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Nutrient Accumulation in Planted Red and Jack Pine

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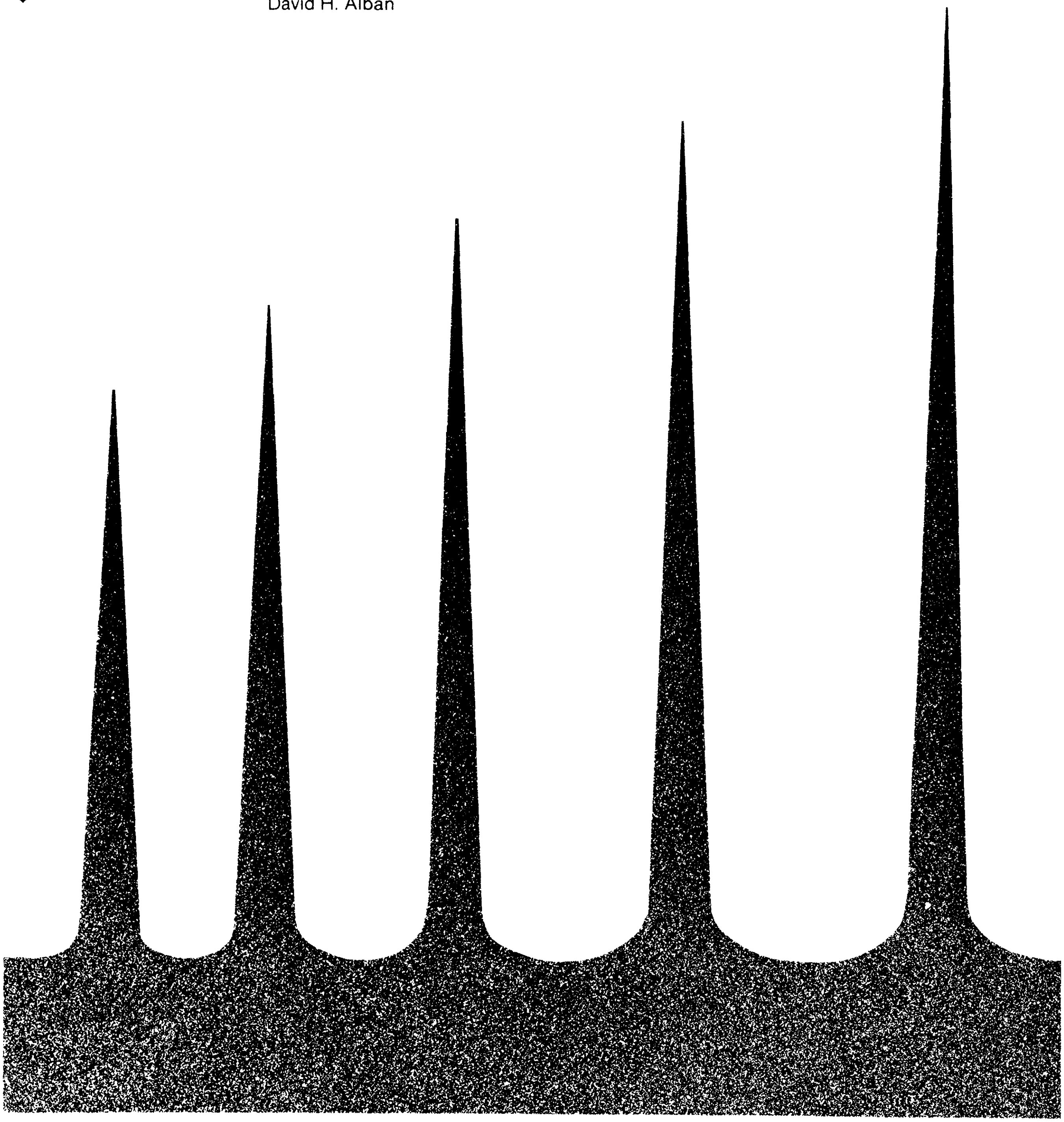

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Compares nutrient accumulation in adjacent plantations of red and jack pine in the upper Great Lakes. Describes equations developed to predict biomass and nutient accumulation based on stand basal area and height.

