Proceedings of the SYMPOSIUM ON INTENSIVE CULTURE OF NORTHERN FOREST TYPES

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FOREWORD

THE NORTHERN FOREST TYPES constitute a vast natural resource for the United States and Canada. For instance, in the eastern United States there are more than 10 million acres of commercial forest land supporting spruce and fir types alone. The magnitude and variety of this resource is such that treating it in any detail at a 3-day meeting was impossible. Rather, the idea that germinated and developed into this symposium was to present a broad picture of the extent of our knowledge of intensive cultural techniques, the status and trends of our research in the northern forest types, and some actual experiences in managing this resource; and to explore those factors that affect our use of the intensive cultural techniques we have at hand.

There is no doubt that we face a new era in the management of northern forests. The production of wood products is no longer the primary objective of many owners, and increased pressure for the social values of our forests is being felt by all landowners. We must recognize these other forest values, which in turn dictates intensification of all aspects of forest management if we are to meet the future demands of a wood-hungry society.

The enthusiastic efforts of the symposium sponsors—the School of Forest Resources, University of Maine; the Maine Bureau of Forestry; the Maine Forest Products Council; and the U.S.D.A. Forest Service—and the individuals behind those efforts, should be commended. Special thanks are due to Great Northern Nekoosa, Inc., and Brooks B. Mills for their help in providing interesting field trips, and to the Casco Bank and Trust Co. for sponsoring the symposium brochure. Also, without the enthusiastic participation of the experts invited to present papers, and the moderators of each session, the Symposium could not have taken place.

—BARTON M. BLUM
Symposium Chairman

PUBLISHER'S NOTE

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Proceedings of the SYMPOSIUM ON INTENSIVE CULTURE OF NORTHERN FOREST TYPES

held 20-22 July 1976 at Nutting Hall, University of Maine, at Orono.

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SITE CLASSIFICATION FOR NORTHERN FOREST SPECIES

by Willard H. Carmean, Principal Soil Scientist, USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minn.

Abstract

Summarizes the extensive literature for northern forest species covering site index curves, site index species comparisons, growth intercepts, soil-site studies, plant indicators, physiographic site classifications, and soil survey studies. The advantages and disadvantages of each are discussed, and suggestions are made for future research using each of these methods. Suggests a complementary framework that coordinates site quality, yield, and forest land classification. Discusses how this complementary framework can help in practicing more intensive timber management.

THE QUANTITY AND QUALITY of timber yield closely depends upon forest site quality. Accordingly, one of the first steps for intensively managing forest land is to determine the site quality of land for various trees so that the most productive and valuable tree can be selected for each parcel of land. Armed with site and yield information, a forest manager can estimate future wood supplies, and thus can make realistic decisions about future costs and benefits of intensive forest management, land acquisition, and industrial investments.

Estimating site quality for forest land has been a primary concern of American foresters since the early days of our profession. An extensive volume of literature has accumulated regarding methods for estimating site quality in the United States (Carmean 1975). Likewise Canadian foresters have long been concerned with site quality estimation and with methods of forest land classification and mapping (Rennie 1962, Rowe 1962, 1971, Burger 1972).

I have three goals for this paper. First, I will give an inventory of the American and Canadian site quality research already accomplished for northern forest species. Second, I will try to show how these accomplishments can be joined into a complementary framework for site quality estimation, yield prediction, and forest land classification. And third, I hope to show how this complimentary framework can guide us in making decisions about where, what, and how intensively we should manage timberlands in the future.

Site Index Curves

Site index based on height growth is the most widely accepted method for estimating site quality in the United States (Carmean 1975). Height and age measurements from free-growing, uninjured, dominant, or dominant and codominant trees are used with a family of height-age (site index) curves to estimate total tree height at a specified index age. For most northern species 50 years is the index age. The site index method is accurate and simple to use when (1) suitable trees are available for measuring site index, and (2) when accurate site index curves are available.

Many site index curves have been constructed for northern forest species, but most of these curves are for conifers (table 1) and relatively few are for valued hardwood species (table 2) such as yellow-birch, black cherry, and white ash. Most of the site index curves now in use are older, "harmonized" curves that accompanied regionwide normal yield tables. These harmonized curves are not based on actual tree height growth studies, but on dominant and codominant tree height and age measured from growth and yield plots scattered throughout a particular forest region. An average height-age curve is calculated and this curve is used to construct a family of proportional site index curves all having the same shape or pattern of height growth. Thus harmonized curves are based on the assumption that the pattern of tree height growth is the same for all site classes, localities, and soil conditions included in a regional yield study. We now know that this assumption is not valid and that height growth patterns may vary greatly (are polymorphic) for many species that grow on contrasting sites, or that have a wide geographic distribution (Carmean 1970, 1975).

