Ecological site F088XY010MN
Bedrock Controlled Upland Forest

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General information

Provisional. A provisional ecological site description has undergone quality control and quality assurance review. It contains a working state and transition model and enough information to identify the ecological site.

MLRA notes

Major Land Resource Area (MLRA): 088X–Northern Minnesota Glacial Lake Basins

MLRA 88 consists of the lake beds of glacial Lakes Agassiz, Upham, and Aitkin. These vast glacial lake beds were formed by meltwaters associated with the last glaciation of the Wisconsin age. The large, flat, wet landscapes are filled with lacustrine lake sediments, wave-washed glacial till, and vast expanses of organic soils. This area is entirely in Minnesota and makes up about 11,590 square miles (30,019 square kilometers).

The western boundary of MLRA 88 with MLRA 56B is gradual. MLRA 56B is a portion of the Red River Valley that was formed by glacial Lake Agassiz and is dominantly prairie. The southern boundary of MLRA 88 with MLRA 57 consists of distinct moraines that formed from the glacial drift sediments of Late Wisconsin age. The eastern and southeastern boundaries are with portions of MLRAs 90A and 93A. These MLRAs are in a distinct glaciated region of sediments of the Rainy and Superior Lobes, and much of MLRA 93A is bedrock controlled (USDA-Ag Handbook 296, 2022).

Ecological site concept

Bedrock Controlled Upland Forest sites occur on gently sloping to steep Hillslopes and Ground Moraine land forms. Well drained loam to gravelly loam soils are relatively shallow, as bedrock is typically present within 20 inches of the soil surface.

Associated sites

F088XY015MN	**Loamy Upland Wet-Mesic Mixed Forest** Depending on adjacent components, this site can exist in complex with both deeper soils, containing rich forests heavily dominated by sugar maple, or with shallower soils, dominated by mixed hardwood-conifer woodlands or sparsely vegetated bedrock shrublands. Loamy Upland (093AY013) is the only other ecological site description developed as yet. That ecological site is commonly mapped adjacent to, and often surrounds Bedrock Controlled Upland Hardwood Forests. In contrast, the soils found on the Till Upland Hardwood Forests ecological site are very deep (>60 inches to bedrock) and have dense till substrata within 60 inches, making that site richer and floristically more productive. However, these two ecological sites can sometimes appear very similar, especially when in community phases are dominated by sugar maple.

Similar sites

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Table 1. Dominant plant species

Tree	(1) *Quercus rubra* (2) *Acer saccharum*
Shrub	(1) *Ostrya virginiana* (2) *Corylus cornuta*
Herbaceous	(1) *Carex pensylvanica* (2) *Lathyrus ochroleucus*

Physiographic features

These sites are located in glacially scoured landscapes. They occur on high elevation, bedrock-controlled moraines. Hillslope positions are mostly shoulder slopes and backslopes, ranging from 2 to 35 percent slope. They can also occur on summits and narrow ridges. Runoff is medium to very high due to the exposed bedrock and slope. Slopes often are complex and occur in a stair-stepping pattern, with rock outcrops frequently occurring at major slope breaks. Slope shape is convex or linear upslope, and linear across slope, thereby effectively shedding water to adjacent, downslope ecological sites. Aspect does not appear to be important for this ecological site, although MN DNR (2005) has previously stated that these native plant communities may be more prominent on south and east facing aspects. Elevation is mainly above 600 feet (182 meters) and below 1,600 feet (487 meters). These sites do not flood or pond.

Table 2. Representative physiographic features

Slope shape across	(1) Convex
Slope shape up-down	(1) Convex
Landforms	(1) Hillslope (2) Moraine (3) Ridge (4) Hillslope
Runoff class	Medium to very high
Flooding frequency	None
Ponding frequency	None
Elevation	183–488 m
Slope	2–35%
Ponding depth	0 cm
Water table depth	203 cm
Aspect	Aspect is not a significant factor

Climatic features

The average annual precipitation is 25 to 28 inches (635 to 711 millimeters). Most of the rainfall comes from convective thunderstorms during the growing season. Snowfall generally occurs from October through April. The average annual temperature is 43 to 46 degrees F (6 to 8 degrees C). The mean frost free period ranges from 86 to

110 days, with the mean freeze-free period ranging from 117 to 135 days.

Table 3. Representative climatic features

Frost-free period (characteristic range)	83-110 days
Freeze-free period (characteristic range)	117-135 days
Precipitation total (characteristic range)	635-711 mm
Frost-free period (actual range)	75-112 days
Freeze-free period (actual range)	114-141 days
Precipitation total (actual range)	610-711 mm
Frost-free period (average)	97 days
Freeze-free period (average)	128 days
Precipitation total (average)	660 mm

