SILVICULTURAL SYSTEMS FOR BIOMASS PRODUCTION IN CANADA *

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(Received for publication 1 October 1999; revision 5 January 2000)

ABSTRACT

Four combinations of biomass value, stand condition, site, and management objective are discussed. An emphasis is placed on short- and medium-rotation coppice systems using natural and artificial regeneration. Artificial systems which parallel agricultural production require both very high yields and good biomass prices to offset high input costs.

At present, low fossil fuel prices in Canada do not make utilisation of biomass for energy economically attractive. Government policy may dictate more biomass use for energy for political, environmental, and especially carbon balance reasons.

Keywords: silvicultural systems; biomass.

INTRODUCTION

Whether silvicultural systems are related to energy biomass production really depends on the value of the biomass. In British Columbia with 25 million ha of public commercial land under licence, the topic is of little interest since there are abundant supplies of cheap energy from oil, natural gas, coal, and hydro electricity. Biomass for energy is of interest only on a very local scale for firewood or at mills where waste wood already transported to a mill can be used for energy.

As this paper was being written I read a newspaper article announcing that President Clinton "orders work on crops and trees for fuel" with a goal of tripling biomass use equivalent to 348 million barrels of oil per year (equal to 158 super tankers). I do not think Prime Minister Chretien will be making orders like that. Also, the Federal Government has no authority in this matter. Forest resource management is a Provincial concern.

The point of this is that silvicultural systems that are designed to grow biomass for energy have been historically, and are still today, products of situations where wood is valuable for energy. Before the industrial revolution in Europe when there really was no way to transport energy, communities relied on wood for fuel and construction. The standard silvicultural systems of coppice and coppice with standards are very ancient (National Academy of

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* Paper presented at IEA Bioenergy Task 18 "Conventional Systems for Bioenergy" Workshop, Charleston, S.C., 19–25 September 1999.

New Zealand Journal of Forestry Science 30(1/2): 5–15 (2000)

Sciences 1980). These two systems could supply short-rotation fuelwood and charcoal and longer-rotation construction timbers within horse-and-cart distance of a village. When iron was first made using charcoal, the ironmakers fostered coppice production. This was the first silvicultural system in the United States.

European peasants in Western Europe fought to maintain the right to "assart" (i.e., clear forests for crops), collect branches and dead wood, and rake litter in the wooded preserves of kings and nobles (James 1981). The early forest laws and individuals' struggle for "rights" were centred on forest and energy use issues. The point here is that all of these issues are more important than ever globally as millions of people raid the forest for energy and food. We are in the period of greatest forest destruction in history because of this situation. Most of the world's wood use is for firewood. The Medieval European situation is now world wide in Third World countries.

Silvicultural solutions to shortages of wood for energy in undeveloped countries are plagued by institutional, social, political, and economic problems that are well beyond the scope of this paper. This paper will give a Canadian overview, exploring some of the features that are relevant to growing or utilising wood for energy in large areas of natural temperate and boreal forests.

THE SETTING

Silvicultural systems (seed tree, shelterwood, selection, clearcutting, and coppice) were developed over 200 years, originally to upgrade devastated and high-graded forest landscapes.

Historically, and still today, forests are successively high-graded time and time again. Loggers first take the most valuable and accessible stands and trees and leave the rest. They return only when the residual stands have recovered enough volume, or markets improve for poorer species and grades. The end product of this high grading is large landscapes of naturally regenerated, fully stocked, low commercial value forest. In both the United States and Canada, some states and provinces are characterised by such low-value forests, especially on private lands where there has been no regulation.

During the OPEC oil crisis of the 1970s, when oil was forecast to reach US$50/barrel, calculations of forests for energy purposes suggested biomass harvesting of low-grade forests would be feasible. Wood-burning stoves and heating plants became fashionable. Sweden started using central-heating plants powered by logging slash. The Chernobyl nuclear disaster focused great attention on the possibilities of short-rotation energy plantations.

With oil, natural gas, and coal still so cheap and abundant, the economic efficiencies of biomass for energy are really seen only at wood-processing plants with woody residues whose harvesting and transportation costs are already covered.

