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Growth of some pine-spruce stands in the Yukon: a 27 - year record

G.M. Bonnor

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by

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Abstract

Permanent sample plots were established at Watson Lake in 1961 and remeasured in 1978, 1982 and 1987. The plots were located in three types of stands: Stratum RC -- an area cleared of vegetation about 1941 which subsequently regenerated to lodgepole pine (*Pinus contorta* Dougl.); Stratum RS -- an area largely cleared (also about 1941) but containing some residual pine, black spruce (*Picea mariana* (Mill) BSP), and white spruce (*Picea glauca* (Moench) Voss); and Stratum MA -- a mature, undisturbed lodgepole pine-spruce stand. All three strata contained a minor component of hardwoods, mostly trembling aspen (*Populus tremuloides* Michx.). After conversion to metric units in 1978, the plots were 400 m^2 in size. Data from 19 plots in each of strata RC and RS and from 10 plots in stratum MA were available for analysis.

Stratum RC grew from 4 to 72 m^3 ha^{-1} (gross total volume) between 1961 and 1987. Pine comprised the largest component in this stratum (about 80%) throughout the period. Growth rate for the three intervals between measurements was constant at 2.5 m^3 ha^{-1} yr^{-1}. Stratum RS grew from 1 to 49 m^3 ha^{-1} between 1961 and 1987. Pine also comprised the largest component in this stratum but only at 58%; it remained constant at that level throughout the period. The growth rate in stratum RS increased from 1.3 to 2.7 m^3 ha^{-1} yr^{-1}. Stratum MA grew from 174 to 224 m^3 ha^{-1} between 1961 and 1987. Pine again comprised the largest component in this stratum, decreasing slightly from 57 to 51% during the period. Overall growth rate in stratum MA also decreased, from 2.1 to 1.0 m^3 ha^{-1} yr^{-1}. The decrease occurred in pine and white spruce, while black spruce increased in growth.

Résumé

Des parcelles d'échantillonnage permanentes ont été constituées à Watson Lake en 1961 et remesurées en 1978, 1982 et 1987. Les parcelles étaient situées dans trois types de peuplements ; Strats RC - zone mise à nu vers 1941, et repeuplés ultérieurement de pin lodgepole (*Pinus contorta* Dougl.); Strate RS - zone en grande partie mise à nu (également vers 1941), mais conservant une végétation résiduelle de pin, d'épinette noire (*Picea mariana* (Mill) BSP), d'épinette blanche (*Picea glauca* (Moench) Voss); Strate MA - peuplement adulte intact de pin lodgepole et d'épinette. Les trois strates renfermaient toutes un pourcentage mineur de feuillus, principalement des trembles (*Populus tremuloides* Michx). Après conversion en unités métriques en 1978, les parcelles avaient 400 m^2 de superficie. On disposait de données provenant de 19 parcelles dans chacuns des strates RC et RS de 10 parcelles dans la strate MA.

La strate RC est passé de 4 à 72 m^3/ha (volume total brut) entre 1961 et 1987. Tout au long de cette période, le pin représentait la composante la plus importante de cette strate (environ 80 %). Le taux de croissance pour les trois intervalles entre les mesures etait constant : 2.5 m^3/ha/an. La strate RS a progressé de 1 à 49 m^3/ha entre 1961 et 1987. Ici aussi le pin était la composante la plus importante, mais avec 58 % seulement, pourcentage qui est demeuré stable pendant la période. Le taux de croissance dans la strate RS a augmenté de 1.3 à 2.7 m^3/ha/an. La strate MA est passée de 174 à 224 m^3/ha entre 1961 et 1987. Le pin est toujours demeuré la composante la plus importante de la strats, le pourcentage diminuant légèrement, de 57 % à 51 %, pendant cette période. Le taux de croissance global dans la strate MA a également baissé, passant de 2.1 à 1.0 m^3/ha/an. La baisse se situait chez le pin et l'épinette blanche, alors que l'épinette noire accusait une augmentation.