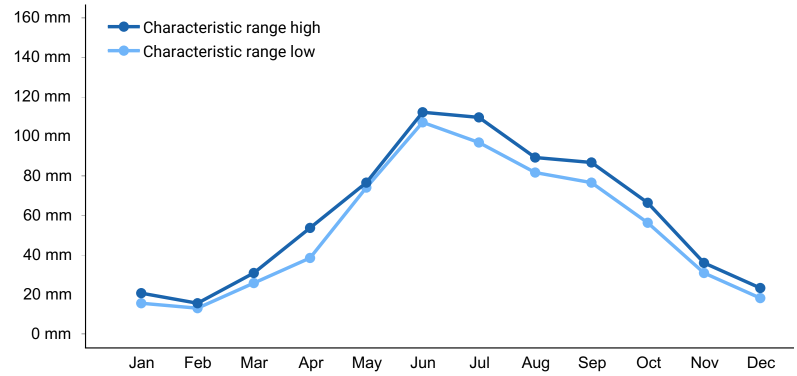


Figure 1. Monthly precipitation range

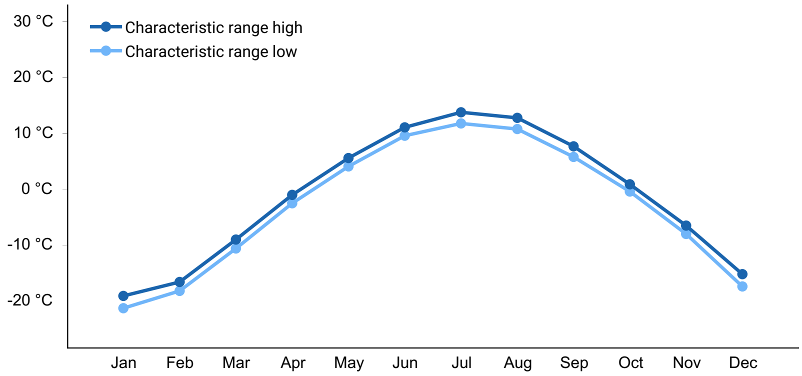


Figure 2. Monthly minimum temperature range

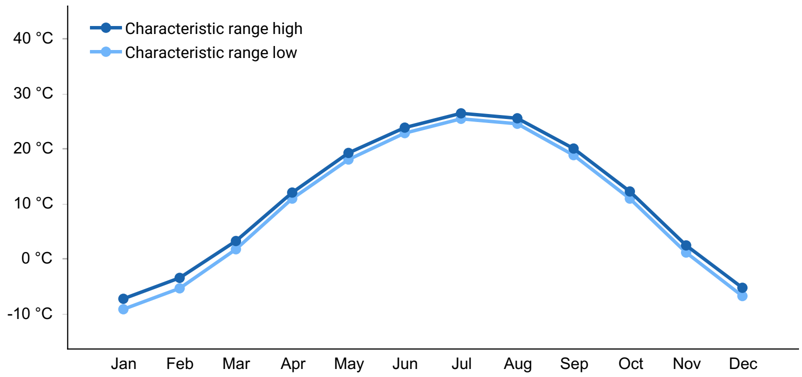


Figure 3. Monthly maximum temperature range

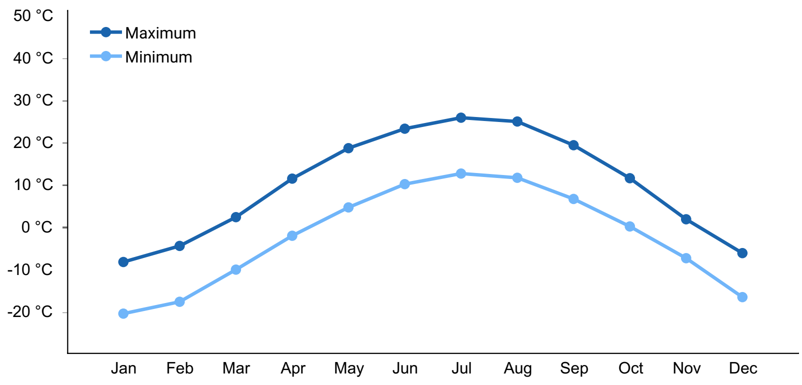


Figure 4. Monthly average minimum and maximum temperature

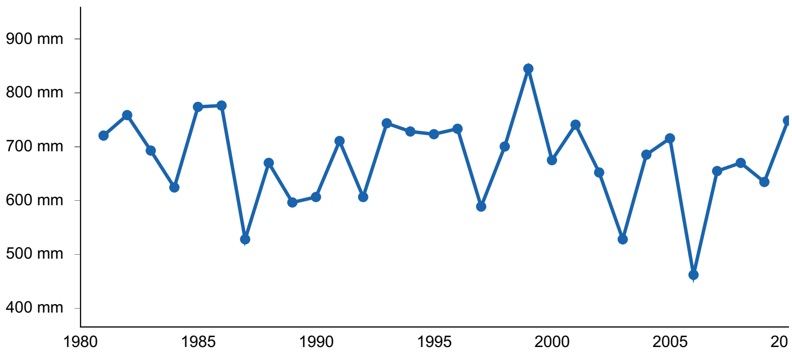


Figure 5. Annual precipitation pattern

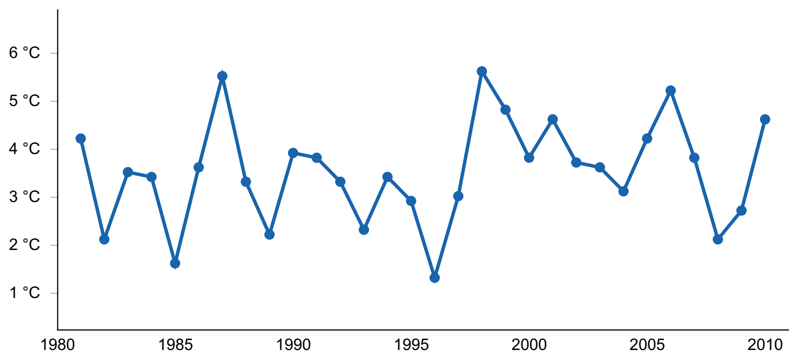


Figure 6. Annual average temperature pattern

Climate stations used

- (1) INTL FALLS INTL AP [USW00014918], International Falls, MN
- (2) LITTLEFORK 10 SW [USC00214809], Big Falls, MN
- (3) BIG FALLS [USC00210746], Big Falls, MN
- (4) WASKISH 4NE [USC00218700], Big Falls, MN
- (5) BAUDETTE INTL AP [USW00094961], Baudette, MN
- (6) CAMP NORRIS DNR [USC00211250], Beltrami Isl State for, MN
- (7) WARROAD [USC00218679], Warroad, MN
- (8) EVELETH WWTP [USC00212645], Eveleth, MN
- (9) FLOODWOOD 3 NE [USC00212842], Floodwood, MN
- (10) HIBBING CHISHOLM HIBBING AP [USW00094931], Hibbing, MN
- (11) SANDY LAKE DAM LIBBY [USC00217460], McGregor, MN
- (12) POKEGAMA DAM [USC00216612], Cohasset, MN
- (13) GRAND RPDS FOREST LAB [USC00213303], Grand Rapids, MN
- (14) LEECH LAKE [USC00214652], Bena, MN

Influencing water features

This ecological site is not influenced by wetland or riparian water features.

Soil features

These soils were formed in coarse loamy glacial drift and till, deposited during the first and most extensive advance of the Superior Lobe of the Wisconsin Glaciation. Depth to bedrock is generally 20 inches or less. Drainage class is well drained. Soil family is characterized as coarse-loamy, having less than 18 percent clay within the majority of the rooting zone. Soil textures include loam and gravelly loam. Coarse fragments are mostly between five and 30 percent, becoming more abundant with depth. Depending on depth to bedrock, available water capacity is 1.5 to 1.7 inches of available water. Soil pH ranges from very strongly acid to moderately acid (4.5 to 6.0).

Soils in the Bedrock Controlled Upland Forest Ecological Site are all within the Inceptisol order. These soils can further be classified as Humic Eutrudepts, Humic Lithic Eutrudepts, and Lithic Dystrudepts. Soil series within this site include Quetico, Insula, and Mesaba.

Table 4. Representative soil features

Parent material	(1) Glaciolacustrine deposits (2) Till
Surface texture	(1) Loam (2) Gravelly loam
Drainage class	Well drained to somewhat excessively drained
Permeability class	Moderately rapid to rapid
Depth to restrictive layer	10–51 cm