KEY WORDS: *Pinus banksiana*, *Pinus resinosa*, nitrogen, phosphorus, potassium, calcium, magnesium, upper Great Lakes.

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NUTRIENT ACCUMULATION IN PLANTED RED AND JACK PINE

David H. Alban

As forest management intensifies, rotations are usually shortened, trees are more completely utilized, and nutrient removals from a site are increased. The possibility of lowering site productivity through nutrient removals in timber harvesting is an increasing concern as forest management has intensified (Freedman 1981, Gessel 1986, Leaf 1979, Turvey 1981). Both red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.) can produce high yields under plantation management (Benzie 1977a,b; Lundgren 1983). Red pine, in particular, yields more than its most common associates under a range of site conditions (Alban 1985). Because red pine and jack pine are most commonly found on sandy, nutrient poor soils, the possibility for site degradation through nutrient loss is perhaps greater for these species than for others.

Rational decisions concerning nutrient management and long-term site productivity require knowledge of the nutrient content of forest stands and the amount of nutrients removed under various harvesting options. Few data are available on nutrient accumulation in red and jack pine plantations in the upper Great Lakes. Bockheim *et al.* (1986) reported nutrient accumulation in a red pine plantation in Wisconsin, and Perala and Alban (1982) documented nutrient accumulation in red and jack pine on two sites in Minnesota. Green and Grigal (1980) reported nutrient accumulation in natural stands of jack pine more than 50 years old from a restricted area of northeastern Minnesota.

In other geographic regions, Foster and Morrison (1976) examined nutrient accumulation in three natural jack pine stands in northern Ontario. Wittwer *et al.* (1975) determined nutrients in plantation red pine on potassium-deficient sites in New York. The applicability of these results to the upper Great Lakes is unknown.

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The purposes of this paper are to compare the nutrient accumulation in adjacent plantations of red and jack pine, and to develop models to predict nutrient content in these species as functions of easily measured stand variables.

METHODS

We sampled 24 stands of adjacent red and jack pine plantations scattered throughout the upper Great Lakes and ranging from 19 to 46 years in age (table 1). The sites represent a wide range of soils (although most are sandy) and nearly the complete range of site index for these species. None of the stands had been thinned.

In most cases the adjacent red and jack pine plantations were established the same year. For three stands, the ages for the two species differed (2, 3, and 5 years). For these stands the basal area (B) and height of dominant and codominant trees (H) of red pine were adjusted to the age of the jack pine stands. The B adjustment was made by the program REDPINE (Lundgren 1981), and the H adjustment was made from the site index equations for red pine (Lundgren and Dolid 1970). After this small adjustment, red and jack pine growth on each of the 24 adjacent stands could be compared directly.

At each site, soil borings were made to ensure that the adjacent plantations had been established on the same soil. Soils on each area were described and classified by National Forest or by Soil Conservation Service soil scientists. At each site, three 0.04 ha plots were established in both the red pine and the jack pine. On each plot the diameter (d.b.h.) of every tree was measured, and height was measured on 10 trees representing the range of diameters. Mean tree diameter and a height-diameter curve were calculated in the field. On each plot, one tree of mean bole volume was felled. Most of these trees were in the codominant crown class, as are most trees in the plantations sampled.

For each sample tree, the limbs and 1-meter bolts from the bole were removed and weighed in the

