Resource sustainability in commodity systems: the sawmill industry in the Northern Forest

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Abstract

Many natural resource-based commodity systems exhibit a trio of undesirable behaviors—price instability, resource unsustainability, and inequity among people along the commodity chain. In this article we share findings from a modeling project that focuses primarily on the second problem, unsustainability, in the forest products economy and forest ecosystem of the Northeastern United States. The model shows the structural potential for lumber industry capacity to overshoot the timber resource of the regional forest. Many of the policies commonly advocated in response to resource shortage, such as boosting mill efficiencies and eliminating log exports, appear unlikely to solve the problem. We identify several policies with the potential to help sustain both the industry and resource base. We also share insights on how to design a modeling and intervention process when addressing policy problems for which no single organization has direct responsibility. Finally, we consider ways to navigate through three prevalent ''defensive routines''—denial, resignation, and despair—that are often barriers to constructive discussion on how to address potential limits to growth.

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Our modeling work on the Northern Forest is part of a larger research effort at the Sustainability Institute to understand the structural roots of a number of commonly occurring problematic behaviors in natural resource-based commodities. Because such commodities have a significant impact on habitats, renewable resources, and our environment, we feel that improving the sustainability of our commodity system could be a high leverage point. Our goal is to model, understand, and disseminate understanding of commodity systems. We are exploring several interrelated questions:

1. *Instability*. Commodity prices are notorious for their volatility (Meadows 1970; Sterman 2000). They exhibit both semi-regular cycles and occasional ruinous booms and busts. Why are commodity markets so notoriously unstable in price and quantity?
2. *Unsustainability*. Commodities tend to be harvested, extracted, and/or processed in ever-increasing quantities and in ways that undermine

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produced the global computer model "World3" for the Club of Rome and provided the basis for the best-selling book *The Limits to Growth*.

regenerative sources (Forrester 1971; Meadows *et al*. 1992). Why do commodity systems so often push extraction (and waste emissions throughout the value chain) beyond sustainable limits?

3. *Inequity*. Traders, transporters, and financiers receive most of the final sale value of the products, while communities of loggers, farmers, fishers, or miners, who work most directly with the natural resource, are often impoverished (Cronon 1991). As anecdotal evidence, consider the three lowest rated jobs in the U.S.A. out of 250 analyzed in 2000—lumberjack (#248), oil field roustabout (#249), and fisherman (#250) (*Jobs Rated Almanac* 2000). Why do commodity economics so often impoverish the communities that do the extracting, while enriching others up the value chain, far from the original source?

Finally, can these three behavior modes of commodity systems reinforce each other? Unsustainable extraction practices can be exacerbated by either price rises or price crashes. Impoverishment of the resource base compounds the impoverishment of communities that extract the resources. The financial and perhaps political instability of these communities can contribute to instability of supply and price.

Forest resources are one of several commodities we are exploring. To serve our overall goal of promoting a sustainable economy and ecosystem, we seek to understand how these behaviors are expressed, to work with in-the-system stakeholders to determine if improvement is necessary, and, if needed, to facilitate action towards improvement. Second, we seek generalizable insights that are relevant across all the commodities.

To work with a specific forest region, we chose the "Northern Forest," which spans 26 million acres across four states at the far northeast corner of the United States. We spent the first six months working with an advisory board representing various interest groups in the region (industry, environmentalists, policy groups), learning about the challenges they faced and whether any of our hypothesized commodity behavior modes appeared in the real system. We spent the next year collaborating with the same board, gathering data, learning how the system works, creating theories, and building a system dynamics simulation model to test the theories. After converting the model into a flight simulator and designing interactive exercises around it, we spent the next year running a dozen half-day model-based workshops for diverse stakeholder groups across the region—for example, industry groups, environmental groups, government offices, logging companies, professional societies. Our research and workshops led us to focus on the fastest-growing demand on the forest resource—the sawmill industry. We are currently using the model to help engage regional leaders in answering what we call the "three overshoot questions":

1. Does the system have the structural potential for lumber mill demand for timber to overshoot the sustainable yield of the forest?
2. If so, does it matter? Would overshoot be something worth avoiding?
3. If so, is there anything we can do about it?

This article describes what we have learned on several fronts. First, expanding on the extensive system dynamics work on management of renewable resources (Forrester 1971; Meadows *et al.* 1972; 1992; Meadows DL *et al.* 1993; Moxnes 2000), we explain how the interaction of forest growth, market dynamics, and forest industry decision rules can lead mill capacity to overshoot the sustainable supply of timber, and explore policies that could improve system performance. Second, we share our insights regarding the use of simulation modeling and facilitation to catalyze action when there is no single entity with direct responsibility for the problem, critical actions are diffused amongst many players, and the ''intervenors'' themselves have an agenda. Third, we share some of our process lessons from working with Dana Meadows to help people avoid three common defensive routines—denial, resignation, and despair—and remain engaged in the challenging work of confronting the potential for overshoot in resource systems.

Sustainability of the sawmill industry and the Northern Forest

The Northern Forest (Figure 1) is the largest area of intact forest remaining in the eastern United States. It stretches 400 miles across New York, Vermont,

Fig. 1. The Northern Forest of the northeast U.S.A.

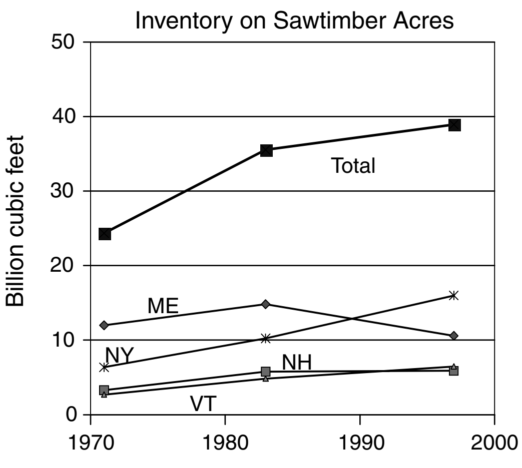
New Hampshire, and Maine from Lake Ontario to the Atlantic Ocean. There are three primary forest product chains in the region. Pulp and paper mills create paper products out of smaller and lower quality timber, called pulpwood or fiber. Sawmills create lumber and veneer out of larger and higher-quality timber, called sawlogs. Individuals and businesses burn low-quality wood for heating and electricity generation.

Increasingly, society also looks to our forests for both recreational access and for ecological services, increasing the pressure to manage the forest for multiple uses. Environmental concerns include habitat loss, soil erosion from logging practices, biological and age diversity of the forest (particularly the existence ‘‘big old trees’’), and the impact of acid rain on tree growth rates. Communities within the Northern Forest are also concerned about their economic vitality and the continued viability of the forest industry. Recent changes in the regional forest economy, such as mill closures, changes in mill ownership, and large land sales, have shaken people’s confidence in the relationships that have characterized the industry for the last century. Finally, the working forest itself is threatened by urban growth and social and economic changes in landowners. How can leaders in the Northern Forest work together to find a sustainable future for the forest?

Our action plan at this point followed the conventional wisdom in our field about modeling for learning—engage a ‘‘client team’’ around a problem of concern, surface and capture their mental models, and improve their understanding of what action to take (Thompson 1999; Morecroft and Sterman 1994; Lyneis 1999).

To explore the sustainability of the forest we first looked to the history of the forest and the industry. The most commonly accepted data about the forest come from the U.S. Forest Service inventories. As seen in Figure 2, the overall inventory of timber (measured by volume in billion cubic feet) on

Fig. 2. Timber inventory on sawtimber acres for four Northern Forest states[1]



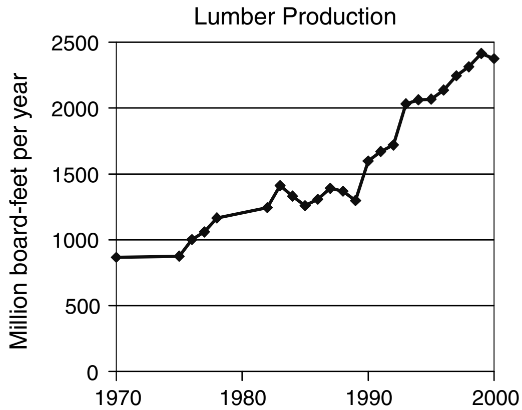


Fig. 3. Total lumber production for the four Northern Forest states since 1970; data from U.S. Department of Commerce (1969–2000)

''sawtimber acres'' (the closest measurement of older, harvestable timber), in the four Northern Forest states has grown over the past 30 years, implying that the overall net timber growth rate has exceed the harvest rate. Other modeling efforts confirm this assessment (Turner and Caldwell 2001). The rate of increase has been decreasing, implying that the gap between harvest and growth is closing. Note that experience at the state level has varied extensively. Forest inventory has fallen, for example, in Maine.

The current harvest appears sustainable. But what about the future? How are harvest rates changing? While the pulp harvest has been reasonably stable over the last decade, lumber production from sawmills in the four states has been growing at about 3.5 percent per year, doubling every 20 years (Figure 3). Additionally, approximately 25% of sawlogs harvested in the Northern Forest are exported to Canadian mills, which are growing as well. Despite increasing wood use efficiency (more usable lumber per cubic foot of sawlogs), the growth in lumber production has led to similar growth in the sawlog harvest rate.

Could growth in the sawmill industry, and thus the sawlog harvest, exceed the capacity of the region to grow sawlogs? What would be the implications for the sawmill industry and for the health of the forest ecosystems? Our advisors reminded us that the region has lived through these dynamics before, about a century ago. Taking a longer-term perspective, lumber production has already grown, contracted and now is growing again (Figure 4). While there were many events surrounding the industry contraction from 1910 to 1930 (a spruce budworm outbreak, the growth of farming, the attractiveness of logging in the U.S. West, the great depression, and the growth of the paper industry), the history raises the possibility of another boom and bust cycle based on the resource (Irland 1998).