Introduction

In 1961, the Canadian Forestry Service established a set of permanent sample plots near the community of Watson Lake in southeastern Yukon. The plots were remeasured in 1978, 1982 and 1987. The resulting data comprise a unique record and provide a rare opportunity to obtain some well-documented growth information for the Yukon.

The purpose of this report is to describe the work undertaken, including compilation of the data and calculation of volumes and increments, and to present the results.

Description of the area

The plots were established on a 3000-ha parcel of land located between Watson Lake and the Liard River (Figure 1, A and B). The forest is predominantly lodgepole pine (*Pinus contorta* Dougl.), white spruce (*Picea glauca* (Moench) Voss), and black spruce (*Picea mariana* (Mill.) B.S.P.), with minor components of trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and white birch (*Betula papyrifera* Marsh).

Lesser vegetation includes labrador tea (*Ledum* spp.), bearberry (*Arctostaphylos uva-ursi*), and fireweed (*Epilobium angustifolium*). Lichen (*Cladonia* spp.) and mosses (*Dicranum* spp.) are also prevalent.

The land in the vicinity of the plots is flat, with an elevation of about 730 m. The soil is predominantly fluvial sands and gravel over till (Oswald 1976). Site quality is rated 5 in the Canada Land Inventory Land Capability for Forestry map (Senyk 1988); this indicates a productivity of 2.2 to 3.5 m^3 ha^{-1} yr^{-1}. Only 2% of the Yukon Territory, or about one million ha, belongs to this class.

Plot history and measurements

In the early 1940's a small site was cleared, possibly as part of the Alaska Highway construction. The square center area (10 ha, Figure 1C) was totally cleared and slash was removed, while in the square perimeter area (30 ha) some small trees were left standing and slash was left on the ground. No trees were planted: stocking is the result of natural regeneration. The plots (in clusters of five) were located in or near this clearing. Based on their location in relation to the clearing, they were assigned to one of the following three strata:

Stratum RC (regeneration/cleared): Clearcut center area (Figure 1). Four clusters of five plots each were established initially. One plot was subsequently destroyed; 19 remain for analysis.

Stratum RS (regeneration/slash): Partially cut perimeter area (Figure 1). Four clusters of five plots each were also established here and one plot was also destroyed; 19 remain for analysis.

Stratum MA (mature): This comprises the undisturbed, natural forest, approximately 120 years old in 1961 (Figure 1). Two clusters (10 plots) are in this stratum.

In 1961, plot size was 0.1 acre; measurements (in imperial units) were made in each plot as follows:
-all trees were tallied by species and one-inch diameter classes, starting with the one-inch class;
-approximately four dominant and codominant trees were measured for stem diameter at breast height and tree height. Tree age (at stump height) was determined from increment cores;
- a regeneration survey was made;
- information relating to plot location was recorded, and relevant maps and air photos were identified;
- stand and soil characteristics were noted.

In 1978, the plots were converted to metric: plot size was reduced slightly to 400 m^2 (0.04 ha). Also, each tree was tagged and numbered individually. Plot measurements were as follows:
- for each numbered tree: species, crown class, diameter at breast heights of 1.30 m and 1.37 m (= 4.5 ft.); every tree that had reached a height of 1.30 m was tagged and measured;
- approximately 10 dominant and codominant trees, representative of the species present in each plot, were measured for height.

In 1982 and 1987, tagged trees had their diameters remeasured and their status (healthy, dead, or damaged) noted. The trees measured for height in 1978 were remeasured.

In 1988 ingrowth trees, i.e. those that had reached a height of 1.30 m since 1978, were tagged and measured for diameter. These measurements were used to estimate ingrowth trees in 1982 and 1987.

