Ecological site F093AY009MN
Bedrock Controlled Upland Forest

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General information

Approved. An approved ecological site description has undergone quality control and quality assurance review. It contains a working state and transition model, enough information to identify the ecological site, and full documentation for all ecosystem states contained in the state and transition model.

Figure 1. Mapped extent

Areas shown in blue indicate the maximum mapped extent of this ecological site. Other ecological sites likely occur within the highlighted areas. It is also possible for this ecological site to occur outside of highlighted areas if detailed soil survey has not been completed or recently updated.

MLRA notes

Major Land Resource Area (MLRA): 093A–Superior and Rainy Stony and Rocky Till Plains and Moraines

The Superior Stony and Rocky Loamy Plains and Hills, Western Part is located and completely contained in northeastern Minnesota (Figure 1). This area has both the highest and lowest elevations in the state, as well as some of the state's most rugged topography (Ojakangas and Matsch, 1982). The MLRA was glaciated by numerous advances of the Superior, Rainy, and Des Moines glacial lobes during the Wisconsin glaciation as well as pre-Wisconsin glacial periods. The geomorphic surfaces in this MLRA are geologically very young (i.e., 10,000 to 20,000 years) and dominated by drumlin fields, moraines, small lake plains, outwash plains, and bedrock-controlled uplands (USDA-NRCS, 2006). There are thousands of lakes scattered throughout the region that were created by these glacial events. Most of these lakes are bedrock-controlled in comparison to adjacent glaciated regions where glacial drift deposits are much thicker and the lakes occur in depressions atop the glacial drift (Ojakangas and Matsch, 1982). In contrast to adjacent MLRAs, the depth to the predominantly crystalline or sandstone bedrock in MLRA 93A is relatively thin because the most recent glacial events were more erosional than depositional (Ojakangas and Matsch, 1982).

Classification relationships

Major Land Resource Area (MLRA): Superior Stony and Rocky Loamy Plains and Hills, Western Part (93A)

USFS Subregions: Northern Superior Uplands Section (212L); North Shore Highlands Subsection (212Lb)

Ecological site concept

Bedrock Controlled Upland Hardwood Forest ecological sites are limited to high elevation landforms adjacent to Lake Superior, and have the benefit of a lake-moderated climate. They are associated with areas of bedrock protrusion within the extent of the Automba phase of the Superior glaciation, the first of several main advances of the Superior Lobe along the north shore of Lake Superior (Wright and Watts, 1969). Soils are moderately deep (20-40 inches to bedrock), coarse-loamy (<18 percent clay), well drained, and have low available water capacity. Parent material above the bedrock is best classified as glacial drift, and is a mix of water-worked and ice contact features associated with the retreating glacier.

Effective free air drainage limits early fall and late spring frosts, thus allowing mesic hardwood species to occur in an otherwise frigid climate (Albert, 1994; Anderson and Fischer, 2015). Limited rooting depth and lower available water capacity produces low to moderate site quality, often resulting in more open conditions. Within a given stand, variation in available water capacity related to differences in rooting depth produce a complex of dry-mesic and mesic hardwood forest. Historically, light surface fires and small extent windthrow were the main disturbances (MN DNR 2014).

Associated sites

F093AY013MN	**Loamy Upland** 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. Till Upland Hardwood Forests (093AY001) 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

F093AY013MN	**Loamy Upland** Till Upland Hardwood Forests (093AY001) is both associated and similar to Bedrock Controlled Upland Hardwood Forests. Till Upland Hardwood Forests are heavily dominated by sugar maple and other species characteristic of richer soils. This ecological site has thicker glacial drift deposit overlying the bedrock (i.e., >60 inches to bedrock, and often greater than 80 inches), and generally has a dense substrata soil horizon within 40 inches. The dense horizon is an aquitard that slows water permeability, and under saturation causes lateral flow downslope. In comparison, the bedrock in Bedrock Controlled Upland Hardwood Forests is an aquiclude. Thus, the main edaphic difference between the two ecological sites is that Till Upland Hardwood Forests have a thicker root zone which fosters a richer and more productive plant community. They are both considered to be dominated by northern hardwood species. Bedrock Controlled Upland Hardwood Forests occur on high elevation, often convex bedrock protrusions. The primary landscapes it occurs in include two Landtype Associations: the Sawtooth Mountain Bedrock Complex, and the Tettegouche Till Plain. The same soils (i.e., Mesaba series) are mapped at lower elevations on the long, linear slopes adjacent to Lake Superior, in the North Shore Till Plain. The primary difference may be climate related, as these sites do not readily shed cold air, which produces more prevalent late spring frosts. These sites also do not receive as much snowfall. More research is needed, and it is likely that an additional ecological site will be correlated to these areas.

