PRODUCTIVITY OF CONIFERS IN WESTERN CANADA BOREAL FORESTS IN RELATION TO SELECTED ENVIRONMENTAL FACTORS

Donald J. Pluth and Ian G. W. Corns

ABSTRACT: The productivity of the conifer-dominated, natural forests within the western Boreal region ranges between 0.7 and 6.4 m^3 $ha^{-1}yr^{-1}$ in gross mean annual volume increment (70 year) or between 12 and 27 m in site index (70 yr) for jack pine, lodgepole pine, white spruce, black spruce and tamarack. Climatic, topographic and soil moisture regime variables are correlated with forest productivity as revealed through simple and multivariate statistical methods. Stratification of Boreal forest land according to community types provides an estimate of current tree productivity at a precision equal to or better than an estimate associated with soil mapping units. Ideas for improvement in the accuracy and precision of estimates of forest productivity emphasize methods that in principle disclose environmental factor-productivity relationships.

INTRODUCTION

Stratification of forest land into groups distinguished according to tree productivity or prediction of tree growth from a complex of climatic, edaphic and site features have been and continue to be the goals in forest site quality investigations. Carmean (1975) reviewed the rationale for requiring knowledge of forest site quality and comprehensively reviewed the methodology for its estimation. A greater intensity of management of forest land is the underlying impetus for determination of productive capacity. Expectations in forest yield and quality, responsiveness to intensive silvicultural practices, species selection for valued products and shorter rotations necessitate an accurate estimation of site quality according to Carmean. His review article provides the conceptual background and terminology for our review of the state-of-the-art in forest site quality estimation for the most prevalent, indigenous coniferous species in Western Canada. We present the actual productivities for coniferous species in unmanaged forests and identify environmental factors associated with the best tree growth. The methods for estimating forest site quality are compared for their apparent accuracy and precision for stratification of forest lands into tree productivity classes.

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DESCRIPTION OF FOREST LANDS

The geographical area referred to as Boreal forests of Western Canada (fig. 1) corresponds with the forest sections Mixedwood (B18a), Lower Foothills (B19a), and Upper Foothills (B19c) of the Boreal forest region, and the East Slope Rockies section (SA1) of the Subalpine forest region (Rowe 1972). Rowe's forest regions essentially represent macroclimatic delineations as inferred from the presence of certain tree species as dominants in climatic climax communities. Forest sections as subdivisions of regions are not defined consistently by specific criteria. The criteria vary according to the forest region. Roughly, limits for the geographical area are latitude 50°N to 59°N and longitude 98°W to 123°W. Ranges and modal values of some natural features characteristic of the forest sections are shown in table 1. The four forest sections occur within the soil moisture subclasses "humid" and "subhumid", defined as water deficits being very slight (2.5 - < 6.4 cm) and significant (6.4 - 12.7 cm), respectively, during the growing season. Soil temperature classes range from moderately cold to cold cryoboreal (Clayton et al. 1977). It is highly probable even though not specifically stated

Table 1--Natural features characteristic of forest sections in the Boreal and Subalpine forest regions[1]

Forest section	Elevation	Tree species[2]			Surficial/bedrock geology	Upland soils
		Predominant	Major	Minor		
	m					
East Slope Rockies	1530-2070	lP	eS, eS-wS hy, sF	wP, aL	Thin glacial drift overlying uplifted Mesozoic shales & sandstone	Variable, shallow to bedrock
Upper Foothills	1220-1530	lP	wS	bS, sF	Glacial drift overlying uplifted & folded Mesozoic and late Paleozoic sedimentary rocks	Eutric Brunisol & Gray Luvisol
Lower Foothills	760-1220	lP	A, bP, wS	bS, bF, sF, T	Glacial drift overlying Mesozoic sedimentary rocks	Gray Luvisol
Mixedwood	200-900	A	bP, wS bF	wB, jP, bS, T	Glacial drift overlying Mesozoic sedimentary rocks	Gray Luvisol

[1]Abstracted from Rowe (1972) and Clayton et al. (1977).

[2]lP - lodgepole pine, A - aspen, eS - Engelmann spruce, eS-wS hy - Engelmann spruce-white spruce hybrid, sF - subalpine fir, wS - white spruce, bP - balsam poplar, bF - balsam fir, wP - whitebark pine, aL - alpine larch, bS - black spruce, T - tamarack, wB - white birch, jP - jack pine.

