Wisconsin Silviculture Guide

Chapter 11

Site Productivity

11/11/2021
Last Full Revision: 11/12/2012
Note- this chapter has not been fully revised since the restructuring of the Wisconsin Silviculture Guide, therefore some subject areas may be missing in the current version of this chapter.

TABLE OF CONTENTS

11/11/2021
Last Full Revision: 11/12/2012
Note- this chapter has not been fully revised since the restructuring of the Wisconsin Silviculture Guide, therefore some subject areas may be missing in the current version of this chapter.

List of Figures

Note- this chapter has not been fully revised since the restructuring of the Wisconsin Silviculture Guide, therefore some subject areas may be missing in the current version of this chapter.

List of Tables

11/11/2021
Last Full Revision: 11/12/2012
Note- this chapter has not been fully revised since the restructuring of the Wisconsin Silviculture Guide, therefore some subject areas may be missing in the current version of this chapter.

1 SITE PRODUCTIVITY

This chapter outlines some of the key tools and methods for evaluating forest site quality in terms of productivity and site capability (potential) in Wisconsin. For each of these methods, the forester will have to collect and evaluate a number of different measurements. For further information, refer to the forest recon sections in the Public Forest Lands Handbook (WDNR 2009a).

There are a number of ways to define a “site,” including the following:

1. The area in which a plant or stand is located, considered in terms of its environment, particularly as this determines the type and quality of the vegetation the area can carry.
2. A spatially explicit, relatively homogeneous portion of land a) characterized by specific physical and chemical properties that affect ecosystem functions and b) where a more or less homogeneous forest type may be expected to develop.
3. The sum total of environmental conditions available to the plant. The physical and biotic factors interact to yield the light, heat, water, and chemicals that are directly available to and used by the plant, as well as other chemical and mechanical disturbance factors.

The concept of a site can range greatly in size from a landform, to a stand or community, to a small microsite surrounding an individual plant. In addition, the environment that characterizes a site changes across space and time, and change can vary from coarse and abrupt to fine and gradual. Sites are influenced by both past and current environments.

The reason for evaluating a site will influence the methods used. Forestry practices are most commonly carried out on stands. These may loosely be defined as contiguous groups of trees sufficiently uniform in species composition, arrangement of age classes, and general condition to be considered homogeneous and distinguishable units.

2 SITE PRODUCTIVITY (QUALITY)

Site quality in terms of productivity refers to the growth capacity of a site, usually expressed as volume production of a given species. It can also be defined by the maximum timber crop the land can produce in a given time. Site productivity varies with tree species and the time-frame chosen. Site characteristics can also greatly affect timber productivity for a given tree species. One site may exhibit very good growth, yet another site with the same species, at the same age, may grow very poorly.

Growth of trees is possible when the amount of photosynthesis exceeds respiration. Carbon dioxide, sunlight, heat, water, and chemical nutrients are required for photosynthesis, and any of these can be limiting factors. Environmental factors that affect these basic requirements for photosynthesis will, ultimately, affect tree growth and therefore site productivity. Major environmental variables influencing tree and stand growth and productivity include:

- Climate – moisture, temperature, and sunlight

- Water available in the soil – availability, amount, timing
- Nutrient content of soil - availability, amount, timing
- Topography, elevation, and aspect, as they all can influence energy, moisture, and nutrient balances
- Biota – competition for and alteration of resources required for growth

Site quality can be changed by fertilization, vegetation control, irrigation, or drainage. Only highly intensive treatment can make a productive site out of a poor one. Conversely, productivity can be rapidly lowered by poor or intense management, as well as erosion or other site degradation.

Growing a fully stocked stand of the desired species on a site for a designated period of time precisely determines site productivity for that species during a certain period of time (historic environment) and under a certain management regime. Direct measurements of site productivity include historical growth and yield, mean annual increment (MAI), and periodic annual increment (PAI). Site index and growth intercept methods may also be considered direct measures of site quality. All of these measures reflect productivity for a specific species, under a specific management regime, and under past environmental conditions, so future site productivity will vary based on these factors.

2.1 Historic Yields

Historic yields measured in terms of volume/area/unit of time can give an indication of site productivity. This method relies on data from past harvests for a particular stand or area. Interpretation of productive potential is limited to the species being grown on that particular site; it would be difficult to estimate potential for other species. The management regime used could also affect yield, especially if different management techniques or residual stocking levels were used with each harvest.

2.2 Mean Annual Increment

Mean annual increment (MAI) is defined as the total increment of a tree or stand (standing crop plus thinnings) up to a given age divided by that age. Mean annual increment (MAI) represents the average annual growth a tree or stand of trees has exhibited up to a specified age. For example, a 20-year old tree that has a diameter breast height of 10.0 inches has an MAI of 0.5 inches/year.

MAI is calculated as:

$$MAI = \frac{Y(t)}{t}$$

where Y(t) = yield at time t.

Since the typical growth patterns of most trees is bell-shaped, the MAI starts out small, increases to a maximum value as the tree matures, then declines slowly over the remainder of the tree's life. Throughout this, the MAI always remains positive. The culmination of mean annual increment (CMAI) is the age in the growth cycle of a tree or stand at which the MAI for volume, basal area, diameter, or height is at its maximum. This point at which the MAI peaks is commonly used to identify the stand’s rotation age that maximizes volume over time. The MAI for timber volume provides the best estimate of the maximum production rate that can be continuously sustained by a given combination of species and site quality provided that the stands are rotated near maximum MAI (Smith et. al 1997).

In Wisconsin, an MAI of 20 cubic feet /acre/year is commonly used as a threshold to determine whether or not a site is considered productive.

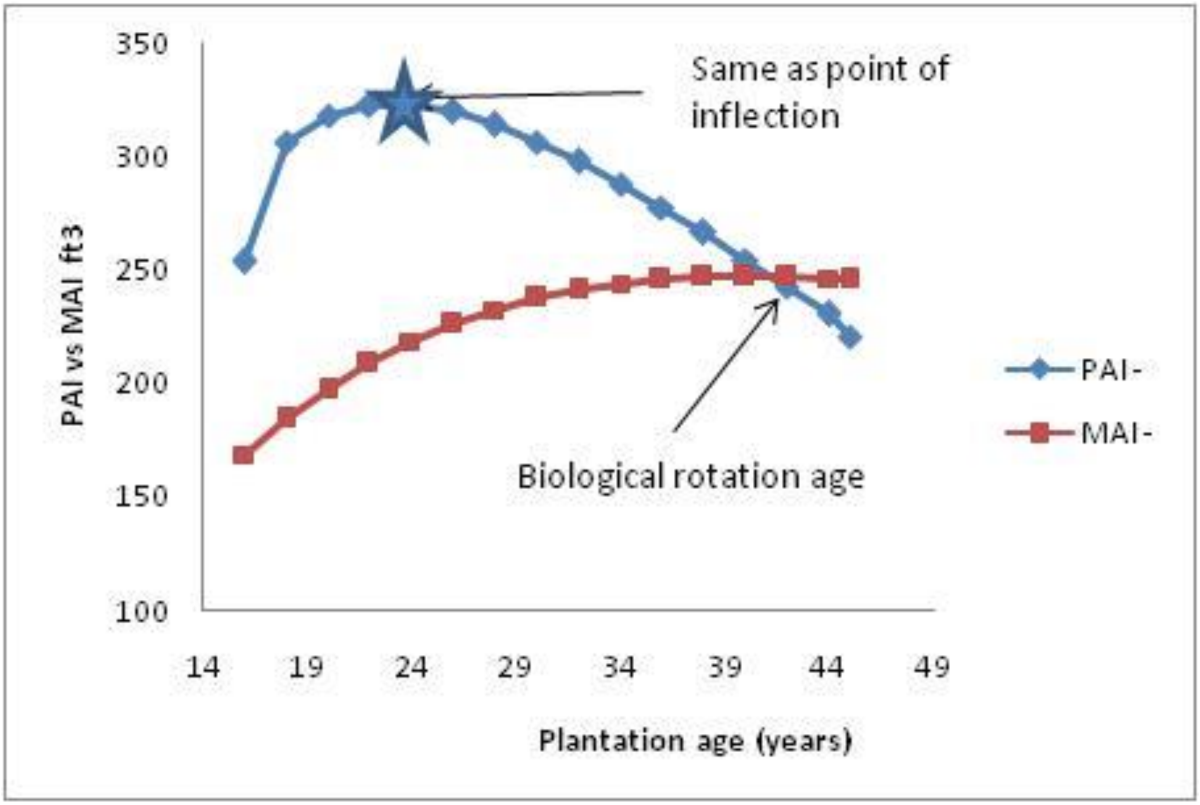

Figure 11.1. Graph of stand periodic volume growth over time showing PAI and MAI

2.3 Periodic Annual Increment

Periodic annual increment (PAI) is defined as the growth of a tree or stand observed over a specific time period divided by the length of the period. It is an indicator of a tree’s capacity, at a certain age or size, to grow. PAI is species specific.