For intensive timber management we need site index curves that are more accurate than harmonized curves. Stem analysis is the method most favored for developing more accurate site curves, and we need such curves for all important northern forest species. Because height growth patterns may vary from area to area we may have to construct separate site curves to fit certain localities, or certain soils and climates. For example, stem analysis data (Hegar and Lowry 1971) indicate that Plonski's (1960) harmonized curves are applicable to black spruce (see Appendix list of common and scientific names) in Ontario and Quebec. However, black spruce in the maritime climate of eastern Canada has much different height growth patterns than in continental areas (Page and van Nostrand 1971), thus separate curves may be needed for the maritime areas. In contrast, northern hardwoods in the White Mountains of New Hampshire (Solomon 1968) have height-growth patterns similar to hardwoods in Vermont's Green Mountains (Curtis and Post 1962a), thus the site curves prepared for Vermont northern hardwoods should be usable in New Hampshire.

Table 1.--SITE INDEX CURVES FOR NORTHERN CONIFER FOREST SPECIES

Species	Area	Reference
Jack, red, and white pines	Lake States	Brown and Gevorkiantz (1934)
Jack pine	Lake States	Sterrett (1920), Wackerman et al. (1929), Eyre and LeBarron (1944), Gevorkiantz (1956a)
Jack pine	Saskatchewan	Kabzems and Kirby (1956), Jameson (1963)
Jack, red, white pines; black spruce	N. Ontario	Plonski (1960), Payandeh (1974a)
Red pine	N. Minnesota	Eyre and Zehngraff (1948)
Red pine	Lake States	Gevorkiantz (1957e)
Red pine	Central New England	Reed (1926)
Red pine	Connecticut	Bull (1931)
Red pine	Northeast and Lake States	Spurr (1956)
Red pine	Quebec	Phu (1974)
Red pine	Ontario	Stiell and Berry (1973b)
Red pine	Pennsylvania	Kinsley and Bartoo (1967)
Red pine	Illinois	Gilmore (1967)
Red and white pines	S.E. Ohio and S. Indiana	Gaiser and Merz (1953)
Red and white pines	S.E. Ontario	Ardenne (1950)
Red and white pines	Quebec and Ontario	McCormack (1956), Horton and Bedell (1960)
Red, white, and Scotch pines	Vermont	Hannah (1971)
White pine	N. England and Mid-Atlantic States	Frothingham (1914)
White pine	New England	Leak et al. (1970)
White pine	New Hampshire	Husch (1954)
White pine	New Hampshire	Barrett and Goldsmith (1973)
White pine	Wisconsin	Gevorkiantz and Zon (1930)
White pine	Lake States	Gevorkiantz (1957d)
White pine	S. Appalachians	Barrett (1934), Vimmerstedt (1959, 1962), Doolittle and Vimmerstedt (1960), Beck (1971b, 1971c)
White pine	Illinois	Gilmore (1968)
Spruces and balsam fir	Northeast	Meyer (1929)
Spruces and balsam fir	Maine	Mount and Gore (1952)
Spruces and balsam fir	Newfoundland	Van Nostrand (1964), Page (1968)
Spruces and balsam fir	Quebec	Linteau (1955)
Spruces and balsam fir	Ontario	Payandeh (1974b)
Spruces and balsam fir	Saskatchewan	Payandeh (1974c)
Spruces and balsam fir	N. Michigan	Bowman (1941)
White and black spruces	Central and E. Canada	Heger (1968, 1969, 1971) Heger and Lowry (1971) Page and Van Nostrand (1971)
White spruce	Ontario	Stiell and Berry (1967, 1973a)
White spruce	Saskatchewan	Kabzems (1971)
White spruce	Lake States	Gevorkiantz (1957c), Ek (1976)
Red spruce	Maine	McLintock and Bickford (1957)
Black spruce	Minnesota	Fox and Kruse (1939), LeBarron (1948)
Black spruce	Lake States	Gevorkiantz (1957b)
Black spruce	Alberta	Horton and Lees (1961)
Black spruce	Saskatchewan	Kabzems (1953)
Black spruce	Manitoba and Saskatchewan	Jameson (1964)
Black spruce	Ontario and Quebec	Bedell et al. (1955), MacLean and Bedell (1955)
Balsam fir	Lake States	Gevorkiantz (1956c)
Jack, red, and white pines; white and black spruces; balsam fir; tamarack; white-cedar	Lake States	Lundgren and Dolid (1970)
White-cedar	Lake States	Gevorkiantz (1957a)
Tamarack	Lake States	Gevorkiantz (1957f)
Hemlock	New York, Michigan, S. Appalachians	Monserud and Ek (1976)