In the Third World where firewood is the primary value of forests, and fossil fuels are unaffordable, forests are sacrificed for fuel and this is often followed by clearing for agriculture. This is a worldwide tragedy as we live in an era of massive destruction of the world forest resources. The classical solutions of short-rotation coppice and community forests for sustainable energy are very difficult to implement.

Thus, silviculture for biomass is quite different in the Third World and developed countries.

It is interesting to note that before the industrial revolution in Europe, villages and towns developed coppice and coppice with standards silvicultural systems to supply fuel and construction timber within the area that could be served by horse and cart. Records of coppice go back in Europe to the Romans. Some stands in Britain have been coppiced on a 10- to 11-year cycle for over 300 years (National Academy of Sciences 1980).

Recently, conversion of old coppice to more-valuable high forest has been slowed due to the biodiversity values in coppice. Coppice production for charcoal and early iron smelting was the first silviculture system in the United States and a dominant landscape use in central France in the 1800s.

Canada had its first energy crisis in 1840, when its biggest city, Montreal, ran out of wood for fuel at reasonable cost. The solution was a bridge and railroad to import US coal.

The historical record in the United States and Canada in the 1800s of unregulated logging and great forest clearance for agriculture, followed by land abandonment and natural forest recovery by the end of the 1900s, is a lesson of great forest ecosystem resilience. Vast areas of forests have regrown without any formal silviculture at all (MacCleery 1992).

With the development of the forestry profession and rules and regulations on forest regulation and silviculture systems in this century, forest destruction and high grading have been controlled. Wood science and new technologies have created new uses and values for low-value trees and stands. Biomass for energy is not a priority in forest management because North America has cheap fossil fuels, nor is there any really significant amount of deforestation. Currently, Canadian interest in biomass is not from an energy viewpoint but because of the ability of forests to fix carbon.

SILVICULTURAL OPTIONS FOR BIOMASS PRODUCTION IN NATURAL FORESTS

Silviculturists have the task of preparing prescriptions which are implementable and which will meet the objectives of the owner. Biomass production can be the stand management objective or the byproduct of more-valuable timber product objectives. Stands can be regenerated on cutovers or bare ground that has not had trees on it previously. Established natural origin stands can be tended to produce the desired objectives. Regeneration prescriptions can be melded with stand tending prescriptions to produce a crop plan to full rotation.

Thus, there are many options for combinations of biomass value/stand condition and site condition and productivity. The main options are outlined below.

(1) Bare Land / Valuable Biomass / Biomass as the Management Objective Using Short-rotation Plantations

There is a large body of literature on how this is done, much of it with hybrid poplars. Tuskan (1998) reviewed what is known and not known and what is needed to be known. Some of the characteristics are given in Fig. 1. Nutrient cycling questions have been addressed by Heilman & Norby (1998). The "Ontario Growers' Guide to Hybrid Poplar" gives details (Boysen & Strobl 1991). Stettler *et al.* (1996) reviewed the biology of *Populus*

