Nature and Nurture Forest Management Plan

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Introduction

This forest management plan has been prepared Michael Levine and Erica Kempter, owners of Nature and Nurture, LLC. Their farmstead property hosts a diversified portfolio of agricultural business ventures alongside a mixture of high quality and highly disturbed forest stands. Mike and Erica are concerned with balancing the ecological health of their land with the productivity of their business. In the fall of 2014 Andrew Harmon, a graduate student at the University of Michigan School of Natural Resources and Environment, contacted Mike and Erica about the possibility of pursuing a master's practicum project on their farm. Over the following winter they arranged to produce a plan that integrates the management of their forested land with the expansion of their current shiitake mushroom production. Stand surveys began in August 2015 and continued until November 2016.

The plan that follows begins with a forest management plan that addresses the current condition of the forest stands, proposes a series of management interventions, and describes how these interventions can be used to support the growth of the shiitake mushroom business. Following the plan itself are chapters describing the methods and results of the forest stand inventory, the fungal inventory, a cost-benefit analysis of implementing the recommended management practices, and a forest gap model created to provide additional ecological insight into the management plan. Additional sections include an in-depth review of specific challenges in the management of oak forests, guidelines for selecting crop trees and release trees, strategies for maintaining the forest stands in alignment with organic principles instead of herbicide-reliant methods, best management practices for outdoor mushroom production, and the benefits of recycling spent mushroom substrate as a soil amendment.

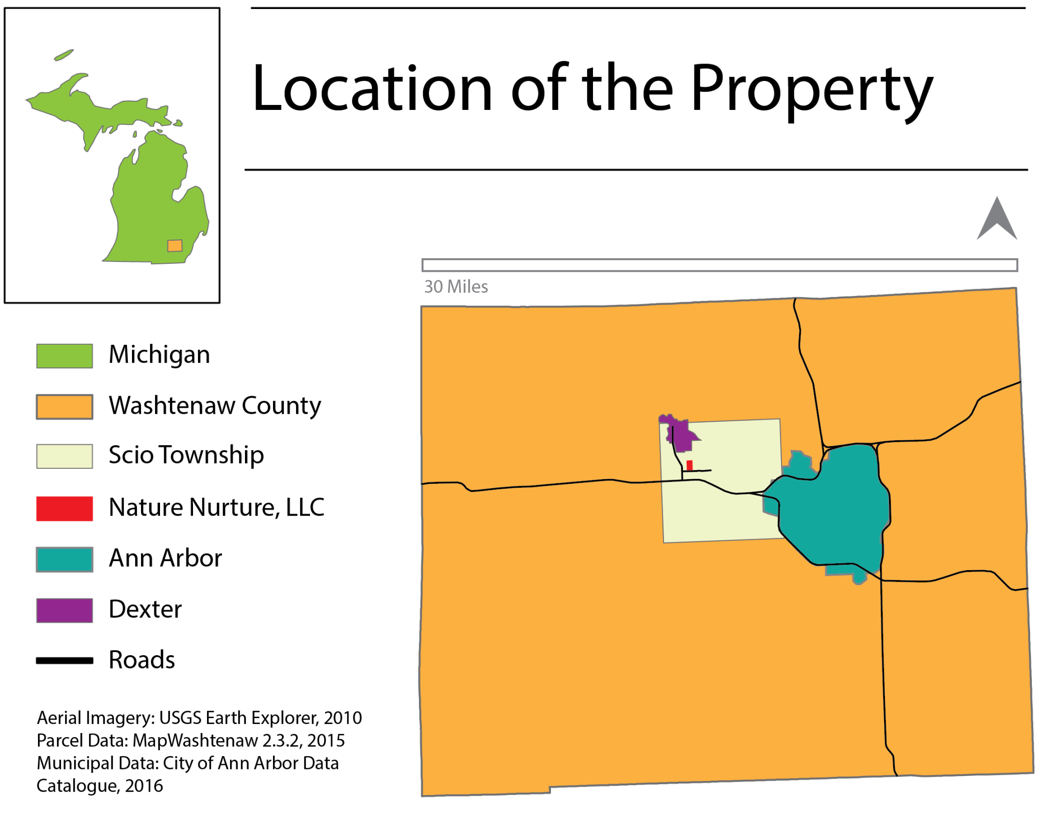
Management Plan

General Property Description

The property at 7100 Marshal Road in Dexter, Michigan is a 77.5-acre parcel of agricultural land in Washtenaw County, Scio Township. It is located 2.5 miles South of downtown Dexter and 8 miles West of downtown Ann Arbor. All but 20 acres are under a permanent Conservation Easement, restricting development of the majority of the property for any purpose other than agricultural use. Out of the total acreage 32.5 are forested and about 2.1 miles of field edges have been planted to hardwood trees.