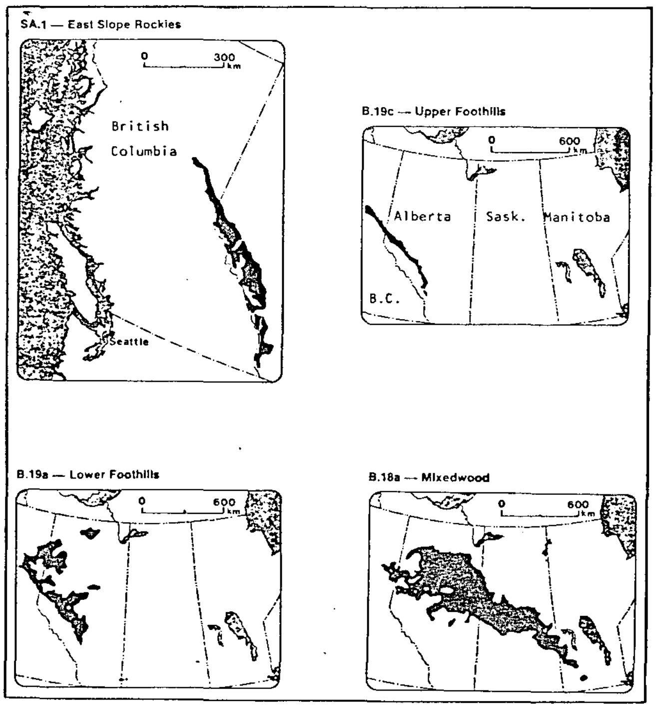

Figure 1.--Some forest sections of the Subalpine (SA) and Boreal (B) forest regions in Western Canada constituting the Boreal forests of Western Canada (from Rowe 1972).

in all of the studies, that the tree components of sampling units for productivity studies on upland soils were natural stands of wildfire origin, and thus even-aged. Those stands with white spruce *(Picea glauca* (Moench) Voss), tamarack *(Larix laricina* (Du Roi) K. Koch), and black spruce *(Picea mariana* (Mill.) BSP) in lowlands would be the most likely to depart from an even-age condition as a result of forest succession and/or of a non-fire origin (black spruce on fens or bogs).

Because estimates of forest productivity in the reviewed studies were from natural stands, actual rather than potential productivity is represented.

FOREST SITE QUALITY STUDIES

In this review we have included quantitative results in contrast with reports with a data base of an observational nature or with a sampling design not amenable to statistical analysis. A minimum level of statistical analysis for review acceptance is a means range test (e.g., Tukey's or Duncan's) or analysis of variance. Those forest site quality studies qualifying on those bases are summarized in table 2. A considerable range in area of a study and in variability in respect to physical site factors affecting productivity is evident.

For a further perspective, the reviewed studies may be categorized according to Carmean's (1975) indirect methods for estimation of site quality. For lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), all of the site quality studies related a parameter of tree growth to a soil taxonomic class, commonly at the soil series level of generalization. All studies except Duffy (1964) also attempted the plant

Table 2--Forest site quality studies of conifers in the Western Canada Boreal forest region and a description of their samples including sample size

Species	Reference	Area	Sample description (no. plots)
		km²	
Lodgepole pine	A. Duffy (1964)	3,500	3 soil series (70)
(Pinus contorta Dougl. var. *Latifolia* Engelm.)	C. Lesko and Lindsay (1973)	1,200	2 forest types and 12 soil series (ns[1])
	D. Dumanski et al. (1973)	15,000	Community type not determined. Forest inventory data of merchantable volume (60-110 year age class), several soil series and complexes (1116)
	F. Corns (1978)	17,500	8 vegetation types and several soil series (83)
White spruce *(Picea glauca* (Moench) Voss)	B. Duffy (1965)	13,700	Typical species of productivity classes noted, 9 parent materials and 6 soil drainage classes, r-vp (414)
	C. Lesko and Lindsay (1973)		9 forest types and 15 soil series (ns[1])
	E. Kabzems et al. (1976)	76,400	8 ecosystems and 5 soil drainage classes, vr-i (ns[1])
	F. Corns (1978)		3 vegetation types and several soil series (30)
Black spruce *(Picea mariana* (Mill.) B.S.P.)	E. Kabzems et al. (1976)		5 ecosystems and 4 soil drainge classes, mw-vp (ns[1])
	F. Corns (1978)		2 vegetation types and several soil series (15)
Jack pine *(Pinus banksiana* Lamb.)	E. Kabzems et al. (1976)		4 ecosystems and 4 soil drainage classes, vr-i (ns[1])
Tamarack *(Larix laricina* (Du Roi) K. Koch)	E. Kabzems et al. (1976)		3 ecosystems and 1 soil drainage class, vp (ns[1])