PAI is calculated as:

$$PAI = \frac{(Y_2 - Y_1)}{(T_2 - T_1)}$$

where Y = yield at times 1 and 2, T_1 = first year of the growth period and T_2 = end of the growth period.

Typically, PAI for volume growth increases fast and then quickly declines, approaching 0. It may go negative if the tree loses volume due to injury or disease. If PAI is measured using immature stands, the productivity rates appear high but cannot be sustained over a long period.

Using a period longer than one year smoothes over the effects of climatic variations, as well as errors in estimates of beginning and ending values.

2.4 Growth Intercept

Growth intercept (GI) values can be used directly to assess site quality (growth intercept indices) or indirectly to measure site index. GI, commonly defined as the total length of the first five internodes above breast height, is usually a reliable indicator of height growth for the next 5-20 years. Growth intercept is most useful in young stands (3-30 years old) of uninodal species that display annual branch whorls (e.g., pines) or for multinodal species where spring whorls are clearly identifiable. The advantages of GI include it can be used in stands too young to evaluate using standard site index curves, stand age is not required, and the length of the specified number of internodes is usually easier to measure than total heights of dominant trees. (Schreuder, et al. 1993). Effects of short-term climatic fluctuations and the fact that early growth of a stand does not always accurately reflect later growth are disadvantages of the GI method (Alban 1972). Growth Intercept cannot be used in uneven-aged stands.

When measuring GI, use only dominant or co-dominant trees without obvious insect, disease, or fire damage that are not suppressed (same criteria as for measuring site index). Use a measuring pole to measure the length of five internodes beginning at the first whorl above breast height (4.5 feet). The number of trees to measure depends on the variation among trees and the desired precision. Typically, five to 10 sample trees are selected, and 10 to 20 trees would be best. Site index for each intercept measurement can be determined from the appropriate species growth intercept table. Average the site index values to arrive at an average stand site index.

Growth intercept commonly uses the total length of the first five internodes above breast height; however, seedling establishment and early growth are strongly affected by seedling vigor, competition, animal and insect damage, which affect growth less later in life. To reduce the influence of these factors, David H. Alban (1972) recommends for red pine that the total length of the five internodes starting from the first whorl above 8 feet be measured (GI_8). Site index can then be predicted using the equation: $Ht_{50} = 32.54 + 3.434GI_8$.

2.5 Site Index

Site index (SI) is a species-specific measure of forest productivity (usually for even-aged stands), expressed in terms of the average height of trees in a specified crown class (dominants, codominants, or the largest and tallest trees) at a specified index or base age. In Wisconsin, fifty years is the most commonly used site index base age.

The height growth of seed origin trees is considered to be independent of stand density and strongly related to site quality in that better sites produce taller trees; however, it should be noted that tree height growth can be reduced at very high densities and very low densities (Larsen 1999). In addition, indicator trees should have been free to grow throughout their lives (never suppressed) and their height growth never damaged by exogenous factors. SI is species dependent, and SI values are not usually equivalent between species.

Site index curves show the expected height growth pattern for trees of the specified stand component in even-aged stands of a given site index. Site index curves convert ages other than the base age to the expected height at the given age. SI curves for a species will differ among authors and regions. It is important to consistently use the same set of SI curves.

Historically site index equations and curves were constructed from tree height/age data pairs. Anamorphic site index curves were constructed using a single guiding curve derived through regression techniques. This guiding curve was then scaled to produce other curves, harmonized to reflect the same form and trend reflecting differing site quality. The most common method since 1980 is to perform stem analysis on individual trees, and fit polymorphic curves to the growth pattern of individual trees.

2.5.1 Limitations of the use of SI:

- Factors other than site which can influence height growth are:
  - extremes of stand density
  - genetics
  - suppression
  - past management (e.g., site prep, soil compaction)
  - height growth damage (e.g., from animals, disease, or weather)
  - root or stump sprouting.

- It cannot be used in uneven-aged stands and deforested areas.
- Age seems to affect site index for certain species (University of Minnesota 1992).
- During construction of curves, extrapolation of data across range of sites and ages can introduce error
- SI is a relative measure, depending on regional variation and databases and methods used in curve construction. It is important to consistently use the same set of SI curves appropriate for the region in which you are evaluating.
- Accurate determination of site index requires careful measurement. Stand and tree selection and measurement errors can result in highly inaccurate results.
- Published curves are based on too few plots
- Curves are species-specific.

2.5.2 Field Application

Ideally, the most precise way to determine SI is to fell, measure heights, and take sections to count rings from representative trees. In practice, however, trees are typically sampled using increment cores and indirect height measurements. To obtain SI while performing routine forestry field work requires measuring the heights and ages of sample trees and then obtaining the SI from appropriate site index curves.

Stands must have the following characteristics for applying this method:

  - even-aged with less than a 10 year age difference among overstory trees (excluding reserve trees);
  - fully stocked;

- mostly free of trees killed by wind, insects, or disease;
- not disturbed by fire, grazing or heavy thinning from above since establishment;
- at least 20 years old and preferably more than 50 years old (actual age, not measured at breast-height); and
- representative of a large area and of relatively uniform site quality.

To measure the site index:

1. For each species, select five to 10 sample trees. Sample trees must be
    - Dominants or strong co-dominants
    - Above average diameter for the stand (considering all trees >5-inches dbh)
    - Single stemmed, no sprout clumps
    - Without serious animal, insect, disease, wind, fire, or logging injuries
    - At least a tree height away from reserve trees
    - Straight and without pronounced lean
    - Free of most surface defects, epicormics, bumps, and dead branch stubs
    - Full-Crowned, without dead tops and large forks
    - Trees that have never been suppressed (consistent growth rings)
    - Evenly distributed across the stand and occurring on micro-sites that represent average site productivity

2. Measure total tree heights with a clinometer, altimeter or similar device
3. Determine tree ages by taking increment cores at dbh and adding the proper number of years according to the site index curve publication. Count the rings carefully using a hand lens if necessary, because each 1 year error can cause a 1 to 2-foot error in site index.
4. Use tree age and height data and site index curves appropriate for the species and physiographic region to determine site index for each tree.
5. Average site index values for all sample trees to obtain the mean site index of the stand.

3 SITE CAPABILITY (POTENTIAL)

Site capability, or potential, refers to the sum total of all the factors affecting the capacity to produce forests or other vegetation. It integrates the collective physical resources (e.g., moisture, nutrients, heat, and light) available for plant growth. Different potentials facilitate growth of some species and limit growth of others. Consequently, site potential has a strong effect on plant community development.

Site type is a classification of site potential based on indirect measures utilizing site factors (individually or in combination) such as climate, topography, geology, soil, and vegetation. Classification of site types can be used as an indirect measure or estimation of potential tree and stand growth and yield (productivity), as well as potential community development.

3.1 Vegetation

In general, “vegetation” refers to the plant life or total plant cover of an area. Plants typically occur together in repeating groups of associated species, sometimes called communities. A plant community is an assemblage of plants grouped by environmental factors. Plant communities change in time and space. In plant ecology, “vegetation” refers to plant communities in terms of composition and structure, particularly the identity and growth form of the most abundant species, the largest species, and the most characteristic species (i.e., it is more than a list of flora).