Soil depth	10–51 cm
Surface fragment cover <=3"	0%
Surface fragment cover >3"	0%
Available water capacity (0-101.6cm)	3.81–4.32 cm
Soil reaction (1:1 water) (0-25.4cm)	4.5–6.5
Subsurface fragment volume <=3" (0-50.8cm)	2–26%
Subsurface fragment volume >3" (0-50.8cm)	1–6%

Ecological dynamics

On a multi-regional scale, northern hardwoods forest types are transitional between the oak-hickory types to the south and the boreal forest types to the north (Johnson et al., 2009; Tubbs, 1997). The distribution of this ecological site abuts the southern edge of the boreal forest biome. The climate-moderating effect of Lake Superior allows this forest type to persist (Albert, 1994; Anderson and Fischer, 2015). In addition to Lake Superior's overall temperature moderation, the insulating effect of the elevated snowfall on the rooting zone and the near absence of late spring frosts due to high elevation, free air drainage, provide the opportunity for this forest type to exist in an otherwise inhospitable climate (Albert, 1994; Anderson and Fischer, 2015; Houston, 1999). Even so, this forest type is on the limit of its botanic range and faces a myriad of disturbance factors such as frost cracking, ice damage, and fungal pathogens, as well as herbivory from insects and mammals; and as a result produces comparatively poor quality timber.

Bedrock Controlled Upland Hardwood Forests were historically uneven-aged forests with canopies dominated by a mix of hardwood and coniferous species, ranging in their ability to tolerate shade. Highly variable available water capacity, due to variable depths to bedrock, allow a diversity of tree species to proliferate on this site. This prevents domination of sugar maple in the canopy, which is common in the related Till Upland Hardwood Forests ecological site. Hardwood species included: northern red oak, sugar maple, American basswood, and sometimes yellow birch

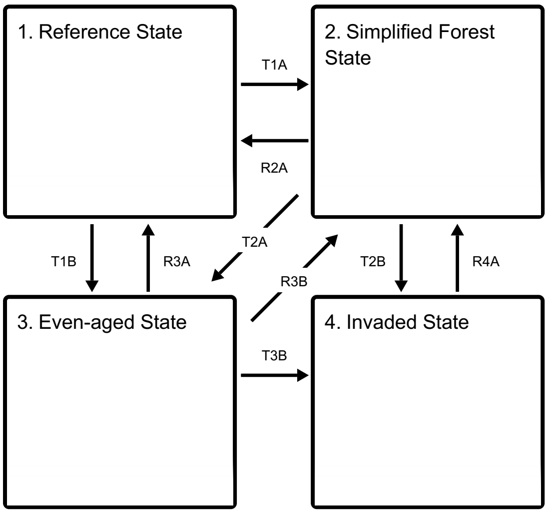
(Betula alleghanienis). Shade-tolerant conifers like white spruce and balsam fir were common in older forests. Although rarely encountered today, eastern white pine would theoretically be well suited to compete on these sites. Along with white spruce, they typically occurred as super canopy trees, and regenerated in a variety of settings (MN DNR, 2014). Small to moderate sized canopy openings, produced by light surface fire and wind, allowed paper birch, bigtooth aspen (*Populus grandidentata*) and quaking aspen (*Populus tremuloides*) to be common. These periodic disturbances kept most forests from reaching an old growth stage (i.e., >120 years).

