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SITE INDEX COMPARISONS AMONG NORTHERN HARDWOODS IN NORTHERN WISCONSIN AND UPPER MICHIGAN

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SITE INDEX COMPARISONS AMONG NORTHERN HARDWOODS IN NORTHERN WISCONSIN AND UPPER MICHIGAN

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Northern hardwoods are the principal species found in many of the more important and widespread forest types of the United States and Canada. Forest types composed primarily of northern hardwood species cover about 37 million acres in the Lake States, the Northeast, and the Appalachian Plateau (USDA Forest Service 1973); in Canada, hardwood and mixedwood stands cover about 74 million acres (Quigley and Babcock 1969). Characteristic species in the Lake States are sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubrum* L.), and yellow birch (*Betula alleghaniensis* Britton). In certain areas American beech (*Fagus grandifolia* Ehrh.), American basswood (*Tilia americana* L.), American elm (*Ulmus americana* L.), and white ash (*Fraxinus americana* L.) are important stand components. Other associated species that occur less frequently are black ash (*F. nigra* Marsh.), black cherry (*Prunus serotina* Ehrh.), northern red oak (*Quercus rubra* L.), paper birch (*B. papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), and bigtooth aspen (*P. grandidentata* Michx.).[1]

Because of this profusion of species in northern hardwood forests, forest managers often are uncertain about which tree species to favor on a given area of land. For each site, species may differ in rate of growth and in volume and value of yield produced. Selecting the most desirable tree species for each site is a problem frequently encountered in timber stand improvement, thinning, final harvest prescriptions, stand conversion, and tree planting.

Site index is the most widely accepted method for estimating site quality in the United States and is based on age and height measurements taken from free growing, uninjured, dominant and codominant trees (Carmean 1975, 1977). Such trees are most commonly found in even-aged, fully stocked stands not severely disturbed by past logging. Even-aged, fully stocked, second-growth stands are common throughout the range of northern hardwood species; they developed following the removal of the original old growth stands by clearcutting or heavy harvest cutting. Dominant and codominant trees in these even-aged hardwood stands are well suited for site index estimation. Site index can now be estimated for northern hardwoods using recently published site curves for 13 species commonly found in the northern hardwood stands of northern Wisconsin and Upper Michigan (Carmean 1978).

Selecting the most desirable northern hardwood tree for each site not only requires accurate site information for each species of tree but also detailed information about site relations among the various hardwood species that might be considered for management. On a certain site should we favor yellow birch, black cherry, and white ash for veneer and high value log production, or should we manage aspen on short rotations? When a forest manager knows the site index for several alternative species he can then estimate the yield attained for each tree species. Such site and yield information provides a means for estimating and comparing the volume and value of wood products that different sites are capable of producing when stocked with these alternative tree species.

Even when site index curves are available northern hardwood stands rarely have measurable trees of all species for which site information is desired. For such stands site index of the absent species can be estimated from the site index of species that are present through the use of site index comparison graphs or equations (Curtis and

[1]Tree names follow Little (1953).

Post 1962, Foster 1959, Carmean and Vasilevsky 1971). No site index comparison studies are available for the northern hardwood species commonly found in the Lake States. Accordingly, this site index comparison study was made for hardwood species commonly found in even-aged northern hardwood stands of northern Wisconsin and Upper Michigan.

THE DATA

This site index comparison study is based on data collected from 204 plots established in or near the Chequamegon, Nicolet, Ottawa, and Hiawatha National Forests in northern Wisconsin and Upper Michigan. All plots were approximately 1/5-acre and were located in fully stocked, even-aged, undisturbed northern hardwood stands between 41 and 105 years of age; trees on each plot had a range in age no greater than 10 years. Several tree species usually occurred on each plot, and one to six dominant or codominant site trees of each species were felled. Sections were cut at a 6-inch stump height, at 2 feet, at 4.5 feet, and at 4-foot intervals thereafter up the bole; annual rings were carefully counted from disks cut at each section point.

Individual tree height-age curves were plotted using age counts at each section point. Trees with signs of early suppression, top breakage, or dieback, or that exceeded the defined 10 year age range for even-aged stands were deleted from the data. A total of 3,402 dominant and codominant trees were retained for computing site index curves for 13 species (Carmean 1978). For each species on each plot the individual tree height-age curves were combined into an average height-age curve. Site index (height at 50 years) for each species on each plot was then read directly from these average height-age curves. Most plots had site index estimates for at least two species, and a few plots had estimates for as many as eight. Site index values were recorded for all paired species combinations found on each plot (table 1). Species pairs such as sugar maple-yellow birch and sugar maple-American basswood were found on a large number of plots. In contrast, some species such as American beech, black cherry, paper birch, and the aspens were less common and paired combinations of them were rarely encountered.

ANALYSIS AND RESULTS

Scatter diagrams for 51 paired species combinations were made that compared site indices of the two paired species (table 1). This preliminary plotting revealed that certain species pairs were distinctly different and other species pairs were similar in site index. The scatter diagrams indicated that northern hardwood species, when growing together on the same plot, can be placed in four

Table 1.—*Species site-index comparisons were based on site index measurements for all possible species pairs found on 204 site plots located in northern Wisconsin and Upper Michigan*

Species	RM	YB	AB	B	E	WA	BA	NRO	BC	PB	A
	number of plots having paired observations										
Sugar maple (SM)	89	109	19	109	94	59	27	26	36	23	7
Red maple (RM)		71	13	45	39	30	19	23	33	16	8
Yellow birch (YB)			15	70	60	37	20	14	25	16	7
American beech (AB)				[1](4)	(3)	(3)	(0)	(1)	(6)	(2)	(0)
American basswood (B)					86	64	31	29	15	20	8
American elm (E)						51	34	15	16	12	7
White ash (WA)							27	22	(6)	9	7
Black ash (BA)								10	(1)	(3)	(3)
Northern red oak (NRO)									(6)	15	7
Black cherry (BC)										(5)	(1)
Paper birch (PB)											7
Aspens (A)											

[1]Numbers in parentheses are for those species pairs having too few plots for regression analyses.

general site index groupings: (a) *very high site* - aspens; (b) *high site* - white ash, American basswood, American elm, black ash, black cherry, northern red oak, and paper birch, (c) *medium site* - sugar maple, red maple, and yellow birch, and (d) *low site* - American beech.

No curvilinear trends appeared, so linear regression equations were computed for each species pair using site index of one species as the dependent variable and site index of the other species as the independent variable. Because either of the species can be used as the dependent variable, two separate equations were computed for each of the species pairs (table 2). The resulting equations accounted for from 38 to 91 percent (r^2) of the variation in site index of the dependent variable associated with the various species pairs.

The two computed equations for each species pair are the most precise means for directly calculating site index of one species based on measured site index of an associated species (table 2). However, when making such calculations the equations should be used only to estimate site index of the dependent and not site index of the independent variable—that is, the equations should only be solved forward and not backward. One of the goals of this study is to construct site index comparison graphs that can be used to convert site index measured from species present in the stand to site index of other species that are absent. For convenience we should be able to use such graphs forward or backward to estimate site index of either of the paired species. So a third equation was determined graphically that averaged the two equations computed for each of the species pairs (table 2) (Carmean and Vasilevsky 1971).

Group Combinations

Preliminary plotting had indicated that site indices for several species pairs were similar, thus the next step in computation was to group the species with similar site indices and regressions. Trend graphs were plotted using the average regression equations for each of the 51 species pairs. These graphs were then used to observe the magnitude of the site index differences between the two paired species. The regression coefficients of the two computed equations and their associated standard errors were also examined to determine if significant differences existed between regressions for the two paired species.

This examination of graphs and regression coefficients confirmed the initial general species groupings observed by the preliminary plotting. Also an additional 4 groupings were found among the 7 "high site" species (table 3). On each plot, species within each group were combined to obtain a weighted average site index for the group. Linear regressions were then computed for 14 group pairs (table 4). A graphically determined average equation also was obtained for each of the 14 group pairs based on the two computed equations.

For each species or group pair the most precise site index estimates can be made using either of the two computed equations (tables 2 and 4). But site index estimates from the graphically determined average equations are similar to values estimated using either of the two computed equations; similar site index estimates are most likely for medium levels of site index and when the two computed equations do not differ greatly. The graphically determined average equations are convenient because they can be solved forward or backward and thus are suited for calculating species site index comparison graphs.

