this sort has been done in Maine at Austin Pond on intensively managed spruce fir and somebody may already be translating that into C terms. The additional work on financial analysis has also been done.

Some carbon work comparing stands at Penobscot Exp Forest has been published and more is in the pipeline.

ADD SUMMARY OF Puhklick et al

I used to thin redpine at Scout camp with a "Swede saw". Have liked it ever since. We have plantations suited to this in Maine but pathological issues are a concern. All the same I think at least some are being prematurely cut. Would we actually plant redpine to bring stand to this condition? Not sure of that. These midwestern stands by age 100 are producing wood nicely and holding stand level volume roughly constant in the familiar sawtooth pattern. You could take a carbon credit at the low point.

Check out 320 bd ft/yr – <u>Not too shabby!!! If that's worth $100/M, it's $32/A/Yr,.</u>

Redpine Example, from Buckman, in D& J. text.

Age		Residual			Volume		
		Stand ft3	cords	M bd ft	cut ft 3	cords	M bd ft
25		900	8.7	0	0	0	0
35		1300	12.6	0	780	7.5	0
45		1670	16.2	8.5	880	8.5	0
55		1970	19.1	10	920	8.9	4.7
65		2210	21.4	11.2	890	8.6	4.6
75		2430	23.5	12.4	850	8.2	4.3
85		2610	25.3	13.3	780	7.6	4
95		2760	26.7	14.1	710	6.9	3.6
105		2890	28	14.7	630	6.1	3.2
115		2980	28.9	15.2	550	5.3	2.8
125		3050	29.6	15.6	470	4.5	2.4
135		3110	30.1	15.8	410	4	2.1
145		3140	30.5	16	350	3.4	1.8
155		3180	30.8	16.2	320	3.1	1.6
165					3480	33.7	17.8
				Yield: Cum Rem + resid. Stand			
				ft 3	cords	M bd ft	
		Total		12,020	116.3	52,900	
		per yr		*72.8*	*0.7*	*320.6*	

I understand this work has been updated. Will be way cool to see this.

Old plantations on abandoned farmland, sandy soils, central lower Michigan. Producing a cord per acre per year, 10 yr cut cycle, and all wood is log size/grade, in some cases multiple sorts are made. When these were planted, nobody dreamed of wood production like this and certainly never thought about carbon.

Redpine thinning stand age in 40's Michigan Mar. 2005

5/19/2020
SFR 345 intensive mgt

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https://www.nrs.fs.fed.us/pubs/8192

Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States

Publication Toolbox

- **Download PDF** (1611262)
- Order a printed copy of this publication
- Download a zip file containing the contents of the companion CD (369.6 KB)

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A.

Year Published

2006

Publication

Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.

Abstract

This study presents techniques for calculating average net annual additions to carbon in forests and in forest products. Forest ecosystem carbon yield tables, representing stand-level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested forest products are included. Although these calculations are simple and inexpensive to use, the uncertainty of results obtained by using representative average values may be high relative to other techniques that use site- or project-specific data. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. The CD-ROM included with this publication contains a complete set of tables in spreadsheet format

Discussion paper: Tensions in Managing for Wood and Carbon as Joint Products: Stand Level Lense

Analysis of Unmanaged Stands

LCI June 25

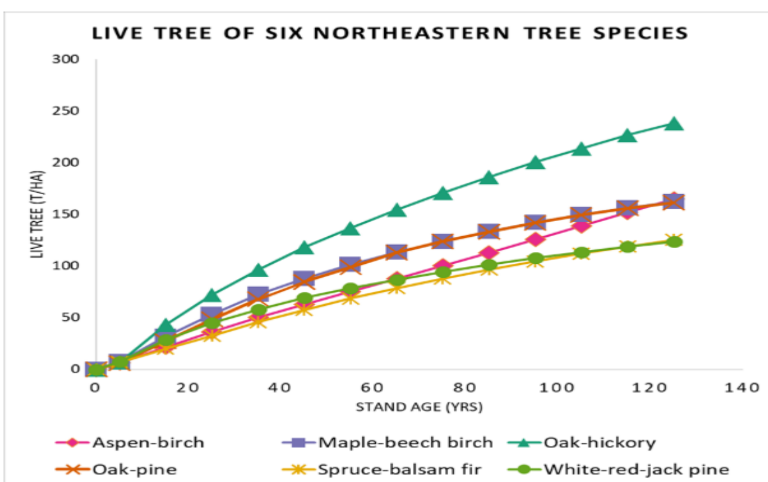
This is a concentrated summary of exploratory work I have been doing to develop illustrations of these tensions. These results cannot be applied to prescriptions, as they do not use well validated local yield information. Comments, criticisms, suggestions welcomed.

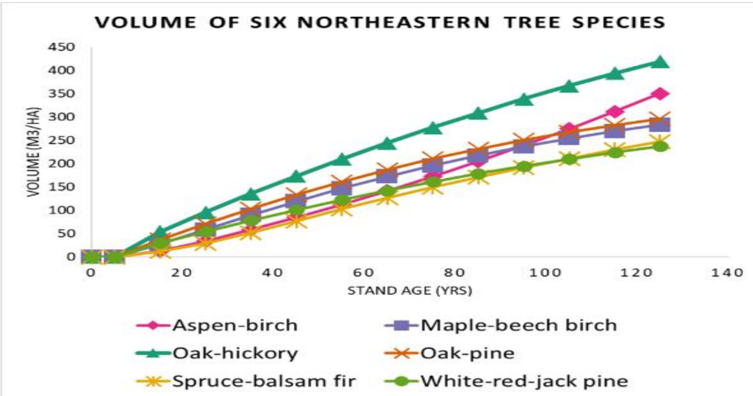
I think they supply insight into the tensions involved in the unmanaged condition.

1. The NE -343 Yields

I use data from NE -343, applicable to entire Northeast. For ease of reference: first chart is tons of live tree Carbon (not CO2); second one is merch volume in m3. Spreadsheets available on request.

There are many questions about these. But for illustrating general ideas they make it easy. These are live tree Carbon and merchantable wood.



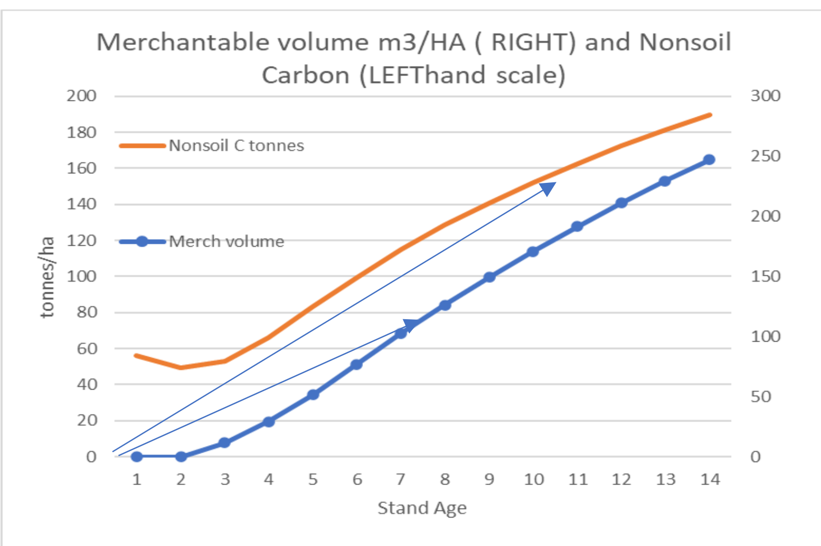


Should I be surprised at the ranking of these?

2. Spruce fir Example

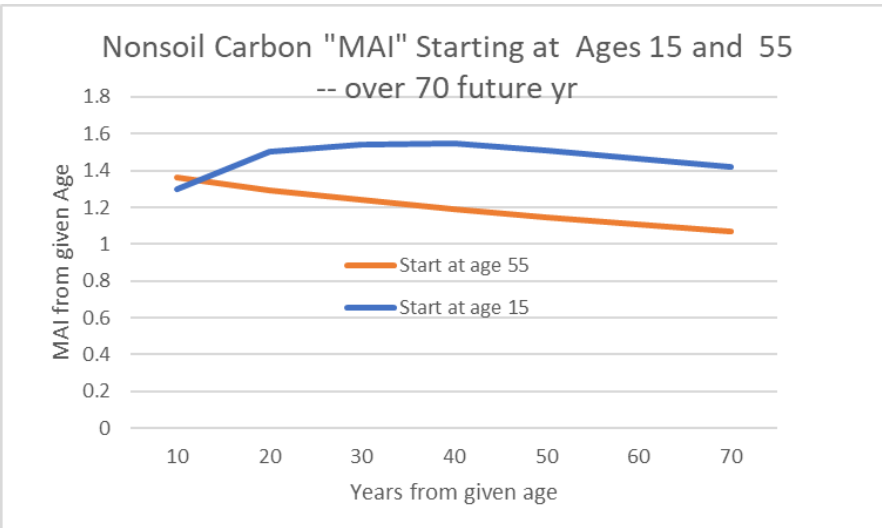
Excel will not let me enter the ages correctly on this one—they go from zero to 125.

This models a regenerating clearcut stand. Note that it starts with a legacy of C from forest floor DWD etc and perhaps initial regrowth of Rubus etc. Anyway nonsoil C takes a few decades to catch up with the initial level. (note: this is why calculating MAI and PAI from this nonsoil C gives nonsense results, which I failed to notice when presenting this before)



Arrows represent MAI's

We don't know volume or age of the previous stand, but in northern Maine it was probably not older than 50 or 60 yrs; could have been younger and even poorly stocked. But from this data we can calculate how nonsoil carbon would develop if a stand is grown for 70 yr from ages 15 or 55.



This tempts us to ask a question that has been asked by others before:

Nonsoil Carbon					
Which is Better? 3 - 125 yr rotations, or 7 -55 year ones?					
Series of 55 yr rotations		**Series of 125 yr rotations**			
rotation	tons/ha	rotation	tons/ha		
1	115	1	190		
2	115	2	190		
3	115	3	190		
4	115				
5	115				
6	115				
7	115				
cum total					
385 yr	**805**	**375 yr**	**570**	Less!	
memo: think of use paths; keep last rotation forever?					
above not a prescription just a question					

It also raises several others:

a. What does the yield curve look like beyond age 125?
b. What would it look like if we included budworms in it?
c. So we grow it to age 250 to store carbon – what then?
d. Does the unit value of the stand improve with age? At some point does it plateau or begin to decline? (see timber opportunity cost below)

Cost of Holding mature Growing stock is not Zero

There are several costs:

1. Annual taxes – are low in TGT, maybe $2.50/yr.
2. Administration, linework etc. Maybe $2.00 + per acre on large properties.
3. Opportunity cost of capital tied up in the inventory.
    a. I estimate that the value of stocking at age 55 could be as high as $2,600.00/Ha. (I welcome benchmarking and correcting this guesstimate)
    b. At 3%, the interest on this would be upwards of $70 per yr.
    c. I call this TOC, or Timber Opportunity Cost[1]
4. Some owners may not feel the impact of one or more of the above costs: NGO's, public agencies, or individual owners who value the forest for other purposes and do not miss the opportunity cost. Some doctors and lawyers may even want to avoid taxable income altogether.
5. *Dr Doom again*: But: what about their heirs? I calculated an estimate of the value of the stocking at age 125 but I don't believe it. Anyway, it'd be far higher than the $2,600 figure noted above.
6. But for owners who do feel these costs, add them up for 70 years, to be paid out of other income sources….
7. Matter of taste: discount this cost stream to the present, or compound it forward to the future 70 yr from now. Gives you a number, but you get the idea….

[1] Economists will note that I ignore land cost. For our purposes this can be defended.

Rotations based on the Financial Maturity Concept

(chart on next page)

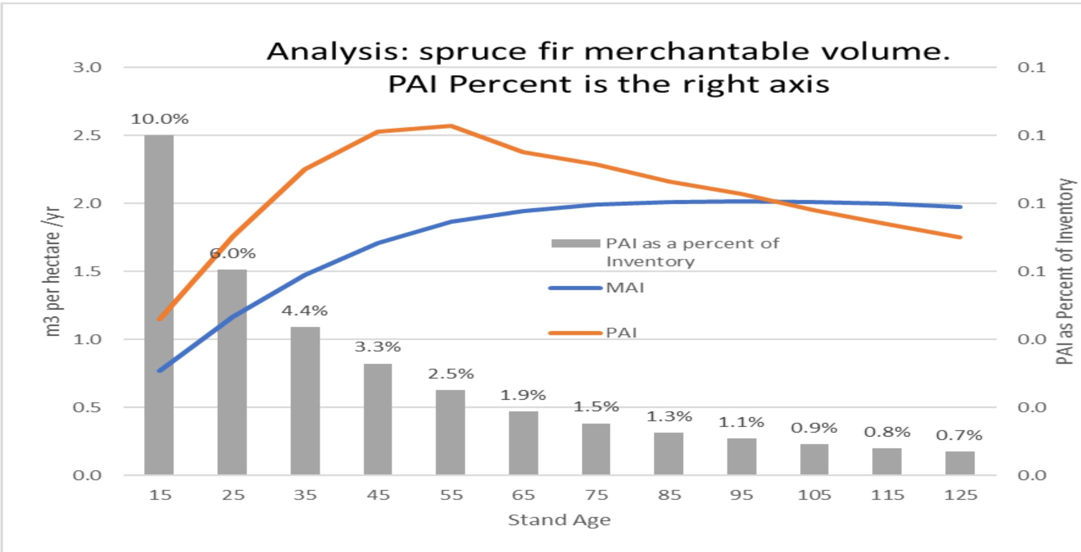
For spruce fir the volume MAI stands at a plateau from age 75 all the way to age 125. PAI falls below at age 95 plus or minus. The classic volume maximization defined as optimum rotation. But as noted, not all owners can ignore timber opportunity costs. For them, the growing stock needs to produce a return on its capital value. This is the series of bars plotted against the left axis. On these numbers, PAI as % of inventory falls below 3% between 45 and 55 years. This is about what, back in the day, industry foresters told me was their planned rotation for spruce and fir. Given that was a time of budworm damage, pathological thoughts were prominent in their thinking.

By age 105, the percentage falls below 1%.

What will the heirs say when they look at this chart?

What matters would be *value growth percent not volume*.

Longer rotations and bigger trees do confer advantages; lower logging costs (to a point) and perhaps greater silvicultural flexibility. Yet most spruce fir now standing in Maine is at a size not likely to reach really high unit values within decades or perhaps ever – it is too small now. It would be interesting to learn the maximum log sizes bought by the high production spruce mills these days. I believe large grade logs will have a market at good prices but the volumes will be small. The wood will go to small mills and prices will not reflect the value in the wood.



Some thoughts:

1. **Spruce fir is probably not the best example for growing wood and carbon fast and holding stands longer.** Low growth rates; poor current condition of typical acre; budworm.
2. In the past, longtime family ownerships managed to diameter limits inconceivable today. Certainly the economics were different then, but stumpage prices were lower. They could maintain good value growth on dominant trees that made them worth retaining. I believe this could be modeled with relevant price information to see how that approach would comport with C storage. (see Exemplary Forestry?)
3. Seems clear to me that artful use of shelterwood-like systems could sustain volume growth percentages to make holding higher growing stock volumes appealing to landowners.
4. Zeb White at Yale used to argue that short rotations have the disadvantage that you have to cut so much more land to get the same amount of wood compared to the older long rotation systems used, say, on lumber company properties in the South.
5. I understand the **Austin Pond** experiment has been remeasured again and work is underway analyzing the data. We need to look into this one.

3. White Pine

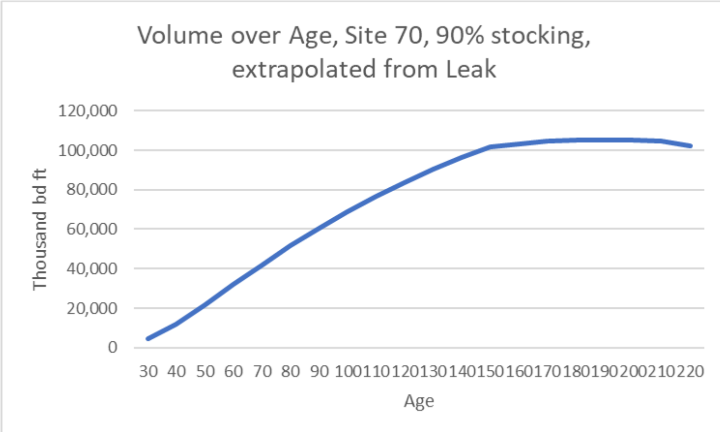
White pine is probably our leading example of an opportunity to grow wood for value, enabling owners to justify holding large growing stock volumes and hence large carbon stocks over long periods of time. Past research has shown that when given room to grow, pine can produce rates of return on its own value up to sizes 25" and more (Chapelle, 1966, NH Coop Extension note, n.d., among others). But probably not in unmanaged stands.

> You read that virgin stands in Northeast/Lake
> states
> reached 100 Mbf, but I bet those were exceptional ones
> which is why they were mentioned. What was the average?

Many years ago I took 2 Forestry Deans one a field visit to see Chadbourne's lands. We stood in a stand containing fine pines 20" dbh and up. Selected trees were being pruned, I asked Bob, "What is your rotation age for these?" Bob looked at me, seemingly puzzled… I elaborated, "at what age do you plan to cut these?" "Why would I cut a tree that's gaining me 5 percent or more on its value every year?" he replied. Clif Foster would say about the same thing. But they were both speaking of individual trees in managed stands that would not be clearcut. (note: at the time, Bob owned the sawmill)

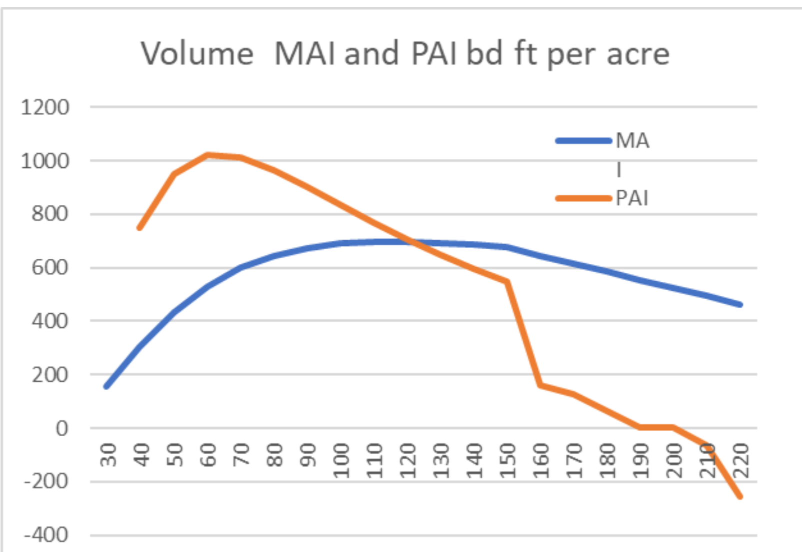
I would welcome better data than I am using here, but to illustrate my general argument, perhaps this will do for the moment…. I would not make management recommendations for a specific property based solely on these numbers.

Here is a Kentucky-Windage extrapolation from Leak et al.'s old white pine report. His estimates do reach 100 Mbf by age 150.



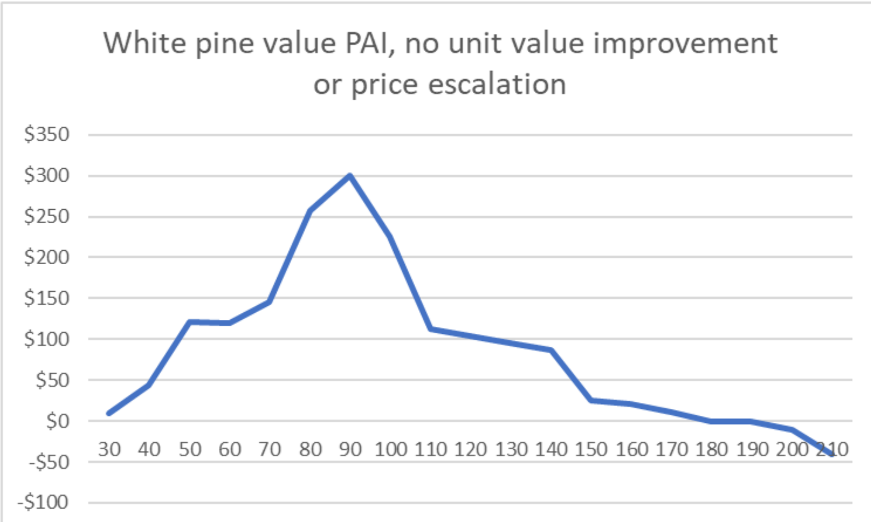
PAI is bumpy because I did not spend time making a nice smooth curve.

The broad plateau of MAI supports what Bob Chadbourne was saying. Not until age 130 does PAI cross MAI… and this is within the range of Leak's estimates, not the extrapolations.

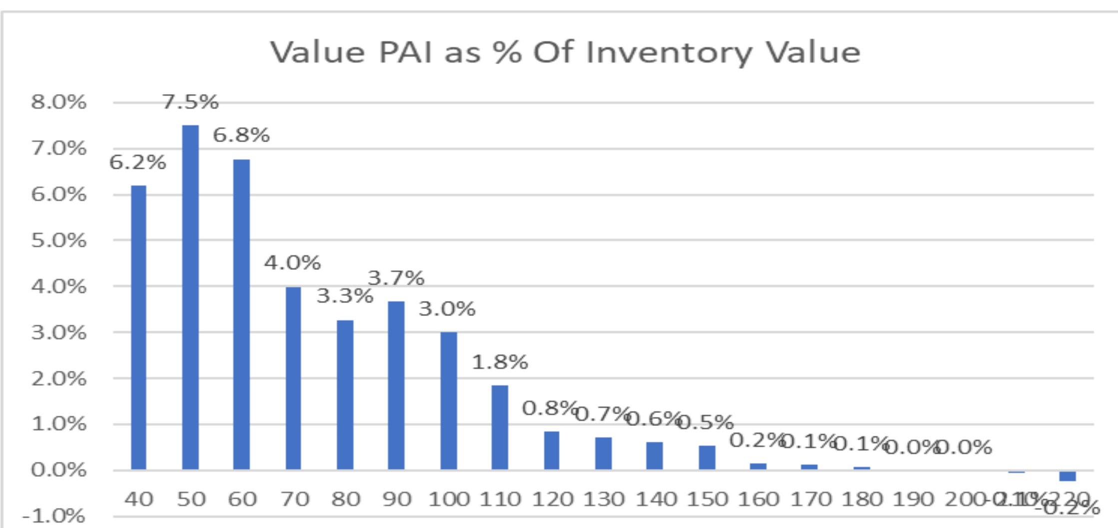


I believe there is a very strong case that if you can show how unit stumpage values increase with age under management, and if owners can expect (no guarantee on this) rising stumpage prices, holding trees even longer makes sense.

The value PAI is above $145/a/yr between ages 80 and 110.



We have not yet figured in opportunity costs. Years ago, the mill was sold. The land is on the market (status?). A new owner will gaze with approval on these fine stands of quality pine. Will they be thinking, "Gee, think of how much more carbon we could store if we wait a few decades?" Maybe they will do this arithmetic:



The return on value of the stand remains above 3% till after age 100. What return will the new owner be looking for?