Table 1.—Mean stand and site characteristics

	Stand age (Years)	Red pine Basal area	Red pine Site index	Jack pine Basal area	Jack pine Site index	Location	Soil
		m^2/ha	m	m^2/ha	m		
	19	20.3	18.6	20.7	19.5	Minnesota	Menahga
	25	37.4	20.8	30.2	22.1	Minnesota	Zimmerman
	26	31.7	19.8	29.5	22.3	Minnesota	Unnamed
	30	50.1	22.3	37.1	21.0	Minnesota	Redby
	32	41.6	17.4	25.0	17.1	Wisconsin	Plainfield
	32	36.2	16.4	20.0	13.0	Upper Michigan	Grayling
	32	49.8	21.2	32.2	23.1	Upper Michigan	Rubicon
	32	44.9	19.8	32.5	21.5	Upper Michigan	Rubicon
	32	35.0	12.6	24.9	13.9	Lower Michigan	Grayling
	33	50.4	23.5	25.6	20.5	Lower Michigan	Graycalm
	34	39.0	16.3	28.2	18.8	Upper Michigan	Rubicon
	34	49.2	22.5	35.9	23.7	Minnesota	Unnamed
	34	51.8	21.7	33.4	24.2	Minnesota	Itasca
	35	36.5	15.7	22.9	14.8	Lower Michigan	Grayling
	35	54.7	20.0	21.9	18.1	Lower Michigan	Croswell
	35	36.4	19.0	22.2	17.6	Wisconsin	Vilas
	36	26.9	13.3	15.9	12.4	Lower Michigan	Grayling
	36	46.1	21.2	31.5	21.7	Upper Michigan	Kalkaska
	36	39.4	20.5	30.5	22.6	Wisconsin	Vilas
	39	49.5	22.0	26.8	21.9	Wisconsin	Padus
	39	51.9	20.7	35.1	21.0	Minnesota	Warba
	41	49.3	19.3	30.4	21.9	Minnesota	Cutaway
	46	57.2	18.9	25.2	18.7	Lower Michigan	Grattan
	46	61.5	21.1	30.3	19.3	Lower Michigan	Kalkaska
Mean	34	44	19.4	28	19.6		
Range	19-46	20-62	13-24	16-37	12-24		

field. Subsamples of the limbs and discs from the bolts were sealed in plastic bags and taken to the laboratory for separation of foliage from limbs and bole bark from the wood. All components (foliage, live branches, dead branches, bole bark, and bole wood) were dried at 75° C to determine oven-dry weights. Nutrients in each of the components were determined by a Technicon II AutoAnalyzer[1] (nitrogen and phosphorus) or by a Perkin-Elmer 5000 Atomic Absorption spectrophotometer (calcium, magnesium, potassium).

Stand biomass and nutrient content for each plot were obtained by multiplying the biomass and nutrient content of the sample tree times the number of trees per plot. Stand tree biomass and nutrient content were calculated as the mean of the three plots per species. The biomass and nutrient content of red and jack pine in each adjacent stand were compared by analysis of variance. Statistical testing was done at the 5 percent confidence level.

Stand tree biomass and nutrient content models were developed by regressing these variables against stand basal area or basal area times height. The form of the models developed was:

$$\ln(Y) = a + b \ln(X)$$

where Y is biomass or nutrient content, X is BH or B, and a and b are the coefficient estimates.

The ln-ln model form is appropriate for most forest biomass applications, but results in a bias in the a coefficient and the standard error. Bias was corrected by the method of Baskerville (1972).

[1]Mention of trade names does not constitute endorsement by the U.S. Forest Service.

Table 2.—*Total above-ground biomass and nutrient contents for each red and jack pine stand*