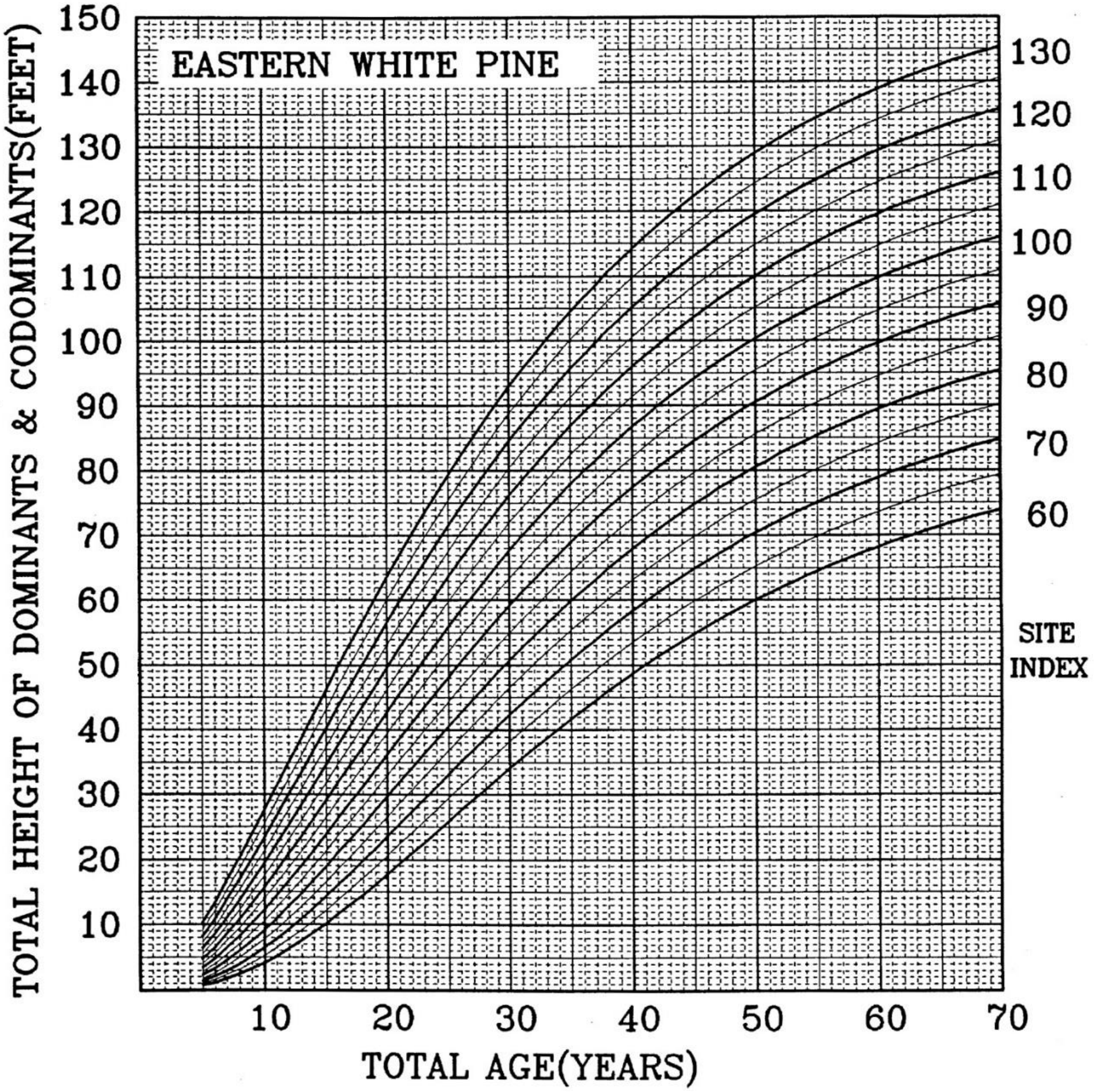

Figure 11.2. Example site index curve

3.1.1 Indicator Species

Plant indicator species are plants that, by presence, frequency, or vigor, indicate any particular property of the site, particularly of the soil. Different plant species have different environmental requirements and limitations for survival and growth. The presence of a species at a given location, particularly if abundant and vigorous, indicates that its habitat requirements are being met. For example, blue cohosh (*Caulophyllum thalictroides*) requires moist (mesic to wet-mesic) and nutrient rich soils to thrive, whereas sweetfern (*Comptonia peregrine*) commonly occurs on dry, nutrient poor soils. The abundance of either of these species across a forested site (rather than very small, isolated individual patches) indicates soil moisture and nutrient balances which influence the presence and productivity of other species, including trees. For example, potential productivity for sugar maple would be considered good for a forested site where blue cohosh is abundant, but poor where sweetfern is abundant.

3.1.2 Vegetation Associations

Vegetation associations group vegetation (i.e., plant communities) into types or kinds, based on systematic description of recurring vegetation patterns. These abstract vegetation types (typical communities) are defined and described in terms of floristic composition and structure, often including successional and developmental patterns, and environmental relationships. Vegetation development is both dependent on and modifies the environment; therefore, different vegetation associations have different environmental requirements and limitations for development. Descriptions of vegetation associations often include interpretation of management potentials.

Vegetation types are often developed through methods of classification or ordination. Classification groups sampled communities that are similar into types (i.e. group similar entities into clusters). Examples of vegetation classification systems include forest cover type and forest habitat type classification systems. Ordination interprets sampled communities in relation to one another according to their similarities and dissimilarities (i.e. represent relationships in a low-dimensional space). A classic example of vegetation ordination is the Vegetation of Wisconsin (1959) developed by John Curtis.

3.1.3 Cover Types

Forest cover types are categories of forests usually defined by dominant vegetation as based on percentage cover of trees. They are vegetation associations classified based on the dominant floristic composition (uniformity and abundance) of the forest overstory. The trees are the largest, most characteristic structures of these plant communities, and of utilitarian interest. Some tree species and cover types have similar environmental requirements and limitations.

3.1.4 Forest Habitat Type Classification System (FHTCS)

The forest habitat type classification system is a site classification system based on the floristic composition of plant communities. The system depends on the identification of potential climax associations, repeatable patterns in the composition of the understory vegetation, and differential understory species. It groups land units with similar capacity to produce vegetation. The floristic composition of the plant community is used as an integrated indicator of those environmental factors that affect species reproduction, growth, competition, and community development. This classification system enables the recognition of ecologically similar landscape units and vegetation communities.

A forest habitat type is an aggregation of sites capable of producing similar late-successional (potential climax) forest plant communities. Each recognizable habitat type represents a relatively narrow segment of environmental variation that is characterized by a certain limited potential for vegetation development. Although at any given time, a habitat type can support a variety of disturbance induced (seral) plant communities, the ultimate product of succession is presumed to be a similar climax community. Field identification of a habitat type provides a convenient label (habitat type name) for a given site, and places that site in the context of a larger group of sites that share similar ecological traits. The FHTCS provides a tool to improve the process of assessing site potential and evaluating management alternatives.

See Chapter 12 within this handbook for a more detailed description of the FHTCS in Wisconsin.

3.2 Soils

Soils and the forest litter layer are essential to tree growth, providing nutrients and physical support for trees, a medium for supplying water and air to tree roots, and sites for microbes and other soil fauna to decompose organic material and release nutrients. The physical, chemical, and biological properties of soils are all important in determining site productivity and forest composition. Most soil properties are related, directly or indirectly, to the geologic history of soil parent materials. An understanding of the geology of a site can provide insights into its productive potential.

Topography affects site productivity through moisture relationships. Sites on north and east-facing slopes are typically more mesic, supporting forests that have higher moisture and nutrient demands. Geologic processes are largely responsible for topography. Glacial features such as steep, hilly end moraines, gently rolling ground moraines, and nearly level outwash and lake plains have characteristic surface shapes related to glacial processes. The steep, dissected topography of the unglaciated area (also known as the “driftless area”) was formed by erosion processes over millions of years.

Physical properties of soils include texture, structure, porosity, density, drainage, and hydrology. Soils in Wisconsin vary widely in physical properties due to the different characteristics of parent materials. This variability includes loamy and clayey soils formed in glacial till and glacial lakebeds, stratified silty and loamy soils on alluvial plains along rivers and large streams, and droughty sand soils on glacial outwash deposits. Eroded soils occur on steep hillsides in the unglaciated area of southwest Wisconsin. Shallow soils overlying bedrock of igneous, metamorphic, and sedimentary origin are common in the unglaciated area and in other scattered locations around the state. An area near Lake Superior is formed of lacustrine clay interlayered with strata of sand, pushed up from Superior’s lakebed by glaciers. Wisconsin also has large areas of organic soils formed in wetlands. Many soils throughout the state are overlain with an aeolian silt loam “loess cap” deposited by wind after glaciers melted, and the thickness of the loess deposit has a strong influence on soil productivity.

Soil chemical properties include nutrient status and rates of cycling, and pH. Biological properties refer to the organisms that live in soil and have a role in plant growth. These include mycorrhizae, other fungi, bacteria, and many invertebrates (Fisher and Binkley 2000). Chemical and biological properties are related to physical properties. Loam, silt, and clay soils typically have higher nutrient-holding capacities and, also, higher levels of biological activity due to the supply of moisture and nutrients.

3.2.1 Soils of Ecological Landscapes

The 16 Ecological Landscapes of Wisconsin provide a framework for a general description of the varying soil characteristics of the state. See the Ecological Landscapes of Wisconsin Handbook for more information (WDNR 2009b).

