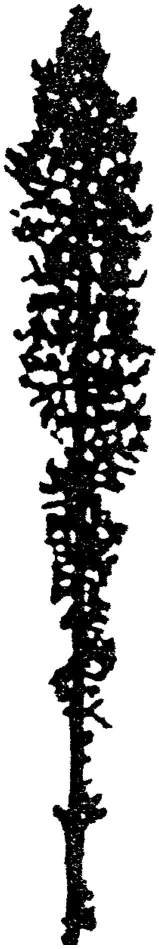

FORESTRY PRODUCTIVITY LIMITS: REAL, IMAGINED AND POTENTIAL'

Dr. Conor Boyd'

Forest Industry Lecturer

Forestry Program
The University of Alberta
January 24, 1985

FOREST INDUSTRY LECTURE SERIES NO. 14

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THE FOREST INDUSTRY LECTURES

Forest industry in northwestern Canada is cooperating with Alberta Energy and Natural Resources to provide funds to enrich the Forestry Program of the Faculty of Agriculture and Forestry at the University of Alberta through sponsorship of noteworthy speakers.

The Forest Industry Lecture Series was started during the 1976-77 term as a seminar course. Desmond I. Crossley and Maxwell T. MacLaggan presented the first series of lectures. The contribution of these two noted Canadian foresters is greatly appreciated.

Subsequent speakers in the series have visited for periods of up to a week, with all visits highlighted by a major public address. It has indeed been a pleasure to host such individuals as C. Ross Silversides, W. Gerald Burch, Gustaf Siren, Kenneth F.S. King, F.L.C. Reed, Gene Namkoong, Kenneth A. Armson, John J. Munro, Peder Braathe, Vidar J. Nordin, and Juhani Paivanen. The subjects of their talks are listed at the end of this paper.

This paper contains Dr. Conor Boyd's major public address given on 24 January 1985.

DR. CONOR BOYD

Conor Boyd was born in England, is a Forestry graduate of the University of Edinburgh, Scotland, has an M.Sc. from the University of New Brunswick and a Ph.D. in Civil Engineering from McGill University. He has served as an Assistant Professor of Forest Engineering at the University of British Columbia, worked overseas with Forestal International of Vancouver and joined Weyerhaeuser Company in 1972.

At Weyerhaeuser, Boyd has held several positions including Director of Raw Materials Research and Development, Director of Forestry Research and Development and, most recently, Director of High Yield Forestry where he has had responsibility for providing leadership and direction to the near and long term management of his Company's forest and land assets.

We would like to take this opportunity to express our thanks again to the sponsors of this program — we appreciate very much their willing and sustained support:

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1. INTRODUCTION

Alberta currently occupies a rather enviable position as a North American timber supply region. Amongst its many attributes it has a surplus supply of high quality, relatively low cost, wood. Because wood is the principal cost component of most manufactured wood products and because unit wood costs tend to decrease as biological productivity increases, Alberta's future competitive position is linked to the productive potential of its forest.

The issues I will explore in this paper are twofold:

> What are the current or potential limits to forest productivity?
>
> How productive are Alberta's competitor geographies, specifically the Douglas-fir region and the southern pine region?

We will first define what is meant by the term "productive potential" and, with your indulgence, I will draw on my experience in the Douglas-fir region to illustrate the concept.

We will then examine the biological limits to growth and seek to define a spectrum of productivity limited at the upper extreme by fundamental biological processes and at the lower extreme by the productivity of unmanaged natural stands. Within this biological spectrum the imposition of financial considerations will be used to define the narrower band of productivity associated with today's practices.

Following this we will explore the potential impact of new technology as a route to improving productivity. Finally we will compare the productivity of loblolly pine, the dominant species in the U.S. South, with the productivity of Douglas-fir, under today's management practices.

2. THE BIOLOGICAL PRODUCTIVITY SPECTRUM

I have chosen to define this spectrum with reference to productivity on a single acre. This concentrates our attention on a management unit to which we can all relate. For discussion purposes, Douglas-fir, growing on the west side of the Cascades on an average site (Site III; 105 ft. at age 50), has been chosen as descriptive of our representative acre.

