The following information is taken from Michigan State University Extension: Michigan Forests Forever Teachers Guide

http://mff.dsisd.net/Environment/Environment.htm

TREE PHYSIOLOGY

Quite a bit of time is spent on tree physiology, which is key to understanding many of our forest management practices, especially the concepts of shade tolerance and vegetation succession. Additionally, the topics of forest health, hydrologic cycle, and nutrient cycles are discussed.

This is a fairly long section for several reasons. One, it provides the basis for much of what is addressed later in terms of forest management. Two, it has many connections to the Michigan Curriculum standards, particularly in science. Three, there are a lot of neat activities and observations associated with the topic.

Little Known or Interesting Factoids About Tree Physiology

- *Trees both produce AND consume oxygen.*
- *Young forests capture more carbon from the atmosphere than old forests.*
- *Old forests have more stored carbon in the biomass than young forests.*
- *The food that trees produce for themselves are sugars.*
- *The purpose of photosynthesis is to capture and store energy.*
- *Green light is the only part of the visible light spectrum that plants can't use.*
- *The timing of Autumn color change is largely controlled by lengthening nights.*
- *Conifers lose needles each fall, just the same as broad-leaf trees.*
- *Trees grow TWO rings each year, one in the spring and another during the summer.*
- *Swamp trees don't necessarily prefer swamps.*
- *Tree species have highly variable requirements for light, nutrients, and moisture.*
- *Oceans produce more oxygen and store more carbon than forests.*

Some Important Terms

- Photosynthesis
- Respiration
- Oxygen
- Carbon Dioxide
- Trophic Level
- Food Chain
- Chlorophyll
- Anthocyanin
- Carotenoid
- Annual Rings
- Springwood & Summerwood
- Cellulose
- Mycorrhizae
- Producer
- Consumer
- Glucose
- Shade Tolerance
- Crown

- Abscission Layer
- Cambium
- Meristem
- Canopy
- Compartmentalization

The Necessities of Life

The following is brief discussion of each of six key requirements for trees. More detail of some topics is found later in this guide.

1. **Sugars** supplied by photosynthesis. Air and water are chemically recombined to form glucose, which stores energy captured from the sun. Oxygen is a byproduct.

2. **Water** is required for most metabolic activities and serves as a vehicle to carry materials through a tree. A large tree may move as much as 50-100 gallons of water on a hot summer day.

3. **Nutrients**. It's not how much of a particular nutrient exists in the environment, it's a matter of how *available* the nutrient is to the tree. For example, the atmosphere is largely composed on nitrogen, but trees can only use nitrogen in forms that have been altered by soil bacteria and other organisms. The major chemical elements used by plants are: carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, and magnesium. You might be able to remember this by a jingle formed using the abbreviations for these elements: C H O P K N S Ca Fe Mg . . . "see hopkins café, might good."

4. **Hormones and enzymes**. These chemicals are critical in the controlling the timing and activity of physiological processes. They are usually produced in the roots or leaves. We don't often think of plants having "hormone" deficiencies, but they are critical to the survival of any organism, including trees.

5. **Mycorrhizae**. Pronounced *"my-core-HI-zee",* this a group of beneficial fungi associated with most tree roots. It represents an ecologically symbiotic relationship where the fungi receive food from the tree and the trees receive greatly enhanced nutrient and water absorption. Mycorrhizae will also protect tree roots from other invading fungi. There tends to be very specific species relationships between fungus and tree.

6. **Environmental factors**. A tree needs an appropriate mix of precipitation, temperature, sunlight, and soils in order to thrive. These factors need to occur at the right time. Each tree species has a different set of environmental requirements. Changing climate will lead to changing environmental factors, which can lead to changes in forest ecosystems.

Tree Parts

The parts and structure of a tree has obvious components and some not so obvious components.

> ***Definition of a tree:*** *A woody perennial plant, typically large and with a well-defined stem or stems carrying a more or less definite crown -* **note***, sometimes defined as attaining a minimum diameter of 5 inches and minimum height of 15 feet at maturity with no branches within 3 feet of the ground.*
>
> *-Society of American Foresters, 1998*

What makes a tree a tree?

First, a tree has all the characteristics of green plants. Beyond that, a tree is a tall plant with woody tissue. It has the capability to "push" its crown (the primary location for photosynthesis) above other vegetation competing for light. Also, most people don't readily connect trees with having **flowers** but they do, although our conifers (pines, spruces, firs, etc.) don't have true flowers with petals. The reproductive structures of each species are particularly unique and are used more than any other structure to categorize trees. This categorization is called **taxonomy**. The tree identification section talks more about taxonomy.

A tree has a dilemma in terms of gathering its resources. It has a distinct light-gathering advantage of having its leaves high above other plants, but there is the problem of getting water and soil nutrients to the upper tissues. The microenvironment in the upper canopy is also rather hostile to sensitive tissues. At the other end of the tree, the roots are dependent upon materials produced way up in the crown. This problem, of course, is solved by the structure of the tree **trunk, or bole**, a most distinctive feature of trees.

Most of a tree trunk is dead woody tissue and serves only to support the weight of the crown. The very outside layers of the tree consists of bark. Underneath the bark is a **cork cambium** layer that generates new bark. Under the cork cambium lies a thin band of **phloem**, which is living tissue that transports materials from the crown to the roots. Under the phloem is another **vascular cambium zone** that produces both new phloem cells and new xylem cells. The wider band of **xylem,** or **sapwood,** transports water to the crown, but is not necessarily living. The innermost portion of the trunk is non-living **heartwood**, which is a repository for many waste products of the tree's living tissue. Only a thin band around the trunk, roughly a centimeter wide, is living tissue.

Each year, a tree grows a pair of **annual rings** (TWO rings each year!). In the spring, the usually wider and thinner-walled layer grows. It is called "**springwood**". In the summer, through about mid-July, a usually darker and thicker-walled layer is produced. It is called "**summerwood**". Annual rings are typical in temperate forest trees and tropical forest trees that have regular, annual dry seasons. In tropical humid rainforests, trees grow continually and do not have rings. The oldest portion of a tree is at the bottom and on the inside.

Parts List

Without going into a lot detail, important parts of a tree are:

Leaves	Broad-leaf or needles, the primary site of photosynthesis and the production of hormones and other chemicals
Twigs & Branches	Support structure for leaves, flowers, and fruits. Arrangement varies from species to species by growth strategy. Can sometimes have photosynthetic tissues. Two kinds of growth tissue, at the twig tips and cambium under the bark.
Crown	The upper region of the tree made up of leaves, twigs, branches, flowers, and fruits. Crowns of many trees are collectively called the "canopy".
Flowers	May have both female & male parts, or only one or the other. Some trees are either all female or all male (e.g. aspen). Flowers may have a full complement of flower parts, or may be missing certain elements. Conifers do not have petals and associated structures.
Fruits & Seeds	All trees have seeds. Most trees have seeds inside fruits. Most fruits are NOT edible, but many are, such as apples, cherries, nuts, etc.
Trunk or Bole	Most definitions of trees include a "single bole" concept, but many of our tree species sometimes occur with multiple stems. The main functions of a trunk are transport and support. The trunk has growth tissue called cambium.
Bark	A highly variable tree part. The main function is to protect the sensitive living tissues from weather and predation (by animals, insects, fungi, etc.)
Roots	Roots serve two main functions; collection of nutrients and water, and anchoring the tree. Roots also have growth tissue, bark, and wood. Like twigs and branches, roots have two kinds of growth tissue, at the twig tips and cambium under the bark. Fine root hairs are where absorption occurs.

Photosynthesis and Respiration

All trees (most plants) both photosynthesize and respire. Photosynthesis is a process unique to green plants and produces sugars, which are "tree food." Animals only respire and cannot produce their own food. That's why plants are called "**producers**" and animals are called "**consumers**."

Photosynthesis can be visualized in a couple ways.

- Sugars produced are analogous to a "solar battery." The sugar is a chemical way to store energy for future use (metabolism).
- Trees produce their own food. We call "tree food" sugar. These sugars are not usually of the chemical structure of refined sugar and don't usually taste sweet, but the basic organic components are similar.

The basic chemical formula for photosynthesis is:

Inputs: 6 carbons, 24 oxygens, 24 hydrogens

Outputs: 6 carbons, 24 oxygens, 24 hydrogens

Note: Inputs and outputs must balance in a chemical equation. In other words, what goes in, must come out!

Energy IN	$(6)CO_2 + (6)H_20 \rightarrow C_6H_{12}O_6 + (6)O_2$ *Carbon Dioxide + Water + ENERGY* → *Glucose + Oxygen*
	Summary equation for photosynthesis

Energy is stored in the bonds of sugar molecules such as "**glucose"** and **"fructose.**" Oxygen is a by-product of photosynthesis. The oxygen molecules produced by photosynthesis are not necessarily the same oxygen molecules the plants use for respiration.

These sugars are later broken apart and the released energy drives a variety of metabolic actions. The process of breaking down these sugars is called "**respiration**." It is the same process that animals (and people) use when they respire (not to be confused with "breathing"). So, either the plant uses its own stored sugars, or some animal (or decomposer) consumes the plant, and uses the stored sugars. In either case, the sugars are valued chemicals because they contain energy, as well as important elements (carbon, hydrogen, and oxygen).

$C_6H_{12}O_6 + (6)O_2$	→	$(6)CO_2 + (6)H_20$	**ENERGY OUT**
Glucose + Oxygen	→	*Carbon Dioxide + Water + ENERGY*	

Summary equation for respiration

Apply the Concept: *The "10% rule of thumb."*

*Plants are able to "fix" about 10% of the solar energy that reaches plant surfaces (usually less, however). "Fixing" means converting solar energy into chemical energy (sugars). Organisms that consume plants, are able to extract about 10% of the energy stored in the plant. Organisms that consume other consumers can extract only about 10% of the energy stored in their prey. These levels of energy consumption are called "**trophic levels**." Energy flow through an ecosystem (large or small) is a key life process. Threads of energy transfer are called "**food chains**." Food chains also include the transfer of chemicals other than sugar. Many nutrients, amino acids, and other compounds are digested and recombined by consumers along any particular food chain.*

Apply the Concept: *Crown size and photosynthesis*

*All the leaves and branches of a tree are collectively called the "**crown**." All the crowns of a forest are collectively called the "**canopy**." As forests age and trees grow, crowns begin to touch each other and the forest canopy closes. Most of the tree crowns will be unable to grow as rapidly as if they had free space to occupy. The photosynthetic capacity will be spread among a greater number of trees. That means less photosynthesis per tree, which translates into slower growth. Slow growth can be a contributor*

What does a tree use its photosynthate for (glucose and fructose) in addition to energy storage and subsequent release?

to tree stress, which can lead to tree health problems. Foresters understand how different forests grow in different ways. They can recognize a forest that is too crowded and prescribe a thinning, where some trees are removed so that others may grow better.

