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NATURAL REGENERATION OF WHITE SPRUCE FOLLOWING HARVESTING OF ALLUVIAL FLOODPLAINS IN THE LIARD RIVER DRAINAGE, YUKON

BY

© A.C. GARDNER

A THESIS
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MASTER OF SCIENCE

1986

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ...NATURAL.REGENERATION.OF.WHITE.SPRUCE.FOLLOWING.HARVESTING.ON.ALLUVIAL.FLOODPLAINS.IN.THE.LIARD.RIVER.......DRAINAGE,.YUKON..

submitted by ......A.C..GARDNER...

in partial fulfilment of the requirements for the degree of Master of Science.

....

Supervisor

Richard L Rothwell

D. Pluth

....

Date January 29, 1986

ABSTRACT

A dearth of information relating to natural restocking of white spruce (Picea glauca (Moench) Voss.) on alluvial floodplains of the Liard River drainage in the southeast Yukon following harvesting, prompted the establishment of a study utilizing large-scale aerial photography to assess 104 cutovers rapidly for regeneration status.

Linear relationships between: i) photo-stocking and ground stocking, ii) ground stocking and cutover age, iii) age of regeneration and age of cutover, iv) height and age of ingress were determined. Large-scale aerial photography proved to be rapid and efficient although shadowing resulting from inferior light conditions and residual vegetation limited detection effectiveness. Natural regeneration over 25 years following harvesting produced densities approaching 2500 stems per hectare but a maximum estimated stocking of only 60 percent, based on $10m^2$ quadrats, indicating inadequate site occupancy.

The results indicate that stocking levels obtained on floodplain cutovers in the southeast Yukon are not related strongly to cutover age but may be limited by a lack of well-distributed, receptive seedbeds immediately following harvest.

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1. INTRODUCTION

Forest lands capable of sustaining commercial timber production in the south-east Yukon are largely confined to alluvial floodplains of the Liard and Hyland rivers and their tributaries.

These forests have been subjected to commercial harvesting operations for the past 30 to 35 years. Nyland (1977) documented that over this time period no effort was expended on artificial regeneration or on determining to what extent natural processes have restocked these areas to white spruce (*Picea glauca* (Moench) Voss), the prime commercial species.

Application of large-scale aerial photography (LSP) can be useful in determining conifer stocking of cutover-lands (Haapala and Neumann 1972; Ball and Kolabinski 1979; Kirby 1980; Hall 1984a). Colour imagery of scale 1:500 can be used to detect conifer seedlings 60 cm in height and larger permitting the determination of stocking to minimum standards. Photographic systems are air-based, thus minimizing access problems, and Morgan (1982) demonstrated substantial cost-savings (approximately 89% on a per-plot basis) of LSP systems over conventional ground survey procedures when the technique was applied to timber inventory surveys in the Yukon. The expediency of these systems coupled with the availability of a tested system at the Canadian Forestry Service, Northern Forest Research Centre (Edmonton, Alberta) (Kirby 1980) suggested that utilization of LSP would be an appropriate procedure for determining regeneration status of cutover lands in the Yukon.

In addition to generating data on current total stocking, the existence of a series of cutovers covering a known age range permitted an examination of stocking levels over time. This afforded the opportunity to determine if stocking levels could be expected to increase in direct relation to age of cutovers. The nature of the relationship of stocking levels to time has important implications with respect to management strategies in that it may show that site treatments are required to secure regeneration or that simply a passage of time will result in full restocking.

2. OBJECTIVES

The first objective of this study was to estimate white spruce regeneration stocking on alluvial floodplains of the Liard River and its tributaries using large-scale aerial photographs. To achieve this, an estimate of the correlation between photo-visible stocking and actual ground-stocking was derived. The estimation of this relationship was accomplished by testing the following null hypothesis:

> White spruce regeneration stocking estimated by large scale aerial photographic techniques is not related to actual ground-stocking.

The second objective of the study was to determine the correlation of estimated ground-stocking with cutover age. The null hypothesis tested was:

> Percent stocking of white spruce regeneration on cutover lands in the Liard River drainage is not correlated with cutover age.

The applicable alternative hypotheses are that definable relationships do exist between elements - that the regression analysis to be used in evaluation of these relationships will produce equations with slopes greater than zero. Simply determining that relationships exist is inadequate for practical purposes. A subjective evaluation of the relative strength of the relationships is necessary to support conclusions.

Six ancillary objectives were also identified. These included: i) evaluation of the cost-effectiveness of the double sampling procedure used to derive the photo-stocking/ground-stocking correlation, ii) determination of photo detection percentages, by height class, of seedlings recorded on ground-truthing plots; iii) determination and presentation of current ground-stocking data by age class of cutover; iv) derivation of the estimated number of white spruce stems on a per hectare basis; v) estimation of the correlation of seedling age and cutover age; and vi) estimation of the total height-total age relationship of the general regeneration seedling population.

3. STUDY AREA LOCATION AND DESCRIPTION

3.1 Location, Climate and Soils

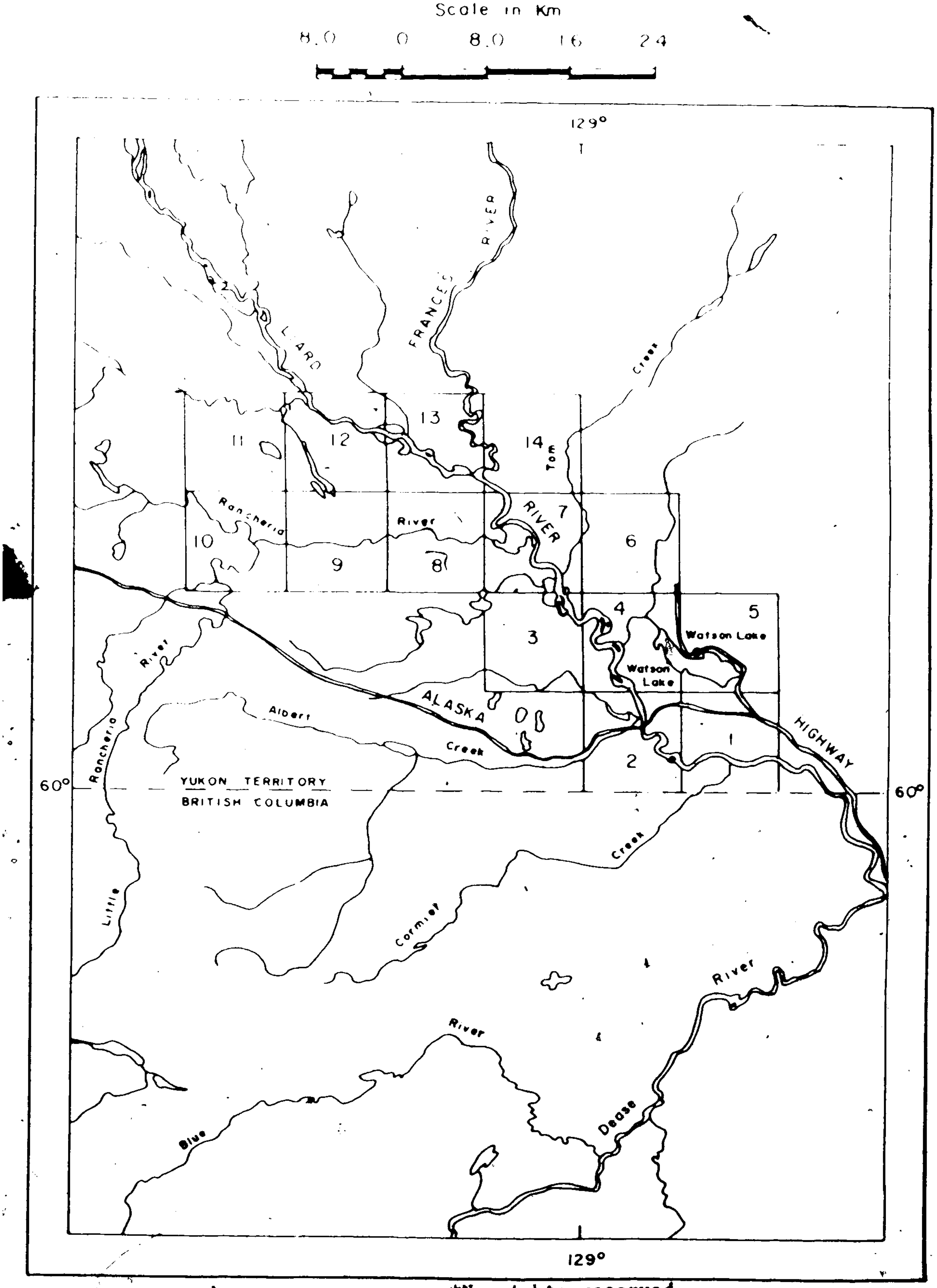
Cutovers assessed for stocking were confined to floodplains of the Liard River and it's major tributaries, the Meister and Rancheria Rivers and Albert Creek. The area is in the south-east Yukon adjacent to the British Columbia and Northwest Territories borders and bounded approxiamtely by 60°20'N x 129°35'W (Fig. 1). The area lies within the B.24 section of the boreal forest (Rowe 1972) and the Liard River ecoregion as classified by Oswald and Senyk (1977).

