



Forest Industry Lecture Series No. 43

**The Question of Scale in the
Management of Poplar**

by

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THE FOREST INDUSTRY LECTURE SERIES

The forest industry in western Canada cooperates with the Canadian Forest Service and the Alberta Environmental Protection Agency to provide funds to sponsor noteworthy speakers. This initiative significantly enriches the Forest Management Program in the Department of Renewable Resources in the Faculty of Agriculture, Forestry and Home Economics at the University of Alberta.

The Forest Industry Lecture Series was started during the 1976-77 University term as a seminar course. The late Desmond I. Crossley and Maxwell T. MacLaggan presented the first series of lecturers. The contributions of these two noted Canadian foresters are 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. Visitors have come from throughout North America, Europe, Africa and Asia. Their talks have dealt with a wide range of topics, such as: forest ecology, forest science, silviculture, wildlife management, forest management, ecosystem management, lumber and paper sales, labor, international trade, forest economics and forestry related social issues. Speakers have been scientists, industry and business leaders, senior government officials, academics and forestry alumni. A complete list of the speakers and their topics is presented at the end of this pamphlet. Copies of most presentations are available from our Department Office upon request. A select number of copies are also available from the department FILS website at <http://www.rr.ualberta.ca/Fils/index.html>.

The following paper contains the text of the talk presented by Reinhard Stettler, Professor Emeritus, University of Washington, Seattle, U.S.A. on November 4, 1999.

SPONSORS

We take this opportunity to thank again the sponsors of the 1999 Forest Industry Lecture Series. We greatly appreciate their willing and sustained support, through which we have been able to provide the latest concepts and practices of forest management from around the world to the foresters and forestry students within Alberta. Also because of this Series, we have been able to showcase the excellent forest management practices in Alberta to foresters elsewhere. We are of course dedicated to the goal of understanding and teaching people about forestry in Alberta and elsewhere. This program allows us to do just that, and for that we are grateful.

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REINHARD F. STETTLER

Dr. Reinhard (Reini) F. Stettler is an Emeritus Professor at the College of Forest Resources at the University of Washington, Seattle. Dr. Stettler has studied in Switzerland, at the University of British Columbia (1955/56) and the University of California in Berkeley, where he completed his Ph.D. in genetics. Dr. Stettler has worked as a Research Officer for the British Columbia Forest Service (1956/58), as a Research Associate at the Swiss Forest Research Institute (1958/59) but for most of his career he was an academic at the University of Washington (1963/95).

Dr. Stettler is well known for his contributions on the reproductive biology of Northwest hardwoods, specifically, for his contributions to the induction of haploid parthenogenesis in *Populus* spp.; interspecific crossability and its facilitation in the genus *Populus*; genetic improvement of poplar for short-rotation culture; biomass production for fiber and energy; and the genecological studies of *Populus trichocarpa* in the Pacific Northwest. His research has been well funded.

Dr. Stettler has published many scientific and professional articles to include book chapters, monographs and conference proceedings. Most recently, he served as the senior editor of the book titled: Stettler, R.F., H.D. Bradshaw, Jr., P.E. Heilman, and T.M. Hinckley (eds.). 1996. Biology of *Populus* and its implications for management and conservation. NRC Research Press, National Research Council of Canada, Ottawa. 539 p.

ABSTRACT

Questions of scale are a recurrent theme in forest management and also of central importance in the management of poplar (*Populus* L.). Three scales are considered in this presentation, the biological, the spatial/numerical, and the temporal scales. They are applied to three typical scenarios in which poplar is managed, (1) the Agricultural Model,

(2) the Forestry Model, and (3) the Conservation Model. Examples are drawn from different parts of the world and illustrated with slides.

The Agricultural Model has as objective the maximum sustainable production of wood of predictable quantity and quality, obtained in short rotations under intensive culture on good sites (agricultural and marginal-agricultural land). As a system of aggressive tree domestication it makes use of large-scale biological resources through hybridization and genetic engineering, taking advantage of molecular information and of genes from model plants (e.g., *Arabidopsis*). Economy of scale favors large operations, which allow the integration of genetic materials with carefully tailored cultural regimes, resulting in high yields. Rotations of 7-15 years offer products ranging from pulp to timber. Rapid turnover of genetic materials and cultural control should minimize losses to pests. This model is generating a disproportionately high output of raw material and is likely to be an important source for meeting future wood demands in the world.