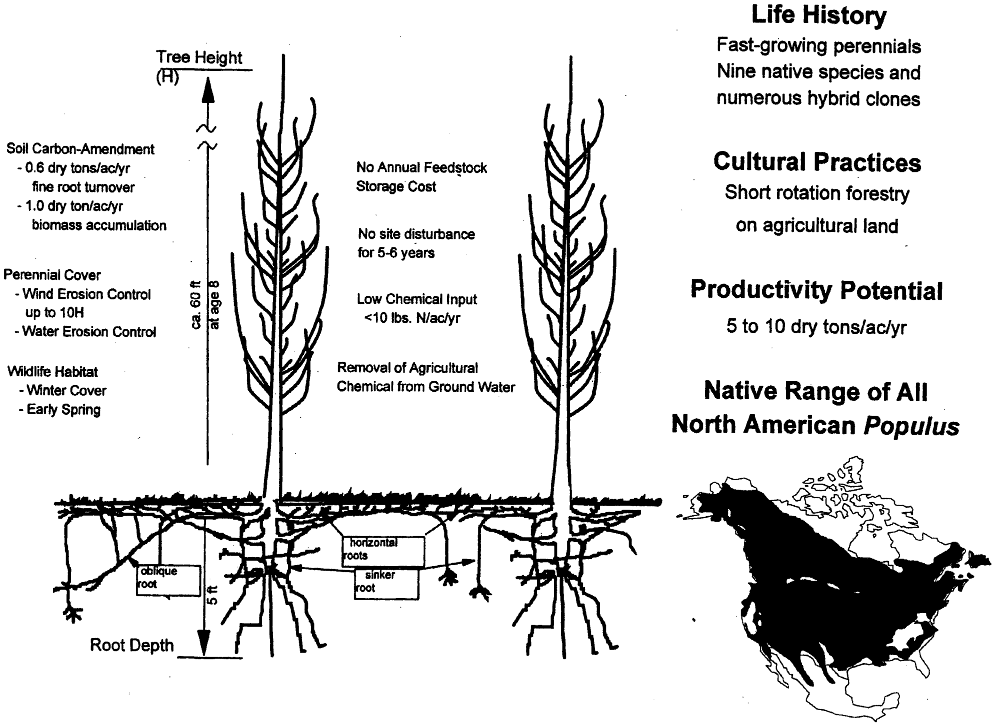


FIG. 1–Illustrative example of the biological and environmental attributes of a short-rotation woody crop, hybrid poplar (from Tuskan 1998).

and its implications for management and conservation. A Canadian Energy Plantation Workshop was held in 1991 (Karau 1996).

This agronomic approach is costly and risky and requires fertile soils. In Canada to date the risks and costs have outweighed the biomass value, even with demonstrated very high yields. There is one sustainable approach being used for pulp fibre production for tissue paper in the Fraser Valley and other river deltas in British Columbia. The Domtar Co. in Windsor, Quebec, and Cornwall, Ontario, are also involved in growing hybrid poplar for pulp.

(2) Cutover Land / Fibre Production Using Natural Coppice with a Biomass Byproduct

Aspen (*Populus tremuloides* Michx), which reproduces by suckers, and balsam poplar (*Populus balsamifera* L.), which reproduces by seeds, suckers, stump sprouts, and buried branches, cover huge areas of North America (Fig. 2). Their ecology, biomass production, and management have been reviewed by Petersen & Petersen (1992). The aspen managers' handbook (Petersen & Petersen 1995) gave practical details. Recently the use of poplar for oriented strand board and pulp has increased utilisation of these former "weed" species. The boreal mixedwood silvicultural "problem" is one of Canada's most extensive silviculture issues. The problem is the replacement of poplar/white spruce mixtures by aspen-dominated