It would be very valuable if we could:

Adapt existing data to model management regimes for such stands to see how much flexibility there would be in adapting cutting cycles, removal rates, residual stand growth, and improvement in unit values. Then see how various constraints on carbon content of the inventory interact with these considerations.

==

In general:

Interesting question is, how might carbon payments change the results for both above cases? How high wild they need to be? Adam Daigneault is at work on this very question.

Some day, we should do similar but better-grounded examinations of northern hardwoods and oak pine and oak dominated mixed hardwoods of southern Maine…

Carbon in Wood Products – Translated to Plain English.

Lloyd C. Irland

Draft Jan. 8

Word count: 1,293

(both photos by author)

You have been reading a lot about the value of wood structural materials as ways to store carbon for a long time, thus slowing the accumulation of CO2 in the atmosphere. This would be one benefit of building larger structures with advanced wood composites instead of steel and concrete. So, people often ask, how much carbon does get stored in a new house? How much CO2 emissions can saved by using wood to replace other building materials? This can get confusing very fast, for five reasons:

Metric versus English units

Confusing carbon with CO2

Wood measurement by weight versus volume

Logs versus finished product carbon content

Carbon in the board, or total cradle to the gave emissions involved?

I offer this somewhat simplified primer to prepare you for a series that will walk you step by step through some of the practical issues we encounter when trying to think about carbon emissions and the role of forestry and wood products in the global carbon cycle. If we cannot think clearly about these matters, then our individual consumption choices or our state and national policies may be misguided.

First, metric units:

A metric tonne (note spelling) is equal to 1,000 kilograms, or 2,200 pounds, or 1.1 english tons. The rest of the world measures CO2 in metric tonnes, and scales wood in cubic meters. We're the outliers who use "English" units (even the English use metric). International treaties on CO2 emissions, emissions trading systems, and scientific work measuring carbon stocks and flows, all use metric units. So, we need to translate a lot of information into familiar English units. Here is a photo of a graduate student hugging a cubic meter of wood. This nifty information graphic stands in the ground floor lobby of the Forestry program at the Technical University of Munich's campus in Freising.

This cubic meter of wood is roughly equivalent to a tonne of carbon dioxide. But we're getting ahead of the story a bit.

Here is what a tonne of CO2 looks like:

This is also a nifty infographic; it stood outside the large conference hall where the Copenhagen Climate Conference was held in 2009.

How big is a ton of CO 2? A ton of CO 2 would fill a modest one story ranch house with a footprint of 1250 sq feet and an average height of 13 feet. buildingenergy.cx-associates.com/2012/06/what...

Confusing Carbon with CO2:

You often read of “carbon storage”, or “carbon sequestration”, followed by numbers of tons. It can be hard to keep track of whether the writer is talking about carbon or CO2. Obviously carbon does not hang around in the atmosphere by itself – it only get there because organic material (or something) gets burned or oxidized to CO2. Ecologists have spoken for decades about the “carbon cycle”, and have measured ecosystem productivity in terms of carbon fixed per unit of area. This was an extremely important breakthrough in how ecosystems were perceived and understood. But gases forcing climate change are always discussed in terms of CO2, or the equivalent.

The number to remember here is 3.67. High school chemistry told us that every carbon dioxide molecule consists of two oxygen atoms (atomic weight 16), attached to one carbon atom (atomic weight 12). So, two times sixteen plus one times 12 equals 44. For every ton of carbon atoms in wood cellulose, you’ll have 44/12 (or 3.67) tons of CO2. This factor is dimensionless so you can use it with metric or English tons.

Measuring Weight versus Volume:

At one time, we thought of forest products in volume terms – we stick-scaled board feet of sawlogs or veneer, as well as cords of pulpwood, firewood, or pallet wood. Since we scale standing trees in volume terms, this made good sense. In the 1970’s however, many paper mills converted to what was then termed “weight-scaling”, followed years later by spruce sawmills. The state price reports show prices per ton for many products now, so if you want log volume you need to convert back. Today, the USFS timber resource reports do us a favor, by reporting wood volumes in the forest as tons in addition to traditional volumes.

Now we can walk through a table illustrating how this all works. The first table deals with one cubic meter of wood raw material, as in the photo and takes it to US tons per cubic meter of solid wood raw material. Numbers used below are illustrative, but reasonable; you'll find different ones here and there if you look long enough. You'd be amazed at how the weight of a cord of spruce fir can vary by soil type, age, and season.

	Tons of CO2 per cubic meter of wood					
Row #				**Canadian Spruce**	**Oaks***	**Douglas fir**
1	Dry weight per m3	Given	kg	450	750	530
2	percent Carbon	row 1 X .5	0.5	225	375	265
3	kg Co2 per kg C	row 2 * 3.67	3.67	826	1,376	973
4	tonnes CO2 per m3	row 3 / 1000		0.83	1.38	0.97
5	US (english) tons per m3	row 4 * .907	0.907	**0.75**	**1.25**	**0.88**
	* midpoint of range					

In the US we typically measure lumber in *nominal* volume units, not actual volumes; also we traditionally measured pulpwood by the stacked cord, which is not the actual volume of wood in the pile. So it can be some work to bring all measures to a common unit.

The next table shows the tons of CO2 in familiar volume units use in the US:

Tons of CO2 per American Unit of Wood								
		Spruce Lumber	White Pine Lumber	Doug fir plywood	Aspen lumber	Oak Lumber	Spruce/fir Pulpwood	Mixed Hardwood pulpwood
Per Mbf Zero MC		4.0	3.5	4.9	3.8	6.2	n.a.	n.a.
Per green cord		n.a	n.a	n.a	n.a.	n.a.	1.9	2.3

So. one Mbf of spruce lumber contains 4 tons of CO2, of oak, 6.2 tons. A green cord of spruce-fir pulp contains 1.9 tons CO2, while a cord of mixed hardwood would be 2.3 tons.

Standing timber to end products

A ton of standing timber does not all end up in a finished product. Depending on species and tree size, anywhere from 4 to 12% of this weight might be bark. There is inevitable shrinkage in processing. For lumber, for example, as much 50% of the wood in a small log goes into slabs, shavings, sawdust and fines, not into the lumber pile. When a ton of wood goes in one end of a sulfate pulp mill, only half a ton of pulp emerges from the other end. A ton of finished glossy paper can be 30% nonwood fillers and coatings.

Carbon in a Board? Cradle to Grave emissions?

Many times you'll read that a ton of wood "contains" so and so much carbon or CO2. This may mean the carbon in the board itself (as I show above). In some analyses it also includes the board plus "cradle to the grave" emissions -- counting all fuel and power usage during harvesting, processing, kiln drying, and shipping. Does it include allowance for onsite construction waste or other falldowns along the way? Even more complicated, many mills produce all or most of their onsite energy from bark, offcuts, or other residuals. Trouble is, a writer may have found this number someplace and have no idea exactly what it actually means. We often read of the carbon "stored" in a house. This seems to refer only to the C content of the products themselves.

Confused yet?

You're not alone. Every time I return to this topic I find myself confused until I get back into the groove again.

Call for Woodworkers: I have asked several people to make copies of the cubic meter of wood (translated to English units) and place them in places where many people will see them. They were all too busy. Is there someone out there with a wood shop who will make one and prepare plans that others might use?

To learn more: see the EPA's website where you can see many equivalents between products you already use and their CO2 content.

https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Author note: Lloyd Irland is a semi-retired consultant in Wayne, Maine. In a former life he attended the Copenhagen and Cancun global climate summits as an adviser for graduate students and speaker at side events. He has worked extensively on biomass energy issues in the Northeast.

Forest Practices and Soil Carbon in Maine

Lloyd C. Irland

Dec. 18, 2020

In a recent FCDG, the question was raised, "how do different management practices, especially clearcutting, affect soil carbon and nutrients?" This is an important concern so it may be useful to the group for me to offer a few comments. Not being a soil scientist I have asked a few people to peer review a first draft and let me know of additional information on this topic that needs to be considered. Ivan Fernandez responded with a great set of recent articles that I think get us all we need. He has contributed in a big way to this knowledge. I see this note only as a quick intro to the subject.

A first thing is to make sure of terminology when speaking of soil.

The forest floor consists of

(1) down woody debris -- logs, branches, pine cones, etc.
(2) the "forest floor" of leaves, partially decayed organic matter, humus, etc, resting atop the horizon that is predominantly mineral soil. This is the "organic mat".
(3) the "Soil" which is the mineral soil.
■ in some soils the boundaries between (2) and (3) may be indistinct.

A great deal of inventory and research has been done on (1). Sometimes, large and sound down logs are removed in logging, if only biomassed.

Maine forests, especially the softwoods, usually have thick organic mats. Some loss of organic matter and C in these can be expected

I had learned back in soil science that plowing farmland causes longterm depletion of soil organic matter (items (1) and (2) above being long gone). When first began working on forest carbon a few decades ago, I expected to see the same for clearcutting. Was I surprised! I read up on what was then known and learned that in most temperate forests at least, even in the hot southern pine region, cutting the trees hardly affects **soil** C (In the sense used above) at all.

Why?

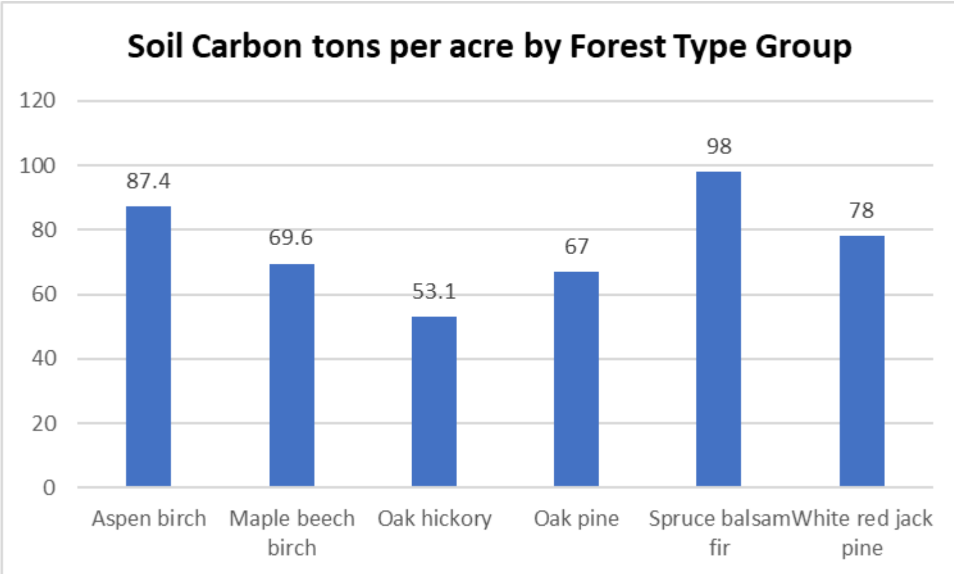
Soil carbon includes finely divided and highly modified organic matter, in some soils brought there by action of worms and other guys. (not so much for acid podzols, or whatever they call them now). The C would not be there if it were not in highly durable forms by then.

Further, if a stand is clearcut, in our region it usually regenerates to something, often dense shrubbery, very quickly and temperatures do not rise noticeably to any depth, or become abnormally dehydrated. Forces that would accelerate decomposition of the soil C are very much muted compared to the forest floor that sits above the mineral soil.

Now, in the case of abusive logging on steep slopes with erosive soils, it's a different matter. This does occur. How to account for it empirically on the ground is a good question.

Now, with these preliminaries, what about the amounts involved?

The NE-343 dataset (Smith et al. 2006) gives us a way to illustrate the proportions and how they change over time after cutting. Below I show their data for spruce fir and also for oak hickory in the Northeast. Also available are aspen-birch, maple-beech-birch, oak-pine, and white-red-jackpine. The experts can probably tell us why these carbon stocks differ so much. I don't know. A careful read through this bulletin will give you a good grounding not only in the measurement issues but in the methods used to develop their data and ways they suggest their estimates be used.



NE-343 assumes that soil carbon does not change over time. I assume this is a sound generalization and based on all the research then available. (See citation and link at end of this note)

Importantly, these reflect regional conditions which are surely different on average from Maine. The question is to what extent these general relationships are sufficiently similar to yield reasonable general conclusions or not. It might be an interesting exercise, and not a totally academic curiosity, to benchmark some of these values against actual Maine data. FIA or otherwise….

This data are for metric tons **carbon, not CO2e (all tons metric in this note)**

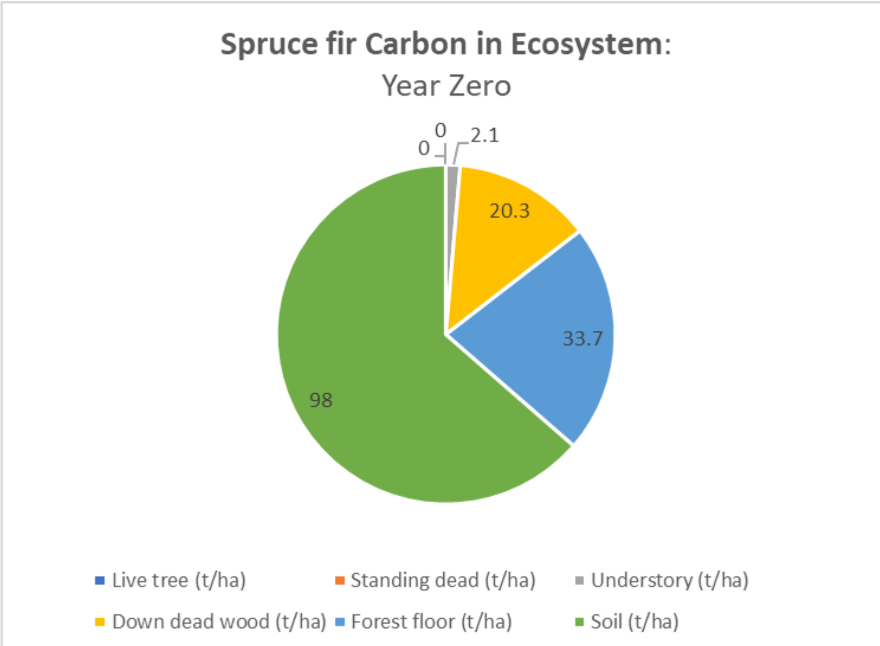
Year zero is immediately after clearcutting.

Spruce Fir Example

At that time, 98 metric tons/a are in the mineral soil pool for spruce fir.

By assumption this is a true silvicultural clearcut so no live trees are present, though in the real world this is not always true. So after the loggers leave 36% of the carbon on the site is in what I'm calling the "Legacies" left behind from previous generations of stands on that acre.

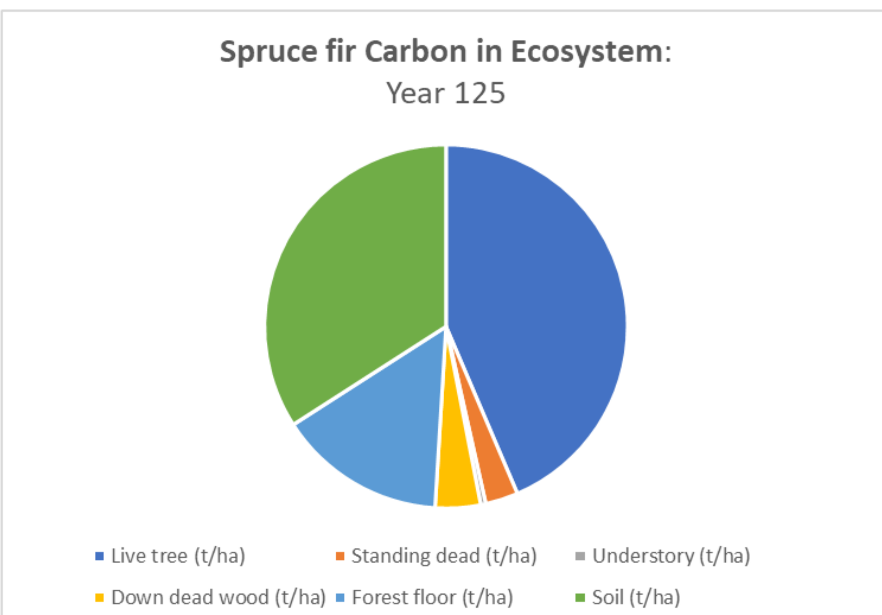
NE 343 projects to year 125. By this time, legacies are 40% of the total, due mostly to the accumulation of standing dead wood.



Taking the whole stand at age 125: 44% of the C is in live trees

34% is in the soil

40% is in the legacies

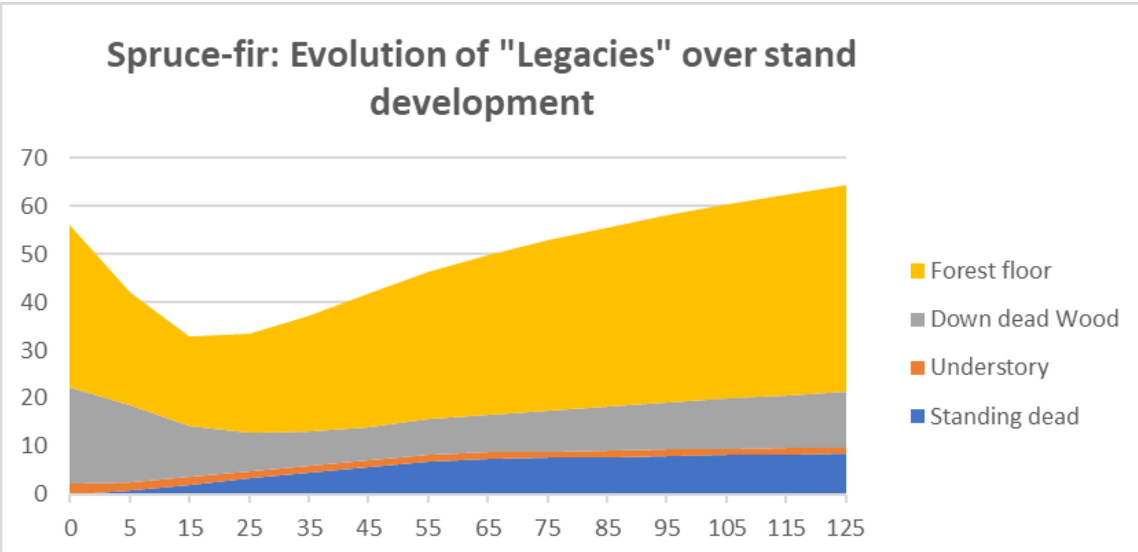


The legacies shrink for about 2 decades, as we'd expect.

Forest Floor declines but about one third, and then (why?) seems to exceed its initial postharvest level by year 125.

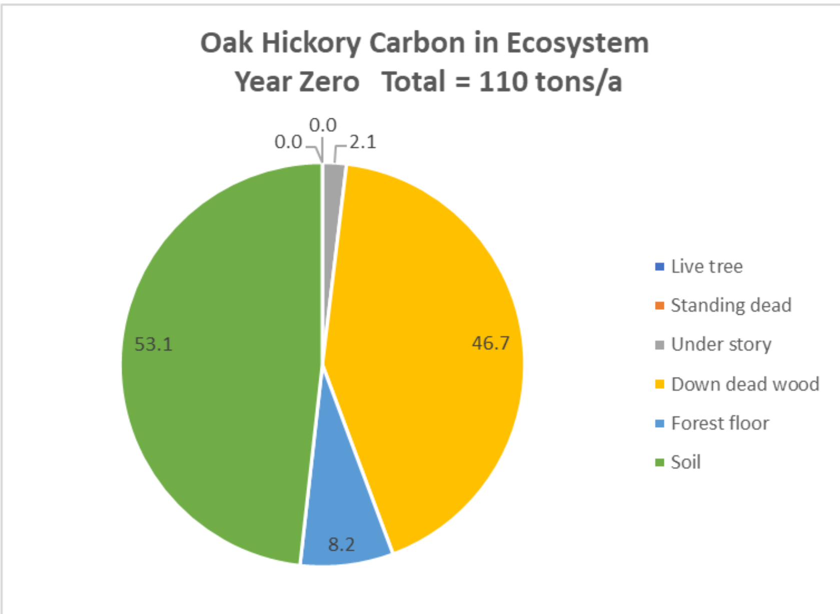
Live Tree C does not exceed soil C until almost age 95.

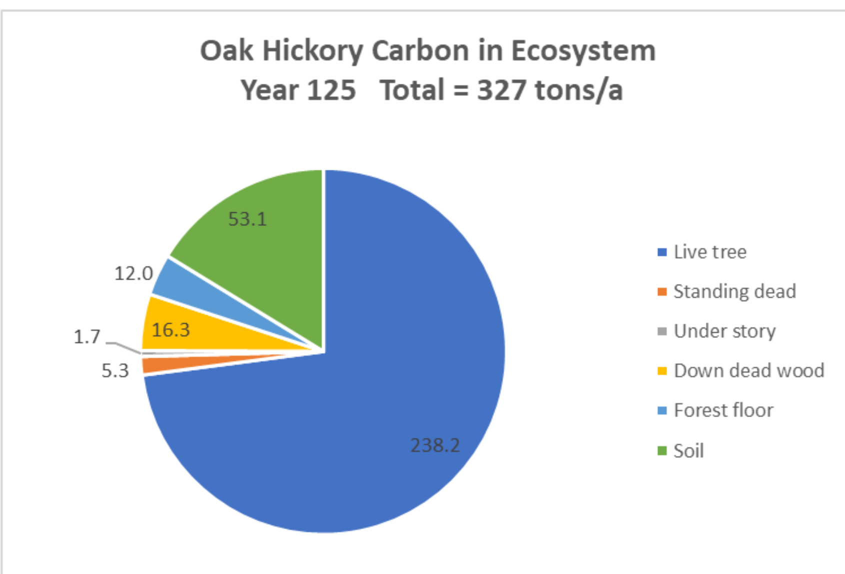
At the same time, DWD never recovers its postcut level. Presumably because the logging slash is on top of the usual precut DWD level that would have been present.

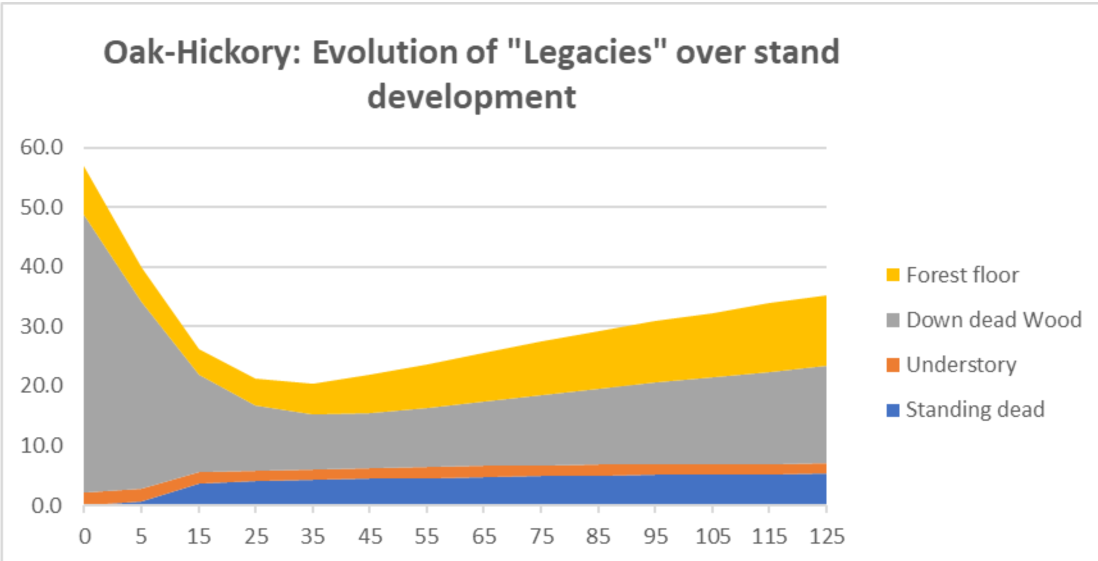


Oak-Hickory

For those of us who kind of grew up on spruce fir and northern hardwoods, the Oak Hickory numbers are very interesting. They reflect soils and climate perhaps more than just species composition.