In addition to channeling more growth onto a fewer number of trees, thinning the canopy can have a very positive impact on the understory. More light to the forest floor will stimulate the regeneration of trees and promote more vegetation in the understory layers of a forest. More vegetation in the understory creates more vertical structure, which often leads to greater species diversity in the forest.

- Cell walls are made of **cellulose** ($C_6H_{10}O_5$). Cellulose shows up in many plant parts in combination with other molecular elements. It is not only vital to the tree, but is also a very important material for people (wood, lumber, fuel, fibers, chemical extracts, energy, etc.).

- Production of **carbohydrates** such as sugars ($C_6H_{12}O_6$), starches ($C_6H_{10}O_5$), vegetable ivory (form of hemicellulose), pectins (for jellies, jams), gums (used in many products, including food products).

- Many **fats and oils** are common plant products (some of which come from trees). These are compounds of mostly carbon, hydrogen, and oxygen, but with lots more molecules of each.

- **Proteins** are formed when the C, N, O elements are combined with nitrogen, sulfur, and sometimes phosphorus. Certain proteins used by animals (and people) can only be obtained by ingesting plant products.

- There are numerous **secretions** produced by trees (and other plants) that are important to people, such as clove oil, cedar oil, resins, pitch, gums, balsam, camphor, natural rubber, pigments, drugs (legal and illegal), etc.

A note about energy allocation within trees. Energy is not a limitless resource for trees. A tree will typically move energy according to these priorities. As energy in the form of glucose becomes limited, a tree will begin to reduce resources spent beginning with the lowest priority. As you can see, a tree with a diminishing crown will become more vulnerable to insects and diseases rather quickly. That’s one reason why foresters are so keen to maintain a vigorous growing environment.

1. Maintain respiration of all parts.
2. Produce fine roots and leaves.
3. Produce flowers and seed.
4. Extend branches and roots.
5. Store energy rich chemicals.
6. Add wood to stem, roots and branches.
7. Create anti-pest chemicals for defense.

Chlorophyll

Chlorophyll is the chemical compound where solar energy (light) is captured and photosynthesis happens. Chlorophyll is continuously produced and broken down during the growing season. The heart of the chlorophyll compound is a magnesium molecule. The magnesium molecule is bonded to many molecules of hydrogen, carbon, oxygen, and nitrogen.

$C_{55}H_{72}O_5N_4Mg$ *Chlorophyll "a", one of several forms of chlorophyll*

There are different kinds of chlorophyll that absorb different colors in the light spectrum. The only color that is pretty much useless to plants is green, which is why plant tissues containing chlorophyll appear green. It's the color that is reflected back into the environment. The process of photosynthesis is very complicated and driven by a series of enzymes. Enzymes function within fairly narrow temperature windows. Within these temperature windows, heat accelerates photosynthesis to a certain point and cold slows it down. Outside the temperature window, photosynthetic activity drops off, most quickly with hot temperatures.

> ***Experiment Suggestion:*** *Grow plants (beans, peas, fast-growing plants) in containers of different light. Transparent plastic wrap covering containers will filter light spectra. Compare growth rates of plants.*

Tree Growth

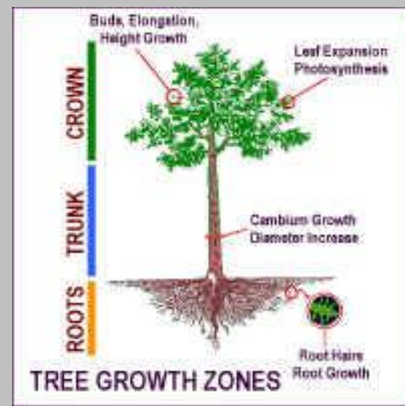
So, photosynthesis produces all this glucose. . . what then? Essentially, the energy in glucose is used by trees (and most other living things) to drive metabolic processes that produce tissues and maintain life functions. Keep in mind that this whole thing called life is a big solar powered system!

A tree will draw nutrients and minerals from the soil, break them down and put them back together to form compounds and chemicals that we recognize as a tree. The most common material made by a tree is "cellulose." Cellulose is a complex sugar that is the main component of wood and many other plant tissues. It's also an extremely useful material for lots of human uses, such as food products, paper, strengthener in plastics and concrete, clothing, and other things.

Wood is the answer to the tree challenge of pushing a crown as high as possible to obtain the best light-capturing position as possible, while maintaining a connection with water and nutrient supplies in the soil.

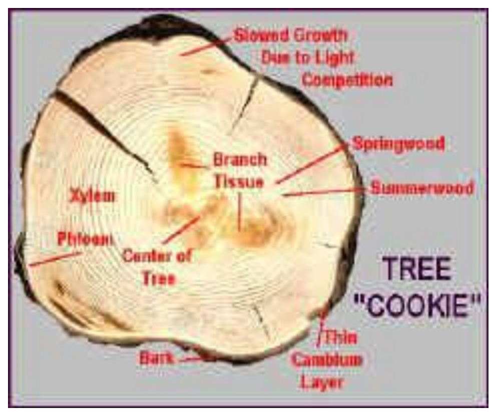
<u>Where does a tree grow</u>? In three places.

- *At the twig tips (meristem).*
- *At the root tips (meristem).*
- *Around the outside of the trunk, branches, and roots (cambium).*



A tree with growth zones illustrated, branch meristem, root meristem, cambium.

One region of tissue expansion or tree growth is at the tips of both twigs and roots, called the "meristem." This is unspecialized tissue that can form wood, buds, or flowers. Each year, trees will lengthen twigs and roots, produce flowers and fruit, and grow new buds. The meristem and newly produced tissues are rich with nutrients and are often the target of attack by diseases, insects, and animals. Deer, for example, are Michigan's most significant browser. In areas of high populations, deer can destroy years of growth on small trees and entirely eliminate regeneration.



Most of a tree trunk, branch, or root is dead wood. The living part is only a narrow band on the outside edge. This living layer is produced by thin bands of regenerating tissue called "cambium." Cambium produces new wood on the inside and new bark on the outside. The cambium grows only from the inside out, not up or down the length of a trunk, branch, or root. For awhile, the new wood and bark are living. The wood actively transports many materials up and down the tree and performs other functions. After the wood dies, it still serves as a transport route for several years. Eventually, even that function is diminished and the wood serves primarily as structural support.

Each year the cambium produces TWO distinct rings of tissue. In the spring, a layer of thinner-walled cells are grown. In the summer, a layer of thicker-celled, sometimes larger cells are grown. The layers are called "springwood" and "summerwood," respectively. When counting the age of tree "cookie," either the springwood or summerwood rings can be counted, but don't count both (unless you divide your sum by two!). Most people count the typically narrower and darker summerwood. Tree such as oaks, ashes, and all the conifers produce fairly distinct rings which are easy to count. Other trees, such as aspens, red maple, and birch have less distinct rings. Foresters can count rings without cutting a tree down. A tool called an "increment borer" will extract a thin wood core from the tree, which can be used to age the tree.

Why do leaves change colors in the Autumn?

*The short answer is that chlorophyll production drops-off as night length increases. The green part of the light spectrum is no longer reflected and other compounds, chemicals called "**anthocyanins**" (reds) and "**carotenoids**" (yellows), become the dominant pigments in the leaves. The longer answer involves discussions of changing day lengths and weather, and strategies dealing with nutrient loss with the dropping of leaves.*

> ***Project:*** *Have kids collect different colored leaves in the fall. Categorize leaves by species and color. The same species may have many different colors, especially red maple. Also, have kids record the dates when trees at home, at school, or in another selected place begin to change color. Make notes by species and see if any patterns can be observed. It would be interesting to have a "sister" school in a different part of the state to compare color change with.*

What is the story behind Autumn leaf fall?

*The purpose of Autumn leaf fall is to prepare for **winter dormancy**. The cold temperatures prevent trees and plants from functioning in at least three ways. Water would freeze in the plant tissues, causing cell rupture. Water in the upper soil layers often freezes, making absorption impossible. Lastly, the low temperatures are far outside the operating windows for the enzymes that control a tree's metabolic processes, such as photosynthesis and respiration. To avoid these environmental limitations, trees prepare for dormancy in the Autumn.*

Trees drop leaves because they are too difficult to "winterize" (unlike most conifers that have strategies to maintain their green parts during the winter and needles have a much different structure than broad leaves). Or, in the case of conifers, the needles that have grown old after two to three years, no longer receive as much light, and are shed each Autumn. However, dropping tons of biomass per acre presents the problem of losing significant amounts of valuable nutrients. Much of the sugars and valuable nutrients are resorbed from the leaves, but the annual leaf drop still means the loss of a lot of good "stuff." In our north temperate climates, dropped leaves become part of the "organic layer" on the surface of the soil, to be recycled (in part) by decomposers.

*There are two components influencing the Autumn color display, the **timing** and the **intensity**. The timing is usually controlled by lengthening nights and the intensity is strongly influenced by weather.*

The most dependable seasonal environmental factor is the change in daylight, or more accurately, the lengthening dark period. Such things as rainfall or temperature might "fool" a tree into retaining leaves too long. For this reason, the timing of leaf-drop is regulated by the consistent movement of the Earth around the Sun. However, a late spring or extremely dry summer can postpone the response to lengthening nights by a *week or two. Just "when" a tree begins to turn color varies from species to species, and geographically from north to south. In our northern forests, black ash is the first to change color. Tamarack (a needle-bearing tree) is the last.*

The intensity or brilliance of the color change is influenced by weather conditions during the period of declining chlorophyll production. A series of sunny days and cool nights (above freezing) result in a more colorful display. The warm days increase production of both sugars and anthocyanin pigments. Sugars "stranded" in the leaf and greater concentrations of anthocyanins bring out the scarlets and reds, especially the deep purple of northern red oak. Carotenoids yield the yellow and golden colors but tend to remain at fairly constant concentrations regardless of weather.

So, how might weather affect the fall colors?

- *Warm Autumn weather will generally reduce the color quality.*
- *Moist soils following a good growing season contribute to better displays.*
- *A few warm, sunny days and cool nights (at the right time) will increase brilliance.*
- *Droughts will usually result in poorer displays.*

What causes the leaves to actually fall off?