Broad-scale, stand-regenerating disturbances were uncommon, and likely occurred only once in 1,000+ years (MN DNR, 2014; MN DNR, 2005). Nutrient cycling in the forest floor is high, producing enrichment of the soil and resulting in comparatively little accumulation of leaf litter in organic surface horizons (Nyland, 1999). Altogether, these attributes provided little opportunity for large fires to spread. The main regenerating disturbances were light surface fires and light to moderate windthrow (i.e., one to many trees), particularly in areas with shallower soils. This disturbance pattern occurred in an estimated 130 year rotation (MN DNR, 2014; MN DNR, 2005); which is at a higher rate on this ecological site than on other northern hardwoods sites (e.g., Till Upland Hardwood Forests). Resulting stands allowed all of the aforementioned tree species to perpetuate themselves, and formed were a complex of young and mature forests.

Due to the dominance of undesirable hardwood tree species, these forests were not clearcut like other forests in the Great Lakes states during settlement times. Instead, they were selectively logged (i.e., high-graded) in multiple pulses during the early part of the Twentieth Century, leaving behind stands of inferior quality and composition (Johnson et al., 2009). Very few old-growth stands exist today. As a result of these selective logging practices, some formerly common overstory species were essentially extirpated, such as eastern white pine. Past logging practices and subsequent slash fires are largely responsible for the forest we see today. Most areas are second- or third-growth, and vary in composition depending on extent and timing of past disturbance and management. Many areas have been significantly affected by exotic earthworms and historically high white-tailed deer (Odocoileus virginianus) densities. Earthworms, which were introduced post-settlement, significantly alter soil surface horizons and disrupt nutrient cycling dynamics, and thus directly affect habitat conditions for native flora (Great Lakes Worm Watch, 2013). Increased herbivory resulting from high deer densities has caused decline in many genera and an overall loss of species diversity. Deer and earthworm damage is most prevalent near developed areas.