The south-eastern Yukon lies within the subartic climatic zone and is characterized by long, cold winters and short warm summers (Hirvonen 1968). The mean annual temperature is below freezing (-3°C) while the mean May-September temperature is 11.0°C (Rowe 1972). Rowe (1972) reports a growing season length of approximately 140 days while Hirvonen (1968) suggests the frost-free period may not exceed 60 days.

With an annual precipitation of 450 mm, the climate is classified as moist, subhumid indicating a small surplus for the year (Rowe 1972). July, August and September are often the wettest months and Oswald and Senyk (1977) reported that about 34% of the annual precipitation falls from June to August.

Merchantable white spruce stands, within the study area, are most commonly located on alluvial deposits such as point bars and low terraces adjacent to the rivers. Soils are generally cumulic ~~regosols~~ (Jeffery 1964) with orthic, dystric brunisols and orthic regosols as minor associates. Cumulic regosols are well to imperfectly

Fig. 1 Location of study area (from Hirvonen 1968)* Cutovers surveyed were located in all delineated squares with the exception of Nos. 5 and 6



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drained mineral soils consisting of well stratified sands, silts and gravels (Lavkulich 1973) underlain by calcareous parent materials (Day 1972). Textures range from silt loam in the upper C horizons to sandy loam or sand in underlying layers. Soil analysis conducted at the Pacific Forest Research Centre indicated upper horizons (0-30 cm depth) ranged from very acidic (pH 3.7) to mildly acidic (pH 6.6). Elevations of floodplains in the region vary from 180 to 200 m above sea level (Oswald and Senyk 1977).

3.2 Forest Species Composition and Succession

Ecological investigations of alluvial floodplains in northern Canada have been conducted in considerable detail by Raup (1934), Lacate *et al*. (1958), Jeffery (1964), Wagg (1964) and Rostad *et al* (1976).

Floodplain sites of the type examined in this study are typically occupied by stands of pure white spruce or spruce in mixture with balsam poplar (*Populus balsamifera* L.). Jeffery (1964) observed a five-layered canopy in these stands on alluvial sties on the lower Liard River, which was substantiated by Wagg (1964) in northern Alberta and Rostad (1976) in the Northwest Territories. Essentially, a treed overstory is underlain by tall shrub (underwood), shrub, herb and bryophyte layers in descending order.

In the tree layer, balsam poplar is dominant or codominant with white spruce up to a stand age of about 100 years with white spruce assuming dominance thereafter (Zasada 1982). Black spruce (*Picea mariana* (Mill.) B.S.P.) and tamarack (*Larix laricina* (Du Roi) Koch) are not common associates in this area but may be present on older floodplain sites. White birch (*Betula papyrifera* Marsh.) is present on some sites and usually restricted to the underwood layer.

In the underwood or tall shrub layer, thin-leaf alder (*Alnus incana* (L.) Moench.) dominates while white spruce, balsam poplar and paper birch contribute in minor ways to stocking. Of these tree species, white spruce is more frequent, particularly in older stands.

Dominant species in the shrub layer include red-osier dogwood (*Cornus stolonifera* Michx.), high-bush cranberry (*Viburnum edule* (Michx.) Raf.), rose (*Rosa acicularis* Lindl.), buffalo berry, (*Shepherdia canadensis* (L.) Nutt.) and gooseberry (*Ribes oxyacanthoides* L.).

Herbaceous forbs common to this forest type include horsetail (*Equisetum pratense* Ehrh.), dwarf raspberry (*Rubus pubescens* Raf.), miterwort (*Mitella nuda* L.), bedstraw (*Galium boreale* L.), and *Pyrola* spp., bunchberry (*Cornus canadensis* L.), twin flower (*Linnaea borealis* L.) and bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) constitute minor associates.

White spruce forests on floodplains have a dense bryophytic layer represented chiefly by *Hylocomium splendens* (Hedw.) B.S.G., *Pleurozium schreberi* (Brid.) Mitt., *Peltigera aphthosa* (L.) Willd, and *Ptilium crista-castrensis* Hedw. (Jeffery 1964).

The basic primary successional pattern on alluvial soils from *Alnus* to *Salix* to *Populus* to *Picea* was described by Raup (1946) and has been supported essentially by Lacate *et al*. (1958)., Jeffery (1961), Wagg (1964), Viereck (1970), Nanson and Beach (1978) and Van Cleve *et al*. (1980). Table 1 summarizes primary succession on alluvial soils and represents a composite of information from Jeffery (1961) and Van Cleve *et al*. (1980).

Table 1 Summary of primary succession on alluvial soils of the northern Boreal forest (Jeffery 1961, Van Cleve et al 1980)

Stage	Years from Initial Deposition of Mineral Soil	Overstory		Dominant Understory		
		Dominant	Subdominant	Shrub	Forb	Moss
I	0-1			Bare mineral surface		
II	1-2			Mineral surface- salt crust		
III				Salix	-	-
IV	2-5			Salix-Alnus	-	
V	5-10			Alnus-Equisetum		-
VI	20-40	Populus	-	Alnus-Equisetum		-
VII	80-100	Populus	-	Alnus-Equisetum	-	Hylocomium
VIII	200-300	Picea	-	Alnus-Equisetum -		Hylocomium- Pleurozium

3.3 White Spruce Seed Production, Dispersal and Seedbed Requirements

Substantial seed production, in natural stands in the north, likely does not begin until about age 40 in white spruce (Zasada 1971). Heavy seed crops are periodic, the normal interval being 1 to 6 years (Anon. 1965) and ranging upwards to possibly 10-14 years (Zasada and Viereck (1970). Crops during intervening years may be light to non-existent. Seed production in a good year is approximately 8,000 cones per tree, yielding 184,000 to 250,000 viable seeds (Anon. 1965; Nienstaedt and Zasada 1981).