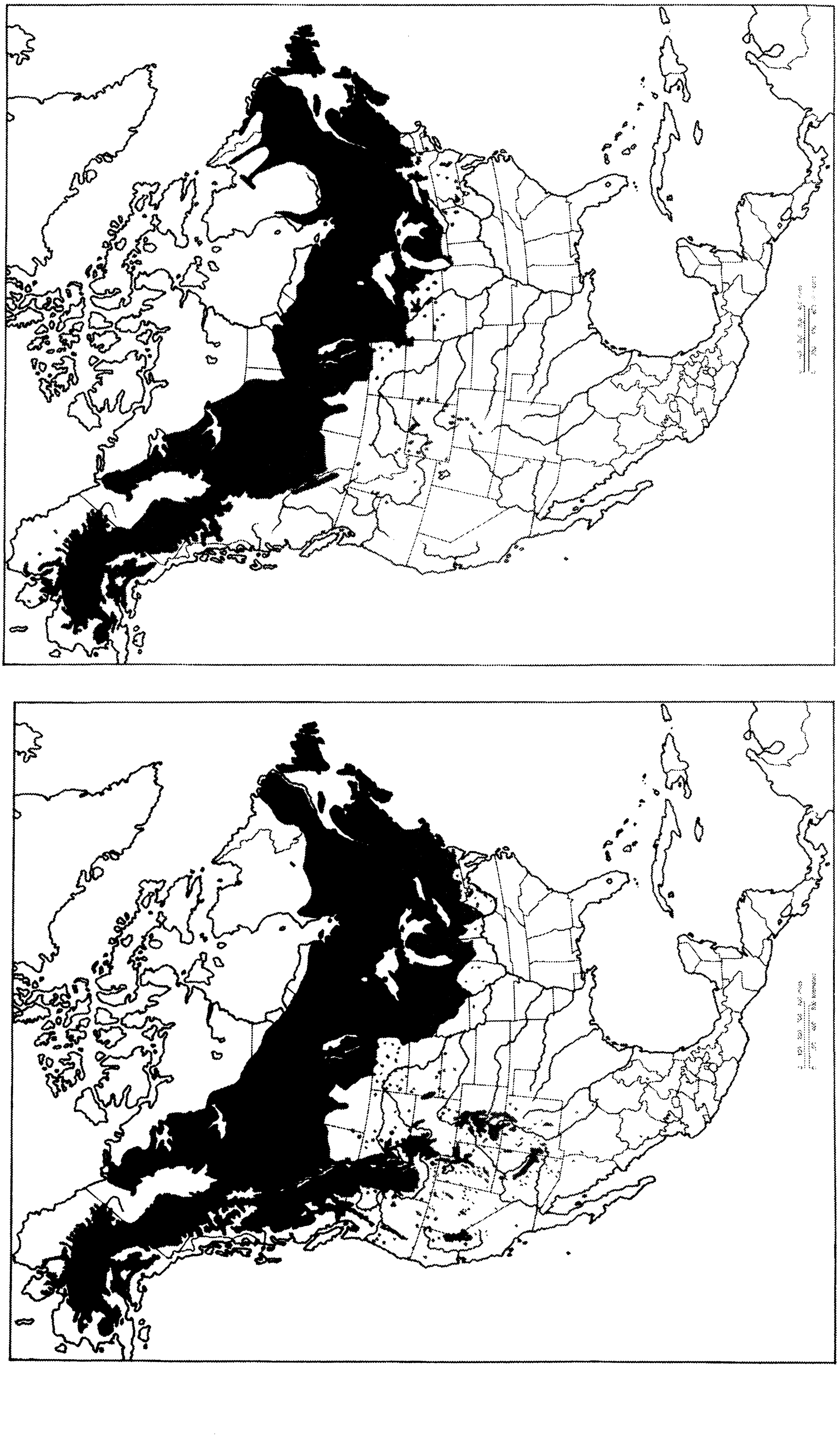


FIG. 2–Current natural distribution of aspen (left) and balsam poplar (right) in North America (from Petersen & Petersen 1992).

stands (Samoil 1988)). With more commercial use of poplar they are regarded as "acceptable species" for legal regeneration requirements on commercially clear-cut lands. Today there are fewer "heroic" silviculture attempts to control the prolific poplar regeneration of many cutovers.

Unmanaged stand biomass of aspen at age 40 has been given as 83 000 and 165 000 kg/ha on Site Indexes of 16 m and 24 m respectively. There are no growing costs. Much of the production is from clones. Coppice production is possible on a grand scale. Over most of the poplar range fossil fuel energy is cheap and abundant so there has been little interest in poplar biomass production since the OPEC oil crisis in the 1970s. Not all sites regenerate well. Diseases are a problem. Silvicultural decision keys for aspen stemwood, wildlife, livestock use, biodiversity, and integrated resource management have been prepared (Petersen & Petersen 1995). (The ability of aspen and birch to reproduce with age is indicated in Fig. 3.)

From a North American perspective, Canada could produce large amounts of biomass energy from boreal aspen and balsam poplar at little silvicultural effort and cost if the need should ever arise.