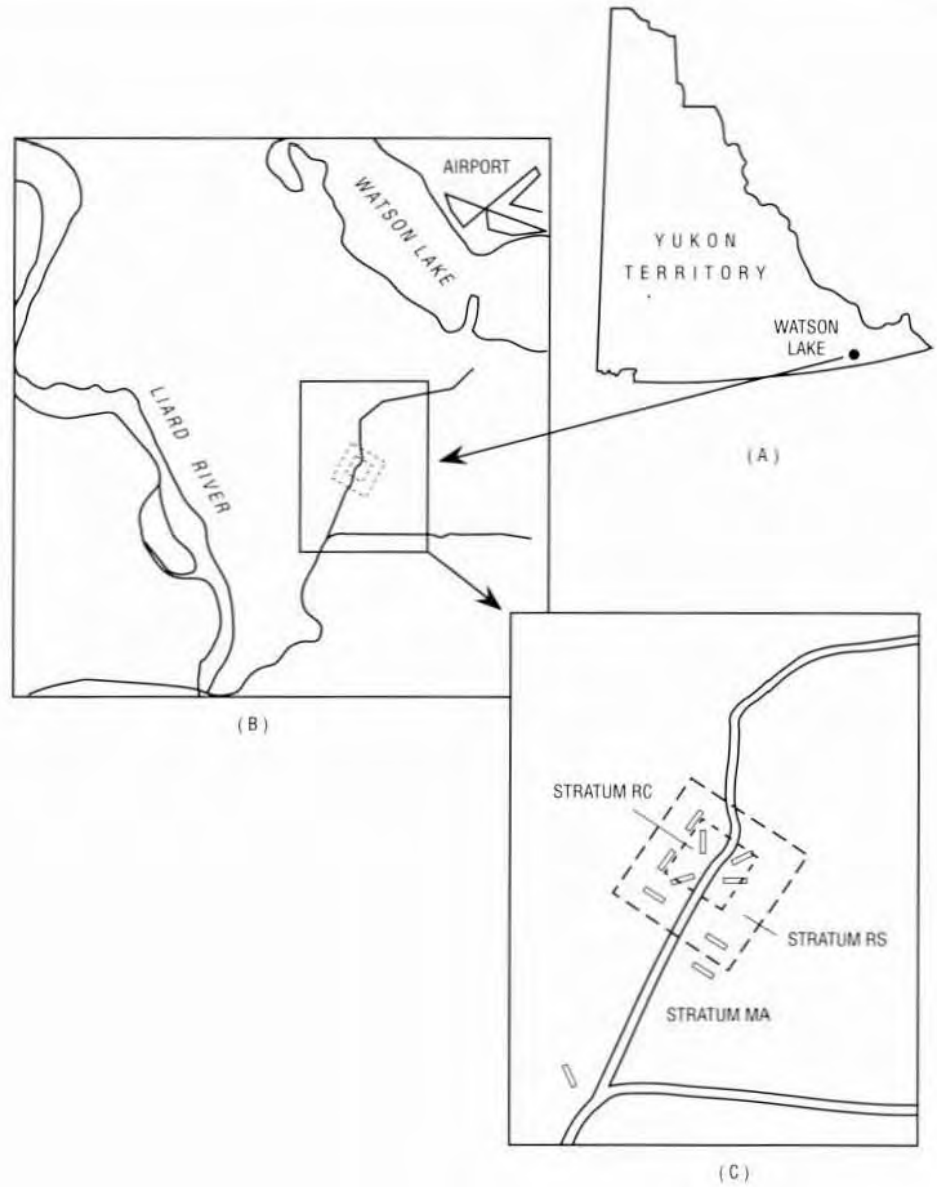

Figure 1. Location of the study area and permanent sample plots.

Compilations

Conversion of the raw data to volume and growth per hectare included the following steps: conversion of the 1961 tree data to metric units; derivation of height-diameter equations and application of equations to trees without height measurements; calculation of tree volumes; calculation of plot volumes and volumes per hectare; and derivation of growth estimates.

