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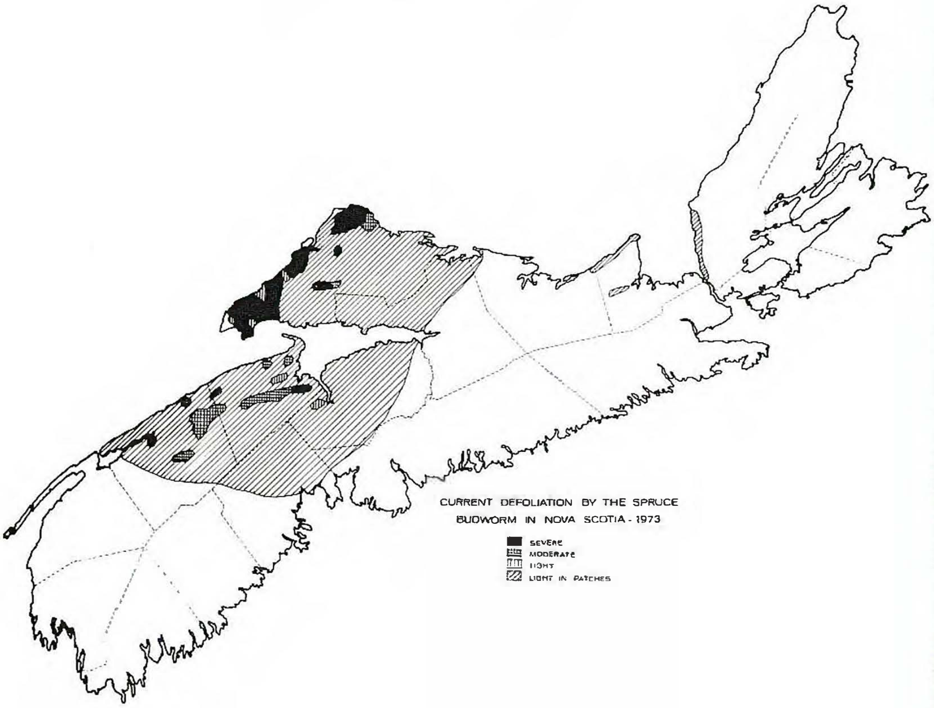
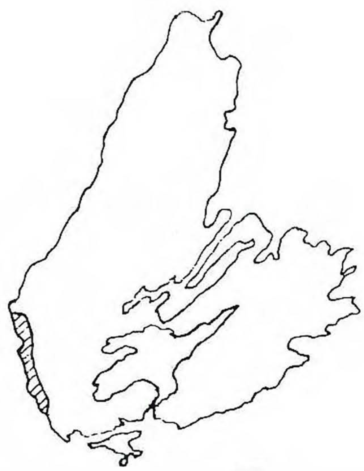


GROWTH RESPONSE TO FERTILIZERS IN BALSAM FIR FORESTS ON CAPE BRETON HIGHLANDS, NOVA SCOTIA

by
P. O. SALONIUS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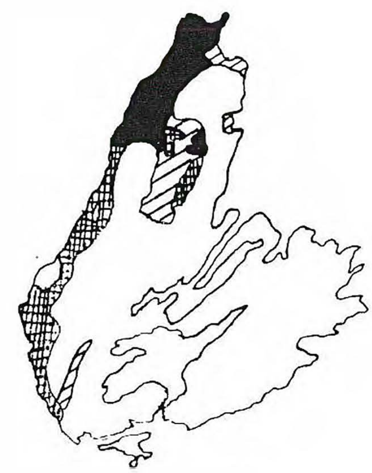
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Maritimes Forest Research Centre
Fredericton, New Brunswick

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ABSTRACT

A series of forest fertilization experiments in semimature balsam fir (Abies balsamea (L.) Mill.) stands on the Cape Breton Highlands of Nova Scotia were established in the early 1970's. Treatments consisted of one application of various combinations of nitrogen, phosphorus, and potassium fertilizers. Foliar analysis and remeasurement of diameters and heights were conducted until seven years after the original experiment was established; the work was then stopped because of a serious spruce budworm epidemic. Foliar nutrient levels peaked during the first growing season after fertilization. No significant growth responses were found to have been caused by fertilizer addition. Mortality in these stands was generally high. A discussion of strategies for measuring fertilizer response in non-uniform forest stands is presented.

RESUME

Une série d'expériences de fertilisation forestière a été établie au début des années 70 dans des peuplements semi-matures de sapin baumier, Abies balsamea (L). Mill., sur les hauteurs du Cap-Breton en Nouvelle-Ecosse. Les traitements consistaient en diverses combinaisons d'engrais azotés, phosphorés et potassiques. L'analyse foliaire et les remesurages des diamètres et des hauteurs ont été effectués jusqu'à la septième année après l'établissement de l'expérience inaugurale; les travaux ont alors été suspendus, à cause d'une grave infestation de la tordeuse des bourgeons de l'épinette. Les niveaux des éléments nutritifs dans le feuillage ont atteint leur maximum au cours de la première saison de croissance consécutive à la fertilisation. Aucune réaction significative de croissance ne s'est avérée imputable à l'addition d'engrais. La mortalité était généralement élevée parmi les arbres de ces peuplements. Une discussion des stratégies de mesurage de la réponse aux engrais dans les peuplements forestiers non homogènes est présentée.

INTRODUCTION

During the last two decades, world use of fertilizers in forestry has increased tremendously. By far the heaviest use of fertilizers as growth promoting tools has been in Scandinavia and the west coast of North America. Interest in forest fertilization was originally prompted by forecast localized wood shortages, increased costs of transporting wood supplies to utilization centers, expected decreased harvesting costs, earlier merchantability and increased yield of fertilized stands (Anonymous 1973). On the basis of these possible benefits of forest fertilization, a network of forest fertilization trials in various coniferous species was established across Canada. The balsam fir study on the Cape Breton Highlands that is described in this report formed part of this network, known as the Interprovincial Forest Fertilization Program (Anonymous 1973).