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 associated with the Automba phase of the Superior Lobe glacial advance. They occur on high elevation, bedrock-controlled moraines close to Lake Superior, primarily in the Sawtooth Mountains Bedrock Complex and Tettegouche Till Plain Landtype Associations (LTAs). Hillslope positions are mostly shoulder slopes and backslopes, ranging from 15 to 45 percent slope. They can also occur on summits and narrow ridges. 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 1,100 feet and below 1,600 feet. These sites do not flood or pond.

Table 2. Representative physiographic features

Landforms	(1) Moraine (2) Dome (3) Hill
Flooding frequency	None
Ponding frequency	None
Elevation	1,100–1,600 ft
Slope	15–45%
Aspect	Aspect is not a significant factor

Climatic features

The average freeze-free period of this ecological site is about 140 days, and ranges from 131 to 149 days. Effective drainage of cold air to lower elevation landforms (i.e., free air drainage) prevents the likelihood of late spring frosts and is an important component of this ecological site. Average annual precipitation is 32 inches, which includes rainfall plus the water equivalent from snowfall. About 65 percent of the precipitation falls as rain during the growing season (from May through September), and about 21 percent falls as snow. Most of the spring snowmelt runs off the steeply sloping or high relief surfaces into high gradient drainageways and then into wetlands, streams or lakes. Most of the rainfall during the growing season is transpired by plants, which leaves a small proportion of the total precipitation for deep aquifer recharge. The high ridges above Lake Superior which support this ecological site receive the most snowfall in Minnesota, averaging over 70 inches annually (Flaccus and Ohmann, 1964; MN DNR, 2013a). This lake effect snow is the result of warm, moist air rising and moving inland from the lake, ultimately cooling to produce localized snowfall (Anderson and Fischer, 2015; MN DNR, 2013a). The average annual low and high temperatures are 28 and 48 degrees Fahrenheit, respectively. These data are derived from 30-year averages gathered from four National Oceanic and Atmospheric Administration (NOAA) weather stations contained within the range of this ecological site and located on correlated map units.

Table 3. Representative climatic features

Frost-free period (average)	119 days
Freeze-free period (average)	139 days
Precipitation total (average)	34 in

Climate stations used

- (1) LUTSEN 3NNE [USC00214918], Lutsen, MN
- (2) WOLF RIDGE ELC [USC00219134], Finland, MN
- (3) DULUTH [USW00014913], Duluth, 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, deposited during the first and most extensive advance of the Superior Lobe of the Wisconsin Glaciation. Depth to bedrock is moderately deep (20 to 40 inches to bedrock). 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 sandy loam, loam, silt loam or their gravelly analogues. Coarse fragments are mostly between five and 30 percent, becoming more abundant with depth. Depending on depth to bedrock, available water capacity can range from 1.7 to 6.9 inches (in 40 inches), in stark contrast to the related, and more productive Till Upland Mesic Hardwood Forests ecological sites, which can range from 4.0 to 8.5 inches of available water. Soil pH ranges from very strongly acid to moderately acid (4.5 to 6.0). Small-scale windthrow is an important tree regenerating disturbance on this ecological site. Characteristic pit and mound micro-topography (also known as cradle-knolls) can be scattered throughout a stand and provide microenvironments for certain plants and wildlife. For example, the mounds produce microsites for tree recruitment (Kabrick et al., 1997) and the pits can temporarily hold water, thus allowing species characteristic of wetter environments to persist. The relatively constant supply of downed woody debris is an important characteristic of properly functioning natural communities within this ecological site. Downed woody debris helps the soil retain moisture, provides refuge and habitat for wildlife (particularly amphibians), and act as nurse-logs that are essential for some tree species to regenerate (Erdmann, 1990; Great Lakes Worm Watch, 2013; Johnston 1990). The Mesaba series, an Inceptisol, is primarily associated with this site.