Table 2.--Site index curves for northern hardwood forest species

Species	Area	Reference
Sugar maple, yellow birch, white ash, paper birch	Vermont, New Hampshire	Curtis and Post (1962a), Solomon (1968)
Sugar maple, white ash	Vermont	Farrington and Howard (1958)
Sugar maple	Vermont	Hawes and Chandler (1914)
Sugar maple	New York	Farnsworth and Leaf (1963)
Sugar maple	N. Lower Michigan	Shetron (1972b)
Red maple	Connecticut and Massachusetts	Hampf (1965)
Beech	Northeast	Hampf (1965)
Sugar maple, yellow birch, beech, elm, basswood	Lake States	Monserud and Ek (1976)
Black cherry	New York	Hampf (1965)
Black cherry	N.W. Pennsylvania	Ward et al. (1965)
Paper birch	N. Wisconsin	Cooley (1958, 1962)
Q. Aspen and paper birch	Lake States	Lundgren and Dolid (1970)
Aspens	Lake States	Kittredge and Gevorkiantz (1929), Brown and Gevorkiantz (1934), Gevorkiantz (1956b)
Aspens	Lower Michigan	Graham et al. (1963), Zahner and Crawford (1965)
Aspens	N. Cent. Minnesota	Schlaegel (1971)
Aspens	Saskatchewan	Kirby et al. (1957)
Aspens	Alberta	Horton and Lees (1961)
Aspens	Newfoundland	Page (1972)
Aspen, paper birch, tolerent hardwoods	N. Ontario	Plonski (1960), Payandeh (1974a)
Q. aspen, paper birch	Alaska	Gregory and Haack (1965)
Quaking aspen	Rocky Mountains	Jones (1966, 1967), Jones and Trujillo (1975)

Site Index Comparisons Between Species

More intensive timber management requires the ability to select the most desirable tree species for each parcel of land. Should we, for example, choose from among several species of pine, or should we manage aspen on short rotations? On other areas should we consider favoring certain hardwood species for veneer and high value saw log production? Stands rarely have measurable trees of all species for which we need site index comparisons. But even when a stand does not contain the tree species for which site index estimates are desired, we can still estimate site index using the tree species actually present. Species comparison graphs can be used to convert site index of the species present to site index of the desired species. Unfortunately, only six site index comparison studies are available for northern forest species (table 3).

Table 3.--Site index comparisons for northern forest species

Species	Area	Reference
White pine; eastern hardwoods; shortleaf, pitch, and Virginia pines	S. Appalachian Mts.	Doolittle (1958)
White pine and red maple	N. Connecticut, W. Massachusetts, E. New York	Foster (1959)
Northern hardwoods	Vermont	Curtis and Post (1962b)
Northern conifers and hardwoods	N. Minnesota	Carmean and Vasilevsky (1971)
Red, jack, and white pine	Upper Michigan	Shetron (1975)
Red pine and quaking aspen	N. Minnesota	Alban[a/]

[a/] Alban, D. H. 1976. U. S. Forest Service, North Cent. For. Exp. Stn. (unpublished manuscript).

Site index comparison graphs are most useful in areas having great ranges in soil and site, and where the forest manager has the problem of selecting the most desirable tree from among many alternative species. However, when selecting the most desirable tree species we should keep in mind that site index comparisons are merely that--comparisons of tree height at index age--and they are only the necessary first step in choosing the most desirable species for a particular site. We should also consider tree height growth before and after index age. And we should also compare both volume and value of wood produced in addition to comparing site index.

Growth Intercept

The growth intercept method uses a period of early height growth rather than long-term height growth as an index of site quality. The method was developed for conifers having distinct internodes marking annual height growth; usually the total length of the first 5 internodes above breast height is used an an index of site. Several growth intercept studies have been published for red and white pine (table 4). This method is particularly useful for areas where trees are too young for the usual 50-year site index curves. However, the method has the disadvantage of basing site quality estimation only on early height growth, and this may not be a very good indication of height growth in later years.

We need additional growth intercept studies for red and white pines in areas where existing studies may not apply. Futhermore, the method also might be applicable to jack pine, spruce, and larch, or even to hardwoods such as ash and maple. Internodes are not as distinct on these species, nevertheless, internodes still can be observed when trees are relatively young.