Several rows of oak saplings were planted along the southeastern border of the property for future harvest as shiitake mushroom logs. Conifers have been planted on the North, East, and South sides of the house, which serves as the year-round primary residence of the owners, Michael Levine and Erica Kempter. Another row of conifers is located to the west of the home and driveway. The farm currently supports a variety of agricultural uses including land rented for forage production, organic farming, locally adapted seed propagation and sales, a native plant nursery, a landscaping business, and mushroom production.

Several natural ponds have formed in the northwest corner of the property. Second growth oak-hickory forest stands grow in the northern portion of the property. A drainage channel has been dug from a buttonbush pond at the northwest corner of the land to the deciduous hardwood swamp at its center. Along this ditch grow a variety of floodplain species. A small retention pond is located near the driveway at the southern edge of the property. The whole property shows signs of heavy deer browse and tree mortality due to emerald ash borer and Dutch elm disease.



Management Units

For the purposes of this management plan, the property has been separated into four different management units: three forest units, and a fourth unit that combines the field border plantings and shitake log planting.

Unit 1 is 5.1 acres of oak-hickory forest in the north-west corner of the property. Stand 1 is bounded by the property line on its northern and western edges, an agricultural field on its southern border, and the dredged channel on its eastern edge. This stand has the most variable topography, the best forest structure, and many high quality floral and fungal species. Although there has been some selective timber harvest this stand supports many of the largest hardwood trees on the property.

Unit 2 is 14.5 acres of oak-hickory forest along the remainder of the northern boundary of the property. It is bound by the drainage channel on the west, alfalfa fields to the south, and the property line again at its eastern extent. There is a small stream running along the northern edge of this stand. Stand 2 has been selectively harvested, and has since become over-crowded with smaller diameter stems. In general the groundcover in this unit is suppressed by the dense shade and the fungal community is dominated by generalist saprotrophs.

Unit 3 is a 6.0-acre hardwood swamp on muck soils that remain saturated for much of the year. It is bounded to the north and south by fields and on the east and west by two-track access lanes. This stand has a very unique groundcover and a high number of snags and deformed boles. The fungal community of this stand includes several species with commercial potential.

Unit 4 comprises the field border and oak coppice plantings. The border plantings mostly consist of black-walnut trees that have not reached their rotation age. Many of these trees are damaged or misshaped and require salvage or removal. The oak coppice planting consists of a ¼-acre plot of oak saplings planted along the southern border of the property.

Overarching Management Goals

1. Conserve and enhance the ecological value of the forested land
2. Conserve and enhance the timber value of the forested land for occasional harvest and insurance value
3. Integrate forest management with current mushroom cultivation and sales of wild-harvested mushrooms
4. Produce a sustainable yield of small diameter polewood for mushroom cultivation
5. Manage the forest in a manner consistent with the organic ethics and practices of the overarching farm business