Comparisons:

Item	Oak Hickory	Spruce fir
Yr Zero tons of C/a.	**110**	**154**
Yr 125 tons/a	**327**	**288**
Annual C seq.	**1.9**	**1.0**
Soil C/acre, yr zero	**53**	**98**
Soil as % total C yr 125	**16%**	**34%**
Live Trees as % total C	**73%**	**44%**
Legacies as % of Total yr 125	**11%**	**22%**

I'm calling standing dead, understory, DWD, and forest floor as "Legacies" -- at yr zero that is what the stand inherits from the past.

I sense that some thinking and discussion of what these relationships might mean for carbon credits and management might be fruitful – just to think about the issues even as we recognize that the numbers themselves might not represent Maine conditions well.

Nutrients

During the 80's there was considerable interest in biomass harvesting, which began with thinning and extended itself to extensive use of culls and topwood, and even entire stands as demands for biomass for energy increased. Concern arose that this could deplete soil nutrients as much of the nutrient capital of a stand is in the tops, branches, and leaves. I know of two principal programs of research relevant to Maine.

First, at Hubbard Brook were over the years intensive measurements were undertaken on nutrient balances and biomass growth. My recall of the conclusion was that in that setting, northern hardwoods at moderate elevations, clearcutting on rotations exceeding some 85 years or so would not deplete soil nutrient capital. Shorter rotations would likely do so, though. It is not clear how this might apply to the kinds of periodic heavy cuts we now see commonly in northern Maine.

The increase in biomass usage prompted establishment of detailed studies at Weymouth Point, in spruce fir by the CFRU. Recently 35 year results were made available though not, far as I am aware, published in journals as yet. This showed that forest floor C declined considerably after removals of total biomass. Soil nutrients were not much affected.

Recent Literature Reviews

A 2020 global literature review by Mayer, et al (and 15 co-authors!) gives an authoritative summary of the literature. The abstract is quoted here in full and may be all that most of you need. (highlights supplied by myself)

> Almost half of the total organic carbon (C) in terrestrial ecosystems is stored in forest soils. By altering rates of input or release of C from soils, forest management activities can influence soil C stocks in forests. In this review, we synthesize current evidence regarding the influences of 13 common forest management practices on forest soil C stocks. **Afforestation** of former croplands generally increases soil C stocks, whereas on former grasslands and peatlands, soil C stocks are unchanged or even reduced following afforestation. The conversion of primary forests to secondary forests generally reduces soil C stocks, particularly if the land is converted to an agricultural land-use prior to reforestation.

> Harvesting, particularly **clear-cut harvesting**, generally results in a reduction in soil C stocks, particularly in the forest floor and upper mineral soil. **Removal of residues by harvesting whole-trees and stumps** negatively affects soil C stocks. Soil disturbance from **site preparation** decreases soil C stocks, particularly in the organic top soil, however improved growth of tree seedlings may outweigh soil C losses over a rotation. Nitrogen (N) addition has an overall positive effect on soil C stocks across a wide range of forest ecosystems. Likewise, higher stocks and faster accumulation of soil C occur under tree species with N-fixing associates. Stocks and accumulation rates of soil C also differ under different tree species, with coniferous species accumulating more C in the forest floor and broadleaved species tending to store more C in the mineral soil. There is some evidence that increased tree species diversity could positively affect soil C stocks in temperate and subtropical forests, but tree species identity, particularly N-fixing species, seems to have a stronger impact on soil C stocks than tree species diversity. **Management of stand density and thinning** have small effects on forest soil C stocks. In forests with high populations of ungulate herbivores, reduction in herbivory levels can increase soil C stocks. **Removal of plant biomass** for fodder and fuel is related to a reduction in the soil C stocks. Fire management practices such as prescribed burning reduce soil C stocks, but less so than wildfires which are more intense. For each practice, we identify existing gaps in knowledge and suggest research to address the gaps.

A previous review by Nave et al. 2010) is also of interest and focused on temperate forests. This review carefully sorts out how effects vary across major categories of soils (termed "orders" in soil science… a bunch of unpronounceable terms you don't want to get into). The reviews are not always entirely clear about the duration of measurements reported and how duration might affect results.

An earlier report by Fernandez (2008) gives a detailed account of the issues and important results focused directly on Maine. An interesting older contribution by Yanai, Currie, and Goodall (2003) offers a detailed picture of methodological and hypothesis testing issues. It's a very nice extended essay on how to analyze this problem and interpret existing literature. It's written in a way accessible to ordinary folk who are not soil scientists. I recommend both of these.

Finally, a nice report on work at Penobscot Experimental Forest is Puhlick, Fernandez, and Weisskittel, 2016, which gets you down the brass tasks on a specific place with which many of us are familiar. This contrasts soil carbon across three different treatment regimes versus a control, over more than 60 years. This is likely the longest-duration study of its kind anywhere in the northeast. However that may be, it deals with treatments and a time period relevant to management decisions in Maine on similar soil conditions.

Things we Don't know

In the North, a common management practice is a periodic, moderately heavy partial cut. Statewide average is that some sort of cutting happens on every acre every 40 years. It is virtually certain that the interval is shorter in the Northwoods. Further, in many best practice operations, tops and branches are returned to the land after limbing and bucking at the landing. On the other hand, stems or segments of stems of low quality or unwanted species often come to the landing and get chipper for fuel. Specifics as to how common these and related practices actually are over the landscape are not available. We don't know what the implications of this sort of management regime might be for either soil/forest floor carbon stocks or for nutrients.

Most importantly, the NE-343 estimates are necessarily extrapolations from existing studies, few of which span more than a few decades at most.

And, as noted above, because of the high cost of sustaining studies like this over long periods, our sample of soil types, vegetation types, management practices, and climatic conditions directly relevant to Maine is pretty limited. So, to help mangers we have to reason from what we know.

Carbon accounting and Policy Implications?

I think for research purposes it's good to know about total stocks of soil carbon and how they vary in different ecosystems and across time. But in regions like Maine, it appears that we cannot affect C levels in the soil itself very much by management. Or, by non-management either. The stock of C there is a legacy of past centuries.

Also, I think that estimates extrapolated from a few research studies cannot possibly be accurate for particular properties, and the cost of digging holes in the ground to make valid estimates is very high. From what I know of how variable glacial soils can be from spot to spot, it seems pointless.

For these reasons:

(1) I can see no point in giving people carbon offset credits and paying them for the carbon in the soil.
(2) I am unable to see why should be considered in national GHG accounting at all. (is there some Arms Race to see who has the biggest total carbon stock????)

Information Sources:

Fernandez, Ivan, 2008. Carbon and nutrients in Maine Forest Soils. Maine Agr. and For. Exp. Sta. Tech Bulletin 200.

Mayer, et al. 2020. Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. Forest Ecology and Management. 466, 118 to 127. (7 pages of citations in small print!)

Nave, L.E. et al. 2010. Harvest impacts on soil carbon storage in temperate forests. Forest Ecology and Management 2509. 857-866.

Puhlick, J.J., I. J. Fernandez, and A. R. Weisskittel, 2016. Evaluation of forest management effects on the mineral soil carbon pool of a lowland, mixed-species forest in Maine, USA. Canadian Journal of Soil Science. 96:207-218.

Smith, J. E., et al. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the U.S. USDA FS Northeastern res, Sta. Gen Tech Rep. NE-343.

https://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2006/ne_gtr343.pdf

Great thing on this is that on the Station website, an Excel workbook is available with all the data.

Happy to share my spreadsheet used to do these calculations and graphs.

S. T. Smith et al. 2020. Longterm impacts of whole-tree harvesting: The Weymouth Point Study. CFRU Adv Com meeting may 6, 2020. Powerpoint. In author's file.

Yanai, R. D., W. S., Currie, and C. L. Goodale. 2003. Soil carbon dynamics after forest harvest: an ecosystem paradigm reconsidered. Ecosystems 6: 197-212.

	NE-343 Data			Legacies, not live trees					Comparisons		
Region	Forest type	**Stand age (years)**	**Live tree (t/ha)**	**Standing dead (t/ha)**	**Understory (t/ha)**	**Down dead wood (t/ha)**	**Forest floor (t/ha)**	**Soil (t/ha)**	**Total Legacies**	**Total above & Below**	**Legacies as % Total**
NE	Spruce-balsam fir	0	0	0	2.1	**20.3**	**33.7**	98	56.1	154.1	36%
NE	Spruce-balsam fir	5	7	0.7	1.8	**16**	**23.6**	98	42.1	140.1	30%
NE	Spruce-balsam fir	15	20.1	2	1.6	**10.6**	**18.6**	98	32.8	130.8	25%
NE	Spruce-balsam fir	25	32.5	3.3	1.5	8	20.7	98	33.5	131.5	25%
NE	Spruce-balsam fir	35	45.7	4.6	1.4	7.1	24.2	98	37.3	135.3	28%
NE	Spruce-balsam fir	45	57.4	5.7	1.4	6.9	27.7	98	41.7	139.7	30%
NE	Spruce-balsam fir	55	68.7	6.9	1.4	7.3	30.7	98	46.3	144.3	32%
NE	Spruce-balsam fir	65	78.6	7.4	1.3	7.8	33.3	98	49.8	147.8	34%
NE	Spruce-balsam fir	75	87.9	7.6	1.3	8.4	35.5	98	52.8	150.8	35%
NE	Spruce-balsam fir	85	96.5	7.8	1.3	9.1	37.4	98	55.6	153.6	36%
NE	Spruce-balsam fir	95	104.5	8	1.3	9.7	39.1	98	58.1	156.1	37%
NE	Spruce-balsam fir	105	111.9	8.2	1.3	10.4	40.6	98	60.5	158.5	38%
NE	Spruce-balsam fir	115	118.8	8.3	1.3	11	41.9	98	62.5	160.5	39%
NE	Spruce-balsam fir	125	125.3	8.4	1.3	11.6	43.0	98	64.3	162.3	40%

Note, as to the legacies, we really don't know age of previous stand assumed here -- likely much less than 125 yrs unless in NY Forever Wild or Baxter SP.

Forest type		Stand age (years)	Live tree	Standing dead	Under story	Down dead wood	Forest floor	Soil	Everything	Legacies	Legacy % of Everything
Oak-hickory		0.0	0.0	0.0	2.1	**46.7**	**8.2**	53.1	110.1	57.0	52%
Oak-hickory		5.0	6.9	0.7	2.1	**31.4**	**5.7**	53.1	99.9	39.9	40%
Oak-hickory		15.0	43.0	3.6	1.9	**16.5**	**4.1**	53.1	122.2	26.1	21%
Oak-hickory		25.0	71.9	4.0	1.9	**10.8**	4.5	53.1	146.2	21.2	15%
Oak-hickory		35.0	96.2	4.2	1.8	**9.2**	5.3	53.1	169.8	20.5	12%
Oak-hickory		45.0	118.2	4.5	1.8	**9.2**	6.3	53.1	193.1	21.8	11%
Oak-hickory		55.0	136.8	4.6	1.8	9.9	7.3	53.1	213.5	23.6	11%
Oak-hickory		65.0	154.3	4.8	1.8	10.8	8.1	53.1	232.9	25.5	11%
Oak-hickory		75.0	170.6	4.9	1.8	11.8	8.9	53.1	251.1	27.4	11%
Oak-hickory		85.0	186.0	5.0	1.8	12.8	9.7	53.1	268.4	29.3	11%
Oak-hickory		95.0	200.4	5.1	1.8	13.7	10.3	53.1	284.4	30.9	11%
Oak-hickory		105.0	213.9	5.1	1.7	14.6	10.9	53.1	299.3	32.3	11%
Oak-hickory		115.0	226.5	5.2	1.7	15.5	11.5	53.1	313.5	33.9	11%
Oak-hickory		125.0	238.2	5.3	1.7	16.3	12.0	53.1	326.6	35.3	11%
		tons/A /yr	**1.9**			age 125	live tr % tot		73%		
							soil %		16%	0.108083	

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ECOSYSTEM MANAGEMENT IN NORTHERN FORESTS: POTENTIAL ROLE IN MANAGING THE CARBON CYCLE

AN EXPLORATORY ASSESSMENT

FOREST POLICY CENTER

ECOSYSTEM MANAGEMENT IN NORTHERN FORESTS: POTENTIAL ROLE IN MANAGING THE CARBON CYCLE

AN EXPLORATORY ASSESSMENT

by

Lloyd C. Irland[1]

Forest Policy Center
1516 P Street, NW
Washington, DC 20005
(202) 667-3300
FAX 667-7751

V. Alaric Sample
Director

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1 President, The Irland Group, RR #2, Box 9200, Winthrop, ME 04364 (207) 395-2185 FAX 395-2188

ABOUT THE FOREST POLICY CENTER

The Forest Policy Center, a program of AMERICAN FORESTS, serves as a bridge between the scientific community and policymakers, providing timely, impartial synthesis of scientific information relating to current issues in the protection and sustainable management of forest ecosystems.

A primary function of the Forest Policy Center is to identify current and emerging information needs, coordinate research among scientists with specific knowledge and expertise on the topic, and interpret the results to policymakers and the public.

As part of AMERICAN FORESTS, the Center plays an important role reinforcing the scientific underpinning for AMERICAN FORESTS action–oriented programs in policy, urban forestry, and international resource policy. Research conducted at the Center facilitates the work of these programs by providing information and data to program staffs, and educating and informing key audiences.

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Executive Summary

Highlights of Findings

1) This report provides an exploratory assessment of the relationship between ecosystem management practices and the storage of carbon in existing forests of the northeastern and north-central United States (the "Northern Forest"). Though our focus is specific to this region, many of the methodological implications of our work are applicable to other regions as well.

2) Ecosystem management (EM) is not a clearly defined package of practices. It is, instead, a philosophy of managing forests as ecosystems with particular long-term objectives that apply on a landscape scale. Prescriptions in EM plans would include preservation, streamside protection, intensive wood management, extended rotations, and others. This analysis does not consider plantings that expand forest area, short-rotation intensively-cultured plantations, or type conversions.

3) Northern forests are providing a significant annual carbon sink at present, amounting to millions of tons of carbon each year, even though a significant portion of annual growth is harvested annually.

4) Wood production and carbon storage are joint products. There is no nonarbitrary method of allocating costs between these (and other) forest outputs. But one way to look at costs is to examine what costs incurred solely for carbon storage are incremental to those of woodgrowing. This implies that carbon storage projects might be undertaken on management treatments that fail traditional economic tests for woodgrowing.

5) Costs and storage impacts of EM practices can be examined at the levels of the individual treatment, the management unit, or the region. Analyses of individual practices are the least useful, because they cannot capture important interconnections over time.

6) Analyses at the management unit level can account for important interconnections not considered at the stand level:
   - changes in the untreated benchmark condition with which treatment is compared;
   - sources of wood used to offset harvests that are reduced to meet ecosystem management goals;
   - effects of changing mixes of silvicultural prescriptions over time; and
   - time patterns of treatment implementation and responses.

   Financial analyses at the management unit level require data on cost impacts that are not readily available; analyses using simulation models can be costly.

7) At the regional level, more aggregative methods can exploit existing datasets and offer some hope of providing general results at a relevant scale.

8) Economic management treatments are already being applied. These have significant potential over time for increasing wood growth and annual carbon storage still further, at no cost attributable to carbon storage.

9) Many management treatments that are undertaken to increase timber value yield actually reduce carbon storage for a period of years because they open up the canopy. Many of these practices have a larger impact on value growth than on volume growth, and many are intended to produce wood yields while employing a minimum amount of growing stock per acre.

10) Stand treatments that are economically submarginal are available in large supply. Further work, using consistent growth and yield datasets and up to date cost and price assumptions, could place limits on the costs and quantities involved.

11) Substituting forest biomass for fossil fuels may offer additional carbon storage benefits at little or no cost. Significant movement in this direction depends on an increase in fossil fuel prices. In local areas, use of biomass for energy is currently declining.

12) Market forces in the lumber, plywood, and other panel markets are causing shifts in forest utilization that will increase the usage of northern forests for long-lived building materials. This utilization will provide additional cost-free carbon storage.

13) Ecosystem management practices will be largely neutral over the long run for forest carbon storage. Though the preservation prescription will provide a one-time benefit, it will have the opportunity cost of foregoing the use of the utilization pathway to store carbon. A model EM program for a test county in Maine yielded a small increase in total growing stock volume above the present level, though it maintained a significantly higher future inventory than continuation of current management. But annual wood output was significantly reduced.

14) In contrast, employing intensive management using 40-50 year rotations increases the annual volume yield of the property, but significantly reduces the carbon in the inventory.

15) These relationships will vary from region to region based on growth-cut balances, age class structure, inventory conditions and trends, and the regional industry mix.

Policy Implications

1) We conclude from our exploratory analysis that one would not propose shifting to an EM approach simply as a carbon storage policy. The results take a long while to become significant, and are dwarfed in the short run by the natural growth, by the shifts to alternative building materials, and by the potential for fossil fuel displacement. EM will be justified by its effects on other forest values.

2) It may be that the utilization pathway is more readily changed by market forces and by public policy than is the management of private forests. For example, mandates and incentives for recycling and for wood-fired electric generating plants have affected wood use in some areas.

3) Dramatically changing stumpage prices and wood markets will affect forest management and also how the wood is used in the economy. A number of improved analytical tools are becoming available, and U.S. Forest Service Forest Survey data can be more easily accessed and analyzed than ever before. Using these capabilities, it would be desirable to conduct more detailed case studies around the U.S. and Canada, simulating the carbon cycle impacts of the likely future management regimes and changes in the utilization pathway.

4) Clearly, public sentiment and regulatory programs will push forest managers to adapt, likely in a piecemeal fashion, individual ecosystem management practices. A more comprehensive approach is well under way on many public land units. It does not appear that relevant carbon cycle considerations are being considered in these policy changes.

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Foreword

Forest resource managers in all regions of the United States are currently exploring the ways in which an ecosystem-based approach to forest management might differ from traditional sustained-yield management techniques in use in this country for more than a century. Generally, an ecosystem-based approach expands upon traditional approaches by considering (1) a broader array of resources and values, (2) longer time horizons, and (3) larger spatial scales. This broader and more comprehensive approach is regarded by many as key to avoiding inadvertent cumulative impacts on water quality, biological diversity, and other ecosystem values that can only be protected and sustainably managed by operating at a landscape scale.

At this early stage of development, there are many questions about ecosystem-based approaches to forest management that remain unanswered. Among them are how much it will cost. How will these techniques affect revenue from the utilization of commodity resource products, such as timber or game? What are the costs associated with additional planning and environmental analyses that consider much larger spatial areas and model the function and response of natural ecosystems much further into the future? How will more sensitive, "light on the land" approaches influence the costs of normal management activities such as silvicultural treatments, timber marking, watershed protection, wildlife management, and maintaining road access? In the real world of scarce budget resources and multiple, competing priorities, these are important considerations for resource managers, on federal and state public lands as well as on corporate and non-industrial private forest lands.

Another question that seems to have gotten little consideration is, how will these new management techniques affect forests' ability to store carbon? Forests are one of the world's most effective mechanisms for the sequestration and long-term storage of atmospheric carbon, an important greenhouse gas, in both woody biomass and forest soils. Following the 1992 UNCED conference in Rio de Janeiro, the United States committed to an effort to reduce carbon dioxide emissions to 1990 levels by the year 2000 and, while much of this effort has focused on reduced emissions, carbon sinks like forests are also recognized as having an important role to play. Will our simultaneous goal of shifting toward ecosystem-based approaches to forest management also enhance the carbon-storing functions of forests, or impede them?

The following study represents a first step toward addressing some of these issues. As an exploratory assessment, its objective is not so much to provide definitive answers as to provide some empirical guidance in asking the right questions, and gathering the data that will eventually enable us to answer them accurately and thoroughly. This study focuses on the "Northern Forest," the central and northern hardwood and mixed-conifer forests of the northeastern and north-central United States. It was conducted by Lloyd C. Irland and others at The Irland Group in Winthrop, Maine, which has long specialized in providing comprehensive forest management, planning, and economic analysis services throughout the region. While many of the specific management techniques will differ from those of ecosystem-based forest management in other major regions of the United States, Irland provides the basis for an analytical methodology that is readily adaptable to other forest regions.

The analytical approach taken here recognizes that wood production and carbon storage are "joint products," and that much of what can be done to enhance carbon storage is already done as part of forest management. But this also makes if difficult analytically to separate the costs of wood production from those of carbon storage. Irland's approach is to examine the ways in which management aimed at maximizing carbon storage might *differ* from traditional forest management, and to count the increased costs (or reduced revenues) as carbon storage costs. Interestingly, Irland describes situations in which active management may be uneconomical considering wood production benefits alone but where the additional benefits from carbon storage may warrant the greater investment of time and resources.

Irland's results suggest that the effect of ecosystem-based approaches to forest management on carbon storage will be neutral over the long run, but that there are a number of important near-term considerations. Silvicultural treatments aimed at maximizing timber values are likely to reduce carbon storage in the short term by reducing stand densities and woody biomass production per acre. Over the longer term, however, the utilization of larger-diameter, higher-quality wood as long-lived forest products may compensate by delaying the release of stored carbon through natural decay and decomposition. This exploratory assessment is focused primarily on carbon storage in above-ground woody biomass. Clearly, the choice of silivicultural treatments and other management activities will affect the rate and capacity of carbon storage in forest soils and in below-ground woody biomass, as well as rates of decomposition and carbon release. These factors are outside the scope of this particular analysis, but will need to be addressed before a complete picture emerges of the effect of ecosystem-based approaches to forest management on the carbon cycle.

Major support for this assessment was provided by the U.S. Environmental Protection Agency, which is leading the effort to identify effective and cost-efficient means to reduce greenhouse gas accumulation in the global atmosphere. Steven Winnett of EPA's Office of Policy, Planning, and Evaluation (Climate Change Division) provided valuable guidance and review comments on the study, as did Richard Birdsey and Robert Moulton of the USDA Forest Service. Other questions, comments, and suggestions on this Forest Policy Center working paper are welcome and encouraged.