Where will the current growth in the industry lead? Will a falling forest inventory drive the mills to slow their growth, creating a smooth transition from growth to balance? Or will mill investors overshoot the long-term sustainable level? In the forest, will the transition create a ''draw-down'' of the resource? Figure 5 shows several scenarios for the transition in the industry and forest that were discussed during the model building process and workshops.

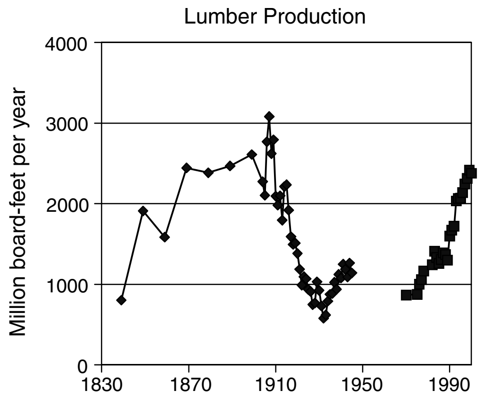


Fig. 4. Total lumber production for the four Northern Forest states since 1839; data from Steer (1948) and U.S. Department of Commerce (1996–2000)

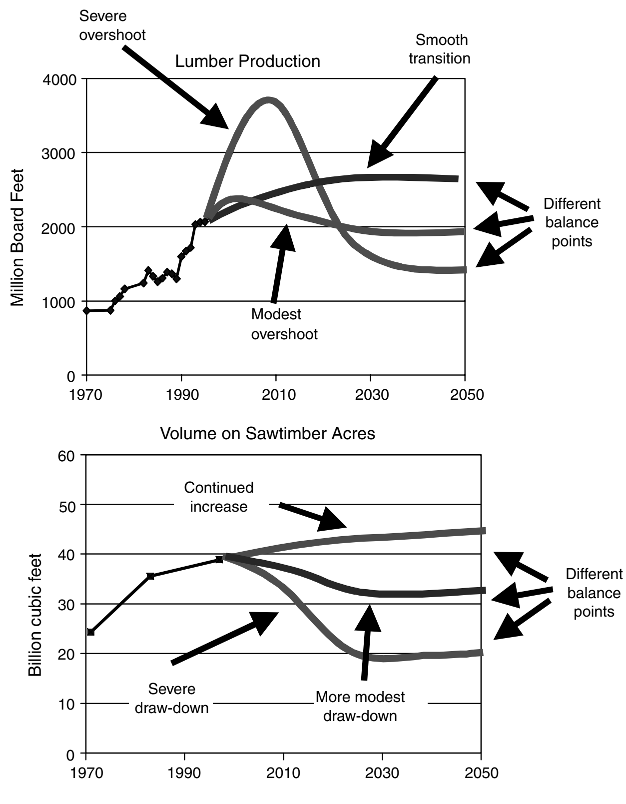


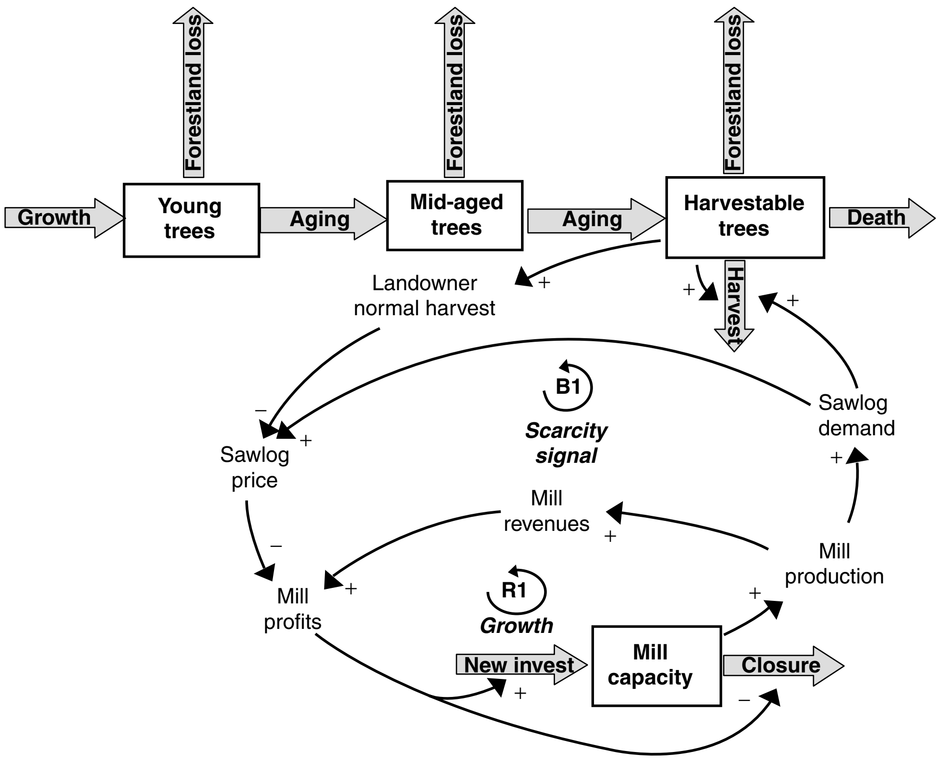
Fig. 5. Possible future behavior of lumber production and sawtimber volume

While the sawmill industry is just one sector within the forest economy, our goal was to leverage concern about this fast-growing sector to explore more general concerns about how a growing industry interacts with a renewable resource on which it depends.

Theory for systemic drivers of behavior

At the heart of our theory is the growth process of the forest itself (Figure 6). Trees mature and increase volume as they age from *Young trees* to *Mid-aged trees* to *Harvestable trees*. We capture this process with a standard aging chain (Boyce 1985; Sterman 2000, Ch. 12). At any moment in time, the forest is comprised of a mix of ages, species, and quality (fiber or sawlogs). Trees of sufficient size and quality are considered harvestable sawlog trees, the rest are fiber/pulp and firewood. This diagram specifically focuses on the sawmill industry but we hypothesize that a similar feedback structure exists for the other forest industries.

Fig. 6. Core stock-and-flow and feedback structure for the dynamic hypothesis



The other key stock in the system is regional *Mill capacity*. Our research in the behavior of mill capacity suggests that when there are no constraints from demand or from resource availability, some *Mill profits* are reinvested in additional *Mill capacity*, boosting *Mill production*, and *Mill revenues*, augmenting profits still further and leading to continued growth roughly in proportion to the size of the existing industry (R1—*Growth*).

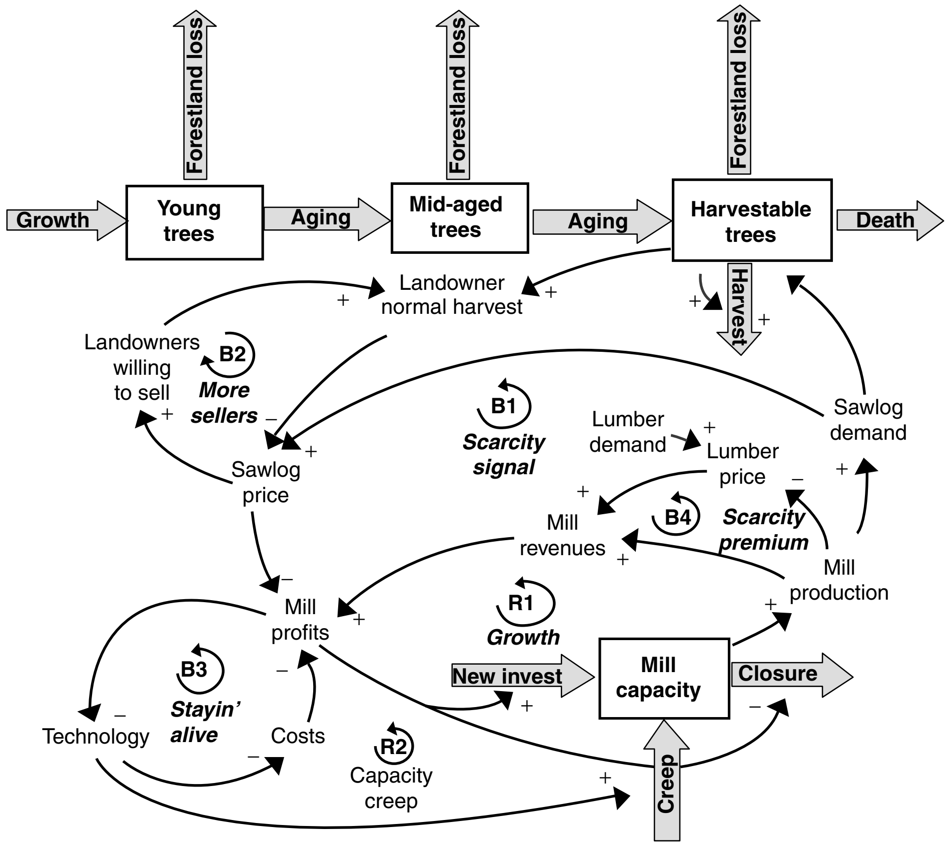
Growth can be constrained by a number of factors. We were most interested in how the availability of sawlogs might constrain the growth in mill capacity. At the simplest level, we expect the market, through pricing signals, to balance the capacity of the mills with the capacity of the forest. If the *Sawlog demand* from growing mill capacity approaches the amount that the landowners would like to sell in a given year (the *Landowner normal harvest*, set by harvest decision rules and the physical availability of sawlogs in the forest), *Sawlog price* should increase, reducing *Mill profits*, slowing *New investment* and potentially leading to mill *Closures* (B1—*Scarcity signal*).