Although some seed may be dispersed year-round, seed fall generally begins in August or early September with the majority of seed falling during September through November (Ganns 1977). Zasada (1971) observed the onset of seed dispersal as early as August 19 during a warm, dry year and as late as September 5 during a cool, moist year. Wind is the primary agent of seed dispersal and dispersal distances generally approximate two tree heights (40-60m) (Ganns 1977, Nienstaedt and Zasada 1981).

Seed fall can range between 290 - 440 seeds per square meter of forest flood per year in good seed years. In average to less than average years, seed fall may be 10 - 18 seeds/m^2/y (Nienstaedt and Zasada 1981, Waldron 1965).

Determination of seedbed characteristics suitable for the establishment of spruce following disturbance was the subject of numerous investigations in northern Boreal and Subalpine forests (Day 1963; Eis 1965; Ganns 1977; Hughes 1967; Place 1955; Wagg 1964; Zasada and Grigal 1978).

There is general agreement that natural regeneration of spruce consists of three distinct phases: germination of the seed, initial survival of the germinant, and a juvenile stage of indeterminate length during which the seedling establishes itself and begins to thrive on the site (Arnott 1973; Baker 1950). Seedbed characteristics are critical to seedling success, particularly in stages one and three. Success in stage three combines site and seedling capability with environmental conditions, particularly weather.

At the germinative stage, moisture is the single most important factor controlling success (Arnott 1973; Baker 1950; Day 1963; Eis 1965). Observations by Wagg (1964) and Zasada (1971) indicate that, for northern spruce forests, mineral soil, by virtue of its superior moisture retention (Day 1963), provides the best seedbed for germination in open areas.

Other common seedbeds in boreal forests include litter-duff-humus complex, mosses and rotten wood. Litter and duff and humus are generally poor seedbeds in open areas because of poor moisture retention and a tendency to dry and overheat quickly especially when exposed to direct sunlight (Arnott 1973). Mosses are considered good seedbeds for germination due to high moisture content but certain, fast growing mosses, particularly sphagna, can engulf seedlings. However, mosses also dry out very quickly when exposed to direct sunlight. Rotten wood is a common seedbed in spruce forests on alluvial sites in northern Alberta. Wagg (1964) found that it was the only alternative to mineral soil under undisturbed forest conditions. It has excellent water retention and thermal conductivity and permits good root growth (Day 1963). Place (1955) cautions that upon decomposition and disintegration, rotten wood tends to assume similar characteristics to ordinary humus and dries quickly when exposed to direct sunlight. Burned surfaces following wildfires have detrimental effects on germination and tend to heat up too much during dry weather (Place 1955).

Observations from this study and Wagg (1964) indicate that organic seedbeds ranging from undisturbed moss to litter-duff-humus layers are the most common seedbeds following logging on northern alluvial sites. Most harvesting is conducted during the winter on snow with the result that there is very little disturbance of the organic layer. Wagg 1964) reported less than 10 percent mineral soil exposure following logging on floodplains in northern Alberta - all of it confined to skid trails and roads. General field observations by the author suggested similar conditions were prevalent within the study area.

4. METHODS

Application of the aerial photographic system developed by the Northern Forest Research Centre for regeneration surveying was conducted utilizing procedures described by Kirby (1980) and Hall (1984a). The camera system was mounted on a Bell 206B helicopter. Photos were taken in early May 1980 when herbaceous vegetation had not begun to grow, deciduous vegetation had not flushed and snow had melted recently. Actual flying time was 2.5 hours May 4, 1980 (1400-1630) and 3.0 hours May 5, 1980 (1030-1330) for a total of 5.5 hours. Aircraft altitude was maintained as closely as possible to 183m (600 ft.) a.s.l. which produced colour photography at a scale of 1:500. This scale was chosen as it represented a workable compromise between desired photo resolution and amount of film budgeted for the project. Photographed cutovers were located over a total area of approximately 1300 km^2.

The camera system has been used for regeneration surveys since 1973 (Kirby 1980). The system consisted of two 70 mm Vinten reconnaissance cameras, and a radar altimeter fitted to a modified A-11-A mount bolted to the U-bracket of the helicopter.

One 70 mm camera had a built-in secondary optical system which permitted the altimeter reading and time of exposure to be recorded on each frame of the film. This camera was fitted with a 281.9 mm lens, supplied with Kodak Aerocolour (2445) negative film and produced the 1:500 colour imagery in stereo triplets. The other camera (type 518) was fitted with a 77.45 mm lens, supplied with Kodak Aerochrome infrared film (2443) and produced continuous 1:2000 scale colour infrared imagery used for tracking. An intervalometer (Van

Eck and Bihuniak 1978) controlled the cycling rates of the cameras. Aircraft altitude was recorded on each colour exposure by a Honeywell radar altimeter.

Prior to obtaining the photography, all cutovers were mapped onto 1:50,000 U.T.M. maps, with the aid of 1:15,840 aerial photography and records supplied by the Yukon Lands and Forests Service. Following mapping, flight lines were located and drawn on the U.T.M. maps which were used as navigational aids during flying. The exposed films were processed and printed at the National Air Photo Library in Ottawa, Ontario and returned to the Pacific Forest Research Centre for annotation and documentation.

Annotation and documentation involved assigning a number to each frame of colour and infrared photography. Each photo-plot identified on the colour film was also identified on the infrared tracking film and cross-referenced by the numbers on each film type. The smaller scale tracking photography, which was continuous over a given cutover, generally contained reference points (eg. river bank, skid trail, lands, etc.) which facilitated location of the field plots.

A relationship between conifer-stocking on the photographs and actual ground-stocking was established to allow estimates of stocking directly from the photographs. The procedure used was double sampling with regression (Shiue and John 1962; Cochran 1977) which involved obtaining a large primary sample (all photo-plots) from which a smaller regeneration stocking was measured on the photographs and the ground. Photo-stocking estimates were then regressed on ground-stocking estimates and the derived equation used to calibrate photo-acquired stocking estimates.

To maintain the inherent efficiency of double sampling, a cluster sampling design was employed. A cluster sample is a form of simple random sample whereby each sampling unit is a cluster of elements (Freese 1974). In this study, sampling units were the plots (photo and ground) and elements were the quadrats used for stocking estimation (photo and ground). The quadrats measured $10m^2$ on the ground and 39.9 mm^2 on the photos. Quadrats were arranged in a 5 x 5 grid to form the clustered sampling units. The size of a cluster (ie. number of elements) was largely dictated by the photographic scale (Hall 1984b). At a scale of 1:500 a cluster, a designed, fitted well onto the contact prints.

A quadrat was considered stocked (both on the photo and the ground) if one conifer was recorded within the quadrat boundaries.

To obtain ground-stocking data for the photo/ground stocking regression, a number of photo-plots were selected from the total photo sample and paired with ground plots established in the field. The number of photo-plots in the secondary sample was determined by using optimum allocation with respect to cost (Cochran 1977). The method requires cost figures for photo and ground plots and an estimate of the correlation coefficient (r) between photo- and ground-stocking (Hall 1984a). Based on previous work with this system (Kirby 1980), an r value of 0.90 was assumed (for identical plot and quadrat sizes and similar tree sizes).

The formula for allocation with respect to cost (detailed in Appendix I) indicated that 51 ground samples were required. Time and resources permitted 49 ground plots to be sampled.

Once the number of ground plots had been determined all cutovers which had been photo-surveyed were stratified by 5-year classes and the ground plots were distributed proportionately by age classes (Table 2).

Table 2. Distribution of ground sample [illegible] [illegible] cutover age classes.