*Wind, most commonly. As nights lengthen, a layer of cells forms in the leaf stem near the twig, called the "**abscission layer**." Abscission means cutting or severing. This layer blocks transfer of materials to and from the leaf. The abscission layer also makes a weakened connection. Eventually, wind, rain, snow, or animals will knock the leaf from the twig.*

Sunlight and Tolerance of Shade

Relative Sunlight Requirements For Representative Tree Species	
Paper Birch Tamarack Jack Pine	
Quaking Aspen Silver Maple Red Pine	
Red Maple Red Oak White Pine	

Yellow Birch Balsam Fir White Spruce	
Sugar Maple Basswood Cedar	

*It's commonly known that trees and plants need sunshine to live. However, not all trees need the same amounts of sunlight. Trees that require high amounts of sunlight are sensitive to shade. Foresters call this sensitivity "**shade tolerance**" or just "**tolerance**". The shade tolerance of some tree species will vary with age.*

*Tree species such as **aspen, cherry, paper birch, jack pine, and red pine** require lots of sun and are not tolerant of shade. That's part of the reason stands of these species tend to be all about the same age. Seeds of these species that germinate under a canopy of shade do not survive.*

*Other tree species are more tolerant of shade, such as **sugar maple, beech, balsam fir, hemlock, and cedar**. They can survive as seedlings or saplings under a fairly heavy canopy of shade for many years. When exposed to light, the small trees (not always young trees!) can quickly grow to take advantage of the new light regime.*

*There are a number of tree species that fall into the moderately tolerant category, such as **red oak, red maple, yellow birch, white ash, white pine, and white spruce**. The may be able to grow under the light canopy of an aspen or paper birch stand, but would not be very successful under the shade of a maple-beech-basswood stand.*

Shade tolerance is key component of forest management systems.

<u>Other Environmental Factors</u>

There are many environmental factors, both living and not living, that influence the growth of trees. This guide has already discussed some of them, such as light, nutrients, and temperature. Many of these factors interact with other. That's part of the reason why forest management can be complex. Tree adaptation to various environmental factors runs along gradients. Some tree species are more sensitive to a particular gradient than others.

<u>Rainfall or Precipitation</u>

Average annual rainfall varies across a wide geographical area. Some tree species can survive with less annual precipitation. As you move north and west, rainfall declines, and so do the number of tree species. More locally, available water may vary with microsites. The south sides of slopes will be drier, so will a sandy plain or areas with bedrock close to the surface.

Soil Variability

Scientists have identified over 475 soil types in Michigan. It stands to reason that different tree species have preferences for certain types of soil. Red pine and jack pine are well-known for their ability to grow well on sandier, poorer soils where most other trees grow poorly. Sugar maple and basswood prefer richer soils with lots of nutrients. Other species, such as bur oak and quaking aspen grow well on a wide variety of soils. This variability is largely related to the amount of available nutrients in a soil, the nutrient demand of a particular species, and a tree's ability to extract those nutrients.

Moisture

This is related to both rainfall and soils. The amount of available moisture varies during the year. High moisture levels during the dormant season will not help trees. Or usually hurt them. Saturated conditions from spring runoff or flooding does not hurt most trees because they are not actively growing. Some tree species are more tolerant of short periods of flooding during the growing season, such as bur oak or silver maple. Oddly enough, white cedar is quite sensitive to rapid changes in moisture, either wetter or drier. Northern swamp tree species grow on small, dry microsites. They don't usually grow in the water.

Biotic Factors

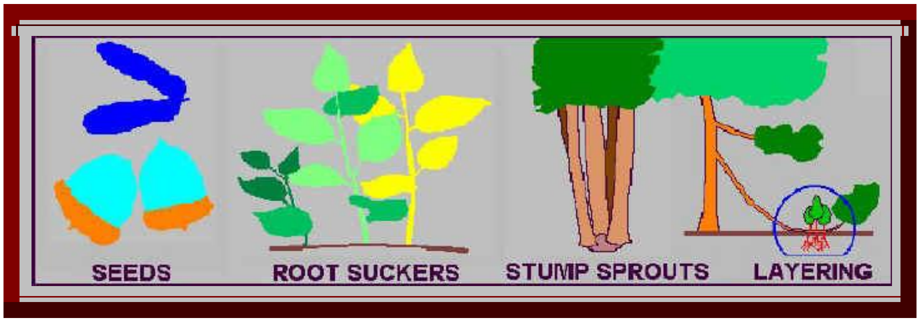
These are the living parts of an ecosystem that trees interact with. Other plants will impact forests. Insects and diseases play a major role in forests. Animals like white-tailed deer, porcupines, and squirrels also have prominent roles. Not all of these impacts are negative. Many are beneficial. Insects pollinate tree flowers. Soil animals loosen soil. Birds eat lots of insects. And of course, humans manage forests for a wide variety of reasons.

Mycorrhizae

Pronounced "my-core-HI-zee", these are beneficial fungi to trees. The fungi are associated with tree roots in a ***symbiotic*** *relationship. That's where both partners benefit from each other. The mycorrhizae increase a tree's ability to absorb water and nutrients. The tree supplies the mycorrhizae with a share of photosynthate. Sometimes, species of mychorrizae are only associated with a particular species of tree. The lack of proper mycorrhizae in the soil can prevent a tree from growing well, or maybe from surviving at all. It may be one of the factors that limit trees to a certain range. Scientists are learning more about these special fungi.*

Tree Regeneration Strategies

There are four ways Michigan trees regeneration themselves.



- *Seeds*
- *Root Suckers*
- *Stump Sprouts*
- *Vegetative Layering*

All trees can reproduce by seeds. Each species has a unique set of requirements for seed production and germination. Seed dispersal strategies vary widely, from wind-driven seed to seeds carried by certain species of animals.

Sprouts and suckers are similar, in that dormant buds "come alive" to form new shoots of parent trees. Sprouts are shoots from stumps or the base of a tree. Suckers are shoots that originate from buds on the root systems. Often times, sprouts and suckers will not grow until the parent tree dies or becomes very sick. The buds are held in dormancy by hormones produced in the leaves. When these hormone levels drop below a certain point, the dormant buds will grow.

Vegetative layering is uncommon, occurring mostly in white cedar and Canada yew (which most would not consider a tree!). When branches or stems come in contact with the soil, cambium tissue sometimes form roots. In this way, former branches of a fallen cedar might become trunks of several "new" trees.

Tree Longevity

Trees do not live forever, therefore cannot be "preserved." A forest condition, or forest type might be preservable (if managed), but not individual trees. While people know that all living organisms eventually die, often times this is not taken into account when people consider forests.

*Tree longevity varies from about 70 years to over 1000 years, depending upon the species. Most trees do not live past 50 years (or 10 years, for that matter), if you consider attrition from the time of germination. Short-lived species tend to be **successional** "**pioneers**", or trees that first colonize an unforested site. Aspens, paper birch, cherries, jack pine are examples of short-lived tree species. They also tend to be intolerant of shade. Long-lived tree species tend to be more shade tolerant, occupy later stages of succession, and employ more "conservative" survival strategies. Sugar maple, basswood, beech, and white cedar are good examples.*

Note: "Succession" is explained in another place in this guide and is one of the most important concepts in forest ecology.

Most Common Michigan Tree Species (by volume) and Their Expected Lifespans (in years) *Note: Maximum lifespans may exceed the ages listed.*			
Sugar Maple	200-300	Balsam Fir	70-100
Red Maple	125-150	White Oak	400-500
Quaking Aspen	60-90	Eastern Hemlock	400-500
Cedar	400-600	Jack Pine	80-100
Northern Red Oak	200-300	Yellow Birch	200-300
Red Pine	200-250	Black Cherry	150-200
Bigtooth Aspen	75-100	White Ash	unavailabl
Basswood	125-175	American Beech	300-400
Paper Birch	70-100	White Spruce	150-200
White Pine	250-300	Black Spruce	200-250

Winter Adaptations of Trees

Trees must have adaptations to survive the cold and drying conditions of winter. Trees cannot change their location or behavior like animals can, so they must rely on physiological and structural adaptations.

The height advantage of trees becomes a liability in the winter, as tissues are exposed to the weather. There are four basic strategies that trees employ.

1. *Either leaf drop or adaptations for leaf retention.*
2. *A physiological acclimatization process.*
3. *Resolution of water issues.*
4. *Methods of reducing mechanical damage.*

Broadleaf trees (hardwoods) drop their leaves during the winter, avoiding the problems of maintaining foliage in cold and dry conditions. Conifers (softwoods) retain foliage and have special adaptations in order to do so (better stomate control and a waxy coating called cutin).

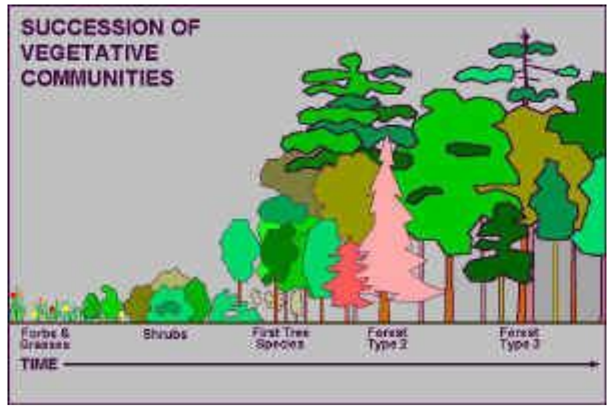
All trees go through an acclimatization process. Like leaf drop, the process is initiated by changes in photoperiod and is controlled by hormones and other chemicals. The process also exploits the physical properties of water.

Winter conditions make finding sources of liquid water and transporting water a challenge. Water loss is minimized in several ways. Water can be obtained from the ground, within the tree, or from the subnivean (under snow) micro-environment.

Conifers have special cell adaptations to facilitate water transport whenever temperatures allow it.

Snow and ice accumulation can cause breakage, especially under windy conditions. Conifers have growth patterns that minimize the chances of damage occurring. Dramatic loss in vegetation from animal consumption increases pressure on woody tissues, especially foliage, buds, and bark. Browse damage can be significant in many regions of Michigan. Lastly, pollutants from highways, particularly road salts and exhaust, can damage trees, especially those more vulnerable to these chemicals.

SUCCESSION AND FOREST CHANGE



What Is Succession?

Succession is one of the most important concepts in natural resource management. The fact that "nature" is always changing is critical in appreciating management systems and natural processes.

Succession is predictable if enough is known about a specific site and most of the factors that influence succession at that place and in that time. A series of vegetation types in a given area is a ***"successional pathway"*** or ***"sere"***. A single vegetation type within a sere is called a ***"seral stage"***. In Michigan, a forester or ecologist will usually be able make fairly accurate predictions of succession.