V. Alaric Sample
Director
Forest Policy Center

Introduction

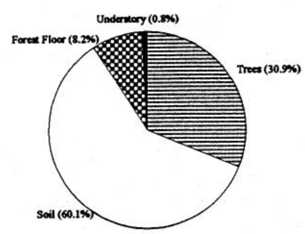
The potential roles of forest management and wood utilization in the global carbon cycle have received considerable attention in recent years[2]. As this discussion moves forward, shrinkages are occurring in supplies of softwood and hardwood timber from traditional sources in the tropics, the former Soviet Union, the western U.S., and Canada. Resulting market pressures are increasing the value of standing timber. These forces will push forest utilization toward building materials and away from paper. At the same time, low oil prices have halted a trend toward increased use of forest biomass for energy. These trends occur at a time when rising interest is being expressed in ecosystem management styles of forestry. Thus it is useful to inquire how these forces--increasing wood use and a shift toward building materials; a lull in wood energy utilization and a shift toward ecosystem management practices --will affect the role of northern forests in the carbon cycle.

Carbon Storage in Northeastern Forests: Current Situation

Data developed by Birdsey (1992) provide a basis for describing the current carbon storage situation in the forest. This is the base from which changes in management practices will affect the overall regional rate of accumulation. In the northeast and mid-Atlantic region, carbon storage is primarily in soils, as would be expected from the generally cool climate of the region's northerly portions (Fig. 1). It is natural, however, that most of the measurements to date have dealt only with the above-ground portion of forest trees, and primarily their merchantable portion. So in analyzing the effects of management, it is necessary to rely on assumptions and extrapolations for effects on soils, forest floor, and understory. This analysis provides quantitative information for trees only and offer qualitative judgments for the other components. Scientists interviewed for this study agreed that effects of management on the soil pool are likely to be of secondary importance, compared to changes in carbon content of canopy trees.

Figure 1

Carbon Storage in Forests, by Component
1987, Northeast and Mid Atlantic
Total = 165,021



Source: Birdsey, 1992, p. 20.

[2] For an up to date summary, see USEPA 1994, and Stone 1994.

The diversity of this region needs to be recognized in comparing the carbon storage rates of different forest types. The climate and soils are very different for oak-hickory and spruce-fir, for example. Certain combinations of type conversions, then, would not be feasible. Also, the current rates of carbon accumulation apply to current forest conditions and may change naturally in the future.

At present, in the Northeast-Mid Atlantic Region, the oak-hickory type has the highest total stock of carbon per acre, while the highest rate of carbon accumulation per acre is in the oak-pine type. Overall, accumulation rates are the highest for the three major hardwood types shown. The conifer types are very near the hardwoods in total carbon stock, but below them in annual accumulation rates, possibly due to climate and soil differences.

In percentage rates of accumulation, the oak-pine and aspen-birch types rank highest, with the aspen-birch type working from a much lower base on average. The conifers are the lowest. These figures show the current situation. The relationships are caused by many different factors and by themselves do not support any specific management recommendations.

In the North Central/Central states region, the annual carbon accumulation rates per acre are significantly higher than in the Northeast for white pine, maple-beech-birch, and aspen-birch, and are lower for the other types and for the overall average.

Table 1
Carbon Stock and Accumulation in Trees,
Northeast and Mid Atlantic Region, 1987
(selected types)

Type	Total Carbon (lbs/ac)	Annual Accumulation (lbs/ac/yr)	Annual Percent Increase
White-Red Jack Pine	47,122	1,115	2.4%
Spruce-Fir	41,829	968	2.3%
Oak-Pine	53,510	1,911	3.6%
Oak-Hickory	55,943	1,719	3.1%
Maple-Beech-Birch	50,971	1,386	2.7%
Aspen-Birch	29,814	1,036	3.5%
All Timberland*	49,436	1,447	2.9%

Source: Birdsey 1992, p. 30, 31, 44, 45.
* Includes nonstocked and three types not shown separately.

For a useful perspective on conditions in Canada, see Auclair and Carter (1993), and Kurz, et al. (1992).

Content of Ecosystem Management

Ecosystem management is an emerging philosophy of land management. Scientists and land managers are absorbing new research findings and attempting to design management programs that reflect ecosystem management principles. In addition the complexities encountered in defining ecosystem management for a given region, there are many concerns and practices to be used in implementing such programs (Table 2), especially so in areas of multiple ownerships (see, e.g., Irland, 1994a).

Table 2
Ecosystem Management Practices
Considered in this Study

- Long Rotations.
- Preservation of unmanaged stands.
- Green tree retention in sites normally clearcut.
- Retain Continuous Canopy: replace clearcut/plant regimes with shelterwood or multi-age systems.
- Streamside Protection Corridors.
- Planting/vegetation management aimed at restoration of species or stands for EM reasons.

A. Defining Ecosystem Management

The most important concept is that ecosystem management (EM) takes a landscape-scale perspective (Table 3). The overarching goal is the maintenance or enhancement of ecosystem integrity. EM works by defining condition goals or desired future conditions for different portions of the landscape. It then attempts to schedule the treatment of individual stands in a way that moves the forest's structure toward those condition goals. In full implementation, wood production would fluctuate as a result of the scheduling of treatments, and traditional even-flow and sustained yield wood production objectives would be abandoned.

Table 3
Criteria for Ecosystem Management

Forest management decisions must be based on an ecosystem perspective. An ecosystem perspective views forests as composed of organisms hierarchically organized into functional groups and linked through complex processes to their physical environment and to each other. An ecosystem perspective for management recognizes the need to design practices sensitive to the balance among various components of the forest.

The effects of forest management need to be evaluated over a range of spatial scales. Emergent properties at each of several spatial scales (microsites, forest stands, watersheds, landscapes, and regions) influence ecosystem response; these properties must be considered when the effects of human activities or natural disturbances are examined and interpreted.

The effects of forest management decisions must be evaluated in light of ecologically relevant time scales. As with spatial scale, extending the time scales for considering effects of forest management causes new perspectives and new issues to emerge. Questions about long-term site productivity, resilience of forest ecosystems in the face of changing climates or other disturbances, and the long-term viability of populations necessitates thinking across a range of ecosystem time scales.

One of the premises of forest management must be maintaining future options. Unresolved societal debates about the role of the forest, uncertainty about future climates, and lack of understanding of basic ecosystem processes force the conclusion that the wisest approach to forest management is to avoid foreclosing on future opportunities by hasty and irreversible decisions.

Source: Condensed from Brooks and Grant 1992, p. 7.

The specific motivation for using any particular practice is not considered here. Clearly, most landowners employ streamside protection buffers because of public regulation. Many owners use partial cutting systems to avoid costs of artificial regeneration. Others use partial cutting systems to take advantage of high value growth rates in stands where sufficient quality growing stock is present to support such a system. Further, many EM practices are adapted in efforts to respond to public concerns about aesthetics, wildlife habitat, and recreational values. Using EM practices to help forests adapt to future climate change has been discussed (Franklin et al. 1991).

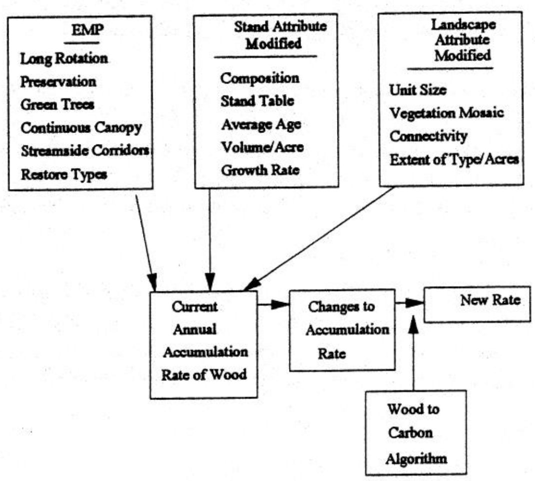
In this report, ecosystem management practices (EMP's) are viewed as results-oriented prescriptions for stand or landscape level conditions. To implement each "EMP", a regime of specific silvicultural treatments may be required. Full development of the technical and biological issues in developing those operational treatment regimes is beyond the scope of this report. On the basis of our practical experience in land management, we believe that workable sets of treatment practices can be designed for the EMP's we consider here.

B. A Broader Perspective: Properties and Landscapes, and the Utilization Pathway

Thus far, analysts have examined the economics of EMP's primarily from a stand-level point of view. But if effective carbon retention policies are to be adopted, a much wider perspective needs to be adopted (Fig. 2). The issue needs to be evaluated at the level of the management unit and the region.

Figure 2

Land Management Considerations



At the management unit or landscape level, models can analyze interconnections not visible in the stand level approach. These interconnections are so important that <u>stand-level analysis cannot be used to draw general conclusions as to the costs or tonnage potential for carbon storage in Northern forests.</u> Stand-level analyses will be important for assessing financial impacts and practicality of particular stand prescriptions, however.

Interconnections that must be addressed to estimate the carbon cycling effects of different treatments include:

<u>Differences in Time Profiles Are Important</u> -- Collapsing tons and costs into single valued numbers and averaging over time can obscure important differences in how carbon levels change over time, as to both speed and level. In many forestry treatments, for example, carbon levels are reduced in a given stand, but they later rebound. How these patterns merge over a landscape will

be important. Also, it has been argued that successful prgrams increasing forest inventories could depress stumpage prices (Winnett, Haynes, and Hohenstein 1993).

The "No Treatment Case" Changes -- In the case of planting bare land, over time the "no treatment case" stays the same -- it remains in grass. In an existing forest, however, the no treatment case may continuously change. For any given stand, a number of such scenarios may be equally plausible.

The Harvest Constraint Affects Results -- If there is no harvest level constraint, then the application of an EM practice that reduces the overall harvest level may simply raise unit costs for the remaining wood output. If there is a harvest level constraint, then prescriptions that reduce cuts in given stands will be offset by prescriptions that increase the cut elsewhere. Carbon effects will depend on the net balance between these two effects.

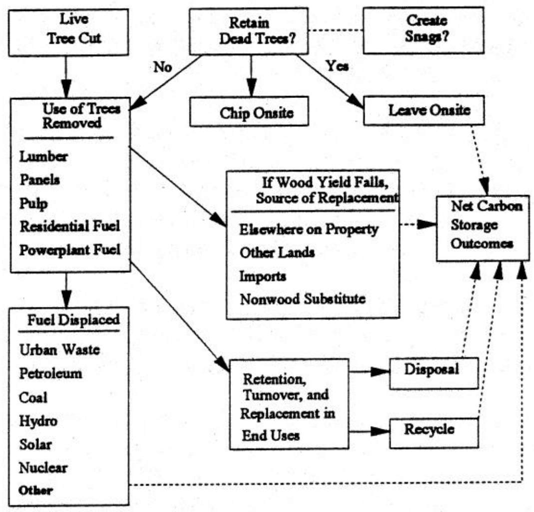
Utilization Path Assumptions Affect Outcomes -- Any forest analysis cannot in itself account for how changes in the utilization pathway may affect carbon cycling. Making assumptions about benchmark cases and future trends involves many complex judgments.

For rough exploratory purposes, quite simple models may be useful. In the absence of any other capabilities, we believe that a simple spreadsheet approach can be useful. For public land units that possess existing databases and models such as FORMAN or FORPLAN, these models would be most helpful, especially since modelbuilding costs are already paid. Models such as these do not fully handle the spatial aspects of EM prescriptions, but they would probably permit fairly rigorous sensitivity testing and comparison of scenarios for management and woodflow implications, total inventory volumes, and cost analysis.

The role of EMP's in management at a landscape scale puts in perspective the carbon storage possibilities of changing growth rates in individual stands. The net effects of EMP's on carbon storage will be small because they affect only small portions of the forest landscape in any given year--rarely more than two to four percent.

On many properties, current timber inventories may exceed what is required to support sustained wood yields under future intensive management. Certainly, across the region, an increasing portion of the forest area is overstocked from a timber production viewpoint. To the extent that this is so, as markets improve and as management is upgraded, the total growing stock on some properties will be reduced. This of course will reduce the carbon stock at any given time. Whether it will reduce the annual rate of accumulation, however, depends on growth rates and on the utilization pathway (Fig. 3).

Figure 3
The Product Utilization Pathway



The role of the utilization pathway has been extensively analyzed (e.g. Kershaw, Oliver and Hinckley 1993; Row and Phelps 1990). First, the trend in regional markets is likely to increase carbon retention in durable building materials at a rate that exceeds the ability of EMP's to increase storage in forest biomass (see next section).

Second, when practices such as preservation or bans on yield increasing technologies cause losses in wood production, the wood needs will be met from some other source. This source may be Siberian virgin stands, New Zealand plantations, heavier cutting elsewhere on the same property, or it may be nonwood substitutes. Unless the source of substitute material is examined for its carbon storage impacts, a complete picture of management effects can not be obtained.

Third, the fuel use pathway has a different relation to the problem. Some experts argue that if wood biomass is used to displace coal or petroleum fuels, a net improvement in the carbon emissions situation results (Brower 1992, p. 108; Cline 1992, p. 53; Chupla and Howarth 1992; USEPA, 1994, pp. 25-26). It is not always easy to identify just what fuel is actually being displaced by the use of wood. So claiming a carbon emissions credit for woodfuel use should be done with care. But considering the millions of cords of wood used for industrial, residential, and utility fuels at this time, this part of the utilization pathway needs to be considered.

Changes in Utilization and Stumpage Values

The level of wood consumption, and its allocation among different uses, are important variables in the utilization pathway. Further, the level of demand, type of wood needed, and the level of stumpage prices will affect management decisions. So it is useful to understand how these are changing.

A. Fossil Fuels Displacement

During the energy price spiral of the 70's and 80's, installation of household and commercial woodstoves, development of industrial boilers using wood, and of cogeneration plants and stand-alone biomass electric generators produced a large increase in the use of wood biomass for energy. In the early 80's, the Forest Service estimated that about 40 million cords were used for energy nationally. Since the mid 80's, the costs of oil and coal have fallen, however, leading to a significant cutback in residential and commercial use of fuelwood. This has placed the stand-alone generating plants in several northeastern states under heavy scrutiny for their high-cost power.

The need to dispose of wood wastes, and incentives provided under the Public Utilities Regulatory Policy Act (PURPA) led to a dramatic increase in wood-fueled cogeneration and stand-alone power plants through the late 1980's. Today, due to the high cost contracts under which utilities purchase this power, to glutted power markets in some regions, and to new technologies, these plants are under pressure. Utilities are cancelling contracts for proposed plants, are dispatching the plants less frequently when they are able to do so, or are buying out the contracts.

At the same time, a number of forces are motivating utilities and other electricity users to consider co-firing biomass with coal to solve a number of problems (Irland Group and Dames and Moore, 1993). Co-firing may help utilities reduce sulfur emissions, and it can help cogenerators at industrial sites like pulpmills in disposing of wastes such as bark or dewatered sludge. Successful co-firing of biomass with coal requires solving a number of materials handling and boiler problems, and may worsen traffic problems and emissions of some air pollutants.

In the residential sector, due to low oil prices, many wood stoves installed over the past 2 decades are no longer in use. This is another example of the importance of timing. When another sustained period of high oil prices seems likely, residential stoves will be restored to service, and industrial and utility electricity generators and Independent Power Producers will look at wood anew. A new round of growth in wood energy usage may occur. But the timing for this event cannot be reliably predicted. This will vary from location to location. The volume used and the net cost impact will be site specific. Also, offset effects vary depending on the fuel displaced (see, e.g. Marland and Marland 1992, p. 186ff). As a result of these uncertainties, little can be said at present about either the carbon offset potential or the cost per ton in the North.

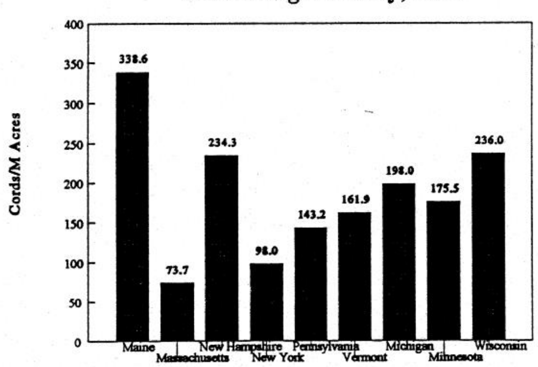
B. Shift toward Building Materials

For half a century, northern forests have been rebounding from a history of overcutting and burning. Large areas were returning to forest after failing farms were abandoned. Extensive planting programs beginning during the Depression established new young stands. The trees in this recovering forest were small, and many of the species most desirable for lumber had been virtually eliminated. The nation's wood product supply was coming from the old growth forests of the West, and increasingly from the South and Canada. Paper companies acquired extensive landholdings, and the region's forests became the supply base for a major pulp and paper industry.

Gradual changes in technology made possible a steady shift toward lumber production in the North. Important developments were the chipping headrig, and the increasing ability of pulpmills to use chips and other residues from sawmills for pulping. Increasing market acceptance of western species, such as spruce, balsam fir, and hemlock also contributed. During the 1970's, large sawmills were established by the Maine paper industry. By the late 1980's, increasing U.S. competitiveness in export markets fostered a significant increase in exporting by northern mills who could supply quality wood in species in strong export demand. This trend also supported a slow increase in the region's sawmilling industry.[3]

Figure 4

Lumber and Round Pulpwood Harvesting Intensity, 1987



Source: Waddell, 1987, and U.S. Bureau of Census and USDA-FS lumber and pulpwood production data.

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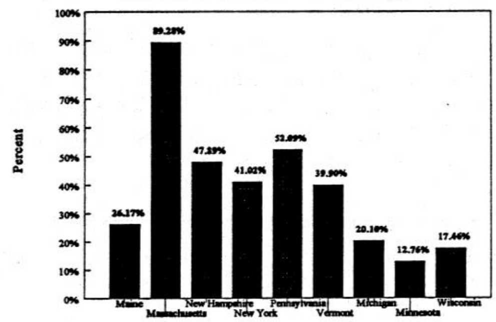
[3] It should be noted that the estimates of lumber production in the North by the Census and other sources have many weaknesses, and are generally believed to underestimate lumber production there.

Not only does the intensity of management vary across the region, but so does the intensity of utilization, measured by the harvest level per thousand acres of forest land (Fig. 4). Because of these variations in the level of utilization, the opportunity to change carbon accumulation rates also varies from place to place. Also, the degree to which the timber harvest is used for lumber varies across the region (Fig. 5), being especially low in the Lake States. But this difference is offset by the high use of aspen for waferboard there.

Figure 5

Lumber as Percent of Total Lumber and Round Pulpwood Harvesting, 1987



Source: Waddell, 1987, and U.S. Bureau of Census and USDA-FS lumber and pulpwood production data.

A new technology for making panel products from chipped logs was invented during the 1960's, but was unable to compete until the housing booms of the late 1970's stretched timber supplies for plywood manufacturers. This process, called waferboard, and later oriented strandboard (OSB), enables mills to make a construction grade panel from species like aspen that were available in abundant quantities and at low costs. As a result, by 1992, 30% of the Minnesota timber harvest was for waferboard/OSB, compared to none in the mid 1970's. From 1985 to 1993, OSB production in the North rose from 1.9 million sq. ft. (3/8" basis) to 3.5 million sq. ft. But because of rising production in the South, the region lost share in the national market (Adair 1993, p. 10).

OSB is now an important member of a new family of Engineered Wood Products. These products include manufactured trusses which can be supplied in long lengths to customer specification. These trusses use waferboard from abundant species. They can actually reduce the tonnage of wood used in a structure, and reduce onsite labor costs. They relieve pressure on the large old growth trees that were formerly needed to manufacture wide structural lumber (12-14" widths) and timbers.

The technology of veneering has a major advantage in that it eliminates waste in the saw kerf. A new family of laminated veneer lumber (LVL) products is emerging that provides structural products that also can be made from abundant species of timber.

Market growth for these engineered products is expected to be rapid, and at least some of the increased production will likely be in the North. The worldwide supply tightening being experienced in the early 1990's will accelerate this process (Irland Group and Joel Popkin 1993; Perez-Garcia 1993). Widmann Management, Ltd. estimates that in just 1993-95, engineered products could increase in production by 464 million bd. ft., or 63% above 1992's level (Widmann World Wood Review Dec. 1993, p. 5). Major production growth can be expected through the first decade of the next century.

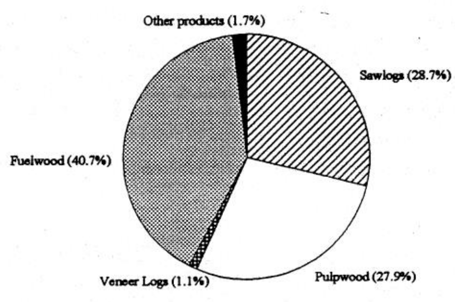
High prices for lumber will also foster the increased usage of lower-valued species for lumber. Species such as aspen, red pine and jack pine, and red maple have been increasing in use for lumber and their markets will continue to increase. In the past they were used only in rough green form for rough rural construction if at all. The increasing sizes of timber in the North will also aid in the shift of usage toward building materials.

The region's current wood use mix is roughly balanced between fuel, pulp, and sawlogs (Figs. 6-8). A five percent shift of wood toward building materials regionwide would amount to 2.6 million cords, or 1.6 million tons of carbon per year.

Figure 6

End-Use Mix: Percent of Volume of Roundwood Produc
Harvested in the North, Total

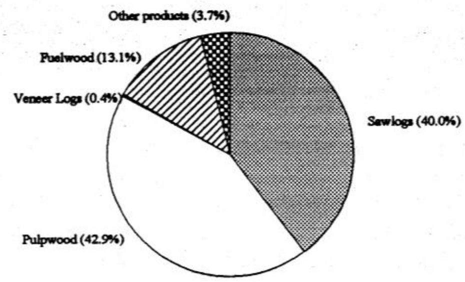
Total = 4,140,128 Mcf



Source: Powell, et al., 1993, unpub.

Figure 7

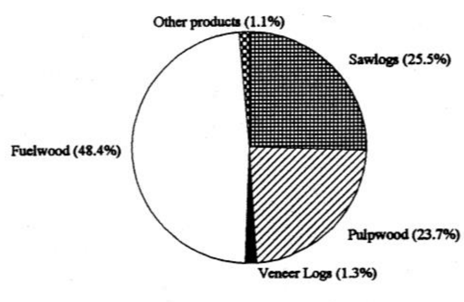
End-Use Mix: Percent of Volume of Roundwood Produ
Harvested in the North, Softwoods
Total = 907,096 Mcf



Source: Powell, et al., 1993, unpub.

Figure 8

End-Use Mix: Percent of Volume of Roundwood Produ
Harvested in the North, Hardwoods
Total = 3,233,032 Mcf



Source: Powell, et al., 1993, unpub.