The average equations can be used to calculate individual site index comparison graphs for any of the species pairs (table 2) or group pairs (table 4). However, a single graph combining all 13 species is most convenient for field use; also a single graph can better illustrate differences in site index between tree species at different levels of site quality. Accordingly, the average equations for the group pairs were used to construct a graph that compared site indices among all 13 species (fig. 1). This comparison graph was calculated using the six average equations where predicted site index is the weighted average combining sugar maple, red maple, and yellow birch; similar trends are predicted by the other eight equations that use other species groups as the dependent variable (table 4). Trend lines of this graph are restricted to the range of site index observed on the plots and also to the range in which site indices differ by no more than 5 feet when calculated by either of the two computed equations.

Site Relations and Soil Drainage

The previous analyses showed that the regression equations accounted for from 38 to 91 percent

Table 2.—*Regression equations relating site index between all possible species pairs among northern hardwood species (also given are equations that average the trends of the two equations listed for each species pair)*

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
	No.	feet			feet
Sugar maple	89	42-74	[1]$SI_{SM} = 3.336+0.930\ (SI_{RM})$	0.79	3.14
Red maple	89	42-73	[1]$SI_{RM} = 9.362+0.851\ (SI_{SM})$	0.79	3.00
			$SI_{SM} = -3.563+1.048\ (SI_{RM})$		
Sugar maple	109	42-75	[1]$SI_{SM} = 6.787+0.885\ (SI_{YB})$	0.73	3.66
Yellow birch	109	40-76	[1]$SI_{YB} = 10.327+0.825\ (SI_{SM})$	0.73	3.53
			$SI_{SM} = -2.119+1.036\ (SI_{YB})$		
Sugar maple	19	47-65	$SI_{SM} = 25.063+0.611\ (SI_{AB})$	0.38	3.86
Am. beech	19	45-61	$SI_{AB} = 17.057+0.628\ (SI_{SM})$	0.38	3.91
			$SI_{SM} = 4.902+0.989\ (SI_{AB})$		
Sugar maple	109	42-75	[1]$SI_{SM} = 6.299+0.832\ (SI_{B})$	0.68	3.77
Am. basswood	109	45-80	[1]$SI_{B} = 15.101+0.821\ (SI_{SM})$	0.68	3.74
			$SI_{SM} = -4.970+1.008\ (SI_{B})$		
Sugar maple	94	43-75	[1]$SI_{SM} = 10.609+0.766\ (SI_{E})$	0.71	3.52
Am. elm	94	47-81	[1]$SI_{E} = 8.840+0.925\ (SI_{SM})$	0.71	3.87
			$SI_{SM} = 1.262+0.912\ (SI_{E})$		
Sugar maple	59	42-75	$SI_{SM} = 11.189+0.728\ (SI_{WA})$	0.69	3.88
White ash	59	46-84	$SI_{WA} = 10.572+0.941\ (SI_{SM})$	0.69	4.41
			$SI_{SM} = 1.006+0.880\ (SI_{WA})$		
Sugar maple	27	42-70	$SI_{SM} = 7.706+0.801\ (SI_{BA})$	0.60	4.48
Black ash	27	52-78	$SI_{BA} = 20.285+0.743\ (SI_{SM})$	0.60	4.31
			$SI_{SM} = -7.746+1.041\ (SI_{BA})$		
Sugar maple	26	42-70	$SI_{SM} = 0.906+0.885\ (SI_{NRO})$	0.44	4.23
N. red oak	26	57-72	$SI_{NRO} = 35.432+0.493\ (SI_{SM})$	0.44	3.16
			$SI_{SM} = -25.774+1.304\ (SI_{NRO})$		
Sugar maple	36	42-68	$SI_{SM} = 14.384+0.729\ (SI_{BC})$	0.73	3.22
Black cherry	36	47-73	$SI_{BC} = 2.176+1.000\ (SI_{SM})$	0.73	3.77
			$SI_{SM} = 6.752+0.854\ (SI_{BC})$		
Sugar maple	23	43-69	$SI_{SM} = 6.306+0.809\ (SI_{PB})$	0.59	4.24
Paper birch	23	47-72	$SI_{PB} = 21.018+0.726\ (SI_{SM})$	0.59	4.24
			$SI_{SM} = -8.975+1.055\ (SI_{PB})$		
Sugar maple	7	42-75	$SI_{SM} = 2.624+0.780\ (SI_{A})$	0.61	7.82
Aspens	7	65-85	$SI_{A} = 25.430+0.776\ (SI_{SM})$	0.61	7.81
			$SI_{SM} = -12.575+0.998\ (SI_{A})$		
Red maple	71	42-73	$SI_{RM} = 7.837+0.876\ (SI_{YB})$	0.70	3.60
Yellow birch	71	40-72	$SI_{YB} = 10.943+0.802\ (SI_{RM})$	0.70	3.44
			$SI_{RM} = -2.119+1.048\ (SI_{YB})$		
Red maple	13	50-63	$SI_{RM} = 28.555+0.547\ (SI_{AB})$	0.38	3.47
Am. beech	13	45-60	$SI_{AB} = 13.616+0.688\ (SI_{RM})$	0.38	3.89
			$SI_{RM} = 9.510+0.904\ (SI_{AB})$		
Red maple	45	43-72	$SI_{RM} = 4.068+0.881\ (SI_{B})$	0.79	3.40
Am. basswood	45	45-74	$SI_{B} = 9.417+0.892\ (SI_{RM})$	0.79	3.42
			$SI_{RM} = -2.628+0.991\ (SI_{B})$		

(Table 2 continued on next page)

(Table 2 continued)

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
Red maple	39	46-71	$SI_{RM} = 19.926+0.628\,(SI_E)$	0.56	4.09
Am. elm	39	47-76	$SI_E = 8.686+0.899\,(SI_{RM})$	0.56	4.90
			$SI_{RM} = 6.729+0.844\,(SI_E)$		
Red maple	30	46-70	$SI_{RM} = 21.977+0.593\,(SI_{WA})$	0.63	4.02
White ash	30	44-76	$SI_{WA} = 0.017+1.065\,(SI_{RM})$	0.63	5.39
			$SI_{RM} = 11.937+0.751\,(SI_{WA})$		
Red maple	19	43-68	$SI_{RM} = 5.616+0.870\,(SI_{BA})$	0.60	4.42
Black ash	19	51-70	$SI_{BA} = 20.283+0.688\,(SI_{RM})$	0.60	3.93
			$SI_{RM} = -9.376+1.119\,(SI_{BA})$		
Red maple	23	46-72	$SI_{RM} = -1.339+0.951\,(SI_{NRO})$	0.72	3.79
N. red oak	23	50-74	$SI_{NRO} = 18.470+0.760\,(SI_{RM})$	0.72	3.39
			$SI_{RM} = -11.597+1.114\,(SI_{NRO})$		
Red maple	33	42-72	$SI_{RM} = 19.203+0.655\,(SI_{BC})$	0.58	4.33
Black cherry	33	42-73	$SI_{BC} = 8.391+0.889\,(SI_{RM})$	0.58	5.05
			$SI_{RM} = 6.478+0.864\,(SI_{BC})$		
Red maple	16	46-72	$SI_{RM} = -3.591+0.999\,(SI_{PB})$	0.67	4.75
Paper birch	16	47-70	$SI_{PB} = 21.976+0.675\,(SI_{RM})$	0.67	3.90
			$SI_{RM} = -16.538+1.215\,(SI_{PB})$		
Red maple	8	46-70	$SI_{RM} = -11.216+1.047\,(SI_A)$	0.80	4.01
Aspens	8	53-75	$SI_A = 21.133+0.766\,(SI_{RM})$	0.80	3.44
			$SI_{RM} = -18.897+1.168\,(SI_A)$		
Yellow birch	15	51-65	[1]$SI_{YB} = 25.611+0.614\,(SI_{AB})$	0.43	2.80
Am. beech	15	48-61	$SI_{AB} = 12.459+0.703\,(SI_{YB})$	0.43	3.00
			$SI_{YB} = 7.717+0.948\,(SI_{AB})$		
Yellow birch	70	40-76	$SI_{YB} = 2.585+0.883\,(SI_B)$	0.78	3.45
Am. basswood	70	45-78	$SI_B = 11.951+0.880\,(SI_{YB})$	0.78	3.44
			$SI_{YB} = -4.758+0.998\,(SI_B)$		
Yellow birch	60	43-76	$SI_{YB} = 11.861+0.746\,(SI_E)$	0.78	2.93
Am. elm	60	47-81	$SI_E = 1.371+1.050\,(SI_{YB})$	0.78	3.47
			$SI_{YB} = 5.216+0.850\,(SI_E)$		
Yellow birch	37	43-76	$SI_{YB} = 12.318+0.715\,(SI_{WA})$	0.68	4.02
White ash	37	46-84	$SI_{WA} = 9.273+0.956\,(SI_{YB})$	0.68	4.65
			$SI_{YB} = 1.885+0.872\,(SI_{WA})$		
Yellow birch	20	48-68	[1]$SI_{YB} = 22.082+0.585\,(SI_{BA})$	0.61	3.49
Black ash	20	52-78	[1]$SI_{BA} = 1.628+1.049\,(SI_{YB})$	0.61	4.68
			$SI_{YB} = 11.436+0.751\,(SI_{BA})$		
Yellow birch	14	51-68	$SI_{YB} = 3.045+0.849\,(SI_{NRO})$	0.74	2.52
N. red oak	14	58-72	$SI_{NRO} = 14.390+0.867\,(SI_{YB})$	0.74	2.55
			$SI_{YB} = -6.197+0.992\,(SI_{NRO})$		
Yellow birch	25	42-71	$SI_{YB} = 18.053+0.674\,(SI_{BC})$	0.61	4.06
Black cherry	25	42-73	$SI_{BC} = 7.385+0.899\,(SI_{YB})$	0.61	4.69
			$SI_{YB} = 6.718+0.863\,(SI_{BC})$		
Yellow birch	16	42-67	$SI_{YB} = -0.735+0.903\,(SI_{PB})$	0.73	3.79
Paper birch	16	47-72	$SI_{PB} = 17.342+0.806\,(SI_{YB})$	0.73	3.58
			$SI_{YB} = -10.258+1.058\,(SI_{PB})$		