More recently, inventories in some parts of eastern Canada have demonstrated adequate supplies of mature timber to supply immediate industrial needs and adequate potential supplies of young growing material which will supply industrial needs in the distant future, but a probable inadequate supply of mature wood in the medium-future (10-30 years). Thus another rationale for forest fertilization studies has arisen: the possibility of using fertilizers to maintain mature forest stands in a viable condition for longer than would be the case with no treatment, so that mature stands which are in excess of present requirements might still be available at a time when disease, windthrow, and general decadence would otherwise have rendered them unharvestable.

Fertilizer treatments in this balsam fir study included those specified by the Interprovincial Forest Fertilization Program plus several other combinations of nitrogen, phosphorus, and potassium. Damage to the forests on the Cape Breton Highlands in 1975, 1976, and 1977 by spruce budworm necessitated the cancellation of the study before the prescribed 10-year measurement period had been completed. Results reported here are, consequently, for various response periods up to seven growing seasons after fertilization.

STUDY AREAS

The trials described here consisted of a test of various combinations of nitrogen, phosphorus, and potassium in a replicated experiment established in 1969 and fertilized in 1970 (main trial), and in a series of replicated satellite trials, with fewer fertilizer combinations, which were fertilized in 1973. The treatments for the satellite trials were established based on the best preliminary responses from the main trial; they were established to assess whether there was some uniformity in response to various fertilizer combinations and levels in areas of fairly similar forest.

The study areas (Figs. 1 and 2) were on Crown land leased to Nova Scotia Forest Industries and are within the Acadian Forest Region, Forest Section A.6: Cape Breton Plateau (Rowe 1972). Soil classifications (Table 1) are according to the Canadian system (Canada Soil Survey Committee 1978). The elevation of the study areas is about 400 m above sea level. The climate is humid and temperate. Mean annual precipitation is 1270 mm, one-third of which falls during the growing season (Bailey and Mailman 1972). The frost free period is about 90 days. The stands were mostly balsam fir (Abies balsamea (L.) Mill.) with scattered white spruce (Picea glauca (Moench) Voss.) and a few white birch (Betula papyrifera Marsh.).

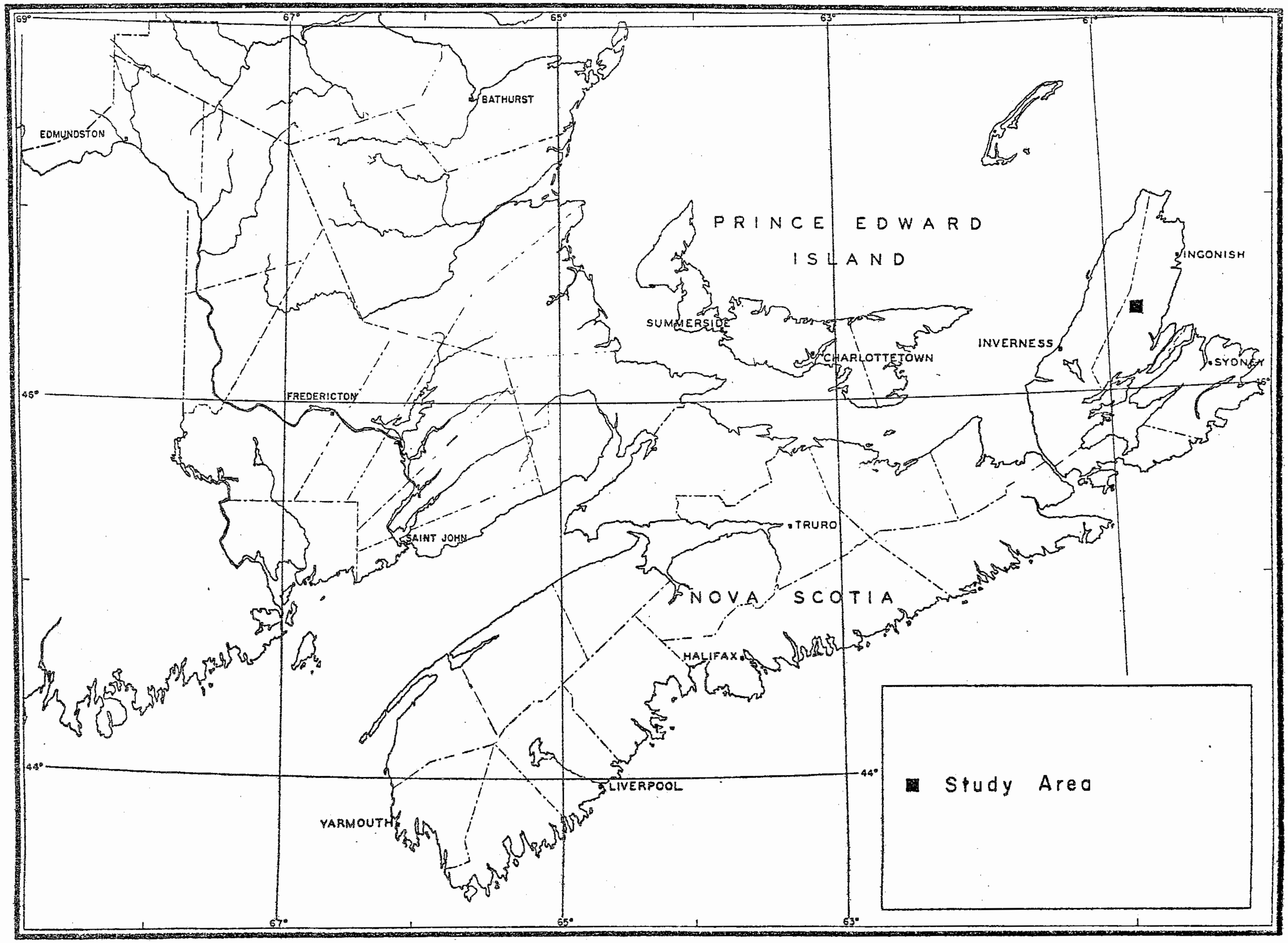

Figure 1. Location of study area.