Table 4. Representative soil features

Parent material	(1) Drift–sandstone
Surface texture	(1) Gravelly sandy loam (2) Loam (3) Silt loam
Family particle size	(1) Loamy
Drainage class	Well drained
Permeability class	Very slow
Soil depth	20–40 in
Surface fragment cover <=3"	0–1%
Surface fragment cover >3"	0–1%
Available water capacity (0-40in)	1.7–6.9 in
Calcium carbonate equivalent (0-40in)	0%
Soil reaction (1:1 water) (0-40in)	4.5–6
Subsurface fragment volume <=3" (Depth not specified)	5–30%
Subsurface fragment volume >3" (Depth not specified)	0–7%

Ecological dynamics

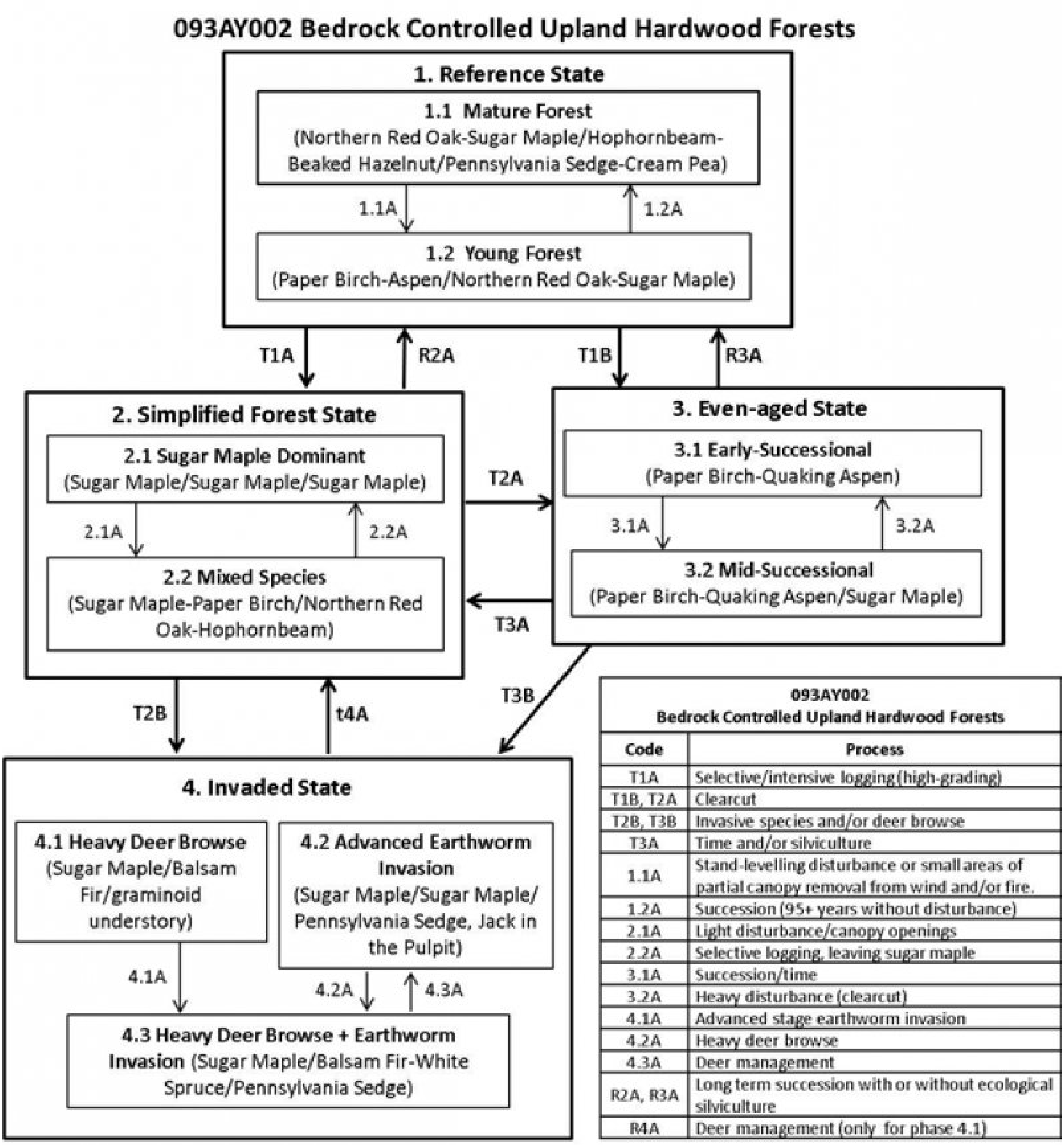
On a multi-regional scale, northern hardwoods forest types are transitional between the oak-hickory types to the south and the boreal forest types to the north (Johnson et al., 2009; Tubbs, 1997). The distribution of this ecological site abuts the southern edge of the boreal forest biome. The climate-moderating 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