Stand age (Years)	Biomass		N		P		K		Ca		Mg	
	RP	JP	RP	JP	RP	JP	RP	JP	RP	JP	RP	JP
	t/ha		*kg/ha*									
19	46	56	148	185	16.7	19.5	68	75	86	105	19.8	21.2
25	117	120	287	282	31.6	27.7	138	133	183	164	45.6	36.2
26	85	111	180	226	22.5	22.9	92	93	133	169	28.1	29.3
30	153	147	341	311	45.3	33.0	128	110	239*	182	62.4*	49.8
32	120*	87	249	191	26.7*	16.3	114*	70	225*	124	39.6*	23.0
32	112*	66	268*	204	27.8*	15.8	109*	65	181*	128	35.3*	19.0
32	153	134	279*	237	33.4*	21.2	150*	101	258*	178	50.0*	32.6
32	146	129	323*	263	31.2*	21.8	127	06	255*	173	49.6*	32.9
32	77	84	214	229	23.5	21.6	99	90	185	156	32.8	28.3
33	194*	110	366*	230	43.5*	22.1	179*	93	343*	153	62.5*	26.6
34	111	116	229	228	23.7	19.1	103	99	152	130	32.0	29.7
34	186*	150	314*	217	37.7*	21.3	157*	113	266*	168	62.7*	37.2
34	180	171	291	243	33.6	27.4	165	132	274	219	51.0	43.6
35	106*	80	224	196	24.7*	17.8	100	77	182*	117	34.4*	21.8
35	191*	90	321*	202	28.6*	17.1	154*	89	306*	126	55.8*	21.5
35	118*	82	232*	146	23.8*	12.7	114*	75	183*	104	38.0*	20.8
36	69*	52	163*	139	16.3*	10.2	60*	49	146*	90	22.0*	12.1
36	162	145	276	254	31.7*	21.5	132	103	260*	177	46.2*	31.8
36	142	129	247*	175	28.3*	17.3	133*	88	207*	153	42.9	28.5
39	197*	131	371*	214	41.5*	18.0	176*	85	294*	150	63.1*	28.0
39	198*	148	343*	258	40.9*	24.5	174*	97	307*	197	57.3*	37.3
41	175*	130	287	229	32.3*	19.5	155*	105	271*	163	54.7*	34.6
46	235*	117	440*	216	42.0*	2.3	135*	78	408*	153	75.2*	24.8
46	284*	148	463*	320	50.0*	27.5	159*	95	395*	174	81.2*	29.9
Mean	148	115	286	228	32.0	21.0	130	94	239	154	48.0	29.5
Mean percent by which red pine is greater than jack pine	29		25		52		38		55		63	

*Significantly different from jack pine at the 5 percent confidence level.

RESULTS AND DISCUSSION

Accumulation in Adjacent Stands

In most plantations, red pine accumulated significantly more biomass and nutrients than jack pine (table 2); and in all the other cases, the differences were not significant. In its early years, jack pine grew more rapidly than red pine (Benzie 1977a,b), but by about age 20, the accumulation of volume, biomass, or nutrients was similar for these two species. Beyond this age, red pine accumulated significantly more biomass and nutrients in nearly all of the adjacent plantations examined (table 2).

Red pine biomass averaged 29 percent greater than jack pine biomass (table 2), which is somewhat less than the 40 percent differential in bolewood volume reported previously (Alban 1978). Species differences in volume are greater than in biomass, primarily because wood density of jack pine is about 10 percent greater than that of red pine (Alban 1978).

Red pine averages 25, 52, 38, 55, and 63 percent greater accumulation than jack pine of N, P, K, Ca, and Mg, respectively (table 2). Nutrient differences between these species are (except for nitrogen) larger than biomass differences. The greater nutrient accumulation of red pine is explained part-

Table 3.—*Mean tissue nutrient concentrations in adjacent stands of red and jack pine*

	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	RP	JP	RP	JP	RP	JP	RP	JP	RP	JP
	(ppm)									
Foliage	9,770*	12,800	1,090*	1,200	4,070	4,020	3,060*	3,350	940*	812
Live branch	3,320*	4,360	476*	534	1,910*	2,280	3,280*	2,060	615*	538
Dead branch	1,960*	2,360	96*	118	273	249	3,150*	1,720	331*	222
Bole bark	2,930	3,010	399*	287	1,290*	1,100	4,830*	4,390	581*	424
Bole wood	856*	786	80*	58	445	430	825*	710	192*	162

*Significantly different from jack pine at the 5 percent confidence level.

ly by its greater biomass and partly by its generally higher tissue nutrient concentration (table 3). Red pine nutrient concentrations of Ca and Mg are significantly higher than jack pine Ca and Mg concentrations for most tissues (table 3). For N and P, red pine concentrations are significantly higher or equal to jack pine concentrations in bole bark and bole wood, but lower in other tissues. Tissue K differed only slightly for red and jack pine.