State and transition model

Ecosystem states



T1A - Logging

T1B - Clearcut

R2A - Clearcut

T2A - Clearcut

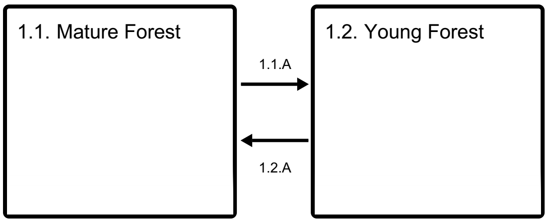
T2B - Invasive species; deer

R3A - Succession; restoration

T3B - Earthworms; deer

R4A - Deer management

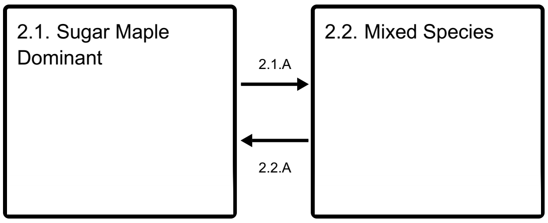
State 1 submodel, plant communities



1.1.A - Disturbances; partial canopy removal

1.2.A - Succession; no distrubance

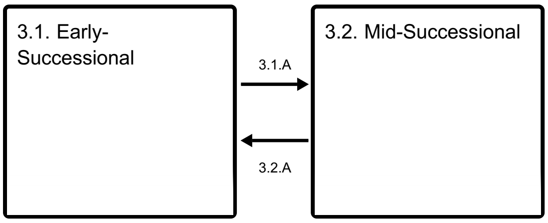
State 2 submodel, plant communities



2.1.A - Canopy openings

2.2.A - Selective logging

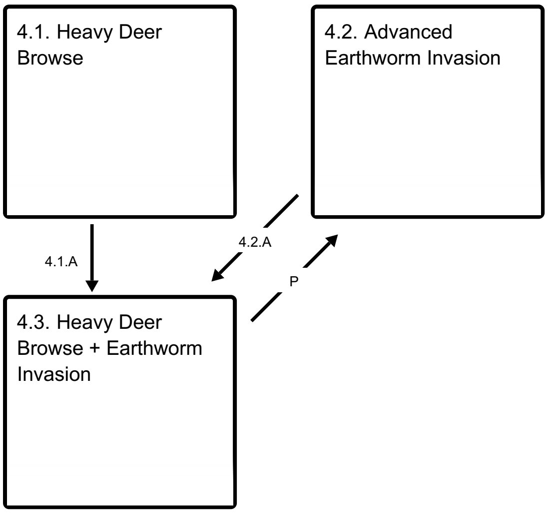
State 3 submodel, plant communities



3.1.A - Succession

3.2.A - Tree removal

State 4 submodel, plant communities



4.1.A - Advanced earthworm invasion

4.2.A - Heavy deer browse

P - Reduction in deer browsing

State 1
Reference State

Community phases within the Reference State follow classic successional trajectories. However, stands rarely became old growth because of periodic low severity disturbances, such as light surface fires and small to moderate windthrow events. An estimated rotation of such events is 130 years (MN DNR, 2014; MN DNR, 2005). This produced a patchwork of young and mature forests of mixed hardwood composition. Sugar maple and northern red oak are the most influential species and can even be co-dominant with paper birch and aspen in the young forest community phase due to their ability to accumulate as advance regeneration. However, if blowdown events are followed by a combination of drought and fire, quaking aspen and paper birch will be favored (Frelich, 1999; Landfire, 2007). As stands age, old paper birch and aspen are still present, but mostly give way to more shade tolerant species, such as younger generations of sugar maple. Historically, older forests had higher cover of coniferous species, including eastern white pine, white spruce, and balsam fir. Forests rarely grew older than 130 years before small to moderate scale regeneration disturbance occurred (MN DNR, 2014), but scattered super canopy trees of eastern white pine and white spruce may have persisted through these events and lived to old age. Small to medium scale windthrow events would have provided habitat for forest interior wildlife, microsites for tree regeneration, and opportunity for some disturbance-adapted species to maintain themselves (such as beaked hazelnut; Kabrick et al., 1997 Landfire, 2007). Coupled with this is the accumulation of coarse woody debris in the way of snags and downed wood in various sizes and levels of decomposition (Hale et al., 1999). Today, good examples of the Reference State are uncommon. However, some do exist in a few state parks or natural areas, mostly limited to northern populations within large intact landscapes having high biological significance. Post-settlement logging and contemporary forest management in part mimic early- and mid-successional dynamics, and are more common today.

Dominant plant species

- northern red oak (*Quercus rubra*), tree
- sugar maple (*Acer saccharum*), tree
- hophornbeam (*Ostrya virginiana*), shrub
- beaked hazelnut (*Corylus cornuta*), shrub
- Pennsylvania sedge (*Carex pensylvanica*), grass
- cream pea (*Lathyrus ochroleucus*), other herbaceous

Community 1.1
Mature Forest

By stand age 95, quaking aspen, paper birch and early-successional shrubs and ground flora have largely subsided. Forest interior, shade-tolerant ground flora take over, particularly spring-flowering species. The dominance of sugar maple and yellow birch may begin to subside while the extremely shade-tolerant white spruce and northern white cedar become more prominent in the overstory (MN DNR, 2013b). At this stage the forest is essentially self-sustaining, with small to medium scale wind throw events providing opportunities for gap and patch regeneration (Kabrick et al., 1997). The resulting pit and mound micro-topography adds to habitat and structural complexity, providing unique niches for certain plant and wildlife species. Beyond age 95, the stand continues to develop structural complexity through structural layering as well as build-up of coarse woody debris (Hale et al., 1999). Old stumps, downed logs, and the mounds created from fallen trees provide regeneration sites for species like northern white cedar, yellow birch, and even the sun-loving paper birch (Erdman 1990; Johnston 1990; and Safford 1990). These structural dynamics result in habitat diversity essential to support many species of birds, amphibians, and other forest interior species. Historically, this was a common community phase on the landscape.

Community 1.2
Young Forest

The initiation of the stand development follows windthrow events. Increased light and heat on the forest floor favor ruderal trees and shrubs such as quaking aspen, paper birch, beaked hazelnut, and Rubus species. However, dominance can be shared with sugar maple and northern red oak advance regeneration already in place. An estimated 40 percent of these sites burned in the years following the blowdown due to extreme fuel buildup and dry conditions (Landfire, 2007). In these cases, the fire-intolerant suite of overstory dominants (such as sugar maple) would have been further set back, favoring complete dominance of quaking aspen and paper birch.

Pathway 1.1.A
Community 1.1 to 1.2

Stand-levelling disturbance or small areas of partial canopy removal from wind and/or fire.

Pathway 1.2.A
Community 1.2 to 1.1

Succession (>95 years without disturbance).

State 2
Simplified Forest State

The simplified forest state was a common state that followed the pre-settlement forests, and may be the most common state existing today. In general, forests on this ecological site were not completely cleared like other forests in the Great Lakes states (as in many coniferous forest types). This was largely due to the abundance of less desirable hardwoods, and partially because maple (and other hardwoods) could not be easily transported along waterways (Johnson et al., 2009). Instead, destruction of reference communities came in the way of selective logging of sought after species of adequate size (i.e., high-grading). This occurred in numerous pulses, with large eastern white pine and white spruce removed initially, which likely accounts for the limited occurrence and/or decline of these species today. In many cases, overstory vegetation turned into monotypic sugar maple stands; however, in other cases some level of diversity in the overstory was secured, although probably less than before. These two situations represent each of the community phases within this state. Like the reference state, these forests tend to be uneven-aged and, with natural succession or careful silviculture (e.g., retention of snags, removal of poor quality trees, etc.), it may be possible to restore some sites to reference conditions (Hale et al., 1999). Communities in this state are a common occurrence on the modern landscape, particularly in private landholdings, which tend to be unmanaged. Today, depending upon the specific location, there may be early stages of earthworm invasion (e.g., Dendrobaena octaedra) as well as some elevated deer browse, but not enough to push it into the Invaded State.