Table 4.--Growth intercept studies for estimating site quality of red and white pines

Species	Area	Reference
Red pine	New York	Ferree et al. (1958), Richards et al. (1962)
Red pine	Michigan and S. Ontario	Day et al. (1960), Schallau and Miller (1966), Gunter (1968)
Red pine	Wisconsin	Wilde (1964, 1965)
Red pine	N. Minnesota	Alban (1972a)
White pine	S. Appalachian Mts.	Beck (1971a)

Soil-Site Evaluation

The soil-site method has received more emphasis in the United States than other methods of indirectly estimating site quality (Carmean 1975), and many studies have been published for northern forest species in the United States and Canada (tables 5 and 6). This method is particularly useful for areas that vary greatly in soil and site, and where forest stands are usually not suited for direct measurements of site index, for example in unevenaged, poorly stocked, too young, or heavily cut stands.

The soil-site method relates soil, topography, and climate in a forest area to site index. Studies are made using many plots representing the range of site quality, soil, topography, and climate found within the area. Site index is estimated from the trees on each plot, and then multiple regression methods are used to relate site index to the associated soil, topographic, and climatic features. The resulting multiple regression equations are used to calculate tables and graphs for estimating site index in the field. Field foresters can easily measure the needed features which may include surface soil depth, texture, stone content, aspect, slope position, and slope steepness. The features found to be important in soil-site studies may differ depending on tree species, soil, topography, and climate of the area. So results are valid only for the particular study area, and for the soil and topographic conditions sampled within the study area. Except for the listed studies (tables 5 and 6) large gaps exist in our knowledge about soil-site relations of many northern forest species.

Plant Indicators

Understory vegetation has long been used for classifying forest site quality in northern Europe using methods first developed by Cajander (1926) in Finland. The method received considerable support in the early days of American forestry, and in Canada an active

program of site classification developed following a visit by Ilvessalo (1929). Most plant indicator research for northern forest species has been done by Canadians (table 7) and several articles review its philosophy and methodology (Holman 1929, Kabzems 1951, Linteau 1953, Long 1953, Rowe 1956, Jurdant 1969, Jurdant et al. 1975, Burger 1972).

Table 5.--Soil-site studies for northern conifer forest species

Species	Area	Reference
Red pine	Connecticut	Haig (1929), Hicock et al. (1931)
Red pine	New York	Stone et al. (1954, 1958, 1962), Richards et al. (1962), Richards and Stone (1964), Dement and Stone (1968)
Red pine	Massachusetts	Mader and Owen (1961), Mader (1968)
Red pine	Lower Michigan	Van Eck and Whiteside (1958, 1963), Hannah (1969)
Red pine	S.E. Minnesota	Scott and Duncan (1958)
Red pine	N. Minnesota	Alban (1972b, 1974)[a/]
Red pine	Quebec	Popovich (1975)
Red and jack pines	Lower Michigan	Hannah and Zahner (1970)
Red, jack, white pines; white and Norway spruce	Wisconsin	Wilde et al. (1951, 1964a, b, c, d, 1965), Wilde, Maeglin and Tanzer (1966), Wilde, Paul and Mikola (1951), Wilde, Tanzer and Trautmann (1963), Wilde (1970)
Red and white pines	S.E. Ohio, S. Indiana	Caiser and Merz (1953)
Jack pine	N. Minnesota	Pawluk and Arneman (1961), Frissell and Hansen (1963)
Jack pine	N. Ontario	Chrosciewicz (1963)
White pine	Maine	Czapowskyj and Struchtemeyer (1958), Stratton and Struchtemeyer (1958)
White pine	S.E. New Hampshire	Husch and Lyford (1956)
White pine	New Hampshire	Barrett and Goldsmith (1973)
White pine	Massachusetts	Mount (1976)
White pine, spruces	Maine	Young et al. (1950), Young (1954), Mader et al. (1952)
White, red, Scotch pines	Vermont	Hannah (1971)
Northern conifers and hwds.	N. Minnesota	Bakuzis et al. (1962)
Northern conifers and hwds.	Quebec and Ontario	Bedell and MacLean (1952), MacLean and Bedell (1955)
Northern conifers and hwds.	Manitoba	Halliday (1935)
Black spruce	N. Minnesota	Heinselman (1963), Watt and Heinselman (1965)
Black spruce	Newfoundland to W. Ontario	Lowry (1964, 1970, 1975)
White spruce	Cent. Alberta	Duffy (1965)
Red and white spruce	Maine	Hoar and Young (1965)
Japanese and European larches	S. New York	Aird and Stone (1955)

[a/] Also Alban, D. H. 1976. U.S. Forest Serv., North Cent. Forest Exp. Stn., (unpublished manuscript).