Tree height estimation as well as volume and growth calculations were done by the following species groups: lodgepole pine, white spruce, black spruce, and hardwoods.

1. Conversion to metric units

The 1978 diameter measurements were made at both 1.37 and 1.30 m and could therefore be used to convert the 1961 diameters to metric breast height. Equations of the following form were constructed:

$$D_M = a + bD_I$$

where

D_M = stem diameter at metric breast height (1.30 m);

D_I = stem diameter at imperial breast height (1.37 m); and

a,b = regression coefficients (Appendix 1).

Table 1. Basic tree data by stratum, species group and year

Stratum	Species group	Average age (years)	1961 Number of trees per ha*	1961 Average dbh (cm)	1961 Average height (m)	1987 Number of trees per ha*	1987 Average dbh (cm)	1987 Average height (m)
RC	Lodgepole pine		1485	3.6	3.2	2551	7.8	10.4
	White spruce		-	-	-	239	1.1	-
	Black spruce		10	2.7	3.4	470	3.9	-
	Hardwoods		360	3.0	3.4	204	5.4	-
	All	12	1856	3.4	3.3	3464	6.6	10.4
RS	Lodgepole pine		317	2.8	2.8	853	8.6	10.4
	White spruce		109	3.2	3.3	255	3.7	10.2
	Black spruce		178	3.4	2.9	1100	5.7	9.3
	Hardwoods		259	3.2	3.9	487	6.5	-
	All	20	863	3.1	3.1	2694	6.6	10.0
MA	Lodgepole pine		576	18.3	17.6	428	20.6	20.2
	White spruce		37	6.4	-	348	6.7	20.8
	Black spruce		993	10.3	15.6	1200	7.7	18.3
	Hardwoods		267	15.4	-	175	15.9	-
	All	112	1872	13.4	17.6	2151	11.2	19.6

* Figures may not add up due to rounding

These equations were applied to the 1961 (imperial) diameters to derive the metric equivalents.

2. Height-diameter relationships

All trees which had heights (and diameters) measured over the years were used to derive the height-diameter equations. Several different models were tested. The models finally selected were:

for lodgepole pine: $H = a + bD + cD^2$

for other species : $H = aD^b$

where

H = tree height (m);

D = stem diameter at breast height (cm); and

a,b,c = regression coefficients (Appendix 2).

Using these equations, a height was estimated for each tree.

3. Volume calculations

The volume equations and coefficients given by Bonnor and Oswald (1988) and listed in Appendix 3 were used to calculate gross total and gross merchantable tree volumes. The individual tree volumes thus calculated were summarized by species group and year within each plot. These summaries were used to derive volumes per hectare (using appropriate conversion factors) by stratum, plot, species group and year (Appendix 4). Volume growth data (in m^3 ha^{-1} yr^{-1}) were obtained from the above list by dividing volume differentials for each measurement period by the number of growing seasons in that period.

Results

The average age of trees in 1961 (Table 1) was 12 years in stratum RC, 20 years in stratum RS, and 112 years in stratum MA. The difference between RC and RS is to be expected: some trees were left standing in RS after the clearing operation in the early 1940's, resulting in the higher average age. This is supported by standard deviations which are 1.6 and 14.1 for RC and RS, respectively, indicating a much higher spread of ages in stratum RS.

The number of trees per hectare in stratum RC was quite high in 1961, attesting to the influx of regeneration - largely lodgepole pine - on this cleared land. In comparison, stratum RS started out with a smaller number of trees per hectare, and contained fewer lodgepole pine and more spruce. By 1987, stem frequencies of both strata had increased significantly but the initial differences in stem frequency and species composition of the conifers persisted. The hardwood component, on the other hand, decreased in stratum RC and increased in stratum RS during the 1961-87 period. While the differences in tree size

between the two strata were not large, trees in stratum RS grew faster in diameter than those in stratum RC, largely due to better growth of the pines.