> ***Succession:*** *The gradual supplanting of one community of plants by another.*
>
> Note 1- *The sequence of communities is called a* ***sere****, or seral stage.*
> Note 2- *A sere whose first stage is open water is termed a* ***hydrosere****, one whose first stage is dry ground, a* ***xerosere****.*
> Note 3- *Succession is primary (by* ***pioneers****) on sites that have not previously borne vegetation, secondary after the whole or part of the original vegetation has been supplanted,* ***allogenic*** *when the causes of succession are external to and independent of the community (e.g. accretion of soil by wind or water, or a change of climate), and* ***autogenic*** *when the developing vegetation is itself the cause.*
>
> *-Society of American Foresters, 1998*

With forests, trees are the dominant life form and it is these associations of trees that give rise to the names of forest types. These types are often names of individual seres within a successional path. For instance, an aspen stand may be taken over by red maple and balsam fir. Decades later, sugar maple may become dominant. On richer soils, the number of potential successional pathways increase. On an infertile, dry, sandy soil, jack pine might be the only forest type that will occur. On a wet soil with *microtopography*, northern white cedar might maintain itself for centuries.

The progressive change in forest types has a huge impact on the complement of wildlife species and *understory* plant species that live there. The forest type will also influence soil development, erosion potential, soil pH, organic matter volume, water retention, water quality, and similar forest characteristics. Forest types also have visual components that influence the way people perceive forests.

Successional change is not abrupt, but quite gradual. Some plants and animals are specific to a particular vegetation or forest type and are rarely present in earlier and later seres. Most plants and animals are more general in their habitat strategy, often finding habitat needs in a variety of vegetation types. Most plants and animals can also get by through using their "second" or "third" choices of preferred habitat. Plants and animals that are very specific and narrow in their habitat needs are often indicator species of particular condition or vegetation type. If these species occur in low number in few places, they are usually on either the federal or state endangered / threatened species list.

Case Study: *Kirtland's warbler is small migratory bird closely and nearly exclusively associated with young, moderately open stands of jack pine while they in the north for the breeding and summer season. Early logging, subsequent fires and agricultural failure almost drove Kirtland's warbler to extinction. Through active management of jack pine age structure and stand size, the warbler has made a successful comeback. Managing jack pine successional was a critical element in bringing this bird back from the brink of extinction.*

What Drives Successional Change?

There are biological (biotic) factor and non-biological (abiotic) factors that drive succession.

Biological factors usually involve plants, but sometimes animals. In forests, trees are generally the primary biotic driver. To understand how trees cause succession, you have to know about the habitat requirements for various tree species. The most important requirement, in terms of succession, is soil characteristics and a tree's tolerance of shade.

Animals influence succession in a number of ways, too. A major insect epidemic that kills trees, will usually setback succession to an earlier stage. High populations of white-tailed deer over a decade or more will selectively remove some species from a forest type. Crippling the successful regeneration of most (or all) tree species will have major impacts on the succession of plant communities.

Abiotic factors are such things as soil types, moisture levels (swamp vs. upland), weather, and climate. Red pine / red oak forest types grow on sandier, well-drained soils. Cedar, black spruce, and tamarack types typically grow in swamps. Weather impacts succession in the form of windstorms, droughts, late spring frosts, etc. Climate differs from weather in terms of time and geography. Climate change generally occurs over very long periods of time and across large regions. Weather is more variable from year to year and has more localized impacts.

> ***Case Study Abiotic Factors:*** *American beech distribution dramatically stops in the Upper Peninsula where soil types change from richer glacial deposits in the east to low fertility soils derived from granitic bedrock in the west. Most hickories, many oaks, sassafras, and sycamore are central hardwood tree species that only grow in southern Michigan's milder climate. On the other hand, the pines and spruces are more adapted to the colder climates and soils of northern Michigan.*

Fire is a particularly strong abiotic factor in succession. Many of our forest types have adapted to regular wildfires. Minnesota forests bordering the prairie are almost entirely comprised of forest types adapted to frequent fires. Frequent fire and a drier climate have resulted in a forest with fewer tree species and forest types. In the Upper Peninsula of Michigan, many forest types have developed where wildfire is often less frequent and average rainfall is higher.

Succession Case Study

A young aspen stand lacks much height but has many stems per acre. Because aspen is intolerant of shade, we know something catastrophic occurred about 10-15 years ago, maybe a harvest or maybe a windstorm or fire. In any case, the aspen is regenerating well. There is often a diversity of other tree species, such as black cherry, oak, and paper birch. The high number of stems provides good breeding and escape cover for animals such as rabbits and grouse. Deer heavily browse the young trees. The vigorous young trees actively transpire large quantities of water and produce much more oxygen than they use. Beavers and broad-winged hawks prefer this forest type.

As the aspen ages, the trees will thin themselves out and the forest will become taller and less dense. Grouse love the more mature flower buds but will prefer raise their young elsewhere. The aging aspen will provide uses for red-eyed vireos, woodpeckers, and maybe some owls. Mature aspen allow a fair amount of light to reach the forest floor, so there is still an actively growing understory. On sandy soils, hazel may be common, whose nuts are important food for many animals. On heavier soils, there may be buckthorn, Juneberry, and viburnums. It's also likely that the seedlings from more shade tolerant tree species have begun to grow. They will make up the next forest type.

On sandier and dryer soils, the next forest type might be a mix of white or red pine, oak, and red maple. On heavier soils, the new generation might be sugar maple, balsam fir, and white spruce. There are about 35 tree species in Michigan aspen associations, second in diversity to only northern hardwoods. Left unmanaged, over a number of decades, the aspen will eventually die out. The next type might be a white pine-red oak association, or a northern hardwood stand. In wet soils, cedar might become dominant.

Forest Disturbance

A successional path spans a long time, from the human perspective. Over the course of time, it's quite likely the stand will experience some form of disturbance. Disturbances occur from natural causes, such as wind, fire, pest infestation, or it can come in the form of timber harvest. In either case, the course of succession is altered. With forest management, the manipulation of succession is intentional, with a set of goals in mind, ideally within the context of a greater landscape.

Activity Suggestion: *Research when and where a recent forest disturbance occurred near you. Was it natural? Was it human-caused? What happened? Visit the site if you can. What tree species are growing in the disturbed area that are not growing in the adjacent undisturbed area? What tree species are more abundant in the disturbed area? Why is this?*

Disturbance is essential to the regeneration of many tree species. Jack pine and paper birch were largely dependent upon *wildfire for regeneration*. Successful fire suppression programs have created a management dilemma for these species that forest scientists needed to overcome. Northern hardwood (sugar maple, beech, basswood, and others) stands need small scale disturbances to create "holes" in the forest canopy to regenerate many species and maintain higher levels of species diversity. Selection harvest and thinning complements this natural process to produce more forest outputs in a shorter period of time.

Since the Glaciers

We typically think of succession in terms of current climate conditions and a time frame of just a century or two. Climate is one of the main drivers of succession but is not constant over the millennia. Climate change studies have demonstrated a progression of widely different successional regimes.

The climate of Michigan has varied considerably since the continental glaciers receded 10,000 - 12,000 years ago. For centuries during the recession, the climate was cool and moist. Boreal species and plant community types extended into Indiana and Illinois. Relict populations of boreal types can still be found scattered across the normally more temperate climates.

During the current post-glacial period, climates have varied considerably from we experience now. There have been cooler moister periods where our forests had much stronger boreal characteristics. There have also been warmer drier periods where much of Michigan was prairie. That's part of the reason why Michigan still has a few prairie remnants.

FOREST ECOLOGY BASICS

A forest is a collection of biological organisms and non-biological factors. From an ecological perspective, the definition of a forest includes all these things, from the trees to the bacteria, and the soil type to the microclimates. See the "Tree Basics" page for more about the definition of a forest. Forest management systems are rooted in forest ecology (pun intended!).

There are three groups of concepts with forest ecology, or the ecology of just about any natural system. Each of the three groups of concepts interact with each other to variable degrees, at variable times, and in variable ways.

- **Composition**: These are the pieces of the puzzle.
- **Structure**: This is how the pieces are arranged.
- **Function**: This is what each piece does and the interactions among the pieces.

Ideas on this page:

Diversity Populations Communities Forest Layering Crown Cover Edge Effect Fragmentation Parcelization	**Snags Microenvironment Visual Quality Aesthetics Food Chains Nutrient Cycles Organic Matter**	**Trophic Levels Weathering Hydrologic Cycle Temperature Humidity Succession Disturbance**

Composition

Composition has to do with species, taxonomy, and biological diversity. The number of species and how they relate to each other according to taxonomic classes is a reasonably straight-forward concept. *Biological diversity*, on the other hand, is a bit more slippery to wrap our minds around. At first, diversity sounds like a simple species count and relative abundance of each species. This is certainly a component of the diversity question. It's also the easiest to identify and study. However, the diversity of ***species*** is only one level of several.

> ***Species:*** *the main category of taxonomic classification into which genera are subdivided, comprising a group of similar interbreeding individuals sharing a common morphology, physiology, and reproductive process. Note 1, there is generally a sterility barrier between species, or at least reduced fertility in interspecific hybrids. Note 2, the species is the basic unit of taxonomy on which the binomial system has been established; the lower taxonomic hierarchy is species, subspecies, variety, and forma.*

At the most fundamental level of diversity, there is ***genetic diversity***. How many genes and pieces of genetic information are present in a forest? The chlorophyll gene, for example, is common throughout most of the plant kingdom (although there are several variants). Many other attributes or genetic characteristics are also quite common in a forest system. Vertebrates have far more genetic commonality than genetic difference. The loss of a species may not represent a loss of genetic diversity, only the loss of particular combination of genetic material. The raw material will probably remain in the biota. If you remove the word "the" from the English language, it would make our speech awkward, but it would not eliminate all words with the letters "t", "h", and "e".

Species diversity is the next level of diversity. These are the combinations of genes that we are most accustomed to dealing with in the life sciences and from legal perspectives (e.g. endangered species laws). Yet, the definition of the word species escapes a single, concise, universally-accepted agreement. Species ***abundance*** addresses the issue of how common a particular species is, often in the context of particular region or ecosystem. There might be 100 species in a suite of characters. However, 90% of the biomass might consist of only 3 species. There may be a few species that are very uncommon, or have low abundance. It is usually the species with low abundance that we are concerned about from the perspective of potential species loss. It is usually the abundant species that we derive the most of economic base from. See the *tree species diversity* page for more information about Michigan forests.