Table 1. Balsam fir fertilizer trials

Trial	Year fertilizer applied	Age of stand (yr)	Soil Type
Main	1970	50	Ferro-Humic Podzol
1	1973	63	Mini Humo Ferric Podzol
2	1973	59	Gleyed Humo Ferric Podzol
4	1973	52	Mini Ferro Humic Podzol
5	1973	47	Orthic Ferro Humic Podzol
6	1973	40	Mini Ferro Humic Podzol
13	1973	51	Ferro Humic Podzol
14	1973	58	Orthic Humo Ferric Podzol
15	1973	48	Mini Humo Ferric Podzol

The spruce budworm (Choristoneura fumiferana (Clem.)) invasion first produced significant defoliation in 1975 the severity of which increased until 1977 when almost complete defoliation was noted in some of the stands. Generally, the budworm spread from north to south across the study area (Fig. 2).

METHODS

In the main trial, 32 concentric double circle plots (0.04 ha outer and 0.02 ha inner) with stocking as uniform as possible were established in 1969. For each satellite trial, 10 similar plots were established in 1973. In both trials, all living trees over 5 cm dbh in the inner circle were numbered, recorded as to dominance, and the point of measurement of diameter at breast height was marked. Heights of trees representing the various diameter classes in the stand were measured on the control plots so that local height-diameter relationships necessary for volume calculations (Honer 1967) could be prepared. The inner and outer circles received fertilizer (Table 2) and the outer circle served as a buffer area such that all measured trees had the bulk of their roots in soil which had received fertilizer.

Fertilizers were applied in the spring of 1970 on the main trial and the spring of 1973 on the satellite trials. Fertilizers were divided into four lots per plot for each nutrient applied and spread uniformly by hand on each plot quarter. Five dominant or codominant trees per plot were designated for foliage sampling, which was carried out by shooting branches from the top third of the crown before treatment and annually for several years after treatment. The original plans were to sample foliage at 7 and 10 years after treatment but defoliation by spruce budworm after 1975 made this impossible. Current-year foliage from the five designated trees on each plot was pooled, oven-dried at 70°C, cleaned, and ground to pass through a 1-mm sieve. The ground samples were analysed according to MacDonald (1977) for total nitrogen, phosphorus, potassium, calcium, and magnesium.

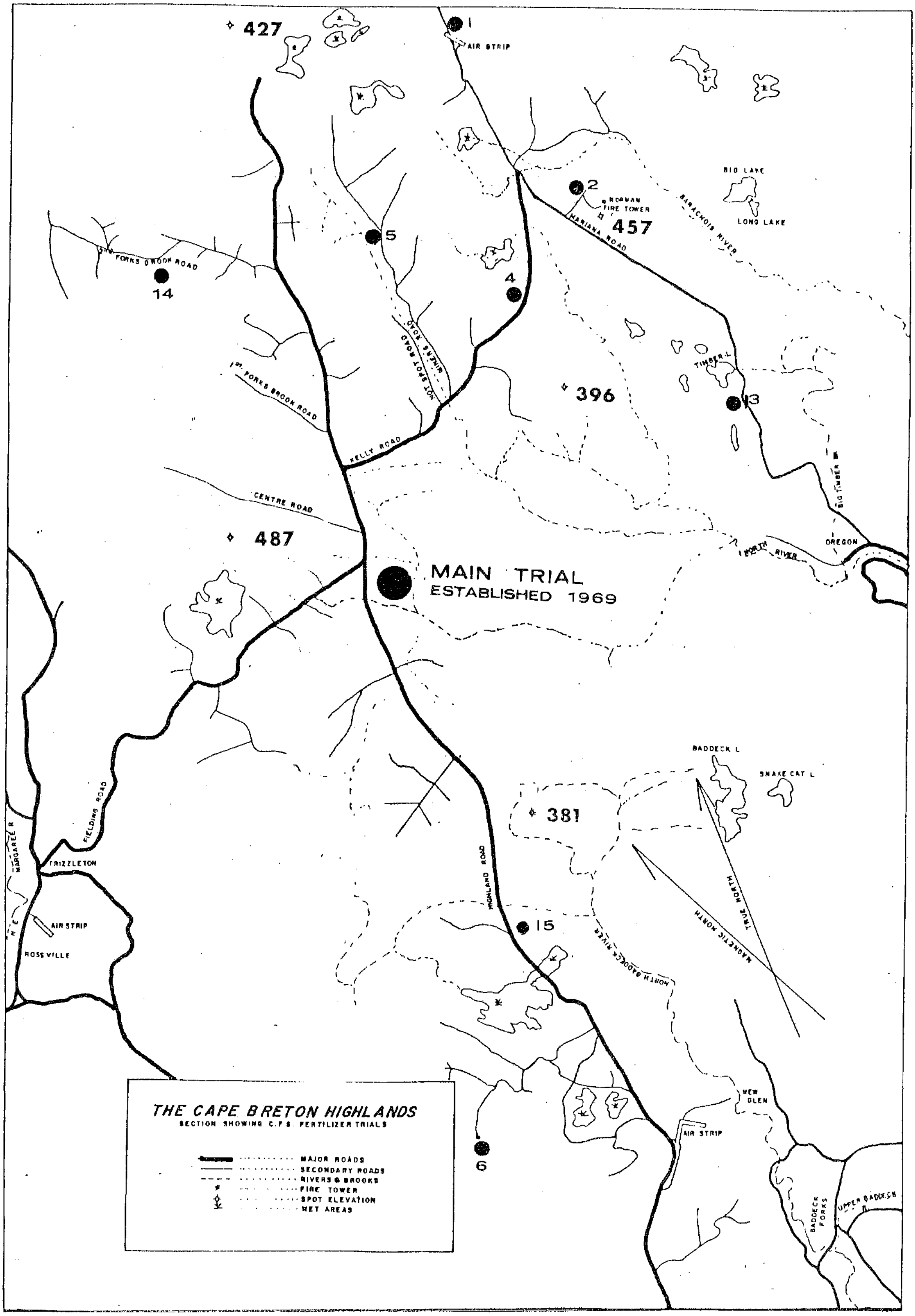

Fig. 2. Locations of main and satellite trials (●).