Dominant plant species

- sugar maple (*Acer saccharum*), tree

Community 2.1
Sugar Maple Dominant

In this phase, sugar maple accumulates to an extreme extent, dominating all structural layers in the overstory, subcanopy, and understory. Presumably all or nearly all other overstory species have been selectively cut, leaving sugar maple to dominate. This is essentially a high-graded condition. By removal of the sub-dominants (e.g., northern red oak and scattered conifers), there is a high potential for near-extirpation of these species from the site, partly because a legacy seed source is no longer present and partly because of the overwhelming competitive nature of sugar maple. Small sugar maple seedlings may also carpet the forest floor, outcompeting forb species and further simplifying the diversity of the ecosystem. Due to the lack of high quality browse and mast, these monotypic stands produce limited habitat for most wildlife species (MN Division of Forestry, 2008), but are often an important local source for maple syrup and probably are under-utilized in this regard.

Community 2.2
Mixed Species

This community phase is very similar to 2.1 but has higher species diversity in the overstory and understory. It is not well-understood why some sites retain more diversity than others. It is likely these communities may have benefited from legacy trees not removed during post-settlement logging activities. In some cases paper birch, beaked hazelnut, and other sun-loving species are more common, possibly resulting from light to moderate disturbances. This could also be related to inherent site factors affecting drainage and available water capacity. While still within the aforementioned range of correlated soils, these communities are sometimes found on soils containing higher amounts of sand and rock fragments than is typical. This could be enough to allow a greater diversity of vegetation to compete with the sugar maple. It is presumed that the higher diversity in composition and structure characterized by this community produces better wildlife habitat; however, more investigation is needed to understand these dynamics. Similar management recommendations as described in 2.1 should be considered here. Given time and appropriate silvicultural prescription to improve diversity and structural development, this community phase could be restored to a reference condition.

Pathway 2.1.A
Community 2.1 to 2.2

Light disturbance providing canopy openings, possibly coupled with underplanting of appropriate tree species, such as northern red oak, American basswood, yellow birch, white spruce, and eastern white pine. The size of the gap will affect light levels, and thus affect the tree seedlings ability to compete.

Pathway 2.2.A
Community 2.2 to 2.1

Selective/intensive logging (high-grading), leaving sugar maple to dominate. This community may succeed to 2.1 without management in locations where sugar maple is particularly competitive.

State 3
Even-aged State

Clearcutting in state 1, or more typically in state 2, will convert the community to an even-aged stand, which is an uncharacteristic age structure for this ecological site. However, community phases within this state can be similar to community phase 1.2 from the reference state, particularly in terms of stand structure. Communities in this state are most common in managed forest settings where forest managers often have goals of improving the sugar maple quality as well as providing better wildlife habitat for various game species, such as white-tailed deer and ruffed grouse (Bonasa umbellus; Tubbs, 1977). As the stand matures, opportunities develop for management and restoration to states 1 or 2. There may be early stages of earthworm invasion (e.g., Dendrobaena octaedra) as well as some elevated deer browse in this state, but not enough to significantly alter vegetation or dynamic soil properties.

Dominant plant species

- paper birch (*Betula papyrifera*), tree
- quaking aspen (*Populus tremuloides*), tree

Community 3.1
Early-Successional

Clearcut management produces the potential for more tree diversity in the future canopy. Due to heavy seedling accumulation and advance regeneration, sugar maple may continue to be a dominant woody species, even in the early years following overstory removal. Due to its ability to stump sprout, northern red oak can be a co-dominant, depending on stand history. Sun-loving species such as quaking aspen and paper birch will be co-dominant, along with other early-successional species. Without fuel management, these areas will be prone to wildfire, particularly if a period of drought follows the clearcut.

Community 3.2
Mid-Successional

Shade-tolerant species (particularly sugar maple) will begin to accumulate in the understory. Quaking aspen and paper birch begin to die out, while sugar maple, northern red oak, and possibly yellow birch begin to dominate the young forest. Similar transitions are occurring in the herbaceous layer, with shade-tolerant mesophytes becoming more prevalent. After about age 75, a more complex canopy structure develops and dominant and co-dominant trees become more susceptible to windthrow, providing the first opportunities for gap regeneration. During this phase, shade-tolerant coniferous species, such as white spruce, also begin to accumulate in the understory and midstory.

Pathway 3.1.A
Community 3.1 to 3.2

Succession (>40 years without disturbance).

Pathway 3.2.A
Community 3.2 to 3.1

Clearcut, mechanical removal of all or nearly all trees.