A collection of individuals of a given species make up a ***population***. The size, frequency, and distributions of populations are important elements of diversity. A Canada lynx might be listed as endangered in Michigan, but across its range it is a common animal. Sometimes populations on the edge of species range will display unique set of genes. Northern populations of animals tend to have larger size and shorter appendages. Flowering times of a tree species varies with climate conditions. The conservation of distinct populations may be important in some cases.

With a given ecosystem, populations interact with other.   There are identifiable associations of species. These ***species associations*** are called ***communities***. Community diversity is more difficult to measure in the landscape because there are usually a large number of components. To make identification possible, key species are used to describe a community, such as "northern hardwoods", which is defined by such tree species as sugar maple, beech, and basswood. However, northern hardwood associations in the western Upper Peninsula lose the beech component. Community descriptions have an inherent degree of variability across a large geographical region. This is another element of "diversity".

Lastly, there is something called ***"ecosystem diversity"***. A collection of communities and the association physical factors make up an ecosystem. Ecosystem diversity is commonly described in terms of biomes, eco-regions, and similar large-scale terms. However, ecosystems can also be quite small. The various communities within a rotting log are distinct from the surrounding forest. That rotting log, or all the rotting logs in a forest, can be considered an ecosystem.

While the above levels of diversity suggest a strong hierarchy, the classifications are less distinct in the natural world. A considerable amount of flexibility and "confusion" exists. Diversity is complex set of concepts, despite our understandable tendency to reduce it to a species level.

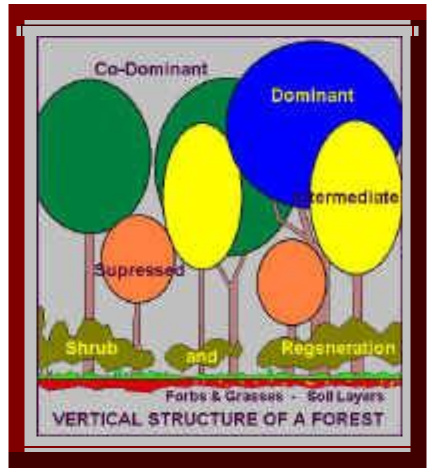
Structure

The structure, or "architectural" arrangement of a stand and forested region is important. Structure impacts wildlife habitat in a major way. It also influences light, water, and nutrients levels. These things, in turn, impact the trees and other vegetation. Structural components of a forest, or lack of a particular component, are not inherently "good" or "bad", or "natural" or "unnatural". Structure is an ecological feature of a forest that can be measured, and subsequently evaluated against a set of criteria. Seven elements of structure are discussed.

- Vertical & Horizontal Arrangement
- Heterogeneity and Forest Density
- Edge Effects
- Islands and Fragmentation
- Dead Trees and Snags
- Micro-Environments
- Appearance

Vertical & Horizontal Arrangement

This is the physical arrangement of a forest; the different tree heights, ***"layers"*** of forest, and the continuity of branches from tree to tree. A forest with more structure generally has more habitat characteristics. A continuous forest offers transport routes for arboreal animals (animals that live in trees). ***"Crown cover"*** is the percent of the ground that has tree crown growing over it. A forest will have variable percentages of "holes" in the canopy. These "holes", or the amount of crown cover or crown closure, have important ecological ramifications.



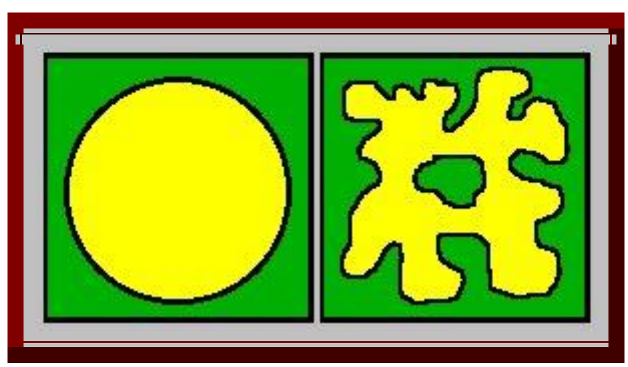
Classical tropical humid rain forests probably have the most structure of any forest on Earth. Our north temperate forests are different. Not all forest types have a full complement of layering (understory, shrub, mid-size trees, main canopy trees, really tall trees). Jack pine stands, for instance, generally lack much vertical structure, especially with the kinds of soils they typically grow on. Northern hardwoods, if managed accordingly, will have a well-developed structure. Left unmanaged, they tend to lose structure close to the ground.

Heterogeneity and Forest Density

The level of ***"heterogeneity"*** refers to how similar or different the parts of a forest are to each other. Diversity is a big part of this, but so is structure and other forest descriptors. Heterogeneity might be evaluated within a single stand of trees, or be assessed across a large landscape, such as a national forest or the eastern Upper Peninsula.

"Density" has to do with how many trees are in an area and how large the trees are. A thousand trees per acre may, or may not, be a lot of trees depending upon their size. A thousand seedlings are generally more than recommended, but the density is still low. 250 large, saw-timber sized trees per acres would likely be a high density forest. Density is typically measured in units of square feet and is called ***"basal area"*** *(link to the Forest Descriptor page in the Tree Basics section).*

Edge Effects



"Edge" refers to the transition zone between two different vegetation types. Some "edge zones" are sharp or narrow, such as the transition between a lake and the shoreline vegetation. Other transitions are more gradual, such as the change in forest composition up a slope in the Keweenaw Peninsula. These edge zones usually have representative species from both vegetation types, so they tend to be more diverse than either of the constituent types. Edge zones may also have species not found in either constituent type. In terms of broad-brush diversity, forest edge is a good thing, especially if higher numbers of species were the only measure.

The design of a timber harvest can have significant on habitat quality. Within a given area, more or less "edge" can be created according to the management objectives of the forest stand.

The downside of forest edge is the affect on species that prefer or require "deep woods" conditions. The introduction of edge to a "deep woods" type forest will stress those species that don't benefit from edge effects. The ovenbird is often cited as an example of an animal that can only be found in undisturbed, mature forests. This conclusion is arguable, as ovenbirds can often be heard in other forest types. What the ovenbird really needs is protection from ground predators, as they build their nests on the ground. Deep, dark forests tend to have fewer species and do not support high numbers of large predators.

<u>Islands and Fragmentation</u>

The process of changing a large forested area into an area of forest patches is called ***"fragmentation"***. These forest patches are referred to as ***"islands."*** The fragmentation of forest has important ecological impacts. These impacts are not necessarily "good" or "bad" but they are definable, at least in part.

Forest fragmentation is the land use change from forest cover to a non-forest cover. This is represented in the above image starting from the upper left and moving clockwise.

Forest fragmentation should not be confused with forest ***"parcelization"***. Parcelization is an ownership phenomenon that often, but not always, translates into forest fragmentation. Parcelization has direct economic impacts, as well as potentially direct ecological impacts.

Mathematical theories relating biological diversity and fragmentation were promulgated by a man named E.O. Wilson. These theories were developed to explain ecological trends and patterns found among the islands of the South Pacific. The theory is called "island biogeography". Both the original theory and its subsequent application to continental situations remain highly controversial.

Dead Trees and Snags

Dead trees, both on the ground and standing, provide habitat elements for many species, particularly cavity nesters. Dead wood also provided habitat for a number of insects which, in turn, are important parts of some food chains. A standing dead tree is called a ***"snag"***. Large snags and fallen trees have more value than small ones.

"Snag management" means producing more snags in a forest where snags are uncommon. From a strict timber perspective, snags are trees that could have been merchantable had timber been the only management goal and management implementation was perfect. As a legacy of our forest history, many of our forests remain in younger, more vigorous age classes. Snags become increasingly common as forests grow older. Forests of short-lived species already display an abundance of snags. The presence of snags in longer-lived forests can sometimes be accelerated through management. Snags in short-lived forests are usually retained during timber harvest.

Micro-Environments

Small areas within a forest environment that have markedly different characteristics are called ***"micro-environments"***. Examples might be rock outcrops, large rotting logs, pit-mound topography (tree tip-ups), springs and seeps, vernal (spring-time) ponds, or other features. These micro-environments sometimes harbor special sets of species, occasionally endangered or threatened species. Seeds of some tree species may depend on micro-climates / micro-environments to enhance their reproduction success. Manipulation of the forest canopy through management practices alters micro-environmental conditions such as light, temperature, and humidity.

Appearance

The ***"appearance"*** of a forest is not really an ecological factor, but it has great influence on how forests are managed or not managed. Forest management or lack of management can have significant ecological impact. The appearance of a forest strongly influences public opinion and public policy of the "goodness" or "badness" of a particular forest practice. An entire of compendium of "pseudo-science" has been developed to support what is essentially an argument against forest practices resulting in poor appearance. Generally, balanced ecological and biological information is not considered. This phenomenon is not unique to natural resources, of course.

"Visual quality" is the term often used as an objective in forest management. ***"Aesthetics"*** is a misnomer that is also quite common. An aesthetic involves the appreciation of something. Appreciation has deeper meaning than mere visual appearance. A well-done and properly applied clearcut can have high aesthetic value, but rather low visual quality.

Function

The ***"function"*** part of an ecosystem involves *"how"* things happen. It's equivalent to *"economics"* in our human society, or the themes of geography that involve the movement of goods and interactions between humans and the environment. How ecosystem functions are played-out can be highly complex, but the functions themselves are fairly easy concepts to understand. These areas of forest ecology are probably the least understood, but the most resilient.

Energy Capture & Trophics

Nearly all life on Earth is solar-driven. Plants capture solar energy and store it as chemical energy (*photosynthesis*). Animals eat plants to obtain this stored energy, among other things. Some animals eat other animals, for the same reasons. These threads of energy transfer are called ***"food chains"***. Energy can be likened to the currency that measures an ecosystem economy. Life bucks the laws of entropy. In this sense . . . life is not "natural", but eventually all the energy is dispersed.

The ***"rule of 10 percent"*** says that only 10 percent of the energy in each transfer is actually captured. So, plants only capture about 10 percent of the solar energy available to them. Herbivores capture only 10 percent of the energy stored in plants. And, the same is true "on down the line" of the food chain. Energy transfers occur between ***"trophic levels"***.

Mineral & Nutrient Cycling

In addition to energy, a host of minerals and nutrients cycle through the biota. Understanding these cycles involves chemistry, biology, and physical geography. The most common elements are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, and magnesium. A jingle to help remember these nine elements is "**CHOPKNS CaFe Mg**" or "**see Hopkins Cafe, might good**". There are another couple dozen or so elements needed, too.