(Table 2 continued on next page)

(Table 2 continued)

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
Yellow birch	7	53-76	$SI_{YB} = -5.865+0.934\ (SI_A)$	0.89	3.75
Aspens	7	53-85	$SI_A = 12.670+0.958\ (SI_{YB})$	0.89	3.80
			$SI_{YB} = -9.885+0.994\ (SI_A)$		
Am. basswood	86	48-80	$SI_B = 14.611+0.770\ (SI_E)$	0.70	3.59
Am. elm	86	47-81	$SI_E = 6.421+0.904\ (SI_B)$	0.70	3.89
			$SI_B = 4.856+0.921\ (SI_E)$		
Am. basswood	64	45-80	$SI_B = 18.977+0.689\ (SI_{WA})$	0.70	3.66
White ash	64	44-84	$SI_{WA} = 0.885+1.012\ (SI_B)$	0.70	4.45
			$SI_B = 9.642+0.828\ (SI_{WA})$		
Am. basswood	31	47-78	$SI_B = 13.427+0.797\ (SI_{BA})$	0.63	4.19
Black ash	31	51-78	$SI_{BA} = 13.243+0.789\ (SI_B)$	0.63	4.17
			$SI_B = -0.256+1.010\ (SI_{BA})$		
Am. basswood	29	45-75	[1]$SI_B = -5.183+1.065\ (SI_{NRO})$	0.76	3.10
N. red oak	29	50-74	[1]$SI_{NRO} = 19.132+0.711\ (SI_B)$	0.76	2.53
			$SI_B = -15.079+1.221\ (SI_{NRO})$		
Am. basswood	15	50-74	$SI_B = 26.527+0.592\ (SI_{BC})$	0.68	3.96
Black cherry	15	49-74	$SI_{BC} = -10.699+1.151\ (SI_B)$	0.68	5.53
			$SI_B = 18.257+0.725\ (SI_{BC})$		
Am. basswood	20	49-74	$SI_B = 9.115+0.825\ (SI_{PB})$	0.67	3.81
Paper birch	20	47-72	$SI_{PB} = 13.238+0.813\ (SI_B)$	0.67	3.78
			$SI_B = -1.913+1.001\ (SI_{PB})$		
Am. basswood	8	45-78	$SI_B = 1.483+0.855\ (SI_A)$	0.72	6.40
Aspens	8	53-85	$SI_A = 17.712+0.847\ (SI_B)$	0.72	6.37
			$SI_B = -8.775+1.004\ (SI_A)$		
Am. elm	51	49-81	$SI_E = 10.769+0.807\ (SI_{WA})$	0.78	3.28
White ash	51	46-84	[1]$SI_{WA} = 4.696+0.963\ (SI_E)$	0.78	3.58
			$SI_E = 3.405+0.916\ (SI_{WA})$		
Am. elm	34	45-76	[1]$SI_E = 13.004+0.804\ (SI_{BA})$	0.65	4.19
Black ash	34	48-76	[1]$SI_{BA} = 11.452+0.814\ (SI_E)$	0.65	4.22
			$SI_E = 0.946+0.993\ (SI_{BA})$		
Am. elm	15	60-75	$SI_E = 7.671+0.903\ (SI_{NRO})$	0.39	3.91
N. red oak	15	59-72	$SI_{NRO} = 35.862+0.429\ (SI_E)$	0.39	2.69
			$SI_E = -24.195+1.402\ (SI_{NRO})$		
Am. elm	16	47-73	$SI_E = 14.628+0.792\ (SI_{BC})$	0.78	3.89
Black cherry	16	42-74	$SI_{BC} = -0.755+0.984\ (SI_E)$	0.78	4.33
			$SI_E = 8.384+0.893\ (SI_{BC})$		
Am. elm	12	49-76	$SI_E = 5.168+0.899\ (SI_{PB})$	0.71	4.49
Paper birch	12	47-72	$SI_{PB} = 14.042+0.784\ (SI_E)$	0.71	4.20
			$SI_E = -5.084+1.066\ (SI_{PB})$		
Am. elm	7	49-81	$SI_E = 5.206+0.816\ (SI_A)$	0.83	4.81
Aspens	7	53-85	$SI_A = 6.593+1.011\ (SI_E)$	0.83	5.35
			$SI_E = -0.214+0.896\ (SI_A)$		
White ash	27	51-76	$SI_{WA} = 3.969+0.981\ (SI_{BA})$	0.75	3.44
Black ash	27	52-76	$SI_{BA} = 12.862+0.766\ (SI_{WA})$	0.75	3.04
			$SI_{WA} = -5.428+1.128\ (SI_{BA})$		

(Table 2 continued on next page)

(Table 2 continued)

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
White ash	22	44-76	$SI_{WA} = -22.933+1.362\ (SI_{NRO})$	0.77	3.95
N. red oak	22	50-72	[1]$SI_{NRO} = 27.478+0.566\ (SI_{WA})$	0.77	2.55
			$SI_{WA} = -34.762+1.549\ (SI_{NRO})$		
White ash	9	46-74	$SI_{WA} = -3.853+1.023\ (SI_{PB})$	0.69	5.18
Paper birch	9	47-70	$SI_{PB} = 21.765+0.674\ (SI_{WA})$	0.69	4.21
			$SI_{WA} = -16.344+1.225\ (SI_{PB})$		
White ash	7	44-84	$SI_{WA} = -17.000+1.111\ (SI_{A})$	0.85	5.86
Aspens	7	60-85	$SI_{A} = 23.089+0.767\ (SI_{WA})$	0.85	4.87
			$SI_{WA} = -23.105+1.201\ (SI_{A})$		
Black ash	10	52-76	$SI_{BA} = -9.946+1.154\ (SI_{NRO})$	0.51	4.99
N. red oak	10	58-72	$SI_{NRO} = 35.708+0.444\ (SI_{BA})$	0.51	3.09
			$SI_{BA} = -37.214+1.579\ (SI_{NRO})$		
N. red oak	15	50-74	$SI_{NRO} = 0.014+0.997\ (SI_{PB})$	0.63	4.35
Paper birch	15	54-70	$SI_{PB} = 23.734+0.628\ (SI_{NRO})$	0.63	3.46
			$SI_{NRO} = -16.401+1.255\ (SI_{PB})$		
N. red oak	7	50-74	$SI_{NRO} = 15.208+0.672\ (SI_{A})$	0.59	5.38
Aspens	7	56-80	$SI_{A} = 13.919+0.883\ (SI_{NRO})$	0.59	6.16
			$SI_{NRO} = 1.756+0.872\ (SI_{A})$		
Paper birch	7	47-69	$SI_{PB} = 5.271+0.849\ (SI_{A})$	0.91	2.37
Aspens	7	53-75	$SI_{A} = -0.239+1.077\ (SI_{PB})$	0.91	2.67
			$SI_{PB} = 2.296+0.818\ (SI_{A})$		

[1]Correlations significantly improved (0.05) when a drainage variable is added to the listed linear regressions.