The lower bound on productivity from this acre might best be described as the yield one would expect from an unmanaged stand. Here "unmanage" refers to natural regeneration following logging with no site preparation or subsequent management intervention until final harvest. For Site III, the average annual yield under these conditions is approximately one cunit per acre per year' (Chambers and Wilson 1972). In other words, this is the average annual yield one would expect from nature without intervention from man until time of harvest.

In contrast to this lower bound on productivity which is based on field measurements (Chambers and Wilson 1972), the upper bound on productivity can only be estimated as it is based on theoretical assumptions. Based on some pioneering work on agricultural crops (Loomis and Williams 1969), John Gordon and colleagues (1982) have made some preliminary estimates of this theoretical productivity limit for Douglas-fir. Their fundamental assumption has been that solar radiation is the ultimate factor limiting biological productivity. Gordon *et al.* (1982) have described two limiting cases of potential productivity: a "low" and a "high" yield case.

The "low" yield case describes yields that are biologically possible with today's technology. This would be represented by cases where field seed sources were matched to a given site and where establishment, silvicultural and management treatments are chosen to optimize yield, independent of any cost considerations. Converting Gordon's estimates of total tree biomass to merchantable volume, the "low" case yields approximately 3 cunits per acre per year. This figure compares favorably with an independent estimate of productivity for the same site made by our Research and Development group. Their estimate was derived using our current Douglas-fir growth and yield model to predict the maximum potential yields possible within the limits of today's technology. The resulting prescriptions, although economically unacceptable, did support Gordon's concept and quantification of a biological ceiling to yields associated with best current technology.

'Note: This assumes harvest at age 55, 80 percent of normal basal area, and a 5 percent deduct for logging breakage.

The "high" yield case (Gordon *et al.* 1982) represents an estimate of the ultimate limits of biological productivity of Douglas-fir growing on the west side. This estimate is based on the assumption that the fundamental bio-chemical and bio-physical processes governing the growth of trees can be identified, selected and combined to perform at optimal levels. To achieve the high yield case, a basic restructuring of the genetic makeup of Douglas-fir will be required. Again, converting Gordon *et al's* (1982) estimate of biomass production to merchantable volume, this theoretical upper bound is approximately 22 cunits per acre per year for Douglas-fir, a staggering number!

From a pragmatic stand point, it is questionable whether the pursuit of such ultimate productivity levels is meaningful. Perhaps more meaningful is the selection of a target productivity level for Douglas-fir in the manner proposed by Farnum and colleagues (1983). They propose a target level that converts to yields of approximately 5 cunits per acre per year over a rotation. Their choice falls within the range proposed by Gordon *et al.* (1982), and is close to maximum measured yields for conifers growing in north temperate latitudes (Westlake 1963; Fogel and Hunt in press), and is close to another theoretical estimate of ultimate productivity (Monteith 1977). Although the 5 cunits average yield, per acre per annum, is somewhat arbitrary, it does have the appeal of being potentially achievable and will be used in this paper as a practical upper bound on productivity.

Using the bounds described in this section a biological productivity spectrum for Douglas-fir growing on Site III on the west side has been assembled as Figure 1. From this we can conclude:

> That unmanaged natural stands for this site are producing at one-third the yield biologically possible with today's technology and at only 20 percent of the levels potentially achievable.

3. PRODUCTIVITY OF CURRENT MANAGEMENT PRACTICES

From the previous discussion it is evident that current management practices should produce yields that are bounded by unmanaged natural stands at the low end and by Gordon's (1982) estimate of maximum possible yields with current technology at the upper end. Based on the Department of Natural

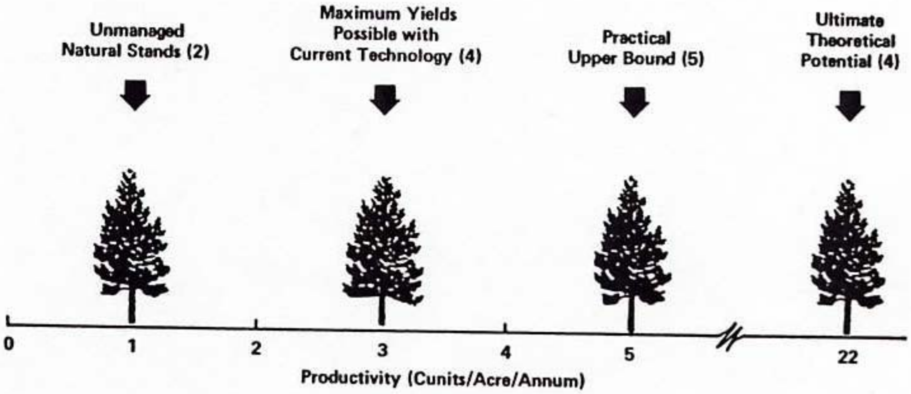

Figure 1. The biological productivity spectrum (Site III, Douglas-Fir, Western Washington.