The Forestry Model is aimed at the sustained production of wood in pure and mixed stands on forest sites. It applies especially to aspen and other poplar species on less productive forestland but wide occurrence. Biologically more conservative, this system takes advantage of natural variation available in native stands, selecting for the more desirable phenotypes, and managing them for rotations of 40-50 years in 2-3 consecutive coppice cycles. Hybridization (e.g. *P. tremula* x *P. tremuloides*) has shown promise of increased yields. The longer rotations argue for the maintenance of greater genetic diversity on a smaller scale to prevent pest problems.

The Conservation Model has the dual purpose of maximizing protection functions and serving as long-term reservoir of genetic resources. It plays an especially important role where poplar forms part of riparian ecosystems. Here, the emphasis is on maintaining the native populations and their associated species at their local scale. In view of the widespread loss of riparian vegetation to human activities (i.e. housing, agriculture, and dams) major conservation and restoration efforts are required.

The three models can be pursued side by side in an integrated fashion, mutually complementing each other and jointly serving to augment the information base of poplar.

Introduction

The management and conservation of forest resources presents us with problems of scale at every turn. For what scale should forest policy be formulated: for a country, a province, a region? What should be the different levels in the organizational structure of a forest administration? Are we managing forests, ecosystems, or landscapes? If so, what should be the temporal scale of planning? What rotations do we envision, what size harvest cuts?

We are the temporary stewards of land and of its renewable resources. Hence we worry about the potential impact of our actions on global change at one end of the spectrum, and on quarterly returns at the other.

The reason I have chosen scale as the organizing principle for my deliberations today is that it is a recurrent theme in forestry in general, and that it is of central importance in how we manage poplar (and by poplar I mean trees of the genus *Populus* L., including aspens, cottonwoods and poplars from all parts of the world). In fact, I know of no forest tree that offers such a wide range of scales at which it can be sensibly manipulated towards different objectives.

I hope in my talk to illustrate how we can approach the management of a forest tree with an eye towards intensive domestication on the one hand, and towards careful conservation on the other. I will draw my examples from both the Pacific Northwest (USA) and other parts of the world. Some of the specifics will be unique to poplar, others may eventually find their way into the management of other forest tree species.

I will consider three scales: the biological, the spatial/numerical, and the temporal. With regard to the **biological scale** we may ask ourselves, at what level can we or should we manipulate the genetic constitution, the genome, of poplar? Should it be at the level of the genus, the species, the local population, the individual genotype, or the gene? Can we even go 'outside' and borrow genes from other plants, other organisms? If so, is that biologically wise?

Questions arise at the **spatial/numerical scale**, such as, for what space are we selecting genetic materials and cultural regimes? What are economically efficient and biologically acceptable plantation sizes? What number of operational clones should be in deployment at any one time, and in what configuration?

Lastly, we need to think about the **temporal scale**. Specifically, over what time spans should poplar be managed? What product options are offered at which rotations? Additionally, over what periods should germ plasm resources be maintained?

These three scales will be discussed in the context of three scenarios: the **Agricultural Model**, the **Forestry Model**, and the **Conservation Model**.

The Agricultural Model

The objective of the Agricultural Model is *the maximum sustainable production of wood of predictable quantity and quality, obtained in short rotations under intensive culture on good sites.*

To satisfy this objective, what is the appropriate **biological scale** we should adopt? For this, let us first examine just how diverse the genus *Populus* is, which after all is

distributed over a good part of the Northern Hemisphere. In one of the more recent taxonomic classifications of the genus, Eckenwalder (1996), whom I consider a refreshing ‘lumper’ rather than ‘splitter’, recognizes 29 species that fall into six separate sections (see Table 1).