State 4
Invaded State

The Invaded State is the furthest removed from the Reference State and can transition here from either state 2 or state 3 following long-term heavy deer browse or advanced stage earthworm invasion from Aporrectodea spp. and/or Lumbricus spp. This state is more common throughout the southwestern part of this ecological site's distribution, where habitat fragmentation and human development are prevalent. Stands in this state can be either even-aged following clearcutting, or uneven-aged following selective logging. Herbivory by deer affects both woody and herbaceous vegetation by direct consumption of plant material. In areas of high deer densities sugar maple may become even more favored due to preferential browsing of other woody species, such as yellow birch (Rooney and Waller, 2003). Deer herbivory by itself has the potential to cause extirpation of the most preferred, palatable forb species, such as those in the lily family (Augustine and Frelich, 1998). In extreme cases, vegetation can become so sparse it is possible that changes in soil moisture, soil temperature, and dynamic soil properties may occur; for example, a reduction in soil organic carbon, which may result in a decline in soil moisture or an increase in soil temperature. Overall, elevated herbivory can result in distorted vegetation composition and structure in the forest understory (Alverson et al., 1988; Augustine and Frelich, 1998) and indirectly alter the trajectory of the entire forest ecosystem, thus creating novel, deer-induced natural communities affecting vegetation as well as wildlife patterns (Rooney and Waller, 2003; White, 2012). This ecological site (and mesic hardwood forests in general) is particularly susceptible to earthworm degradation (Frelich et al., 2006). The type of leaf litter (e.g., sugar maple, American basswood, etc.) these forests produce has high nutritional value for earthworms compared to drier and less nutrient-rich pine and spruce-fir forests (Frelich et al., 2006; Godman et al., 1990). In previous states, the organic surface horizons may or may not have been affected by the epigeic (i.e., above the soil surface) Dendrobaena octaedra species of earthworm. This species does not by itself cause transition to the invaded state because it only affects the organic surface horizons, which happens by mixing the Oa (i.e., well decomposed) and Oe (i.e., partly decomposed) horizons, but leaving the Oi (i.e., recent litter) intact (Frelich et al., 2006). The advanced stages of earthworm invasion include the presence of D. octaedra as well as the deeper burrowing endogeic (i.e., beneath the soil surface) species in the Aporrectodea and Lumbricus genera, which cause the most significant dynamic soil property changes (Hale et al., 2006; Loss et al., 2013). Aporrectodea and Lumbricus species completely consume the organic surface horizons and incorporate that material into the upper mineral soil horizons (Frelich et al., 2006), producing an uncharacteristic bloated A horizon, along with mixing of any existing E horizons. In earthworm-free forest soils, there tends to be a net increase in organic material on the soil surface (Great Lakes Worm Watch, 2013). By comparison, in the advanced stages of earthworm invasion, all of this organic material can be completely removed within 3-5 years, making the only input of organic material from new leaf litter each fall, which is quickly consumed, leaving bare soil at the surface by the next fall (Great Lakes Worm Watch, 2013). This process completely alters the nitrogen cycle (in which nitrogen is depleted by leaching) and produces a dense, pan-like layer similar to plowed agricultural soils (Frelich et al., 2006). Changes in dynamic soil properties, such as loss of the organic surface, along with higher bulk densities in the subsoil, produce drier growing conditions for plants, affecting the ability for characteristic native species to persist. The loss of the organic surface also can expose tree roots, potentially causing long-term effects on the life and/or health of trees. However, immature trees (i.e., saplings and seedlings) are likely to be the most at risk to root exposure. Sugar maple seedlings in particular decrease dramatically as a result of earthworm invasion (Hale et al., 2006). Forb seeds also are affected, as the duff layer provides insulation from hot and cold weather extremes and protection from predation by small mammals and birds (Great Lakes Worm Watch, 2013). Another negative consequence of advanced earthworm invasion is the alteration of important soil bacterial and fungal networks, especially symbiotic mycorrhizae, which facilitate essential water and nutrient uptake to many native plant species (Great Lakes Worm Watch, 2013). Advanced earthworm invasion results in a physically and chemically altered plant rooting environment. Some species are able to handle these changes, while others are not. Pennsylvania sedge (*Carex pensylvanica*), one of the few non-mycorrhizal species, along with wild leeks (*Allium tricoccum*) and jack in the pulpit (*Arisaema triphyllum*), which produce toxic secondary chemicals hazardous to herbivores (and may also be avoided by earthworms), have been shown to increase in these situations (Frelich et al., 2006; Holdsworth et al., 2007). In contrast, other species like bigleaf aster, twisted stalk, and wild sarsaparilla tend to decrease (Holdsworth et al., 2007; Great Lakes Worm Watch, 2013). Although earthworms do not kill canopy trees, it is expected that long-term recruitment will be affected, particularly in the sapling stage. This may cause elevated sunlight to the forest floor, increasing the likelihood for dry-mesic, mid-tolerant species to establish (Frelich et al., 2006). Overall, the combined effects of invasion by deer and earthworms can initiate an ecosystem decline syndrome that can negatively affect all parts of the ecosystem, from overstory structure, to forb diversity, soil properties, bacteria, fungi, insects, birds, reptiles, amphibians, and mammals. Sites near larger cities, heavily-used lakes, or other developed areas are particularly susceptible to the combination of deer and earthworm problems. Currently, we do not believe any community phases with advanced earthworm invasion can be restored. More research on this topic is needed.

Dominant plant species

- sugar maple (*Acer saccharum*), tree
- Pennsylvania sedge (*Carex pensylvanica*), grass

Community 4.1
Heavy Deer Browse

This community phase can be variable depending on the type, amount, and timing of deer browse. If browse occurs in both summer and winter, all vegetation types are affected. If browse is more common in the winter months, woody vegetation will be affected. In these cases no species are spared, however, balsam fir and white spruce are less preferred (Anderson et al., 2002; White, 2012). If browse occurs in the summer, mostly forb species are affected, often increasing the importance of grasses, sedges (Carex spp.), and less palatable forb species, such as jack in the pulpit and wild leeks (Frelich et al., 2006; Rooney and Waller, 2003). Significant deer browse is most common near developed areas, especially around the City of Duluth. Deer browse is not common in more natural, undeveloped landscapes common in the northeastern extent of this ecological site. In the summer months, deer use these areas as corridors and sporadically browse individual plants. During the winter months, these sites often experience heavy lake effect snow that can accumulate to several feet in depth. As a result, deer tend to migrate closer to the shore of Lake Superior where temperatures are warmer and there is less snowfall (Chel Anderson, MN DNR Ecologist, personal observation). In addition, the open nature of a hardwood-dominated canopy does not shelter snow well, as one would expect beneath a coniferous forest.