Resource's estimates° (Larson and Wadsworth 1982), the productivity expected from increasing levels of management intensity - for Site III - is listed in Table 1. It should be noted that a rotation age of 55 years has been assumed in all cases, that all estimated yields have been adjusted to those for net productive acres and for a 5 percent, rather than a 10 percent, loss to account for logging breakage. Also implicit in this table and in the subsequent discussion is the assumption that our representative acre is on ground that can, if required, be commercially thinned. The productivity levels listed in Table 1 appear to be within the error of estimation of Curtis, *et al's* (1981) new Douglas-fir yield forecasting model and are consistent with the general productivity expectations of forest managers within the industry.

TABLE I. PRODUCTIVITY OF CURRENT MANAGEMENT REGIMEN SITE III, DOUGLAS-FIR, WESTERN WASHINGTON

Regimen

Unmanaged natural stands

Productivity (Cunits/acre/annum)

Plant (includes site prep, vegetation and animal control)

1.0

Plant and thin (includes precommercial 1.7 and one commercial thinning)

1.5

Plant, thin and fertilize (all above 2.0 treatments plus 2nd commercial thinning and fertilize at 15, 25, and 35 years

Given that an acre of bare land is going to be managed for wood production, a decision on the appropriate level of management intensity must be made. Which, if any, of the regimens listed in Table 1 yields the highest expected returns? In answering this question, the most common approach has

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°With adjustments identified in this text, and no genetic improvement.

been to select the regimen that maximizes the discounted values of future cash flows. The inherent limitation of this approach has been, and continues to be, the problem of accurately forecasting market values of wood products 50 years in the future. However, if judgement is used such analyses can serve as a useful reference point. The recent work by Larson (1977) for the Department of Natural Resources is useful as one such reference point.

Based on this (Larson 1977) and other sources, I have generalized the cost, revenue, producvity relationships for Douglas-fir management on Site III for 1982 technology. These relationships are shown graphically as Figure 2.

The generalized cost curve includes all establishment and silvicultural costs on a discounted basis. These costs typically increase linearly up to productivity levels associated with the most intensive management levels listed in Table 2 and then increase exponentially as shown. The exponential increases result from smaller productivity gains associated with added treatments.

The generalized "revenue" curve includes estimates of all discounted revenues from thinnings and final harvest net of harvesting costs. This net revenue curve tends to be linear up to average annual yields of about 1.5 cunits and takes a step shift up when commercial thinnings are initiated. Beyond productivities of 2 cunits, on this scale, revenues tend to fall off. For this site, productivity above 2 cunits per acre per year can be achieved by carrying higher levels of stocking but this is invariably associated with smaller tree diameters and thus lower raw material values and higher log production cost.

The difference between the discounted revenues and discounted costs is the net present value. In Figure 2 this can be seen to increase with intensity of management up to the "plant, thin and fertilize" regimen and then to decrease. If one accepts these generalized relationships, the conclusions are:

> That increased management intensity leads to increased net returns up to a maximum for the regimen that produces approximately 2 cunits per acre per annum (on Site III). This provides a financially constrained productivity limit and a definition of the maximum level of management intensity justified by these relationships.
>
> Intensive forest management on this site results in twice the productivity achievable from unmanaged stands.