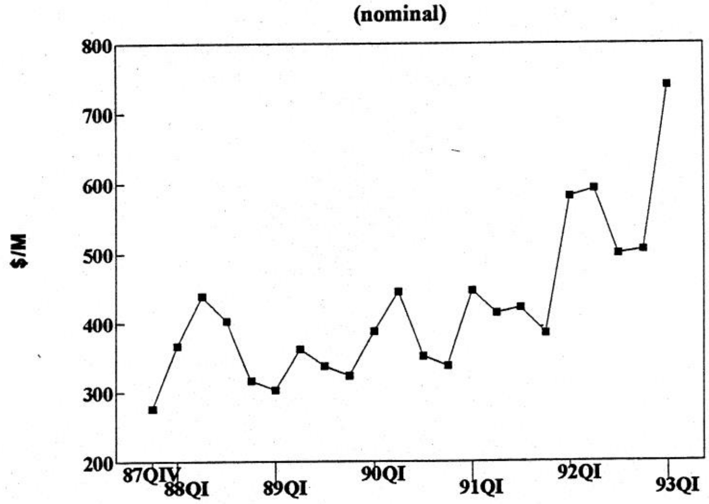
C. World Demand/Supply Balances are Changing—Increasing Stumpage Values

Regional stumpage markets will change markedly in the future. Softwood lumber output is declining in the Russian Republic, at one time the world's leading producer. A timber harvest decline of between 5 and 10 billion board feet per year is under way in the western USA. The cut level will decrease in Canada as well. While logs, lumber and chips from emerging suppliers like Chile and New Zealand will increase, they are unable to offset these changes. In hardwoods, a major reduction in output from tropical sources is under way.

The upshot is that product prices and stumpage prices are going through another of their periodic upward adjustments to a new level of real costs. At this new higher price level, new reconstituted building products will be increasingly used, and stumpage prices for northeastern species will rise. How rapidly this will occur or by how much is uncertain. Indicators from around the North show that this is already occurring (Figs. 9-13).

Figure 9

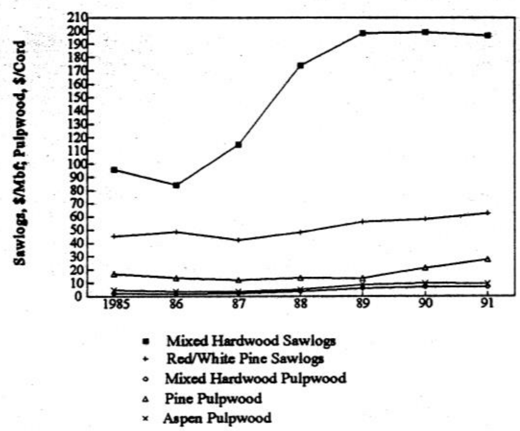
Pennsylvania Black Cherry Stumpage
Average Price, 4th Qtr. '87 to 1st Qtr. '93
(nominal)



Source: PA Coop. Extension, PSU. Quarterly price reports.

Figure 10

Real Price Trends by Species/Product
Ottawa National Forest, Upper Michigan, 1985-1991



Source: Ottawa NF 5-yr. Eval. & Mon. Rep., 1992, p. 44.

Figure 11

Average Pulpwood Prices Received for Stumpage Sold By Public Land Agencies in Minnesota: 1984-92
(nominal)

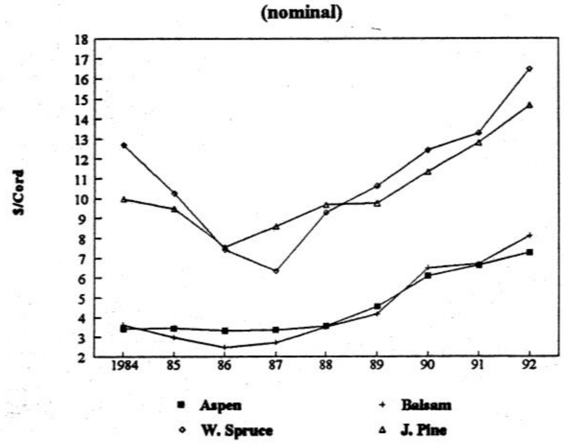


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Figure 12

Average Sawtimber Prices Received for Stumpage Sold By Public Land Agencies in Minnesota: 1984-92 (nominal)

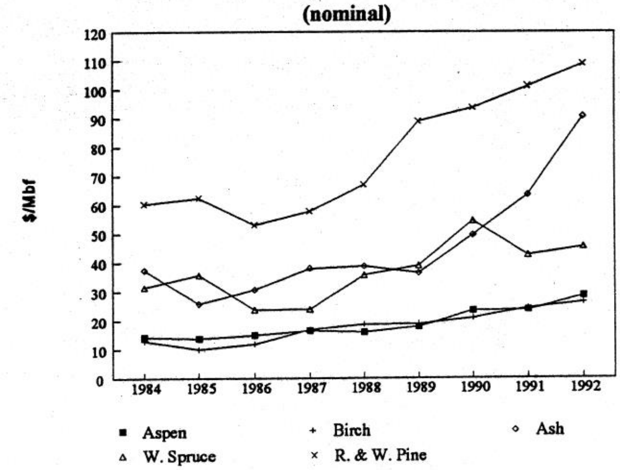
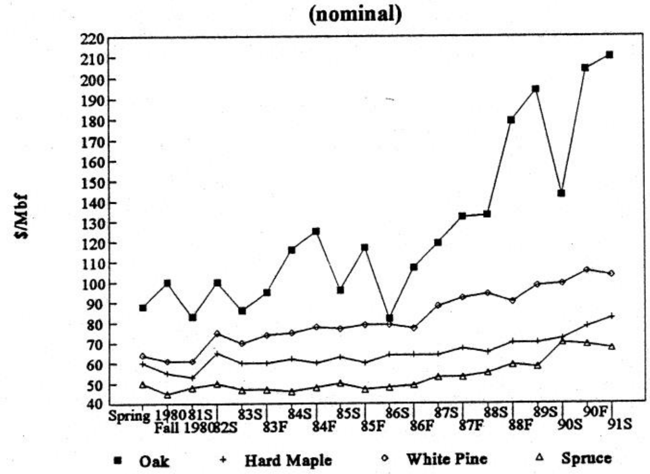


Figure 13

Sawlog Stumpage Prices in Maine, 1980-91 (nominal)



Source: Maine Forest Service.

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This improvement in markets is occurring at a time when the forests of the North are just emerging from a long period of regrowth following the cutting of 1880-1920. Natural stands have been crossing the size threshold into sawtimber size classes, and even becoming increasingly overstocked. Plantations dating from the 20's to the 50's are maturing, many have already seen one thinning, and large acreages are overdue for additional thinnings. Many sawmills in the Lake States already rely heavily on thinnings from red pine plantations. Thinnings can be sold for respectable prices (Irland 1994b).

The paper industry succeeded the lumber industry in this region because, among other things, it could use the small timber that grew here in the wake of logging and farm abandonment. For this reason, a large part of the forest's yield is used for pulp and paper. The nationwide push toward recycling has produced a new source of raw material, from the region's large cities. A shift away form land filling and incineration will have other carbon cycle effects that are not of interest here. This urban recycled paper can be hauled back to any of the region's mills. The huge volume of raw material this represents will be digested by the region's paper industry during the 1990's, which will at the least moderate demand growth for pulpwood and may even reduce it. Government mandates and incentives have helped accelerate this trend.

D. Implications

This market outlook and the slow shift in forest condition have two powerful implications for northern forests in relation to carbon accumulation. First, it provides, for the first time in this century, a level of demand for wood that will enable distinctively more intensive forestry to be practiced here. Second, it will likely increase the proportion of the North's timber harvest used for long-lived building products in contrast to pulp and fuel. Beyond the matter of carbon, it means that past investments in fire control, plantations, thinnings, and stand improvement, made on faith in future needs for wood, are finally likely to pay off financially. Demonstrated financial payoffs will then improve the ability of foresters to convince public, industrial, and small private owners to upgrade management programs.

Costs of Carbon Sequestration through Ecosystem Management

To date, most analyses of the costs of carbon sequestration through forestry have focused on planting. For planting, datasets for costs and yields can be assembled, as has been done by Dixon, Winjum, and Schroeder (1993), van Kooten and co-authors (1992) and others.

When we are managing existing forest stands, however, the applicability of the bare-land analysis used for analyzing planting is questionable. The focus shifts to the incremental cost and yield impact of decisions concerning how heavily stands are to be cut, whether yields are to be deferred, and what the desired rotation age, tree size, or species mix at harvest is to be. Additionally, the dedication of some lands to preservation may reduce average yields per acre, thus boosting unit costs for the remaining wood produced.

A. Accounting Stances

Economic analysis of forest management strategies must begin with a clear view of the contrasting accounting stances involved. The term accounting stance originated in the benefit cost analysis literature, notably the Water Resources Council's guidelines which required that federal agencies analyze water projects using four accounts:

- National Income Account
- Regional Development Account
- Social Well Being Account
- Environmental Account

For further background on accounting stance, see Howe (1971, ch. 2). In resource management controversies, we often find that conflicting views of the economic impact of different policies are due to the fact that arguments are being made from very different accounting stances.

For ecosystem management, we can identify a number of relevant accounting stances (Table 4). The table notes a few points on which the stances are likely to differ. They do not exhaust the possibilities, and to save space, fully developed accounts are not presented.

Table 4
Accounting Stances for Analyzing Economics of Ecosystem Management -- Examples

	Important Concerns
1. Forest Landowner	Cash revenues; Wood flows
2. State and Local Governments	Tax revenues; Local employment
3. Global Carbon Cycle	Net change in carbon cycle
4. National Economic	National economic growth; Trade balance; Noncommodity Benefits, recreation, endangered species, etc.
5. Local Wood Industry	Wood flows, costs, and reliability
6. Local and Regional Hunting	Effects on habitat and fishing groups and access

No single accounting stance is the correct one, although most economists prefer to use the national economic account as a measure of the allocative consequences of decisions. Most analysts agree that developing information according to several of these accounting stances is useful. In the present case, the costs will be viewed from the perspective of the global carbon cycle accounting stance, recognizing that this is not the only stance that is important in analyzing ecosystem management issues.

B. The Problem of Joint Cost Accounting

In forest management and utilization, the production of wood crops and the sequestration of carbon are joint products. That is to say, the accomplishing one goal also accomplishes the other. There is no economically correct way to allocate costs between the two joint products. In analyzing the costs of planting to sequester carbon, most studies have viewed carbon storage as the sole product (see recent review by Wisniewski & Sedjo 1994; Dixon, Winjum & Schroeder 1993, p. 162). By attributing all of the costs to carbon storage, this approach overstates the costs of carbon storage, because some of the costs can be attributed to wood production in cases where wood is a relevant output.

For non-wilderness forests in the North, wood outputs are relevant to at least some extent. We must then seek some way to allocate costs between wood and carbon storage. This problem has been prominent in the water resources literature, where a single dam may provide a number of different benefits to different user groups (Eckstein 1965, ch. IX; James and Lee 1971, ch. 23). An attempt to settle on a final methodology for solving this problem is beyond the scope of this project, but a simple expedient can be considered.

As a first approximation, it could be assumed that management regimes now in place are covering the costs of wood growing. A reasonable way to allocate costs would simply be to attribute incremental costs beyond such regimes to the carbon storage "product." While this method may not be fully satisfactory on a theoretical basis, it offers a way to develop an initial view of the situation. One point to recognize is that ecosystem management produces other incremental benefits for wildlife habitat, aesthetics, and recreation in addition to carbon storage.

The analysis of management economics needs to be dealt with at three distinct levels:

- The individual stand
- The management unit
- The region

C. Analysis at the Stand Level

Stand-level analysis corresponds primarily to the landowner accounting stance. Analyzing management practices at this level is hindered by the lack of documented information on logging costs and how they are affected by different prescriptions, and by the complexity of northern forests which has slowed development of validated computer simulators. While the stand-level analysis is only one way to analyze the carbon storage issue, it is important because land managers will be concerned that specified management practices can be made to work for them in financial, operational, and woodflow terms.

Streamside Protection

A review of the economics of streamside protection suggests that there is not a firm basis for documenting the costs of such prescriptions (Irland 1986, unpub. Irland Group 1994). This situation has not changed very much since that review was done, as illustrated by the difficulties experienced by the EPA in documenting the cost and benefits of Management Measures considered recently under the Coastal Zone Management Program. In the Pacific Northwest, it has been estimated that the costs of streamside buffers were offset by gains in fishery values protected. Whether this might be the case in the North is unclear.

Long Rotations

A number of species in the North live to long ages and are relatively windfirm on many sites. Examples include white pine, red spruce, beech, yellow birch, and sugar maple. The global supply changes now occurring are already boosting stumpage values for these species. Assuming rising stumpage values over time, this factor increases desired rotation lengths. Further, for some of these species, unit values of wood can be expected to rise as management improves log grade.

The analysis of optimum rotations has been a field of some debate within forestry (see, e.g., Newman 1988; Calish, Fight, and Teeguarden 1978). Some experts believe that rotations should be determined on the basis of a bare land analysis of multiple rotations. Such analyses usually yield very short rotations. Others (see, e.g., Davis 1989; Chapelle 1966) believe that for existing stands, a financial maturity approach is appropriate in choosing the desired time for cutting individual trees or stands. On this philosophy, the forester takes the trees and stands as they are found and does not impose an arbitrary rotation age on them.

Analysis of extended rotations for white pine suggests that white pine can be economically grown on very long rotations by landowners who value the high annual incomes such stands are capable of producing, but who are less concerned about the low rate of return on inventory value that older stands yield. Other evidence shows that pines can be profitably retained to large sizes and old ages as long as management is increasing their grade on average. But once trees have reached the maximum quality that can be achieved for them, returns on their value fall rapidly, signalling that they should be cut (Irland, Maass, and Seymour 1994).

Analysis of the effects of different management strategies for black cherry, a valuable species in Pennsylvania, and for aspen, a widespread type in the Lake States, shows that simply retaining these stands provides only slow rates of wood growth and carbon accumulation, because generally they are at ages when growth rates slow down. Holding these stands for longer rotations requires thinnings and stand improvement cuttings, which cause significant reductions in the growing stock per acre. Essentially, the silvicultural treatments are attempting to reduce growing stock (carbon stored) to a lower level to maintain rates of return on capital.

In the case of aspen, because it is a short-lived tree, holding for rotations longer than about 60 years results in a steady decline in stand volume for several decades, as the aspen dies out. As subordinate trees of other species grow into the canopy, stand volume begins to rise again, but stand volume does not recover to its age 60 peak for many decades. Holding such stands to long rotations has little to offer for carbon storage purposes. But it may be a part of an EM strategy, since the aspen type was not widespread in the presettlement forest, and managers may decide to allow forest succession to proceed to replace aspen. On public lands, significant areas of lands not in the timber management base may fit into this category.

Structural Retention

In Maine, major landowners often retain large white pines in clearcut stands. This practice, known in EM parlance as structural retention or green tree retention, is occurring for a number of practical reasons unrelated to EM objectives. Landowners know that these trees are growing rapidly in value, and view them as a readily accessible bank of value that can be tapped in time of need. They also see them as a seed source that may enhance pine representation in the new stands. There is some possibility that these overstory trees may provide a net increase in carbon accumulation in these new stands compared to an alternative in which the pines are removed. If so, this can be viewed as a source of no-cost carbon accumulation.

A review of the structural retention in the Willamette National Forest of Oregon showed how complex the analysis of costs can be (Weigand and Lynn 1992). These analysts noted that while all the facts are not yet in, the near term impact on wood production and Forest Service revenues has been small.

Intensive Treatments

In the North, intensive treatments have primarily been applied to planting and managing even aged stands of softwoods for pulpwood and lumber. While current published data do not exist, several million acres of planted stands exist in the region, and significant areas are being planted each year. In many areas, herbicide or other treatments are used to accelerate growth in young naturally regenerated stands as well.

The intensive management prescription involves a range of treatments designed primarily to produce higher volumes of wood of desired species. Yield benefits have been advocated, but these treatments are costly and are planned for use only on the better sites (Greenwood, Seymour, and Blumenstock 1988). There has been considerable debate over the economic merit of these treatment regimes, and in Maine at least, most major landowners are reducing the annual implementation of these treatments. There are a number of reasons for this, which makes it difficult to draw strong conclusions as to the landowners' views on the economics alone.

A report by Seymour (1993) argues that because of their ability to concentrate growth on fewer acres and to lower harvesting costs, intensively managed plantations will produce lower cost wood than will most managed natural stands. An intermediate position is occupied by an extended shelterwood system relying on natural regeneration. This helps us understand why many industrial owners practice such management, in the face of an apparent difficulty in making return on investment analyses come out favorably. To the extent that this argument gains wider acceptance, we can see that any carbon storage benefit produced by such management will be available at no net cost.

Preservation

For the preservation prescription, it could take a century or more in the future for a stand to reach equilibrium carbon accumulation. This prescription has an opportunity cost in financial and carbon terms. It removes the option of cutting wood and placing its carbon content in storage in buildings. On the other hand, its nonmonetary benefits can be assumed to be significant.

Some Unit Cost Estimates

Cost estimation for individual management practices can be done in a variety of ways, each of which has its weaknesses. For a broad regional survey such as this paper presents, we can turn to two sources. In Table 5 we present averages from a database on management costs assembled by U.S. Forest Service researcher Mike Vasievich. The data are assembled from a variety of respondents to a questionnaire, representing private, state, and federal lands. These averages mask considerable variation due to local conditions, size of programs, and differences in prescriptions employed. For example, among a sample of ten of the National Forests in the Eastern Region USDA Forest Service (1993), costs for reforestation ranged from $60.52 per acre to $149, and those for timber stand improvement ranged from $44.95 to $174.00; these ranges understate the variability, because they omit the extreme high and low values. Further assessments of this question will need to use sensitivity analyses to account for cost variability.

The short term effect on carbon storage is positive only for the treatment "chemical release of softwood saplings" and for planting when done in conjunction with later release from competition (Table 6). The other management treatments are designed to improve species composition, form, and grade in residual stands. By opening up the canopy, such treatments sacrifice biomass accumulation in order to improve value growth. In the short run, therefore, they will reduce carbon accumulation until crown closure is again achieved. Depending on the severity of the cut, stand condition, and site, this may occur within 5 to 15 years. This is a significant fact given the large amount of acreage annually treated to partial harvests and to these various intermediate treatments. Additionally, it is likely that prescriptions designed to shift stand composition to mimic presettlement conditions, or to improve habitat for wildlife, will rely on partial cuttings. Stands treated in this manner will likely be held to extended rotations, at which time their total carbon accumulations will exceed those of stands cut at normal commercial rotations. Yet, each time the canopy is opened up, carbon storage will be reduced.

Table 5
Cost Data for Forestry Treatments, 1994
Dollars per Acre

Treatment	Lake States	Mid Atlantic
Chemical release of saplings	$67	$73
Cleaning in mature hardwood	$44	$48
Hand plant	$76	$84
Improvement cuts	$22	$24
Post harvest removal of non-commercial trees	$40	$44
Management plan	$ 6	$ 6
Partial cut in hardwood sawtimber stands	$26	$28
Site preparation	$98	$108
Thin softwood	$25	$28

Source: M. Vasievich, USDA-FS, E. Lansing, MI, diskette, 1987 data adjusted upward to 1994 by 10%.

Table 6
Carbon Storage Effects in Northern Forests:
Illustrative Cost Analysis of Individual Management Practices --
Incremental Costs Attributable to Carbon Storage Only

	Cost Per Ton of Carbon Stored
Fossil fuel displacement	Small to none
Shift of usage toward building materials	None
Further accumulation of biomass over coming decades	None
Economic investments in timber growing	None to negative
Selected EM practices	Opportunity Cost
Submarginal timbergrowing projects	$16-40

For the treatments that attempt to increase softwood composition by early herbicide treatments, we can expect, on the same acre, a 20% annual yield increase in cubic measure because of the faster growth rate of softwoods. If such a treatment is performed on a submarginal site solely in order to increase carbon storage, we can make the following estimates:

Unmanaged growth	1/2 cd/A =	1.12 tons/A
Yield increase =	20% =	.22 tpa
20-yr yield diff. =		4.4 tons
Initial cost =		$73/A
For a 20-year period, cost per ton =		$16.60 per ton (undiscounted)

This example ignores differences in specific gravity. Suitably adapted to the circumstances, it could be used in many different situations.

Converting these cost estimates into a supply curve, as has been done for different situations by other authors (Dixon, Winjum and Schroeder 1993; van Kooten, Arthur, and Wilson 1992) is not useful for several reasons.

- In many instances, available information does not permit reliable estimation of the change in wood growth associated with different treatments.
- Allowing for the time profile of storage is impossible without landscape-scale modelling.
- Changes in prices, markets, and forestry policies that are now underway are creating entirely new opportunities and constraints for forestry practices, that may profoundly modify results of any current exploratory analysis.
- Secondary data does not always allow spreading costs and benefits properly over time so that they can be treated in a consistent manner across alternatives.
- Some costs, such as for co-firing for fossil fuel displacement, are poorly known at present.

Analysis at the Management Unit Level: A Maine Case Study

For the local management unit, the implications of the different stand prescriptions and land use allocations become evident over time. The time scales can be long, especially in the case of the preservation prescription. Here we report a Maine case study performed with a simple spreadsheet model.

A. Simulation Assumptions and Methods

This analysis assumes that the forests of Piscataquis County, Maine, are operated as a single management unit, which would amount to a substantial 2.2 million acre forest holding. The aggregate inventory and harvest of this forest is simulated under four different model prescriptions (Table 2). The prescriptions range from no management to an intensive management program. The long-rotation program attempts to represent a modest "ecosystem management" program such as might be visualized for a largely private landscape that is typical in the northern U.S. Most would agree, however, that this prescription would fall some distance short of an EM program that would be specified for an entirely public ownership. The mid-level program simulates the way several major private programs are now being managed using partial cutting methods and generally conservative practices. The intensive program mimics the intensive application of practices that are now in general use on several major industrial properties in Maine and elsewhere. Intensive management practices examined here do not include planting, genetically improved stock, fertilization, or drainage, practices that would be worth examining in other regions.

Table 7
Management Strategies

Four strategies were examined. First, a no management strategy was used to test the model. This provided a basis by which to compare the other strategies and is included in the analysis. Yields are based on Seymour and Lemin (1991), and author judgement.

Intensive Management strategy focused on short rotations and even-aged management for all species groups. Both two-storied stands and uneven-aged stands were converted to even-aged stands.

- white pine: 80 year rotation
- spruce/fir: 50 year rotation
- northern hardwoods: partial cutting and 70 year rotation
- aspen/birch: 50 year rotation
- other hardwoods: 50 year rotation

Mid-Level Management strategy extend rotations compared to the Intensive strategy above and left some uneven-age stands.

- white pine: 100 year rotation
- spruce/fir: 70 year rotation
- northern hardwoods: thinning and 70 year rotation
- aspen/birch: 60 year rotation
- other hardwoods: 60 year rotation

Ecosystem Management strategy, called Long Rotation, in addition to harvest scheduling, removed 10% of the acres for additional protection for streamside buffers and other constraints. This reduced the usable volume. Long rotations were engaged. Uneven-aged stands were left intact and increased.

- white pine: 120 year rotation with partial cutting
- spruce-fir: converted to uneven-age classes
- northern hardwoods: 100 year rotation, thinning, and partial cutting
- aspen/birch: 80 year rotation
- other hardwoods: converted to uneven-aged stands

A financial analysis of these alternative programs is not performed here. Since they are modelled on practices already in general use, there is no issue of feasibility. Further, since themanaged scenarios produced no measurable increase in carbon storage over the period in the forest, there is no question of unit costs in this particular example. The interesting differences are in the structure of the forest that emerges, and the impacts on the utilization pathway, which is outside the scope of this project.