Soils of the Southwest Savanna and the Western Coulees and Ridges (WCR) Ecological Landscapes are similar to each other, but topography is steeper and more dissected in the WCR. Soils on hilltops and sideslopes are formed in loess over loamy to clayey residuum, or sandy to loamy colluvium. Many soils are shallow over limestone, dolomite, or sandstone. The dominant soil is well drained and silty with a silt loam surface, moderate permeability, and moderate available water capacity. Soil drainage classes range from well drained to moderately well drained, and soils typically have silt loam to sandy loam surface textures, moderate permeability, and moderate available water capacity. Some of the larger valleys, particularly in the northern part of the Western Coulees and Ridges, contain stream terraces deposited by outflow from glaciation and have soils formed in outwash sands. Soils of the narrower valleys are dominantly filled by silty and loamy residuum and alluvium. These soils range from well drained to very poorly drained and have areas subject to periodic flooding. Loess deposits are thickest near the Mississippi River, where some areas are mapped as having 8-16 feet of aeolian silt, and nearly all of these Ecological Landscapes has loess deposits at least two feet thick (Hole 1976). Loess forms a fertile soil with excellent moisture-holding characteristics, and floodplain soils with incorporated loess are highly productive. Upland ridges are also generally productive. Sideslopes, particularly on south- and west-facing slopes, tend to be dry and erodible, and their shallow depths to bedrock can limit management options. Johnson et al. (1993) note that the warmer and drier south- and west-facing slopes of this region are dominated by oaks and hickories, while the cooler and moister north- and east-facing slopes support central and northern hardwood tree species. Site indices for oaks and northern hardwoods on the dominant forest soils range from 62 to 74 feet (Johnson et al. 1993).

Soils of the Western Prairie Ecological Landscape are predominantly formed in loamy till glacial deposits, while some are in outwash. A loess cap of aeolian silt is 6 to 48 inches thick over the surface (Hole 1976). The dominant soil is well drained and loamy with a silt loam surface, moderate permeability, and moderate available water capacity. Beneath the silt loam loess cap, most soils are either a reddish-brown non-calcareous dense sandy loam till, or a brown calcareous non-dense loam till. Soil drainage classes range from well drained to somewhat poorly drained; soils generally have silt loam to sandy loam surface textures, moderate to very slow permeability, and moderate to high available water capacity. Some areas are shallow over bedrock of dolomite, sandstone or shale. This Ecological Landscape contains some outwash plain deposits, where soils are formed in loess or loamy alluvium over acid outwash sand and gravel, or entirely in outwash sand. Lowland soils are also present, and they are very poorly drained non-acid muck, poorly drained loamy till, or poorly drained outwash. The major river valleys have soils formed in sandy and loamy alluvium or non-acid muck. Drainage classes range from moderately well drained to very poorly drained, and some areas are subject to periodic flooding.

In the Southeast Glacial Plains Ecological Landscape, most upland soils are formed in brown or reddish-brown calcareous glacial till, ranging in texture from sandy loam to loam or clay loam. Some soils are outwash sands and gravels, or lacustrine clays and sands derived from Glacial Lake Oshkosh. A mantle of silty loess, originating from wind deposition during and after glaciation, is 6 inches to more than 48 inches thick in different parts of the Ecological Landscape (Hole 1976). Nearly all the soils are rich in calcium carbonates derived from the underlying dolomite bedrock and are highly productive. Some of the soils are reddish-colored because of the high iron content in sediments transported by glaciers from the Lake Superior basin. Upland soils range from well drained to poorly drained; they have very slow to rapid permeability and low to very high available water capacity. Most lowland soils are very poorly drained non-acid mucks, but some are silty or clayey lacustrine, or loamy till soils. Soils in the larger river valleys include loamy to silty alluvium, non-acid muck, and aeolian silts over acid outwash sand and gravel. Site indices for oaks and northern hardwoods on the dominant forest soils range from 53 to 70 feet, with lower productivity on soils with outwash in the substratum (Johnson et al. 1993).

Soils of the Southern Lake Michigan Coastal Ecological Landscape are typically loamy and clayey tills with high silt content, though near Lake Michigan there are lake plain soils formed in glacio-lacustrine clay deposits. Most soils have a thin surface layer of wind-deposited silt, six inches thick or less (Hole 1976). Upland till soils are dominantly brown calcareous silty clay loams; they are moderately well-drained with moderately slow permeability and high available water capacity. These are highly productive soils, enriched with organic material from the former prairie vegetation. Development has disturbed a large proportion of these soils, often removing the productive surface soil. The dominant soils have drainage classes of moderately well drained to somewhat poorly drained, surface textures of silt loam to silty clay loam, moderate to slow permeability, and high to very high available water capacity. Lake plain soils are formed in calcareous silty to clayey lacustrine material, with some sands deposited by wave action. Most lowland soils are very poorly drained non-acid muck or silty and clayey lacustrine. The major river valleys have soils formed in loamy to silty alluvium, drainage classes that range from moderately well-drained to very poorly drained, and areas that are subject to periodic flooding.

The Central Sand Hills Ecological Landscape has soils that are primarily sands in the northwest portion (Central Wisconsin Moraines and Outwash Subsection, 222Kb) and sandy loam tills in the southeast (South Central Wisconsin Prairie and Savannah Subsection, 222Kd). In the northwest, most soils formed in sandy glacial till, outwash, or lacustrine materials. The dominant soil has a loamy sand surface over sand, is well drained with rapid permeability, and has a low available water capacity. Some soils are calcareous. Drainage classes range from excessively drained to somewhat poorly drained, and soils generally have loamy sand to sandy loam surface textures, moderate to very rapid permeability, and moderate to low available water capacity. Most soils in the southeast formed in brown calcareous sandy loam till on moraines and drumlins. The dominant soil is well drained and loamy with a fine sandy loam surface, moderate permeability, and moderate available water capacity. The aeolian loess cap is 6 to 24 inches thick (Hole 1976). Soil drainage classes range from well drained to somewhat poorly drained, and soils generally have fine sandy loam to silt loam surface textures, moderate to moderately rapid permeability, and moderate available water capacity. Organic soils occur in wetlands throughout the Ecological Landscape. The major river valleys have soils formed in sandy to clayey alluvial material or non-acid muck. Their drainage classes range from moderately well drained to very poorly drained, and some areas are subject to periodic flooding.

Most soils in the Central Sand Plains Ecological Landscape were formed in deep sand deposits of glacial lacustrine or outwash origin or in materials eroded from sandstone hillslopes, sometimes with a surface of wind-deposited (aeolian) sand. Most of this area lacks a loess cap (Hole 1976). The deep sandy soils are typically excessively drained, with very rapid permeability, very low available water capacity, and low nutrient status. In lower-lying portions of the landscape, and where silty lacustrine material is close to the surface and impedes drainage, the water table intercepts the surface. Such areas are extensive in the western part of the Ecological Landscape, where soils may be poorly or very poorly drained with surfaces of muck or mucky peat. Thickness of these peat deposits ranges from a few inches to more than 15 feet (USDA SCS 1991). In the eastern part of the Ecological Landscape, outwash sand deposits are thicker and soils are higher above the water table. Here, many wet soils were ditched and drained and are now commonly irrigated for the growth of vegetable crops. Ditching and drainage has also taken place in other parts of the Ecological Landscape, and soil disturbance for cranberry beds is locally common. In the northwest portion of the Ecological Landscape, in the Neillsville Sandstone Plateau Subsection (222Rb), most soils formed in sandy or loamy hillslope alluvium or colluvium over Cambrian and Precambrian bedrock. These soils are typically somewhat poorly drained and sandy with a loamy fine sand surface. In major river valleys throughout the Ecological Landscape, soils were formed in sandy to clayey alluvium. Their drainage classes range from moderately well drained to very poorly drained, and some areas are subject to periodic flooding. Site indices for these soils range from 55 to 82 feet for pine species (Johnson et al. 1993).