If price signals are able to slow mill growth before the harvest rate exceeds the growth rate, then we would have a sustainable resource and a sustainable industry. So, we asked our advisory team and stakeholder groups through the workshops if they thought a "signal of scarcity" would be sent from the forest to the mills in time to allow the mills to make the transition from growth to balance without overshooting.

Before answering, we need to explore the likely reaction to a rising *Sawlog price* by other players in the system. Additional feedback mechanisms that exacerbate the challenge of regulating mill growth include (Figure 7):

- A higher *Sawlog price* will increase the number of *Landowners willing to sell*, increasing the "normal harvest," moderating price increases and thus delaying the signal of scarcity (B2—*More sellers*).
- If *Mill profits* were to fall, many mills would work to cut their costs and survive. For many mills, the answer is to invest in new *Technologies* that reduce *Costs*, allowing mills to remain profitable despite higher sawlog prices (B3—*Staying alive*). Examples of waste-reducing technologies include thinner saw-blades that produce less sawdust waste, computer-aided scanners that determine the optimal way to saw each log, and saws that can cut a curved log into straight lumber. These technologies have allowed the mills to not only reduce costs, but to use smaller and lower-quality logs as sawlogs. The average sawlog in the early 1970s had a 14–15 inch diameter. Today the average is closer to 7–8 inches with some as small as 5 inches. While further increases in efficiency are expected, they must eventually hit some maximum.
- Investments in technology not only reduce cost, but often involve new equipment with greater throughput efficiencies than the old equipment, boosting *Mill Capacity* via a second inflow, Capacity *creep*. Investments to reduce cost often also increase efficiency, leading to a reinforcing feedback

Fig. 7. Dynamic hypothesis including secondary reactions by landowners, mills, and lumber market

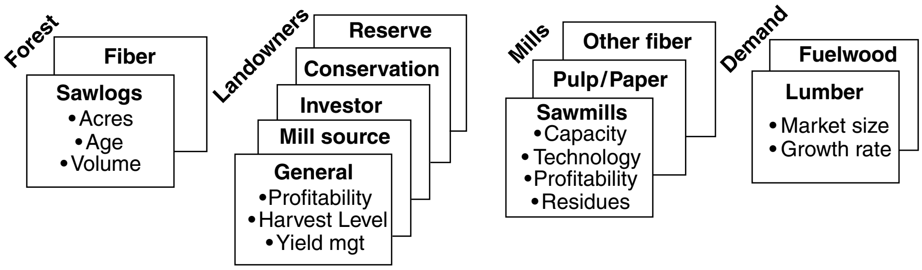


in which falling profitability leads to investment in technology and higher capacity, which causes sawlog demand to rise, higher sawlog prices, and a further erosion of profitability (R2—*Capacity creep*).

- If falling profits cause production to fall relative to sawlog demand, the mills may be able to increase the price of their lumber as a result of the overall market's highly inelastic short-term lumber demand (Beverly and Lempriere 1996) and maintain profitability despite increasing raw material costs (B4—*Scarcity premium*).

The apparently simple story of a single balancing loop slowing capacity growth is not so simple after all. Several secondary reactions by landowners, mill managers, and the market could delay and dampen the signal of scarcity and also create a reinforcing spiral. How will it play out over time? To answer this question and explore the relative strength of these feedback loops, we built a simulation model.

Fig. 8. Model sectors



The model contains four main sectors (Figure 8).[2] The *Forest* sector tracks total acres, the average age/size of trees, and total standing inventory of fiber and sawlogs. The *Landowners* sector represents owners, who make local decisions on allowing harvesting given expected prices. The *Mills* sector drives the regional demand for fiber and for sawlogs. The *Demand* sector captures demand for the lumber and pulp products and sets the final product price.

The regional harvest (for both sawlogs and fiber) is largely driven by regional mill capacity (sawmills, pulp mills, and other fiber industry). New investment in the region in the form of new mills or more efficient technology in existing mills will increase regional capacity, while mill closures will decrease it. We assume that when there is no perceived supply limitation (no signal that there might be scarcity of fiber or sawlogs), then the forest industry will continue to invest in new capacity as long as there is sufficient demand and the mills are profitable.

A critical feedback in the system is how scarcity signals, whenever they are perceived, are communicated to the mills and how the signals influence mill investment, mill capacity utilization, and mill closure. From what we have been able to learn through interviews, the main feedback between the level of forest inventory and the mills is through the landowners and how they make decisions about whether to harvest, how much to harvest, and what price to charge for the trees that feed the mills.

We divided landowners into five classes based not on *who the owners are*, but *how they manage* their forestlands (Table 1). The first two classes, general and mill-integrated, harvest in response to the demand and price for timber. The second two, investment and conservation, harvest based on a planned rotation, with only small variation to accommodate changing price or demand. The fifth, reserve, does not harvest at all.

One of the most interesting changes now going on in the Northern Forest is a great reduction in mill-integrated landholdings, and a rise in investment and conservation holdings. The majority of the land, however, continues to be held by general private owners, often in small plots with relatively rapid turnover of ownership. These general landowners span a wide range of attitudes towards harvesting. In any given year only a fraction of these landowners may be

Table 1. Landowner classes

	General	Mill-integrated	Investment	Conservation	Reserve
Description	Small landholdings, typically with short tenure	Lands managed to make sure a mill is fully supplied	Lands managed to provide a steady return on investment	Lands managed for timber & ecological value	Ecological reserve
Estimated percentage of Forest	52%	13%	20%	5%	10%
Harvest approach	Not planned, responds to price	Responds to mill demand	Plans a rotation, proactively contracts with mills	Plans a rotation, proactively contracts	No harvest
Harvest ‘‘rules’’	A percentage are willing to harvest, and they manage over a ‘‘planning horizon.’’ They limit harvest by raising price	Harvest to keep price down and supply steady	Harvest at rotation goal, but will raise harvest to meet profitability needs or if mills are facing supply scarcity	Harvest with a long rotation goal, will not harvest until forest ages	No harvest
Yield management	None	May put land into plantations where growth is accelerated	Will invest in more thinning if pulp price is high (or less if price is low)	Maintains a steady rate of thinning	None

willing to harvest. Because of the turnover in parcel ownership, it is reasonable to assume that most of the land will become available to harvest over time (Carpenter 1985).

The base run

The base run of the simulation model is a ‘‘no-policy-change’’ scenario, assuming that people continue to make decisions in the future as they have in the past. The result is not a prediction or forecast for the region, but rather a base against which alternative assumptions can be compared. In the base run we are testing to see what would happen in the future if:

- the primary signal about scarcity from the forest to the mills is the rising price of sawlogs or fiber;
- the mills invest in capacity as long as profits are good;

- the mills increase investments in cost-saving technology and speed the closure of old mills as profits go down.

Since price is the main signal from the forest (through landowners and loggers) to the mills, the way in which prices are set is critical. We assume that price begins to rise when demand by the mills exceeds the annual amount that landowners would like to sell, which we termed the ‘‘Landowner Normal Harvest.’’ Each class of owners has an explicit or implicit target for how much timber they would like to sell on an annual basis when prices are at a reference level. When prices are high, they may want to sell above their ‘‘normal’’ level. For landowner classes managing larger tracts for an on-going annual return, the normal harvest rate is based on their targeted rotation length for different species and the current age mix of their standing inventory. The normal harvest is less certain for the wide range of general landowners, who make up over 50 percent of the total acreage and whose primary reason for land ownership is not forest management. Based on interviews and on past harvest levels, we estimate that about 45 percent of the general landowners are willing to harvest in a given year, and that their ‘‘planning horizon’’ (the number of years over which they would like to spread the sales of their current inventory) appears to be around 10 years. We further assume that these landowners will sell above their normal harvest if mills or loggers are willing to pay a higher price.

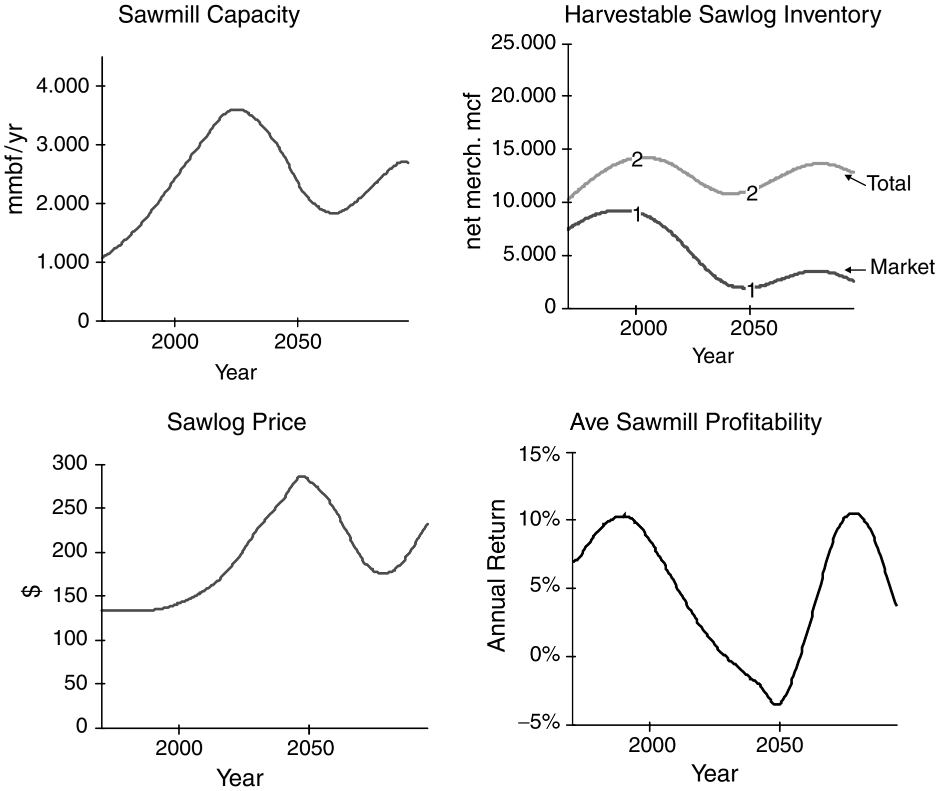
We further assume that urban development removes forest land at a rate of 0.25 percent per year starting in 2000 and that lumber demand grows at 3 percent per year starting in 1970, slowing to 2 percent by 2010 (a relatively aggressive rate, but fitting past growth in demand for Northern Forest lumber).