Table 2. Fertilizer treatment combinations *

Main Trial			
$N_0P_0K_0$	$N_1P_0K_0$	$N_2P_0K_0$	$N_3P_0K_0$
$N_0P_0K_1$	$N_1P_0K_1$	$N_2P_0K_1$	$N_3P_0K_1$
$N_0P_1K_0$	$N_1P_1K_0$	$N_2P_1K_0$	$N_3P_1K_0$
$N_0P_1K_1$	$N_1P_1K_1$	$N_2P_1K_1$	$N_3P_1K_1$
Satellite Trials			
$N_0P_0K_0$	$N_1P_1K_0$	$N_2P_0K_0$	
		$N_2P_0K_1$	
		$N_2P_1K_0$	

* N_0, N_1, N_2 and N_3 - Urea at 0, 112, 224 and 448 kg N/ha.
P_0 and P_1 - Triple superphosphate at 0 and 112 kg P/ha.
K_0 and K_1 - Potassium chloride at 0 and 112 kg K/ha.

New height-diameter curves (control plots) were prepared for the main trial for each of the 5 (1974) and 7 (1976) year remeasurements and for the 3 (1975) and 4 (1976) year remeasurements on the satellite trials. Using Honer's (1967) standard volume tables, adjusted to local conditions, merchantable volumes were calculated for each remeasurement. Mortality was recorded at each measurement. These studies were terminated in 1977 because of the heavy spruce budworm infestation, and salvage harvesting of the main trial and several satellite trials.

RESULTS AND DISCUSSION

Main Trial

The results of foliar analysis for the main trial are presented in Table 3. Significant increases in foliar concentrations of nitrogen and phosphorus were obtained by treatment with these nutrients but no significant increases in foliar potassium were found. Considerable between-treatment variation in the concentration of these nutrients before fertilization (1969) and considerable year-to-year variation in nutrient concentrations within controls during the study suggest that foliar data from single samplings to assess the nutrient status of stands must be used with caution. Higher foliar nitrogen conentrations were achieved with higher dosage rates and these higher levels tended to persist longer than levels on plots treated with lesser amounts of nitrogen.

The absolute increase in merchantable volume on living trees after 7 growing seasons is presented by crown class in Fig. 3. Assessment of fertilizer treatments using post-treatment volume increments on surviving trees is usual in Canadian forest fertilization trials (Weetman et al. 1976, 1978, 1979). Implicit in this handling of growth data is the assumption that all plots have the same original volumes upon which to lay increments in volume growth. Although plots are chosen to have similar stocking and population structure (diameter distribution), identical original volumes are impossible to achieve. Differential mortality between plots further increases the dissimilarity in original volumes when results are reported as volume increment on live trees. Wells et al. (1976) found that small differences in growing stock between plots can completely mask response to fertilization. As can be seen from Fig. 3 original merchantable volumes on trees surviving until the 1976 remeasurement are substantially different between treatments (132-170 m^3/ha). Percentage responses could be a more meaningful method of comparing treatments when differences in original volumes and surviving original volumes are considered. The increase in merchantable volume on living trees as a percentage of original volume on those trees is presented numerically at the top of the

Table 3.

Foliar nutrient concentrations, average of two replicates.

TREATMENT	1969	1970	1971	1972	1973
		% Foliar Nitrogen			
$N_0P_0K_0$	1.51	1.37	1.42	1.30	1.29
$N_0P_1K_0$	1.49	1.46	1.31	1.24	1.25
$N_0P_0K_1$	1.45	1.28	1.04	1.15	1.14
$N_0P_1K_1$	1.50	1.30	1.42	1.38	1.28
$N_1P_0K_0$	1.43	1.41	1.33	1.27	1.22
$N_1P_1K_0$	1.50	1.42	1.43	1.28	1.24
$N_1P_0K_1$	1.46	1.85	1.60	1.41	1.46
$N_1P_1K_1$	1.46	1.67	1.59	1.51	1.36
$N_2P_0K_0$	1.41	1.70	1.49	1.31	1.30
$N_2P_1K_0$	1.45	1.79	1.69	1.49	1.18
$N_2P_0K_1$	1.51	1.66	1.55	1.27	1.25
$N_2P_1K_1$	1.50	1.62	1.50	1.42	1.37
$N_4P_0K_0$	1.36	1.85	1.68	1.48	1.45
$N_4P_1K_0$	1.50	1.85	1.66	1.49	1.43
$N_4P_0K_1$	1.41	1.80	1.67	1.52	1.41
$N_4P_1K_1$	1.50	1.85	1.73	1 54	1.41
		% Foliar Phosphorus			
$N_0P_0K_0$	0.19	.20	.18	.18	.19
$N_0P_1K_0$	.17	.31	.25	.25	.23
$N_0P_0K_1$	.20	.21	.17	.19	.17
$N_0P_1K_1$	.20	.23	.24	.24	.20
$N_1P_0K_0$	.19	.20	.21	.19	.18
$N_1P_1K_0$	.18	.27	.22	.22	.20
$N_1P_0K_1$	.20	.22	.21	.19	.19
$N_1P_1K_1$	.19	.22	.19	.23	.19
$N_2P_0K_0$	.19	.22	.19	.19	.19
$N_2P_1K_0$	.19	.32	.24	.23	.23
$N_2P_0K_1$	.21	.20	.20	.19	.19
$N_2P_1K_1$	.20	.22	.20	.22	.20
$N_4P_0K_0$	.21	.21	.19	.19	.17
$N_4P_1K_0$	.21	.25	.23	.21	.22
$N_4P_0K_1$	.19	.22	.21	.18	.17
$N_4P_1K_1$	.21	.24	.24	.22	.22

Table 3. cont'd.