Stratum MA, comprising a mature undisturbed forest, showed little change in terms of stem frequency and diameter growth. The spruces were more numerous while the pines were larger. The hardwoods formed a small but significant component both in 1961 and in 1987.

Strata RC and RS, which started with virtually no measurable volume in 1961, showed steadily increasing volumes in the years 1978, 1982 and 1987 (Table 2; Figures 2 and 3). It is noteworthy, however, that the volume (gross total) of stratum RC was higher by 23 m^3 ha^{-1} in 1978, and that this difference - due to higher pine volumes - persisted through 1987. Stratum MA started with a relatively high volume which was mostly pine. The subsequent increase through 1987 was, however, largely due to an increase in the white spruce volume (Figure 3), which again reflects an increased stem count (Table 1). Gross merchantable volumes were, as expected, somewhat lower than the gross total volumes; as the trees increased in size and more of the stem became merchantable, the percentage difference decreased.

Volume increments (Table 3) were derived from the volume data using standard procedures: the difference in volume between the beginning and end of each measurement interval was divided by the number of growing seasons in each interval. In Figure 4, these increment data are plotted over the age of the stratum at the midpoint of the interval.

The volume (gross total) increment data show that stratum RC had a higher initial growth than stratum RS, and that this was due to better growth of the pine. The presence of residual, possibly suppressed and slow growing trees in stratum RS may also have contributed to this difference. This accounts, of course, for the higher volume in stratum RC noted previously. However, from 1978 the growth of both pine and black spruce in stratum RS increased to the extent that the growth of the two strata was equal, and by the last period the growth in stratum RS exceeded that of stratum RC.

Growth in stratum MA was over 2 m^3 ha^{-1} yr^{-1} during the first interval but declined in each of the next two (Figure 4). The decline can be traced to declines in the growth of both pine and white spruce (Table 3), although the latter maintains the best overall growth of all the species. Black spruce growth appears to have increased between 1961 and 1987.

Hardwoods are present as a minor component in all strata. In terms of both volume and volume increment they form the largest proportion in stratum RS where in 1987 they comprised 15% of the gross

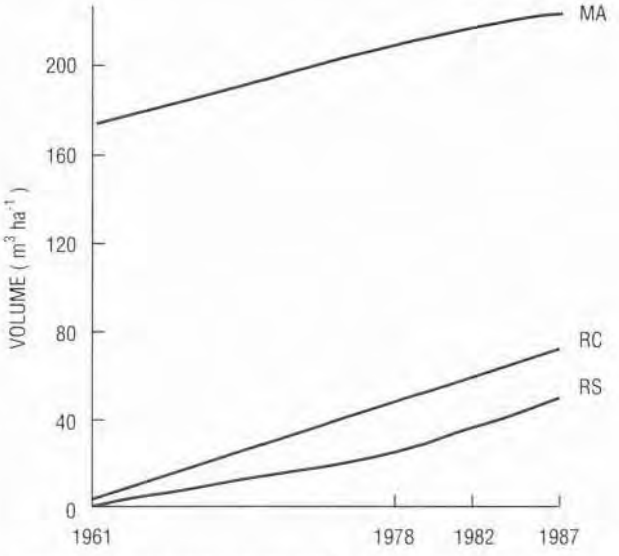

Figure 2. Gross total volume (m^3 ha^{-1}) by stratum and year.