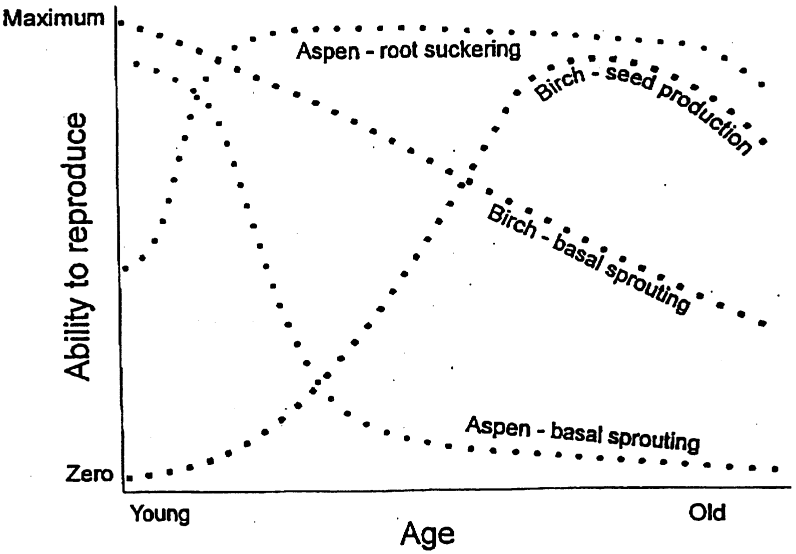


FIG. 3—As aspen stands mature, they maintain a high capability to produce root suckers, but the ability to produce basal sprouts from cut stumps drops off rapidly during stand development (from Petersen & Petersen 1995).

(3) Naturally Regenerated Dense Immature and Mature Conifer and Hardwood Stands of Low Timber Value but Potentially of High Biomass Value

These are extensive forests which have historically been repeatedly high-graded and abandoned. The low commercial values often preclude pre-commercial thinning or stand improvement cuts. Such stands have been degraded to the point where silvicultural interventions are not economic. The traditional despair of North American silviculturists may have a bright side if biomass harvesting becomes feasible. Many such stands are fully stocked, growing at maximum potential for the species' present composition. One option is to clearcut and plant valuable species if the owner can bear the cost. A notable example in Canada has been the replacement of such stands in New Brunswick with spruce plantations by the large Irving organisation.

The recent estimation of total biomass in Maine is an example of an estimate of biomass production potential (Wharton & Griffith 1998). We have biomass regression equations for the stand components. It appears biomass energy values will have to increase much more to formally commit such stands and forests to energy production. I know of no examples. Short-rotation coppice may be feasible biologically as it was in the 1700s and 1800s on a very local scale.

Low-value biomass harvesting of degraded natural forests of mixed species composition will not generate enough revenue to pay for regeneration costs. Clearcutting leads to more intolerant tree species in the next crop which tends to be even aged. Historically, clearcutting for fuelwood and chemical and pulpwood has led to more valuable second-growth stands in Appalachian hardwoods. Many of the tolerant hardwood forests have been repeatedly picked over as markets develop for unused species, grades, and sizes (Smith 1994). Improved biomass markets may create opportunities to bring huge areas of low-value hardwood under more formal silvicultural regulations, i.e., conversion to selection and shelterwood systems.