By the age it is likely to be harvested, red pine will have produced significantly more biomass than jack pine, and will have accumulated even more of some nutrients, particularly P, Ca, and Mg. If nutrient removal by whole-tree harvesting is of concern, substantially fewer nutrients would be removed by leaving the crown on the site. In our study, we found that 36 to 64 percent of total above-ground nutrients are contained in the crown (foliage, live branches, and dead branches) (table 4). Harvesting in which the crown is left on the site will thus remove fewer nutrients, and with little reduction in yield because only 22 to 23 percent of the biomass is in the crown (table 4). For both species, bole-only harvesting will result in about a 50 percent reduction in nutrient removals from a site.

Table 4.—*Percent of total above-ground tree biomass and nutrients contained in the crown (foliage + live branches + dead branches)*

	Red pine		Jack pine	
	Mean percent in the crown	Standard deviation	Mean percent in the crown	Standard deviation
Biomass	22	6.5	23	7.6
N	58	7.1	60	8.6
P	61	6.9	64	7.6
K	55	6.0	53	8.6
Ca	42	9.0	36	8.9
Mg	45	8.5	43	9.0

Estimation of Accumulation

For most accurate results, nutrient accumulation on a specific site should be determined by felling trees, determining biomass, analyzing tree tissues for nutrients, and regressing nutrient contents against easily measured tree variables, such as d.b.h. and height. Such a costly, time-consuming procedure is seldom done.

An alternative approach presented here is to relate nutrient accumulation to easily measured stand variables, such as basal area and height. That such an approach might work is suggested by earlier studies that showed that volume (Buckman 1961) and biomass (Alban and Laidly 1982) were closely related to stand B and H for red and jack pine. For such an approach to work well for nutrients, the nutrient concentrations in a given tissue must not vary greatly from site to site in comparison with the variation in tissue biomass. That a species tissue nutrient concentration might not vary greatly seems reasonable because most nutrients are not limiting on most sites, and if a nutrient is not limiting, its concentration in a given tissue is largely genetically controlled. As an example, red pine bolewood biomass in the 24 stands of this study varied by a factor of 9 (25 to 228 t/ha), whereas N concentration in the same tissue varied by only a factor of 2 (667 to 1,125 ppm).

In the current study, good estimates (based on R^2 and the standard error of the mean) of biomass and macronutrient content accumulation can be made from stand basal area and height (table 5). For biomass, both B and H are necessary; for the nutrient contents, addition of H to the model with B does not improve the fit of the models. In either case, addition of variables for stand age, site index, or crown ratio does not materially improve the quality of fit. Biomass in these models is estimated with $S_{y \cdot x} / \bar{y}$ of 5 to 6 percent, and nutrient contents are about twice as variable.

Table 5.—*Models for estimating stand biomass and nutrient weights in total above-ground tree*[1]

	a	b	R^2	Sy • x	Sy • x/$\bar{y}$
RED PINE					
Biomass[1]	0.676	0.874	0.98	8.04	0.05
Nitrogen[1]	1.779	1.026	.85	32.15	.11
Phosphorus	.439	1.030	.80	4.31	.14
Potassium	1.127	.991	.79	17.48	.13
Calcium	.348	1.355	.91	26.38	.11
Magnesium	1.246	1.350	.91	5.49	.12
JACK PINE					
Biomass	0.015	0.783	0.97	6.90	0.06
Nitrogen	2.934	.751	.74	22.07	.10
Phosphorus	.330	1.006	.67	3.26	.16
Potassium	1.326	.966	.75	11.25	.12
Calcium	1.789	.976	.83	14.58	.09
Magnesium	1.341	1.417	.92	2.59	.09

[1]For biomass the model form is ln(Y) = a+ b ln(X), where Y is biomass in tons/ha, and X is B • H where B is stand basal area in m² /ha and H is height of dominant and codominant trees in m². For nutrients the model form is ln(Y) = a + b ln(X) where Y is nurtient content in kg/ha, and X is basal area in M² /ha.