Table 3.—*Northern hardwood groups that combine species that are similar in site index (site-index comparisons were made among these group pairs)*

Species and species groups	SM RM YB	B E BA	WA	BC	NRO PB	A
		number of plots having paired observations				
LOW SITE—American beech	19	[1](4)	(3)	(6)	(2)	(0)
MEDIUM SITE—Sugar maple, red maple yellow birch		140	70	40	50	12
HIGH SITE—a) American basswood, American elm, black ash			68	21	43	10
b) White ash				(6)	26	7
c) Black cherry					8	(1)
d) Northern red oak, paper birch						10
VERY HIGH SITE— Aspens						

[1]Numbers in parentheses are for those group pairs having too few plots for regression analyses.

Table 4.—*Regression equations relating site index between species groups composed of species that are similar in site index (also given are equations that average the trends of the two equations listed for each group pair)*

Species group comparisons	Paired observations	Site index range	Equations	Coefficient of determination(r^2)	Standard error of estimate
	No.	feet			feet
Sugar maple, Red maple, Yellow birch	19	50-62	$SI_{SM,RM,YB} = 29.156+0.540\ (SI_{AB})$	0.49	2.75
Am. beech	19	45-61	$SI_{AB} = 0.947+0.904\ (SI_{SM,RM,YB})$	0.49	3.57
			$^2SI_{SM,RM,YB} = 16.190+0.783\ (SI_{AB})$		
Sugar maple, Red maple, Yellow birch	140	43-76	$SI_{SM,RM,YB} = 8.024+0.807\ (SI_{B,E,BA})$	0.78	3.08
Am. basswood, Am. elm, Black ash	140	45-80	$SI_{B,E,BA} = 6.004+0.969\ (SI_{SM,RM,YB})$	0.78	3.37
			$^2SI_{SM,RM,YB} = 1.469+0.911\ (SI_{B,E,BA})$		
Sugar maple, Red maple, Yellow birch	70	44-76	$SI_{SM,RM,YB} = 18.632+0.663\ (SI_{WA})$	0.64	3.77
White ash	70	44-84	$SI_{WA} = 4.615+1.033\ (SI_{SM,RM,YB})$	0.64	4.86
			$^2SI_{SM,RM,YB} = 7.913+0.783\ (SI_{WA})$		
Sugar maple, Red maple, Yellow birch	40	42-72	$SI_{SM,RM,YB} = 18.009+0.675\ (SI_{BC})$	0.67	3.74
Black cherry	40	42-74	$SI_{BC} = 2.109+0.998\ (SI_{SM,RM,YB})$	0.67	4.56
			$^2SI_{SM,RM,YB} = 8.697+\ .826\ (SI_{BC})$		
Sugar maple, Red maple, Yellow birch	50	44-72	$SI_{SM,RM,YB} = 0.831+0.905\ (SI_{NRO,PB})$	0.68	3.83
N. red oak, Paper birch	50	47-72	$SI_{NRO,PB} = 19.553+0.748\ (SI_{SM,RM,YB})$	0.68	3.48
			$^2SI_{SM,RM,YB} = -11.199+1.098\ (SI_{NRO,PB})$		
Sugar maple, Red maple, Yellow birch	12	44-76	$SI_{SM,RM,YB} = -0.847+0.857\ (SI_{A})$	0.76	4.80
Aspens	12	53-85	$SI_{A} = 16.972+0.886\ (SI_{SM,RM,YB})$	0.76	4.88
			$^2SI_{SM,RM,YB} = -9.218+0.981\ (SI_{A})$		
Am. basswood, Am. elm, Black ash	68	45-80	$SI_{B,E,BA} = 15.727+0.733\ (SI_{WA})$	0.79	3.01
White ash	68	44-84	$SI_{WA} = -3.361+1.084\ (SI_{B,E,BA})$	0.79	3.66
			$SI_{B,E,BA} = 9.608+0.825\ (SI_{WA})$		
Am. basswood, Am. elm, Black ash	21	48-74	$SI_{B,E,BA} = 21.549+0.681\ (SI_{BC})$	0.70	3.93
Black cherry	21	42-74	$SI_{BC} = -3.436+1.025\ (SI_{B,E,BA})$	0.70	4.82
			$SI_{B,E,BA} = 13.407+0.813\ (SI_{BC})$		

(Table 4 continued on next page)

(Table 4 continued)

Species group comparisons	Paired observations	Site index range	Equations	Coefficient of determination(r^2)	Standard error of estimate
Am. basswood, Am. elm, Black ash	43	45-75	$SI_{B,E,BA} = 0.610+0.982\ (SI_{NRO,PB})$	0.74	3.48
N. red oak, Paper birch	43	47-72	$SI_{NRO,PB} = 15.579+0.757\ (SI_{B,E,BA})$	0.74	3.05
			$SI_{B,E,BA} = -9.013+1.136\ (SI_{NRO,PB})$		
Am. basswood, Am. elm, Black ash	10	45-80	[1]$SI_{B,E,BA} = -2.907+0.923\ (SI_A)$	0.76	5.61
Aspens	10	53-85	$SI_A = 18.510+0.825\ (SI_{B,E,BA})$	0.76	5.30
			$SI_{B,E,BA} = -11.886+1.056\ (SI_A)$		
White ash	26	44-77	[1]$SI_{WA} = -20.429+1.330\ (SI_{NRO,PB})$	0.75	4.47
N. red oak, Paper birch	26	47-72	$SI_{NRO,PB} = 27.222+0.564\ (SI_{WA})$	0.75	2.91
			[1]$SI_{WA} = -33.250+1.534\ (SI_{NRO,PB})$		
White ash	7	44-84	$SI_{WA} = -17.000+1.111\ (SI_A)$	0.85	5.86
Aspens	7	60-85	$SI_A = 23.089+0.767\ (SI_{WA})$	0.85	4.87
			$SI_{WA} = -23.105+1.201\ (SI_A)$		
Black cherry	8	49-73	[1]$SI_{BC} = 4.211+0.927\ (SI_{NRO,PB})$	0.77	4.16
N. red oak, Paper birch	8	49-71	$SI_{NRO,PB} = 11.568+0.826\ (SI_{BC})$	0.77	3.93
			[1]$SI_{BC} = -4.098+1.056\ (SI_{NRO,PB})$		
N. red oak, Paper birch	10	47-71	$SI_{NRO,PB} = 14.394+0.684\ (SI_A)$	0.71	4.07
Aspens	10	53-80	$SI_A = 4.113+1.034\ (SI_{NRO,PB})$	0.71	5.00
			$SI_{NRO,PB} = 5.629+0.819\ (SI_A)$		

[1]Correlations significantly improved (0.05) when a drainage variable is added to the listed linear regressions.
[2]Average equations used for calculating the general species site index comparison graph (fig. 1).

(r^2) of the total site index variation between species pairs (table 2) or group pairs (table 4). Such results represent an acceptable level of precision, however, efforts were made to further reduce data variation and thereby make the regression equations even more precise. Soil profile descriptions for each site plot were used to classify soil drainage based on depth to mottling and on the amount and brightness of mottling (USDA Soil Conservation Service 1975). A comparison between residuals (difference between actual and predicted site index) and soil drainage revealed that a portion of the remaining variation of the regressions was associated with soil drainage.

A linear transformation of the soil drainage classification for each plot[2] was added to all regressions between species pairs (table 2) and group pairs (table 4). An additional quadratic transformation of the drainage variable also was added to test for curvilinear relations. Adding this drainage variable significantly improved the precision

[2]Drainage classes (USDA, Soil Conservation Service 1975) are: poorly drained = 1; somewhat poorly drained = 2; moderately well drained = 3; well-drained = 4; and excessively drained = 5. Drainage classes were estimated to the nearest 0.1 to allow for gradations between classes (fig. 3).