Most soils in the Forest Transition Ecological Landscape are non-calcareous, moderately well drained sandy loams derived from glacial till, but there is considerable diversity in the range of soil attributes in this large Ecological Landscape. The area includes sandy soils formed in outwash, as well as organic soils, and loam and silt loam soils on moraines. There are many areas with shallow soils. Drainage classes range from poorly drained to excessively drained. Density of the till is generally high enough to impede internal drainage, so there are many lakes and wetlands. Soils throughout the Ecological Landscape have silt loam surface deposits of aeolian loess about 6 to 24 inches thick (Hole 1976). Lowland soils include very poorly drained non-acid muck, poorly drained loamy till or residuum, and poorly drained outwash. The major river valleys have soils formed in loamy alluvium or non-acid muck; they range from moderately well drained to very poorly drained and have areas subject to periodic flooding. In the St. Croix Moraine (Subsection 212Qa), most upland soils formed in reddish-brown non-calcareous dense sandy loam till on moraines, in loess over the till on moraines, in loamy alluvium over outwash sand and gravel on moraines and glacial drainageways, and in loamy to silty lacustrine material on lake plains. The dominant soil is moderately well drained and loamy with a sandy loam surface, moderately slow permeability, and moderate available water capacity. Soils of the Lincoln Formation Till Plain, Mixed Hardwoods (Subsection 212Qb), are mostly formed in outwash and in non-calcareous loamy till. The dominant soil is moderately well drained and loamy with a silt loam surface, moderate permeability, and moderate available water capacity. Most of the morainal upland soils in the north part of Subsection 212Qb formed in loess over reddish-brown non-calcareous dense sandy loam till. Most upland soils on the outwash plain in the center of the Subsection formed in loamy alluvium over outwash sand and gravel, or entirely in outwash sand. Upland soils at the southern end of the Subsection formed in brown non-calcareous loamy till on moraines, and in silty to loamy alluvium over residuum from sandstone and shale on pediments. Exposures of Paleozoic bedrock occur throughout the Subsection. In the Lincoln Formation Till Plain, Hemlock Hardwoods (Subsection 212Qc), most upland soils formed in loess over reddish-brown non-calcareous dense sandy loam till or brown non-calcareous non-dense sandy loam till on moraines, and in loamy and silty alluvium over acid outwash sand and gravel on glacial drainageways and outwash plains. The dominant soil is moderately well drained and loamy with a silt loam surface, moderately slow permeability, and moderate available water capacity. Soils range from moderately well drained to somewhat poorly drained and generally have silt loam surface textures, moderate to very slow permeability, and moderate available water capacity. In the Rib Mountain Rolling Ridges (Subsection 212Qd), most soils formed in loamy residuum or a mixture of residuum and till, or in outwash. The dominant soil is moderately well drained and loamy with a silt loam surface, moderate permeability, and moderate available water capacity. Most upland soils formed in non-calcareous loamy till or residuum from igneous and metamorphic rock. These soils range from well drained to somewhat poorly drained and generally have silt loam to sandy loam surface textures, moderate to moderately slow permeability, and moderate available water capacity. Igneous and metamorphic bedrock exposures are common. Site indices for some common soils in the Forest Transition range from 57 feet for red maple to 69 feet for northern red oak (Johnson et al. 1993). Upland soils of the Green Bay Lobe Stagnation Moraine (Subsection 212Ta) are formed in non-calcareous sandy loam and loamy sand till on moraines and drumlins, in loamy alluvium over acid outwash sand and gravel on moraines or outwash plains, and in outwash sand and gravel on outwash plains. The dominant soil is well drained and loamy with a sandy loam surface, moderate permeability, and moderate available water capacity. Soils range from excessively drained to somewhat poorly drained and generally have sandy loam to loamy sand surface textures (loamy sand being more typical in the southern part of the Subsection), moderate to very rapid permeability, and moderate to low available water capacity. Some soils have carbonates within a 6 foot depth, but in most soils the carbonates have leached to a deeper level. Site indices for Subsection 212Ta are higher than is typical for most of the Forest Transition, ranging up to 75 feet for northern red oak on productive soils. Aspen site index ranges from 67 to 76 feet (Johnson et al. 1993).

Most upland soils within the Northwest Sands Ecological Landscape were formed in acid outwash sand and gravel on former glacial spillway terraces and pitted outwash plains. The dominant soil is excessively drained and sandy with a sand surface, very rapid permeability, and very low available water capacity. Soils generally have sand surface textures; drainage classes range from excessively drained to somewhat poorly drained, permeability ranges from rapid to very rapid, and available water capacity is low. Xeric, droughty conditions are common on these soils. A few moraines occur in the northern, hilly portion of the Ecological Landscape, with soils formed in brown non-calcareous loamy sand till or mudflow sediments. These soils have greater nutrient availability and are slightly more productive. They range from well drained to moderately well drained and generally have loamy sand to sandy loam surface textures, moderately rapid to slow permeability, and low to moderate available water capacity. A former glacial lake plain in the southern part of the area has soils formed in gray calcareous lake sediment clay, some with a mantle of wind-blown sands. Another area in the southern part of the Ecological Landscape has soils formed in acid outwash sand over reddish-brown non-calcareous lake sediment clay over acid outwash sand. Wetland soils are typically very poorly drained acid peat or non-acid muck. The major river valleys have soils formed in sandy alluvium or non-acid muck, range from somewhat poorly drained to very poorly drained, and have areas subject to periodic flooding. Site indices for pine on a typical soil range from 55 to 60 feet (Johnson et al. 1993).

In the Northwest Lowlands Ecological Landscape, most upland soils formed in reddish-brown,non-calcareous, dense sandy loam to loamy sand till. Some soils formed in outwash sand and gravel. The dominant soil is moderately well drained and loamy with a sandy loam surface, moderately slow permeability, and moderate available water capacity. Soil drainage classes range from moderately well drained to somewhat poorly drained. They generally have sandy loam to silt loam surface textures, moderate to slow permeability, and moderate available water capacity. The dense till impedes water infiltration in some locations, creating wetlands. Many areas are underlain with igneous bedrock. Aeolian silt (loess) deposits on the surface typically range from 6 to 24 inches thick (Hole 1976). Most lowland soils are very poorly drained to poorly drained loamy till or non-acid muck. The major river valleys have soils formed in sandy to loamy-skeletal alluvium or in non-acid muck. Alluvial soils range from well drained to very poorly drained and have areas subject to periodic flooding. Soils of the disjunct portion of the Ecological Landscape, in southwest Burnett and northwest Polk Counties, are characterized by a fine sandy loam surface over calcareous sandy loam till. These soils are moderately well drained to somewhat poorly drained. The disjunct area also contains very poorly drained non-acid muck soils. Depending on the soil type, site indices for red maple can be around 56 feet, while northern red oak is 75 feet, and aspen ranges from 67 to 76 feet (Johnson et al. 1993).

Most upland soils of the Superior Coastal Plain Ecological Landscape are formed in reddish clay or silty clay loam till that was reworked from lake sediments and are slightly calcareous with pH values around 7 in B horizons, increasing with depth to around pH 8 in C horizons. The dominant soil is moderately well drained and clayey, with a clay loam surface, very slow permeability, and very high available water capacity. Soil drainage classes range from well drained to somewhat poorly drained. Surface textures are generally clay to silt loam; permeability ranges from very slow to moderately slow, and available water capacity ranges from moderate to very high. The fine texture and slow permeability of these soils gives them many of the functional characteristics of wetland soils, even when they occur on uplands.

Water moves out of them very slowly, and surface ponding from runoff can be common in basins and lower-lying areas. Special management considerations for many of these soils are warranted, as they are seldom completely dry. Along the higher elevations of the Ecological Landscape some wave-action sand is intermingled with the clayey till, making these soils unstable in cut banks. Loess deposits are less than 6 inches thick in this area (Hole 1976). Most lowland soils are poorly drained and are also formed in reddish calcareous clay to silty clay loam till. Soils in the major river valleys are formed in sandy to clayey alluvium and are moderately well drained to very poorly drained. Swamps, sloughs, and marshes along Lake Superior and in the Bibbon Marsh are very poorly drained non-acid muck or mucky peat. Site indices on typical soils range from 45 feet for white spruce to 72 feet for aspen (Johnson et al. 1993).

Upland soils of the North Central Forest Ecological Landscape are typically reddish-brown or brown non-calcareous glacial till, ranging in texture from loamy sand to sandy loam and loam. Some outwash sands are also present. Soils vary considerably due to differences in parent materials deposited by glaciation, and the influence of underlying material such as bedrock or older till. Upland soils range from well drained to somewhat poorly drained; they have slow to moderately rapid permeability and low to moderate available water capacity. A mantle of loess 6 to 24 inches thick covers nearly all of the area (Hole 1976). Topography can be steep in end moraines and drumlinized areas. Rocks of various sizes, including stones and boulders, are common on the soil surface at many locations. The Gogebic-Penokee Range has soils that are shallow to bedrock, as do the Blue Hills and a few other locations. Almost all of the Ecological Landscape is underlain by dense till that impedes drainage, so there are many areas of poorly and very poorly drained soils, and few areas of well drained soils. Organic soils are typically acid peat or non-acid muck, poorly or very poorly drained, and there are many additional wetland soils with a shallow water table in outwash sands or loamy alluvial deposits. Site indices on typical soils range from 57 feet for red maple to 75 feet for northern red oak (Johnson et al. 1993).

Most soils in the Northern Highland Ecological Landscape are formed in acid sands and gravels of glacial outwash origin, some with a loamy loess mantle (Hole 1976). The dominant soil is excessively drained and sandy with a loamy sand surface, very rapid permeability, and low available water capacity. Soil productivity, although lower than that of till soils, is still relatively high for outwash sands. Many of these soils are stratified with finer-textured glacial materials, so that drainage is less rapid and moisture availability is relatively high. Soils on outwash plains where fine-textured strata are not present tend to drain rapidly, leading to xeric site conditions and drought impacts. There are remnant moraines and drumlins in the Ecological Landscape, with loamier soils formed in glacial till. Large areas of the Ecological Landscape are wetlands, formed in kettle depressions, or in areas where the water table is held close to the surface by an underlying fine-textured soil layer. Most lowland soils are very poorly drained acid peat or non-acid muck, but there are also areas of poorly drained outwash sand. Site indices for pine on a typical soil range from 55 to 60 feet (Johnson et al. 1993).