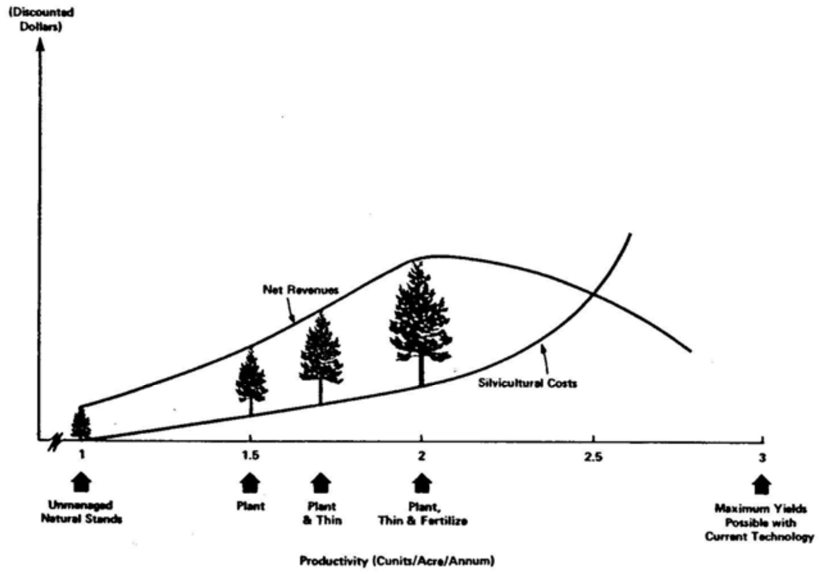

Figure 2. Productivity, cost, revenue relationships - A generalized view (Site III, Douglas -Fir, Western Washington - 1982 Technology.

> Intensive forest management productivity levels are approximately two-thirds the level biologically possible with today's technology. Quite clearly, we are not on a productivity plateau.

A survey of member companies conducted by the Washington Forest Protection Association (Larson and Wadsworth 1982) would suggest there is a broad support for viewing the "plant, thin and fertilize" regimen, of Table 1, as being representative of the most intensive management currently being practiced today.

The subsequent discussion will concentrate on the extent to which our current view of intensive forest management might be impacted by changes in technology. In examining these potential impacts we will explore how the basic relationships between productivity, costs and revenues of Figure 2 might change.

4. POTENTIAL IMPACT OF NEW TECHNOLOGY

Based on the previous discussion it is clear the biological productivity of today's forest is limited by a view of financial returns and not by the capacity of this biological factory to produce. The challenge for technology directed at increasing yields from the forest (both volume and value) is to recognize that the fundamental economic relationships must also be changed. To be implemented by the private sector, new technology must result in some combination of cost reduction and/or value improvement. From a productivity standpoint, success will be measured by how far we can shift the region of maximum expected net returns to the right on our productivity spectrum. Where should technology efforts be directed to enable us to move in this direction?

Two types of efforts are suggested from our previous, single acre, discussion. The barriers to moving from 2 to 3 on our scale (Figure 1) are excessive costs and inadequate returns, not biological barriers. Here the technological challenge is to improve the full array of current practices by removing or reducing these barriers. The principal challenge in moving from 3 to 5 on this same scale is to fundamentally change the genetic composition of Douglas-fir stands. In practice, work to improve the effectiveness of current practices and on genetic breeding can proceed together. It is, however, convenient to separate these efforts concceptually.

4.1 Moving Yield From 2 to 3 on the Productivity Scale

By "current technologies" we are referring to the full array of silvicultural treatment from site preparation through planting, vegetation management, thinning, fertilizing, to final harvest, in use today.

Fertilization serves as a good example to address how costs and returns might be improved through improvements to this technology. Studies (Ballard 1980) have demonstrated that only 15 to 20 percent of the total nitrogen aerially applied to a forest, in the form of urea, enters the tree. Eighty percent does not reach its target. Alternative methods and forms of application which ensure that the fertilizer applied actually enters the tree have significant potential for cost reduction.

An improving understanding of the nutrient requirement of trees also has the potential for improving yield response above levels currently anticipated by five yearly applications (Axelsson 1982). Improving the yield and concentrating it on the larger trees in a stand will result in increased returns from thinnings and final harvest. Thus, improvements in fertilization technology have considerable potential for increased productivity through a combination of lower costs and increased future revenues.

However, fertilization is just one example. The list of possibilities is long and with a concerted scientific effort, the potential for improvement appears high.