Table 1. **CLASSIFICATION OF *POPULUS*** (from Eckenwalder 1996)

Sect. <i>Abaso</i>	<i>P. mexicana</i> Wesmael	Sect. <i>Aigeiros</i>	<i>P. nigra</i> L.
Sect. <i>Populus</i>	<i>P. adenopoda</i> Maximowicz		<i>P. deltoides</i> Marshall
	<i>P. alba</i> L.		<i>P. fremontii</i> Watson
	<i>P. gamblei</i> Haines	Sect. <i>Tacamahaca</i>	<i>P. angustifolia</i> James
	<i>P. grandidentata</i> Michaux		<i>P. balsamifera</i> L.
	<i>P. guzmantlensis</i> Vasq. & Cuv.		<i>P. suaveolens</i> Fischer
	<i>P. monticola</i> Brandege		<i>P. ciliata</i> Royle
	<i>P. sieboldii</i> Miquel		<i>P. laurifolia</i> Ledebour
	<i>P. simaroa</i> Rzedowski		<i>P. simonii</i> Carriere
	<i>P. tremula</i> L.		<i>P. szechuanica</i>
Schneider			
	<i>P. tremuloides</i> Michaux		<i>P. trichocarpa</i> T. & G.
Sect. <i>Turanga</i>	<i>P. euphratica</i> Olivier		<i>P. yunnanensis</i> Dode
	<i>P. ilicifolia</i> (Engler) Rouleau	Sect. <i>Leucooides</i>	<i>P. lasiocarpa</i> Oliver
	<i>P. pruinosa</i> Schrenk		<i>P. glauca</i> Haines
			<i>P. heterophylla</i> L.

All species share the same chromosome number ($2n = 38$). Those within the same section can be crossed quite easily and will do so in nature when the opportunity arises. In fact, that is even true of certain species that belong to different sections, especially those in

Sect. *Aigeiros* and *Tacamahaca*. Thus, we find natural hybrid zones where the ranges of *P. deltoides*, or *P. fremontii* overlap with those of *P. trichocarpa* and *P. angustifolia*. And crosses between select parents of *P. deltoides* and *P. trichocarpa* are not only superior to their parents but are considered among the fastest growing trees in the temperate zone. Even members of more distantly related sections can be crossed if special techniques are applied to overcome hybridization barriers (Stettler *et al.* 1996). However, 'distant' hybrids are often less than desirable, because their quite distinctive genomes in many traits make for incongruous combinations in the final aggregate. Ideally, one would like to borrow from a donor species a trait or two without ending up with a whole set of its chromosomes. A good example is *P. euphratica* (Sect. *Turanga*), a distant relative of poplars in the *Aigeiros* and *Tacamahaca* sections. This species is commonly found growing in the arid lands of the Near East and Asia. Because of evolutionary adaptation to its environment, this species has become very heat and drought resistant, as well as salt tolerant; but it also has very small leaves, a thick bark, and tends to grow slowly. Could other poplars benefit from the selective transfer of genes from this species? Possibly! Fortunately, recent developments in molecular genetics offer us new tools that would make this more feasible.

These new tools are based on the detailed analysis of an organism's genome, resulting in the establishment of genetic linkage maps that show the location of genetic markers in relation to one another. Individual markers (each representing a specific region of a chromosome) may then be associated with specific traits; the subsequent tracking of these markers in a selective breeding program can significantly increase its precision and efficiency. Marker-assisted selection is now widely practiced in the breeding of such agricultural crops as corn, rice, soybean, and tomato.

A nice example to illustrate the power of this approach can be found in the genetic improvement of tomato, which has been described by Tanksley and McCouch (1997). Having identified a genetic marker associated with increased fruit size in the cultivated tomato, *Lycopersicon esculentum*, these scientists were able to locate a corresponding marker in a wild species from Peru, *L. pimpinellifolium*. Paradoxically, the fruit of this species is tiny, about the size of a wild currant. Yet, transferring the located marker for increased size via backcrossing from its genetic background into *L. esculentum* resulted in a 10 % increase in fruit size of the cultivated tomato. More traditional breeding strategies or approaches would have viewed the small fruited Peruvian species as an undesirable parental stock, not realizing that it harbored in its genome a 'positive' gene for fruit size. In this way, molecular maps can offer new insights into the genetic control of individual traits, thereby indicating how they can be manipulated through breeding and selection -- occasionally even pointing to unsuspected sources of valuable germ plasm, as shown in this case.