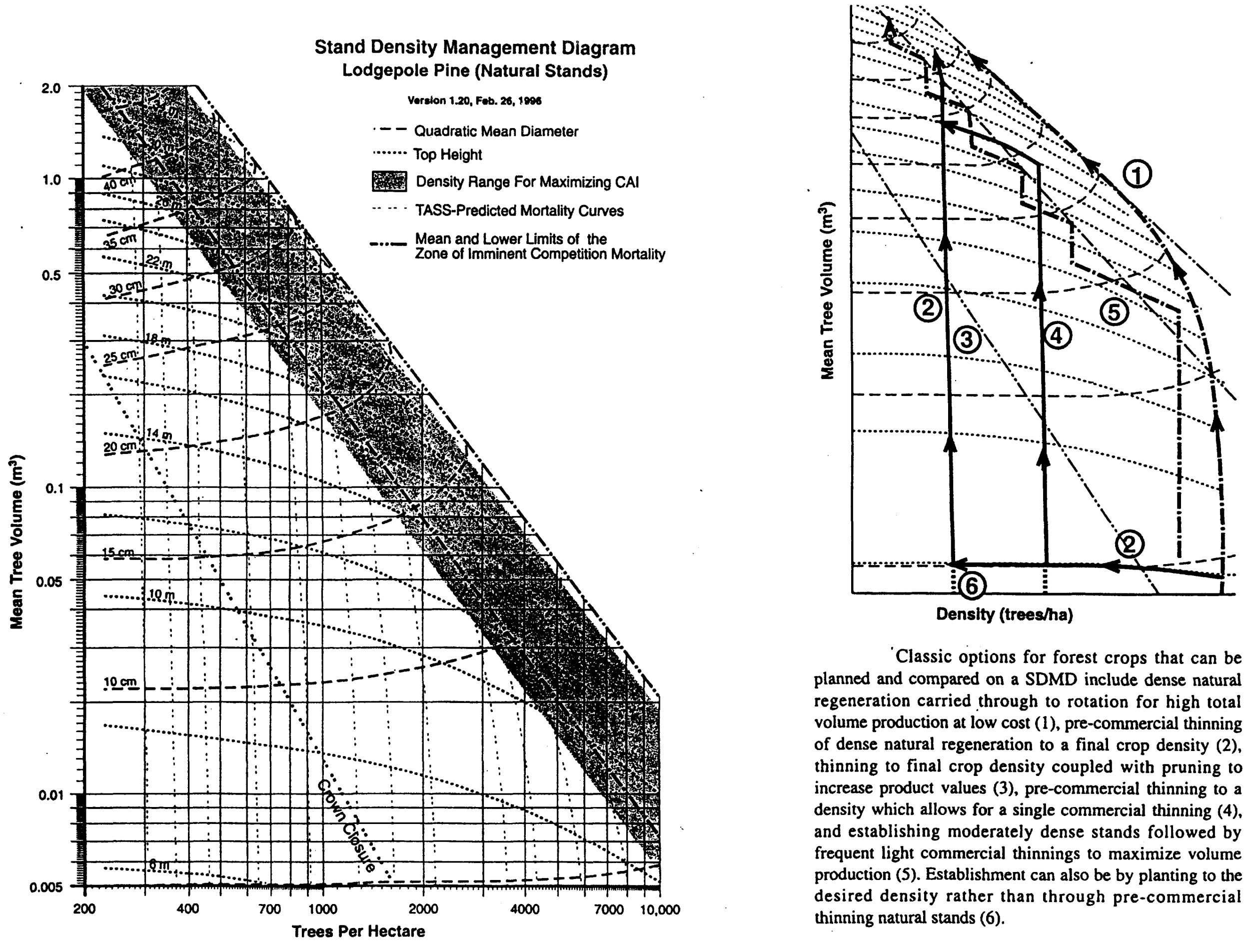
(4) High Timber Value Immature and Mature Stands with Low Value Biomass

As markets and timber values have improved, more and more forest becomes economically operable and stumpage values allow for more formal regeneration and tending treatments. This situation has brought huge areas of Canadian forest into the economic margin. Biomass production is secondary to more valuable sawtimber, pulp, and oriented strand board production. Extensive use of full-tree logging with feller bunchers has concentrated slash at roadsides where it is relatively cheap for biomass use, but this has not yet happened. In some areas there is chipping in the forest for pulp production (Araki 1999). Clearcutting, often with some retention of structure for biodiversity reasons, is the normal feasible silvicultural prescription in natural origin stands that are well past technical maturity.

One point of concern in such forests has been the lack of recovery of competition-induced mortality in thinnings. This "wasted" productivity is not usually considered in biometric regulation based on net merchantable volumes in untended stands. The advent of stand simulators which grow new stands allows determination and understanding of when competition-induced mortality starts and what thinning regimes might be able to recover it. Stand-density management diagrams, which reflect the dynamics of mean stand attributes in even-aged pure stands, have focused more attention on stand dynamics. A diagram for natural stands of lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Lourd.), with the classic options for crop planning, is given in Fig. 4.

Currently pre-commercial thinning is widely used for regulation of stand density to accelerate stand operability.

There is no use for the small trees. Even commercial thinning (CT) must be done late in stand life of untended stands for the trees to be of economic size for mechanised logging.