TREATMENT	1969	1970	1971	1972	1973
		% Foliar Potassium			
$N_0P_0K_0$	0.56	.61	.46	.58	.51
$N_0P_1K_0$	.51	.62	.51	.51	.56
$N_0P_0K_1$	.52	.61	.47	.56	.59
$N_0P_1K_1$	.54	.85	.50	.61	.58
$N_1P_0K_0$	.50	.75	.43	.70	.55
$N_1P_1K_0$	.49	.77	.54	.65	.55
$N_1P_0K_1$	.56	.59	.51	.64	.57
$N_1P_1K_1$	.53	.70	.58	.67	.55
$N_2P_0K_0$	.50	.62	.47	.64	.61
$N_2P_1K_0$	.51	.64	.48	.52	.47
$N_2P_0K_1$	.53	.73	.40	.91	.65
$N_2P_1K_1$	.47	.56	.40	.54	.51
$N_4P_0K_0$	.53	.62	.55	.57	.55
$N_4P_1K_0$	.60	.67	.59	.52	.55
$N_4P_0K_1$	.51	.59	.48	.64	.60
$N_4P_1K_1$	.51	.67	.57	.57	.50
		% Foliar Calcium			
$N_0P_0K_0$	0.43	.54	.50	.36	.42
$N_0P_1K_0$	.41	.58	.58	.37	.44
$N_0P_0K_1$	.43	.52	.35	.31	.32
$N_0P_1K_1$	.40	.63	.45	.39	.41
$N_1P_0K_0$	.42	.47	.58	.40	.43
$N_1P_1K_0$	.41	.49	.56	.39	.42
$N_1P_0K_1$	.47	.56	.43	.42	.45
$N_1P_1K_1$	.44	.53	.46	.36	.46
$N_2P_0K_0$	.46	.54	.56	.35	.35
$N_2P_1K_0$	.47	.53	.43	.41	.40
$N_2P_0K_1$	.39	.35	.40	.27	.46
$N_2P_1K_1$	.46	.37	.40	.40	.43
$N_4P_0K_0$	.38	.46	.45	.32	.35
$N_4P_1K_0$	.39	.33	.36	.29	.31
$N_4P_0K_1$	.45	.51	.32	.32	.35
$N_4P_1K_1$	.44	.36	.44	.30	.39

Table 3. cont'd.

TREATMENT	1969	1970	1971	1972	1973
		% Foliar Magnesium			
$N_0P_0K_0$	0.14	.17	.15	.15	.16
$N_0P_1K_0$	.11	.14	.13	.11	.11
$N_0P_0K_1$	.13	.14	.12	.12	.13
$N_0P_1K_1$	.14	.16	.15	.15	.13
$N_1P_0K_0$	.12	.14	.15	.15	.15
$N_1P_1K_0$	.13	.15	.14	.13	.13
$N_1P_0K_1$	.13	.17	.12	.12	.12
$N_1P_1K_1$	.12	.15	.14	.12	.14
$N_2P_0K_0$	.13	.16	.15	.12	.12
$N_2P_1K_0$	.14	.17	.16	.15	.16
$N_2P_0K_1$	.15	.15	.19	.14	.18
$N_2P_1K_1$	.14	.18	.17	.14	.13
$N_4P_0K_0$	.13	.13	.16	.16	.14
$N_4P_1K_0$	.14	.15	.15	.13	.14
$N_4P_0K_1$	.12	.14	.12	.14	.14
$N_4P_1K_1$	.12	.12	.14	.13	.16

absolute volume growth bars in Fig. 3. Clearly, the ranking of treatments by absolute volume growth and percentage volume growth produces considerably different results. It is interesting to note (Fig. 3) that within each nitrogen-level group of treatments, when compared with the control by the traditional absolute volume growth methods, the treatment with the highest original volume on survivors appears to produce the best response. Thus, the conventional treatment of the data does not appear to be a satisfactory method of assessing response to fertilizer.

Absolute mortality (Fig. 3) was considerably greater than volume increment on surviving trees and thus the fertilizers applied to the stand were shared by survivors and trees which would never be harvested. This is not an efficient system and, as suggested by Weetman et al. (1976), future fertilization in mature stands should be concentrated on planted or spaced stands where mortality, between the time of treatment and harvest, will be minimal.

Mortality and volume data are presented in percentage terms in further treatment comparisons. Thus in Figs. 4 and 5, data are presented for the 1974 and 1976 remeasurements, respectively. Percentage of original merchantable volume on trees alive at