Forest Stewardship, Management, and Planning

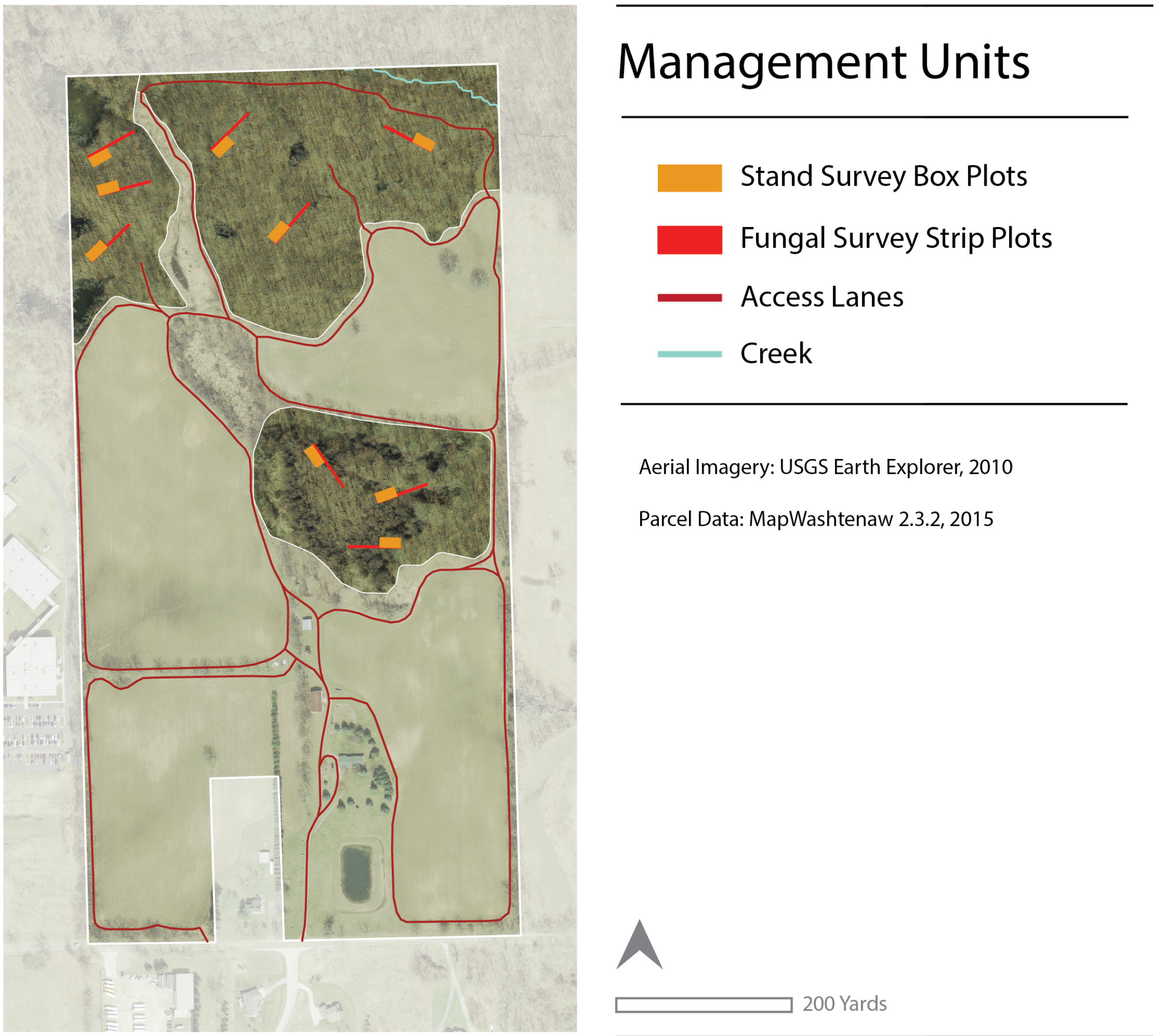
Private forests are increasingly important sources of the ecological goods and services that were historically provided by extensive public landholdings (Botkin, 2014). These forests may be managed for traditional products such as timber, pulp, and fuel. Or, they may be utilized for the production of non-timber forest products (NTFPs) such as edible, medicinal, or ornamental plants and fungi. They might provide habitat for wildlife and game species. Perhaps most commonly these private forests may be valued for aesthetic and recreational uses. Forests also play important roles in ecological processes such as the storage of atmospheric carbon dioxide, percolation of precipitation, or breakdown of pollutants in the soil. Forest stewardship balances the goals of the landowner with the ecological context of the forest and its surrounding landscape.

Forests are dynamic systems that persist within a range of recurrent ecological conditions (Botkin, 2014). What these conditions are and how often they reoccur is specific to each type of forest. If forest conditions fall outside of their natural range it may result in fundamental changes to the forest itself. These changes may or may not be in line with the needs or desires of landowners. In order to maintain a forest within any particular set of ecological bounds, active management is usually required at certain times. Having a plan in place that specifies what interventions should be made, what times to make them, why they ought to be made, and what results to expect will greatly increase the success of forest stewardship.

Agroforestry and Forest Farming

In the United States and Canada "agroforestry" is defined as an "intensive land-use management that optimizes the benefits (physical, biological, ecological, economic, social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock" (Gold and Garrett 2009). To be considered agroforestry the component resources must be intentionally managed as an integrated unit in a way that is intensive, rather than "hands-off", and focuses on manipulating the biological and physical interactions between parts. These practices broadly break down into five categories: riparian and upland buffers, windbreaks, alley cropping, silvopasture, and forest farming.

Forest farming is one way to diversify farm incomes, improve forest management, and promote forest biodiversity and ecological function (Chamberlain et al., 2009). Very simply, forest farming involves the production of some sort of NTFP under the canopy of a managed forest. The level of forest management can range from plantation style even-age forests to lightly manipulated natural stands. NTFPs produced in a forest farming system might include floral and decorative products, medicinal plant products, pine-straw mulch, native plants, syrups, edible plants, or mushrooms.



Stand Assessment

A forest stand inventory for the three stands was completed on August 4, 2016. Three 10 by 20 meter (1/20 acre) plots were established in each of the three stands using a random-stratified approach that ensured that all major landscape positions were represented. All trees in the plots greater than 1-inch diameter at breast height (dbh) were measured, identified, and recorded. Within each plot a nested quadrat of 0.5 by 8 meters (1 milacre) was established at a random corner to quantify forest regeneration by recording all trees under 1 inch dbh. Forest structure and composition were illustrated with this data. Records were also used to calculate stand basal area, trees per acre, stocking density, and marketable volume. For more detailed methods and results see the "Stand Inventory" Chapter.

Site Conditions

Roads and trails

Currently a two-track access lane runs around the parameter of all of the agricultural fields. It extends into the northwestern management unit (1) west of the drainage channel. It runs along the eastern edge of the drainage channel to the northern property line, where it extends nearly to the eastern property line and travels south to rejoin the field edge lanes.