How minerals and nutrients cycle through the biota varies considerably. Decomposers, soil type, water, and climate are determining factors. Cycles tend to be "open" in temperate zones, meaning nutrients are commonly lost to a system or a food web. A significant portion of available nutrients are found in ***"organic matter"***, or the layer of dead material on top of the soil surface. Tropical humid systems tend to be "closed" with very few nutrients slipping out of the system. Soils in these regions have very little organic matter.

The availability of a nutrient differs from the amount of a nutrient in the environment. For example, just because there is a lot of nitrogen in the atmosphere and the soil, doesn't mean it is in the form a plant can absorb. Nutrient availability varies with soil type, pH, and other factors. For more information about mineral & nutrient cycling, try the "*cycles*" page.

Weathering

New minerals and nutrients are added to an ecosystem as rocks and soils are chemically broken down by weather and biological factors. ***"Parent material"*** is the rock or mineral source(s) from which soils are derived. The productivity of a particular soil is highly dependent upon the parent material in the area. Parent material rich in key elements will produce soils that support higher levels of biomass. Weathering is the prime source of "new" minerals and nutrients in an ecosystem.

Water Movement

The ***"hydrologic cycle"*** is commonly taught throughout Michigan at the upper elementary and middle school level. The amount of water on the Earth is a fairly finite quantity. Where it occurs and how it cycles has a tremendous impact on the biota in an area.

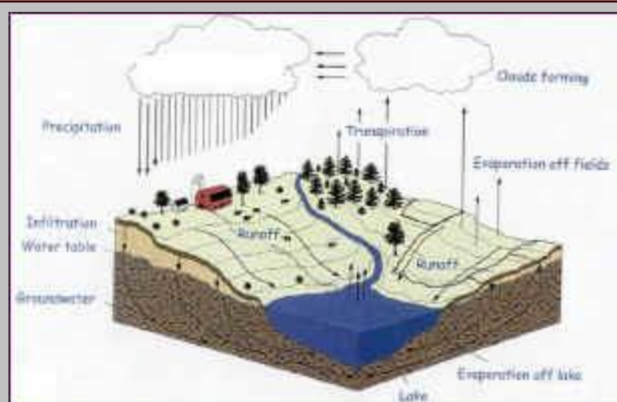


Image courtesy of the Michigan State University
Institute of Water Research/Center for Remote Sensing

Essentially, water cycles through the atmosphere, living matter, and the soil. Movement can be "stalled" by a number of features, such as lakes, underground aquifers, glaciers, etc. As water moves downward through soils, it usually takes soluble nutrients with it. Water movement is the main reason for the "loss" of nutrients in an ecosystem.

Like nutrients, water availability to plants also varies. Coarse soils, those with relatively large particle size and pore size, tend to hold less water. They are drought-prone and most tree species don't grow well on these soil types. Finer soils, such as silts and clays, have very fine particles and hold more water. However, during dry periods, they may just as droughty as coarse (or sandy) soils because the drier these soils become, the tighter that water molecules "cling" to the soil particles. This cohesive property may be stronger than a root system's ability to pull the water molecules out of the soil.

For more information about the hydrologic cycle, try the "*cycles*" page.

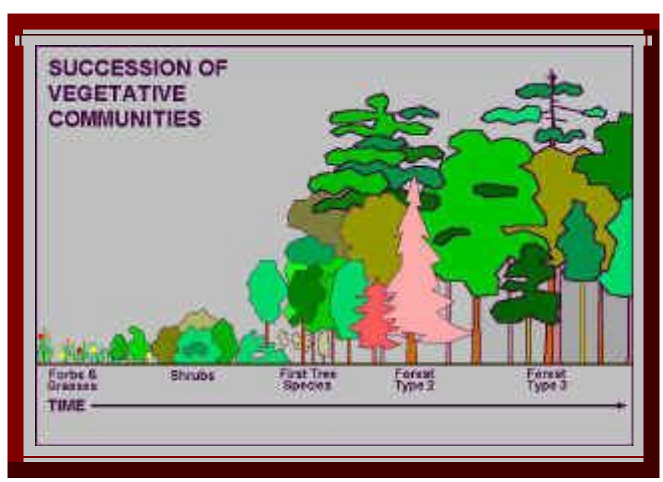
Temperature & Humidity

Temperature and humidity play important roles in the transfer of materials throughout an ecosystem. They also have strong influences on "who grows where" and affect metabolic processes of both plants and animals.

Photosynthetic rates correlate to temperature. Higher temperatures increase rates, to a certain point, after which a plant can "burn out". Very arid environments cause plants to close their pores in order to conserve water. Less water inside the plants can slow photosynthesis to a crawl. Desert plants have special adaptations for dry conditions. So do many plants in our northern bogs and sandy outwash plains. And the temperature-humidity condition immediately above a forest canopy on a hot summer day can be every bit as hostile as that in a desert.

Successful germination of tree seeds and early seedling survival are quite sensitive to temperature and humidity conditions on the forest floor. For example, sugar maple seeds germinate in the spring, soon after snow melt, when the temperature is 34 degrees (F). If an early spring heat wave hits, germination for that year will be poor. On the other hand, yellow birch, a common associate of sugar maple, germinates best around 74 degrees. That's part of the reason why an unmanaged northern hardwood stand will often migrate towards a sugar maple monotype and a managed northern hardwood stand will encourage the regeneration of other northern hardwood tree species.

Succession and Disturbance



As the living (biotic) and non-living (abiotic) components of an ecosystem react with each other over time, the composition, structure, and function of a forest will change. This process of change is called ***"succession"*** which is more fully explained on the *succession web page*. The classic concept of succession is the orderly and reasonably predictable path of vegetational change over time, from bare soil to mature forest. The early vegetation types (seres) are labeling as ***"pioneer"*** types. The final sere, if there is one, is called the ***"climax"*** type.

The progress of succession can be interrupted and set back by disturbances, usually the result of fire, wind, flood, or insect/disease epidemic, and nowadays by forest management. Disturbance might be on a grandiose scale, such a large wildfire, or a small scale, such as single large tree blown over in windstorm or killed by a lightning strike. Depending upon the severity of the disturbance, an earlier vegetational stage (or sere) will result, and succession will restart from that point.

Forest management is closely integrated with an understanding of forest successional pathways. Succession can be accelerated or slowed, depending upon the desired objectives for a particular stand and the natural capabilities of the site. Successional pathways vary according to many factors.

FOREST HEALTH ISSUES

Some people will argue about the difference between "forest" health and "tree" health. One of the main issues is that poor tree health sometimes enhances overall forest health, to a limited degree. It does this by providing more habitat for species that benefit from trees in poor physical condition. This is often an argument made against forest management. For the most part, this section of the Teachers Guide will fall in line with the concept that forest management can never eliminate those elements of an ecosystem dependent upon trees in poor health, even if that were the only management objective. Forest management will increase the number of healthy trees growing vigorously, but will not significantly reduce ecosystem stability in the process. In fact, forest management generally enhances stability.

Insects & Diseases

There are multitudes of insect and disease species that affect trees. Insects can be both beneficial and harmful. Diseases, by definition, are always harmful to trees, even if the harm is minor.

Insects and diseases are often evolved to affect only a certain part of a tree. Wood borers chew through the wood. Shoot beetles attack the young shoots of pine, leaf miners eat leaves, a fungus may attack only phloem, etc. Diseases, alone, are responsible for more wood loss than any other damaging agent, including timber harvest. Often times, a species of insect or disease is specific to a species or genus of tree.

The life cycles of insects and disease are fascinating and quite variable. Population levels are often strongly influenced by weather, seasons, parasites & predators, and the overall vigor of trees in the forest. In dry years, wood borers are usually more numerous because conifers are stressed and more vulnerable to wood borer attack. Some insects are cyclical. Forest tent caterpillar outbreaks occur about every ten years. Spruce budworm reaches epidemic proportions every 40 or 50 years, about the time balsam fir becomes mature and starts to lose vigor.

Damaging insects are often grouped by the kind of damage they cause or the part of the tree they attack.

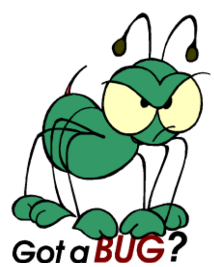
Defoliators	**Leaf eaters, either the whole leaf or just the interior layers of a leaf.**
Bark Beetles	**Tunnels under bark, consuming live tissue.**
Bark Borers	**Tunnels in wood, consuming dead tissue.**
Terminal Feeders	**Eats the young growing tissue of twigs and roots.**
Sucking Insects	**Have specialized mouth parts to penetrate tissues and suck sap.**
Gall Insects	**Produces chemicals causing the tree to from an abnormal swelling, within which the insect carries out part of its life cycle.**

Some of the more common or important forest-damaging insects are:

jack pine budworm
spruce budworm
sawflies
loopers
spanworms
cankerworms
large aspen tortrix
forest tent caterpillar
gypsy moth
leafminers
two-spotted sawyer beetle

pine sawyer beetle
bronze birch borer
sugar maple borer
two-line chestnut borer
white pine tip weevil
pine shoot borer
beech bark scale
aphids
spruce gall adelgid
bark beetles
carpenter ants

larch casebearer
Saratoga spittlebug
scale insects
thrips



Diseases, too, are sometimes specialized in where they attack a tree. Most diseases are fungi, but some can be viral or bacterial. Decay is a normal and essential part of forest ecology and most of the fungi are key players in this vital role. For example, white rots attack the cellulose of wood, but leave most of the lignins and other components behind. The brown rots then move in, and decompose the lignins. Most fungi are not harmful to trees, or at least not healthy, vigorous trees. In fact, mychorrhizal fungi are beneficial and possibility critical to tree health. Generally, the spores and hyphae (living filaments) of fungi cannot penetrate the protective bark layers. A number of different fungi consume particular components of wood. Others may attack foliage or cambium tissues. Interestingly, trees *cannot* heal wounds like animals. Once wounded, the wound remains throughout the life of the tree. The best a tree can do is grow over the wound. Open wounds are not protected by bark and are open to infection by diseases.