[1]ns - sample size not specified for individual tree species. Lesko and Lindsay (1973) had 100 plots ranging over forest types with lodgepole pine, white spruce, and black spruce. Kabzems et al. (1976) had 94 permanent sample plots ranging over ecosystems with white spruce, black spruce, jack pine, and tamarack.

indicator method as an alternative for estimation of tree growth. Soil-site methods (Carmean 1975) were utilized through simple correlation or regression (Lesko and Lindsay 1973, Dumanski et al. 1973). Corns (1978) developed multiple regressions with soil-site and vegetative cover by species as variables in estimation of coefficient parameters of lodgepole pine growth. Except in table 2, where the authors' terms for a vegetation classification are given, the term "community type" is adopted as a single reference to "vegetation type" (Corns 1978), a "forest type" (Lesko and Lindsay 1973), and "ecosystem" (Kabzems et al. 1976).

The studies for estimation of white spruce productivity included similar indirect methods as for lodgepole pine. By stratification according to parent materials and soil drainage classes, Duffy's (1965) method can be considered "quasi-soil survey" in that soil horizon properties were not recognized in sufficient detail to classify his sample sites according to taxonomic unit. Kabzems et al. (1976) stratified by soil drainage class first and then within drainage class by ecosystem. This is a nested arrangement that still may be categorized as a plant indicator method in which sampling units are modified habitat types. Corns' (1978) methodology was multiple: plant indicator, soil survey, and soil-site evaluation (multiple regression).

LODGEPOLE PINE PRODUCTIVITY

Stratification of forest vegetation into community types (a plant indicator method) has provided a convenient framework for estimating productivity of lodgepole pine (Lesko and Lindsay 1973, Corns 1978). Names of community types recognized the abundance or scarcity of some species by vegetative strata (Lesko and Lindsay 1973) or floristic similarity augmented by edaphic and other environmental factors (Corns 1978).

The mean annual increment (m.a.i.) for lodgepole pine (i.e., the mean annual increment in gross bole volume inside bark averaged over 70 years) ranged from a mean of 4.2 m^2 $ha^{-1}yr^{-1}$ (mean site index (SI) = 19.8 m) for the *P. contorta/Viburnum edule/Rubus pubescens* (PICO/VIED/RUPU) type to 1.3 m^3 $ha^{-1}yr^{-1}$ (mean SI = 11) for the *P. contorta/Vaccinium myrtilloides/Cladonia* spp. (PICO/VAMY/CL) type (table 3). Soil-site conditions associated with this m.a.i. range from lodgepole pine are an occurrence in the Lower Foothills forest section at 880-1040-m elevation, commonly on northerly slopes up to a 30 percent slope gradient, and usually well-drained to imperfectly-drained Gray Luvisols and Eutric Brunisols developed on residual and glacial drift parent materials for the PICO/VIED/RUPU type (fig. 2) of highest productivity. The type PICO/VAMY/CL of lowest productivity is restricted to well-drained, coarse-textured Humo-ferric Podzol and Eutric Brunisol soils developed in fluvial and aeolian parent materials (fig. 2).