Special Site Designations and Species of Special Concern

This site is not registered as a historic place. It does not contain threatened or rare natural communities. There are no known threatened or endangered species on this property, although the combination of wet lowland and drier upland habitats is suitable for the eastern massasauga rattlesnake.

Soils

<u>Brookston loam</u>
0-2% slope, 1 acre, 1.3% of site

Brookston soils are found in depressions in till plains and moraines created during the retreat of the Wisconsin ice sheet. They are formed in a loamy till with the upper layer accumulating up to 20 inches of silty material over time. Because of this silt layer and a typical depth of 0 inches to the water table Brookston loams are very poorly drained and tend to pond. They tend to be slightly acid to slightly alkaline in the upper soil horizons. They have low runoff, high water storage potential, and present a low risk of erosion. Use of equipment on these soils is highly limited as the soils are too wet for paths or trails. They are poorly suited to both harvest equipment and mechanical site preparation due to their severe risk of rutting. Red maple, white ash, silver maple, and American basswood are important trees on Brookston loam soils. Sycamore, black cherry, eastern hemlock, eastern white pine, paper birch, and white spruce often do well when planted in these soils. Due to elevated moisture there is a high risk of seedling mortality and a moderate windthrow hazard.

<u>Conover loam</u>
0-4% slope, .5 acre, 0.6% of site

Conover loam soils are typically found on the lower sections of moraines and till plains and form in a loamy till. The depth to the water table is usually 1 to 2 feet, leaving these soils somewhat poorly drained. They have a low potential for runoff and moderate water storage. Suitability for paths and trails is limited by the wetness of these soils. Conover loams are moderately acid to neutral. There are moderate limitations to equipment use due to wetness. Erosion hazard is only slight. Although moderately suited for harvesting equipment and well suited for mechanical site preparation they present a severe risk of rutting. Northern red oak, white oak, pin oak, and American basswood are important tree species on Conover loam soils. Black walnut, eastern white pine, red maple, and white spruce do well planted in these soils. Low seedling mortality and low windthrow hazard are expected.

Conover-Brookston loam
0-2% slope, 4.6 acres, 5.9% of site

Conover-Brookston loam soils can be found in the flats on till plains and moraines. Like their parent soil types they are somewhat poorly drained with negligible runoff. The water table is usually deeper than in Brookston types, at 1-2 feet. These soils have moderate water storage and are slightly to moderately alkaline. Equipment use and trail formation will be limited by wetness and severe rutting potential. Trees that compete well on Conover soils will also perform well here. Northern Red oak, white oak, pin oak, and American basswood are important. Black walnut, eastern white pine, red maple, and White spruce do well also. Moderate seedling mortality and some windthrow hazard are expected.

Houghton muck
0-2% slope, 7.8 acres, 10.1% of site

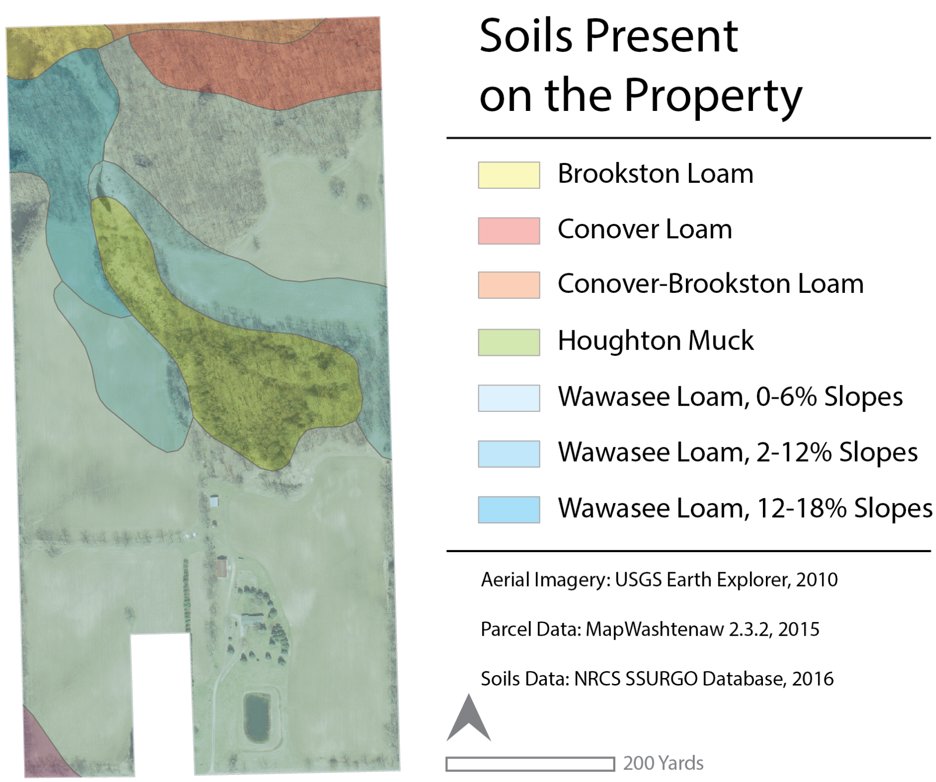
Houghton muck soils are very deep and very poorly drained soils formed in layers of organic matter that are 51 or more inches thick. They are found in closed depressions, in this case in a ground moraine. With so much organic material Houghton soils can range from very strongly acid to only slightly alkaline. Due to frequent ponding and very high water storage these soils are severely limiting to equipment use and trail creation. They are fully unsuited to harvest equipment or mechanical site preparation and are severely at risk of rutting. Important tree species in Houghton muck soils are silver maple, tamarack, white ash, basswood, and aspen. Eastern hemlock, eastern white pine, northern white-cedar, and white spruce are suitable for planting although severe seedling mortality and high windthrow hazard are expected.