093AY002 Bedrock Controlled Upland Hardwood Forests

Code	Process
T1A	Selective/intensive logging (high-grading)
T1B, T2A	Clearcut
T2B, T3B	Invasive species and/or deer browse
T3A	Time and/or silviculture
1.1A	Stand-levelling disturbance or small areas of partial canopy removal from wind and/or fire.
1.2A	Succession (95+ years without disturbance)
2.1A	Light disturbance/canopy openings
2.2A	Selective logging, leaving sugar maple
3.1A	Succession/time
3.2A	Heavy disturbance (clearcut)
4.1A	Advanced stage earthworm invasion
4.2A	Heavy deer browse
4.3A	Deer management
R2A, R3A	Long term succession with or without ecological silviculture
R4A	Deer management (only for phase 4.1)

Figure 6. State-and-transition model.

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.

Community 1.1
Mature Forest

Figure 7. Photo by Kyle Steele, Lake County forest land, Lak

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.

Table 5. Soil surface cover

Tree basal cover	3-10%
Shrub/vine/liana basal cover	5-15%
Grass/grasslike basal cover	15-25%
Forb basal cover	20-35%
Non-vascular plants	0-1%
Biological crusts	0-1%
Litter	18-30%
Surface fragments >0.25" and <=3"	1-3%
Surface fragments >3"	1-3%

Bedrock	0-1%
Water	0%
Bare ground	1-3%

Table 6. Woody ground cover

Downed wood, fine-small (<0.40" diameter; 1-hour fuels)	1-5% N*
Downed wood, fine-medium (0.40-0.99" diameter; 10-hour fuels)	1-5% N*
Downed wood, fine-large (1.00-2.99" diameter; 100-hour fuels)	3-8%
Downed wood, coarse-small (3.00-8.99" diameter; 1,000-hour fuels)	1-5%
Downed wood, coarse-large (>9.00" diameter; 10,000-hour fuels)	0-2%
Tree snags** (hard***)	–
Tree snags** (soft***)	–
Tree snag count** (hard***)	10-30 per acre
Tree snag count** (hard***)	10-20 per acre

*** Decomposition Classes: N - no or little integration with the soil surface; I - partial to nearly full integration with the soil surface.**

**** >10.16cm diameter at 1.3716m above ground and >1.8288m height--if less diameter OR height use applicable down wood type; for pinyon and juniper, use 0.3048m above ground.**

***** Hard - tree is dead with most or all of bark intact; Soft - most of bark has sloughed off.**

Table 7. Canopy structure (% cover)

Height Above Ground (Ft)	Tree	Shrub/Vine	Grass/ Grasslike	Forb
<0.5	1-5%	1-5%	5-25%	5-15%
>0.5 <= 1	1-5%	1-5%	5-15%	15-50%
>1 <= 2	1-5%	5-15%	–	5-15%
>2 <= 4.5	5-25%	25-65%	–	1-5%
>4.5 <= 13	40-75%	5-25%	–	–
>13 <= 40	50-75%	–	–	–
>40 <= 80	25-75%	–	–	–
>80 <= 120	–	–	–	–
>120	–	–	–	–

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 1A
Community 1.1 to 1.2

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

Pathway 2A

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.