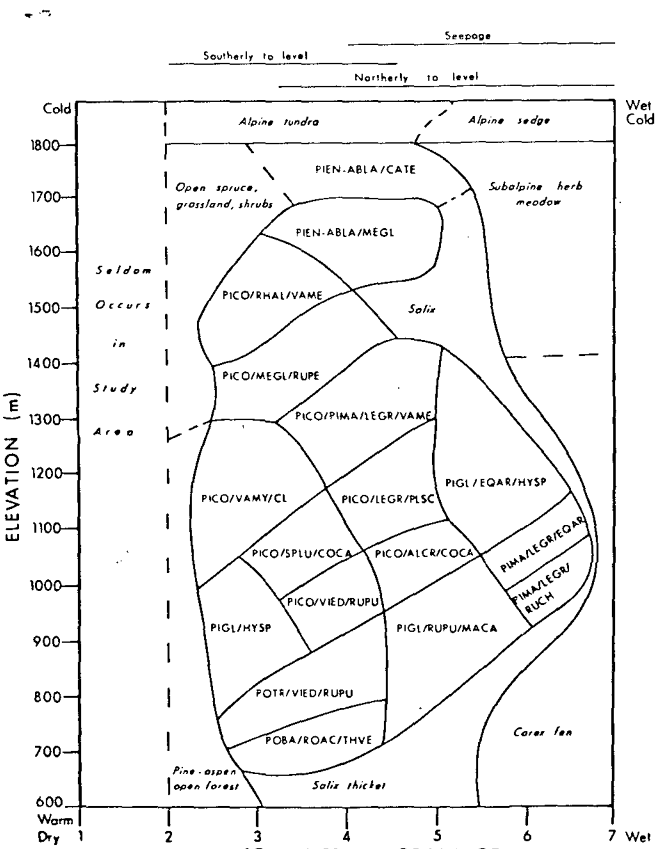

Figure 2--Generalized occurrence of community types of west-central Alberta in an elevation-soil internal drainage class grid (source information from Corns 1978).

Table 4 summarizes productivity-environmental factor relationships for lodgepole pine as disclosed from soil-site studies. Several of these simple statistical relationships suggest either a macroclimate (e.g., length of growing season, precipitation during growing season) or a site moisture regime causal factor. A lodgepole pine productivity that is negatively correlated with elevation (Corns 1978) indicates a macroclimatic influence. Productivity positively correlated with slope angle (Duffy 1964, Corns 1978) and an increase (Corns 1978) or a maximum on north-facing slopes (Dumanski et al. 1973) support a hypothesis of favorable site moisture regime in terms of a tree's water status. That is, short-term productivity depends upon photosynthetic tissue being at a high-water status while stomata are open (Passioura 1982). On the wet or periodically anaerobic end of the scale in site moisture regime, a soil aeration effect on lodgepole pine productivity is inferred from positive correlations with slope angle (Duffy 1964). A periodic annual increment in gross bole volume (p.a.i.) correlation with coarse-textured parent materials (Dumanski et al. 1973) is another possible aeration relationship. More directly, the most favorable site moisture regimes for lodgepole pine are indicated by a site index maximum for moderately well-drained soils (fig. 3). Furthermore, the appearance of the independent variable depth to distinct mottling in a regression for estimation of m.a.i. for lodgepole pine suggests that the most favorable site moisture regime is associated with better drained soils.

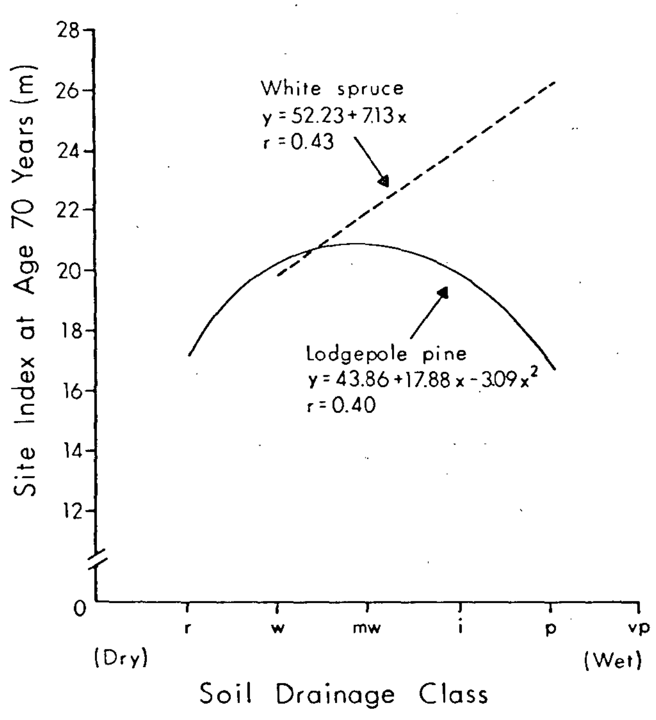

Figure 3--Relationships between the site index of lodgepole pine or white spruce and soil internal drainage class (after Lesko and Lindsay 1973).

Table 3--Some Western Canada Boreal forest types and their associated soil properties and productivity