Some of the more common or important forest-damaging diseases are:

Anthracnoses	Attacks leaves and twigs during moist periods.
Armillaria	A common root rot. The famous "humungous fungus" of Crystal Falls.
Black Knot of Cherry	Charcoal-black swelling common on species of cherry.
Dutch elm disease	Attacks the cambium tissue, girdling the tree.
Eutypella	Causes cankers on tree trunks.
Heart Rots	Decomposes wood tissue and forms large "conks" on trees.
Nectria	Cause cankers on tree trunks, similar to Eutypella.
Oak Wilt	Related to Dutch elm disease and kills the same way.
White Pine Blister Rust	Attacks cambium tissue, can girdle and kill tree.
Mistletoe	A parasitic plant.
Needlecasts & blights	Attacks conifer needles, sometimes the young, sometimes the old.
Beech Bark Disease	Combination of exotic scale insect and exotic canker.
Emerald Ash Borer	Newly identified in 2002, this exotic insect poses threats to trees.

In addition to insects and disease, there are other pests and damaging agents that affect trees and forests, such as air and salt pollution, especially along major travel routes, browsing by deer and other animals, girdling by porcupines, nematodes (a group of worms), frost, hail and ice, wind, freezing, and sun scorch. As our forests age and mature, certain forest types will become much more vulnerable to forest health problems.

Fire

Wildfire is considered a bad thing because it destroys standing timber, buildings, and radically changes the face of the landscape in an uncontrolled manner. Ever since the huge fires in the late 1880s and early 1900s, fire suppression has been a major objective in forest management. That has not changed. However, fire has long been a part of the forest ecosystem. Forests, and in particular some tree species, have adapted to the presence of fire. Despite a negative image and negative effects, fire actually provides many benefits to certain forest types.

> ***Case Study:*** *Jack pine is often used as a classic beneficiary of fire. About 75% of jack pine cones are "serotinous", meaning that they are "glued" shut. A temperature around 120 degrees will "melt" the glue and allow seeds to fall from the cones. Within a day or two of a fire, jack pine cones open and release their seeds. The seeds require the exposed mineral soil created by the fire. Jack pine are quite intolerant of shade, so the open, fire-killed canopy allows the light that the new trees need to grow.*

Some forest management practices (especially clearcutting) have filled the role of wildfire in many ways, but not all ways. Because management cannot use non-fire practices to imitate all the beneficial aspects of fire, foresters will ***prescribe*** fire in certain circumstances.

Prescribed fires can reduce the amount of fuel, therefore reducing the chance of a catastrophic wildfire. Also, smoke intensity from lighter fires will be less than with a major fire. Fire can burn off the dead leaves and expose mineral soil that some tree seeds need to germinate. Burning the dead leaves also eliminates habitat for some kinds of tree-damaging fungi and insects. The ash provides a short-term boost in potassium and other nutrients needed by trees. Fire can increase the amount of herbs, providing better browse for some species of wildlife.

Sometimes a prescribed fire will be used *after* a timber harvest. This way, the benefits of fire can be realized without destroying the standing timber. Of course, the downside is the perception of wanton forest destruction. Other times, prescribed fire will be used under a living canopy. For example, larger red pine have thicker bark, which a light fire cannot penetrate. A light fire will kill the smaller trees and shrubs. The living shrubs provide a "ladder" for a cone-boring beetle that destroys the seed of red pine while it is still in the cone. Foresters may prescribe one or two light underburns to prepare a mature red pine stand for partial harvest, and at the same time, create the kind of forest conditions to naturally regenerate red pine.

Exotic Species

An ***exotic species*** is one that has been introduced from somewhere else and was not part of the natural development of the ecosystems in question. So, a species from Europe or Asia that is surviving in North America would be an exotic. The same would be true of a species from Colorado that now grows in Michigan.

An ***invasive species*** is one that aggressively colonizes new areas. It usually refers to exotic species that can rapidly overtake and disrupt native habitats. However, Pennsylvania sedge, a native, rapidly dominates the ground flora as deer, in high densities, eat just about everything else. Purple loosestrife (an exotic) has a beautiful flower but the plant overtakes wetlands. Common and smooth buckthorn (exotics) dominate sunny understories preventing the regeneration of most native species. Chestnut blight (an exotic) virtually eliminated the chestnut tree from the eastern forest where it once was a dominant native species.

Exotic	Date Found	Origin
Chestnut Blight	1904	Asia
Dutch Elm Disease	1930	Europe
White Pine Blister Rust	1906	Europe
Beech Scale	1890	Europe
Birch Leafminer	1923	Europe
Larch Sawfly	1880	Eurasia
Gypsy Moth	1869	Europe
Pine Shoot Beetle	1992	Europe
Asian Longhorned Beetle	1996	Asia
Emerald Ash Borer	2002	Asia
Hemlock Woolly Adelgid	2006	Europe

To become a problem, an exotic species must reach new territory, become established (growing & breeding), and then spread. This is difficult to do in a foreign ecosystem. The overwhelming majority of introductions fail. Nevertheless, scientists estimate over 40,000 species have been introduced to North America.

Many exotics are not considered problematic and most are not damaging, such as cattle or carrots. How many realize that Great Lakes salmon are exotic? Or, pheasants?

About 400 insects and 20 diseases are exotic pests of trees.   Most exotics have historically come from Europe. Mushrooming trade with China and other east Asian countries present an entirely new threat on the horizon.

Why are some exotics so bad? In terms of forests . . .

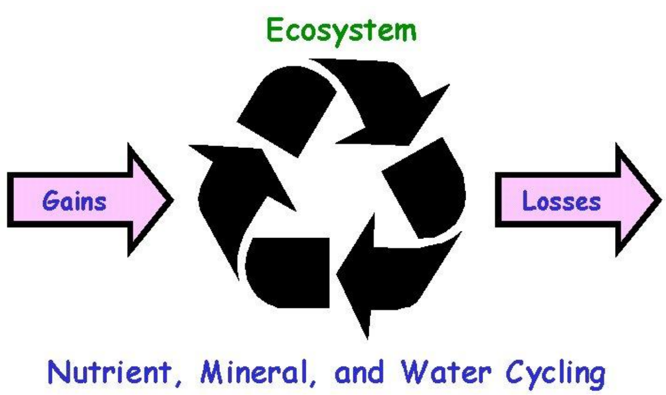
1. Negative effects on native species diversity.
2. Altered diversity can disrupt ecological processes, such as food chains, habitat quality, etc.
3. Major outbreaks can reduce forest productivity across a wide geographical region.
4. Can further threaten endangered species.
5. Necessary quarantines and regulations can significantly reduce economic growth.
6. Control measures cost millions of dollars each year.

Many natural resource professionals consider exotics species one of the top threats to our forests and other native ecosystems.

NUTRIENT & WATER CYCLES

Hydrologic Cycle
Nutrient Cycles
Soil Types, Particle Sizes, Textures

It is easy to get caught into the complexity and chemistry of water and nutrient cycles. As with most things in the natural world, multiple factors interplay with each to produce an immense array of conditions. However, there are some fundamental factors and basic ideas that are good to understand.



- Climate zones are important.
- Soils are the primary medium where "cycles" happen, in terms of their affect on living organisms.
- Stuff enters a system.
- Stuff gets held within a system.
- Stuff is lost from a system.
- A ***"closed system"*** is one where little comes in, little leaves, and most of the "goodies" are held within tissues of plants and animals.

- An ***"open system"*** is where "goodies" tend to have flow in and out of plant and animal tissues.
- Temperate climate systems generally tend to be open systems with a fair amount of cycling.
- There is a difference between the total amount of water or a nutrient in a system and the amount *available* to organisms.
- Chemistry has a great deal to do with what nutrients are available.
- Composition of soils have a tremendous influence on chemistry and nutrient & water movement.

Hydrologic Cycle

The hydrologic cycle is the natural sequence through which water passes into the atmosphere as water vapor precipitates to Earth in liquid or solid form, and ultimately returns to the atmosphere through evaporation and transpiration. The biotic community is only one part of the cycle. The oceans also have large biotic communities, mostly phytoplankton.

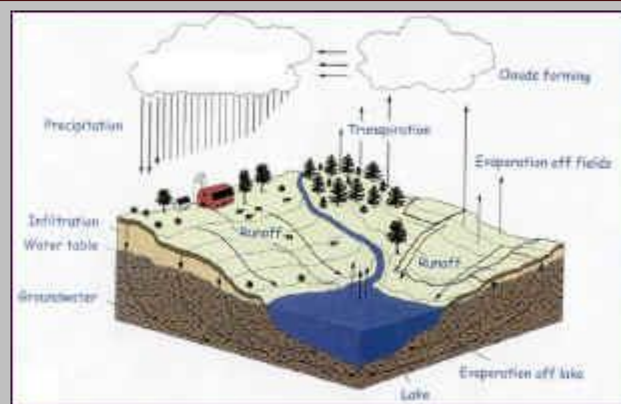


Image courtesy of the Michigan State University Institute of Water Research/Center for Remote Sensing

Scientists believe the total amount of water on Earth has remained unchanged for millions of years. They estimate the amount at 326 *million cubic miles* or about 358,026,240,000,000,000,000 gallons! [Owen, 1971]

Water moves about the Earth. Water movements, especially how they affect the biota, are called the ***"hydrologic cycle"***. At any one time, only about 0.005 percent of the supply is actually moving through the cycle [Owen, 1971], which is a LOT of water. This cycle is solar-driven. The three main theaters are land, air, and ocean. Water is stored in various reservoirs for various periods of time. Water in glacial ice has been there a long time. Water held by trees soon goes somewhere else. There are many connections between the reservoirs and processes described below. Measuring the relative importance of each helps define a particular ecosystem.

Reservoir	Volume (cubic miles)	Percent of Total	Percent of Freshwater
Oceans	166,520,000	96.5	-

Oceans hold about 97.2 percent of Earth's water. If the surface of the Earth were smooth, that's enough water to cover the entire surface under 800 feet of water.

Ice	5,774,000	1.74	68.7
Groundwater	5,614,000	1.7	30.1
Permafrost	72,000	0.022	-
Lakes-fresh	21,800	0.007	0.26
Lakes-saline	20,500	0.006	-
Soil Moisture	4,000	0.001	0.05
Atmosphere	3,100	0.001	0.04
Swamps	2,800	0.0008	0.03
Rivers	500	0.0002	0.006
Biological	300	0.0001	0.003
Total	332,546,000	100.0	100.0

Source: Gleick, P.H. 1996.
Note: Estimates of Earth's water and where it lies are difficult to make, especially for groundwater. This table shows a total amount different than cited by Owen, 1971.

Surface and Groundwater includes lakes, rivers, marshes, and the water in the soil and underground aquifers. This is the water that most people are directly concerned about, although it comprises only a tiny fraction of a percent of all the water on Earth. In the USA, we have over three million miles of rivers that carries 1.2 trillion gallons each day. Surface water satisfies about 80 percent of human needs for water. Groundwater may be closer to the surface in ***"water tables"*** or deeper down in rock strata called ***"aquifers"***. The speed of groundwater movement is much less than that of surface water, ranging from a few feet to a few miles each year. Contamination of groundwater is a serious matter because of the long time required to "flush" the system out.