Table 6.--Soil-site studies for northern hardwood forest species

Species	Area	Reference
Sugar maple	Vermont	Post (1968), Post and Curtis (1970)
Sugar maple	N. Michigan	Westveld (1933)
Sugar maple	Pennsylvania	Nuss and Borden (1968)
White ash	N.W. Pennsylvania	Lewis and Ward (1967)
Black cherry	N.W. Pennsylvania	Davis and Ward (1966)
Yellow and paper birches	New England and Lake States	Post et al. (1969)
Paper birch	N. Wisconsin	Cooley (1962)
Quaking aspen	Minnesota and Wisconsin	Kittredge (1938), Stoeckeler (1948, 1960), Fralish and Loucks (1967)
Quaking aspen	N. Minnesota	Meyer (1956), Voigt et al. (1957) Strothmann (1960)
Quaking aspen	Cent. Wisconsin	Wilde and Pronin (1949, 1950)
Bigtooth aspen	Lower Michigan	Graham and Harrison (1955), Hannah and Zahner (1970)

In Canada plant indicators are mainly used to describe natural "ground vegetation types." As part of a broad land classification system, these types include forests believed to have similar trends in productivity, regeneration, and succession. For this reason these vegetation types might be managed using similar silvicultural practices. This system is useful for stratifying variable forest areas, but in most cases there is little factual evidence about how closely these vegetation types describe forest site quality.

The plant indicator method has been widely used in undisturbed northern coniferous forests because they usually have relatively few understory plant species, and plant communities are usually distinct and easily recognized. But our more southerly forests have often been repeatedly disturbed, and the numerous understory species usually occur as a continuum rather than discrete communities. Nevertheless, plant indicators can supplement other methods of site estimation and forest land classification, despite the complexities and shortcomings of the method.

Physiographic Site Classification

Forest land classification programs in Canada have been in progress for many years (Lacate 1966, Burger 1972) and were initially based on the understory vegetation methods of Cajander. Following World War II, aerial photographs became an important tool in "forest site" mapping (Losee 1942a, 1942b, Hills 1950, Burger 1957, Jurdant 1964b). As a result landforms have become prominent in forest land classification because they are easily identified on aerial photos. The most widely used method of physiographic site classification was developed in Ontario (Hills 1952,

1953, 1954, 1958, 1960, 1961, Hills and Pierpoint 1960, Pierpoint 1962, Brown 1953, Farrar 1960). Using this method Ontario was subdivided hierarchically into site regions, landscapes, land types, and sites. Variations of this method also have been used in other Canadian provinces where northern forest species occur (Wilde, Voigt, and Pierce 1959, Bedell and MacLean 1952, Bedell, Brown, and MacLean 1953, Bedell, MacLean, and Brown 1955, MacLean and Bedell 1955, Duffy 1965, Duffy and Nemeth 1967, Knight and Duffy 1967, Loucks 1962).

Table 7.--Plant indicator studies for estimating site quality of northern forest species

Species	Area	Reference
Jack pine	Saskatchewan	Kabzems and Kirby (1956)
Jack and red pine	Manitoba	Ritchie (1961)
Jack pine and black spruce	Manitoba	Mueller-Dombois (1964, 1965)
White pine	New Hampshire	Hazard (1937), Stanley (1938)
White pine	Wisconsin	Gevorkiantz and Zon (1930)
White pine	Great Lakes and St. Lawrence Valley	Horton and Brown (1960)
Spruce-fir	Adirondack Mts of New York	Heimburger (1934)
Spruce-fir, Northern hwds.	Adirondack Mts, Vermont, N. Hampshire, W. Maine	Westveld (1951, 1952, 1953, 1954)
Spruce-fir, Northern hwds.	Lake Edward, Quebec	Sisam (1938a), Heimburger (1941), Ray (1941, 1956)
Spruce-fir, pines, hwds.	Lake States	Anon. (1930)
Spruce-fir, pines, hwds.	Quebec, Ontario, Saskatchewan	Losee (1942a, 1942b)
Spruce-fir, pines, hwds.	Manitoba, Saskatchewan	Rowe (1956)
Spruce-fir	Newfoundland	Damman (1964), Page (1970a, 1970b)
Spruce-fir	Quebec	Linteau (1940, 1953, 1955), Bellefeville (1932), Lafond (1958, 1960, 1964)
Black spruce	N. Minnesota	Heinselman (1963)
Black spruce	Newfoundland to W. Ontario	Vallée and Lowry (1970, 1972)
White spruce plantations	Quebec	Gagnon and MacArthur (1959)
N. hwds. and oaks	Connecticut	Hicock et al. (1931)
N. hwds.	Upper Michigan	Wilde and Scholz (1934)
Quaking and bigtooth aspens	Petawawa, Ontario	Sisam (1938b)
Quaking aspen	Minnesota, Wisconsin	Kittredge (1938)
Quaking and bigtooth aspens, jack pine	Michigan	Hellum and Zahner (1966)