Type[1] (Reference)	Soil[2]	Drainage[3]	Texture	Productivity m.a.i.[4]	Productivity SI(species)	Age for estimate
				$m^3\ ha^{-1}yr^{-1}$	m	yr
Populus balsamifera/ Rosa acicularis/ Thalictrum venulosum (Corns 1978)	CU.R	w	SL-LS	4.6	18.3 (bP)	70
Populus tremuloides/ Viburnum edule/Rubus pubescens (Corns 1978)	GL.GL, O.GL	w-i	C-HC	4.3 3.0-6.3	19.3 (A)	70
Populus tremuloides/ Aralia nudicaulis/ Linnaea borealis (Kabzems et al. 1976)	Luvisolic	mw	Fine-med.	3.5-3.8	---- (A)	60
Picea glauca/Rubus pubescens-Maianthemum canadense (Corns 1978)	O.GL GL.GL	mw-i	C-HC	4.7 2.9-6.3	18.6 (wS)	70
Picea glauca/Aralia nudicaulis (Lesko and Lindsay 1973)	O.GL, GL.GL	mw-i	C-HC	---	23.8 (wS) 22.9 (1P)	70
Picea glauca/Aralia nudicaulis-Cornus stolonifera (Lesko and Lindsay 1973)	GL.GL	i-p	HC	---	24.1 (wS)	70
Picea glauca-Populus tremuloides/Cornus canadensis (Kabzems et al. 1976)	Luvisolic	w	Fine-med.	3.1	--- (wS)	75
Picea glauca-Populus tremuloides/Cornus canadensis-Rubus pubescens (Kabzems et al. 1976)	Luvisolic	i	Fine	2.4	--- (wS)	75
Picea glauca-Populus tremuloides/Cornus canadensis-Mitella nuda (Kabzems et al. 1976)	Luvisolic	mw	Fine	4.2-4.5	--- (wS)	65
Picea glauca/Picea mariana/Vaccinium myrtilloides (Lesko and Lindsay 1973)	O.GL, GL.GL	i	CL-HC	---	23.2 (wS) 21.3 (1P)	70 70
Pinus contorta-Picea glauca/Arctostaphylos uva-ursi (Lesko and Lindsay 1973)	E.EB, BR.GL	r	LS	---	22.3 (wS) 19.8 (1P)	70 70
Picea mariana-Populus tremuloides/Vaccinium myrtilloides (Lesko and Lindsay 1973)	O.GL	m-w	CL-HC	---	21.3 (1P)	70
Alluvial complex (Lesko and Lindsay 1973)	O.R, GL	m-mw	Med.		21.3 (wS) 20.7 (1P)	70 70
Pinus contorta/ Viburnum edule/Rubus pubescens (Corns 1978)	GL.GL E.EB	i-w	CL-L	4.2 0.7-6.0	19.8 (1P)	70

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Type[1] (Reference)	Soil[2]	Drainage[3]	Texture	Productivity		Age for estimate
				m.a.i.[4]	SI (species)	
				$m^3\ ha^{-1}yr^{-1}$	m	yr
Pinus contorta/Spiraea lucida/Cornus canadensis (Corns 1978)	O.GL, BR.GL	w-mw	CL-L	4.2 3.2-4.6	17.0 (1P)	70
Pinus contorta/Alnus crispa/Cornus canadensis (Corns 1978)	O.GL, BR.GL	mw-i	CL-L	4.0 2.1-5.0	18.2 (1P)	70
Pinus banksiana/Lycopodium annotinum/Pleurozium schreberi (Kabzems et al. 1976)	Luvisolic	mw		2.7-3.2	--- (jP)	65
Pinus contorta/Ledum groenlandicum/Pleurozium schreberi (Corns 1978)	O.GL, BR.GL	mw-i	CL-L	3.8 1.5-5.0	16.3 (1P)	70
Pinus banksiana-Picea mariana/Pleurozium schreberi (Kabzems et al. 1976)	BR.GL	w	CL	1.4-1.7	--- (jP)	75
Picea glauca/Equisetum arvense/Hylocomium splendens (Corns 1978)	O.G, O.LG	p-i	CL-HC	3.7 2.4-6.4	12.5 (wS)	70
Picea glauca/Equisetum arvense (Lesko and Lindsay 1973)	O.GL	vp-p	C	---	24.7 (wS)	70
Picea glauca/Equisetum arvense-Equisetum palustre (Kabzems et al. 1976)	Gleysolic	p	Fine-med.	1.4-1.7	--- (wS)	80
Pinus contorta/Rhododendron albiflorum/Vaccinium membranaceum (Corns 1978)	BR.GL, E.DYB	w-mw	L	3.7 2.1-6.4	--- (1P)	70
Picea glauca/Hylocomium splendens (Corns 1978)	O.R, CU.R	r-w	LS-L	3.6 2.0-4.8	13.2 (wS)	70
Picea glauca/Hylocomium splendens (Lesko and Lindsay 1973)	O.GL	mw	HC	---	22.9 (wS) 22.0 (1P)	70 70
Picea glauca/Abies lasiocarpa/Hylocomium splendens (Lesko and Lindsay 1973)	O.GL	mw-i	CL	---	20.4 (wS)	70
Picea glauca/Lycopodium annotinum (Lesko and Lindsay 1973)	O.GL	mw	CL	---	21.3 (wS) 19.8 (1P)	70 70
Picea glauca/Betula papyrifera/Hylocomium splendens (Lesko and Lindsay 1973)	GL.GL	mw	HC-SiC	---	26.5 (wS)	70