Spinks loamy sand
0-6% slope, 0.6 acres, 0.8% of site

Spinks loamy sand soils are deep and well-drained soils formed during the Wisconsin Age. They are formed in sandy wind carried or outwash materials on dunes, moraines, till plains, outwash plains, beach ridges, and lake plains. Due to their sandiness they have low runoff potential and low water storage. Typically the water table is over 80 inches deep. These soils range from strongly acid to neutral in the upper horizons. Spinks soils are suitable for harvest equipment and mechanical site preparation. Sandiness presents a moderate risk of rutting, erosion, and slight windthrow hazard until slopes become steeper than 35%. Past 35% slope these hazards become severe. Red oak, white oak, basswood, and sugar maple are important tree species on Spinks loamy sands. Paper birch, red pine, and white pine do well when planted in these soils and seedling mortality is expected to be low.

Wawasee loam
2-6% slope, 48.5 acres, 62.3% of site
6-12% slope, 9.6 acres, 12.4% of site
12-18% slope, 5.1 acres, 6.6% of site

Wawasee loam soils are typically very deep and well-drained soils formed on the moraines and till plains left from the retreat of the Wisconsin ice sheet. They are very similar to Miami soils, which were used in their place in older soil surveys. These soils are prime farmland with moderate runoff and rutting hazards. The depth to the water table is usually over 80 inches. These soils are neutral to slightly acid. They are suitable for harvest machinery and mechanical site preparation with some care. These soils are suitable for trails where the slopes are lower. Northern red oak, sugar maple, white oak, and yellow poplar are important trees on Wawasee soils in Michigan. American basswood, black walnut, eastern white pine, northern pin oak, red pine, shagbark hickory, and white spruce should be suitable for planting in these soils. Seedling mortality and windthrow hazards should be low.



Climate

The average temperature between 1981 and 2010 was 49.8 degrees Fahrenheit, with an average low of 40.4 degrees and an average high of 59.1 degrees. The average precipitation during the same period was 37.6 inches per year (GLISA, 2015). A growing season high of 95 degrees and a winter low of -15 degrees can be expected (Annual Climatological Summary). In spite of regional trends the freeze-free season in Ann Arbor has shortened by four days from 1951-2014 (GLISA, 2015), typically this period is about 148 days (between about May 10 and October 5) (NOAA-NCDC, 2016).

Historic communities

The timber stands along the northern property line are derived from the much larger expanses of historic oak-hickory forest that could be found on this property and much of the surrounding county in the 1800s (Comer and Albert, 1997). In Michigan the oak-hickory community was typical of dry-mesic sites on sandy to loamy soils in the southern part of the Lower Peninsula (Kost et al., 2007). The canopy is most often dominated by one or several oak species, with white oak (*Quercus alba*) being most common, codominating with black oak (*Q. velutina*) on drier sites and red oak (*Q. rubra*) on more mesic soils and topographic positions. As the name of this forest type implies, shagbark hickory (*Carya ovata*), pignut hickory (*C. glabra*), and bitternut hickory (*C. coriformis*) are frequent codominants as well.

It is commonly postulated that, historically, relatively frequent low-intensity fires maintained lower tree densities, which helped to sustain oak advance regeneration. As fires were increasingly suppressed post European settlement the forest canopies closed and regeneration of the oak component was interrupted (Kost et al., 2007). The results of the stand surveys suggest that most of these stands have maintained their characteristic oak-dominated overstory but have little to no oak regeneration in the understory.

Ecological Threats

Pests and Disease

Emerald ash borer has already eliminated all of the mature ash trees on the property. There are many young ash in the seedling layer but they are unlikely to survive to maturity as there is no effective treatment for the borer at this time. Similarly, many of the elms on the property show signs of dieback indicative of Dutch elm disease. Although this disease is not always fatal, its presence will likely keep elm from remaining a dominant member of the forest community. Many wet-mesic areas in southern Michigan historically supported elm-ash-cottonwood communities and these two pests have removed two of the three most dominant species in these forests.