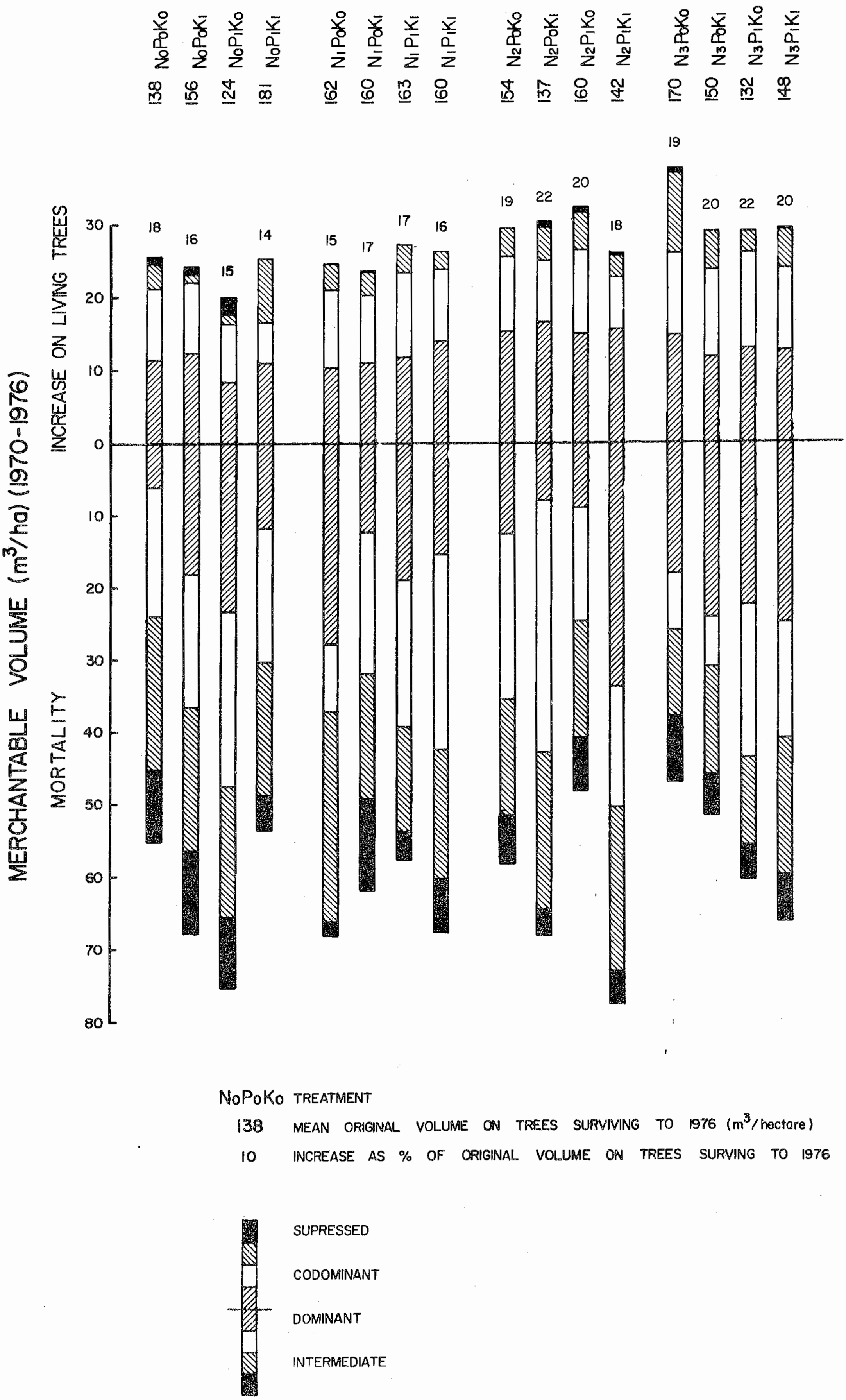

Fig. 3. Stand changes 1970–1976 in balsam fir – Main Trial – volume

each of the measurement periods allows a comparison of treated and control plots that considers a decrease in normal mortality during the response period as a possible response to fertilization. The data in Figs. 4 and 5 include the differences between replicate plots as crosshatched portions of the histogram bars. There appears to have been tremendous within treatment variability (between replicate plots) in the three response measures presented. Analyses of variance of these data for the 1974 (5th year) and the 1976 (7th year) remeasurements showed that none of the treatments produced significantly different results from the control for any of the three response measures. A maximum mean increase ($N_3P_0K_0$, Fig. 4) during the five year period (1974 measurement) of approximately 5% of original volume alive over the control is probably not enough to encourage forest managers to apply fertilizer to such stands especially when the variability within treatments renders this result statistically non-significant.

Large increases in apparent mortality between the 1974 and 1976 remeasurements and the consequent large decreases in percentage of original volume alive, between the two measurement periods, to well below 100% may largely be due to assessment of viability from the ground, based on the presence or absence of live needles in the crown. Damage by budworm in 1975 and 1976 may have thus produced many "apparently dead" trees that still possessed living cambium and buds. Thus, the 1974 remeasurement, which was done before any depredations by spruce budworm, probably produced a better set of data from the standpoint of unadulterated fertilizer effects in a fairly normal environment.

Satellite Trials

Both sets of data resulting from the 1975 (3rd year) and 1976 (4th year) remeasurements of the 8 satellite trials are presented in Fig. 6. The data for 1975, before the budworm infestation became very intense, are probably most indicative of what would have taken place in a more normal ecosystem that was treated with fertilizers. The question being asked in this series of trials was whether fertilizer response was similar in areas of similar forest estate within one ecological zone. The results presented in Fig. 6 suggest there is certainly no generality in the response patterns for the various satellite trials. The apparent maximum mean response of about 8% of original volume alive above the control for the $N_1P_1K_0$ treatment in satellite trial 4 in 1975 is again probably too small to encourage forest managers to invest in fertilization of wild stands of advancing age with considerable mortality such as are represented here. Of interest are the tremendous differences in the data for some of the treatments in the satellite trials between 1975 and 1976 both in percentage of original volume apparently alive and in percentage of original volume apparently dead. This again is probably a budworm-produced exaggeration of mortality because mortality is assessed from the ground, based on the presence or absence of living foliage in the crown.

Table 4 shows the original volumes of survivors on the two control plots in each trial, the absolute merchantable volume increments and merchantable volume increment as a percentage of original volume on these living trees during the period from trial establishment until the remeasurement in 1976.