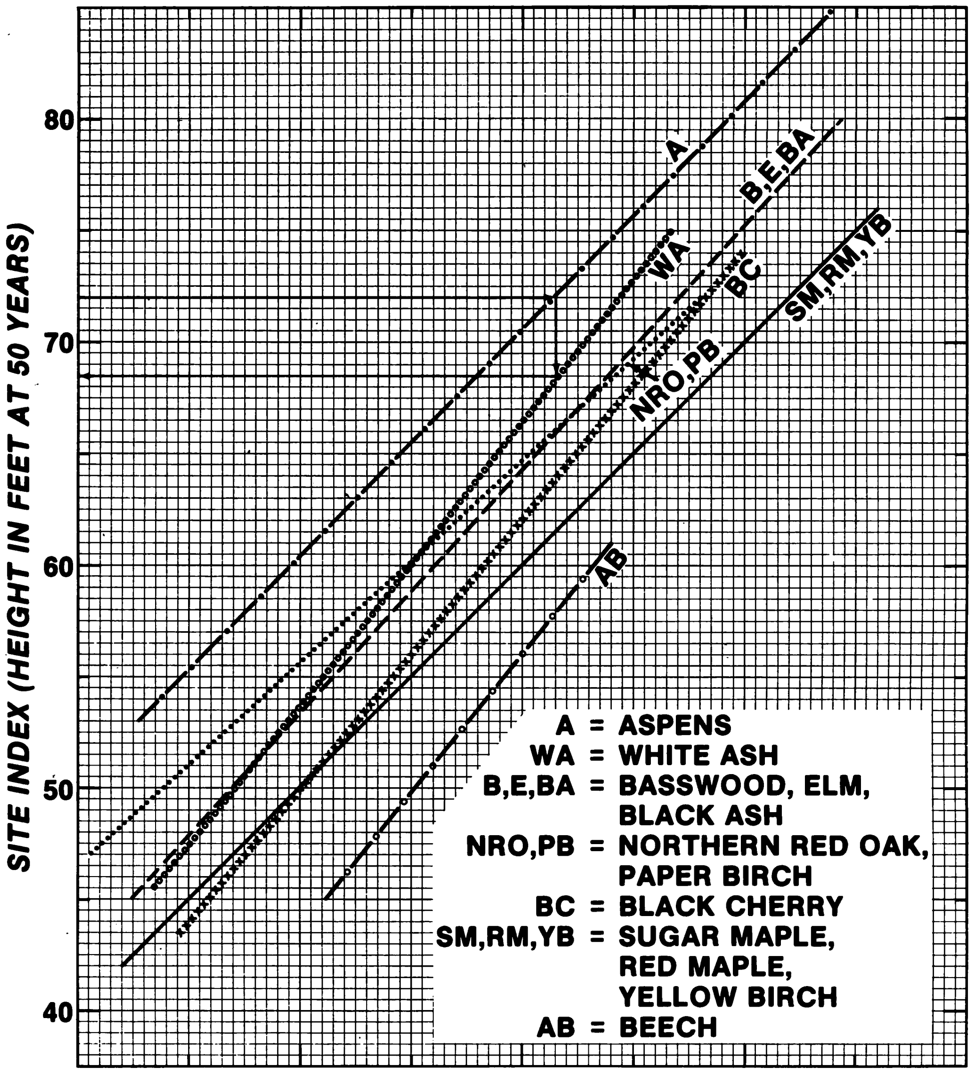


Figure 1.—*Site index comparison graphs for northern hardwood species in northern Wisconsin and Upper Michigan. These graphs can be used to estimate site index for species absent from forest stands by using site-index estimates of tree species that are present. For example, suppose you would like to estimate the site index for white ash in a certain stand, but there are no white ash trees present. However, there are suitable aspen trees present, and their average height and age measurements indicate that their site index is 72 (Carmean 1978). So, on the graph begin at 72 on the site-index scale and read right to the aspen line, then read straight down to the white ash line. Now read left to the site-index scale where estimated site index for white ash is found to be 68.5. The reverse of this procedure also can be used; for example, site index 68.5 for white ash indicates a site index of 72 for aspen.*

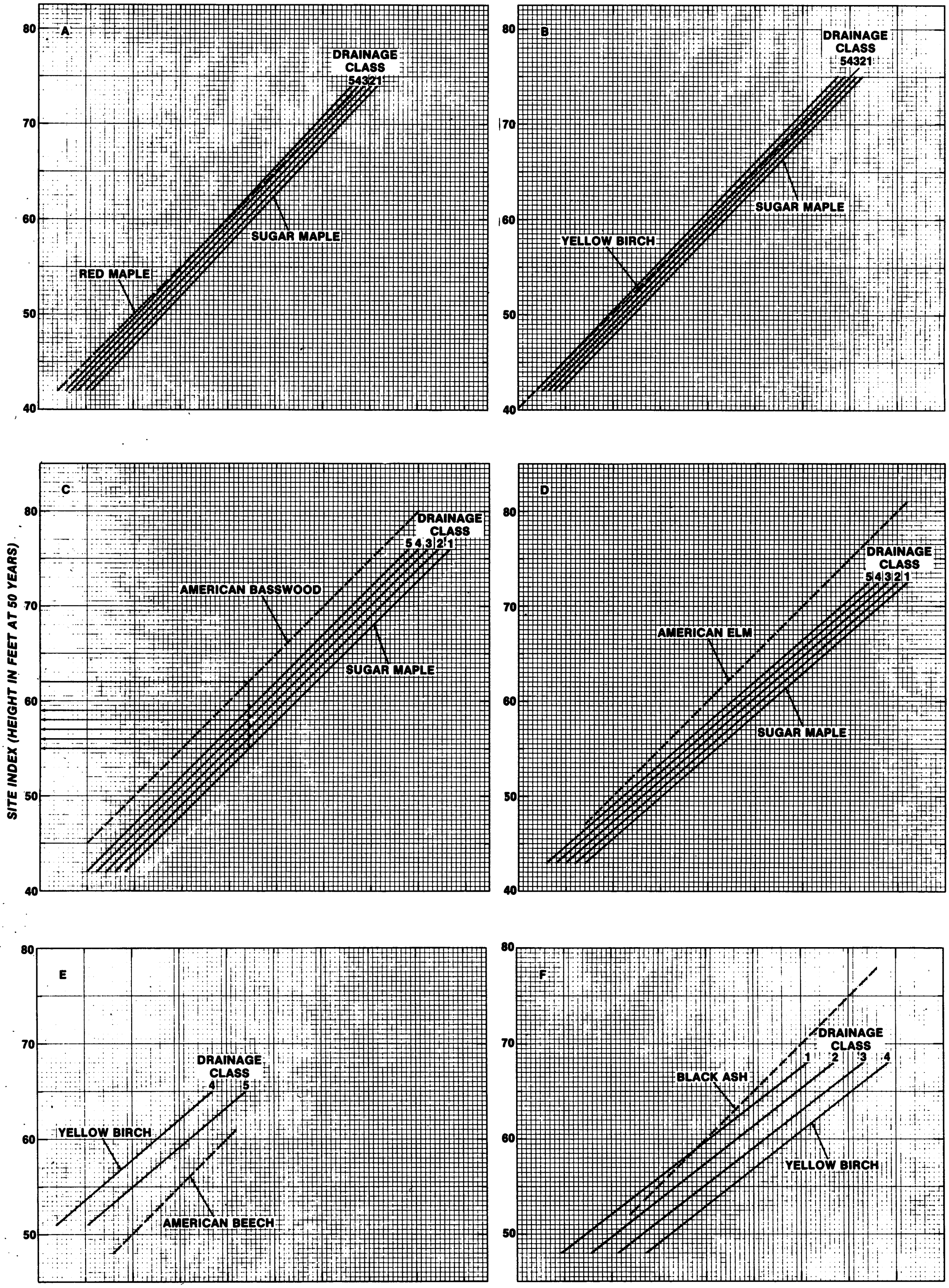
of the regression equations for 14 of the species and group pairs (table 5). The linear transformation was adequate for expressing drainage relations in all regressions, except for the American elm-black ash species pair. For this species pair the quadratic transformation resulted in a significant (at the 5 percent level) improvement in precision in addition to the precision gained from using only the linear transformation.