Oak wilt is a major ecological threat to the oak-hickory forest stands. Oaks, particularly red oak, are the overstory dominant species and major mast producers in these stands. Unfortunately the red oak group is the most susceptible to oak wilt, which may kill a mature tree in less than three weeks. The tendency of the oaks to root graft with one another creates the potential for this disease to quickly pass through an entire stand. Although it may not reach every oak in a mixed forest, it may be enough to dramatically alter the composition of the forest. In plantation-style oak stands oak wilt could eliminate the entire stand in a single month.

Deer

Deer populations have exploded to unprecedentedly high levels over the past several decades. The burgeoning populations of deer have been shown to impact herbaceous plant communities and have long-term impacts on forest composition. Through their browse patterns, they can determine which, if any, species are able to recruit from the seedling to the sapling stage and eventually enter the forest canopy. There are many signs of heavy dear browse in all areas of this property and deer were encountered repeatedly in each stand while conducting the surveys.

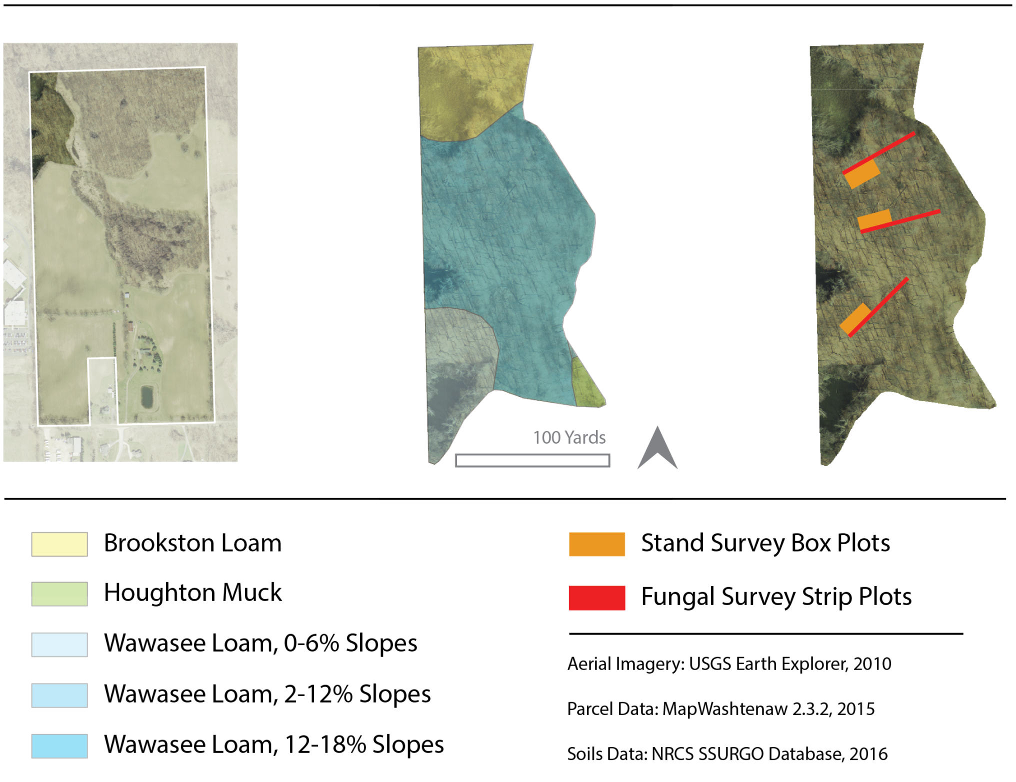
Invasive Species

Invasive species are present but not prevalent in all areas of the property. The herbaceous invaders garlic mustard and Japanese hedge parsley are found scattered in the northern forest stands. Japanese barberry and multiflora rose are present in low numbers. There are scattered individuals of buckthorn species within the forests and some seedlings coming up in areas that do not currently have adult trees. Autumn olive is common along some of the field edges. At the current low levels these species are not immanent threats to the forest. Unfortunately all of these species are adept at taking advantage of any planned or unplanned disturbance. If they do become more dominant each of these species has the potential to change soil nutrient cycles, crowd out native plants, lower the ecological value of the forest, and its decrease its resilience to future stresses.

Suppressed Oak Regeneration and High-Grading

Because of the disease, herbivore, and invasive species pressures on the site it will be sensitive to inappropriate management choices. Inappropriate harvest timing could provide openings for oak wilt infections. Natural regeneration may not successfully reproduce a harvested stand with the same mix of species in the face of massive deer pressure. Invasive species may prevent native plant recruitment all together. A selective harvest that does not take into account the desired future conditions of the forest could potentially leave the forest filled with misshapen and diseased trees of low-value species. These problems could take many decades to recover from. In the interim period the ecological and economic value of the forest would be substantially diminished.