Age class of cutovers surveyed	No. of cutovers surveyed per age class		No. of ground plots located within cutover age class	
1 (0-5 yrs)	46	[illegible]	[illegible]	47
2 (6-10 yrs)	12	[illegible]	10	20
3 (11-15 yrs)	15	[illegible]	9	18
4 (16-20 yrs)	14	[illegible]	4	8
5 (21-25 yrs)	17	[illegible]	3	7
Total	104	100	49	100%

Once a photo-plot was selected, a transparent grid was placed on the photo and arranged such that a baseline could be located between two clearly visible tie points such as stumps or log ends. Baselines were permanently located on each photo-plot.

In the field, 1:15,840 scale aerial photography along with 1:2000 colour infrared tracking photography were used to located the ground sample plots. The grid, delineating the 5 x 5 cluster of quadrats, was assembled on the ground with butcher's twine at each location to represent an approximate duplicate of the transparent grid on the photograph. A separate tally sheet was filled out for each quadrat and contained the following information: a map of all white spruce seedlings present on the quadrat with a height class recorded for each seedling (there were 5 height classes identified: 1) 0-30 cm; 2) 31-60 cm; 3) 61-90 cm; 4) 91-120 cm; 5) 121-150 cm a visual rating of the percent cover of vegetation competition plus a visual estimate of percent slash cover and percent mineral soil exposure.

Following field sampling, all photos, including those which had been used to aid in location of ground-truth plots, were surveyed for photo-stocking. Once completed, those photos which corresponded to ground-truth plots were separated out of the primary sample and compared with the ground tally sheets to verify that quadrats recorded as stocked on the photos, contained at least one seedling. The stocking data obtained from the paired photo-and ground-plots were analysed by linear regression procedures to estimate the relationship between photo- and ground-stocking.

Percent seedling detection (the percentage of seedlings detected on the photographs to those recorded on the ground) was determined by placing ground paired photo-plots under [illegible] 4x stereoscope and mapping visible seedlings (on a quadrat basis) onto a replica of the 5 x 5 grid.

These new seedling "maps" were then compared with the original ground tally sheet seedling maps to calculated percent seedling detection for each height class of seedling.

Photo-estimated stocking data were substituted into the equation derived for photo-ground-stocking correlation in order to obtain ground-stocking estimates for the entire photo-sampled area. The ground-stocking estimate, for each cutover examined, was then regressed against cutover age.

Complete counts were taken of the number of seedlings present in each seedling height class on a quadrat basis. Numbers were summed for each plot, averaged for each cutover age class and then converted to stems per hectare per age-class of cutover. To suppliment this information, total heights and ages were obtained on 159 seedlings collected over 16 cutovers covering all seedling height classes and cutover age classes. Two simple linear regressions were performed to estimate relationships for: i) seedling age versus cut over age and ii) seedling height versus seedling age. For the first regression, seedling ages were averaged for each cutover and these values regressed against individual cutover ages. For the second regression, individual seedling ages were regressed against individual heights.

Cutover ages were derived from Yukon Lands and Forest Service records. Where these records were incomplete, 1:15,840 scale colour and colour infrared photography, taken over the past 20 years, was obtained from the Terrain Ecology Section at the Pacific Forest Research Centre and used to identify and categorize cutovers into the five age classes described in Table 2.

Seedlings collected were measured for total height (root collar to base of terminal bud), de-branched and sectioned. The root collar sections (upper root section plus 10 cm of stem) were wrapped in plastic and shipped to the Pacific Forest Research Centre. Utilizing a band saw, a fresh cut surface was exposed approximately one-half cm above the point where major roots merged into the stem. Cut surfaces were sanded smooth with fine grit sandpaper, moistened with water and placed under a 10x microscope. Seedling ages were determined by ring-count.

5. RESULTS

In this study, 390 photo-plots were identified but only 178 were considered useable (Table 3). Photos of non forested land or non-harvested forests were rejected outright. Other photos were rejected due to obscurity of the forest floor resulting from either the physical presence of residual vegetation and slash or shadows cast by them.

Table 3. Summary of rejected/useable photo plots.

Total number of 1:500 scale colour photo-plots		390 (100%)
Rejected: non-forested, non-harvested land	56	
Rejected: obsourity	156	
Total rejected	212	212 (54%)
Total useable photo-plots		178 (46%)

Photo detection of ground recorded seedlings increased consistently and predictably with increasing seedling height (Table 4).

Table 4. Percent detection, by height class, of ground-recorded white spruce seedlings on 1:500 scale colour aerial photographs.

Height class	Number of ground-recorded seedlings	Number of photo-detected seedlings	Percent detection
(1) 0-30 cm	761	5	0.6
(2) 31-60 cm	838	76	9.1
(3) 61-90 cm	1012	467	46.1
(4) 91-120 cm	108	70	64.8
(5) 121-150 cm	675	532	78.8
Total	3414	1149	

Given the exceedingly low detection rate of seedlings in the first height class it was of little utility to incorporate data from this height class (0-30 cm) into a regression estimate of ground stocking using photographic stocking estimates. All seedlings recorded during the ground-truthing survey which fell into the 0-30 cm height class (23% of total) were removed from the sample. Estimation of actual ground-stocking is, therefore, based only on photo detected seedlings greater than 30 cm in height (Table 5).

Table 5. Regression of ground stocking on photo stocking of white spruce seedlings (30 cm), Liard River drainage, Yukon

Independent Variable : photo stocking (X)
Dependent Variable : ground stocking (Y)

Regression Equation : $\hat{Y} = 14.4 + 1.16X$
$r^2 = 0.703$
$r = 0.838$
$SE = 18.15$
$n = 41$

Regression Coefficient = 1.16
T-Ratio = 9.62**
Critical-T 2.70
(P 0.01)

ANOVA

Source	D.F	SS	MS	F	Critical-F
Regression	1	30468.80	30468.80	92.47**	7.31
Residual	39	12851.90	329.50		(P<0.01)
Total	40	403320.70			

Regression analysis results, particularly the values of the F-statistic and coefficient of determination, permit rejection of the null hypothesis (Sec. 5.2.1) and the conclusion that a strong ground-photo-stocking correlation exists (Fig. 2).

Shiue and John (1962) cite the increased efficiency of double sampling as a major advantage whereby a large number of photo-plots can be established at the same cost as a fewer number of ground-plots. The increase in efficiency is dependent upon the correlation coefficient between photo- and ground-stocking measurements and the ratio of the cost of the photo measurements per plot to ground