4.2 Moving Yield From 3 to 5 on the Productivity Scale

Perhaps the largest opportunities for significant gains in productivity rest in this area. From both a scientific and operational standpoint, tree improvement activities for western tree species are in their infancy. Significant quantities of first generation improved seed have yet to be produced for Douglas-fir. By contrast, genetic breeding and selection for many agricultural crops has progressed through at least 100 generations of improvement. It is because this area is largely unexplored in forestry and because the incremental costs of genetic improvement, relative to other treatments, are proportionately lower that the potential for improvement is so promising.

The scientific challenge is to improve the efficiency of the biological processes that produce wood. Within a single species, trees exist that are photosynthetically more efficient; other trees exist that convert the photosynthate to usable wood more efficiently; and still other trees enjoy a longer growing period. The geneticist's challenge is to combine these (and other) desirable characteristics to capture all the benefits and at the same time restrict undesirable attributes. Using the array of technologies described by Farnum *et al.* (1983), the potential for increasing gain per (breed, test and select) cycle of tree improvement and for shortening this breeding cycle appears very promising. The principal impact of genetically improved material will be to achieve larger diameters earlier and thus improve the expected net returns from forestry investments.

Achieving the 2 cunits per acre per annum potential gains from genetic improvements alone; i.e., going from 3 to 5 on our scale, appears biologically feasible. Whether the private sector will pursue these potential gains, and those from improving current technologies, will depend in large part on its view of the future and on its view of the relative costs and benefits associated with developing each new technology.

If the economic incentive exists, the potential for improving yield through improved technology exists. Increases in productivity over current "intensive" levels on the order of two and one-half times appear feasible for Douglas-fir non-coastal sites.

5. PRODUCTIVITY OF LOBLOLLY PINE

Having spent some time developing the notion of limits to biological productivity with reference to the Douglas-fir region, I would now like to turn our attention to the U.S. South. Because these two geographies are the most productive coniferous tree growing regions in North America, and because high biological productivity tends to be associated with low wood costs, these two regions have particular relevance as long-term competitors to Alberta as a wood producer.

An example of the growth potential of loblolly pine grown on an average site (70 ft. at age 25) on North Carolina's coastal plain is shown in Figure 3.

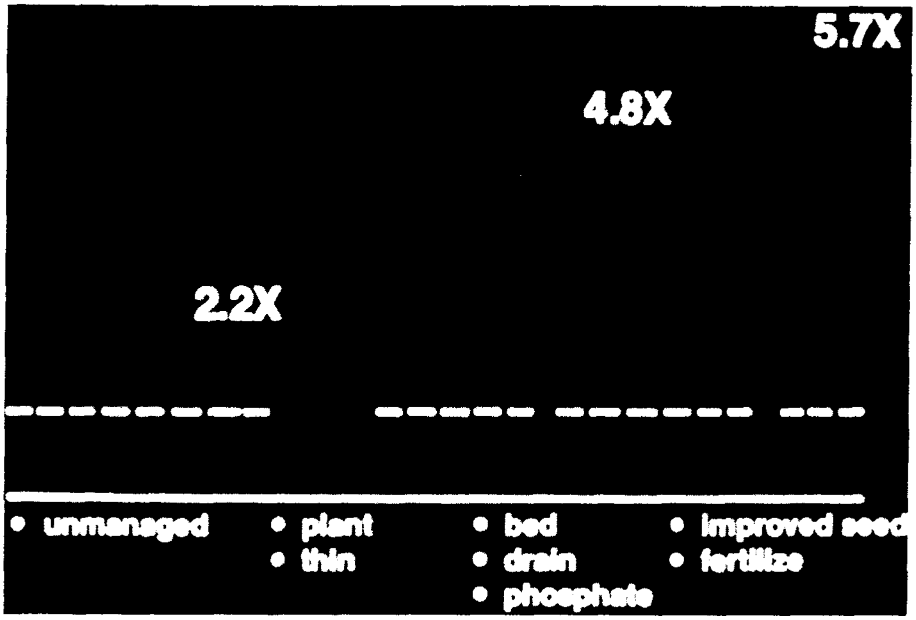

Figure 3. Growth increases of lobolly pine resulting from increasing levels of forest management intensity (North Carolina, coastal plain, example on site 70 thinnable land, with plantation rotated at age 30).