Unit 1: The Northwestern Stand

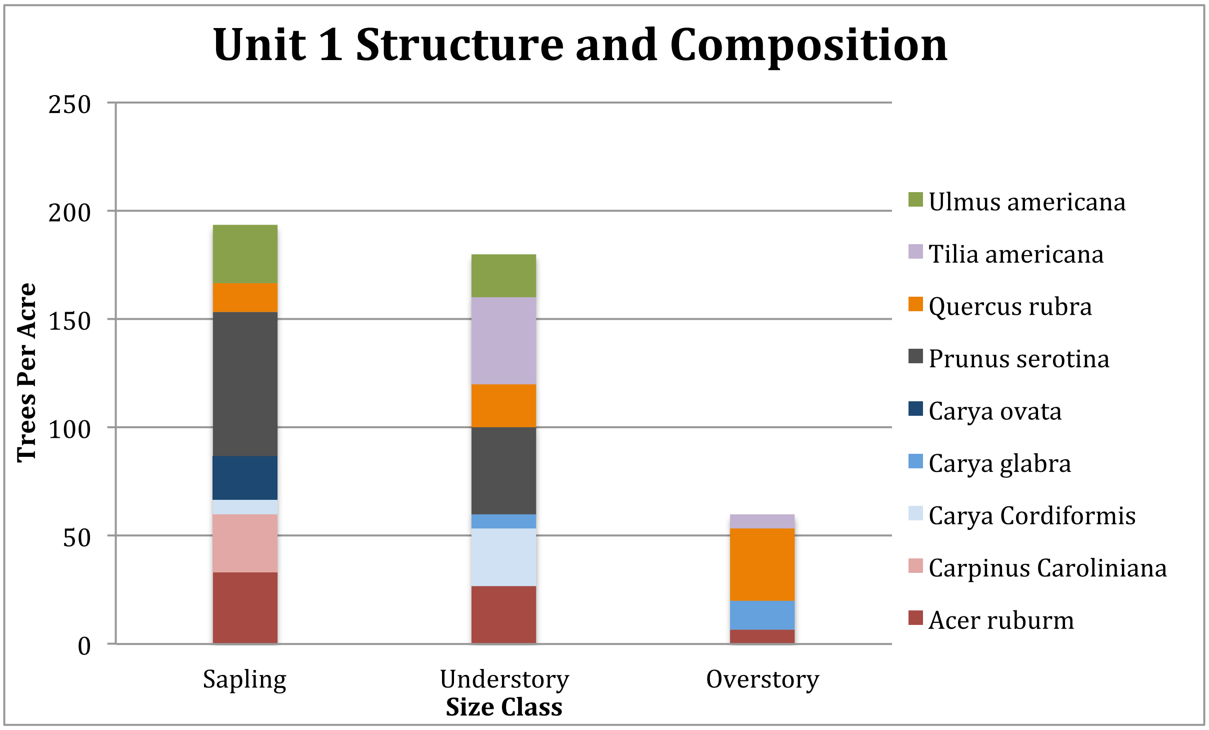


Unit 1 consists of 5.1 acres of oak-hickory forest. This stand is located in the northwestern corner of the property. It is bounded by the property line on its northern and western edges, an agricultural field on its southern border, and the dredged channel on its eastern edge. This stand has the most variable topography, the best overall structure and composition, and many high quality floral and fungal species. Although there has been some selective timber harvest this stand has retained some of the largest hardwood trees on the property.

The soils in Unit 1 are: 10% Brookston loam in the north, 1% Houghton muck in the southeast corner, 18% Wawasee loam with 2-6% slopes in the southwest corner, and 71% Wawasee loam with 12-18% slopes.

This stand is overstocked. The basal area is 149 sq. ft/acre. This stand has 438 trees per acre with an average diameter at breast height of 6.0 inches. The merchantable volume of this stand is 72,175 board-feet using the International ¼-inch Rule.

The dominant canopy of trees larger than 12" dbh is 56% red oak, 22% pignut hickory, and 11% each red maple and American basswood. The subdominant canopy of trees between 4" and 12" dbh is dominated by black cherry and American basswood with 22% each. Red maple and bitternut hickory are third at 15% each. Red oak and American elm make up 11% each of the subdominant canopy. The sapling class is 34% black cherry followed by 17% red maple, 14% American elm, and 14% musclewood. White ash makes up 25% of the regenerating seedlings. Red maple, bitternut hickory, pignut hickory, and common buckthorn each account for just over 10% each of the remaining regeneration. Red oak seedlings make up less than 4% of the seedling class.



The fungal community in unit 1 contains more mycorrhizal species than any of the other stands. This may be related to the lower overall proportion of maple species, and larger number of mature trees in this stand. Notable edible species include honey mushrooms, aborted entoloma, pear-shaped puffballs, white morels, golden chanterelles, and oyster mushrooms. For more detailed information about the fungal community see the "Fungal Inventory" chapter.

Objectives for Unit 1

Because of the high quality of this stand the objectives for unit 1 prioritize the ecological integrity, biodiversity, and habitat qualities of the stand. Economic value is a secondary consideration.