The Great Lakes contain one-fifth of the world's surface freshwater, and Michigan has shorelines on four of the five big lakes! They contain 5,473 cubic miles of fresh water, or six *quadrillion* gallons. Note that this volume of water is only 0.00167 percent of Earth's water! Lake Superior holds the largest amount of water, more than the other four put together. The next largest Great Lakes, in terms of water volume, are Michigan, Huron, Ontario, and Erie. *Click here* for more information on the Great Lakes.

The ***atmosphere*** contains water that has evaporated, primarily from the oceans. The amount of atmospheric water is constant. If water didn't return to the oceans, they would lose 39 inches of water each year. This atmosphere is what keeps heat around the Earth, which would otherwise drop to temperatures around -300 degrees Fahrenheit.

The ***biota***, or plants and animals, store and process water. However, the amount is only 0.003 percent of all freshwater, which is only a few percent of all water on Earth. Nevertheless, this is the water that we most directly concern ourselves with.

Precipitation is what brings water back to the Earth from the atmosphere. Nearly 90 percent falls back into the oceans. Precipitation (rain, snow, sleet, hail, fog, dew) is very unevenly distributed across the landscape and plays a critical role in the distribution of plants and animals. The average *daily* amount of precipitation in the

USA is 4.3 *trillion* gallons. Enough precipitation falls in the USA in an average year to cover the surface of the country with 30 inches of water.

Evaporation moves precipitation right back into the atmosphere. Evaporation occurs from the surface of plants, from soils, and from oceans, lakes, and streams. Evaporation rates are higher in forested areas because of the huge amount of leaf surface area.

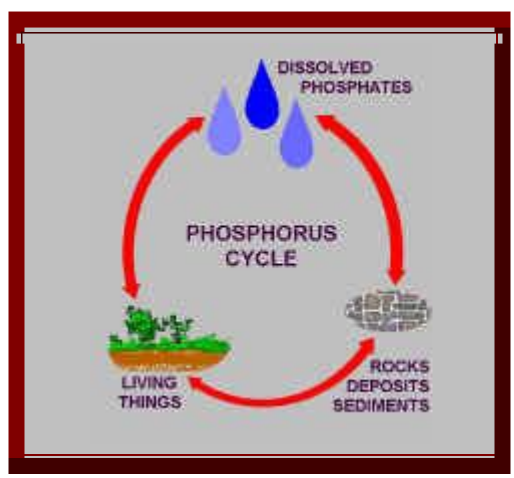
Transpiration is the process where plants move water from the soil to their above-ground parts, and then loses it to the atmosphere. One tree may transpire 100 gallons per day. An acre of corn might transpire 4,000 gallons in a day.

Evapo-transpiration is a combined term that includes both evaporation and transpiration. These processes send back 70 percent of annual precipitation in the USA.

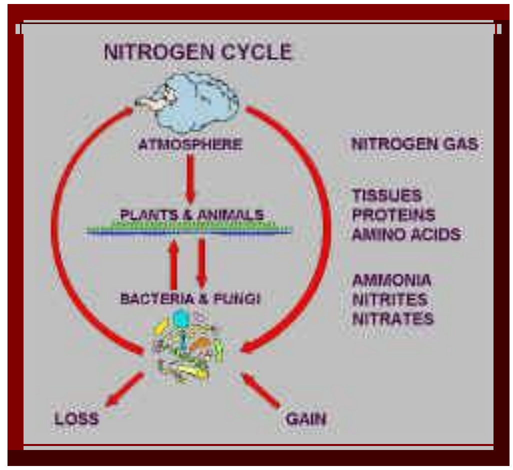
Nutrient Cycles

All minerals and nutrients cycle through soils and living systems. The amount *available* to plants and animals is what is important, not necessarily how much there is in the environment. The processes that influence the availability of nutrients vary from location to location and over time.

As mentioned in the tree physiology section, the most common minerals of life are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, and magnesium. You might be able to remember this by a jingle formed using the abbreviations for these elements: C H O P K N S Ca Fe Mg . . . "see hopkins café, mighty good." Usually, the most limiting minerals are nitrogen, phosphorous, and potassium. These are the three main ingredients of most fertilizers. Decomposers (bacteria and fungi) play a critical role in keeping nutrients within the living system and slowing losses to the open cycles we find in north temperate zones.



The primary reservoir of phosphorus and potassium is the soil. As rock is weathered, soil particles are formed, and minerals become available to plants. Weathering is affected by factors such as freeze-thaw events, pH, wind and water movement, and actions by plants. Phosphorus and potassium are converted to "organic" forms that can be absorbed and utilized by plants.



The primary reservoir of nitrogen is the atmosphere. Nitrogen must be converted from atmospheric forms to forms that plants can use. This process is called ***"nitrogen-fixing"*** and is largely done by certain forms of bacteria and algae. Certain groups of plants, especially those in the legume family, have specialized root nodules containing nitrogen-fixing bacteria in a *symbiotic* relationship. Lightning fixes some amounts of nitrogen. Annual nitrogen fixation averages between one and six pounds per acre [Odum, 1971]. There are several forms of nitrogen, but it is the nitrate form that is useable to plants.

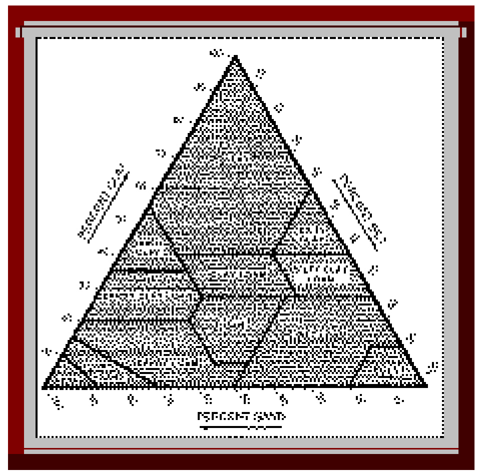
Two dominant factors in nutrient availability are water and pH. Most chemical forms of nutrients available to trees are in a soluble state, meaning they dissolve in water. As water moves through and across soils, it carries valuable nutrients. As a landscape captures water, so too, will it capture many of the nutrients dissolved in the water. This is the very important connection between the hydrologic cycle and nutrient cycles.

pH is simply a scale that measures the acidity and alkalinity of water solution. The scale runs from 0 to 14, with low numbers being acid and high numbers being alkaline. Seven is neutral. Most soils exist in a natural state of acidity. As a soil pH changes, so does the chemical forms of many nutrients. A change in pH may work to the benefit or detriment of plants on a particular soil type, depending upon the soil type. Most forest soils would actually become more productive with moderate decreases in pH. Soils can be ***"buffered"*** against changes in pH if they have higher levels of carbonates. Carbonates "absorb" the ions that cause pH change until their capacity is used up. So, a soil rich in carbonates would require large amounts of inputs to affect a change. Alternatively, poorly buffered soils may experience changes in pH with relatively low levels of inputs.

Aquatic systems operate in a similar way. Lakes in granitic basins tend to have lower pH values, lower biological productivity, and are much more vulnerable to drops in pH with the addition of acid inputs. Lowered pH in these sensitive lakes can have negative consequences on the biota of the lake. This was one of the principal concerns with "acid rain". However, most lakes tend to have fairly substantial buffering capacities.

Soil Types, Particle Sizes, and Soil Textures

According to the Natural Resource Conservation Service, there are about 475 soil types in Michigan. A soil type is defined by characteristics such as soil structure, moisture, soil genesis, particle size, and texture. Different soils are capable of producing certain levels of biological productivity, or so much biomass per year. Soil is one of the foundations of forest ecology. Because soil takes thousands of years to develop, conservation of soils is critical. Recovery from land abuse and excessive erosion cannot be easily overcome. There are many historical examples of collapsed societies due, at least in part, to abusive land practices. For a classic 28 page paper on the topic, click on Lowdermilk (requires use of Adobe Acrobat Reader).



"Soil texture" determined by the relative composition of soil particle sizes. There four soil particle size classes.

- Gravel: particles over one millimeter in diameter.
- Sand: 0.05 to one millimeter.
- Silt: microscopic, from 0.002 to 0.05 of a millimeter.
- Clay: particles less than 0.002 millimeter in diameter.

Most soils have a combination of soil particles sizes. There is usually a component of ***"organic matter"***, which is derived from decomposing plant and animal remains. A ***"loam soil"*** is a mix of sand, silt, and clay that optimizes agricultural productivity. The texture of a soil determines much about the water retention properties. A ***"coarse soil***", mostly sand & gravel, has large pore spaces and allows water to easily run through it beyond the reach of roots. These soils tend to be drought-prone. Additionally, sand and gravel have relatively little surface area for the particle volume, reducing the potential for nutrient weathering. A ***"fine soil"*** has large components of silt and clay, making it "muddy" when wet. Pore spaces are smaller and hold more water. However, when clay soils begin to dry, they may still hold large quantities of water, but due to the small particle size and adhesive & cohesive properties of water, most of it will be unavailable for root uptake.

The rock or original source of soil particles is called ***"parent material"***. The nature of parent material has a lot to do with soil quality. Glacial outwash sands tend to be rather infertile, or hold few minerals and nutrients important for tree growth. Soils derived from other sources may be relatively rich in minerals and nutrients. Usually a combination of weathered parent materials (often re-worked by glacial action in Michigan) and organic matter make a soil. Weathering or erosive actions include those from heating/cooling, freezing/thawing, glaciers, water, wind, chemistry, and plants & animals.

A ***"soil profile"*** is a look at the layers of soil in a particular place. Each layer is called a ***"horizon"***. The *A-horizon* usually contains most of the organic matter and soil goodies. It is usually thin, maybe a few inches or less. The *B-horizon* contains much of the nutrients that are leaching out of the A-horizon. It generally lacks any organic matter. Accumulations of iron or other minerals may create ***"hardpan"***, which is a feature water and roots have difficulty penetrating. The *C-horizon* is raw soil, weathered parent material. This horizon defines a soil's mineral and acidic properties. A granite-based soil will be acid and weather slowly. A limestone-based soil will be much more alkaline and weather rather quickly. The *D-horizon* is unweathered rock formed from basic geological processes such as volcanism and sedimentation.

Distribution of Kalkaska Sands in Michigan

Soil profile of a Kalkaska Sand
Michigan's State Soil

Courtesy of the NRCS