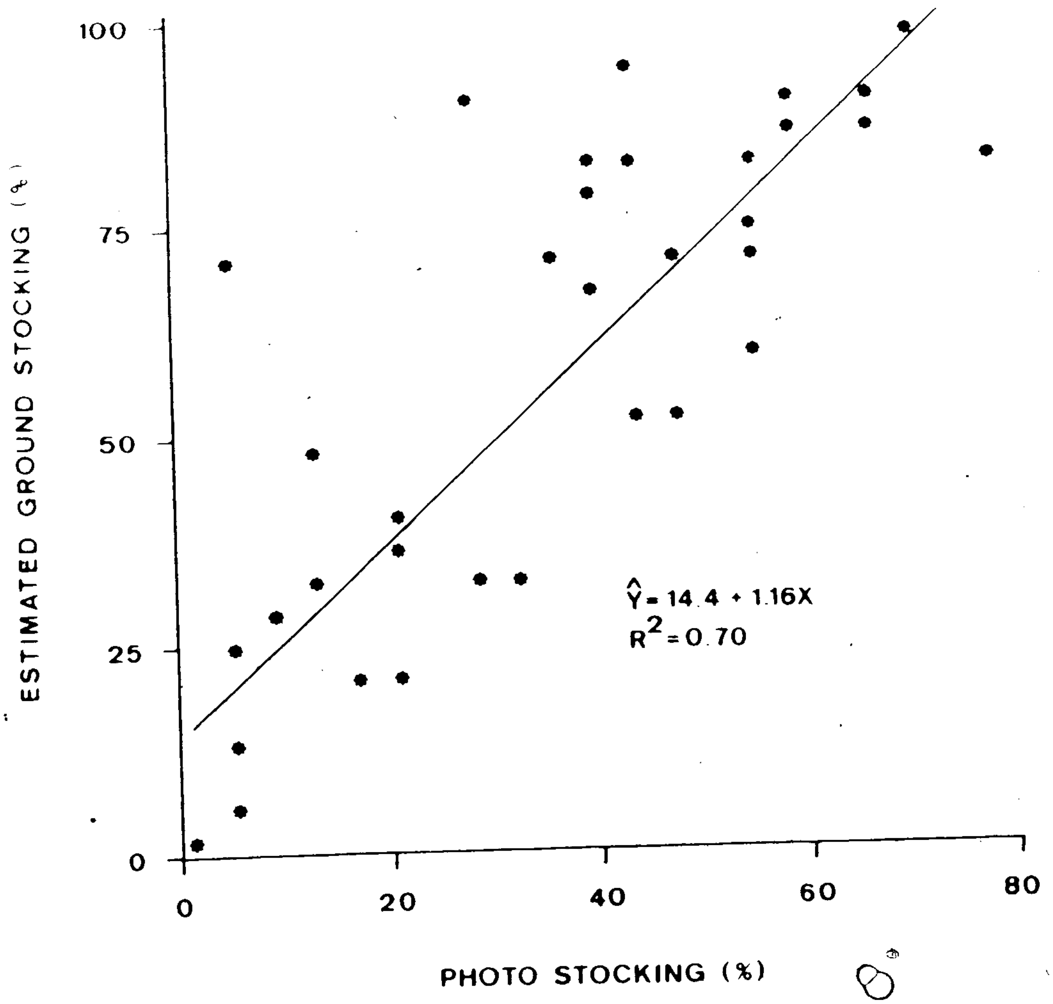

Fig. 2. Linear relationship and data for estimated ground-stocking vs photo-stocking.

measurements per plot. Double sampling becomes cost-effective when the following condition is met (Shiue and John 1962):

$$r^2 > \frac{4\,(Cp \cdot Cg)}{(Cp + Cg)^2} \qquad (Cp \neq 0)$$

where: Cp - cost of one photo plot

Cg - cost of one ground-plot

r^2 - correlation coefficient squared

Establishment costs for ground- and photo-plots were calculated to be $103.00 and $8.23, respectively, thereby indicating that the condition would be met if the correlation coefficient exceeded 0.274. Data in Table 5 show an r-value of 0.838 thereby permitting the conclusion that the double sampling procedure was cost-effective for this study.

Table 6 presents a summary of estimated ground-stocking by age class of cutover.

Table 6. Estimated average ground-stocking of white spruce seedlings (>30 cm) by age class of cutover, Liard River Drainage, Yukon.

Cutover Age Class	Age Range of Cutovers (yrs)	Estimated Average Ground-Stocking (%)
1	0 - 5	32
2	6 - 10	35
3	11 - 15	56
4	16 - 20	53
5	21 - 25	60

The data indicate that there was 30-35% stocking on cutovers in the immediate post-harvest period and that it remained static at this level for up to 10 years. A single, major increase in stocking of 20-25 percent was detected on cutovers 11-15 years old. Maximum observed stocking levels reached 50-60 percent by year 25.

In the immediate post-harvest period, seedling densities approached 700 stems per hectare (Fig. 3). Densities increased to 1670 stems per hectare 15 years after harvesting and 2455 by year 26. The highest seedling frequencies occurred in the smaller height class seedlings, a trend which was consistent through all age classes of cutover.

Percent vegetation cover, organic layer thickness and cutover age were included as variables in a regression procedure to determine if they affected percent ground-stocking significantly. Only cutover age proved to have a significant effect (Table 7; Fig 4.).

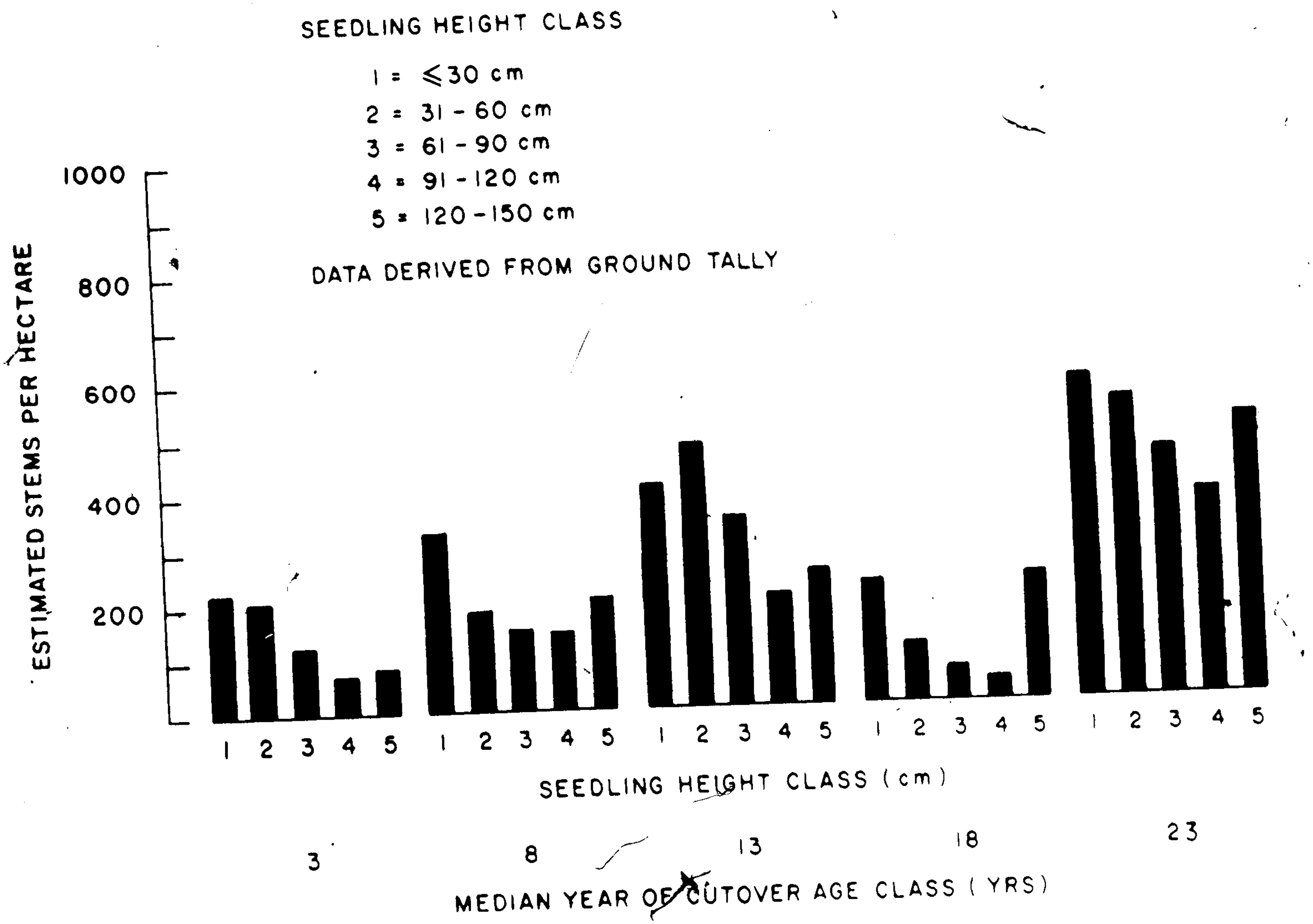

Fig 3. Average number of stems per hectare by age class of cutover and height class of seedling. Liard Drainage Yukon