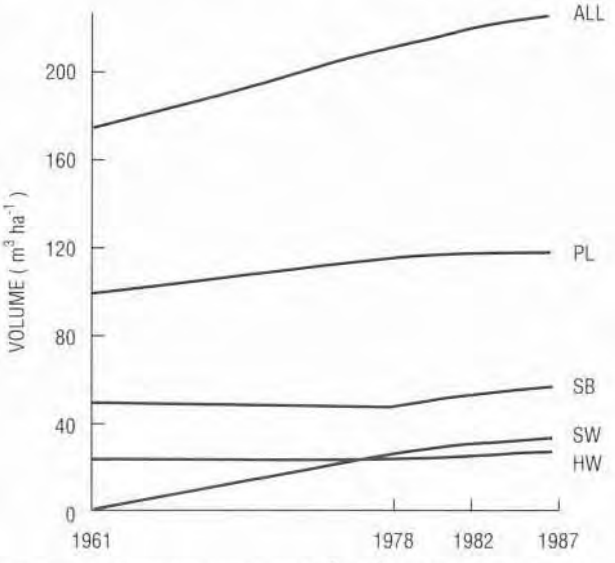

Figure 3. Gross total volume (m^3 ha^{-1}) in the MA (mature) stratum by species group and year.

total volume and 17% of the increment. Of the three species, only two had measurable volumes: white birch comprised 20% of the hardwoods by volume, and trembling aspen comprised 80%.

Discussion and conclusions

As previously noted, a series of height-diameter equation models were tested, including first, second and third degree polynomials as well as exponential equations. None emerged as superior for all species. In plotting the residuals (estimated minus actual height), a pattern related to the year of measurement became apparent. However, when year of measurement was included as an independent variable, the results did not

Table 2. Total and merchantable volume (m^3 ha^{-1})* by stratum, species group and year

Stratum	Species group	1961		1978		1982		1987	
		Total	Merchantable	Total	Merchantable	Total	Merchantable	Total	Merchantable
RC	Lodgepole pine	3	-	45	23	56	33	67	44
	White spruce	-	-	-	-	-	-	-	-
	Black spruce	-	-	1	-	1	-	2	-
	Hardwoods	-	-	2	1	2	1	2	1
	All	4	-	47	23	59	33	72	45
RS	Lodgepole pine	-	-	14	7	21	13	28	20
	White spruce	-	-	1	-	1	1	2	1
	Black spruce	-	-	5	1	8	3	12	6
	Hardwoods	1	-	4	1	6	2	7	4
	All	1	-	24	9	36	19	49	30
MA	Lodgepole pine	99	90	115	106	116	107	115	106
	White spruce	1	1	25	22	28	24	30	26
	Black spruce	50	42	47	38	51	42	54	46
	Hardwoods	24	19	22	19	23	20	24	20
	All	174	151	210	185	218	193	224	199

* Figures may not add up due to rounding

Table 3. Total and merchantable volume increment (m^3 ha^{-1} yr^{-1})* by stratum, species group and period

Stratum	Species group	Period							
		1961-78	1978-82	1982-87	1961-87	1961-78	1978-82	1982-87	1961-87
		Total volume				Merchantable volume			
RC	Lodgepole pine	2.4	2.3	2.3	2.4	1.3	2.0	2.2	1.6
	White spruce	-	-	-	-	-	-	-	-
	Black spruce	-	-	0.1	-	-	-	-	-
	Hardwoods	0.1	0.2	0.1	0.1	-	-	-	-
	All	2.5	2.5	2.5	2.5	1.4	2.0	2.2	1.6
RS	Lodgepole pine	0.8	1.4	1.4	1.0	0.4	1.2	1.3	0.7
	White spruce	-	0.1	0.1	-	-	-	-	-
	Black spruce	0.3	0.7	0.8	0.4	0.1	0.4	0.5	0.2
	Hardwoods	0.2	0.3	0.4	0.3	0.1	0.2	0.3	0.1
	All	1.3	2.5	2.7	1.8	0.6	1.8	2.2	1.1
MA	Lodgepole pine	1.0	0.2	-0.2	0.6	0.9	0.2	-0.1	0.6
	White spruce	1.4	0.6	0.5	1.0	1.2	0.5	0.4	0.9
	Black spruce	-0.2	0.8	0.6	0.2	-0.2	0.8	0.6	0.1
	Hardwoods	-0.1	0.3	0.2	0.0	-	0.1	0.1	0.1
	All	2.1	1.8	1.0	1.8	2.0	1.7	1.0	1.8