Molecular linkage maps have been constructed for poplar (Liu and Furnier 1993, Bradshaw *et al.* 1994). Currently, science can locate specific markers for such specific traits such as growth, form, phenology, and disease resistance (e.g. Bradshaw and Stettler 1995, Villar *et al.* 1996) and others are under constant revision and further refinement. And in the search for the actual genes (linked to the molecular markers) that affect

individual traits, other plants such as *Arabidopsis thaliana*, have proved to be increasingly useful, even for poplar. This small weed has emerged as the model plant *par excellence*, and now serves worldwide as genetic reference for studies in plant growth and development (Somerville 1999). Many single-gene mutants have been identified in it, located on its linkage map, and these have been used as ‘probes’ in the search for corresponding genes in other plants. This approach has proved fruitful in the poplar research going on in Steve Strauss’ laboratory at Oregon State University (OSU).

Work in Strauss’ Group at OSU has focused on the genetic engineering of poplar. Through genetic transformation, select individual genes can be introduced into the genome of a poplar, thereby compensating for a specific deficiency and making the recipient clone more desirable. In this manner, Strauss and his co-workers have for example succeeded in developing new hybrid material that is tolerant of glyphosate, a chemical widely used for weed control in poplar culture (Meilan *et al.* 1999). While of great interest to industry, there is also some concern, however, that pollen or seed from this material might genetically contaminate nearby native poplar. This has raised the question, how one might render the new material genetically sterile. One of the available approaches is to introduce genes from known floral mutants of other plants. Actual experiments conducted with probes from several male-sterility mutants of *Arabidopsis* and *Antirrhinum* (snapdragon) have shown that black cottonwood has a corresponding region in its genome, and that it expresses itself in exactly the same tissue of male anthers as in the donor plants (Skinner *et al.* 1999). In other words, in spite of their distant relationship, poplars seem to share with snapdragon and *Arabidopsis*, genes that have similar DNA sequences and control the same functions.

Other, similar work is conveying the same important message, which is: *Evolution, in DNA terms, has been far more conservative than we ever suspected. There is a remarkable commonality among organisms across wide phyletic space. And its corollary: This allows us in the domestication effort much greater freedom in genetic manipulation, operating at a larger biological scale than in traditional breeding, and drawing from a vast gene pool, beyond the boundaries of a single genus.*

At the same time we must exercise caution. We must always engage in thorough field testing of any new varieties or clones derived from such manipulation before accepting them into our operational planting stock.

What is the appropriate **spatial/numerical scale** of the Agricultural Model? At perhaps its most impressive industrial scale you can find it displayed in the agricultural region of southeastern Washington and northeastern Oregon (USA) where hybrid poplar plantations of Boise Cascade Corp. and Potlatch Corp. form contiguous blocks of up to 3,000 hectares. In fact, I have to confess to some biological unease when I stand there looking at miles and miles of lined up trees. In the aggregate, that region now harbors more than 14,000 ha of hybrid poplar, grown in short rotations (5-7 years) at dense spacing (2-3m) for pulp and paper. Because of the arid climate, irrigation is necessary, requiring thousands of miles of drip lines and highly sophisticated flow-regulation and monitoring systems. At that scale, many different genetic materials can be tested for their

productivity and suitability for a highly integrated management system. Criteria for selecting specific genomes include not only climatic adaptation and growth, but also tree form, allocation patterns, wood quality, pest resistance, and cultural requirements. Here we profit from the cumulative information generated by a long line of morphological, physiological, and anatomical research conducted on poplar, unmatched by any other forest tree (Hinckley 1996).

A similar approach to achieve a similar end product is practiced by the Fort James Corp. in the lower Columbia River Valley of northern Oregon; except that irrigation is not needed and that individual plantations are somewhat smaller. In this situation, these plantations fit harmoniously into the complex landscape of that more populated valley. Having operated its 2,800-3,600 hectare fiber farm for now 17 years, this company has developed an aggressive breeding and selection program that allow for systematic turnover of production clones and the ability to capture added genetic gains in quantity and quality of raw material.