Community 4.2
Advanced Earthworm Invasion

Advanced Earthworm Invasion

Community 4.3
Heavy Deer Browse + Earthworm Invasion

Following the initial pulse of plant mortality by advanced stage earthworm invasion or deer herbivory, the combined effect of both of these unnatural disturbances puts plants at even greater risk of extirpation and produces a more degraded community. Species already affected in 4.1 and 4.2 are now dangerously susceptible to elimination from the site, due in large part to a higher deer-to-plant ratio.

Pathway 4.1.A
Community 4.1 to 4.3

Advanced stage earthworm invasion by species in the Aporrectodea and/or Lumbricus genera.

Pathway 4.2.A
Community 4.2 to 4.3

Heavy deer browse.

Pathway P
Community 4.3 to 4.2

Deer management.

Transition T1A
State 1 to 2

Selective/intensive logging (high-grading) of healthy, large-diameter conifers and subsequently, large-diameter hardwoods.

Transition T1B
State 1 to 3

Clearcut: mechanical removal of all or nearly all trees.

Restoration pathway R2A
State 2 to 1

Long term succession (>95 years without disturbance), including a diversity of canopy species (e.g., northern red oak, yellow birch, American basswood, white spruce, eastern white pine, etc.) from natural or artificial regeneration, along with recovery of relevant herbaceous species indicative of the reference state.

Transition T2A
State 2 to 3

Clearcut, mechanical removal of all or nearly all trees.

Transition T2B
State 2 to 4

Introduction of exotic earthworms (particularly Aporrectodea spp. and Lumbricus spp.) or heavy deer browse.

Restoration pathway R3A
State 3 to 1

Restoration through long term succession with silvicultural practices as necessary.

Restoration pathway R3B
State 3 to 2

Succession (>95 years without disturbance), monotypic maple stands.

Transition T3B
State 3 to 4

Introduction of exotic earthworms (particularly Aporrectodea spp. and Lumbricus spp.) or heavy deer browse.

Restoration pathway R4A
State 4 to 2

Currently there is only one community phase 4.1 believed to be a potentially restorable community, following the management of deer herbivory. At this time there is no evidence showing it is possible to remove earthworms from a forest soil.

Additional community tables

Inventory data references

This is a provisional ecological site, and as such no field plots were inventoried for this project. A review of the scientific literature and expert opinion was used to develop the plant communities and ecological dynamics contained within the state and transition model. Future field verification is needed to refine the plant communities and ecological dynamics described in this ecological site description.

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Rangeland health reference sheet

Interpreting Indicators of Rangeland Health is a qualitative assessment protocol used to determine ecosystem condition based on benchmark characteristics described in the Reference Sheet. A suite of 17 (or more) indicators are typically considered in an assessment. The ecological site(s) representative of an assessment location must be known prior to applying the protocol and must be verified based on soils and climate. Current plant community cannot be used to identify the ecological site.

Author(s)/participant(s)	
Contact for lead author	
Date	05/13/2025
Approved by	Suzanne Mayne-Kinney
Approval date	
Composition (Indicators 10 and 12) based on	Annual Production

Indicators

1. **Number and extent of rills:**

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2. **Presence of water flow patterns:**

3. **Number and height of erosional pedestals or terracettes:**

4. **Bare ground from Ecological Site Description or other studies (rock, litter, lichen, moss, plant canopy are not bare ground):**

5. **Number of gullies and erosion associated with gullies:**

6. **Extent of wind scoured, blowouts and/or depositional areas:**

7. **Amount of litter movement (describe size and distance expected to travel):**

8. **Soil surface (top few mm) resistance to erosion (stability values are averages - most sites will show a range of values):**

9. **Soil surface structure and SOM content (include type of structure and A-horizon color and thickness):**

10. **Effect of community phase composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff:**

11. **Presence and thickness of compaction layer (usually none; describe soil profile features which may be mistaken for compaction on this site):**

12. **Functional/Structural Groups (list in order of descending dominance by above-ground annual-production or live foliar cover using symbols: >>, >, = to indicate much greater than, greater than, and equal to):**

    Dominant:

    Sub-dominant:

    Other:

    Additional:

13. **Amount of plant mortality and decadence (include which functional groups are expected to show mortality or decadence):**

14. **Average percent litter cover (%) and depth (in):**

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15. **Expected annual annual-production (this is TOTAL above-ground annual-production, not just forage annual-production):**

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16. **Potential invasive (including noxious) species (native and non-native). List species which BOTH characterize degraded states and have the potential to become a dominant or co-dominant species on the ecological site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only one to several years (e.g., short-term response to drought or wildfire) are not invasive plants. Note that unlike other indicators, we are describing what is NOT expected in the reference state for the ecological site:**

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17. **Perennial plant reproductive capability:**