Classic options for forest crops that can be planned and compared on a SDMD include dense natural regeneration carried through to rotation for high total volume production at low cost (1), pre-commercial thinning of dense natural regeneration to a final crop density (2), thinning to final crop density coupled with pruning to increase product values (3), pre-commercial thinning to a density which allows for a single commercial thinning (4), and establishing moderately dense stands followed by frequent light commercial thinnings to maximize volume production (5). Establishment can also be by planting to the desired density rather than through pre-commercial thinning natural stands (6).

FIG. 4–A stand density management diagram showing trajectories of stands of different densities with decline in density due to competition-induced mortality. Classic options for crop planning are indicated. Recovery of mortality requires repeated light thinnings which have no economic value at low biomass prices (from Farnden 1996).

These late CTs do not recover mortality; thus CT programmes do not improve total stand yield. If there were a market for small trees for biomass, repeated light thinnings could recover mortality and thus produce 15% to 30% more yield.

At the moment it seems unlikely that the huge "wastage" of competition-based mortality in the vast natural forests of Canada can be recovered when fossil fuel energy is so cheap. It is frustrating for silviculturists to pay over $1000 per hectare to cut down thousands of naturally regenerated trees and not use them. Canada harvests about 1 million ha each year; a large portion of this annual cutover could produce a lot of potential biomass wood currently forecast to be lost in mortality.

Biomass Production, Stand Dynamics, and Silvicultural Systems

In even-aged stands maximum growth rates occur after crown closure and "full stocking" are achieved. Leaf weight per hectare remains relatively constant, then self-thinning takes place. As a consequence 20–30% of the total above-ground net primary production volume dies and falls to the ground (gross *versus* net yields). Theoretically this can be recovered in repeated light thinnings but in practice it is not. In naturally regenerated untended forests the high densities produce small average stand diameters; thus harvesting is delayed with mechanised logging until the trees are big enough. This situation creates unused biomass as:

(a) Natural mortality due to self thinning
(b) Trees too small to harvest with machines
(c) Tops of trees, branches (slash), and stumps left at stump or roadside
(d) Unlogged residual, partially rotten, and crooked trees
(e) Snags—dead standing trees
(f) Non-utilisable tree species and understorey shrubs.

In addition, in natural forests there are huge losses of trees due to fires and insects that in theory might be salvaged. In Canada these losses usually exceed the annual harvest—sometimes up to 3 million ha per year.

The rate at which maximum biomass production is reached in stand development depends on the amount of regeneration and site quality (rate of height growth).

Different silvicultural systems have different lag times in biomass production between rotations:

- For clearcut systems, there is a long lag
- For shelterwoods, there is less lag
- For selection, there is no lag at all
- For coppice, there is the fastest recovery from a clearcut using established root systems.

CONCLUSIONS

For sheer efficiency of production of biomass, coppice systems are hard to beat. No regeneration costs, an even-aged and size crop, and early maximum growth rate are very attractive.

Coppice biomass comes in two versions: those with no growing cost using natural vegetation propagation, and those with high growing cost (clonal, irrigation, fertiliser application) with hybrid poplars.

The latter approach fits areas with high land costs, where short rotations and high yields mean less capital investment in land. However, several major Canadian industrial initiatives have failed economically.

For large areas of natural forests, publicly owned, aspen coppice production can be economically attractive at lower yields with no land costs.

The most economically attractive source of biomass in natural forests is when old stands are harvested on sites with high site index. Such stands have much dead biomass, slash, and unutilised portions. High values and volumes allow long truck hauls of biomass to processing plants; however, the pressure of conservation biology ideas now means that many snags and much coarse woody debris and "residual structure" must be left on cutovers.

The new concern over biodiversity at the stand level has created new challenges for foresters and silviculturists in preparing silviculture and logging prescriptions for old natural forests—what I call "geriatric silviculture". For Canada, where 96% of the forests are publicly owned, and where old natural forest will be harvested for many more decades, and there are higher logging costs associated with biodiversity concerns, and more residual structure, it appears that harvesting residual biomass will be less attractive on the 1 million ha of annual cutover.

The economic attractiveness of biomass utilisation will improve if fossil fuel prices rise faster than forest products prices. At the moment as more and more oil and gas are discovered this seems unlikely. Government policy may dictate more biomass use for energy for general political and environmental correctness reasons, particularly those issues of carbon balance in the world.

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