For the 50-year projection period, the annual cut rates embodied in our model are reasonable:

Prescription	Cut/A/yr
Long rotation	.146 cords
Mid level	.438 "
Intensive	.627 "

B. Simulation Results

In this simulation, no management resulted in a 22% increase in wood inventory volume in this forest. Slow increases might persist for some time beyond that. This regime thus eliminated any age classes below age 50, beyond those created by natural disturbances (Table 8, Fig. 14).

The long-rotation proxy for ecosystem management resulted in a small reduction in total inventory volume, even as it displayed a major increase in more mature age classes in the forest. The intensive strategy, on the other hand, reflecting an aggressive policy of conversion to short rotations, reduced inventory volume significantly and essentially eliminated even aged stands older than age 50, as would be expected under an area regulation scheme.

Figure 14a
Piscataquis County Simulation, Inventory Volur by Age Classes at End of Fifth Decade

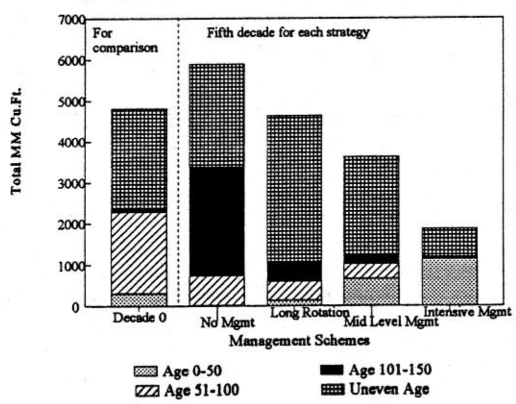

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Figure 14b

Growing Stock Inventory Levels, by Decade: Piscataquis County Case

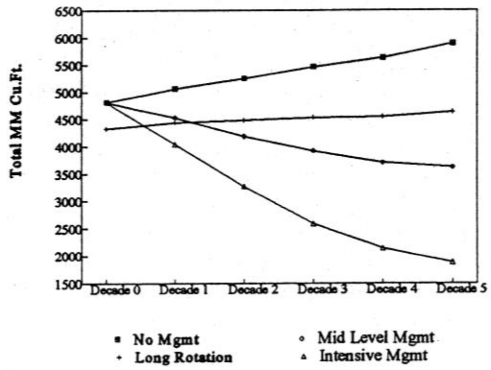


Table 8
Inventory Volume and Timber Harvest
Under Simulated Management Programs, 50-Year Time Period

Management Programs	1 End of Period Inventory (MMCF)	2 Cumulative Harvest (MMCF)	3 Ratio 2/1
Initial Inventory	4,811	n/a	n/a
No Management	5,894	none	n/a
Long Rotation	4,639	1,407	29%
Mid Level	3,624	4,220	88%
Intensive Management	1,878	6,043	125%

Note: Cumulative 50-year harvests in cords:

Long rotation	16.6 million
Mid level	49.7
Intensive	71.1

The long-rotation program led to a 4% reduction from current wood inventory over 50 years. Certainly an ecosystem management strategy more aggressive than the one we have analyzed would result in a net increase in carbon stored in the forest. But this would be at the cost of a still more severe reduction in wood output, and would take many years. If we consider the mid-level strategy in our analysis to represent average conditions for some Maine ownerships, in our examples, a significant reduction in wood production (4,220 to 1,407 in cumulative output) is required to avoid material reductions in initial wood inventory. Measured in cords, the reduction in cumulative output represents 33 million cords. We estimate that in 1993 the average cord of Maine wood, counting biomass, was worth $6 on the stump. The output reduction, valued at this rate, would be nearly $200 million dollars, or $4 million per year. On a per acre basis, the reduction would be only $1.75 per year. This seems a trifle, but it is significant compared to current after tax net income from large forest properties. We think that after 2-3 decades, improvements in wood quality will begin to improve financial returns if management is artfully conducted. But the impact on quantity produced is not so easily offset. The annual loss in output involved in moving from mid level to long rotation management in our example is 660,000 cords, or more than enough wood to run a large paper mill.

The implications for the utilization pathway are also striking. The no management approach puts no wood into the utilization pathway. On the other hand, the intensive strategy provides more cumulative wood production than was present in the initial inventory. This is because its area regulation program harvests all of the land on an accelerated time schedule, and additional growth becomes available during the period. The harvest can be viewed as coming about half from inventory reduction and half from growth. Carbon cycling impacts will depend on how this wood harvest is utilized.

C. Observations on our Simulations

It is difficult to generalize from a single set of stylized simulations, but a few insights from these examples are useful in expanding upon this type of analysis in this and other forest regions.

First, in these examples, major changes in forest structure can be accomplished in as little as fifty years, when there is a high ratio of cut to growth.

Second, in these cases, due to the current age of the forests, a no management program accomplishes only a slow increase in wood volumes.

Third, maintaining the initial level of forest growing stock requires a major reduction in future harvest levels.

Fourth, comparing long rotation management and intensive management, there are large differences in the volumes of wood produced. How this wood is used in the utilization pathway will determine the carbon cycling impacts.

Fifth, this simulation deals with an overall package of practices and has no results that would enable the evaluation of any individual practice. Also, analyzing a longer forecast period would be desirable.

Finally, the changes in storage in the forest seem likely to occur more slowly than the utilization of wood in the energy system can be changed or than wood production cn be diverted into building products.

Analysis at the Regional Level

As Birdsey's data shows, the forests of the North are accumulating carbon at a steady rate, under present management regimes. Since only two or three percent of the region's forests are harvested or otherwise treated in any one year, changes in practices will take considerable time to have a significant effect.

Using a series of economic criteria, Forest Service analysts developed estimates of economic treatment opportunities in the North (Haynes 1990, p. 181-185). They found that economic treatment opportunities existed on only 12% of the region's commercial forest land. These opportunities would produce, over time, an additional 600 million cubic feet at an investment cost of $876 million. This investment could be made over three decades, for an annual cost of $30 million per year. At 15 lbs. of C per cu. ft., this represents an additional 9 billion pounds of C -- the time required to reach this amount, however, is not explicit in the source. Also, the economic assumptions used in the 1990 analysis undoubtedly need updating to reflect the current outlook. But these figures may provide a useful illustration.

Assume, for example, that the objective is to increase carbon sequestration by employing the next tier of management practices beyond this listing that has passed economic muster according the USFS analysts. It might be assumed that an additional investment of $875 million would yield half as much carbon storage as the first increment, or 4.5 billion pounds (22.5 million tons). The investment cost would then be $39 per ton.

Analyzing regional strategies is complicated by the fact that over time the incremental wood production will affect stumpage and wood product prices, which in turn will change economic incentives and modify costs and returns yet again. Accounting for such interactions has been done in the Forest Service's analysis.

A Qualitative Supply Curve for Carbon Storage in the North

From the above considerations, a qualitative supply curve can be developed for carbon storage in the forests of the North in relation to ecosystem management practices. The base case of no action is providing an annual increment of carbon storage at no cost whatever. Let us assume that Birdsey's percentage rates of carbon accumulation apply to the present inventory as given by Powell et al. (1993) as follows:

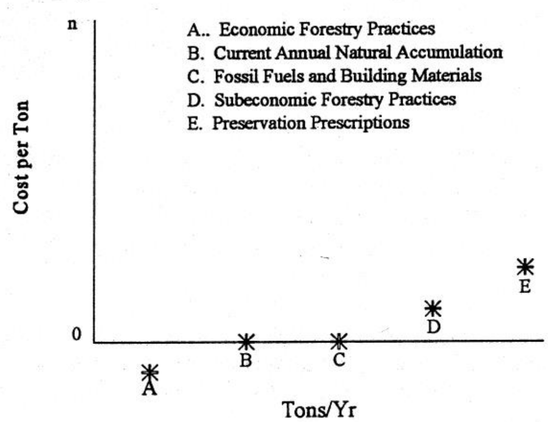
Inventory in North (20 states), 1991:	243 bill. cu. ft.
Percent increase	2.5%
Total annual increase	6 bill. cu. ft.
Annual increase in carbon @ 15 lb.	90 bill. lbs./yr. or 45 million tons/yr.

This estimate is conservative since it applies only to merchantable wood volume, which is perhaps half of the aboveground tree biomass, and it attributes nothing to accumulation in the soil.

A schematic cost (supply) curve for carbon storage in northern forests illustrates the issues to be addressed in further assessment (Fig. 15). This schematic is designed to convey a very general message, and in particular situations the relative positions of different practices may be different.

Figure 15

Schematic Carbon Storage Cost (Supply) Curve



Financial Analysis Procedures

Financial analysis procedures will differ somewhat depending on whether exploratory analyses or final cost estimates are being prepared. For exploratory analyses, rankings are often the critical result, and the precision of the cost numbers is less important. For final cost estimates, considerable effort must be invested in obtaining valid costs that are applicable to local conditions.

A. Stand-level Analyses

Models such as TWIGS, FIBER, SILVAH, and others enable analysts to pose stand management options and treatment regimes over time and to simulate harvests, residual stand conditions, and even changes in species composition. Several of these models contain financial modules to make tracking costs, returns, and investment criteria (ROI) easier. The growth and yield data embedded in these simulators is often from regional sources such as Forest Survey plots. The models are designed for evaluating responses to cutting prescriptions over relatively short periods. When used to forecast stand development over many decades, they are performing a task for which they were not really designed, and they are extrapolating well beyond the age limits of their input data. Such validations as have been done suggest that results have high variability even in 20-year yield predictions.

The principal application of such models in analyzing carbon storage will be in validating feasibility of individual practices, and predicting their yields and impacts on growing stock levels. Results of such analyses can then be used in the management unit analyses.

B. Management Unit Analysis

The interconnections between treatments, time, and "no treatment" cases in existing forests mean that storage impacts and costs must be assessed at the management unit level. The size of management unit defined will be determined by circumstances or by data availability. Basically, the procedure is to simulate inventory, cut, carbon levels, and costs and revenues for alternative management plans. Then, these results are compared with the base case to see how costs change in relation to the changes in carbon storage that are achieved. When wood harvests are projected to decline, care must be taken to account for the net carbon impacts of whatever replacement source is used (Table 9).

Simple spreadsheet models can be developed as was done for Piscataquis County, that will permit the exploratory analysis of these questions on a variety of spatial and time scales, using forest survey data on forest conditions for the area in question. Assumptions must be made, however, about stand ages in many states.

An alternative is to use existing forest regulation models, such as FORMAN or FORPLAN. FORMAN was developed in New Brunswick and has been applied to inventory forecasting problems at a variety of scales in Maine. The FORPLAN models used on National Forests can handle extremely complex management scenarios and can generate output in many different forms. With the availability of PC-FORPLAN, advantage can be taken of rich datasets available on National Forests and some other public land units to study many complex questions and scenarios. The fact that FORPLAN has difficulty handling many of the spatial questions raised by EM prescriptions is not a particular disadvantage for applications when only aggregate, quantitative results are desired, in contrast to more site-specific, geographic results. Many large industrial landowners use one or another of three large, data-intensive models.

Table 9
Steps in a Management Unit Carbon Storage Cost Analysis

Task	Source
1. Define acreages, types, and conditions for volume projections	Inventory; USFS
2. Define treatment regimes, yield curves and responses, especially the base case	Local studies; experience
3. Define conversion ratios to carbon	Birdsey, 1992
4. Define annual fixed and operating costs, revenue assumptions	Records, interviews, price reports
5. Develop spreadsheet or select existing model	
6. Determine utilization path assumptions	
7. Simulate inventory, carbon, and cut under alternative scenarios	
8. Forecast revenues and costs for each scenario	Price forecasts
9. Compare scenarios with base case to determine changes in carbon storage and changes in costs and calculate costs associated with the increment in carbon storage	
10. For management regimes with declining harvests, account for carbon effects associated with the replacement source of wood	

References

Adair, C. 1993. Regional production and distribution patterns for structural panels and engineered wood product. Tacoma: Amer. Plywood Assn. 41 pp.

Auclair, A. N. D., and T. B. Carter. 1993. Forest wildfires as a source of CO_2 at northern latitudes. Can. J. For. Res. 23 (8): 1528-1536.

Birdsey, R. A. 1992. Carbon storage and accumulation in U.S. forest ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-59.51 p.

Brooks, D. J., and G. E. Grant. 1992. New perspectives in forest management: background, science issues, and research agenda. USDA Forest Service PNW Research Station Res. Pap. PNW-RP-456. 17pp.

Brower, M. 1992. Cool energy: renewable solutions to environmental problems. rev. ed. Cambridge: MIT Press. 249 p.

Calish, S., R. D. Fight, and D. E. Teeguarden. 1978. How do nontimber values affect douglas-fir rotations? Jour. For. 76(4): 217-221.

Chapelle, D. E. 1966. Financial maturity of eastern white pine in New York State. State University College of Forestry, Syracuse University, Tech. Pub. No. 91. 261 pp.

Chupka, M. and D. Howarth. 1992. Renewable electric generation, an assessment of air pollution prevention potential. USEPA. EPA1400/R-921005, March. var. p.

Cline, W.R. 1992. Global warming: the economic stakes. Washington, DC. Institute for International Economics. 103 p.

Davis, K. 1989. Forest investment considerations for planning thinnings and harvests. North. J. Appl. For. 8(1991):129-131.

Dixon, R. J., J. K. Winjum, and P. E. Schroeder. 1993. Conservation and sequestration of carbon: the potential of agroforest management practices. Global Environmental Change. 40:159-173. Also avail. as Corvallis Env. Res. Lab., EPA, NITS doc. PB93-229656.

Eckstein, O. 1965. Water-resource development: the economics of project evaluation. Cambridge: Harvard University Press. 300 pp.

Franklin, J. F., et al. 1991. Effects of global climatic change on forests in Northwestern North America. Northwest Environmental Journal 7:233-254.

Greenwood, M. S., R. S. Seymour, and M. W. Blumenstock. 1988. Productivity of Maine's forest underestimated -- more intensive approaches are needed. Univ. Maine Agr. Exp. Sta. Misc Rept. 328. 6 pp.

Haynes, R. W. 1990. Analysis of the timber situation in the U.S. 1989-2040. USDA-FS Rocky

Mountain Forest and Range Exp. Station. Gen. Tech. Rept. RM--199. 268 pp.

Howe, C. W. 1971. Benefit-cost analysis for water system planning. Washington, D.C.: Amer. Geophys. Union. Water Res. Monogr. 2. 144 pp.

Irland, L. C. 1994a. Getting from here to there: Implementing ecosystem management on the ground. Journal of Forestry. August p.12-17.

Irland, L. C. 1994b. Markets soar, sawtimber inventories increase in Lake States Northern Hardwood Belt. Northern Logger. May. p. 8-10

Irland, L. C. 1986. Streamside protection corridors: techniques for weighing costs and benefits. Paper delivered at IUFRO International Congress, Ljubljana, Yugoslavia, unpublished. 43 pp.

Irland Group. 1994. Forestry operations and water quality in the Northeastern states. Nat. Council on Air and Stream Improvement. Report in press.

Irland Group and Dames and Moore. 1993. Assessment of situation and potential for co-firing coal and biomass in energy facilities. Report to Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, Chicago, Ill. 82 pp. + app.

Irland Group and Joel Popkin Assoc. 1993. Assessment of pricemaking forces in the softwood lumber market. Report to American Forest and Paper Assn., Washington, DC. 203 pp.

Irland, L. C., D. I. Maass, and R. S. Seymour. 1994. Unpublished paper.

James, L. D., and R. R. Lee. 1971. Economics of water resources planning. New York: McGraw Hill. 614 pp.

Johnson, D. W. 1992. Effects of forest management on soil carbon storage. Water, Air and Soil Pollution. 64: 83-120.

Kershaw, J. A., C. D. Oliver, and T. M. Hinckley. 1993. Effect of harvest of old growth douglas-fir stands and subsequent management on carbon dioxide levels in the atmosphere. Jour. Sustainable Forestry 1(1): 61-77.

Kurz, W. A., et al. 1992. The carbon budget of the Canadian forest sector: Phase I. Forestry Canada, Northwest Forestry Centre Inf. Rept. NOR-X-326. 93 pp.

Marland, G., and S. Marland. 1992. Should we store carbon in trees? Water, Air and Soil Pollution 64:181-195.

Newman, D. H. 1988. The optimal forest rotation: a discussion and annotated bibliography. USDA-FS SE For. Exp. Sta. Gen. Tech. Rept. SE-48. 47 pp.

Perez-Garcia, J. M. 1993. Global forestry impacts of reducing softwood supplies from North America. Univ. Washington CINTRAFOR. Work. Pap. 43. 35 pp.

Powell, D.S. et al. 1992. Forest resources of the United States, 1992. USDA Forest Service Rocky Mountain For. and Range Exp. Sta. Gen. Tech. Rept. RM-234. 132 pp.

Row, C., and R. B. Phelps. 1990. Tracing the flow of carbon through the U.S. forest products sector. Presented at 19th IUFRO World Cong., Montreal Canada. Unpub. version. 13 pp.

Seymour, R. S. 1993. Plantations or natural regeneration: options and trade-offs for high-yield silviculture. In: R. D. Briggs and W. B. Krohn (eds). Nurturing the Northeastern Forest. Coll. of Nat. Res., For & Agr. Maine Agr. Exp. Sta. Misc. Rept No. 382. pp. 16-32.

Seymour, R. S. and R. C. Lemin, Jr. 1991. Empirical yields of commercial tree in Maine. Orono: Univ. of Maine Agr. Exp. Sta. Misc. Rept. 361. 112 pp.

Stone, R. 1994. Most nations miss the mark on emission-control plans. Science 266: 1939. (23 Dec.)

USDA Forest Service. 1993. Timber cost efficiency study -- final report. Div. of Timber Management, Washington. Apr 16. 140 pp.

USEPA. 1994. Inventory of US greenhouse gas emissions and sinks: 1990-93. Off. Pol., Planning, and Eval. (2122) EPA 230-R-94-014. 73pp. + app.

van Kooten, G. C., L. M. Arthur, and W. R. Wilson. Potential to sequester carbon in Canadian forests: some economic considerations. Canad. Public Policy XVIII(2):127-138.

Vasievich, M. n.d. Unpublished datasheets and computer diskette with management cost database. USDA-FS, E. Lansing, MI.

Weigand, J. F., and A. Lynn. 1992. Economic implications for management of structural retention on harvest units at the Blue River Ranger District, Willamette NF, Oregon. USDA-FS PNW Res. Sta. Res. Note PNW-RN-510. 17 pp.

Widman Management Limited. 1993. Widman World Wood Review. Dec. 1993.

Winnett, S. M., R. W. Haynes, and G. Hohenstein. 1993. Economic impacts of individual climate mitigation options in the U.S.Forest Sector. Climate Research 3: 121-128.

Wisniewski, J., and R. Sedjo. 1994. Literature review on forest practices and carbon sequestration. Washington, D.C.: Forest Policy Center.

Other Forest Policy Center Publications

Forest Policy Center Reports

1. Irland Group, *Ecosystem Management in Northern Forests: Potential Role in Managing the Carbon Cycle, An Exploratory Assessment*, 36 pp., January 1995.

2. Irland, Lloyd C., *Toward A Sustainable Timber Program on the Tongass National Forest: An Introduction to Factual and Policy Issues*, 53 pp., January 1995.

3. Sedjo, R., Moulton, R., Parks, P., and Wisniewski, J., *Economics of Forestry Opportunities to Mitigate Climate Change*, December, 1994.

4. Sampson, R. Neil and Adams, D.L., *Assessing Forest Ecosystem Health in the Inland West*, 101 pp., March 1994.

5. Sample, V. Alaric, *Building Partnerships for Ecosystem Management on Mixed Ownership Landscapes*, 22 pp., January 1994.

6. Hughes, E., Hengen, M. and Svendsen, E., *Factors in the Success of Urban and Community Forestry Programs in the United States: A Literature Review*, 68 pp., November 1993.

7. Kollin, Cheryl and Knack, Emily, *Evaluating the Success of Tree Planting Projects: A User's Guide for Maximizing Tree Survival, Health, and Energy Conservation Potential*, 23 pp., November 1993.

8. Kollin, Cheryl (ed.)., *The National Urban Forest Inventory Project*. Project Compilation, 54 pp., September 1993.

9. Andreasen, Alan R., *Improving Tree Management Practices of Home Builders: A Social Marketing Approach*, 50 pp., September 1993.

10. Sampson, R.N., Apps, M., Brown, S., Cole, C.V., Downing, J., Kauppi, P, Ojima, D., Smith, T., Solomon, A., Twilley, R., and Wisniewski, J., *Terrestrial Biospheric Carbon Fluxes: Quantification of Sinks and Sources of CO_2*. Workshop Statement. (Dordrecht, The Netherlands: Kluwer Academic Publishers), August 1993.

11. Sample, V. Alaric, *Components of a Forest Conservation and Economic Transition Assistance Plan for the Pacific Northwest*, 45 pp. + appendices, May 1993.

12. Parks, Peter J. and Hardie, Ian W., *Least Cost Carbon Reserves: Cost–effective Subsidies to Convert Marginal Agricultural Land to Forests*, 20 pp. + appendices, August 1992.

13. Wellman, J. Douglas and Tipple, Terence J., *Working With the Community in Urban and Community Forestry: A Conceptual Framework for Urban Forest Resource Managers*, 24 pp., August 1992.

14. Beattie, Jeffrey E., *Human Benefits from Protecting Biological Diversity: The Use of Pacific Yew in Cancer Treatment*, 45 pp., July 1992.

15. Sample, V. Alaric and Le Master, Dennis C., *Assessing the Employment Impacts of Proposed Measures to Protect the Northern Spotted Owl*, 65 pp., February 1992.

Books

1. Jaindl, R. and Quigley, T. (eds.), *Sustaining the Land, People, and Economy of the Blue Mountains: A Synthesis of Our Knowledge* (Washington, DC: AMERICAN FORESTS, (forthcoming Winter 1995).

2. Sampson, R.N. and Hair, D.W., *Forests and Global Change: Opportunities for Improving Forest Management*, Volume 2 (Washington, DC: AMERICAN FORESTS, (forthcoming Winter 1995).

3. Sampson, R.N., and Adams, D.L., (eds.), *Assessing Forest Ecosystem Health in the Inland West* (Binghamton, NY: Haworth Press, 1994).

4. Sample, V. Alaric, (ed.), *Forest Ecosystem Management at the Landscape Level: The Role of Remote-sensing and GIS in Resource Management Planning, Analysis, and Decision Making* (Washington, DC: Island Press, 1994).

5. Wisniewski, J. and Sampson, R. (eds.), *Terrestrial Biospheric Carbon Fluxes: Quantification of Sinks and Sources of* CO_2 (Dordrecht, The Netherlands: Kluwer Academic Publishers, 1993).

6. Olson, Jeffrey T., Sample, V. Alaric, and Johnson, Nels (eds.), *Defining Sustainable Forestry* (Washington, DC: Island Press, 1993).

7. Sample, V. Alaric, "Social and Policy Considerations," in: Szaro, Robert C. (ed.), *Biodiversity in Managed Landscapes* (New York: Oxford University Press, 1993).