Resulting behavior

If we run the model under the above assumptions, starting in 1970, sawmill capacity overshoots a sustainable level, as shown by the strong growth in the industry, followed by a peak and eventual contraction (Figure 9). This happens because the mills draw down the inventory of accessible, harvest-sized trees.

The total harvestable sawlog inventory—the volume of sawlogs of harvestable size—has two components: a market stock containing the general lands, mill lands, and investor lands, and the reserve and conservation land. The market sawlog stock is significantly drawn down by the end of the run. Interestingly, the overall volume standing in the forest remains reasonably constant, because the reserve and conservation lands increase in volume (acres in these two categories are constant after 2001). The result is a bi-modal forest, partly covered with large or maturing trees that are ‘‘off limits’’ for harvesting, and partly covered with saplings and poles that are cut quickly once they reach marketable size.

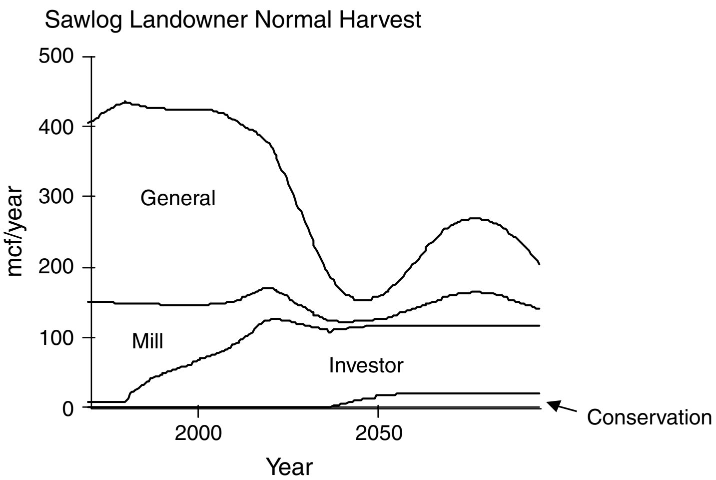
Fig. 9. Base case



The four graphs in Figure 9 trace out the ''Scarcity Signal'' balancing feedback loop shown in the causal diagram (Figure 6). Sawmill capacity grows, propelled by the reinforcing growth loop. When the harvest exceeds the net growth rate of harvestable sawlogs, around 2000, the inventory peaks and then falls over the following decades. Eventually, when the harvest exceeds what landowners would like to sell, sawlog price rises. Despite cost cutting, sawmills feel the price increases as a steady drop in their profitability. The drop in profitability leads sawmill capacity growth to slow and eventually lead to a contraction of the industry. After bottoming out, the same process begins again (Figure 10).

We can see a significant shift in the source of the sawlogs by looking to the *Sawlog Landowner Normal Harvest*, the quantity of sawlogs landowners are willing to sell at the reference price. Early on, there is a surplus on mill and general lands. After that surplus is drawn down, there follows a several-decade-long period of scarcity. During this time most of the supply comes from investor groups managing on a rotation basis.

Fig. 10. Base case for *Sawlog Landowner Normal Harvest*

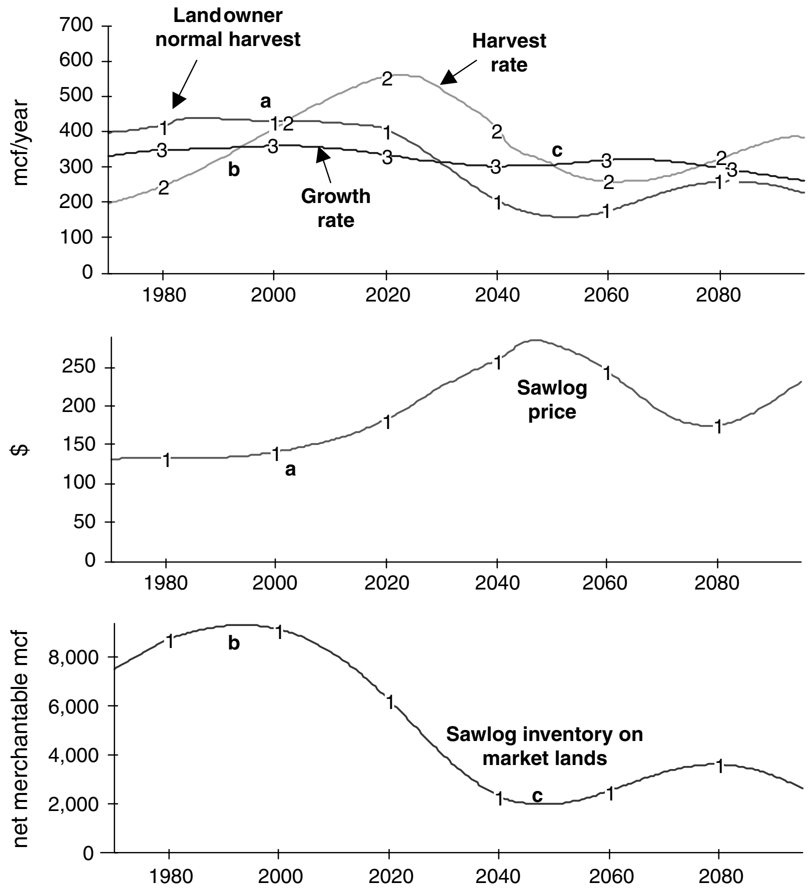


Exploring the sawmill overshoot

Fundamentally, mill capacity overshoots the capacity of the resource because the harvest rate exceeded the growth rate of the forest, which led to a drawdown of the inventory and eventual contraction of mill capacity. Figure 11 illustrates why the harvest rate exceeded the growth rate:

1. *The landowner "normal" harvest level was initially higher than the growth rate*. Because some landowners base their normal harvest levels (the annual volume they are willing to sell at the base price) on their standing inventory, they are willing to sell more than the growth rate when inventories are relatively high. That is, they are looking at the trees currently on the land when deciding how much they are willing to sell, not on how much they have grown that year. Consequently, for the first 30 years the *Landowner normal harvest* exceeds the *Growth rate*. People are willing to sell more than grows each year. As a consequence, when the *Harvest rate* begins to exceed the *Growth rate* (at point b), the *Sawlog inventory* begins to fall. Most importantly, the harvest has exceeded the growth rate **without** triggering a price signal. The price signal only kicks in once the *Harvest rate* exceeds *Landowner normal harvest* (at point a).
2. *Some landowners will sell above their normal harvest goals if the price increases*. When the demand from the mills exceeds the normal harvest level (point a in the top graph in Figure 11), prices begin to rise as the loggers and mills have to bid up the stumpage price to encourage landowners to sell above their normal rate. Prices now indicate some scarcity, but because general landowners are willing to sell more as price increase, the normal harvest level **does not** limit the actual harvest. The actual harvest is only

Fig. 11. Base case behavior for variables that best explain the reasons for overshoot



limited on the land not managed by rotation by the buyers' willingness to pay and the physical limitations of available trees.

3. *The price signal does not immediately reduce the demand for sawlogs (and thus the harvest).* Many balancing effects dampen the price signal, causing a long delay before mill capacity and the *Harvest rate* come back into balance with the *Growth rate*. As sawlog prices increase, more landowners are willing to sell their inventory, increasing the available supply and slowing price increases, while the mills simultaneously invest in technology to reduce costs, increasing production capacity through technology creep. As seen in Figure 11, it is not until about 2050, at point c, that harvest equals growth and the *Sawlog inventory* stops declining.

Note that the industry exceeds its carrying capacity for decades **not** because anyone intends this to happen, but because all actors in the system are taking

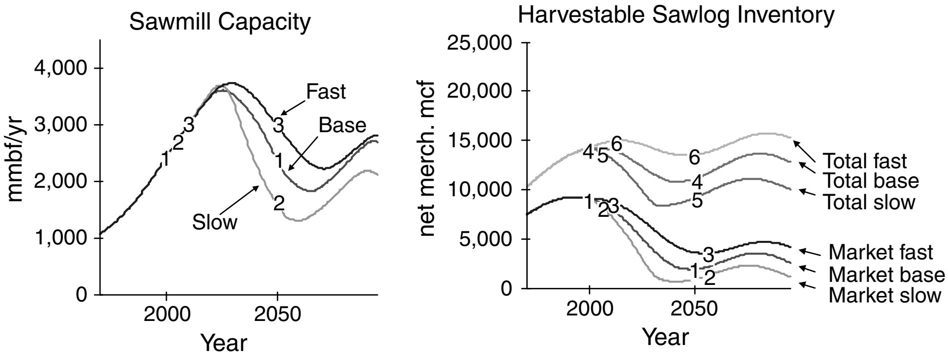


Fig. 12. Model runs with higher and lower growth rates

locally rational actions to preserve their livelihoods. The actors are caught in a ''system trap.'' The system does not provide the information, through prices and profitability, to signal a supply problem in a timely manner and thus does not provide an incentive for long-term forest management.