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				$m^3 ha^{-1} yr^{-1}$	m	yr
Picea glauca/ Pleurozium schreberi (Kabzems et al. 1976)	Luvisolic Luvisolic	w mw	Fine-med. Fine	3.1 4.5	--- (wS) --- (wS)	75 70
Pinus contorta/ Picea mariana/ Ledum groenlandicum/ Vaccinium membranaceum (Corns 1978)	O.GL,	mw	CL-L	3.1 1.3-5.0	14.4 (lP)	70
Populus tremuloides/ Corylus cornuta (Kabzems et al. 1976)	Luvisolic	w	Fine-med.	2.8	--- (wS)	70
Pinus contorta/Menziesia glabella/Rubus pedatus (Corns 1978)	BR.GL	w-mw	L-CL	2.7 1.4-4.3	13.9 (lP)	70
Picea mariana/Pleurozium schreberi-Ptilium crista-castrensis (Kabzems et al. 1976)	Luvisolic	i	Fine-med.	2.1-2.4	--- (bS)	90
Picea mariana/Ledum groenlandicum/ Equisetum arvense (Corns 1978)	T.M, R.G	p	Org-Cl	2.1 1.3-3.2	8.1 (bS)	70
Picea glauca-Populus tremuloides/Corylus cornuta (Kabzems et al. 1976)	Brunisolic	vr-r	CS-Gr	1.7-2.0	--- (wS, A)	80
Picea glauca/ Agropyron subsecundum-Arctostaphylos uva-ursi (Kabzems et al. 1976)	Brunisolic	vr-r	FS	1.0-1.7	--- (wS)	90
Larix laricina/Picea mariana/Ledum groenlandicum/Pleurozium schreberi (Kabzems et al. 1976)	Organic	p	--	1.4	--- (L)	90
Picea engelmannii/ Menziesia glabella/ Rubus pedatus (Corns 1978)	O.GL	mw-i	L-LS	1.4-4.3	17.9 (eS)	70
Pinus contorta/Vaccinium myrtilloides/Cladonia spp. (Corns 1978)	O.HFP	w	LS	1.3	11.9 (lP)	70
Pinus banksiana/ Vaccinium vitis-idaea-Pleurozium schreberi (Kabzems et al. 1976)	BR.GL	w	CL	2.0	--- (jP)	70
Pinus banksiana/ Arctostaphylos uva-ursi-Cladonia spp. (Kabzems et al. 1976	Brunisolic	vr-r	S-LS	0.8-1.0	--- (jP)	80

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Type[1] (Reference)	Soil[2]	Drainage[3]	Texture	Productivity m.a.i.[4]	Productivity SI (species)	Age for estimate
				$m^3\ ha^{-1} yr^{-1}$	m	yr
Pinus contorta-Picea mariana/Arctostaphylos uva-ursi (Lesko and Lindsay 1973)	E.EB	r	LS	---	18.0 (lP)	70
Populus tremuloides/ Rosa acicularis/Elymus innovatus (Kabzems et al. 1976)	Brunisolic	vr-r	CS-Gr	1.3	--- (A)	80
Larix laricina/Carex aquatilis/Sphagnum spp. (Kabzems et al. 1976)	Organic	vp		0.8	--- (L)	100
Picea mariana/Ledum groenlandicum/Carex spp. (Kabzems et al. 1976)	Organic	vp		0.7-0.8	--- (bS)	130

[1]The community types were distinguished on the basis of vegetational and environmental criteria. The types are ranked within the table according to average productivity. Those types adjacent to the same vertical line are similar floristically and environmentally.

[2]Class abbreviations from Canada Soil Survey Committee, Subcommittee on Soil Classification 1978.

[3]Internal drainage classes: vr - very rapidly, r - rapidly, w - well, mw - moderately well, i - imperfectly, p - poorly, vp - very poorly.

[4]Average (single value) and/or range given for m.a.i.