In boreal forest portions of Quebec attempts were made to relate physiographic methods to the Braun-Blanquet plant sociological methods (Jurdant 1964a, 1964b, 1969, Jurdant and Roberge 1965, Jurdant et al. 1975); similar methods have been proposed for the northern Rocky Mountains (Layser 1974). In floristically richer portions of southern Quebec the Zürich-Montpellier sociological methods were combined with physiographic site classification methods (Lemieux 1963). Physiographic site classifications also were included with the nationwide Canada Land Inventory for the agricultural portions of Canada (McCormack 1966, 1967, 1968, Lowe et al. 1972). A "Land Systems Inventory" based on physiographic features also has been proposed for the western United States (Wertz and Arnold 1975).

Hills considers his physiographic method a "total site" classification, and defines site as "an integrated complex of climate, relief, geological material, soil profile, ground water, and communities of plants, animals, and man". Thus, his methods are "holistic" (Burger 1972), paralleling the "ecosystem" viewpoint (Rowe 1953, Rowe et al. 1960). This broad ecological viewpoint differs from the specific site quality viewpoint in which quantitative values of site index and yield are used for classifying forest land productivity.

The physiographic site methods for forest landscape classification provide a good framework for stratifying large inaccessible forest regions into broad subdivisions based on general features of climate, landform, soil and vegetation. However, in most cases relatively little quantitative data is given regarding site quality for forest trees or for the range of site quality that is included within each physiographic subdivision. The physiographic system involves much subjective judgement and intuition, and considerable research is needed to provide the needed site quality information.

Soil Surveys

Soil surveys of agricultural land in the United States have been made for more than 75 years, but only in recent decades have forested lands been surveyed using modern methods of the National Cooperative Soil Survey. Soil survey reports often contain tables listing site index averages for soil mapping units, or for various "Woodland Suitability Groups". Several soil-site and other publications list site index averages for northern forests species using soil survey classification units (table 8).

How reliable are soil survey mapping units for estimating forest site quality? Unfortunately, in many areas most of the mapping units have similar site indexes, even though site index may vary widely within each soil mapping unit. Probably much of the site variation within soil units is due to certain soil and

topographic features that are important for tree growth, but that are not well described in soil unit definitions. For example, surface soil depth, subsoil texture, aspect, slope position, and slope steepness are features often closely related to site quality, but these features may vary widely within definitions for certain soil mapping units. If such important site quality features are not well defined or are not included in soil unit definitions, then excessive site variation within the soil unit can be expected.

Table 8.--Site index of northern forest species in relation to soil survey classification units

Species	Area	Reference
Red pine	Connecticut	Hicock et al. (1931)
Red pine	Massachusetts	Mader (1968)
Red pine	New York	Richards and Stone (1964), Dement and Stone (1968)
Red pine	Lower Michigan	Van Eck and Whiteside (1958, 1963)
Jack pine	N. Cent. Minnesota	Pawluk and Arneman (1961)
Jack and white pines, aspen, northern hwds., oak	Lake States	Roe (n.d., 1935)
Jack, red, white pines; quaking aspen	N. Wisconsin	Stevens and Wertz (1971)
Jack, red, white pines	Upper Michigan	Shetron (1975)
Jack pine, red oak, sugar maple, bigtooth aspen	Upper Michigan	Shetron (1969, 1972a)
Northern hwds. and conifers	E. New York	Diebold (1935)
Northern hwds.	Vermont	Post and Curtis (1970)
Sugar maple	Vermont	Farrington and Howard (1958)
Sugar maple	New York	Farnsworth and Leaf (1963)
Sugar maple	N. Michigan	Westveld (1933)
Quaking aspen	Minnesota and Wisconsin	Kittredge (1938), Stoeckeler (1960)

Classification systems for soil surveys are flexible and provide an excellent framework for the addition of soil phases or other soil and topographic subdivisions needed for more accurately defining site quality--if the requisite soil-site information is available. This information can be provided by soil-site studies that pinpoint the various soil and topographic features closely related to tree growth, and that also express the magnitude of site change associated with each important site features. Some soil-site studies are already available for northern forest species (tables 5 and 6), but for many localities we lack this necessary information.