To reiterate, conventional methods of reporting fertilizer response in

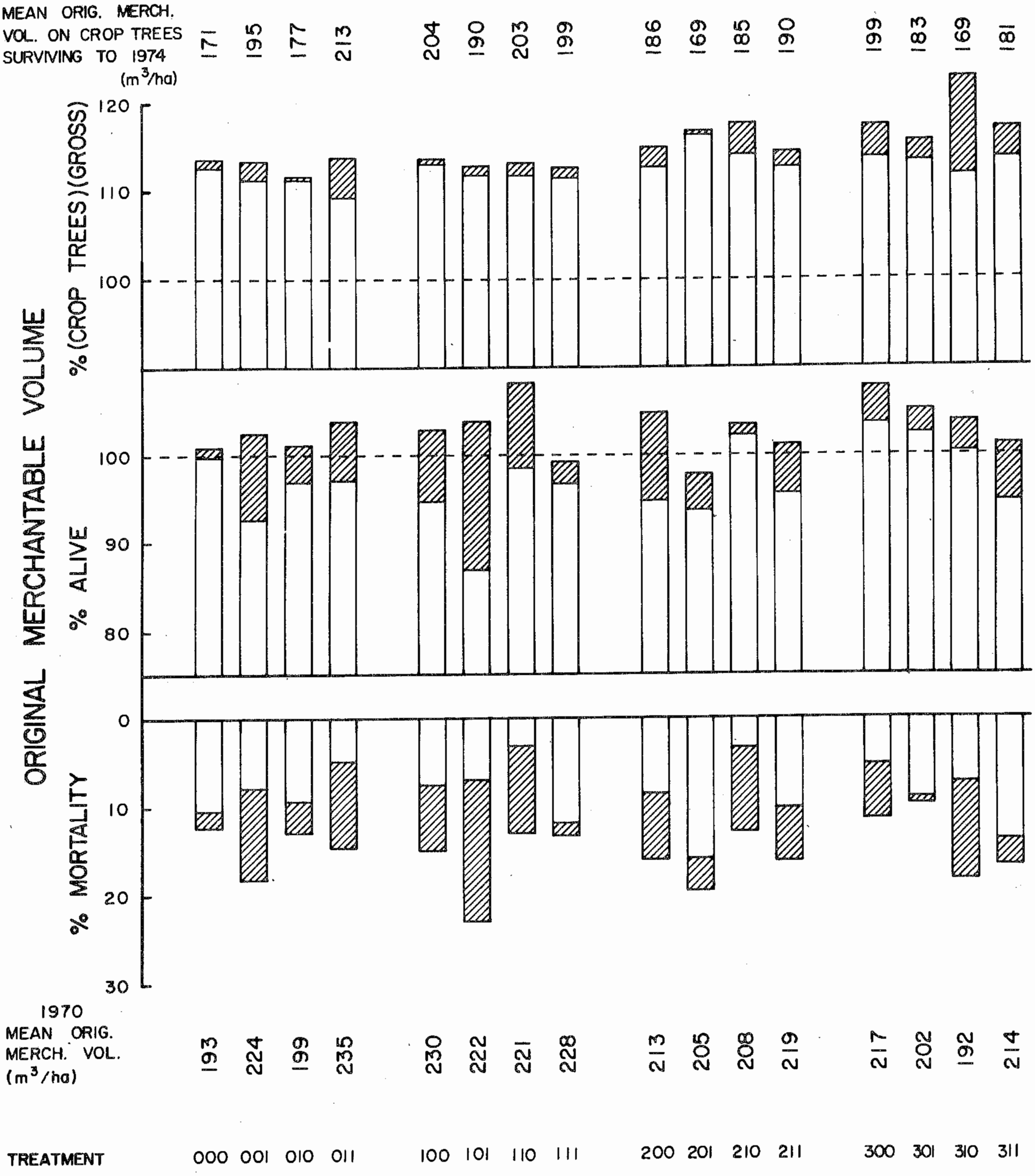

Fig. 4. Percentage merchantable volume status for balsam fir - Main Trial - 1974. (Crosshatched portions of bars represent differences between replicate plots.)

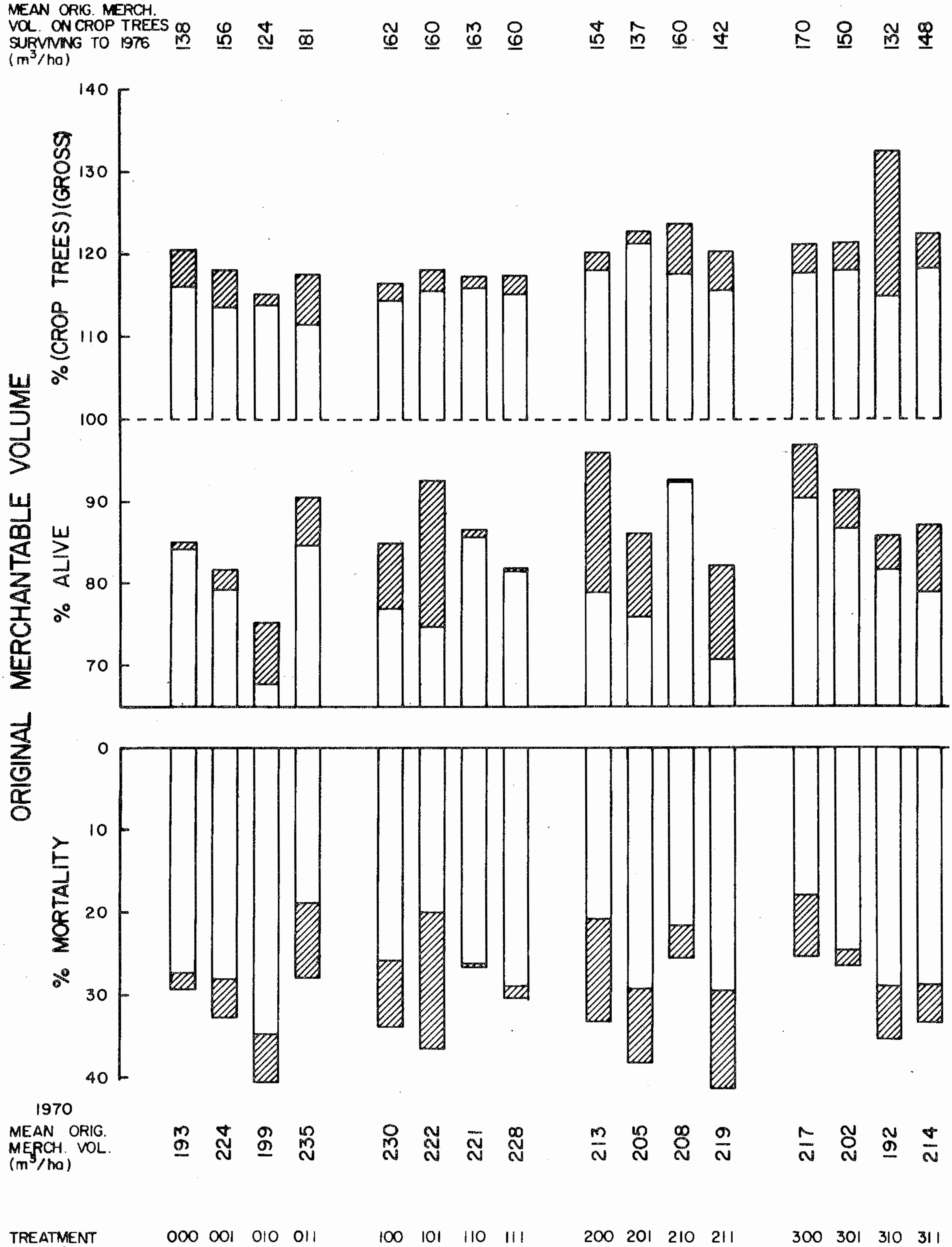

Fig. 5. Percentage merchantable volume status for balsam fir - Main Trial - 1976. (Crosshatched portions of bars represent differences between replicate plots.)