Sensitivity to accuracy of forest growth rate

In building the forest sector of the model, we simplified the complicated growth dynamics of many species of trees, many land and soil types, and many forest management approaches into aggregate growth rates for the forest. Therefore, of all the parameters in the model we were most concerned about the sensitivity of our base run behavior to the growth rate we chose based on the best available modeling (Turner and Caldwell 2001). Specifically, what if we misestimated the forest growth rate? In Figure 12 we change the growth rate ±20 percent starting in 2000.

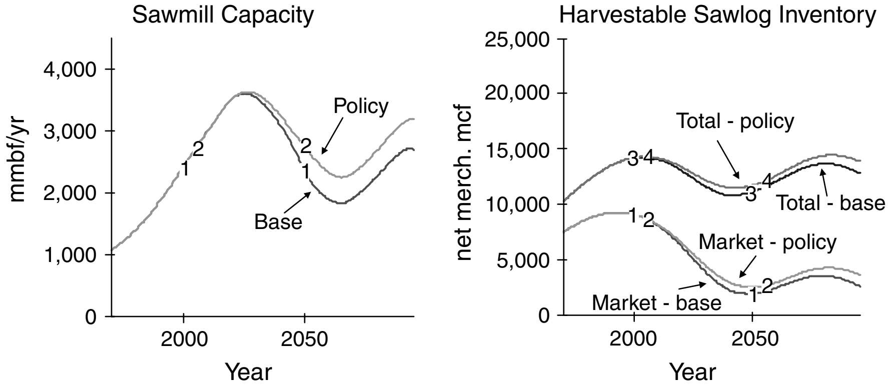
The pattern of behavior—overshoot and recovery for the mills, draw-down and recovery for the forest—does not change. What differs is the *scale* of the dynamic—the height and timing of the peaks and troughs. The low behavior mode sensitivity of the results helps build our confidence that different estimates of growth rates may not lead us to policy conclusions that depend on an intrinsically uncertain parameter.

Policy runs

Ending development of forestlands

Many people's first reaction to the base run is to guess that there would be no overshoot if there were no further development and fragmentation of forestlands. So our first policy test is an elimination of the current 0.25 percent

Fig. 13. Policy test: ending development of forestlands



per year loss of forestlands for housing and other developments. Figure 13 compares the base and no-development runs.

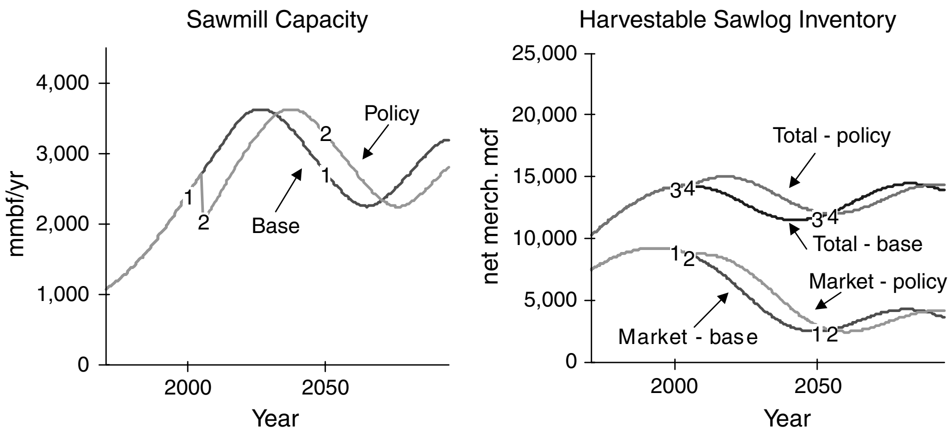
Eliminating development decreases the depth of the sawmill capacity decline—the larger forest can support a larger industry in the long term. But it does not eliminate the overshoot and decline of the industry—the harvest rate still exceeds the growth rate until the mills correct their overcapacity. Interestingly, the policy does little to boost forest inventories. A compensating negative feedback process is responsible: The extra timber supply on the undeveloped lands keeps prices lower, enabling the industry to grow further and consume most of the additional stock. The policy does help somewhat, however. All the remaining base runs and policy/sensitivity tests shown here will also assume no further forestland development.

Eliminating Canadian exports

A popular complaint in the Northeast is that growth in Canadian mills is driving the potential for regional over-harvesting. If only the Canadian mills were prohibited from using Northern Forest timber, says these advocates, the sawmill business south of the border would thrive. To test this proposition, we shut down all exports to Canadian mills in the year 2005. In the base run, sawmill capacity includes mills on the Canadian side of the border, since they are dependent on U.S. forest as their primary resource base. Our policy is modeled by shutting down capacity equivalent to the current export levels to Canada, about 25 percent of total lumber production in the Northern Forest. Figure 14 compares the export reduction policy to the base run.

The reduction in exports does not solve the overshoot problem. It simply extends the time it takes for the industry to grow beyond a sustainable level. The sawmill industry grows through investments and new technology as long as demand is growing and profits sufficient. Eliminating exports allowed the local industry more room to grow, but does no better at avoiding overshoot,

Fig. 14. Policy test: eliminating Canadian exports

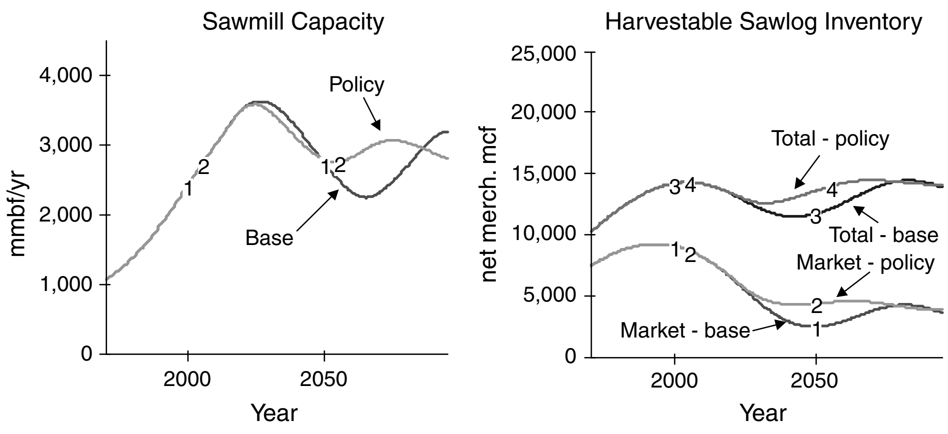


because the basic system has not been changed. The delays in the price signal feedbacks are still in place.

Investing in yield management

On the other side of the solution spectrum is the proposal for landowners to increase their investment in yield-enhancing techniques such as thinning and plantation management. If the forest can just grow faster, the overshoot can be mitigated. In this scenario, we assume that in 2000 the mills start managing one half their land in high-yielding plantations, while investment landowners increase their investment in pre-commercial and commercial thinning. The result of these investments is to increase the growth rate and the fraction of logs that are of sawlog quality (Figure 15).

Fig. 15. Policy test: investing in yield management



The result? Some improvement. Even plantation-grown trees require about 40 to 60 years before harvest, so there is a long delay before significant benefits appear. More importantly, while yield management brings the growth rate closer to the harvest rate, it does not help the system *maintain a balance* between harvest and growth in the long term. Though not explicitly modeled, this policy is controversial because it would promote a monoculture inventory with low age and species diversity, increasing the vulnerability of the forest to disease and pests and threatening other species due to habitat reduction.

Boosting sawmill material efficiency

Many resource policy analysts (the authors included) have looked to improvements in technical efficiency as a solution to economic/environmental challenges such as we face in the Northern Forest. At the extreme, Hawken *et al.* (1999) calculate that ''today's best techniques for using wood fiber more productively could supply all the paper and wood the world currently requires from an area about the size of Iowa.'' What would be the effect of significant acceleration of technological gains in material use efficiency in sawmills? Is the overshoot reduced if the region's sawmills introduce thinner saw-blades, computer-controlled routing and sawing systems, and other scrap-cutting improvements at an even faster rate than projected? The efficiency scenario boosts the rate of increase of the lumber recovery factor from 3.9 percent per decade to 6.1 percent per decade starting in 2000 (Figure 16).

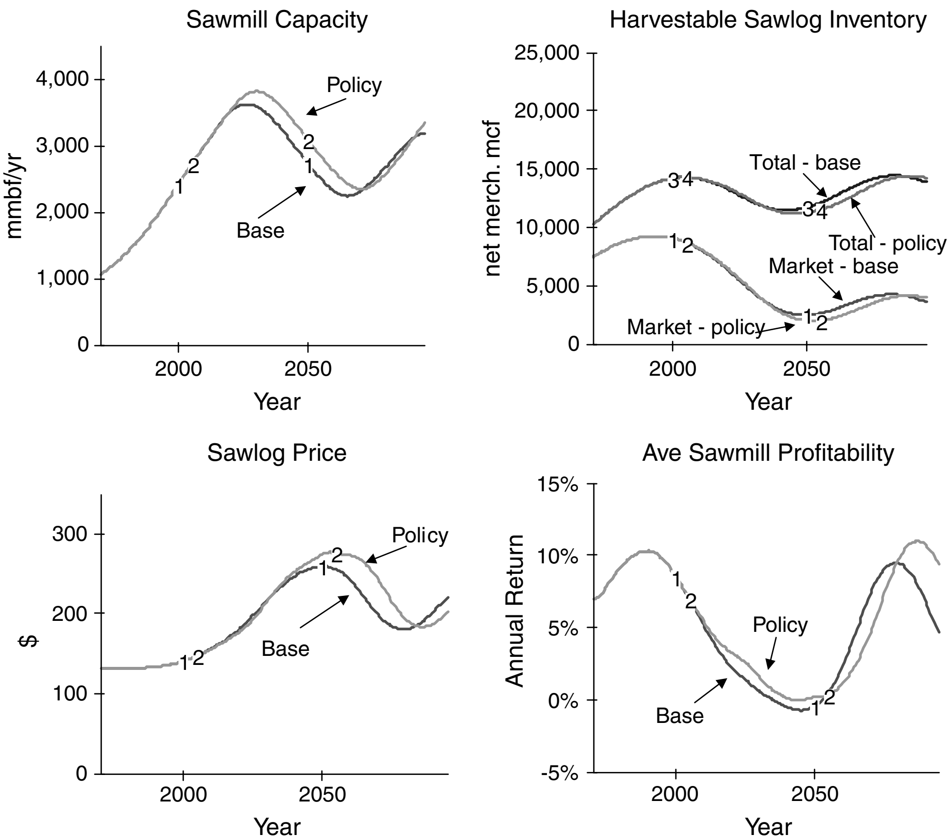
The result is that the mills grow larger and overshoot slightly more than in the base run, with the forest draw-down almost identical. What happened? Improved mill efficiency initially lowers the harvest because it takes less timber to produce every unit of finished lumber. However, two compensating feedbacks reduce the benefits. First, a higher standing inventory lowers sawlog prices and boosts profits, enabling mills to expand and reducing forest inventory faster. Second, better technology allows the mills to stay profitable (and therefore expand) at an even higher sawlog price—the improvement has helped further dampen the scarcity signal from the forest to the mills. Mills expand for ten or so more years and sawlog price rises even higher before the correction.