Although extensive plantations of poplar can also be found in other countries (e.g. Canada, China and India), agronomical poplar culture in Asia, the Near East, and Europe tends to be practiced on a smaller scale (reviewed by Zsuffa *et al.* 1996). Typically grown at wider spacing (5-8m or more) for 12-25 years, these plantations can also accommodate other crops, such as wheat or corn during the early years, or more shade tolerant plants later (e.g., turmeric, ginger). Thus, poplars feature prominently in many systems of agroforestry. The integration of poplar culture into the agricultural landscape can also contribute to the reduction of agricultural effluents, a widespread problem in the maintenance of water quality.

Perhaps the key spatial/numerical question in the Agricultural Model concerns the genetic diversity required to prevent disease organisms from catching up with the crop. The consensus seems to be that past disease problems in regions where poplar culture has been practiced the longest have been the result of inadequate numbers of clones being deployed too widely and those clones, often no more than a handful, being closely related. More attention will have to be given to future breeding and selection, to the generation of independent pedigree lines, and to the regular replacement of operational clones in any region. The abundant genetic diversity available in existing native populations, especially on the North American continent, will provide for a rich gene pool from which this material can be recruited.

As for the **temporal scale** of the Agricultural Model, rotations range from 5 to 25 years, while under less intensive culture rotations are occasionally longer. As an operational example of short-rotation intensive culture, hybrid plantations at the Fort James Fiber Farm in the lower Columbia River valley are harvested in their seventh year. Trees, originally planted as 30-cm tall cuttings, are 18-20 m in height in 7-years and have a dbh of 25-30 cm. They are de-limbed, de-barked, and chipped on site and end up in paper furnish 24 to 48 hours later. Harvested biomass is used immediately the mill, thus resulting in minimal storage time. Stumps are removed after harvesting and, together with

branches and bark, are used as hog fuel by the mill. The site is then prepared for re-planting in the subsequent spring, often with new, improved hybrid material.

Longer rotations (15-25 years) are used to produce larger dimension logs. This strategy allows producers to access to such diverse markets of value-added products as plywood, block board, oriented strand board (OSB), laminated beams, and lumber. Much experience has been gained with such production systems in Europe and Asia and there is growing interest in North America in adopting such market strategies.

In closing this section of my talk, let me say I devoted more time to the Agricultural Model than I will to the two other scenarios because it has more unusual features for a forestry audience, at all three scales when compared to the other models. Also, the ideas presented were indeed different from what is commonly found under more traditional forestry practices. These approaches also represent a more aggressive approach to tree domestication by combining intensive genetic manipulation with intensive culture in remarkably short rotations. Hence, biomass production figures are accordingly high. For example, 1997 data from Italy show that poplar made up only 1 % of the forest area of that country but produced in that year 50 % of its industrial wood (Bisoffi pers. commun.). Correspondingly, statistics from France show poplar covers 1.5 % of the forest area but last year (1998) it accounted for the second highest volume of harvested timber, exceeding even oak (Barthod 1999). Further, production-per-hectare figures from commercial plantations in the Pacific Northwest (USA) were between 17-21 Mg/ha/yr of oven-dry woody biomass; (Schuette 1995). These outputs are high by any temperate-zone standards, due in part to the favorable climate and soils of that region.

Such wood biomass production figures may almost seem excessive. But such output levels will be needed if we are to satisfy the projected world demands for wood, which is expected to double over the next 50 years. In my opinion, intensive poplar culture under an Agricultural Model is a wood production system whose time has come!

The Forestry Model

The objective of the Forestry Model is *the sustained production of wood in pure or mixed stands on forest sites in shorter rotations than is traditional with conifers.*

Here, on typical forest sites, the approach is more conservative and this at all three scales. Aspen (*P. tremuloides* Michaux), the most widespread hardwood in Canada, may serve as a tangible example for our discussion today. On the **biological scale**, the section within this genus and species (Table 1) seems to offer adequate genetic resources from which to draw suitable genotypes. Specifically, for aspen, there is essentially two very similar species (since recent taxonomic revisions). One is found in the boreal forest of the Northern Hemisphere in Eurasia: *P. tremula* and the other in the same biome but in North America *P. tremuloides*. Anybody who has examined these two species in their respective ecosystems will attest to their remarkable similarity in life history,

morphology, anatomy, physiology, reproductive biology, ecology, growth patterns, wood properties, and predisposition for diseases and insects (see Peterson and Peterson, 1992, for a comprehensive treatment of *P. tremuloides*). In fact, as a geneticist, I hope that the next generation of taxonomists will see fit to amalgamate (lump) these two species. (A pair of similarly comparable species, *Alnus sinuata* and *A. viridis*, showing parallel distributions across the northern latitudes of the two continents, are now considered subspecies of *A. viridis*).