COMPLEMENTARY FRAMEWORK FOR SITE, YIELD, AND FOREST LAND CLASSIFICATION

The sheer volume of literature for the many methods of site quality estimation, yield prediction, and forest land classification may at first glance seem confusing, and in some cases, even contradictory. But this confusion is more apparent than real because these fields are in many ways complementary rather than contradictory. All have a common goal--to determine and classify the productivity of land for tree growth. Accordingly, in the future we should not remain separated in mensurational, soil, and ecological lines, but instead we should try to coordinate the various methods for estimating site quality, predicting timber yields, and classifying forestlands (fig 1).

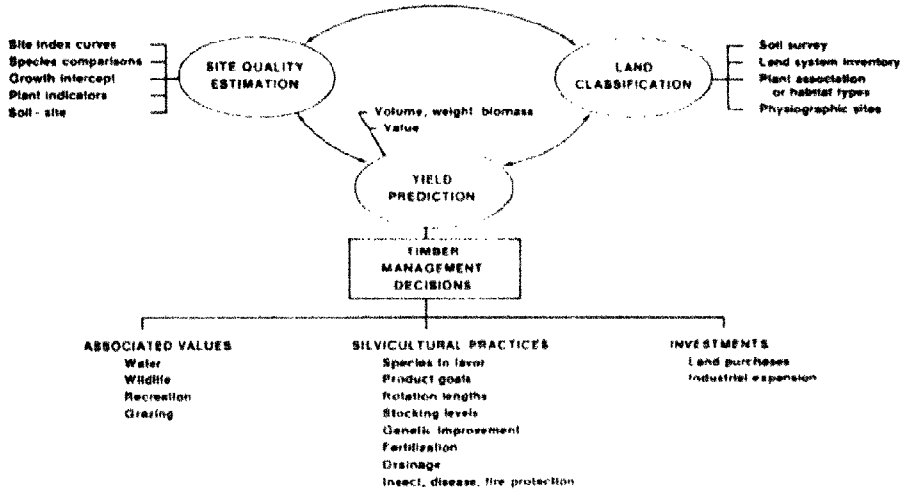

Figure 1.--Decisions about intensive timber management depend upon a complimentary framework of site quality estimation, yield prediction, and forest land classification.

All of us are dealing with separate parts of the overall problem of determining forest land productivity, and regardless of where we begin we eventually will arrive at each of the other important parts. Those concerned with local estimation of site quality will eventually strive to classify site for the entire area, and they also will need to convert site index estimates into yield estimates. Those concerned with yield prediction eventually will need means for determining both local site quality and yield, as well as site and yield estimates for the entire area. And those

concerned with forest land classification will eventually need both site and yield estimates for their classification units. Each of these three major areas--site quality estimation, yield prediction, and forest land classification--have major contributions to make because intensive timber management of the future will hardly be possible without a closer coordination of all disciplines.

How can we coordinate these three major fields? First of all we should recognize that we already have considerable scattered information about site quality, yield, and forest land classification (tables 1 to 8). For any specific area we should gather this information and then determine how much is accurate, applicable, and useful. If information is lacking, is not applicable, or is too general for intensive timber management, we should make the appropriate studies to get this needed information.

Site Quality Estimation

Our goal should be to estimate site quality for all portions of a forest area regardless of the character and condition of existing forest cover. Site index can be directly measured in the few areas having suitable trees. For other areas we might be able to extend site estimates using species comparison graphs or growth intercepts. And plant indicator and soil-site methods can be used for the remaining areas where no suitable trees can be found for direct site index measurements.

Yield Predictions

Site index estimations for local stands, or for the entire forest area, are only estimates of tree height at the 50-year index age. Site index is a qualitative index of relative forest land productivity, and merely ranking areas on the basis of height at index age is not enough. We also must be able to convert site index estimates into quantitative values for timber growth and yield. This can be done if adequate yield tables are available for the many tree species, stocking levels, and sites found in northern forest areas. However, before these yield tables can be applied we must have means for estimating site quality for each local stand as well as for the entire forest area. Accordingly, both site estimation and yield prediction methods should be viewed as complementary fields both of which are needed to attain our overall goal of predicting productivity for forest lands.