Very few statistical relationships between a site nutrient regime factor and productivity of a western Boreal conifer have been identified. For lodgepole pine, a p.a.i. optimum from a modal soil pH 5.5 to 6.0 within a specific group of soils (table 4) (Dumanski et al. 1973) was the only such relationship of statistical significance. Some soil-site studies, however, excluded soil fertility variables from consideration on a deliberate but informed basis (Lesko and Lindsay 1973, Corns 1978). The complexity of site nutrient regime and inadequate measurement and interpretation methodology may have been reasons for an exclusion decision.

As an attempt to improve the estimation of productivity, Corns (1978) compared multiple regressions that had both climatic-topographic-edaphic and vegetative cover by species as independent variables. Precision in the estimation of lodgepole pine productivity improved considerably with the inclusion of vegetative cover variables. R^2 values increased from 0.24 to 0.66 for m.a.i. and from 0.49 to 0.71 for site index at 70 years.

A case has been made (Duffy 1962) for the utilization of soil survey information in stratification of forest lands according to productivity. In a soil-site study limited to just three soil series, Duffy (1964) found lodgepole pine height growth to be significantly greater on the two soil series with the finer-textured profiles. Stratification for lodgepole pine productivity, however, was achieved with better success through community type than through soil taxonomic unit or soil map unit (Lesko and Lindsay 1973, Corns 1978). Community types provided a greater number of productivity groups with statistically-different mean productivities. Certainly some relationship exists between community types and soil taxonomic units (commonly soil subgroup or soil series). Lesko and Lindsay (1973) discovered a community type-soil series relationship to be closest only at the extremes in soil internal drainage. Corns (1978) usually found one or two soil subgroups to be most frequently associated with community type (table 3).

We advocate a continued two-way stratification of western Boreal forest land; i.e., according to community type and soil taxonomic unit or soil map unit. This has a potential advantage over a one-way stratification (either by community type or soil unit) in applications in forest land management that are multipurpose. If a single

Table 4--Productivity-environmental factor relationships for lodgepole pine as revealed from soil-site studies in Western Canada Boreal forests[1]

Environmental factor	Simple relationship	Reference
Climatic-Topographic:		
Elevation	Negative correlation with m.a.i. or SI	Corns 1978
Slope angle	Positive correlation with dominant height for soils developed on till	Duffy 1964
	p.a.i. maximum at 15-30 percent	Dumanski et al. 1973
	Positive correlation with m.a.i. or SI	Corns 1978
Aspect	p.a.i. increases on north-facing slopes with sandy and gravelly soils only	Dumanski et al. 1973
	m.a.i. maximum on north to northeast-facing slopes	Corns 1978
Edaphic:		
Soil internal drainage	Curvilinear with SI maximum at moderately well drained	Lesko and Lindsay 1973
	p.a.i. ranked vp < p < i	Dumanski et al. 1973
	Depth to distinct mottling in regression for m.a.i. estimation	Corns 1978
	Basal area highest for rapidly drained sandy outwash	Wali and Krajina 1973
Texture	p.a.i. greater for glaciofluvial sands and gravels than for fine- and medium-textured till and lacustrine parent materials	Dumanski et al. 1973
Stoniness	p.a.i. decreases slightly	Dumanski et al. 1973
pH	p.a.i. optimum for modal soil pH's 5.5-6.0 within Luvisolic soils developed on a calcareous, medium-textured till	Dumanski et al. 1973

[1]Environmental factor compiled only if its simple correlation coefficient or its multiple regression coefficient was significant at the 0.05 level.

objective of land stratification is for productivity of lodgepole pine, then the research evidence in Western Canada Boreal forests favors a stratification based upon community type. A community (vegetation) type defined conceptually as by Corns (1978), (i.e., including some environmental criteria) appears to have greater utility for lodgepole pine productivity than one solely defined by vegetational criteria.

A community (vegetation) type of Corns (1978) differs from the habitat type of Pfister and Arno (1980). The former classifies the current (at sampling) vegetation development and some environmental factors whereas the latter is based on a dynamically stable (climax) state of potential vegetation development.

WHITE SPRUCE PRODUCTIVITY

The m.a.i. for white spruce ranged from a mean of 4.7 $m^3\ ha^{-1}yr^{-1}$ for the *Picea glauca/Rubus pubescens-Maianthemum canadense* type to about 1.4 $m^3\ ha^{-1}yr^{-1}$ for the *Picea glauca/Agropyron subsecunum-Arctostaphylos uva-ursi* type (table 3). The former community type occurs in the Lower Foothills section at an elevational range of 670-1220 m commonly on north-facing, 0-30 percent slopes with moderately well to imperfectly drained Orthic and Gleyed Gray Luvisols dominant (table 3 and fig. 2). The sites with the lowest m.a.i.'s are found in the Mixedwood section commonly on very rapidly to rapidly drained Brunisolic soils (table 3). The types *Picea glauca/Aralia nudicaulis* and *Picea glauca/Aralia nudicaulis-Cornus stolonifera*, which are similar to the *Picea glauca/Rubus pubescens-Maianthemum canadense* type, had mean site indexes of about 24 m. Very few soil-site factors that are significantly correlated with white spruce productivity have been identified. The m.a.i. was negatively correlated with elevation (Corns 1978). The site index increased linearly along a gradient in soil internal drainage (fig. 3).