8. Sample, V. Alaric, *Land Stewardship in the Next Era of Conservation* (Milford, PA: Grey Towers Press, 1991).

Other publications

9. Sample, V. Alaric, "Building Partnerships for Ecosystem Management on Mixed Ownership Landscapes," *Journal of Forestry*, Vol. 93, No. 8 (August, 1994), pp. 41–44.

10. Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. and Wisniewski, J., "Carbon Pools and Flux of Global Forest Ecosystems," *Science*, Vol. 263 (January 14, 1994), pp. 185–189.

11. Sampson, R.N. and Adams, D.L. "Assessing Forest Ecosystem Health in the Inland West," *Journal of Sustainable Forestry*, Special Issue, Vol. 2, No. 1–4 (1994).

12. Wisniewski, J., Dixon, R., Kinsman, J., Sampson, R.N., and Lugo, A., "Carbon Dioxide Sequestration in Terrestrial Ecosystems," *Climate Research*, Vol. 3, Nos. 1–2 (August 30, 1993), pp. 1–5.

13. Sample, V. Alaric and Le Master, Dennis C., "Employment Impacts of Protecting the Northern Spotted Owl," *Journal of Forestry*, Vol. 91, No. 8 (August 1992).

14. Sample, V. Alaric, "Resource Planning and Budgeting for the National Forest Management," *Public Administration Review*, July/August 1992.

15. Sample, V. Alaric, "A Framework for Public Participation in Natural Resource Decisionmaking," *Journal of Forestry*, Vol. 92, No. 7 (July 1993).

16. Sample, V. Alaric, "Cumulative Impact Assessment in Forest Management: Response of the Courts," *Journal of Forestry*, 1993.

17. Sample, V. Alaric, "Assessing Cumulative Environmental Impacts in National Forest Planning," *Environmental Law*, Vol. 21, No. 3 (1991).

Can We Account for Future Climate Change in Maine

Statewide forest inventory and C sequestration projections?

Lloyd C. Irland

Rev. dft Dec. 10

As we project forest inventories out 30, 50, 100 years, some effect of a changing future climate should be included compared to projected inventories under an in a changing climate. But this is not realistic to expect. Further, in 50 years it still may not be realistic. It's a reality we need to get used to. *We need to be realistic about what science can do.*

Of course, *we can run models* projecting incremental effects of different future climates all we want. The question is, do they tell us anything that we could use for our immediate problem of forecasting sequestration, if not for making land management decisions? Once you've built a model you can tell it to forecast for centuries. Since climate forecasts diverge increasingly in the out-decades, so do the results. Can these tell us anything useful for policy and management?

Spoiler alert: they don't tell us much.

In the end, the USForest Service analysts did not assume any specific effects of climate change on forest growth. they adopted a series of scenarios, in the end boiling them down to a Reference case, and High and a Low case for detailed presentation. It turned out that assumptions about future land use changes had a significant effect. These were the principal differences between the High and Low cases. The effect of land use may not be as critical in Maine. They forecast forest C from 2015 to 2060, 45 years. Here is what the USFS says in its 2016 RPA Update:

> *Our projection models essentially assume that forest productivity remains a constant across the projection period, but warming temperatures and*

> *increasing atmospheric CO_2 levels could result in enhanced photosynthesis and carbon accumulation in forests within the timeframe of our projections. The overall implications for productivity are unclear, however, given the compounding influence of nitrogen deposition, drought, storm events, and phenology leading to differences in response across regions and forest types (Ryan et al. 2012).* (USFS, 2016, p. 8-7)

Considering the extensive data, abundant expertise, and experience of the US Forest Service on this subject, it would be surprising if we in Maine could find some way to solve this problem.

How can this be, with all the science and all the modelling that's been going on for 2 or 3 decades? To answer this, let's walk through the sequence of projections, assumptions, and models that can take us to an answer.

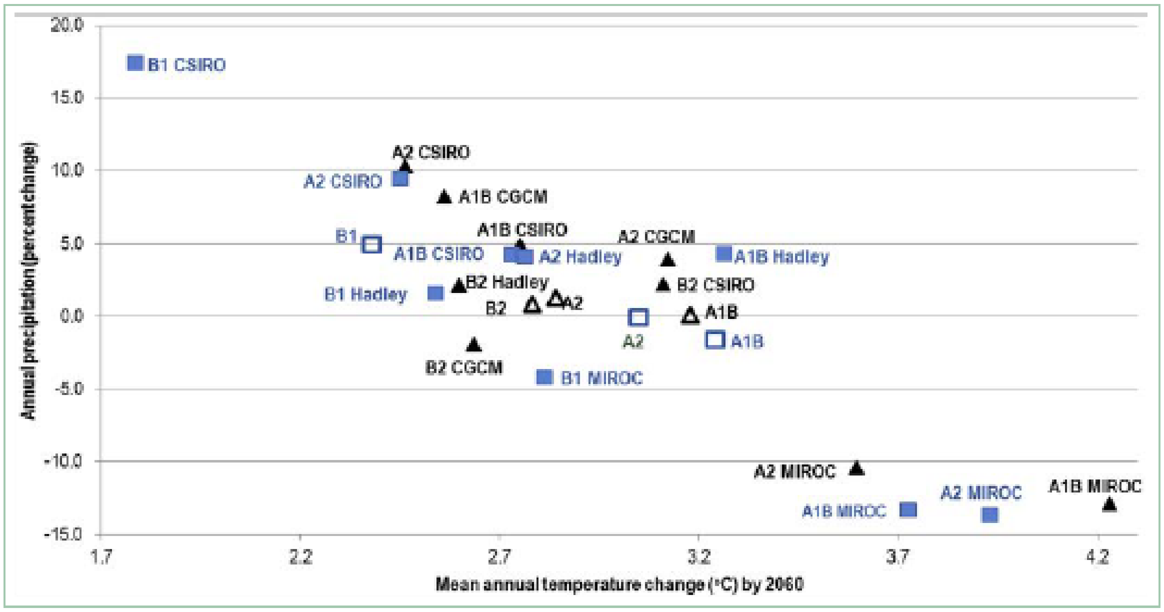
If you want to hear directly from the experts, jump to the References section below and get the reports by Janowiak and Langner cited there. If you haven't yet seen it, a look at the 2020 Maine Climate Assessment update (Fernandez et al 2020) would be a good place to begin.

Steps to Project Future Forest Inventories under changing Climate

1. Adopt a global emissions scenario
    a. This depends on population growth, economic growth, and changing energy intensities, which in turn depend on prices, public policies, and many other things.
2. Choose a climate model (a GCM) into which to input the emissions scenario
    a. There are some 20 GCM models. Their results, for a given emissions scenario, vary.
    b. This will generate a predicted path of future temperatures and other climate variables.

This comparison is for US averages, which are not particularly relevant for Maine, but the illustrate the problem of "choosing your poison".

Figure 13-30. U.S. temperature and precipitation changes from the historical period (1961 to 1990) to the decade surrounding year 2060 (2055 to 2064). Mean changes for each scenario (A1B, A2, B1, B2) are shown as outlined squares and triangles; mean changes for each climate model are shown as solid squares and triangles. Solid black triangles and black outlined triangles are based on climate models used in the 2010 RPA. Solid blue squares and blue outlined squares represent climate models used in the wildlife habitat analyses in this RPA Update.



From: USDA FS 2016, RPA update, p. 9-3.

3. Downscale the GCM to Maine
    a. GCM's model large "boxes" of space. 200 X 300 km.
    b. The models use "gridded" data points for many variables – read "interpolated". Northwestern and Eastern Maine have a scarcity of instrumental data.
    c. Maine may not fit a single "box"
    d. Maine is diverse in elevations and biogeoclimatic regions. How can one of these boxes account for all of this variability?
    e. While well intended and often using a degree of judgment, I consider downscaling these GCM results at present to be little more than a computer programming exercise. Whether it is interesting for science I cannot say, but I'd say for decisionmaking or inventory modelling it's not.
4. Determine, from the downscaled model, key aspects of Maine's climate as they affect plant growth and survival.

a. Problem: we know very little about which specific climate/weather variables most affect plant distribution, competition, vigor, biomass growth, and dispersal.
b. Simple variables such as annual or seasonal temperature or precipitation averages may have little influence by themselves; they are part of suites of variables some of which we cannot even measure. Often, it is the extremes, such as prolonged droughts, winter thaws, or unseasonal frosts, that affect plant seedling survival. (e.g., see Pederson et al. 2014)
c. All the science agrees that in the past, and in future, much of the increase in annual average temperatures occurs due to higher winter minima. So, how does it affect a spruce seedling if it's minus 30 at night in January, or minus 25?
    i. A great deal is being learned about what you might call single-factor relationships… how does soil warming affect the ecosystem? How does the forest respond to more snow or less snow? Shorter snow free seasons? (Contosta et al., 2019; Duveneck, 2017) How does vigor respond to intensified or more frequent drought? To more frequent midwinter thaws/rainstorms –for which we dolt even have real measurements)
    ii. But the forests doesn't respond to one factor at a time… the whole suite of climate influences is changing at once.
d. Maine's forests are fairly diverse with many stands containing a variety of species, and differing in composition between forest floor, midstory and overstory. Each species responds differently to changes in climate.

5. There are several forms of what used to be called "veg" models – details do not concern us (see Janowiak et al). These take as input existing vegetation conditions, and then input changing climate variables and see how the vegetation changes. The question is, which veg model is the right one?
    a. The forests are highly modified by human activity and will continue to be. How those activities affect the future will be shaped by landowner choices in ways that could change in the future.

   b. How do these models account for genetic variability in each species, and the likely existence of geographic races of these wide-ranging species?

6. For many years, models of predicted tree distribution have been produced showing stunning changes in range maps. Converting these changes to forest *volumes*, though, is less well developed. Presumably because a lot harder. A model called P-Net is widely used, along with many enhancements (see Duveneck, et al 2017 for an application to New England and references)
7. In Maine, average annual planting since 1990 has been just under 8,000 acres[2]. Adding up planting and all other practices that MFS tallies as Silviculture brings that total to 44,000 acres per year. From 1990 to 2018, only 7% of all Maine timberland has been affected. In contrast, a total of 13 million acres were harvested in that same period, 77% of the state's timberland. Roughly 3 to 4% of the forest is entered for harvesting every year. These cumulative effects will dominate future timber volumes and conditions, and are difficult to model in any detail.
8. A 30 year period would correspond to perhaps one third of a rotation or so for many of our hardwoods, perhaps 2/3 of a rotation for some commercially grown softwoods. (these are just for comparison -- even-aged management is not the dominant regime in Maine anyway)
9. In contrast, extensive pine forests in the South consisted of planted stands managed on rotations as short as 20 years. For a 30-year forecast period, all of those stands would have been cut and presumably replanted in a 30 year period. At year 20, planters might choose different species or varieties to plant if they believe climate change made the previous stand's genetic stock obsolete. Or they might modify cultural practices. In any case, modelling a single species with predictable management practices is much more straightforward than modelling Maine forests (as many past industrial forest owners and TIMO's discovered)

[2] Note for followup another time: If this planting rate were to continue for 30 years, it would reach a cumulative area of 240,000 acres. Depending on the baseline case (pasture or replanting clearcut forest), and management practices used, this could lead to a doubling to tripling of average growth on those treated acres. This would not be trivial compared to what could be achieved in 30 years in incremental growth on either reserves or forests treated in ways that might boost biomass growth rates.

10. We have learned a great deal about how climate affects insects and diseases, but projecting those effects into the future also depends on fine-grained characterization of temperature and precipitation effects in time and in space. It seems unlikely to me that we will ever be able to make more than very general statements about how these changes will change forest inventories or carbon stocks.
11. Greater occurrence of extreme weather events is expected, but converting these general outlooks into numerical estimates of impacts on forest inventories may never be possible.
12. Once all of the above modelling choices have been made and all assumptions fed into models, the carbon effects still need to be bolted onto a timber inventory projection model, with its own long list of models and assumptions (see Attachment).

Early modelling suggested that growth rates in key northeastern forest type groups would decline for several decades, and then increase again by 2100. (Irland, et al. 2001). Land managers might be glad to believe such a projection and rely on it to increase their current harvests. Shifts in trend like these occur in many projections of various climate variables.

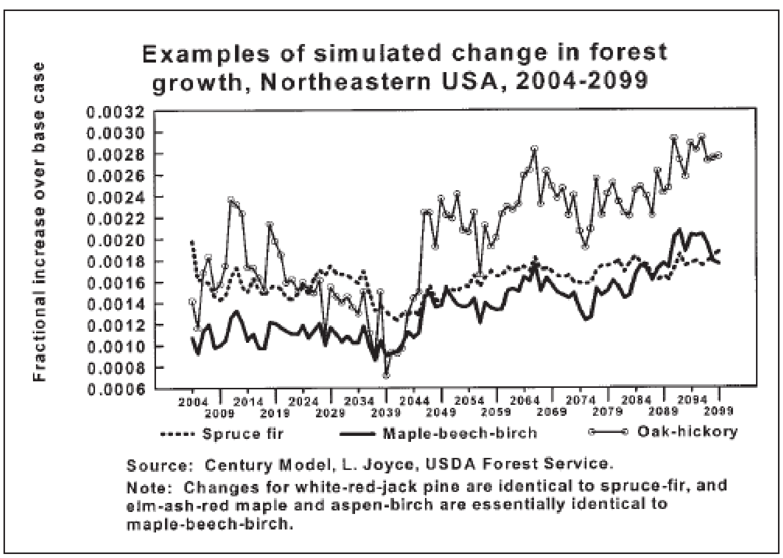


Figure 2. Example of simulated changes in forest growth, Northeast and entire United States, 2004–2009 (fractional increase over base case).

The point is not whether this growth rate projection is correct by current knowledge, but if it isn't, how do we know that in 20 years, today's projections will still be considered reliable? For more on these uncertainties as to growth rates, see Beach et al, 2015, and Duveneck, et al 2017.

Finzi (2020, accepted) have a recent paper showing higher C sequestration at Harvard Forest over past 25 yr. This is potentially relevant to our southern Maine oak types on better sites. They observe that we cannot assume that this rate will continue into the future.

OK, so what can we count on?

1. There is no way to model our way out of this.
2. For now, our focus is on the next 30 years. This lets us relax a little.
3. Trees live a long time. If we are forecasting for Maine, an inventory and Carbon sequestration forecast to 2050, or 30 years, will probably not be affected very much by climate changes unless they are extremely dramatic – in which case we will have no way to predict what they would be (lots of hurricanes? Megadroughts?)
4. Climate change will affect 100% of the forest, but in various ways, and some too subtle even to detect in 30 years. We may discover that the important climate factors are things we have no historical records for.
5. It is easy to forget the huge number of model choices and assumptions in climate and vegetation modelling. In perhaps a Freudian slip, Tang and co-authors (2012) named their model LPJ-GUESS (you couldn't make this up)
6. I think we must accept future climate change as one of a number of uncertainties about the future – That's why they call it "the Future". Analysts and decisionmakers instead will have to be realistic about what is given to humans to know about the future. Perhaps they will have to be content to adopt conservative assumptions when making decisions with important future consequences and high costs.
7. This leaves us with **Adaptation**. We should watch the science closely, but not adopt extreme measures lightly. Good background, literature overview, and suggestions are found in Gunn, Hagan, and Whitman, (2009). Park et al. (2014) survey boreal and temperate regions on the same subject and cite an immense volume of literature. *(There's a tendency to think in this fast-changing field that we needn't read anything published before last month – don't believe it)*

8. Editorial comment: For decades now, the adaptation literature has been citing the same general ideas. But there is still an absence of practical proposals together with minor operational details such as budgets and how much difference they are able to make. Frequently, specific proposals are met with critics arguing that they won't work or will have perverse effects. With so much scientific uncertainty, managers are left to their own judgment. I'd say if you read the two above cited papers, you need read nothing more on adaptation for a very long time. Use your judgment.

References

Beach, Robert H, Yongxia Cai, Allison Thomson, Xuesong Zhang, Russell Jones, Bruce A McCarl, Allison Crimmins, et al. "Climate Change Impacts on US Agriculture and Forestry: Benefits of Global Climate Stabilization." Environmental Research Letters 10, no. 9 (September 1, 2015): 095004. © 2015 IOP Publishing Ltd

Contosta, A. R. et al. 2019. Northern forest winters have lost cold, snowy conditions that are important for ecosystems and human communities. Ecological Applications, 29(7).

Duveneck, M. J., and J. R. Thompson (2017), Climate change imposes phenological trade-offs on forest net primary productivity, J. Geophys. Res. Biogeosci., 122, 2298–2313, doi:10.1002/2017JG004025.

Fernandez, I., S. Birkel, C. Schmitt, J. Simonson, B. Lyon, A. Pershing, E. Stancioff, G. Jacobson, and P. Mayewski. 2020. Maine's Climate Future 2020 Update. Orono, ME: University of Maine. climatechange.umaine.edu/climate-matters/ maines-climate-future/

Finzi, A. C. et al. 2020. Carbon budget of the Harvard Forest Long-Term Ecological Research site: pattern, process, and response to global change. Ecological Monographs. accepted.

Gunn, J.S., J.M. Hagan, and A.A. Whitman. 2009. *Forestry Adaptation and Mitigation in a Changing Climate: A forest resource manager's guide for the northeastern United States.* Manomet Center for Conservation Sciences Report NCI-2009-1. 16 pp. Brunswick, Maine. Available online at: www.manometmaine.org.

Here is an old piece that amazingly is still cited, although surely obsolete in key respects. It does give an easy to read summary of analyzing socioeconomic effects, however.

Irland, Adams, Alig, Betz, Chen, Hutchins, McCarl, Skog, and Sohngen, "Assessing socioeconomic impacts of climate change on US forests, wood-product markets, and forest recreation." BioScience 51(9): 7534-764. Sept. 2001.

https://news.harvard.edu/gazette/story/2020/08/new-englands-trees-capturing-more-carbon-says-25-year-study/

Janowiak, Maria K. et al. 2018. New England and New York forest ecosystem vulnerability assessment and synthesis. USDA Forest Service Northern Res. Sta. Gen. Tech. Rep. NRS-173. 234 pp.

Langner, Linda L.; Joyce, Linda A.; Wear, David N.; Prestemon, Jeffrey P.; Coulson, David; O'Dea, Claire B. 2020. Future scenarios: A technical document supporting the USDA Forest Service 2020 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-412. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p. https://doi.org/10.2737/RMRS-GTR-412.

> Sobering enumeration of all the model choices that are made in national forest carbon projections. With so many scenarios, how do you decide which is most useful for us? I don't know.

Pederson, N., J.M. Dyer, R.W. McEwan, A.E. Hessl, C.J. Mock, D.A. Orwig, H.E. Rieder, and B.I. Cook, 2014: The legacy of episodic climatic events in shaping temperate, broadleaf forests. *Ecol. Monogr.*, **84**, no. 4, 599-620, doi:10.1890/13-1025.1.

Andrew Park, Klaus Puettmann, Edward Wilson, Christian Messier, Susanne Kames & Amalesh Dhar (2014) Can Boreal and Temperate Forest Management be Adapted to the Uncertainties of 21st Century Climate Change?, Critical Reviews in Plant Sciences, 33:4, 251-285, DOI: 10.1080/07352689.2014.858956

Tang, G., B. Beckage, and B. Smith. 2012. Potential dynamics of forests in New England under historical and projected future climate change. Climatic Change. DOI 10.1007/s10584-012-0404-x

USDA Forest Service. 2016. Future of American's Forests and Rangelands. RPA update. General Tech. Report. WO-94. 250 pp. see esp chs 4 and 8.

Vose, J. M. et al. 2012. Effects of climatic variability and change on forest ecosystems: comprehensive science synthesis for the US forest sector. USDA Forest Service Pacific Northwest Res. Sta. Gen. Tech. Rep. PNW- Gtr-870.

Note: If you have a bit of spare time, FASOM is a leading model for analyzing these problems. There is a 267 page manual for it, by Bruce McCarl.

Attachment

Basic Elements of any Regional or State Forest Inventory Projection

Suggestions welcomed

This is intended to be condensed for a 10 minute briefing on the basics for non-modellers… a more compete version might be useful, because many more details could be mentioned.

General:

Maine's diversity challenges statistical adequacy of any plot based system, as the cross-tabs multiply, statistical confidence declines.

Temptation to add modules and detailed subclassifications leads to nontransparency, opportunities for error, confusion, and only limited improvements in precision. *More complicated ain't always better*. (Occam's Razor)

Many assumptions are buried in the math and not explicit – read the footnotes

Error bounds around forecasts increase into the future

Think of these forecasts as tools for understanding how the system works, valid in detail for the first decade or 2 only.

And to see how the "tyranny of small decisions" being made now might shape the distant future.

Recognize that an inventory forecast is an uneasy confederation of many models, all with their own assumptions, traits, uncertainties.

Choose goal of Exercise

Forecast Supply?

Forecast inventory levels?

Scope: a few species? sawtimber, all growing stock, biomass, carbon

Optimization?

Duration?

Choose the Model platform – Spectrum, Woodstock, ATLAS, SRTS, Landis, FORGate

Build the Database

Identify Landbase Being Analyzed & Measure Current Conditions

Stratify the Resource by forest type: Condition or stocking level, species mix, stand structure

Pose Management regimes or intensity classes

Harvest scheduling assumptions

Yield curves for each combination of above

(which may entail extrapolation beyond actual experience)

In partial cut regimes, ingrowth

Other Key Assumptions

Measurement Units: Past inventories have relied upon standardized measures that tally specific sizes and types of trees and shrubs. The goal was originally to measure commercial timber volumes, later extended by various forms of calculation and occasional stem analysis and full-tree weighing to devise favors to convert tree measurements to total biomass. Fortunately, it seems straightforward to convert biomass to Carbon and CO2e, at least to a degree of accuracy widely accepted now. The numerical factors now used will probably remain valid for some time, but whether future managed forests will produce wood of trees and wood matching present factors is uncertain.

The point is, nobody measures biomass. They calculate it using factors developed as noted. Will future eye in the sky technology change this? We'll see.

Effects of Biotic/abiotic stresses. (In Maine nobody needs to elaborate on this.)

Assumed Future Harvest level

= For a managed property, set by management

= for a state or region, imports/exports of wood must be assumed

Method of Economic optimization?

If so, what price and demand assumptions are used?

Desirable Points

Clarity of adopted system and

Clear explanations of results

Useful degree of scenarios, stress-testing or what-if analysis

…. too many combinations of scenarios just leave the user of the information confused and likely to toss the report into the trash.

Don't try to add modules to account for every uncertainty that can be imagined. This results in an awkward megamodel impossible to peer review and impossible for users to understand. Models can't solve everything.

Instead, offer narrative discussions of possible effects of variables not explicitly modelled.

Clearly depict of end of period Conditions compared to present (e.g. age class distributions)

Ability to cross-check/benchmark assumptions against facts outside the model

The Trillion Trees Initiative – Possibilities in Maine?

Rev. Draft 3

Lloyd C. Irland Feb. 15, 2021

One global stage, maintaining and expanding forest area has been a major theme in discussions at all major international climate negotiations. A 2019, a report from Switzerland advocated a global program to plant a Trillion Trees by 2050; the UN Environmental Program has made it a priority. Last year, Rep. Westerman of Arkansas introduced the Trillion Trees Act (TTA), to support this concept globally and increase planting and related programs dramatically. A revised version is in the works in the Senate, with Senator Angus King as a co- sponsor[3]. To convert numbers of trees to acres, you could assume 1,000 trees per acre. So this global program would need one billion acres of land (even more at a lower planting rate). This far exceeds the entire acreage of forest in the US. This could make a considerable contribution to global carbon storage, as well as yield numerous co-benefits.