Not surprisingly, these two aspen species (*P. tremuloides* and *P. tremula*) cross easily and produce fertile hybrids. More remarkably, the hybrids tend to surpass their parents in growth and productivity. Efforts in the 1950s to capture this hybrid vigor have given sufficiently promising results that they have been followed up by new hybridization and selection programs in Canada, Finland, and the USA (e.g. Beuker 1999). As an example of the excellent growth of hybrid aspen in northern latitudes, data from a 27-year-old stand in Mykinge, Sweden showed a current annual increment of 21.9 cubic meters/ha.

But even within a species such as *P. tremuloides* there is plenty of genetic variation available to be tapped for gains in productivity and quality. This variation can be easily recognized thanks to the habit of aspen to send up root suckers, forming contiguous clones. Thus, natural stands of aspen are characterized by a mosaic of distinctive clones, side by side, each with its unique morphological and phenological features more or less faithfully repeated by all its ramets. I cannot think of a more conspicuous display of natural genetic variation in a forest tree than in aspen, and I have made ample use of it in the field over the years in turning doubting foresters into 'genetic believers'.

From a **spatial/numerical** perspective, the conservative management of aspen will tend to work with the natural mosaic of clonal patches, each from one to several acres in size, some occasionally larger and correspondingly older, especially when subject to repeated cycles of fire.

This brings us to the **temporal scale**. Rotations of 40-50 years seem appropriate under these forest conditions, repeated for two to three cycles of re-sprouting. But little do we know about the true age of natural aspen clones or more precisely, of their genetic backgrounds. We know that some of them have been estimated to be several thousand years old. What genetic and physiological features have permitted them to adapt to the drastic changes that took place over such long time spans? Of course, the same could be asked of other tree or shrub species such as birches or willows (or oaks in more southern latitudes) that experience recurrent cycles of fires, where re-sprouting from the same stump can happen over long periods. The widely held view of clones being 'unnatural' and destined to short life may well be a distorted interpretation of nature, fed largely by the negative experience with *extensively propagated* clones. In other words, certain genotypes may well last for a long time, provided they don't exist in too many copies and are neighbored by other clones that differ from them. Clearly, we need more studies to develop a better understanding of this important question.

Finally, the longer rotations in the Forestry Model also offer the opportunity to combine multiple spatial/temporal scales in a single stand by mixing poplar with conifers. I have seen a nice example of such a system in Germany, where on a typical upland forest site

Picea abies was combined with *Populus trichocarpa*; every three rows of the conifer alternated with one row of cottonwood. The stand was at age 25, ready for the harvest of cottonwoods, providing for a first economic return; the spruce would be harvested 40-45 years later. *Populus trichocarpa* was chosen because of its tolerance of less fertile forest soils and because of its narrow crown which would inflict less damage on the remaining conifers during harvest.

In summary, the Forestry Model of managing poplar is far more conservative than the Agricultural Model. But it is applicable on a much larger land area, and therefore its more modest production potential has a strong multiplier effect.

The Conservation Model

The objective of the Conservation Model is *the protection of riparian habitats and of adjacent floodplains, maintenance of water quality, and conservation of germ plasm.*

Although poplars occur in many different ecosystems, I am deliberately focusing here on riparian habitats where they fulfill such a critical role. The last 10 years have also seen a profound re-assessment worldwide of the health of rivers and of riverine environments and how to go about restoring them. This is an urgent task, and through our work with poplar we can make a significant contribution to it.