As was the case for lodgepole pine, a multiple regression analysis for white spruce productivity, which included vegetative cover by individual species, enhanced predictability (Corns 1978). R^2 values increased from 0.53 to 0.86 for m.a.i., and from 0.58 to 0.91 for SI at 70 years. The multiple regression equation predicting m.a.i. and having an R^2 of 0.86 had nine independent variables with five of them being plant cover variables.

PRODUCTIVITY OF OTHER CONIFERS

Site quality aspects of black spruce, jack pine (*Pinus banksiana* Lamb.) and tamarack (*Larix laricina* (Du Roi) K. Koch) have not been extensively studied in the Western Canada Boreal forest region (table 2). Kabzems et al. (1976) in the Mixedwood section within Saskatchewan estimated productivities for these species according to a soil drainage class by community type stratification (table 3). Productivity of black spruce had a considerable range among community types, from an m.a.i. of about 2.3 m^3 $ha^{-1}yr^{-1}$ (*Picea mariana/Pleurozium schreberi-Ptilium crista-castrensis* type) to 0.8 m^3 $ha^{-1}yr^{-1}$ (*Picea mariana/Ledum groenlandicum/Carex* spp. type).

CONCLUSIONS

Stratification of forest lands according to site quality is regarded as a patently essential prerequisite to forest management planning. Forest industry appears to measure forest land productivity by growth and yield of preferred wood products of a defined quality. Any estimation of site quality must therefore be expressed in or closely related to yield of a utilizable wood product and, if possible, to other management concerns.

The number of indigenous tree species present in the Subalpine and Boreal forest regions in Western Canada east of the Rocky Mountains is few. The number of alternative species ecologically adapted to a given site is usually restricted to four or less. For example, the potentially suitable species on a medium-textured, moderately well drained Gray Luvisol site in the Mixedwood section of the Boreal forest region are jack pine, white spruce, black spruce and aspen (*Populus tremuloides* Michx.).

Methods for estimating forest site quality for conifers in Western Canada directly identify or suggest characteristics of site moisture regime and temperature regime as factors controlling productivity. The community type and soil-site evaluation methods have disclosed site factors that can be inferred as direct or indirect controls upon site moisture regime. The method using a soil mapping unit alone seems to provide a stratification by site quality of lesser accuracy than other methods. Perhaps soil mapping units have not been defined to include the appropriate controlling factors of tree productivity or manifestations of these factors. Phasing of a soil taxonomic unit according to mesoclimatic parameters, slope position, aspect, or a parameter related to groundwater flow system may allow improved prediction of forest site quality from a soil mapping unit. Recognition of forest humus form in the soil mapping unit may also aid inferences about site nutrient regime, which is so difficult to quantify for site quality purposes.

A two-way stratification of community type and an appropriately phased soil taxonomic unit is suggested for improvement in the use of landscape units for prediction of site quality. Some site factor-productivity relationships may be inherently expressed by the community type. For example, temperature as a site factor for conifers appears to be neglected in our region, particularly for landscape units near the latitudinal and/or northerly slope extremes for distribution of the species. Community type and edaphic characteristics may be responsive indicators of a temperature factor.

Any substantial increase in the accuracy and precision of an estimate of forest site quality over existing methods probably is dependent upon results from controlled field experiments in our region. Experiments designed to disclose growth and yield-controlling factor relationships are logical as a next step to a functional understanding of factors identified from multivariate statistical analyses common in soil-site evaluations. Presumably, some of the "noise" or "experimental error" sources inherent to current methods of estimation of site quality can be reduced through the experimental approach by manipulation or control of variables such as genotype, stocking level, and spacing on landscape units with some degree of similarity as defined by the current state of knowledge. The extent of valid interpolations and extrapolations for large forest land areas can always be questioned in such an experimental approach. But such results should be applicable to estimates of site quality in artificially regenerated and managed plantations as contrasted with natural conifer stands.

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