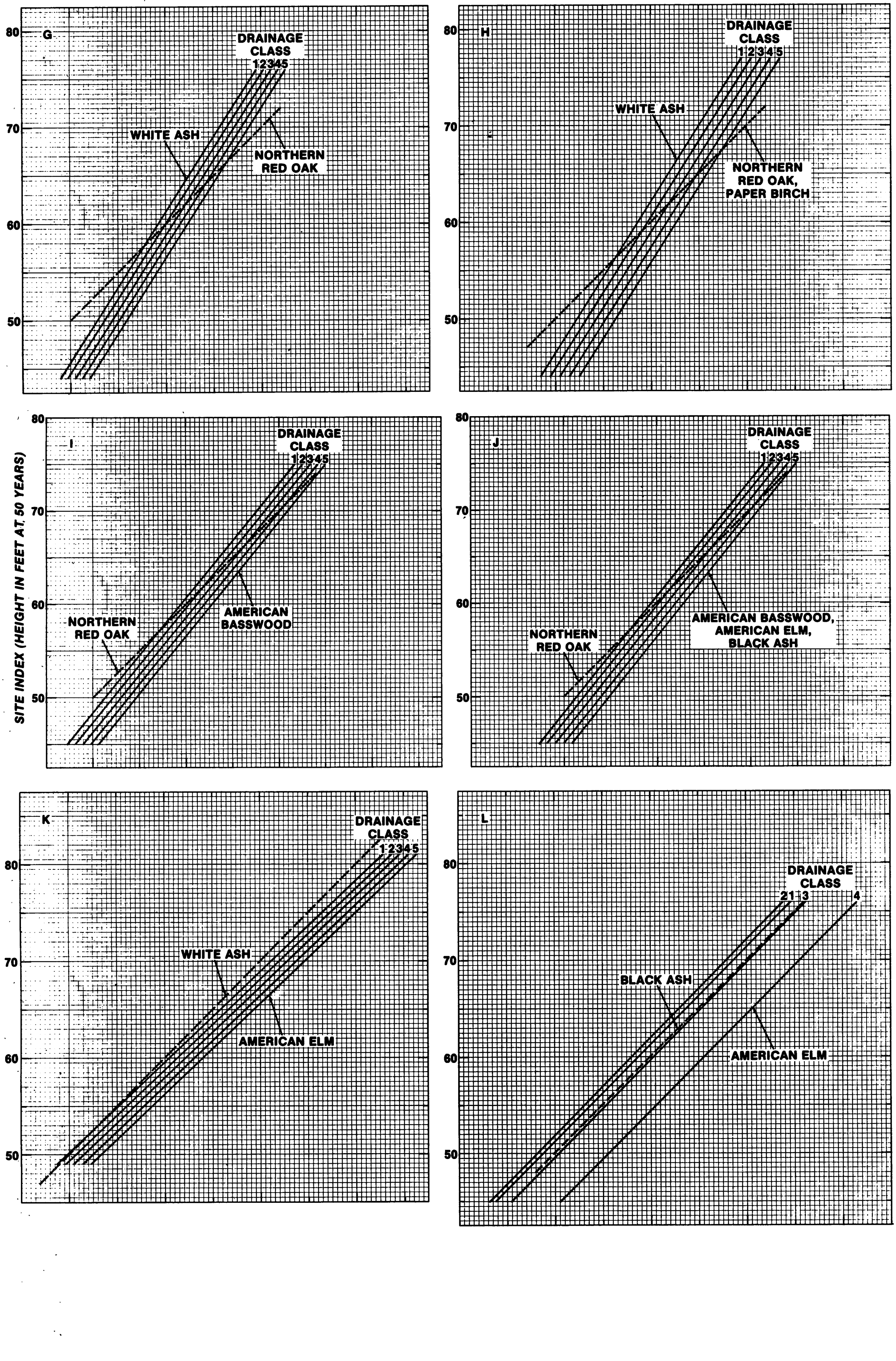
Graphically derived average regression equations were also calculated for the 14 species or

Table 5.—*Regression equations relating site index between species and group pairs when drainage*[1] *is included as a significant (0.05) variable (also given are equations that average the trends of the two equations listed for each species or group pair)*

Species comparisons	Paired observations	Equations	Coefficient of determination(r^2)[2]	Standard error of estimate[2]
				feet
Sugar maple	89	$SI_{SM} = -0.204+0.948\ (SI_{RM})+0.700\ (dr)$	0.81(0.79)	3.04(3.14)
Red maple	89	$SI_{RM} = 11.933+0.852\ (SI_{SM})-0.730\ (dr)$	0.81(0.79)	2.88(3.00)
		$SI_{SM} = -6.778+1.055\ (SI_{RM})+0.715\ (dr)$		
Sugar maple	109	$SI_{SM} = 4.016+0.892\ (SI_{YB})+0.661\ (dr)$	0.74(0.73)	3.60(3.66)
Yellow birch	109	$SI_{YB} = 12.389+0.829\ (SI_{SM})-0.663\ (dr)$	0.74(0.73)	3.47(3.53)
		$SI_{SM} = -4.775+1.037\ (SI_{YB})+0.662\ (dr)$		
Sugar maple	109	$SI_{SM} = 2.136+0.839\ (SI_{B})+1.141\ (dr)$	0.71(0.68)	3.61(3.77)
Am. basswood	109	$SI_{B} = 17.229+0.842\ (SI_{SM})-1.042\ (dr)$	0.71(0.68)	3.62(3.74)
		$SI_{SM} = -8.299+1.000\ (SI_{B})+1.092\ (dr)$		
Sugar maple	94	$SI_{SM} = 8.466+0.750\ (SI_{E})+1.028\ (dr)$	0.74(0.71)	3.37(3.52)
Am. elm	94	$SI_{E} = 9.334+0.957\ (SI_{SM})-0.778\ (dr)$	0.72(0.71)	3.81(3.87)
		$SI_{SM} = 0.820+0.874\ (SI_{E})+0.903\ (dr)$		
Yellow birch	15	$SI_{YB} = 38.764+0.630\ (SI_{AB})-3.060\ (dr)$	0.65(0.43)	2.29(2.80)
Am. beech	15	[3]$SI_{AB} = -11.994+0.897\ (SI_{YB})+2.858\ (dr)$	0.57(0.43)	2.73(3.00)
		$SI_{YB} = 27.645+0.842\ (SI_{AB})-2.959\ (dr)$		
Yellow birch	20	$SI_{YB} = 22.159+0.656\ (SI_{BA})-1.792\ (dr)$	0.70(0.61)	3.16(3.49)
Black ash	20	$SI_{BA} = -6.289+1.069\ (SI_{YB})+2.618\ (dr)$	0.73(0.61)	4.03(4.68)
		$SI_{YB} = 14.950+0.781\ (SI_{BA})-2.205\ (dr)$		
Am. basswood	29	$SI_{B} = -4.459+1.107\ (SI_{NRO})-1.166\ (dr)$	0.80(0.76)	2.84(3.10)
N. red oak	29	$SI_{NRO} = 15.415+0.725\ (SI_{B})+0.980\ (dr)$	0.81(0.76)	2.30(2.53)
		$SI_{B} = -12.118+1.232\ (SI_{NRO})-1.703\ (dr)$		
Am. elm[3]	51	$SI_{E} = 10.869+0.833\ (SI_{WA})-0.704\ (dr)$	0.79(0.78)	3.22(3.28)
White ash	51	$SI_{WA} = 3.201+0.946\ (SI_{E})+1.003\ (dr)$	0.79(0.78)	3.43(3.58)
		$SI_{E} = 4.066+0.940\ (SI_{WA})-0.854\ (dr)$		
Am. elm	34	$SI_{E} = 3.775+0.888\ (SI_{BA})+6.190\ (dr)-1.671\ (dr^2)$	0.78(0.65)	3.46(4.19)
Black ash	34	$SI_{BA} = 10.381+0.852\ (SI_{E})-4.166\ (dr)+1.321\ (dr^2)$	0.79(0.65)	3.39(4.22)
		$SI_{E} = -2.945+1.010\ (SI_{BA})+5.178\ (dr)-1.496\ (dr^2)$		
White ash	22	$SI_{WA} = -22.374+1.414\ (SI_{NRO})-1.419\ (dr)$	0.81(0.77)	3.70(3.96)
N. red oak	22	$SI_{NRO} = 24.477+0.573\ (SI_{WA})+0.956\ (dr)$	0.82(0.77)	2.35(2.55)
		$SI_{WA} = -31.350+1.561\ (SI_{NRO})-1.188\ (dr)$		
Am. basswood, Am. elm, Black ash	30	$SI_{B,E,BA} = -3.801+1.093\ (SI_{NRO})-1.110\ (dr)$	0.78(0.74)	2.99(3.20)
N. red oak	30	$SI_{NRO} = 16.410+0.711\ (SI_{B,E,BA})+0.955\ (dr)$	0.78(0.74)	2.41(2.62)
		$SI_{B,E,BA} = -12.790+1.240\ (SI_{NRO})-1.032\ (dr)$		
Am. basswood, Am. elm, Black ash	10	$SI_{B,E,BA} = -0.054+0.737\ (SI_{A})+3.804\ (dr)$	0.91(0.76)	3.56(5.61)
Aspens	10	$SI_{A} = 10.217+1.123\ (SI_{B,E,BA})-3.681\ (dr)$	0.86(0.76)	4.40(5.30)
		$SI_{B,E,BA} = -4.009+0.806\ (SI_{A})+3.742\ (dr)$		
White ash	26	$SI_{WA} = -21.764+1.422\ (SI_{NRO,PB})-1.775\ (dr)$	0.80(0.75)	4.11(4.47)
N. red oak, Paper birch	26	$SI_{NRO,PB} = 24.219+0.561\ (SI_{WA})+1.270\ (dr)$	0.81(0.75)	2.58(2.91)
		$SI_{WA} = -30.802+1.572\ (SI_{NRO,PB})-1.522\ (dr)$		
Black cherry	8	$SI_{BC} = -10.115+0.995\ (SI_{NRO,PB})+2.831\ (dr)$	0.97(0.77)	1.69(4.16)
N. red oak, Paper birch	8	$SI_{NRO,PB} = 12.211+0.969\ (SI_{BC})-2.774\ (dr)$	0.96(0.77)	1.67(3.93)
		$SI_{BC} = -10.639+1.004\ (SI_{NRO,PB})+2.802\ (dr)$		