* Figures may not add up due to rounding

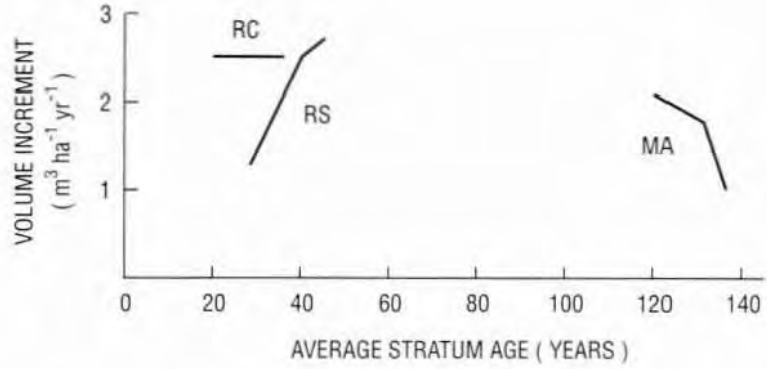

Figure 4. Gross total volume increment (m^3 ha^{-1} yr^{-1}) of each stratum by average stand age.

improve. The reduced height-diameter correlation can be attributed in part to die-back of a small number of trees between 1982 and 1987. Thus, while the estimation of individual tree heights was not as precise as desired, the primary results (stand volume and stand volume increment) were not significantly affected.

The basic plot data behaved as expected except that the average diameter of black spruce in stratum MA decreased between 1961 and 1987, while average height increased (Table 1). The decrease in diameter is due to ingrowth of many small trees in one plot. The simultaneous increase in height can be attributed to the fact that only some trees, and only those measured in previous years, were measured for height.

The scarcity of growth and yield data from the Yukon makes it important to extract as much information as possible from the existing data set. At the same time, the data are very limited in terms of geographic extent, variety of forest types, and statistical design. It is therefore not possible to make any extrapolations from the results. However, they do provide the basis for the following tentative conclusions applicable to this particular forest type.

1)Regeneration of lodgepole pine is promoted by the removal of other vegetation. The basis for this statement is a comparison of the growth records of strata RC and RS: in stratum RC, all vegetation is removed, and pine regenerates as - and remains - the dominant species; in stratum RS, a residual stand including spruce remains mixed pine-spruce, with a minor component of hardwoods. Considering the serotinous nature of lodgepole pine, this is not surprising.

2) Pine grows faster than spruce at an early age, and growth culminates sooner. Rotation age (culmination of MAI, extrapolated from Figure 4 and Table 3) for pine appears to be about 80 years, and for spruce about 110 years.

3) Pure pine stands grow faster than mixed pine-spruce stands up to about 40 years, and slower thereafter. The current data are insufficient to determine if total volume accumulation differs.

Perhaps more important than these tentative conclusions is the availability, for the first time, of some well documented growth data for the Yukon. Many more such data sets are necessary for growth projections and allowable annual cut calculations.

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Appendix 1.

Equations for converting imperial dbh to metric dbh

Equation model:

$D_M = a + bD_I$

where

D_M = stem diameter at metric breast height (1.30 m);
D_I = stem diameter at imperial breast height (1.37 m); and
a,b = regression coefficients:

Species group	Coefficients		N	R^2
	a	*b*		
Lodgepole pine	0.034	0.999	3060	0.998
White spruce	0.136	0.972	285	0.968
Black spruce	0.062	1.000	1591	0.998
Hardwoods	0.038	1.002	703	0.999

Appendix 2.

Height-diameter equations and coefficients

Equation models:

for lodgepole pine: $H = a + bD + cD^2$

for other species : $H = aD^b$

where

H = tree height (m);
D = stem diameter at breast height (cm); and
a,b,c = regression coefficients:

Species group	Coefficients			N	R^2
	a	*b*	*c*		
Lodgepole pine	1.432	0.551	0.00643	1212	0.849
White spruce	0.911	0.974		68	0.972
Black spruce	0.985	0.928		353	0.900
Hardwoods	1.566	0.709		31	0.910

Appendix 3.