My thanks to colleagues in our Maine Forest Carbon Discussion Group who offered comments and suggestions on an earlier draft.

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[3] Sen. Braun of Indiana. S.4985 - Trillion Trees and Natural Carbon Storage Act116th Congress Dec. 2020. Will receive new number as new Senate gets organized. Not sure if might change before re-introduced.

The bill does not set a specific acreage target – it requires the Secretary of Agriculture to develop a program of this kind, and also mandate a variety of related initiatives. Some of these were vigorously opposed by environmental groups in the House bill of last year.

Reading a bill like this is no fun. It opens with pages and pages of definitions in wearisome legalistic language. Much of the text involves changes to existing legislation that you can't understand without reading those too. This reflects Congressional compulsion to micromanage everything and the need to keep many groups happy if you want to get a long bipartisan list of sponsors. As a result, a bill like this ends up with no focus at all. Policy junkies like this author grimace over this every time.

One US environmental think tank (WRI) believes that as many as 21 million acres nationally (21 billion trees) could be reforested in the next 20 years without using land needed for food production. Other programs involving tree planting, such as urban trees, sylvopastoralism, and agroforestry as well as enrichment planting are also proposed. Their total program would be 60 billion (why not think big?) including all of these programs. The national effort would cost up to $4.5 billion per year. The total 2021 budget for the US Forest Service is $5.3 billion, much of this for fire control.

Domke et al (2020) estimate current nursery infrastructure can produce some 1.2 billion trees annually. To meet the 20 year goal of 21 million reforested acres would take all of these, leaving none for burned areas or other restocking needs. Arranging planting on literally tens of thousands of private and public properties, ramping up seedling production and trained planting vendors, funding, and many other issues are raised by this ambitious proposal. The customary political gridlock, however, makes vigorous implementation on public lands unlikely.

In Europe, many countries have used tree planting to help deal with chronic farm surpluses, just as in the US in the past with the Soil Bank and Cropland Reserve programs. In most of the world, however, people have the opposite problem – there is not enough cropland. What they have is often wasting away due to bad crop management, desertification, overgrazing, and erosion.

How might a TTA program look in Maine? In recent years, tree planting in Maine has averaged some 8,000 acres per year, mostly on large ownerships, mostly replanting harvested acres. If all this work were applied instead to current nonforest land, it could plant 240,000 acres of forest by 2050. This is surely nontrivial, yet it is less than 2% of the state's current forest area. If planted to fast growing species the carbon impact would be notable, though. The average Maine forest acre today adds about a ton of CO_2 equivalent in net growth per year. Fast-growing trees could triple this amount, but only if intensive management is applied, which is more costly up front than would be common practice on most ownerships. Further, the administrative overhead to get this much land planted would not be insignificant. Note that 8,000 acres of planting would not offset expected annual loss of forest to other land uses.

An area of this aggregate size could be laid out over the state in ways that would not create extensive monocultures. In fact it's not likely to happen any other way. This concern will be all the more intense in some quarters since the best candidates for rapid growth and carbon storage are hybrid poplar, hybrid larches, and Norway spruce. White pine grows very fast but meet skepticism due to pathological issues –still, it will store biomass. Red pine is a fast grower on even on poor sandy sites but has produced its share of discouragement on the disease front; can we afford to sideline it? These species by species issues raise complexities beyond the scope of this short note and the knowledge of its author.

New kinds of mixtures should be developed to accommodate concerns about monoculture. Even without the carbon storage goal, I would argue that developing workable mixtures has long been needed, and has not received its due in support from researchers and working forest managers.

According to the 2007 NRI, Maine has about 370,000 acres in cropland including hay, 29,000 acres in CRP, and 147,000 acres in pastureland. Total land in farms is about 1.3 million acres. As much as 175,000 acres of the cropland could be in hay, a major land use in Maine. Some of what the USDA Census calls "other rural land" and some of the woodland in farms is poorly stocked land currently in grasses, forbs, and shrubs with the occasional pine, spruce, birch, or popple, in the process of "going back" to forest naturally.

These areas will also store carbon, only not as fast as the planted species would. This natural "baseline" would not count as incremental carbon storage as it would regrow even if the area is not planted.

Adam Daigneault and co-authors at UMO estimate in a 2020 report that Maine has some 360,000 acres of land which could be replanted. They conclude:

> "The average afforested stand was estimated to sequester 2.1 tCO2e/ac/yr, thereby yielding a total of 760,000 tCO2e/yr in additional carbon sequestration. Implementing this ... across Maine was estimated to cost about $22.8 million/yr, or $30/tCO₂e."
>
> In fiscal 2019, The Maine Forest Service's total expenditures from all sources were $15.7 million.

This cost per tonne is far higher than recent prices on compliance markets for carbon credits. In their analysis they assumed 544 trees per acre, so that planting all 360,000 acres would only grow about 196,000 trees.

Surely in Maine there is what economists call a "cost curve" showing the acres that could be reforested at a range of costs. The average does not speak for all the acres. Perhaps future research will give a hint as the shape of this curve and the nature of the situations with the lowest costs per ton (see attachment below giving acres by county).

The UMO report accounts for value of current land uses. The average value of cropland in Maine is about $2,300; this includes southern Maine areas affected by suburban land values as well as remote Aroostook County farms. Hayland not in use would be much less. Annual cash rents for crop or pasture are no longer published by the USDA for Maine. In nearby states, pasture rents for $26 or $27 per acre on average, probably less in areas away from cities.[4]

[4] With white pine, we have ample experience jn planting former farmed/grazed lands. With spruce and other species, perhaps much less.

An important point: a national analysis estimates the US average cost per tonne of CO2e sequestered at $20/tonne (Cook-Patton et al. 2020). That means that very large and lower cost opportunities, not surprisingly, are available in places with better soils and more favorable climates for tree growth than Maine.

Whether the potential is large or small for future planted area, if society wants a maximum of forest retained, and wants a maximum of carbon stored, fast growing trees, including some exotics, will be required. The most likely exotics are not literally so – they are here already. My personal favorite hardwood would be our fast-growing and valuable white ash, but its future is under threat due to the introduced pests that are already spreading in Maine. Might red maple, an abundant seeder and fast grower, be possible?

It is also true that plantations of fast growing species often turn out to be nurse crops for more diverse species mixes that seed in under them. I've seen plantations of chir pine in India whose understory was rich natural forest. Spruce plantations get converted to monocultures at the PCT stage – not at year zero. Even production oriented foresters are recognizing and adapting to this. Why not take advantage of this? Plantations need not be forever – but I thought we were on a 30 year timetable here!

There are many other ways to find sites, such as waterway buffers, that need more trees. In the Delaware Basin, it was found that streamside replantings designed to halt sedimentation unexpectedly turned forlorn cattle trodden brooks into trout streams! (but they were very expensive too)

To enlist any meaningful amount of land, and avoid the leakage problem, in due course these stands will have to produce some commercial wood. I believe that with ingenuity and thrift, management regimes that represent reasonable trade-offs between carbon storage, revenue to fund costs of land management, and nontimber values can be devised. Applied research on the design and evaluation of management regimes of this kind is badly needed. The rates of return, though, will not be enough to attract private capital. How then, can this program be financed? That is obviously a challenge.

One thing we need to avoid is the feeling that if it's small, we should ignore it. Maine cannot reach carbon neutrality by doing just one big thing. It will require many small things, and work and investments by many tens of thousands of landowners, builders and building owners, homeowners, auto owners, and small firms. Planting cannot be seen as a substitute for other measures – though in Maine it is far cheaper, according other UMO researchers, than protecting land for development.

Tensions: at the same time as Maine's climate requires greater per capita use of energy for heating, and more driving per person due to spread out patterns of settlement, as well as a tourism dependent economy, it offers significantly less potential for offsetting CO_2 emissions by growing trees than other places. In this process, then, several tensions must be faced:

- Between low productivity natural forests, versus high productivity monocultures and fast growing exotic species;
- Between users of hay who will have to haul hay longer distances, versus replacing hay production with tree growing
- Between wildlife species that depend on early stage habitats that emerge on recently uncultivated cropland, versus more carbon storage
- Between all the above goals and maximizing C storage as a sole land management objective.
- Between national carbon storage and cost effectiveness goals and Maine's inherently less promising soil and climate compared to other regions.
- Between industrial needs for wood and landowner needs to fund taxes and management costs, and the theoretical opportunity to maximize longterm C storage by never cutting the trees.
- If these tensions are resolved entirely in favor of noncarbon goals, then reforestation in Maine will be unable to contribute to the state's future carbon neutrality goals.
- In the Northeastern US at least, finding workers to plant even the modest area now being done is difficult, made more so by the current political climate on immigration—most planting and brush-saw work is done my immigrant workers. My hypothetical illustration shown above, if implemented could make normal replanting on private lands more costly if not impossible due just to labor shortages.

In another illustration of my *Enthusiasts, Baffled people*, and *Adversaries* model of politics, the Trillion Trees proposal of spring 2020 brought forth strong protests from some 100 environmental groups. As if these trillion trees would materialize overnight! Later in the year, the usual list of scientists basically opposed the idea, attaching enough competing goals to the idea to kill it (DiSacco et al. 2021; note: this article is an interesting read and makes some good points). Thus do ambitious, potentially unrealistic proposals produce strident opposition leaving middle ground untenable (perhaps Mulligan, et al. 2020, is middle ground).

Perhaps in focusing only on new planted stands we are missing something. There are large areas of planted stands out there now. Can we design management regimes that would profit their owners, at the same time as holding higher volumes and carbon stocks to far longer ages than they are now doing? In too many instances, our plantations illustrate the results of planting them (often enough on ill-suited sites) and then doing nothing for decades. Couldn't we come up with ways to do a lot better?[5]

Many would agree that further effort for reforestation and augmenting forest productivity in Maine is surely a worthy task, regardless of the many issues raised by ambitious global targets. So, to me, the attention brought to the issue by the Trillion Trees proposal is most welcome. Just googling "Trillion Trees" on a rainy mud season weekend afternoon is likely to turn up some interesting and informative reading.

[5] Economists always want us to examine management regimes by optimizing stand level economics on the assumption that the starting point is bare land (Faustmann; Soil expectation value). This makes the problem of optimizing existing stand go away. Occasional exceptions can be found; we need more of them.

ATTACHMENTS

Total opportunity for planting, including cropland, by County, Maine.

The top 5 counties account for more than half of this total. Notably, they include Cumberland, where land costs would clearly be very high. Other discounts for slope, soils, wetness, owner objectives, or other traits, and other factors would certainly be considered in any more detailed analysis. It's likely that once all reasonable discounts were applied, the hypothetical 240,000 acre effort noted above could not be reached. Since we would hope that replanting on recently cut areas would continue if not increase, we would not mourn this.

Aroostook Co.	81,883
Kennebec Co.	43,478
Penobscot Co.	43,379
Cumberland Co.	32,126
Somerset Co.	29,786
Androscoggin Co.	26,603
York Co.	26,462
Waldo Co.	22,395
Oxford Co.	21,177
Washington Co.	18,800
Franklin Co.	11,735
Lincoln Co.	10,949
Hancock Co.	10,843
Knox Co.	10,796
Piscataquis Co.	8,809
Sagadahoc Co.	7,925
	407,146

Source: https://www.reforestationhub.org/

Further Reading:

Aashna Aggarwal, Danielle Arostegui, Kendall DeLyser, Bethany Hewett, Emily Johnson, and Alexander Rudee.
"Achieving the Mid-Century Strategy Goals for Deep Decarbonization in Agriculture and Forestry"
Duke Nicholas Institute Working paper July 2018.
https://nicholasinstitute.duke.edu/sites/default/files/publications/achieving_the_mid-century_strategy_goals_for_deep_decarbonization_web.pdf

Cook-Patton et al. 2020. Lower cost and more feasible options to restore forest cover... One Earth, 3, p. 139-752.

Adam Daigneault, Erin Simons-Legaard, Sonja Birthisel, Jen Carroll, Ivan Fernandez, Aaron Weiskittel. 2020. Maine Forestry and Agriculture Natural Climate Solutions Mitigation Potential. Interim Report. Univ Maine at Orono. 78 pp.

County-level national data available at: https://www.reforestationhub.org/

DiSacco, Alice et al. 2020. Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery, and livelihood benefits. Global Change Biol. 2021:00:1-21.

Domke, G. M. et al. 2020. Tree planting has the potential to increase carbon sequestration capacity of forests in the US. PNAS, 117 (40): 24649-24651

Focuses primarily on nonstocked and poorly stocked forest land, not on reforestation

Irland and Cline, Role of northeastern forests and wood products in carbon sequestration. Report to Northeast Regional Biomass Program/CONEG. 1998. Washington, DC. On web at:
https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.111.3770&rep=rep1&type=pdf

At p. 131 this pub. lists extensive early literature on planting and related issues of forest carbon.

Mulligan, J., A. Rudee, K. Lebling, K. Levin, J. Anderson, and B. Christensen. 2020. "CarbonShot: Federal Policy Options for Carbon Removal in the United States" Working Paper. Washington, DC: World Resources Institute. Available online at:

www.wri.org/publication/carbonshot-federal-policyoptions-for-carbon-removal-in-the-united-states.

The White House. 2016. United States Mid-Century Strategy for Deep Decarbonization. This report includes a section on reforestation and other forest options.

https://forestclimateworkinggroup.org/resource/united-states-mid-century-strategy-for-deep-decarbonization/

Irland and Cline, Role of northeastern forests and wood products in carbon sequestration. Report to Northeast Regional Biomass Program/CONEG. 1998. Washington, DC. On web at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.111.3770&rep=rep1&type=pdf

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Mulligan, J., A. Rudee, K. Lebling, K. Levin, J. Anderson, and B. Christensen. 2020. “CarbonShot: Federal Policy Options for Carbon Removal in the United States” Working Paper. Washington, DC: World Resources Institute. Available online at: www.wri.org/publication/carbonshot-federal-policyoptions-for-carbon-removal-in-the-united-states.

Forest Carbon Reading List

If you have worked through Irland's Famous 3- Step Plan for assessing forest carbon for your land, read these.

Sources starting with primers and summaries all the way to where to get reams of data and detailed scientific Studies

Lloyd C. Irland   working draft July 15

Accessible Primers on Forest Carbon

Catanzaro, Paul, and Anthony d'Amato.   Forest Carbon: essential natural solution for climate change. No facts of publication given. Assume Univ of Massachusetts. 2019.

Excellent well illustrated introduction with good reading list

Bowyer, J. et al. 2011. Managing forests for carbon mitigation. Dovetail Partners, 16 pp.

Good intro and includes carbon in wood in use. Extensive reading list for this date.

Skog, Kenneth E.; McKinley, Duncan C.; Birdsey, Richard A.; Hines, Sarah J.; Woodall, Christopher W.; Reinhardt, Elizabeth D.; and Vose, James M., "Managing Carbon" (2014). *USDA Forest Service / UNL Faculty Publications*. 274. http://digitalcommons.unl.edu/usdafsfacpub/274

Looks pretty technical at first glance but a good intro.

Bai, X. et al. State of Maine Carbon Budget, 2006-2016 v 1.0. 2 pp. 2020

https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/

MWO Forest C articles --

Several nontechnical articles on forest carbon in Maine can be found at this link:

https://drive.google.com/drive/folders/109NTQxkHDBOPBO0vocz2lg4Bv6H707Fo

If you REALLY Want to learn more, Try these:

Doorstop Volumes

These are major textbooks and highly technical monographs in case you get really interested. Interesting to dip into these; usually good graphics.

Irland and Cline, Role of northeastern forests and wood products in carbon sequestration. Report to Northeast Regional Biomass Program/CONEG. 1998. Washington, DC. On web at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.111.3770&rep=rep1&type=pdf

Economics of carbon sequestration in forestry

Author: Roger A Sedjo; R Neil Sampson

Publisher: Boca Raton : Lewis Publishers, ©1997.

Ashton, Mark, et al. 2012. Managing forest carbon in a changing climate. New York: Springer, 414 pages.

> *Intended as an introduction, highly detailed. Treats issues globally. Technical in places and cites abundant literature. Readers may find individual chapters useful, esp. ch 7. 10, and 12.*

Janowiak, Maria K. e t al. 2018. New England and New York forest ecosystem vulnerability assessment and synthesis. USDA Forest Service Northern Res. Sta. Gen. Tech. Rep. NRS-173. 234 pp.

Good maps and illustrations, but fairly technical. Good news, you can download from Web or even get a fee copy from NRS website.

Vose, J. M. et al. 2012. Effects of climatic variability and change on forest ecosystems: comprehensive science synthesis for the US forest sector. USDA Forest Service Pacific Northwest Res. Sta. Gen. Tech. Rep. PNW- Gtr-870.

Smith, J. E,. et al. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the U.S. USDA FS Northeastern res, Sta. Gen Tech Rep. NE-343.

https://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2006/ne_gtr343.pdf

Policy Issues including Carbon Credits

EESI Feb 2020

A Breakdown of 2019 Climate and Environment Congressional Hearings

https://www.eesi.org/articles/view/a-breakdown-of-2019-climate-and-environment-congressional-hearings

Katie Hoover and Anne A. Riddle. 2020. Forest carbon primer. Washington: Congressional Research Service. CRS R46312. 34 pp.

Snyder. W. M. 209020. Vermont Forest Carbon Sequestration Working Group, Report of a working group established by 2019 legislation. 39 pp.

https://legislature.vermont.gov/Documents/2020/WorkGroups/House%20Energy%20and%20Technology/Agencies%20&%20Departments/Department%20of%20Forest,%20Parks,%20and%20Recreation/W~

Michael%20Snyder~Vermont%20Forest%20Carbon%20Sequestration%20Working%20Group%20Final%20Report~1-8-2020.pdf

Beane, Julie. 2012. Selling forest carbon: practical guide to developing forest carbon offsets for Northeast forest owners. Manomet Center for Conservation Sciences.

Excellent summary and checklist on going through the process of selling carbon credits.

Other?

Maine Climate Council

All documents on formation and mission of Council and reports and minutes of the various working groups:

https://www.maine.gov/future/initiatives/climate

Draft recommendations of the NWL Working Group, June 2020.

Organizations

https://forestclimateworkinggroup.org/about/

National Carbon and Climate Change Policy Assessments and Policy Advocacy

Solving the Climate Crisis, Action Plan for a clean Energy Economy and a healthy, resilient, and just America. Democratic Party's proposals. Extremely detailed staff report covering wide range of issues. 325 pp.

https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf

United States Mid-Century Strategy for Deep Decarbonization **2016.**

https://forestclimateworkinggroup.org/resource/united-states-mid-century-strategy-for-deep-decarbonization/

Achieving the Mid-Century Strategy Goals for Deep Decarbonization in Agriculture and Forestry Aashna Aggarwal,* Danielle Arostegui,‡ Kendall DeLyser,‡ Bethany Hewett,‡ Emily Johnson,§ and Alexander Rudee

Duke Nicholas Institute Working paper July 2018.

https://nicholasinstitute.duke.edu/sites/default/files/publications/achieving_the_mid-century_strategy_goals_for_deep_decarbonization_web.pdf

Mulligan, J., A. Rudee, K. Lebling, K. Levin, J. Anderson, and B. Christensen. 2020. "CarbonShot: Federal Policy Options for Carbon Removal in the United States" Working Paper. Washington, DC: World Resources Institute. Available online at www.wri.org/publication/carbonshot-federal-policyoptions-for-carbon-removal-in-the-united-states.

Carbon market Status Reports -- WB and Forest Trends tbo

Scientific Reports Relevant to Maine and nearby

A. Regional or large management units

Gunn, J. S. and Thomas Buchholz. 2018. Forest sector greenhouse gas emissions sensitivity to changes in forest management in Maine. Forestry. Doi:10.1093/forestry/cpy013

Cameron, R. E. et al. 2013. Comprehensive greenhouse gas balance for a forest company operating in northeast North America. J. Forestry 111(3)194:205

Elliott Forest stuff

B. Individual stands

Joshua J. Puhlick[1], Aaron R. Weiskittel[1,2], Laura S. Kenefic[3], Christopher W. Woodall[3,4], Ivan J. Fernandez[1,5] Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests Article submitted.

Puhlick JJ, Weiskittel AR, Fernandez IJ, et al. Long-term influence of alternative forest management treatments on total ecosystem and wood product carbon storage. Can J For Res. 2016;46(11):1404-1412.

Keeton article on NH

Jiunn-Cheng Lin, Chih-Ming Chiu, Yu-Jen Lin & Wan-Yu 2018. Thinning Effects on Biomass and Carbon Stock for Young Taiwania Plantations

ScienTiFic **Reports** | *(2018) 8:3070* | DOI:10.1038/s41598-018-21510-x 1

(*Taiwania cryptomerioides*)

Get new Knoke thing

David I Maass, Lloyd C Irland, James L Anderson, III, Kenneth M Laustsen, Michael S Greenwood, Brian E Roth. 2020. **Reassessing Potential for Exotic Larch in Northern United States** *Journal of Forestry*, Volume 118, Issue 2, March 2020, Pages 124–138, https://doi.org/10.1093/jofore/fvz066

Wei Peng, Timo Pukkala, Xingji Jin, Fengri Li. Optimal management of larch (Larix olgensis A. Henry) plantations in Northeast China when timber production and carbon stock are considered. *Annals of Forest Science* **volume 75**, Article number: 63 (2018)

https://link.springer.com/article/10.1007/s13595-018-0739-1

Need a Good one on SRIC willow --- from Quebec? SUNY ESF…

Some Web Information Sources:

Carbon Storage in **Forests** | U.S. Climate Resilience Toolkit
toolkit.climate.gov/tool/carbon-storage-forests
Carbon Storage in **Forests** The U.S. Environmental Protection Agency's Report **on** the Environment (ROE) presents the best available indicators of **national** trends in the environment and human health. One of these indicators is **carbon** storage in **forests**, and the ROE **Carbon** Storage in **Forests** tool can be used to explore the trends related to this ...

Seeing **Forests** for the Trees and the **Carbon**: Mapping the ...
earthobservatory.nasa.gov/features/ForestCarbon
Forests in the U.S., as well as their **carbon** content, are mapped down to 30 meters, or roughly 10 computer display pixels for every hectare of land (4 pixels per acre). “This data set is a comprehensive view of **forest** structure and **carbon** storage, and it provides an important baseline for assessing changes in the future.”

Interior Releases Study of **Carbon** Storage and Sequestration ...
www.doi.gov/news/pressreleases/interior-releases...
National Carbon Sequestration Assessment. The report, Baseline and Projected **Carbon** Storage and Greenhouse Gas Fluxes in the Ecosystems of the Western United **States**, was congressionally mandated **by** the 2007 Energy Independence and Security Act. ...

Forest Inventory and Analysis **National** Program - **Forest Carbon**
www.fia.fs.fed.us/forestcarbon
Forest Inventory & Analysis **National** Office U.S. **Forest** Service 1400 Independence Ave., SW Washington, D.C. 20250-0003 (703) 605-4177

EIA emissions