The Northeast Sands Ecological Landscape has upland soils that were mostly formed in acid outwash sand on outwash plains or outwash heads. The dominant soil is excessively drained and sandy with a loamy sand surface, rapid permeability, and very low available water capacity. Overall, the soils range from excessively drained to somewhat poorly drained and generally have loamy sand to sandy loam surface textures, rapid to very rapid permeability, and low to very low available water capacity. Remnant moraines are present in part of the area, and they have soils formed in brown to reddish-brown non-calcareous to calcareous loamy sand, sandy loam and loam till. Igneous and metamorphic bedrock exposures are common in the northern part of the area. Most lowland soils are very poorly drained acid peat or non-acid muck. Site indices are similar to those given for the Northern Highland Ecological Landscape.

In the Central Lake Michigan Coastal Ecological Landscape, most upland soils formed in reddish-brown calcareous loamy till and lacustrine deposits on moraines and lake plains. The dominant soil is moderately well drained and loamy or clayey with a silt loam surface, moderately slow permeability, and high available water capacity. Drainage classes range from well drained to somewhat poorly drained. Soils generally have silt loam surface textures, moderate to very slow permeability, and moderate to very high available water capacity. Soils that are shallow to limestone or dolomite bedrock occur here. A few areas have soils formed in acid wind-blown sand. Along the Lake Michigan shoreline are soils formed in calcareous clayey and silty lacustrine and in acid to calcareous wave-action beach sand, silty to sandy lacustrine materials, and wind-blown sediments. Most lowland soils are very poorly drained non-acid muck, or poorly drained outwash, till, and lacustrine materials. The major river valleys have soils formed in sandy, loamy, or silty alluvium; some areas are subject to periodic flooding.

Most upland soils in the Northern Lake Michigan Coastal Ecological Landscape formed in brown to reddish-brown, calcareous to neutral loam or sandy loam till on moraines and drumlins. The dominant soil is moderately well drained and loamy with a silt loam surface, moderate permeability, and moderate available water capacity. Drainage classes range from well drained to somewhat poorly drained, and soils generally have silt loam to loamy sand surface textures, moderate to moderately slow permeability, and moderate to high available water capacity. Part of the area has upland soils formed in acid to calcareous outwash or wind-blown sand on outwash plains, lake plains, and former beach terraces. They range from excessively drained to poorly drained and generally have loamy sand to fine sand surface textures, rapid to very rapid permeability, and low available water capacity. Most lowland soils are very poorly drained non-acid muck, poorly drained loamy till, or poorly drained outwash.

3.2.2 Use of soil surveys for forest site productivity interpretations

Soil surveys include maps and descriptions of soils, along with interpretation tables that can be useful in assessing site productivity. There are limitations of soil classification based primarily on soil morphology because the influences of geologic landforms are not fully incorporated, and this contributes to variability in forest productivity within a map unit. Also, interpretations for SI provided with the soil surveys are sometimes based on a sample of a few trees regionally, so these SI values may not be accurate for some sites, particularly sites on soil map units of minor extent. See Rennie (1963), Carmean (1968, 1975), Jones (1969), and Grigal (1984) for further discussion of the uses and limitations of soil surveys in forest management.

The soil map unit is usually the area of interest in forest management since these are the units delineated on soil maps. Map units may be consociations, complexes, or undifferentiated groups. They are mapped at a scale of around 1:24,000. Usually, a map unit delineates one major component (consociation). Some map units include a combination of phases of two soils (complex). Occasionally, a map unit is based on a higher level of soil classification, such as 'Histosols', indicating that a group of soils have been mapped together (undifferentiated group). Users of soil surveys need to know which type of map unit their site is on, and how this affects variability and productivity.

A soil map unit consists dominantly of the soil for which it is named, but it also includes other soil components. A map at the scale of a soil survey cannot differentiate site-level variations that are too small to be drawn on the map (inclusions). Also, boundaries between soils are often gradual and cannot be plotted precisely on a map, so the areas of gradual change along boundaries may differ from the central part of the map unit. Some soils are so intermingled that they cannot be mapped separately, and some soils are similar enough with regard to use and management that they were not mapped separately. More information about the composition of soil map units can be found in the Soil Survey Manual, Chapter 2 (Soil Survey Division Staff 1993).

> Consociations - A consociation is the most homogenous kind of map unit. Generally, at least half of the map unit is made up of the named soil component. Most of the rest of the map unit consists of soil components similar to the named soil, and major interpretations are not affected significantly. The total amount of dissimilar inclusions of other components in a map unit does not exceed about 15 percent if limiting (to management interpretations) and 25 percent if nonlimiting. The amount of dissimilar inclusions in an individual delineation of a map unit can be greater than this if no useful purpose would be served by defining a new map unit.
>
> Complexes - Soil map units made up of complexes consist of two or more dissimilar components occurring in a regularly repeating pattern that cannot be mapped separately at the scale of soil mapping. The major components are sufficiently different in morphology or behavior that the map unit cannot be a consociation. Proportions of the major soil components may vary. The total amount of inclusions within a complex map unit that are dissimilar to any of the major components does not exceed about 15 percent if limiting and 25 percent if nonlimiting.
>
> Undifferentiated groups - Undifferentiated groups consist of two or more components that are not consistently associated geographically and, therefore, do not always occur together within each mapped unit of the group. They are mapped together because use and management are the same or very similar for common uses. Often, steepness, stoniness, or flooding makes these soils similar for use and management.

When using soil survey information at the site level, the user should consider which type of map unit their site is on. If the map unit is a complex, it is important to know which components occur there and whether productivity may be lower or higher in different parts of the site. The possibility of inclusions should be considered on any type of map unit. The user should apply knowledge of glacial and erosional geologic processes and slope/aspect considerations; this will provide context for the soils information and help to understand soil variability.

3.2.3 Site level determinations using soils

Some forest managers will want to examine soils on their sites to get more detailed information than is available from the soil survey. Again, it is useful to first understand the geologic history of the site, including the type of soil parent material and geomorphic processes active during soil development. After this, texture, drainage (indicated by mottling), and pH are the most important site-level soil characteristics to consider in forestry applications in Wisconsin.

In general, loamy soils have moisture and nutrient status sufficient to support nutrient-demanding forest types such as northern hardwoods and oaks, while sandy soils generally support pine forests. Sandy soils with strata of fine-textured material, even when the strata occur at a depth below five feet, often have higher productivity than soils that are entirely sand. In soils of any texture, a high-water table will restrict forests to lowland types. The pH of soils varies considerably in Wisconsin depending on whether glacial deposits were enriched with limestone and dolomite, and although soils formed in acid tills will still support northern hardwoods and oaks, their growth will likely be slower than for a site on calcareous till.

Soil depth, horizon thickness, and color are other indicators of site productivity. Soils that are shallow to bedrock have less volume available for moisture and nutrient storage. Carbonate bedrock can contribute calcium and sometimes magnesium to soils, while volcanic bedrock and sandstone do not add to soil nutrients. Darker colors of surface horizons are usually associated with high organic matter content and nutrient status, although in recent years soil mixing by earthworms has changed these colors somewhat. Thicker surface layers (O, A, and B horizons) are also typically indicative of a higher nutrient status.

Soil bulk density is another indicator of productivity and can provide clues to past site impacts, but it is difficult to measure in the field. A higher than normal bulk density is a sign that compaction may have occurred, and this would be a factor to consider in choosing a prescription. Naturally dense soil layers, such as fragipans or basal till, may result in saturated conditions or seasonally perched water tables.

Because site conditions often vary from characteristics shown on soils maps, it is important for individuals making forest management decisions to evaluate the geology, topography, and soil at the site level. Site-specific information helps the manager develop individualized prescriptions to ensure that sites are utilized to best advantage, and that forest management activities retain the productive capacity of soils.

3.3 Ecological Site Classification

3.3.1 National Hierarchical Framework of Ecological Units

Wisconsin DNR’s Division of Forestry uses an ecological land classification system based on the National Hierarchical Framework of Ecological Units (NHFEU). The structure of the NHFEU was developed by staff of the USDA-Forest Service, in cooperation with federal and state partners (Cleland et al. 1997). The purpose of the classification is to distinguish land areas that differ from one another in ecological characteristics, specifically a combination of physical and biological factors including climate, geology, topography, soils, water, and vegetation. These factors are known to control or influence biotic composition and ecological processes and provide an approximation of ecosystem capability. Land areas identified and mapped based on these characteristics are known as ecological units. Maps of ecological units can be developed at many spatial scales, depending on the needs of the user. The maps, along with information about the ecological units, convey information about land characteristics and capability. An important application of this information is in planning for future land uses. Understanding an area's ecological characteristics informs management decisions about vegetation composition and structure, suitable wildlife species, and desirable recreational uses.