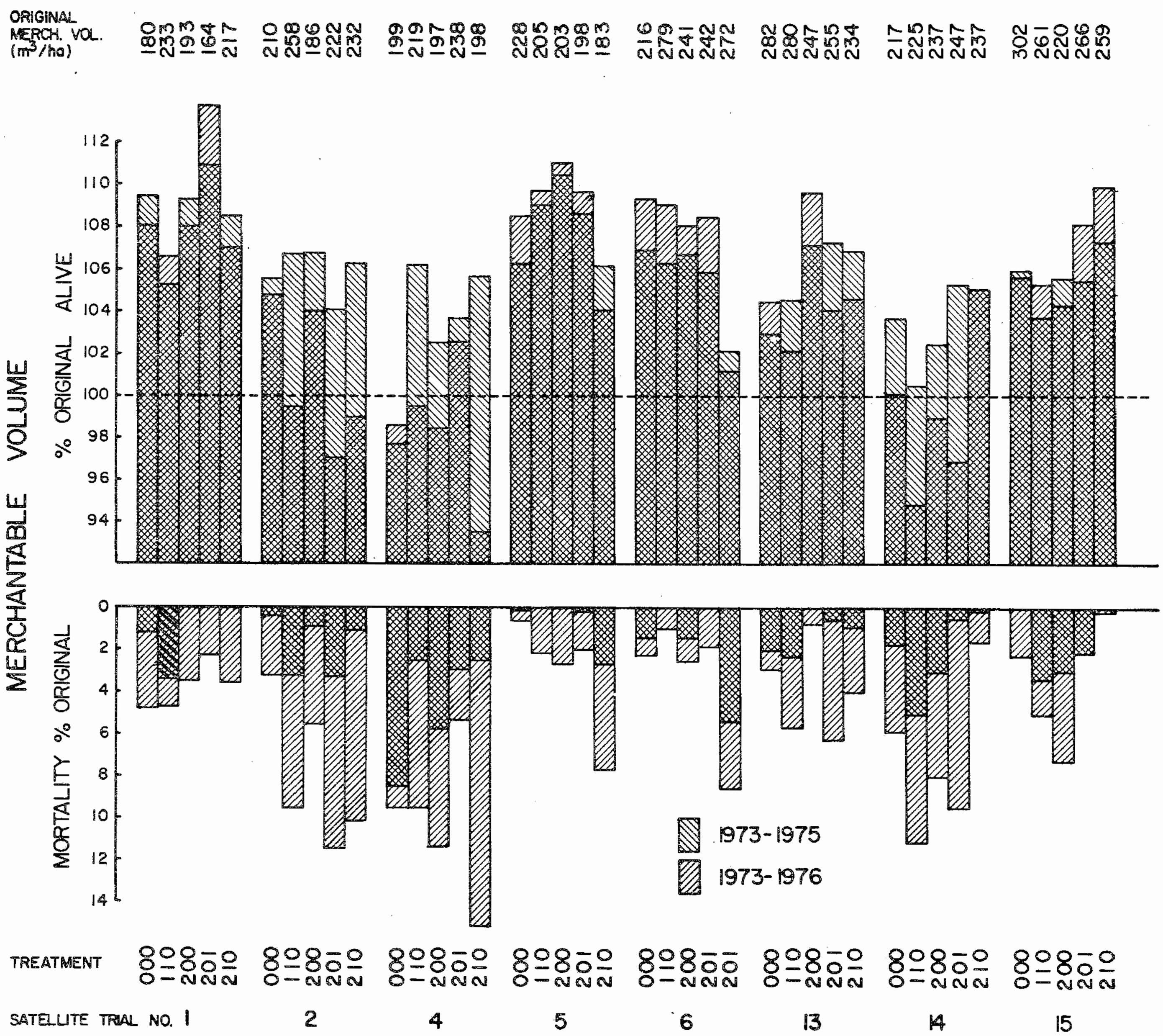

Fig. 6. Percentage merchantable volume status on Satellite Trials 1973-1975 and 1973-1976.

Table 4. Merchantable volumes on untreated plots on main trial and satellites

Trial	Merchantable volume: Original on stems surviving (m^3/ha)	Increment on living trees (m^3/ha)	% Increment
3	150.81	28.95	19.20
	158.88	25.19	15.85
1	161.23	24.60	15.26
	182.26	21.96	12.05
2	181.36	14.61	8.06
	225.16	18.86	8.38
4	150.84	14.64	9.71
	209.17	17.51	8.37
5	189.28	19.61	10.54
	264.79	21.93	8.28
6	170.25	23.66	13.90
	251.77	26.46	10.51
13	269.63	20.57	7.63
	278.89	22.04	7.90
14	201.79	13.09	6.49
	206.66	12.81	6.20
15	276.25	25.06	9.07
	313.24	23.52	7.51

Canada (Weetman *et al*. 1976, 1978, 1979), assume that original volumes on treated and untreated plots are similar. The conventional method also implicitly assumes that growth rates in the untreated state are similar, and thus any differences in growth between fertilized and control plots after treatment are the result of fertilizer addition. The percentage method of reporting results (Table 4) also makes this second assumption which appears to be incorrect. In 7 of the 9 trials reported in Table 4, the control replicate with the highest original merchantable volume produced the highest absolute volume increment while in 2 trials the opposite was true. In 7 of the 9 trials the control replicate with the lowest original merchantable volume produced the highest percentage volume increment, but in 2 of the trials the opposite was true. This suggests, in addition to the confounding influence of differential stocking on fertilizer response measurement, that differential growth rates or vigor, between plots, can be a confounding influence in attempting to asssess response to fertilizers. Salonius *et al*.* have suggested that one method of dealing with these problems is to treat each tree as its own control by comparing the growth of each tree in the post treatment period (10 years) with its own growth in the pretreatment period (10 years); summed growth for all trees on a plot after treatment is then reported as a percentage of summed growth for all trees on the plot in the pretreatment period. Percentage comparisons between treatments are then reported as relative responses to fertilization along with percentage mortality. This latter method could not be used in these stands because in many plots the trees have been removed during salvage harvest.

CONCLUSIONS

This study supports the view of Weetman *et al*. (1976) that further work in forest fertilization in mature stands should be confined to situations where significant mortality will not be experienced between treatment and harvest. Some of the results in the study shed serious doubts on the usefulness of much of the forest fertilization work published to date, which has used comparisons of absolute growth rates after treatment on fertilized and untreated control plots to assess fertilizer response with the implicit assumption that survivor stocking and growth rates in the absence of treatment are similar and thus differences in growth rates are solely the result of nutrient addition.

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