Table [illegible] Regression of estimated ground stocking (%) of white spruce seedlings on cutover age (yrs), Liard River drainage, Yukon

Independent Variable	cutover age (X)
Dependent Variable	estimated ground stocking (Y)
Regression equation	$\hat{Y} = 21.5 + 1.95X$
	$r^2 = 0.52$
	$r = 0.72$
	SE 14.5
	n 50
Regression coefficient	1.95
T Ratio	7.40**
Critical T	2.67 ($P < 0.01$)

ANOVA

Source	DF	SS	MS	F	Critical-F
Regression	1	11507.1	11507.1	54.7**	7.08 ($P < 0.01$)
Residual	48	10725.6	210.3		
Total	49	22232.7			

The analysis indicated statistical significance for both the regression coefficient and F-value, permitting rejection of the null hypothesis that white spruce regeneration stocking was not correlated with cutover age.

Seedling age was weakly correlated ($r^2 = 0.345$) with cutover age (Table 8: Fig. 5).

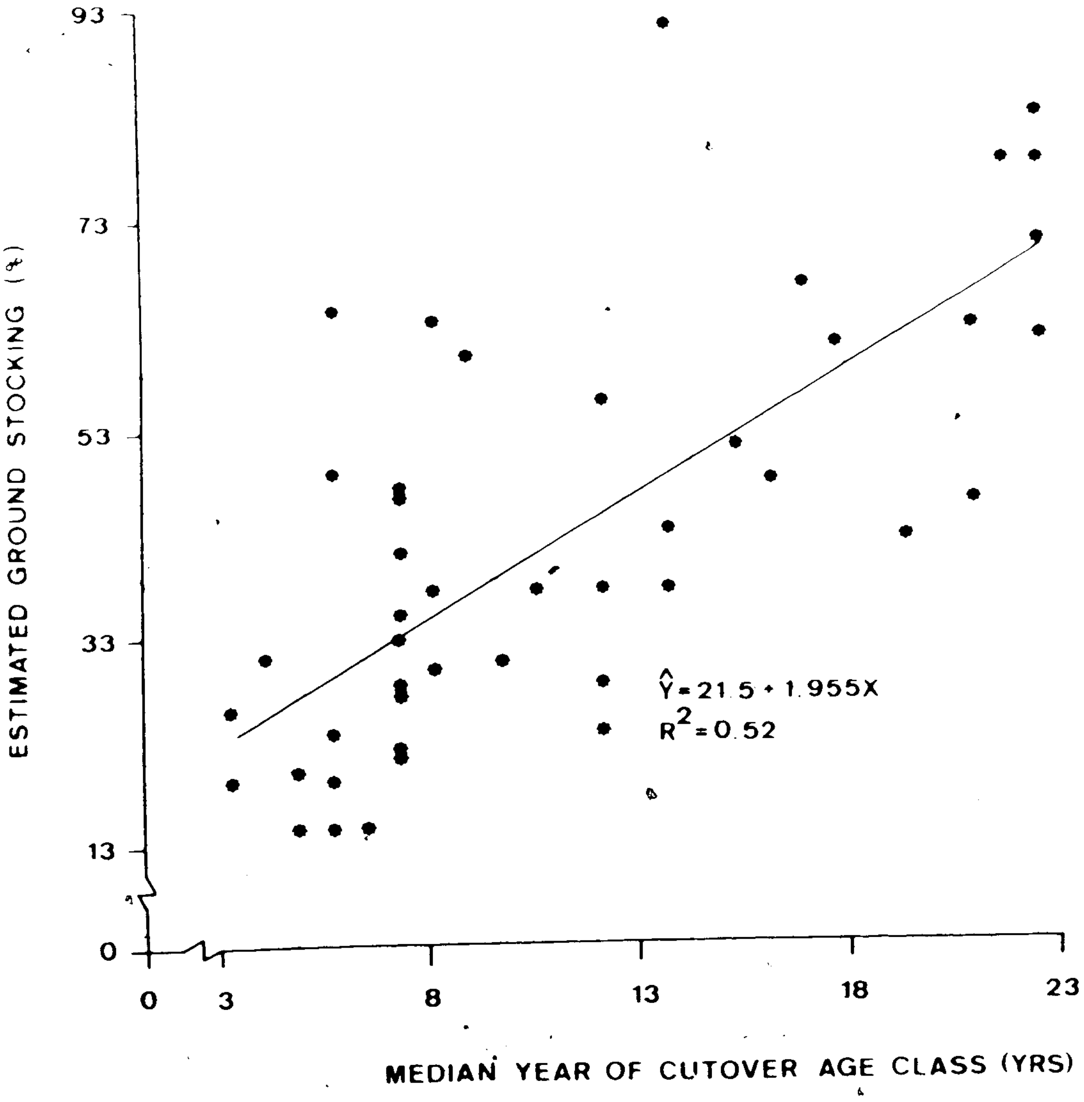

Fig. 4. Linear relationship and data for estimated ground-stocking vs cutover age.

Table 8. Regression of average seedling age (yrs) on cutover age for white spruce regeneration, Liard River drainage, Yukon

Independent Variable		cutover age (X)
Dependent Variable		seedling age (Y)
Regression Equation	$\hat{Y}$	$= 9.76 + 0.269X$
	r^2	0.34
	r	0.58
	SE	2.90
	n	16
Regression Coefficient (X)		0.269
T Ratio		2.65*
Critical T		2.14 ($P < 0.05$)

ANOVA

Source	DF	SS	MS	F	Critical-F
Regression	1	59.34	59.34	7.047*	4.60
Residual	14	117.90	8.42		($P < 0.05$)
Total	15	177.24			

The Y-intercept indicates that the average age of advance reproduction approaches 10 years on fresh cut areas but slope of the regressions shows that a four year increase in cutover age yields only a one year increase in average seedling age. This gradual increment in average seedling age suggests that ingress is continually establishing, thereby producing the weak correlation with cutover age.