Community 2.1
Sugar Maple Dominant

Figure 8. Photo by Kyle Steele at Magney-Snively Natural Are

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

Figure 9. Photo by Kyle Steele at Magney-Snively Natural Are

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 1A
Community 2.1 to 2.2

Sugar Maple Dominant

Mixed Species

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 2A
Community 2.2 to 2.1

Mixed Species

Sugar Maple Dominant

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.

Community 3.1
Early-Successional

Figure 10. Photo by Kyle Steele on Lake County forest land,

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 1A
Community 3.1 to 3.2

Succession (>40 years without disturbance).

Pathway 2A
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 earthwork invasion can be restored. More research on this topic is needed.

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

Figure 11. Photo by Kyle Steele at Magney-Snively Natural Are

Advanced stage earthworm invasion from Aporrectodea spp. and/or Lumbricus spp. This community phase results in removal of organic duff layers incorporated into the mineral surface horizons, affecting rooting and nutrient availability. Pennsylvania sedge and jack in the pulpit increase while others decrease or become extirpated. Downed woody debris decays at an accelerated rate, affecting various wildlife species such as salamanders.

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 1A
Community 4.1 to 4.3

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

Pathway 2A

Community 4.2 to 4.3

Heavy deer browse.

Pathway 3A
Community 4.3 to 4.2

Deer management.

Transition 1A
State 1 to 2

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

Transition 1B
State 1 to 3

Clearcut: mechanical removal of all or nearly all trees.

Restoration pathway 2A
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 2A
State 2 to 3

Clearcut, mechanical removal of all or nearly all trees.

Transition 2B
State 2 to 4

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

Transition 3A
State 3 to 2

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

Transition 3B
State 3 to 4

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

Transition 4A
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.

Transition 4A
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

Table 8. Community 1.1 forest overstory composition

Common Name	Symbol	Scientific Name	Nativity	Height (Ft)	Canopy Cover (%)	Diameter (In)	Basal Area (Square Ft/Acre)
Tree							
northern red oak	QURU	*Quercus rubra*	Native	20–70	10–75	2–15	–
sugar maple	ACSA3	*Acer saccharum*	Native	20–70	10–50	2–10	–
paper birch	BEPA	*Betula papyrifera*	Native	20–70	5–25	2–10	–
bigtooth aspen	POGR4	*Populus grandidentata*	Native	20–70	0–25	2–10	–
quaking aspen	POTR5	*Populus tremuloides*	Native	20–70	0–25	2–10	–
American basswood	TIAM	*Tilia americana*	Native	20–70	5–25	2–10	–
hophornbeam	OSVI	*Ostrya virginiana*	Native	10–25	5–25	2–6	–