The results are not an argument against increasing wood use efficiency—extracting more finished product out of every log is an improvement. But technological improvements do not solve the problem of stopping the growth of mill capacity before it exceeds forest capacity.

Changing land ownership to reserve/conservation

Many people look to different land ownership patterns as a leverage point to improve the behavior of the system. To shelter wildlife, restore ecosystems, and provide recreation and tourism, many people propose an increase in the

Fig. 16. Policy test: boosting sawmill material efficiency



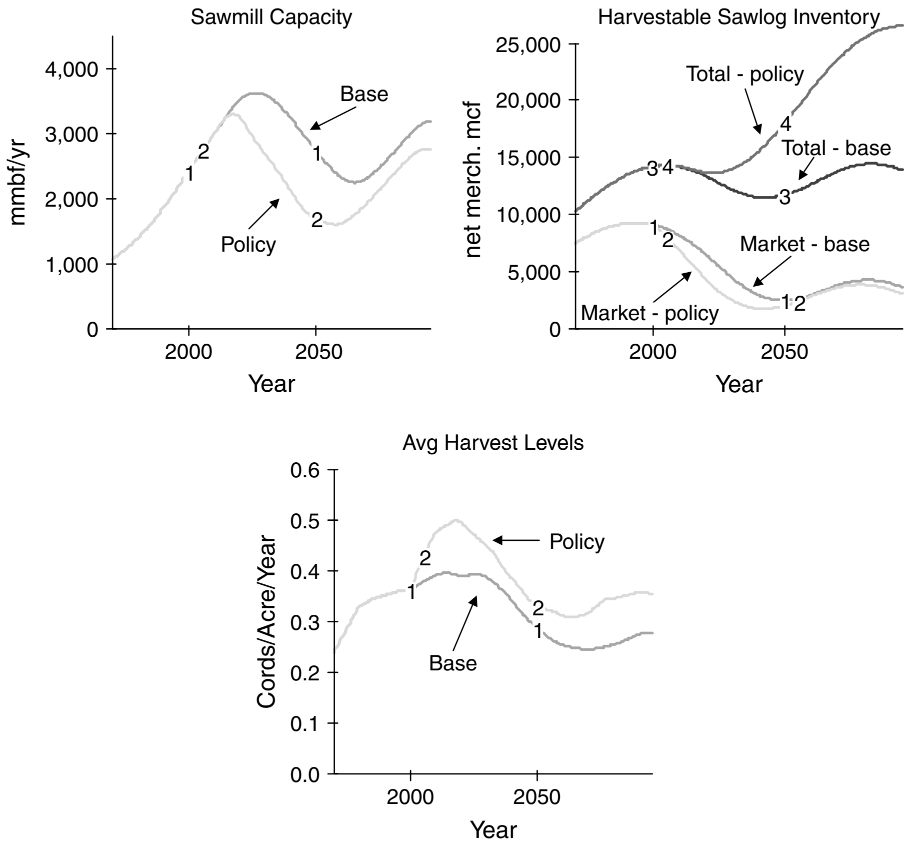
amount of land managed by conservation groups and held in reserve. Table 2 outlines the initial values for 1970, the 1997 values (which persist through the base run), and then a reserve-dominated scenario.

The policy leads to a starkly bi-modal Northern Forest—part big old trees, part quickly harvested poles (Figure 17). The fraction of land held in conservation and reserve increases significantly starting in 2005. With

Table 2. Land allocation for reserve/conservation policy test

	Initial values (1970)	1997 (base case)	Reserve-dominated
General	65%	52%	47%
Mill	20%	13%	3%
Investor	2%	20%	15%
Conservation	4%	5%	10%
Reserve	9%	10%	25%

Fig. 17. Policy test: more reserve/conservation land



less timber on the market, sawlog prices climb earlier and sawmill capacity contracts earlier, but still overshoots. The harvestable sawlog inventory on all lands skyrockets relative to the base—the reserve and conservation lands are adding more and more ''big old trees.'' In one sense, the policy has succeeded, increasing the amount of land with significant inventories. But the sawlog inventory on the harvestable lands actually crashes faster. What happened?

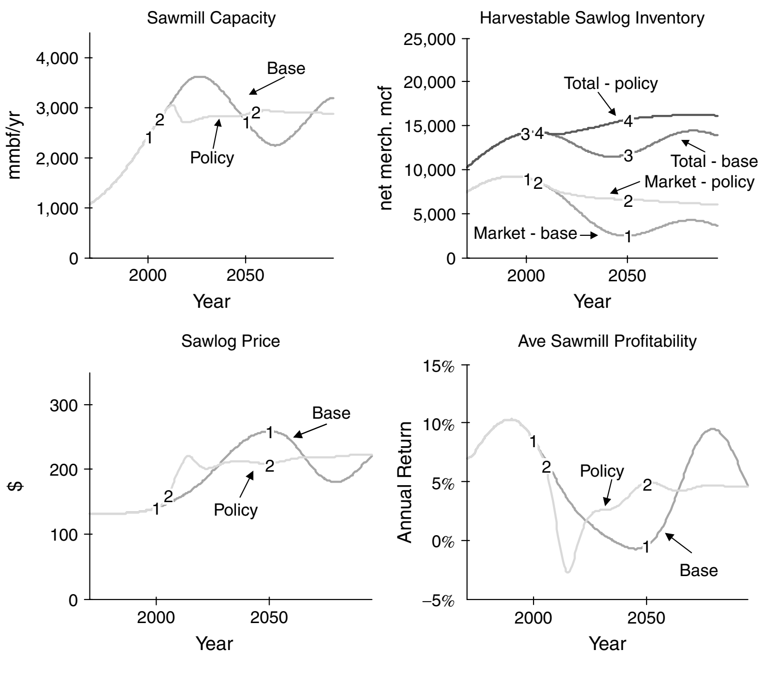
One can see the answer by examining the harvest rate on the general (primarily non-industrial, smaller scale, privately held) lands. With more land shifted to reserve and conservation use, the growing demand for sawlogs must be met by a smaller ''working forest,'' leading to more intense harvesting on those lands. The protected lands are eventually mature and well-stocked but the working forest is young and thinly stocked. One could guess that around 2030 to 2050, when mills are closing, the industry is cutting jobs and sawlog prices are very high, there would be significant public pressure to harvest some of the attractive and valuable sawlogs in the reserve and conservation land, pitting ''jobs'' against ''the environment.'' Just such a conflict recently occurred in the Pacific Northwest, where overharvesting of private lands led to industry contraction and pressure to open up public lands.

Changing general owner land management policy

What would happen if the general landowners operated closer to a planned management basis? In this scenario we extend their planning horizon and decrease their sensitivity to price. These changes phase in starting in 2000. The planning horizon determines, for those landowners willing to harvest, how much of their inventory they are willing to sell in a given year at the base price. In the base case general landowners have an average 10-year planning horizon (a tenth of their inventory sets the normal harvest rate). The policy extends it to 15 years. When demand exceeds annual market volume, loggers and mills start offering higher prices. Our base assumption is that the supply elasticity is one, meaning that loggers and mills would have to increase price by about 20 percent to induce landowners to offer 20 percent more stumpage. The policy reduces the elasticity so that it takes a 50 percent price increase to boost supply by 20 percent.

The results? With the longer planning horizon and lower sensitivity to price, sawlog prices rise faster than in the base scenario (Figure 18). Sawmills reduce

Fig. 18. Policy test: changing general landowner management



investment in new capacity sooner than before. The market sawlog inventory continues to decline, showing that industry is still harvesting above the sawlog growth rate, but the decline is slower.

Interestingly, while sawmill growth is less than in the base run, and mills are hit hard by the sudden reduction in supply from the general lands, they maintain significantly higher profitability and avoid the boom and bust cycle. The policy creates a ‘‘worse-before-better’’ future for the mills and avoids a significant draw-down of the forest resource.

To a limited degree, Northern Forest leaders are working to implement this policy already. Landowner co-operatives such as ‘‘Vermont Family Farms’’ pull many small landowners and plots together into larger holdings under longer time-horizon management plans and presumably more power in the market to garner higher prices for their timber. The acreage in co-operatives would have to expand significantly to create the radically different behavior mode shown above.