The correlation between seedling height and age, using a quadratic polynomial approach for the total seedling population, was weak ($r^2 = 0.42$). Analysis of these data, which are comprised of single observations of seedlings at one point in time as opposed to

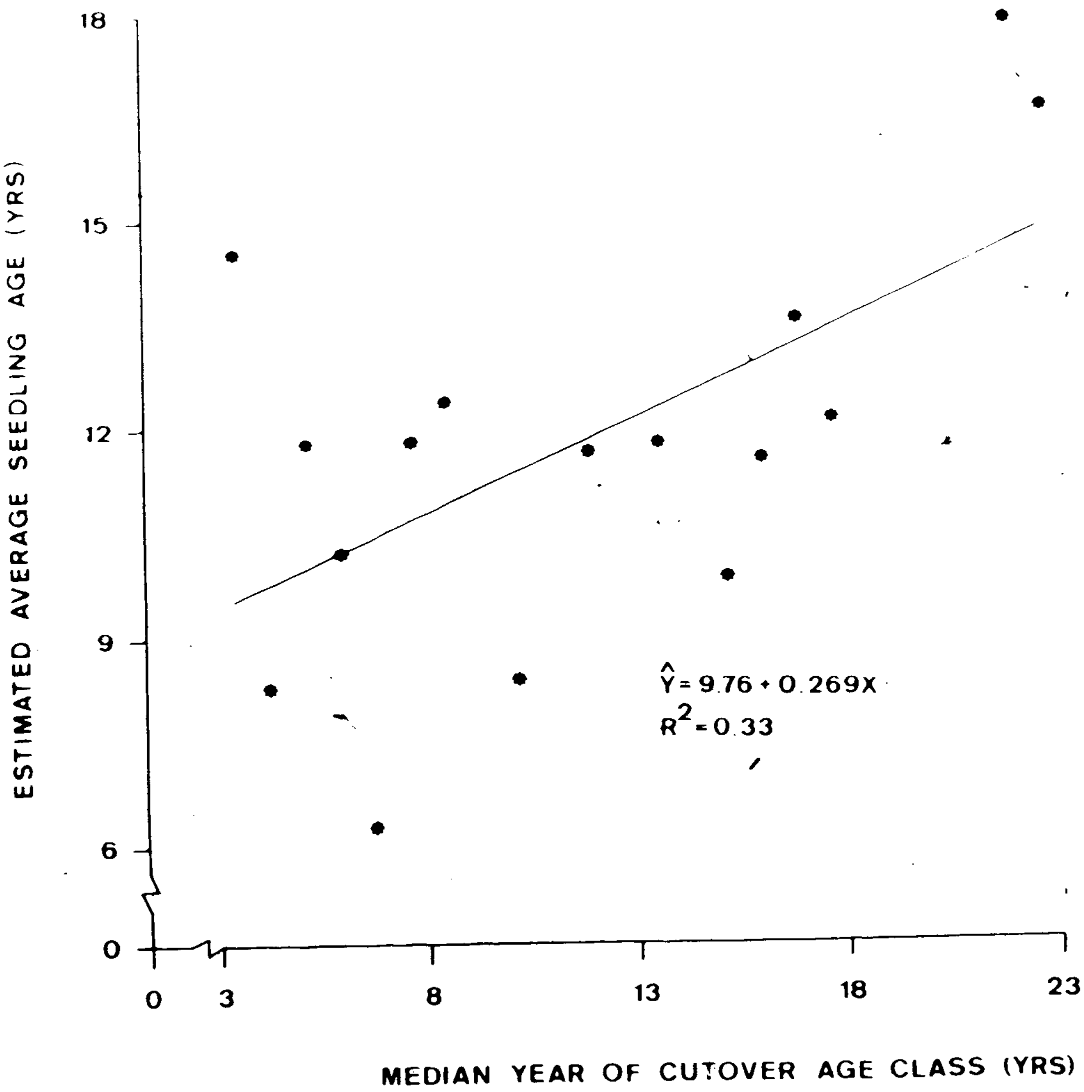

Fig. 5. Linear relationship and data for estimated average seedling age vs cutover age.

a number of observations of seedlings over time, was better served by simple linear regression ($r^2 = 0.55$, Table 9, Fig. 6).

Table 9. Regression of total height (cm) on seedling age (yrs) for white spruce regeneration, Liard River drainage, Yukon

Independent Variable : Seedling age (X)
Dependent Variable : Seedling height (Y)

Regression Equation : $\hat{Y} = -11.3 + 6.78X$
$r^2 = 0.55$
$r = 0.74$
SE = 28.47
n = 159
Regression coefficient: 6.78
T Ratio = 9.53**
Critical-T = 2.617 (P< 0.01)

ANOVA

Source	DF	SS	MS	F	Critical-F
Regression	1	73520.0	73520.0	195.17**	2.79
Residual	157	59155.8	376.7		(P≤ 0.01)
Total	158	132675.8			

The low correlation between seedling height and age is attributed to the mix of advance and ingress seedlings and the presence of a negative Y-intercept is likely due to the influence of suppressed advance seedlings in the population and the attempt to fit a mathematical relationship to biological data.

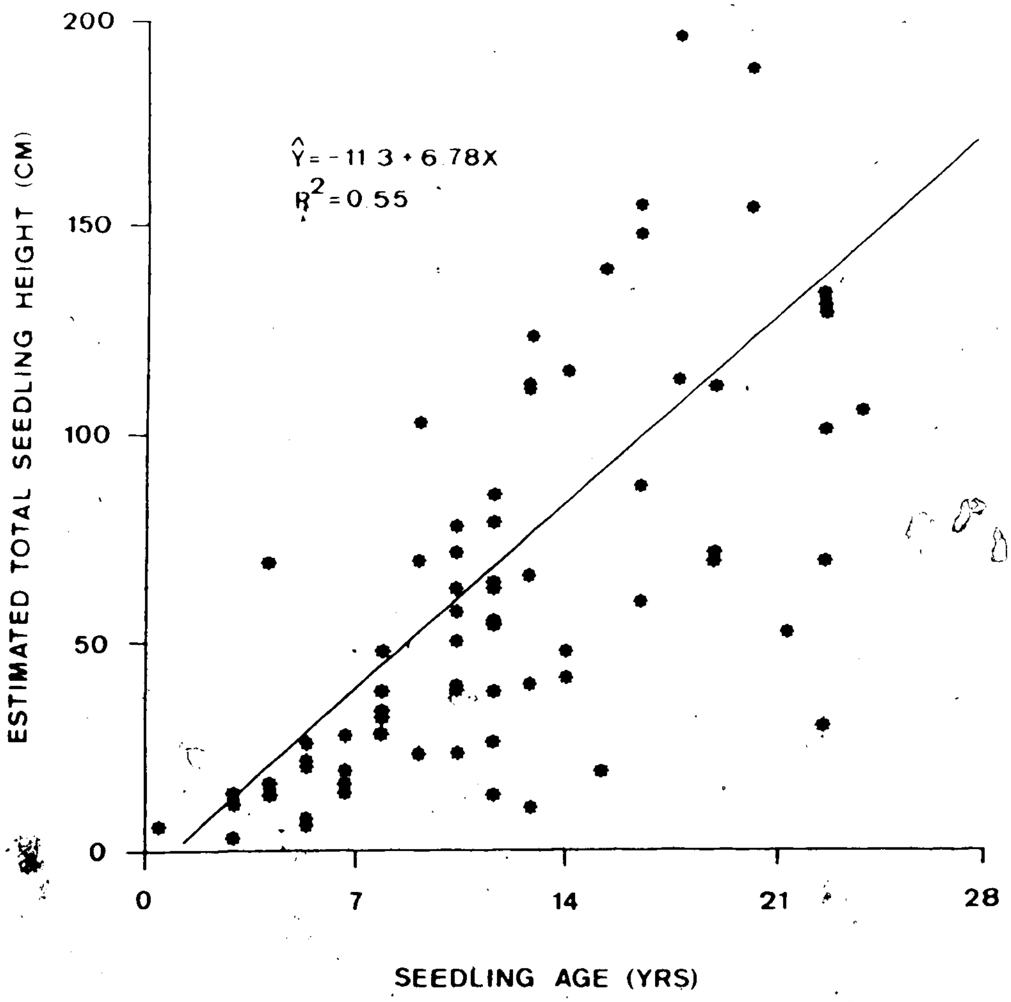

Fig. 6. Estimated height-age relationship for white spruce natural regeneration, Liard River drainage, Yukon.