The National Hierarchical Framework of Ecological Units (NHFEU) is a hierarchical classification system. Ecological units at each spatial scale are nested within the broader scales. Appropriate uses of ecological units vary by scale. Table 11-1 shows the scales that have been developed within the NHFEU.

Table 11.1. Levels of spatial scale used in the National Hierarchical Framework of Ecological Units, and their applications. Scales used by WDNR are Province, Section, Subsection, and Landtype Association.

Ecological Unit	General polygon size	Map scale range	Application
Domain	1,000,000s of square miles	1:30,000,000 or smaller	National and international monitoring, assessment, modeling, and strategic planning.
Division	100,000s of square miles	1:7,500,000 to 1:30,000,000	National and international monitoring, assessment, modeling, and strategic planning.
Province	10,000s of square miles	1:5,000,000 to 1:15,000,000	National or multi-state monitoring, assessment, strategic planning and reporting. Cumulative effects analysis area for statewide or regional planning.
Section	1,000s of square miles	1:3,500,000 to 1:7,500,000	Multi-state, statewide or regional monitoring, assessment and strategic planning. Cumulative effects analysis area for Forest or County-level planning.
Subsection	10s to 1,000s of square miles	1:250,000 to 1:3,500,000	Statewide or regional monitoring, assessment and planning. Cumulative effects area for Forest, County, or project-level planning. Stratification for research and monitoring.
Landtype Association	1,000s to 100,000s of acres	1:60,000 to 1:250,000	Forest or County-level monitoring, assessment and planning. Cumulative effects area for project-level planning. Stratification for research and monitoring. Template for displaying ecological information to the public.
Landtype	10s to 100s of acres	1:24,000 to 1:60,000	National Forest project and management area monitoring, analysis, and planning. Template for displaying ecological information about projects. Stratification for research and monitoring.
Landtype Phase	Less than 100 acres	1:24,000 or larger	National Forest project area monitoring, analysis, and planning. Template for displaying ecological information about projects. Stratification for research and monitoring.

3.3.2 Provinces

The broadest spatial scale of the NHFEU used by WDNR is the Province level. Provinces are distinguished by climatic factors that control the distribution of biomes, such as solar radiation and continental precipitation patterns. Potential natural vegetation zones like those mapped by Kuchler often correspond with Province boundaries.

Province 212, the Laurentian Mixed Forest Province, encompasses the northern Lake States. Province 222, the Eastern Broadleaf Forest Province, includes southern Wisconsin as well as much of the central portion of the Eastern United States. The division between these Provinces corresponds to the area known as the "Tension Zone" in Wisconsin. Along this Zone, the northern coniferous-deciduous forest changes gradually into the southern oak forest/savanna and former prairie region.

3.3.3 Sections

Section-level ecological units are nested within Provinces. Sections are based primarily on climate and broad-scaled glacial or bedrock geology. Section boundaries in Wisconsin follow former glacial lobes of the Wisconsin glaciation and also separate the Driftless Area.

3.3.4 Subsections

Subsection-level ecological units are nested within Sections. Subsections in Wisconsin are often based on associated groups of glacial features such as morainal systems. In the parts of the state not glaciated during the Wisconsin Ice Age, patterns of topography formed by erosion on different bedrock surfaces are the basis for differentiating Subsections.

3.3.5 Landtype Associations

Landtype Associations (LTA's) are a level of the NHFEU that is used extensively in Wisconsin, primarily for property Master Plans and project-level planning. LTA’s are nested within Subsections. They are identified by surficial geology, patterns of vegetation, soil parent materials, and water tables (Jordan et al. 2001, Zastrow et al. 2001). LTA's are mapped at a landscape scale (1:60,000 to 1:250,000). Most LTA's in the Lake States are between 10,000 and 300,000 acres in size. In Wisconsin, they are usually based on glacial features like individual moraines or outwash plains. LTA's that are formed in outwash sand are often infertile and droughty, and support vegetation adapted to these harsh conditions. LTA's on moraines have nutrient-rich, moist conditions, and vegetation adapted to a rich environment.

LTA's can often be identified visually by trained individuals, because they are based on glacial features that form topographic features like hills, valleys, and plains. Some distinctive LTA's have local names (e.g. Harrison Hills), indicating that residents of the area recognize them as outstanding landscape features.

Many National Forests in the Lake States have used LTA boundaries as the basis for Management Areas and used LTA information to help describe ecological characteristics and capability. Goals for the Management Areas are developed so that vegetation objectives, wildlife management, and recreation uses will be suited to land capability. Regional Planning

Commissions and Counties have used LTA and Subsection information in similar ways for community planning projects.

LTA information can be used in project planning, to help describe the setting of the surrounding area, and particularly to address landscape considerations. The LTA is a suitable scale for examining the area around a proposed project, to see whether the project would contribute to landscape connectivity or provide a type of forest composition and structure that is scarce or declining (e.g., jack pine forest, hemlock and yellow birch, structurally complex stands). This is also an appropriate scale for examining whether a proposed project would have negative effects, such as fragmenting a large forested area, or creating a disproportionate amount of a single forest age-class.

Maps and tabular information about each LTA's are available on the WI DNR's website at: http://dnr.wi.gov/ using the keyword "landscapes."

3.3.6 Landtypes and Landtype Phases

The Landtype and Landtype Phase levels of the NHFEU have not been developed in Wisconsin outside of the National Forests. A combination of Forest Habitat Types and soils are typically used for project planning and stand or site level management.

3.3.7 Ecological Landscapes

Ecological Landscapes are an application of the Subsection level of the NHFEU, used in the Ecological Landscapes of Wisconsin Handbook (WI DNR Handbook 1805.1). Some Subsections were combined, resulting in 16 Ecological Landscapes. These units are at a scale between the Subsection and Section levels of the NHFEU. The units are still relatively similar in certain ecological characteristics and management opportunities, and there are few enough of them that users can remember their general character and outstanding features.

Ecological Landscapes are primarily a tool for property-level planning, but there are applications for other types of projects, as well. The Handbook contains information about management opportunities that contribute to the ecological integrity of an area, and many of these opportunities can be implemented at the project level.

4 WATER TABLES & PRODUCTIVITY

Forests on sites that have a water table near the surface are sometimes subject to a rise in water tables after a harvest. The rise in water tables (also known as "swamping out", "watering up", or "wetting up") occurs due to the loss of transpiration by trees, and the loss of direct evaporation that occurs when trees intercept precipitation. Plant roots and soil organisms are directly affected by the lack of oxygen that results from a water table rise. Normally, oxygen needed for root respiration is obtained from air in soil pore spaces, and while water flowing through soil carries some oxygen (e.g., in floodplains), stagnant water in closed depressions is very poorly aerated. A rise in water table also limits nutrient availability, because the chemical reactions that oxidize soil nutrients to forms available to plants cannot occur under anaerobic conditions, and microbial decomposition is also limited by the lack of oxygen. Thus, a long-term rise in the water table can lower site productivity. Smerdon et al. (2009) provide an overview and description of the hydrologic effects of forest harvesting, and some management implications of water table changes.

Increases in water table levels after harvests have been observed in many locations. In Florida, water tables rose after slash pine harvesting (Riekerk 1989) and cypress harvesting (Bliss et al. 2002). Atlantic coastal plain sites in South Carolina exhibited water table rises after light selection, heavy selection, seed tree, and clearcut harvests (Williams and Lipscomb 1981, Xu et al. 2002) Clearcutting in Quebec raised water tables on seven of eight study sites, with wetland/upland transition zones being more susceptible to rises (Dube et al. 1995), and another Quebec study found a correlation between the percent basal area removed and the amount of increase in water tables (Pothier et al 2003). On fragipan soils in Idaho, the height, volume, and duration of perched water tables increased after canopy removal (Rockefeller et al. 2004).

Increases in soil moisture after harvest on susceptible sites can last for many years and inhibit regeneration (Pritchett 1979, p. 459, Dube et al. 1995). Water tables higher than pre-harvest levels were still apparent at the end of the monitoring period (4-8 years) for nearly all of the studies cited above, although some water levels showed partial decreases as vegetation re-grew.

Concerns for increased erosion and sediment transport, along with equipment limitations, have also been associated with changes in the water table, especially on soils shallow to bedrock or fragipans. Keppeler et al. (1994) noted a concern for slope stability due to increased moisture at the soil-bedrock interface that persisted for the four years monitored following clearcutting, and Rockefeller et al. (2004) described an increased potential for lateral transport, and issues with road suitability on fragipan soils.

Rises in the water table can be avoided by considering subsurface soil conditions and their effect on drainage and avoiding excessive harvesting on these sites. Swamping typically occurs on “moist, level to gently sloping sites where lateral drainage is restricted and impervious layers prevent downward movement of water” (Pritchett 1979, p. 459). Information on restricted and impervious layers can be found in soil map unit descriptions in Soil Survey Reports.