Here, the appropriate **biological scale** is that of the local population in its ecosystem. In other words, as the term 'conservation' implies, this model attempts to conserve the extant biological status and complexity. The conservation of native populations and their associated species is also the most practical way to maintain genetic resources in their natural diversity. Natural 'gene banks' will also be the reservoir for future breeding and selection. By comparison with other parts of the world, we are fortunate on the North American continent to still have an extensive network of indigenous poplar along many of our rivers. The longer history of settlement in Eurasia has severely reduced these resources over time, and aggressive efforts are now underway to try to conserve what is left, as for example under the new EUFORGEN program for *P. nigra* (Frison *et al.* 1994). But our generally more favorable conditions hardly allow for complacency.

This becomes clear when we consider the **spatial and temporal scales**, which here are closely intertwined. Rivers are by their very nature dynamic systems (Leopold 1994), and poplars are highly attuned to these dynamics. The seasonal fluctuations in discharge, the occasional peak flows and their erosion and accretion, and the changing meanders over time, all are critical elements in the recruitment and establishment of riparian poplar, as in other disturbance-dependent species (Braatne *et al.* 1996). On large rivers with extensive poplar populations, this can be simulated by a management system involving carefully placed and timed harvest cuts. I have seen this at work in the lower Fraser River Valley east of Vancouver, where the Scott Paper Company managed native black cottonwood stands in an extensive way. Mature stands were harvested at a scale of a few hectares; the

debris resulting from the operation would then resprout; gaps would be filled with whips from the area (P. McAuliffe pers. commun.) Thus, a stand with similar genetic constitution would be regenerated. And the neighboring stands would serve as sources for all other components of flora and fauna.

Significant changes in the natural regime of a river are likely to have a negative impact on the riparian vegetation. Thus, river regulation typically interferes with the characteristic dynamics, either by preventing periodic floods - thereby preventing opportunities for seedbed formation and for asexual propagation, or by holding back water during the critical period of seedling establishment. As a result, poplar populations along many dammed rivers tend to senesce and die out. This eliminates shade as well as the source for large woody debris, both important factors for the fish and wildlife component of a healthy river. Successful efforts have been made to reverse this process in the case of several rivers (e.g. Mahoney and Rood 1998), and they may serve as examples not only of how poplar can be restored, but in a broader sense, of how a more enlightened approach to river regulation will satisfy the broader needs of natural resource management.

Another related problem, which has to be addressed, is the systematic elimination of riparian poplar through agriculture, housing, gravel exploitation, and other human activities. Bank erosion, sedimentation, and water pollution are the natural consequences. *Thus, restoration of riparian vegetation, of which poplar forms an integral part, is an urgent mandate in our region. The recent placement of several salmon species on the US endangered species list will provide further incentives for such efforts.*

A final aspect in our consideration of the three Models of poplar management is to remember that there is every reason to view them as mutually compatible. That is to say that all methods of production and management (Models) can be practiced *side by side in the same landscape*. This is especially true when and where we can minimize, or eliminate altogether, any gene flow from intensively managed plantations to the native stands that serve conservation purposes.

Closing Remarks

Poplar is an intriguing genus. It is a versatile and dynamic tree. Thanks to its inherent growth and demographic patterns it can satisfy many biological and economic needs. During the past 20 years, we have gained many insights into its biology and ecology. Today we are trying to make use of this information in how we deal with poplar in different management contexts at different biological, spatial, and temporal scales. The forest industry and some of the public agencies have been important partners in this effort. Several companies have done remarkable pioneering work in developing highly integrated production systems on a large scale. Research cooperatives between universities and industry have been instrumental in enabling research and providing for its continuity. Thanks to poplar's unique combination of favorable features, we have also

been able to push it to center stage as a model organism for the understanding of tree growth and development. That has made it possible to attract scientists from many non-forestry oriented disciplines to its study its properties and it's future possibilities. As you know there are scientists here at the University of Alberta who are also contributing to this body of knowledge. Today there is a large research community worldwide sharing in this information and attracting

funding from previously barren sources.

But we have barely scratched the surface and are reminded daily of how little we know about this tree, let alone how little others know about it. Further, we often get frustrated in trying to see it properly recognized in forestry circles as a worthy object of attention and financial support. *Not being a conifer* seems to be its major handicap! Well, speaking for myself, I'll go for the angiosperms every time: they are far more exciting!

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