Insights

In system terms, when you have one large stock (mills) that both affects and is affected by another (trees in forests), you have a structure that is likely to oscillate, as each stock tries belatedly to adjust to the other. When both stocks contain long-lived, slowly growing entities, the oscillations are likely to be very long—decades of growth, followed by decades of decline. It is difficult to base the economy of a region on such a system.

In the Northern Forest, the overshoots are exacerbated by the network of decision-makers (landowners, loggers, mill managers, mill investors) who are trying to react to either abundance or scarcity of the forest resource. Some of the decisions they make, designed rationally to keep themselves in business or to shore up falling profits, have the effect of making the boom and bust cycle worse. For example, when landowners (including the public) have standing forest inventory that they are willing to sell above the growth rate, and when mills are able to adapt to higher prices and continue producing even when landowners start to signal scarcity by raising price, then the forest industry will grow beyond the size that can be sustainably supported by the forest base.

The model demonstrates several processes that can worsen the overshoot:

- *A large initial standing inventory* allows the mills (and the harvest) to grow for a long time before the inventory is drawn down enough to create a sense of scarcity among the landowners. The larger the initial inventory (and the lower the ‘‘threshold’’ at which landowners feel that the inventory is becoming scarce), the larger the gap will be between the harvest rate and the growth rate when the system finally tries to come into balance.

- *The more responsive landowners are to price*, meaning that they are willing to sell more when price increases, the further inventory will be drawn down before the price signal is too strong to ignore.
- *The greater the capability of mills to absorb or adapt to price increases* (through, for example, new technologies that increase efficiency), the longer they will be able to ''ignore'' the price signal, and the longer production and harvest stays out of balance with the growth rate.
- *The faster the mills are growing*, and the longer the life of the capacity, the more funds will be invested in the region as sunk cost at the time when signals indicate that production is out of balance with the supply. While sunk costs should be ignored, they often are not. The sunk cost creates an incentive to continue operations, even at a negative net present value, to pay back the sunk investment, increasing the delay between a signal of scarcity and reductions in capacity and production.
- Finally, *the greater the ability of producers to pass price increases on to consumers* without reducing demand, the less effective raw material price will be at reducing production (and harvest). If the consumer is willing to pay virtually any price (as is the case with some tropical hardwoods used for luxury manufacture) or if lumber price is a small percentage of total product price, the longer production can exceed forest growth.

How might we stabilize the system?

Improving mill efficiency, banning exports, raising forest growth rate—all these actions cause only small changes in the basic overshoot scenario. They do not affect the basic system flaw—the long-delayed feedback between forest inventory and mill capacity—that determines the system's basic tendency to oscillate. But other changes do.

If there was no growth in consumer demand and if demand remained within the capacity of the forest, there would be no danger of overshoot. Alternatively, if the industry did not use profits to increase capacity and production, there would be no increase in the harvest rate and therefore no danger of overshoot. Model runs (not shown here) support these conclusions.

If capacity reinvestment and consumer demand for lumber and fiber continue to increase (not only from global demand growth, but from decreasing supply in other forest regions), we need to look for leverage points to prevent overshoot within the regional forest system.

We have found the most powerful leverage points in the ways that the system sends and responds to scarcity signals. There are two ways for a signal of scarcity to travel from the forest to the mills. If **price** is the primary signal, then it is necessary to raise price strongly and quickly as the harvest rate exceeds the forest growth rate. One way to do so (at least in theory) is to push landowners towards a longer planning horizon, so that their desired sales are more in line with the sustainable yield, and to reduce landowners' tendency to sell more if price is high. As discussed earlier, landowner co-operatives may be a practical way to implement such a policy.

The other alternative is to design signals *other than price*. People in the region could agree to cap the regional harvest rate (maximum allowable cut) below the growth rate. Such action, of course, would trigger a wide range of other effects through the system. Regarding implementation, a cursory scan of the political climate around forest issues (e.g., a recent contentious battle in Maine over regulating clear-cutting forests, the rise of the so-called ''Wise Use'' movement, and antiregulatory climate in Washington) reveals that enacting a harvest limit would be quite challenging indeed.

Various combinations of these leverage-point policies—slowing demand and industry growth, enhancing the timing and strength of the price signal, managing the forest from resource-based signals rather than price-based signals—can, in the model, damp or eliminate the overshoot and decline of forest-based industries. *A profitable, stable, sustainable forest economy is possible*. There is no single magic bullet to produce it; there are many possible ways. It is up to the people and the industry players in the region, not the modelers, to work them through.

Project design insights

We entered the model-building phase planning to use a ''modeling for learning'' approach designed to improve the mental models of people who manage the system under study—identify a client team, begin the modeling process by eliciting their mental models, and iterate multiple times, improving the computer models and mental models along the way (Thompson 1999; Morecroft and Sterman 1994; Lyneis 1999; Sterman 2000, Richardson and Anderson 1995). As it turned out, identifying an appropriate client team proved to be among the most difficult phases of the process. We first asked a leader on forest issues from the non-profit sector to help convene a board of advisors from several stakeholder groups—industry, environmental non-profits, conservation landowners, forest policy consulting—to work with us. We sought to span stakeholder groups, ensure that people could work together effectively, and work with people with the power to take action. We hoped that, once engaged in the modeling process, the advisors would feel driven to explore the problem and theory at a deeper level for themselves, leading towards action to improve system behavior. However, by the end of the process, while we had built credibility with our advisors and learned a lot from them, we had not built broad commitment to take action on the problem or even explicitly decided that inaction was appropriate. The insights arising from the process, while helpful to us in our research about commodity systems, did not appear to address the most pressing problems they faced in their work and lives. They had helped *us* build *our* model. Our experience has led us to no longer count on an invited advisory board whose help we are seeking to ‘‘implement’’ or ‘‘roll out’’ model insights.

Still convinced that we had framed a problem that deserved honest, rigorous exploration, we continued to search for people who would want to work with us to think through the ‘‘three overshoot questions’’ outlined earlier (i.e., could it overshoot? Would it matter? Could it be avoided?). With help from advisors and funders (primarily environmental), we designed and ran, over a period of 14 months, eight half-day workshops and eight shorter briefings for about 300 people around the region, for industry groups, environmental advocacy organizations, state government staff, and policy councils. We ran several workshops for mixed groups, but most sessions were among a single stakeholder group, to maximize their comfort level and minimize political posturing. The workshops featured group discussion of possible futures for regional sawmill production (exponential, S-shaped, overshoot and oscillation, overshoot and collapse), facilitated causal diagramming of their feedback theory of the drivers for the behavior modes, and extensive testing of the model set up as a flight simulator (with the group talking about anticipated behavior before the model was run). We also included a physical demonstration of overshoot, cartoons illustrating systems principles, and various jokes and anecdotes we picked up from event to event.

Individual workshops did little to spark direct follow-up action. However, we saw two clear outcomes. First, many people declared their answers to our three overshoot questions to their peers, and often explained some of the assumptions that drove their thinking. These declarations led us to believe that people had moved a step closer to action or reasoned inaction. Second, participants in each workshop would follow up with a letter or email or invite us back for a second workshop with a second group, or recommend to others that they invite us to run our workshop.

The growth in workshops via referrals or return trips eventually led us to discover our current partners—a group of state forestry officials in each of the four Northern Forest states. They are charged as stewards for both the forest products industry and the forest it depends on, and have generally close working relationships with industry leaders. The group has asked to co-host a set of workshops with forest products industry and sawmills. Part of the group’s mission is sustaining the sawmill industry in the region and they see potential in our model to frame a regional dialogue within industry about sustainability.

We took away three general process design insights from our experience trying to understand and change a system where responsibility is diffused across many organizations, individuals, and regions.

Frame ''sustainability'' within a process of inquiry, rather than assuming that there is a shared goal

To complete an honest exploration of the possibility of overshoot in a system, either towards action or well-reasoned inaction, we found it helpful to focus again and again on the basic questions raised by the modeling process and to try to rigorously work with stakeholders through the thinking process:

- *Does the system have the potential for overshoot* (exceed the ability of the forest to support the mills)?
- *If so, does it matter? Would overshoot be something worth avoiding*?
- *If so, is there anything we can do about it?*

Despite our best intentions and espoused theories to the contrary, we did not sufficiently respect the importance of individuals working their way through each of these questions for themselves. We often asked people to think about action before they had come to believe that there was a problem worth addressing. Note that we are not assuming that someone who stays ''engaged'' in these questions will necessarily conclude that action is necessary. It may not be. The system may not overshoot, overshoot may not be undesirable, and there may be no alternative. But we do believe that engagement in these questions will lead either to action or to informed, intentional inaction. Committing to patience and genuine inquiry rather than advocacy, particularly when one cares about the system in question, is much easier said than done.

Workshops are a good vehicle to engage larger groups of people with the inquiry process

By ''shotgunning'' our theory to anyone who would assemble, we found we could engage many diverse people in thinking through the three core questions. Few people came because they were concerned about sawmill overshoot—they were often drawn by the systems thinking approach, a fun workshop, a new approach to modeling, or the cross-stakeholder dialogue—yet many reported that they left intrigued by the overshoot challenge and a smaller set committed to moving forward emerged.

Connect long-term questions to current concerns

We saw increased commitment from collaborators when we re-framed our investigation from ''how can leaders resolve environmental and economic pressures'' to ''how can we ensure the survival of a sawmill industry that feels threatened by both short-term competitive pressure and long-term resource pressures.''

Face-to-face process insights

Through the process of building the model and leading model-based workshops, we found ourselves in familiar territory for the environmental movement—talking about how to manage an economy within ecological limits. Our society's disappointingly poor track record in taking action when we run up against the limit of a system—for example, fisheries, species extinction, greenhouse gasses—illustrates the challenge.