Some sites may be unsuitable for harvesting because of the potential for long-term loss of forest. Peterson and Peterson (1996) wrote, “…earlier investigators have noted the rise of water tables after aspen is harvested or burned. Elevated water tables reduce aspen suckering and sucker growth rates, in extreme cases creating sites no longer productive for future tree crops. In general, aspen should not be harvested in depressional areas, with the uncut stands left to support wildlife habitat and forest biodiversity management objectives.”

Practices that will limit water table rises to some extent during forest management include: maintaining a partial tree canopy, preserving understory vegetation, retaining woody debris, and limiting surface ponding. These practices are intended to allow some interception of precipitation and transpiration to continue after a harvest, and to facilitate drainage of surface water away from the site. For pine flatwoods in Florida, Riekerk (1989) recommends leaving more than half of the canopy. Dube et al. (1995) provided guidance for forested wetlands in Quebec. For these forests, made up primarily of Eastern white cedar, spruces, balsam fir, and red maple, strip clearcuts were not effective in preventing water table rises. Rather, “silvicultural treatments to maintain interception and transpiration by leaving logging debris, small trees, and preestablished regeneration would be more effective.” Dube et al. (1995) also noted the importance of preventing surface water ponding by careful layout of skid trails, the use of low-pressure equipment, and harvesting during frozen conditions. Other authors also note the need for caution in use of heavy equipment or road development in situations where water tables are elevated (Keppeler et al. 1994, Rockefeller et al. 2004). The use of planted “nurse crops” to promote evapotranspiration is an option to consider when regeneration has failed (Smerdon et al. 2009).

5 REFERENCES

Alban, D.H. 1972. An improved growth intercept method for estimating site index of red pine. Research Paper NC-80. St Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station

B.C. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA Report 255. 246 p. Accessed 11 August 2011 at http://www.for.gov.bc.ca/hfd/pubs/docs/frr/Frr255-2.pdf

Bliss, C.M. and N.B. Comerford. 2002. Forest harvesting influence on water table dynamics in a Florida flatwoods landscape. Soil Sci. Am. J. 66: 1344-1349.

Carmean, W. H., J. T. Hahn, and R. D. Jacobs. 1989. General Technical Report NC-128, Site index curves for forest tree species in the eastern United States. USDA-Forest Service, North Central For. Exp. Sta.: St. Paul, MN.

Carmean, W.H. 1968. Tree height-growth patterns in relation to soil and site. p. 499-512. In C.T. Youngberg and C.B. Davey, eds. Proceedings of the Third North American Forest Soils Conference. Raleigh, North Carolina, August, 1968.

Carmean, W.H. 1975. Forest site quality evaluation in the United States. Adv. Agron. 27: 209-269.

Cleland, D.T.; Avers, P.E.; McNab, W.H.; Jensen, M.E.; Bailey, R.G., King, T.; Russell, W.E. 1997. *National Hierarchical Framework of Ecological Units.* Published in, Boyce, M. S.; Haney, A., ed. 1997. Ecosystem Management Applications for Sustainable Forest and Wildlife Resources. Yale University Press, New Haven, CT. pp. 181-200.

Curtis, J.T. The Vegetation of Wisconsin: An Ordination of Plant Communities. 1959. The University of Wisconsin Press, Madison, WI. 657 pp.

Dube, S., A.P. Plamondon, and R.L. Rothwell. 1995. Watering up after clear-cutting on forested wetlands of the St. Lawrence lowland. Water Resources Research 31(7): 1741-1750.

Ferguson, D.E., P. Morgan, and F.D. Johnson, compilers. 1989. Proceedings – land classification based on vegetation: applications for resource management. 1987 November 17-19; Moscow, ID. USDA For. Serv. GTR INT-257. 315 pp.

Fisher, R.F., and D. Binkley. 2000. Ecology and Management of Forest Soils. 3rd Edition. John Wiley & Sons, Inc. New York.

Grigal, D.F. 1984. Shortcomings of soil surveys for forest management. p 148-166. In J.G. Bockheim, ed. Forest Land Classification: Experiences, Problems, Perspectives. Proceedings of the symposium. Madison, Wisconsin, March 18-20, 1984. 276 pp.

Hole, F.D. 1976. Soils of Wisconsin. University of Wisconsin Press. Madison, Wisconsin.

http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.Hole01

Johnson, J.E., J.G. Bockheim, and J.M. Cain. 1993. Forest Soils of Wisconsin: An Overview. Univ. of Wisconsin Extension, Cooperative Extension publication G3452. Madison, WI.

Jones, J.R. 1969. Review and comparison of site evaluation methods. U.S.D.A. Forest Serv. Res. Paper RM-51. Rocky Mtn. Forest and Range Expt. Sta., Fort Collins, Colorado. 27 pp.

Jordan, J.K., E.A. Padley, and D.T. Cleland. 2001. Landtype Associations: concepts and development in Lake States National Forests. In: Smith, M.L. ed. *Landtype Associations: development and use in natural resources management, planning, and research.* Proceedings of the conference; 2001 April 24-26: Madison, Wisconsin.

Keppeler, E.T., R.R. Ziemer, and P.H. Cafferata. 1994. Changes in soil moisture and pore pressure after harvesting a forested hillslope in Northern California. Effects of Human-Induced Changes on Hydrologic Systems: American Water Resources Association. June, 1994.

Larsen, D.R. 1999. Site index. Natural Resource Biometrics. The School of Natural Resources, University of Missouri-Columbia

Peterson, E.B., and N.M. Peterson. 1996. Ecology and silviculture of trembling aspen. Pp. 31-51. In: P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and K.D. Thomas (eds.). Ecology and Management of B.C. Hardwoods. Workshop Proc., December 1-2, 1993, Richmond,

Pothier, D. M. Prevost, and I. Auger. 2003. Using the shelterwood method to mitigate water table rise after forest harvesting. Forest Ecology and Management 179: 573-583.

Properties and Management of Forest Soils. Pritchett, W. L., New York: John Wiley & Sons, 1979.

Rennie, P.J. 1963. Methods of assessing site capacity. Commonwealth Forest. Rev. 42: 306-317.

Riekerk. H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. Water Resources Research 25(4): 713-719.

Rockefeller, S.L., P.A. McDaniel, and A.L. Falen. 2004. Perched water table response to forest clearing in Northern Idaho. Soil Sci. Soc. Am. J. 68: 168-174.

Schreuder, H.T., G.B. Wood, and T.G. Gregoire. 1993. Sampling Methods for Multiresource Forest Inventory. Wiley Interscience. 446p.

Smerdon, B.D., T.E. Redding, and J. Beckers. 2009. An overview of the effects of forest management on groundwater hydrology. BC Journal of Ecosystems and Management 10(1): 22-44. Accessed 11 August 2011 at http://www.forrex.org/publications/jem/ISS50/vol10_no1_art4.pdf

Smith, David M., B. C. Larson, M. J. Kelty, and P. Mark S. Ashton. 1997. The Practice of Silviculture, Applied Forest Ecology, Ninth Edition. John Wiley & Sons, Inc. p.69-81

Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. http://soils.usda.gov/technical/manual/

United States Department of Agriculture, Soil Conservation Service (USDA SCS). 1991. Soil Survey of Juneau County, Wisconsin.

University of Minnesota Extension Service. 1992. Forest Soil – Climate – Site Index Relationships for Minnesota. University of Minnesota Extension Service. MR-06062

Wenger, K.F. 1984. Forestry Handbook, Second Edition. John Wiley & Sons, Inc. p.322-360

Williams, T.M. and D.J. Lipscomb. 1981. Water table rise after cutting on coastal plain soils. Southern Journal of Applied Forestry 5(1): 46-48.

Wisconsin Department of Natural Resources (WDNR). 2009a. *Ecological Landscapes of Wisconsin.* State of Wisconsin, Dept. of Nat. Resources, Handbook 1805.1. Madison, WI.

Wisconsin Department of Natural Resources (WDNR). 2009b. *Public Forest Lands.* State of Wisconsin, Dept. of Nat. Resources, Handbook 2460.5. Madison, WI.

Xu, Y., J.A. Burger, W.M. Aust, S.C. Patterson, M. Miwa, and D.P. Preston. 2002. Changes in surface water table depth and soil physical properties after harvest and establishment of loblolly pine in Atlantic coastal plain wetlands of South Carolina. Soil & Tillage Research 63: 109-121.

Zastrow, D.E., Hvizdak, D.J., Moline, M.C. 2001. Development of Wisconsin's Landtype Associations - a layer within the National Hierarchical Framework of Ecological Units. In: Smith, M.L. ed. *Landtype Associations: development and use in natural resources management, planning, and research.* Proceedings of the conference; 2001 April 24-26: Madison, Wisconsin.