Table 6.—*Models for estimating percentage of total tree biomass and nutrients in the crown (foliage + live branches + dead branches)*[1]

	a	b	R^2	Sy • x	Sy • x/$\bar{y}$
RED PINE					
Biomass[1]	99.0	−12.03	0.78	3.07	0.14
Nitrogen[1]	142.3	−13.09	.75	3.68	.06
Phosphorus	140.0	−1.030	.75	3.70	.06
Potassium	115.8	−9.44	.55	4.12	.07
Calcium	127.7	−13,42	.51	6.44	.15
Magnesium	141.0	−15.04	.70	4.75	.11
JACK PINE					
Biomass	111.8	−14.84	0.68	4.42	0.20
Nitrogen	161.5	−16.85	.67	5.09	.08
Phosphorus	157.7	−15.41	.72	4.14	.06
Potassium	160.7	−17.86	.75	4.41	.08
Calcium	141.9	−17.55	.68	5.17	.14
Magnesium	152.4	−18.27	.73	4.82	.11

[1]Model form:

$$Y = a + b \ln(X)$$

where Y is the percent of biomass or nutrients in the crown, and X = basal area (m²/ha) times height (m).

Total stand tree biomass estimated from the model in table 5 agrees very closely (nearly always within 5 percent) with values obtained from equations developed earlier (Alban and Laidly 1982). In that study, more stands were sampled because the restriction of adjacent plantations was not necessary. That study should be consulted for equations useful in calculating stand biomass by tree tissue components as a function of stand basal area and height.

The proportion of biomass and nutrients in the crown is also a function of stand B and H and can be estimated from the models in table 6. Models in tables 5 and 6 should be applicable to typical unthinned red and jack pine plantations from ages 20 to 50 throughout the upper Great Lakes region.

The restriction of no thinning should be no problem for jack pine, which is seldom thinned, and no problem for red pine grown on short rotation for maximum fiber; but for red pine grown on longer rotations, thinning is a common practice that typically first occurs at ages 25 to 35. The models in table 5 should be applicable up to the first thinning, but beyond that time, insufficient data exist to ge certain of the effects on nutrient accumulation. Thinning will certainly increase the size of a tree's crown (Stiell 1966), but it will also increase the tree's diameter so that the ratio of crown weight to total tree weight might not change greatly. For example, Bockheim *et al.* (1986) measured biomass 7 years after thinning in a 37-year-old red pine plantation in Wisconsin (crown weight was 26 percent of total above-ground tree), identical to the value calculated from the models in table 6. For a 52-year-old Minnesota red pine plantation thinned 12 years previously, we measured the crown weight to be 19 percent of total tree weight. For this stand, the crown proportion from table 6 was 21 percent. Thus, from an admittedly small sample, there is little evidence to indicate major changes in the proportion of crown weight for red pine. If thinning does not affect the nutrient concentration of the tissues, then the models of tables 5 and 6 may be applicable (with caution) to thinned stands also. Clearly, studies are needed to establish the effects of thinning on biomass and nutrient distribution in red pine plantations.

If the tissue nutrient concentrations for a given stand differ substantially from those in table 3, large errors may result in nutrient estimates based on the models in table 5. Such might be the case, for example, in areas known to be severely deficient in one or more nutrients. In that case, one way to derive nutrient content estimates short of a full scale biomass and nutrient inventory would be to use the nutrient concentrations determined for that site combined with generalized biomass estimates for each tissue based on basal area and height, which have been reported and verified previously (Alban and Laidly 1982). This approach was used successfully for jack pine by Green and Grigal (1980) in an area known to be low in phosphorus availability.

In addition to predicting nutrient accumulation for specific forest stands, the models presented here could also have more general application. For example, much of the growth information in the manager's handbooks for red and jack pine (Benzie 1977a,b) is presented in terms of basal area and height. Table 4 in the jack pine manager's handbook gives volume as a function of stand density (B), tree height (H), site index, and age. The models in table 5 of the current study could be used in conjunction with table 4 of the manager's handbook to estimate the effects of stand age and site index on nutrient accumulations.

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