There is extensive literature on the challenge. Renewable resource systems often have multiple players who individually gain more by drawing on a shared resource than they lose as part of the community—''tragedy of the commons'' behavior (Hardin 1968). Further, even when managers have full property rights, studies have shown that people have great difficulty managing growing demands on a renewable resource; these systems are dynamically complex enough that misperceptions of feedback dynamics often lead them to overshoot sustainable levels (Moxnes 2000; Fiddaman 2002; Sterman and Booth Sweeney 2002). Our modeling work in the Northern Forest shows similar potential.

Through the workshops and discussions about the forest economy, we also learned that even raising questions of growth and limits can trigger strong defensive routines (Argyris 1985; AtKisson 1999), both at the individual level and the organizational level, that make it difficult even to remain engaged in thinking about ecological limits and, therefore, taking any action. Managing these complex process challenges effectively was essential to using systems modeling to help people move towards well-reasoned action or inaction.

Consider an example from one of the workshops. We were presenting our base run to a group of mill executives and landowners from five different companies. During the walk-through of the base-run behavior of mill capacity (which begins to contract severely several decades in the future) we found that a few participants quickly dismissed that possibility, saying, ''Sawmill capacity in this region will never shrink like that,'' and aggressively pressing us on what factors we had included so that (we presume) they could uncover something missing or incorrect and dismiss the findings. Their body language and tone of voice led us to believe the participants were angry and emotionally charged.

As we encountered similar emotion-laden or disengaged reactions in other settings with other groups (not only industry representatives), we came to identify a recurring set of defensive routines, that is, both emotionally laden reflexive responses to seeing the graphs of overshoot in which participants did not connect their critique to an underlying structural theory, or simply disengaged from thinking about the questions at hand. Of course, emotion often breeds emotion. When we encountered these reactions, we found ourselves torn between avoiding the conflict (the ''flight'' reaction; modifying our story to fit within their pre-existing assumptions, de-emphasizing the behavior of the model and switching to interview mode, talking about the systems methodology rather than implications of this particular model) or by pushing harder on our own viewpoint (the ''fight'' reaction; explaining why our assumptions are right, defending the logic behind our model). Neither of these responses was effective.

Back to the presentation to the industry group. During a break, after we had just survived the morning's tensions and had struggled to avoid ''fight or flight,'' Dana walked up to us, smiling, and said, ''Isn't this going great?'' ''What?!?,'' we thought.

''The main purpose of our modeling,'' she said ''is to bring people to this moment—the moment of discomfort, of cognitive dissonance, where they can begin to see how current ways of thinking and their deeply held beliefs are not working anymore, how they are creating a future that they don't want. The key as a modeler who triggers denial or apathy is to bring the group to this moment, and then just *breathe*. Hold us there for as long as possible. Don't fight back. Don't qualify your conclusions about what structures create what behaviors. State them clearly, and then just hold on.''

Our theory about the forest economy and the resulting behavior could be wrong, of course, but our goal for the workshops was to move the level of discussion to talking about systemic structures that generate this behavior, not just talking about its surface implausibility.

Over time, we began to notice some patterns emerging in the defensive routines. We noted three in particular—*denial, resignation*, and *despair*—that surfaced when asking our three ''overshoot questions.'' We now explore these routines and describe some of the lessons we learned from Dana Meadows on ways to work through them.

Denial and false hope

While addressing the first of the three overshoot questions—Does this system have the potential to overshoot?—we found that participants often reacted to the presentation with what appeared to be denial, recounting all the reasons why this behavior could not happen. Some people became angry and aggressive when they saw the model run that showed a contraction of mill capacity in the future, citing concerns about model boundary, parameter values, or level of aggregation in the model (e.g., ''that's not the correct cost for an acre of land. This model is wrong.''). Often people would work to divert the conversation towards other, related problems in the system.

In these situations we found it most helpful to avoid our own reflex to defend ourselves or avoid the conflict, and focus instead on guiding the discussion in two directions: first, towards helping people see the implications of their assumptions over time and second, towards uncovering the mind-sets that ''lay beneath the assumptions.''

Dana was particularly effective at uncovering mindsets by encouraging people to state them clearly. For example, here are some quotes from the workshops:

- ''The current proposed policy of (radical improvements in efficiency, banning sawlog export, subsidies to mills, etc.) will bail the mills out.''
- ''No one in the region would let [overshoot] happen.''
- ''Market forces will solve that problem.''

Dana would hear the belief clearly stated, repeat it back, and often not argue against it as much as document it and return to it later in the workshop. Some of these beliefs would prove to be false hopes and would dissolve when they could not be connected back to the structure driving the system's behavior.

Such pushing and digging into assumptions is standard system dynamics practice—what was remarkable was Dana's ability to do it with an accompanying message of love and respect. Her style often helped people to truly explore the potential for overshoot without getting stopped by the defensive routine of denial.

Resignation

When we moved from considering the structural potential for overshoot to asking whether it was a problem, something to be avoided, and something that they cared about, we often found people would resign themselves to this new future. It is as if they erode their goals for system performance, accepting overshoot and an undesirable economy and ecosystem as inevitable. Resignation also seemed a way for people to accept the systems potential for this behavior without engaging emotionally in the consequences.

We saw the following reactions as examples of this defensive routine:

- ''This is the natural way that this system behaves. It booms and busts.''
- ''The best thing we can do is prepare social services to help the communities when the sawmill leaves.''
- ''Well, we'll be retired by the time it really gets bad.''
- ''It will happen and we will get blamed for it.''

These reactions continue to be the most difficult process challenge we grappled with—how to know if we are encountering resignation and need to work through it, or if the potential for overshoot is just not a ''problem'' that is compelling for stakeholders and for us to let it go. Dana has always maintained that the best way to respond to resignation is with a time in the gathering for visioning. She wrote, ''Visioning means imagining, at first generally and then with increasing specificity, what you really want. That is, *what you really want*, not what someone has taught you to want, and not what you have learned to be willing to settle for'' (Meadows *et al.* 1992, p. 224).

Despair

On the occasions when workshop participants accepted the possibility of overshoot as a problem that they cared about, and we moved to the third ''overshoot question''—Is there anything we can do to change the system's behavior?—we found that people often felt frustrated and helpless.

First, they feel despair. They convince themselves that the necessary changes are too difficult even to consider. We noticed that many environmental activists fell prey to this defensive routine. The despair often came out as blaming industry for its greed or malice.

Examples of this mindset include:

- ''There's nothing we can do.''
- ''This is just how capitalism works, and we can't do anything about *that*.''

We helped people work through helplessness in two ways. First, we shortened the time spent discussing each policy run so that we could cover more, different runs. Then we would remind the group of the 8–10 possible futures we had just shown and assert, as Dana often wrote, that we ''face not a preordained future, but a choice.'' (Meadows *et al.* 1992, p. 236) Second, we found it helped to conclude by pointing to the typically sprawling causal diagram that engulfed the room's white board and say, ''the system you are managing is so complex and so tricky, it might feel overwhelming. But remember that everything in this system was created by us. If we created it, we can change it to work better.''

The second source of powerlessness seemed to come from clinging to mindsets that prevent action in new ways. These included:

- ''Industry must grow to stay competitive.''
- ''It is hubris to think we can change the way markets work.''
- ''Landowners can't collaborate.''
- ''Mill owners can't work together.''
- ''A harvest limit is impossible.''

While any of these may in fact be true, the sense of powerlessness came from asserting these assumptions as absolute unquestioned truth, closing out any exploration of alternatives. Dana, who was always game to question a deeply help assumption, would respond to these statements by pushing back on the ''conventional wisdom'' and asking ''Why?'' over and over again. She worked to surface the data behind these assumptions. She did not let people limit their imaginations to systems currently in place, or the belief that people are only economically rational. She pushed beyond these statements to help us see where the possibilities lie, to reach beyond the easy answers and to try something different, something that actually addresses the problems of the system.

Conclusion

Our research has shown that regional sawmill capacity in the Northern Forest has the structural potential to overshoot the long-term supply of the forest resource. Over a wide range of assumptions about landowner and mill manager decision-making, the sawlog price signal is not a sufficient or timely signal of scarcity to slow mill capacity growth in time to avoid overcapacity and subsequent industry contraction. Policies designed to help avoid overshoot must address the effectiveness of the price signal of scarcity or else strengthen other feedbacks that balance the harvest with forest growth.

However, these insights bring us only part way to our goal, which is policy change that leads to improved system performance. Working for several years with our advisory board and then with workshop participants has led us to a conclusion that we suspect all of us know but many (including ourselves) have trouble accepting and acting on: The most brilliant model and insights have no impact if they are not embedded in an effective learning process. When the troublesome dynamics are in the future, when no one directly owns the problem, and when clients (and modelers) have diverse goals, models and insights alone are even less useful.

In an effective learning process addressing a potential limit to growth, modeling creates a space where people are willing and able to confront their assumptions and prejudices and steadily work their way through challenging questions concerning the potential of the problem, that problem's importance, and the creation of solutions. Along the way, the group—modeler/facilitators and clients alike—must retain enough hope, courage, commitment, and emotional stability to work through the defensive routines that so often lead to disengagement. Our experience shows it can be done, helping to build the understanding and commitment to action required to, as Dana said, ''bring about a revolution to a better world.''

Notes

1. Data compiled from multiple USDA Forest Service reports, called ''Forest Inventory Analysis'' (FIA). Data sources: Maine: Ferguson and Longwood (1960), Powell and Dickson (1984), Griffith and Alerich (1996); New York: Ferguson and Mayer (1970), Considine and Frieswyk (1982), Alerich and Drake (1995); New Hampshire: Kingsley (1976), Frieswyk and Malley (1985a), Frieswyk and Widmann (2000a); Vermont: Kingsley and Barnard (1968), Frieswyk and Malley (1985b), Frieswyk and Widmann (2000b).

2. The model is available at http://sustainabilityinstitute.org.

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