[1]Relative drainage classes are: 1=poorly drained; 2=somewhat poorly drained; 3=moderately well drained; 4=well drained; 5=somewhat excessively drained (USDA, Soil Conservation Service 1975).
[2]Numbers in parentheses are the coefficients of determination, and the standard errors of estimate for regression equations without drainage variable (table 2).
[3]Coefficient for the drainage variable not significant because probability of error exceeds 5 percent.


A
DRAINAGE CLASS
54321
SUGAR MAPLE
RED MAPLE
B
DRAINAGE CLASS
54321
SUGAR MAPLE
YELLOW BIRCH
C
DRAINAGE CLASS
5 4 3 2 1
AMERICAN BASSWOOD
SUGAR MAPLE
SITE INDEX (HEIGHT IN FEET AT 50 YEARS)
D
DRAINAGE CLASS
5 4 3 2 1
AMERICAN ELM
SUGAR MAPLE
E
DRAINAGE CLASS
4 5
YELLOW BIRCH
AMERICAN BEECH
F
DRAINAGE CLASS
1 2 3 4
BLACK ASH
YELLOW BIRCH
40
50
60
70
80


SITE INDEX (HEIGHT IN FEET AT 50 YEARS)
G
DRAINAGE CLASS
1 2 3 4 5
WHITE ASH
NORTHERN RED OAK
H
DRAINAGE CLASS
1 2 3 4 5
WHITE ASH
NORTHERN RED OAK, PAPER BIRCH
I
DRAINAGE CLASS
1 2 3 4 5
NORTHERN RED OAK
AMERICAN BASSWOOD
J
DRAINAGE CLASS
1 2 3 4 5
NORTHERN RED OAK
AMERICAN BASSWOOD, AMERICAN ELM, BLACK ASH
K
DRAINAGE CLASS
1 2 3 4 5
WHITE ASH
AMERICAN ELM
L
DRAINAGE CLASS
2 1 3 4
BLACK ASH
AMERICAN ELM
80
70
60
50

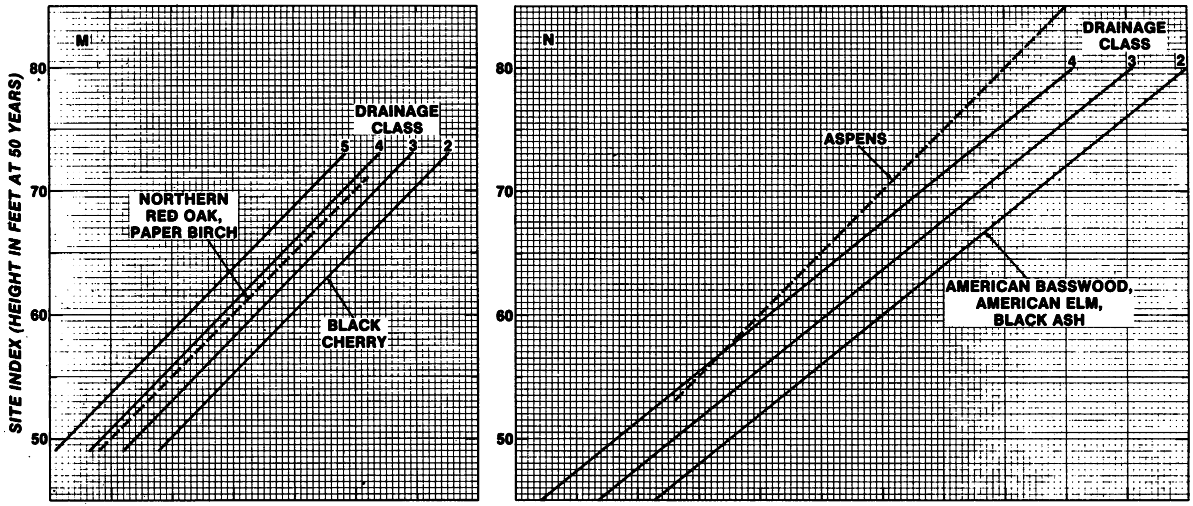


Figure 2.—*Site index comparison graphs for northern hardwood species whose site index relations differ depending upon soil drainage. For example, suppose you would like to estimate site index for sugar maple in a certain stand, but there are no sugar maple trees present. However, there are suitable American basswood trees present, and their average height and age measurements indicate that their site index is 62 (Carmean 1978). Find the graph that compares the two species you are working with—graph C. On the graph begin at 62 on the site-index scale and read right to the American basswood line, then read straight down to the sugar maple lines for various classes of soil drainage. Now read left to the site-index scale where site index for the various drainage classes can be found. For basswood site index 62 sugar maple site index is estimated to be 59, 58, 57, 56, and 55 for soils that are somewhat excessively drained (class 5), well drained (class 4), moderately well drained (class 3), somewhat poorly drained (class 2), and poorly drained (class 1), respectively. The reverse of this procedure also can be used to estimate site index for basswood if sugar maple site index and drainage class are known.*

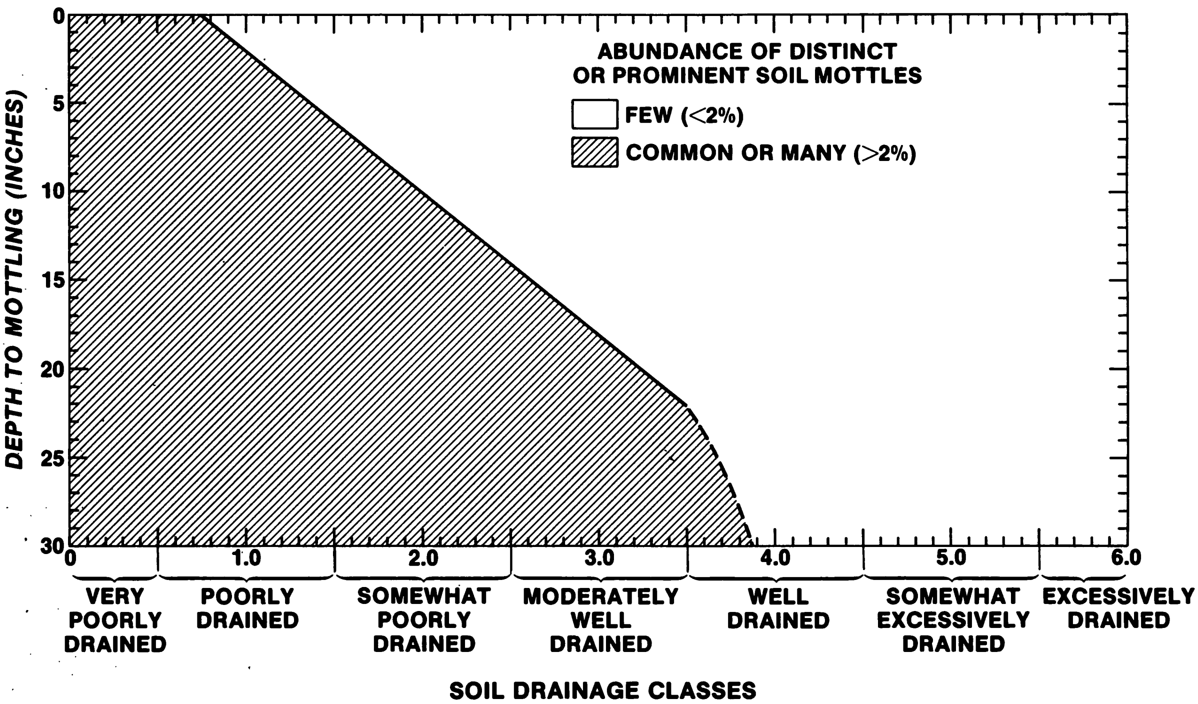


Figure 3.—Soil drainage classes can be estimated from depth to a soil horizon having common or many mottles that are distinct or prominent when contrasted to the soil matrix (USDA Soil Conservation Service 1975).

group pairs where site relations were found to be significantly related to soil drainage (table 5). These average equations were used to plot graphs that show site relations between species or group pairs for different soil drainage classes (fig. 2). Each graph is restricted to the observed range of site index and drainage observed on the site plots. More precise estimates of site index can be obtained with these comparison graphs that include drainage than can be obtained with the general site index comparison graph (fig. 1). And the most precise site index estimates of all can be obtained using either of the two computed regression equations (table 5).