6. DISCUSSION

Results of this study with respect to photo-plot rejection and detection of small seedlings suggested that the quality of the photography obtained was adversely affected by inferior light conditions during filming in early May. Buffo et. al. (1972) reported that, at 60° north latitude, maximum sun angle during the first week of May is only 40° compared to 45° by May 21 and 53° by summer solstice. Atmospheric reflection, refraction and scattering of light waves all affect light quality at high latitudes and lower sun angles exacerbate their effects (Hall 1984). These conditions result in reduced clarity of the photographs and a shadowing caused by physical presence of objects such as stems of residual vegetation and logging slash. On 40% of the photo-plots, shadowing was heavy enough to cause their rejection (Table 3). Shadowing and reduced clarity interacted to reduce the contrast betweem green conifer seedlings and background colours on others. When contrast is reduced, the ability to detect seedlings is weakened - particularly small seedlings under 60 cm in height. A reduction in ability to detect seedlings on the photographs resulted in lower detection percentages which in turn affected the correlation between photo-stocking and actual ground-stocking adversely, making photo-stocking estimates conservative. In this study, detection rates of seedlings in all height classes averaged about 36% lower than those of Hall (1984a) working with the identical camera system, similar photographic scales and seedling height classes for conifer regeneration reconnaissance in central Manitoba. Correspondingly, the r^2 value for the ground-photo-stocking correlation in this study ($r^2 = 0.70$) was lower than that of Hall's ($r^2 = 0.87$ (Hall 1984a)). Despite this circumstance, the level of significance of the ground-photo-stocking regression in this study (Table 5) suggested that application of the LSP procedure for photo reconnaissance of conifer regeneration in the Yukon was successful.

The regression analysis results indicated that percent stocking was not correlated strongly with age of cutover (Table 7). This suggested that stocking did not increase gradually over time, but attained a maximum level in a short time period following harvest. Observation of natural seeding on floodplains of the Liard and Meister Rivers in the Yukon revealed no statistically significant increases in stocking after 3 growing seasons following harvest (Gardner 1983). In this study, a large increase in stocking percentage was observed 11 to 15 years following harvest. The ingress which produced this increase was established during the previous 10 years. Stocking estimates were based on photo detectable seedlings, therefore, the stocking increase detected on cutovers 11 years and older probably occurred because the seedlings became visible on the photographs by this time. The largest gain in percent detection of seedlings was realized between years 11 and 15 (Table 4). The implication is that the large increase in stocking observed on cutovers older than 11 years was due to ingress establishing within the first five years (maximum) following harvest and needing 10 to 15 years to become large enough to be detected on the photograhs.

Stem density data presented in Figure 2 suggested that overcrowding occurred on available receptive seedbeds. Based on a stocking standard of one tree per 10 m^2, full stocking would yield a density of 1000 stems per hectare. Ground tallies of seedlings in this study, showed stem densities on cutovers older than 11 years to approach 1670 stems per hectare, yet the stocking level was only 56 percent. By 26 years, stocking increased to 60 percent yet densities were estimated to be 2455 stems per hectare. This represented an increase of 4 percent in stocking and 68 percent in density. The histograms of age classes three, four and five (Figure 2) indicated that smaller height class seedlings have the highest frequencies within the seedling population. On cutovers of these ages, smaller seedlings are most likely to be ingress as opposed to advance regeneration. This is supported by the regression of seedling age on cutover age. Increases in stem densities observed on cutovers in the third, fourth and fifth age classes, were due to the continual establishment of ingress on a declining number of receptive seedbeds. Stocking was not increased substantially by this and it implied that serious overcrowding was occurring.

Adequate seed supplies, receptive seedbeds, favourable microclimates and freedom from vegetative competition are essential factors in successful white spruce regeneration (Lees 1972, Place 1955, Stiell 1976, Waldron 1966, Zasada 1972). Evidence of continued seedling accumulation over 26 years suggested that seed supplies were adequate and that microclimate and vegetative competition were not restrictive to establishment. Since site preparation following harvesting was not a general practice prior to 1980, it follows that restocking of cutovers was likely limited by a lack of well distributed, receptive seedbeds. This contention is supported by the results of a seeding trial (Gardner 1983) on floodplains of the Liard and Meister Rivers in the Yukon where percent stocking on scarified sites following broadcast, natural and spot seeding of white spruce, was eight times that recorded on unscarified sites after five growing seasons.

7. CONCLUSIONS AND RECOMMENDATIONS

Procedures utilizing large-scale aerial photographic (LSP) techniques were used to survey 104 cutovers. Total flying time amounted to 5.5 hours. Total time for film documentation, ground-plot selection and location, photo reconnaissance and ground-truthing equalled 34 days. Ground plots in this survey were 12.5 times more expensive to establish than equivalent photo-plots. The LSP system proved to be rapid, efficient and cost-effective for reconnaissance-level regeneration surveys in the Yukon.

Seedling detection on the large-scale photographs was comprised in this study by excessive shadowing from residual vegetation and debris and from a reduction in the quality of contrast between seedlings and background material. These conditions were likely associated with inferior sun angles at the time of photography which affected light quality adversely. Low percent detection of smaller seedlings (0-30 cm height) produced a weaker coefficient of determination from the regression of ground-stocking versus photo-stocking in this study than was achieved in other work with the same photographic system (Hall 1984a). This resulted in a reduction in precision of the photo-stocking estimates. In contemplating future applications of LSP at high latitudes, careful consideration must be given to determining the timing of photography with respect to both time of season and time of day.

Post-harvest restocking of cutovers on floodplains in southeast Yukon was not gradual because available seedbeds were colonized quickly and became progressively more overcrowded with time. From this, it is suggested that provision of well-distributed seedbeds, through site preparation immediately following harvest, plus a seed source, may be all that is required to achieve basic restocking of cutovers. Regeneration surveys to check stocking levels should be performed three years following site preparation. A decision to remove or retain seed sources should be made at this time. If the decision is to retain seed sources, check surveys should be conducted in year five. If by year five, full stocking has not been realized and prepared seedbeds appear less receptive to germination and seedling establishment, site preparation should be made. At either year three or five, depending on the levels of stocking and condition of seedbeds, consideration could be given to suppliment natural seeding with some form of direct seeding. The results of this study suggest that direct seeding would not be required in many cases and that monitoring to ensure removal of seed sources at the appropriate time, to prevent overcrowding, would be a major concern.

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OPTIMUM PLOT ALLOCATION WITH RESPECT TO COST

APPENDIX I

OPTIMUM PLOT ALLOCATION WITH RESPECT TO COST

In determining the initial sample size for the secondary (ground) sample, the optimum allocation with respect to cost procedure was followed (after Cochran 1977).

Photo-plot acquisition cost:

helicopter	$2,332.06
Film processing and printing	877.00
	$3,209.06

390 Total photo-plots with tracking photography.

210 samples orginally estimated to be usable.

$3,209.06/390 = $8.23 per sample plot

(one sample plot = 25 quadrats each 10m^2).

Assume (Hall 1984a) photo-stocking/ground-stocking correlation = 0.9.

$$\text{Ground-plot/photo-plot ratio} = \sqrt{\frac{1-r^2}{r^2} : \frac{Cp}{Cg}}$$

Where Cp = Cost photo-plots

Cg = Cost ground-plots

Estimate that 60 ground-plots would be sufficient:

$$\text{ground-plot/photo-plot ratio} = \sqrt{\frac{1-.9^2}{.9^2} \cdot \frac{8.23 \times 60}{3795}} = 1/5.7 \approx 1/6$$

Where $3,795 = cost of establishing and measuring 60 ground-plots.

This indicates that an appropriate sample size would require 1 ground-plot for every 6 usable photo-plots.

210/6 = 35 ground-plots required.