Table 9. Community 1.1 forest understory composition

Common Name	Symbol	Scientific Name	Nativity	Height (Ft)	Canopy Cover (%)
Grass/grass-like (Graminoids)					
Pennsylvania sedge	CAPE6	*Carex pensylvanica*	Native	0.1–1	10–50
roughleaf ricegrass	ORAS	*Oryzopsis asperifolia*	Native	0.1–1	5–25
longstalk sedge	CAPE4	*Carex pedunculata*	Native	0.1–1	1–15
Forb/Herb					
wild sarsaparilla	ARNU2	*Aralia nudicaulis*	Native	0.1–2	10–50
bigleaf aster	EUMA27	*Eurybia macrophylla*	Native	0.1–1	10–50
twistedstalk	STLAL3	*Streptopus lanceolatus var. longipes*	Native	0.1–1	5–25
Canada mayflower	MACA4	*Maianthemum canadense*	Native	0.1–1	5–25
wood anemone	ANQU	*Anemone quinquefolia*	Native	0.1–1	5–25
fragrant bedstraw	GATR3	*Galium triflorum*	Native	0.1–1	5–25
bluebead	CLBO3	*Clintonia borealis*	Native	0.1–1	5–25
hairy Solomon's seal	POPU4	*Polygonatum pubescens*	Native	0.1–1	5–25
starflower	TRBO2	*Trientalis borealis*	Native	0.1–1	5–25
cream pea	LAOC2	*Lathyrus ochroleucus*	Native	0.1–1	1–15
Virginia strawberry	FRVI	*Fragaria virginiana*	Native	0.1–1	1–15
downy yellow violet	VIPU3	*Viola pubescens*	Native	0.1–1	1–15
zigzag goldenrod	SOFL2	*Solidago flexicaulis*	Native	0.1–2	1–15
red baneberry	ACRU2	*Actaea rubra*	Native	0.1–1	1–5
white baneberry	ACPA	*Actaea pachypoda*	Native	0.1–1	1–5
whip-poor-will flower	TRCE	*Trillium cernuum*	Native	0.1–1	1–5
dwarf red blackberry	RUPU	*Rubus pubescens*	Native	0.1–1	1–5
spreading dogbane	APAN2	*Apocynum androsaemifolium*	Native	0.1–2	1–5
waxflower shinleaf	PYEL	*Pyrola elliptica*	Native	0.1–1	1–5
largeflower bellwort	UVGR	*Uvularia grandiflora*	Native	0.1–1	1–5
Maryland sanicle	SAMA2	*Sanicula marilandica*	Native	0.1–1	1–5
Fern/fern ally					
common ladyfern	ATFI	*Athyrium filix-femina*	Native	0.1–2	5–25
western brackenfern	PTAQ	*Pteridium aquilinum*	Native	0.1–3	1–15
tree groundpine	LYDE	*Lycopodium dendroideum*	Native	0.1–1	1–5
Pennsylvania clubmoss	LYHI2	*Lycopodium hickeyi*	Native	0.1–1	1–5
Shrub/Subshrub					
beaked hazelnut	COCO6	*Corylus cornuta*	Native	1–10	15–50
roundleaf dogwood	CORU	*Cornus rugosa*	Native	1–10	5–15
American fly honeysuckle	LOCA7	*Lonicera canadensis*	Native	1–5	5–15
serviceberry	AMELA	*Amelanchier*	Native	1–10	5–15
sugar maple	ACSA3	*Acer saccharum*	Native	1–10	5–15
northern bush honeysuckle	DILO	*Diervilla lonicera*	Native	1–5	5–15
hairy honeysuckle	LOHI	*Lonicera hirsuta*	Native	1–5	0–5
eastern leatherwood	DIPA9	*Dirca palustris*	Native	1–5	0–5
white spruce	PIGL	*Picea glauca*	Native	1–10	0–5

Inventory data references

A total of 24 integrated plots, ranging from Tier 2 to Tier 3 intensity, were used as a basis for this ecological site. Three of these were Type Locations representing the data-supported community phase 1.1 in the state-and-transition model (Figure 2), and included all necessary data elements for a Tier 3 dataset (Table 11). No other community phases were supported with quantitative data analysis, and were composed mostly of community phases closely resembling 1.1, 2.1, 2.2 and 4.2. All 24 plots had soil pedon and site data collected by a professional soil scientist using a form equivalent to SF-232. Most pits were hand-dug using spade shovels, sharpshooters, and/or bucket augers. Of the 24 plots, 18 were located at established MN DNR relevé points, obtained and used with permission from the MN DNR County Biological Survey (see list below). List of MN DNR relevé plots used with verified soils data: 890, 914, 5110, 5187, 8274, 8277, 8287, 8288, 8289, 8290, 8300, 8409, 8448, 8482, 8851, 8852, and 8854.

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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	
Approved by	
Approval date	
Composition (Indicators 10 and 12) based on	Annual Production

Indicators

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

---

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):**

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

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:**

17. **Perennial plant reproductive capability:**