For many species combinations the site changes associated with soil drainage are minor even though they are statistically significant. For example, when the drainage variable is added to the regressions for the sugar maple-red maple and the sugar maple-yellow birch pairs, the site index estimates are statistically improved (table 5), but the magnitude of the site index changes are small (figs. 2A and 2B)—site index changes less than 1 foot for each unit (1.0) change in drainage. In contrast, adding the drainage variable for species pairs such as yellow birch-American beech and yellow birch-black ash, greatly improves statistical precision (table 5) and also results in large site index changes (figs. 2E and 2F). For example, for the yellow birch-American beech species pair site index changes about 3.0 feet for each unit (1.0) change in drainage. Other pairs such as American elm-black ash, and black cherry-(red oak and paper birch) also appear to have large site index changes associated with drainage (figs. 2L and 2M). However, many of these species or group pairs are based on few plots and the standard errors for the drainage coefficients are large, thus we cannot place much confidence in the actual magnitude of the estimated site changes associated with drainage.

DISCUSSION

This study shows that species found in northern hardwood stands have large differences in site index. Differences in site index may average as much as 15 feet between aspen and American beech when they occur on small 1/5-acre plots. On good sites the site index for white ash may average 8 or more feet higher than site indices for sugar maple, red maple, and yellow birch. Northern hardwood species can be placed into four general site index groups: (a) *Very high site*-species include quaking and bigtooth aspens. These species have rapid early height growth and at 50 years of age will be taller than all other species, (b) *High site*-species include 7 intolerant species - white ash, American basswood, American elm, black ash, black cherry, northern red oak, and paper birch. Differences in site index occur among these species depending upon level of site quality. On good sites white ash has site indices exceeding those of the other high site species; on poor sites northern red oak and paper birch have the highest site indices. Black cherry has high site indices on good sites but relatively low site indices on poor sites, (c) *Medium site*-species include sugar maple, red maple, and yellow birch, (d) *Low site*-species is American beech, which has the lowest site indices at all levels of site quality.

These site relations frequently differ depending upon soil drainage; species that have similar site indices on well-drained soils often have dissimilar site indices on less well-drained soils. For example, on well-drained soils the site indices for sugar maple, red maple, and yellow birch are similar. But on less well-drained soils sugar maple site index is lower than red maple and yellow birch site index (figs. 2A and 2B). Comparisons between sugar maple, American basswood, and American elm (figs. 2C and 2D) reveal similar relations. On well-drained soils basswood and elm may have site indices 3 or more feet higher than sugar maple, but on poorly drained soils site indices may be as much as 7 feet higher than for sugar maple.

On well-drained soils black ash grows faster than do many associated trees. For example, black ash and yellow birch have similar site indices on poorly drained soils, but on well-drained soils black ash has site indices averaging 7 or more feet greater than yellow birch (fig. 2F). Similar relations occur when white ash (fig. 2K) and black ash (fig. 2L) site indices are compared to American elm site index. Site indices for these three species are similar on poorly drained soils, but on well-drained soils site indices for the ashes are at least 5 feet higher than for elm. Site indices for white ash, northern red oak, and paper birch also differ for different levels of site quality (figs. 2G and 2H). On poor sites white ash has much lower site index and differences become greater as drainage improves. In contrast, on good sites white ash has much higher site index than red oak and paper birch and these differences become greater as drainage becomes poorer. Somewhat similar but less pronounced relations also occur when northern red oak site index is compared to site indices for American basswood, American elm, and black ash (figs. 2I and 2J).

Other site index comparison studies for northern hardwood species have been made in Vermont (Curtis and Post 1962), and included sugar maple, yellow birch, white ash, and paper birch. A study in northern Minnesota (Carmean and Vasilevsky 1971) included site comparisons for American basswood, northern red oak, paper birch, and quaking aspen. Results from these two studies are similar to this study for northern Wisconsin and Upper Michigan except for paper birch. In Vermont paper birch apparently had rather low site indices on poor sites, but in the present study paper birch had higher site indices on poor sites. In northern Minnesota paper birch had site indices 3 to 5 feet higher than for northern red oak, but in this study paper birch and red oak had similar site indices at all levels of site quality.

Most of the regression equations developed in this study have exceptionally high r^2 values. The major reason for this good precision is that a large number of site trees were measured on many carefully selected even-aged plots, and that all site index values are based on detailed stem analyses from each site tree. Stem analysis permits a direct and more accurate observation of site index in contrast to estimating site index using only total height and age measurements in conjunction with site index curves.

Site index comparisons among alternative tree species are a necessary first step in selecting the most desirable tree species for a given site. During selection we should remember that site index comparisons are merely comparisons of tree height at index age and that height growth before and after index age should also be considered. Aspens grow rapidly in early years and thus are taller than sugar maple and other northern hardwoods at 50 years (site index age). But after 50 years aspen height growth slows while most hardwoods maintain more rapid height growth until older years. Rapid early height and volume growth of aspen is a desirable feature for short rotation pulp and fiber products. But valued hardwoods might be preferable to aspen on good sites because better growth in later years would be an advantage in growing quality saw logs and veneer logs.

Site index camparisons enable forest managers to also compare the volume and value of wood produced by different species on different sites. On good sites species such as yellow birch, black cherry, and the ashes might be preferable to aspen even though they do not grow as rapidly in height and volume as do aspens. These species might be preferred because comparisons with aspen on a value basis may show that even though they produce less volume they have the potential for producing high quality veneer and saw logs and thus may produce more value return than may be gained by aspen. White ash is a particularly desirable tree because it combines rapid early height and volume growth with great value for quality saw log and veneer logs. American beech combines slow early height and volume growth with wood products that are relatively low in value.

HOW TO USE THE SITE INDEX COMPARISON GRAPHS AND EQUATIONS

1. Select the stand or plot for which site index estimates are needed. Measure total height and total age of several dominant and codominant trees of the tree species present that are suitable for estimating site index. Use site index curves (Carmean 1978) to estimate site index for these species.

2. Classify soil drainage using standard soil profile descriptions based on depth to mottling and on abundance and contrast of mottles (USDA Soil Conservation Service 1975) (fig. 3).

Abundance of mottles: few = < 2%; common = 2-20%; many = > 20% of soil matrix.

Contrast of mottles: faint = mottles and matrix closely related in hue and chroma; distinct = mottles and matrix contrast by 1-2 units in hue and by several units in chroma and value; prominent = mottles and matrix contrast by several units in hue, chroma, and value.

Northern hardwood stands rarely occur in "very poorly drained" swampy areas, or on "excessively drained" sandy and gravelly soils with little profile development. But northern hardwood stands commonly occur on "well drained" glacial till soils that lack large amounts of mottles; stands also commonly occur on "somewhat excessively drained" glacial outwashed sandy soils that have well developed soil profiles.

3. List the absent tree species for which site index estimates are desired. Then list paired combinations between the species that are present and the absent species for which you desire site index estimates.

4. Determine if the tree species you wish site index estimates for are among the 14 paired combinations in which soil drainage is important for estimating site index (fig. 2 and table 5). If drainage is a significant factor, estimate site index for the absent species using the individual site index comparison graphs that include drainage as a factor for estimating site index. Even more precise site index estimates are possible using the computed equations that express relations between site index and soil drainage (table 5). If drainage is not a significant factor in estimating site index, or if you do not have the soil profile descriptions needed to classify soil drainage, use the general site index comparison graph (fig. 1) to estimate site index of the absent species based on site index of species present. More precise site index estimates are possible using the computed equations for either the group pairs (table 4), or the species pairs (table 2).

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