Forest Land Classification

Each of the various methods of estimating site quality and yield are still only point estimations regardless if we use trees, understory vegetation, or soil-site features. Still to be resolved

is the problem of abstracting point observations into a site and yield classification for the entire landscape. Such site classifications can be made for the entire area if detailed forest land surveys are available that use mapping units known to be closely related to site quality and yield.

Unfortunately forest land surveys are usually made using "basic" soil, physiographic, or vegetal mapping units defined by soil scientists or ecologists. After the survey is completed, attempts might then be made to interpret the survey in terms of the site quality and timber yield associated with each mapping unit. At this time it may be discovered that site quality and yield vary so much within mapping units that only very broad and general conclusions are possible. But more accurate and usable mapping units could have been achieved if, prior to the survey, factual soil-site information had been used to define mapping units that included the specific soil, topographic, and climatic features known to be closely associated with forest site quality. This requires coordinated research efforts to acquire factual soil-site information prior to the survey rather than after the survey has been finished. And such coordinated research requires the knowledge and skill of mensurationists, soil scientists, ecologists, and foresters as well as cartographers capable of using aerial photographs and other remote sensing techniques.

USING SITE, YIELD, AND FOREST LAND CLASSIFICATION FOR INTENSIVE TIMBER MANAGEMENT

How can the inventory of site information (tables 1-8) and the complimentary framework (fig. 1) help us practice more intensive timber management?

One of the first steps is to map and stratify the landscape into categories of management intensity. Usually the superior sites will be managed most intensively, less productive sites will be managed less intensively, and the poorest sites will receive little or no management, or perhaps will be designated for other land uses.

Next, decisions must be made about what silvicultural practices are appropriate for each site shown on our landscape classification. We know that thinning, fertilization, drainage, and other silvicultural practices can be very effective for certain species and sites. However, we often are not certain about the specific sites and soils where these practices should be applied or, further, how intensively these practices should be applied on each site. Because growth responses differ on different sites we must have growth and yield information for all sites so that estimates can be made of the increased growth achieved by applying each silvicultural practice. And knowing growth responses from

silvicultural practices on each site we then can estimate costs and benefits associated with the various practices employed in intensive forest management.

Likewise, decisions about land acquisition and industrial investments also require specific knowledge about site quality and about timber growth and yield. Such knowledge enables a manager to weigh the costs of these investments against the anticipated additional growth, yield, and income to be derived from the intensively managed forest. A further consideration is that compromises and restrictions on timber management might be needed because of other associated values (water, wildlife, recreation, grazing) and such compromises may decrease timber yields. Accordingly, we need specific knowledge about site and yield so that we can estimate the amount of these growth reductions, and hence the economic costs, resulting from such compromises.

In addition to timber values, forest land also has values for water, wildlife, recreation, and grazing. Managing land for these values requires much the same information as for timber--soil, topographic, and climatic data. Accordingly, for each of these associated values we could reason, as we have done for timber (fig. 1), that a coordinated approach is needed for local site estimation, yield prediction, and land classification. In many cases we may find that land features associated with timber site quality and yield may also be important in determining yields for these other associated values. If so, forest land classification for timber might be integrated with land classification for these other values resulting in a multiple use forest land classification.

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Appendix: Common and scientific names of tree species (Little 1953

Common name	Scientific name
Balsam fir	*Abies balsamea* (L.) Mill.
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Yellow birch	*Betula alleghaniensis* Britton
Paper birch	*Betula papyrifera* Marsh.
American beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
European larch	*Larix decidua* Mill.
Tamarack	*Larix laricina* (Du Roi) K. Koch
Japanese larch	*Larix leptolepis* Murr.
Norway spruce	*Picea abies* (L.) Karst.
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Jack pine	*Pinus banksiana* Lamb.
Shortleaf pine	*Pinus echinata* Mill.
Red pine	*Pinus resinosa* Ait.
Pitch pine	*Pinus rigida* Mill.
Eastern white pine	*Pinus strobus* L.
Scotch pine	*Pinus sylvestris* L.
Virginia pine	*Pinus virginiana* Mill.
Bigtooth aspen	*Populus grandidentata* Michx.
Quaking aspen	*Populus tremuloides* Michx.
Black cherry	*Prunus serotina* Ehrh.
Northern red oak	*Quercus rubra* L.
Northern white-cedar	*Thuja occidentalis* L.
American basswood	*Tilia americana* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.