Tree volume equations and coefficients

1. Gross total volume

Equation model:
$TV = aD^bH^c$

where
TV = gross total volume (m^3);
D = stem diameter (cm);
H = tree height (m); and
a,b,c = regression coefficients:

Species group	Coefficients		
	a	b	c
Lodgepole pine	0.0000515	1.95239	0.91923
White spruce	0.0000433	1.77531	1.10980
Black spruce	0.0000429	1.82290	1.07309
Hardwoods	0.0000392	1.88989	1.04839

2. Gross merchantable volume

Equation model:

$MV = TV\ (r_1 + r_2X + r_3X^2)$

where

MV = gross merchantable volume (in m^3);
$X = t^2D^{-2}\ (1 - 0.04356b)^{-2}\ (1 + S/H)$
with t = top diameter inside bark = 8 cm
S = stump height = 0.3m and
b = coefficient; and r_1, r_2, r_3 = coefficients:

Species group	Coefficients			
	r_1	r_2	r_3	b
Lodgepole pine	0.9568	-0.1278	-0.8108	0.118
White spruce	0.9611	-0.2456	-0.6801	0.176
Black spruce	0.9526	-0.1027	-0.8199	0.164
Hardwoods	0.9057	-0.0708	-0.8375	0.145

Appendix 4.

Sample plot volumes (Gross total volume in m^3 ha^{-1})

Stratum	Plot no.	Year			
		1961	1978	1982	1987
RC	1	4.4	53.0	66.0	78.0
	2	4.7	49.1	63.1	74.1
	3	7.9	62.4	76.0	85.5
	4	6.4	72.5	88.2	99.8
	5	5.9	74.3	89.5	101.2
	7	1.5	20.2	27.0	35.0
	8	1.1	26.9	35.2	46.0
	9	3.4	41.6	53.2	67.8
	10	5.0	56.9	69.7	88.4
	11	1.0	20.5	28.1	37.2
	12	2.6	47.8	63.4	79.0
	13	3.4	39.4	49.6	59.6
	14	4.6	46.2	56.4	69.3
	15	2.8	34.6	44.8	56.4
	16	2.7	47.2	63.6	81.3
	17	2.9	31.7	40.4	47.3
	18	3.6	47.9	60.0	75.0
	19	5.6	65.7	83.7	101.0
	20	2.9	50.1	65.4	79.0
RS	1	0.4	13.1	22.6	34.4
	2	0.8	12.2	21.0	31.6
	3	1.4	25.1	38.4	53.2
	4	1.2	21.0	33.4	48.5
	5	0.7	13.6	22.2	32.1
	6	1.2	20.7	31.7	41.2
	7	0.8	28.8	43.8	59.9
	8	2.2	33.7	50.1	68.6
	9	2.3	35.8	53.6	73.4
	10	2.8	46.0	63.0	80.1
	11	0.6	12.7	20.0	28.8
	12	1.3	27.2	39.2	53.9
	14	0.4	13.3	22.4	33.3
	15	0.4	10.7	18.1	28.0
	16	0.8	19.9	32.9	46.6
	17	0.3	16.1	26.5	37.8
	18	0.8	19.2	30.8	43.7
	19	4.5	56.1	76.2	95.2
	20	1.3	23.4	36.7	49.2
MA	16	117.1	177.1	185.1	198.7
	17	192.8	222.5	214.5	220.1
	18	177.2	217.0	232.8	233.3
	19	164.7	215.0	226.7	239.7
	20	183.8	221.6	227.9	240.3
	57	190.3	235.8	263.0	259.7
	58	202.7	218.5	217.4	216.6
	59	156.3	164.7	172.0	178.0
	60	127.3	157.4	167.5	176.4
	61	230.2	267.8	278.9	273.0