The "unmanaged" condition represents a base case, and reflects the productivity one would expect on this site from natural pine regeneration followed by clear cutting at age 30 - i.e., approximately 40 cu. ft. per acre per annum. By just planting and controlling stocking levels through thinning, the productivity can be increased by a factor greater than 2. Modifying the site, through bedding, draining and the addition of phosphorus, results in a further doubling of the productivity on these wet organic sites. When first generation genetically improved seed and urea fertilizer are added to the preceding treatments the productivity is expected to be approximately 5.7 times that of the unmanaged base case.

The productivity gains of this example are also representative of the gains achievable from today's intensive forest management levels on other sites in the South. Thus the relative impact of intensive forest management is greater in the U.S. South than in the Douglas-fir region (5 - 6X vs 2X). With current technology the absolute productivity of these two regions is now similar on similar sites. That is, the best sites in the U.S. South produce wood at the same rate as the best sites in the Douglas-fir region. However, the in-place tree improvement programs in the South are more advanced and have the potential for pushing Southern productivity ahead of the Douglas-fir region, on a site for site basis. This results from the lobolly pine genetic tree improvement programs being at least one generation of breeding and testing ahead of the Douglas-fir programs.

Clearly other factors than biological productivity also play a key role in any region's competitive position. A large legacy of natural stand inventory, wood quality, and access/proximity to markets are crucial competitive considerations for Alberta's forest industry.

6. FOREST PRODUCTIVITY LIMITS

From our Douglas-fir example the potential limits to productivity are at least two and one-half times greater than today' "intensive" management levels. From a theoretical standpoint similar relative increases should be achievable for many other coniferous forest species growing in other North temperate locations.

In the context of the Douglas-fir example, intensively managed stands are twice as productive as unmanaged stands and financial returns, not biological barriers are limiting. I would define this as the current real limit to productivity - at least for this example.

Imagined limits to productivity tend to be conservative. Many people view today's level of intensive forest management as a ceiling on forest productivity. For a variety of reasons this view is quite pervasive.

I would argue that any wood producing region that currently competes in world markets will ultimately restrict its competitiveness with such conservative thinking. An acceptance of the idea of potential limits to productivity and of the gap between real and potential limits is, in my view, a prerequisite to action and an important key to future competitiveness.

REFERENCES

Axelsson, B. 1982. Ultimate Forest Productivity, What is Possible? IUFRO Symposium of Forest Site and Continuous Productivity, University of Washington, August.

Ballard, R. 1980. Forest Plantations, Shape of the Future. Proceedings of Weyerhaeuser Science Symposium, #1, Tacoma, Washington.

Chambers, C.J. and Wilson, F.M. 1972. Empirical Yield Tables for the Douglas-Fir Zone. Dept. Nat. Resources, State of Washington, Dept. Nat. Resources Rept. No. 20R.

Curtis, R.O., Glendenen, G.W. and DeMars, D.J. 1981. A New Stand Simulator for Coast Douglas-Fir: DFSIM User's Guide. USDA, For. Serv. PNW. 128.

Farnum, P., Timmis, R. and Kulp, J.L. 1983. Biotechnology of Forest Yield. Science, Jan., Vol. 219, pp. 694-702.

Fogel, R. and Hunt, G. (In Press). Contribution of Mycorrhizae and Soil Fungi to Nutrient Cycling in a Douglas-Fir Ecosystem. Ecology.

Gordon, J., Farnum, P. and Timmis, R. 1982. Theoretical Maximum Phytomass Yields as Guides for Yield Improvement. Proc. of 7th North American Forest Biology Workshop, Lexington, Kentucky, July.

Larson, D.N. 1977. Economic Analysis, Phase II, Washington Forest Productivity Study. Dept. Nat. Resources, State of Washington, Oct. 1977).

Larson, D.N. and Wadsworth, R.K. 1982. Washington Forestry Productivity Study, Phase III, Part II. Dept. Nat. Resources, State of Washington, Jan.

Loomis, R.S. and Williams, W.A. 1969. Maximum Crop Productivity: An Estimate. Agri. Sci. Review 7.

Monteith, J.L. 1977. Phil. Trans. R. Soc. Land B. 281 177. Westlake, D.F. 1963. Biol. Rev. 38, 385.

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