1. Maintain oak species as at least 40% of the dominant canopy
2. Open the canopy and reduce basal area to 100 sq. ft/acre
3. Retain snags and den trees
4. Increase canopy recruitment for subdominant black cherry

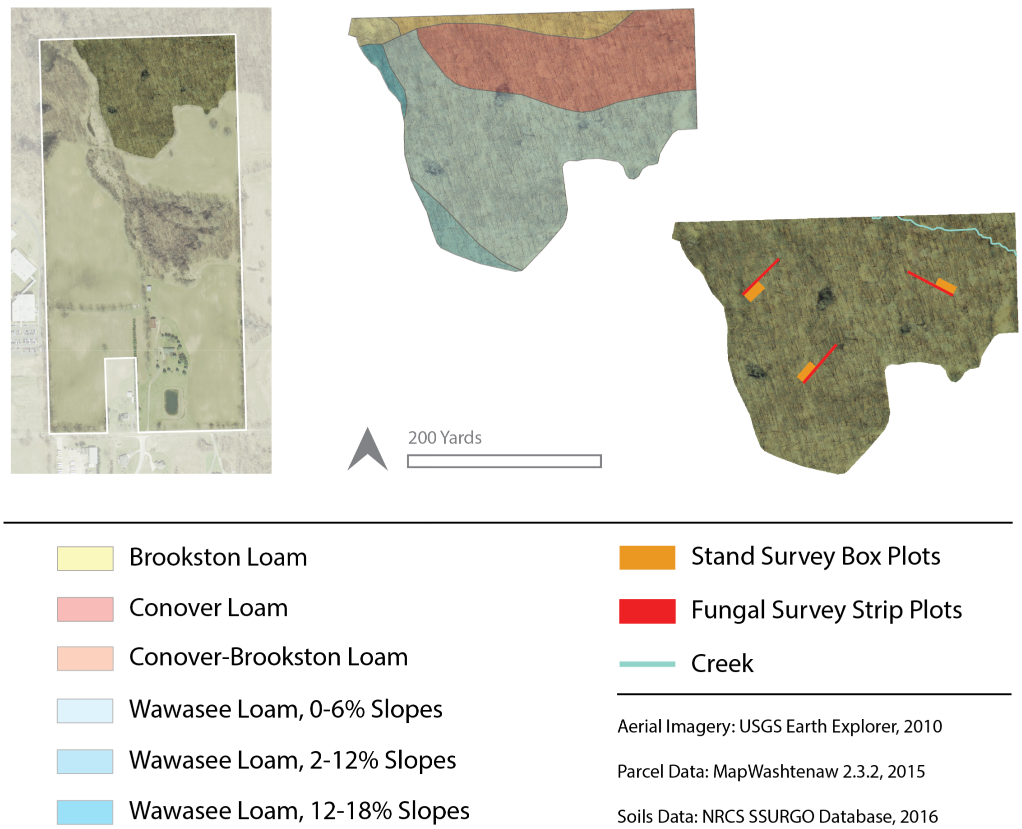
Recommendations

1. Select approximately 15 crop trees per acre (about 75 in total)
    a. Select at least 60% oak, 20%black cherry, and 15% hickory
    b. Include at least 15 trees selected primarily for physical habitat qualities like nesting sites, and dens
2. Perform crop tree release (see the "Crop Tree Release and Selecting Trees for Removal" chapter for more details)
3. Thin the residual basal area of large saplings and understory size trees until basal area is around 100 sq. ft/acre and there are about 200 trees per acre Focus thinning on:
    a. Diseased trees
    b. Heavily suppressed trees
    c. Trees with misshapen or underdeveloped crowns
    d. Trees that could become hazards to people, property, or crop trees if damaged
    e. Maple species
    f. Separating 4-6" dbh stems by around 10 feet
    g. Separating 6-10" dbh stems by around 15 feet
    h. Separating stems larger than 10"dbh by around 20 feet
4. If an overstory tree falls or is harvested ensure that oak species have an opportunity regenerate
    a. Cage the fresh stump if it is an oak species
    b. Thin undesirable trees from the canopy gap
    c. Cage several oak seedlings if they are present
    d. Plant oak several oak saplings in the gap if they have a good chance of survival and there is no natural oak regeneration
5. Use a weed torch to burn off invasive woody shrubs, buckthorn seedlings and garlic mustard rosettes in the early spring
6. Evaluate the need for further release every 20 years

Rationale

Crop tree release of the recommended proportion of species should maintain oak dominance for many decades by increasing their survival above base levels for the stand. This is desirable because oaks are an important component of native Michigan forests and valuable for both wildlife and timber. Releasing black cherry will accelerate the growth of the highest value timber in the stand. Releasing hickory species will maintain this species in the canopy and provide mast for wildlife. Combining canopy release and understory thinning will increase the health and value of residual trees over time while increasing the amount of light that reaches the ground. It should encourage a stand with a wider tree spacing characteristic of historic conditions and increase the success of oak seedlings.

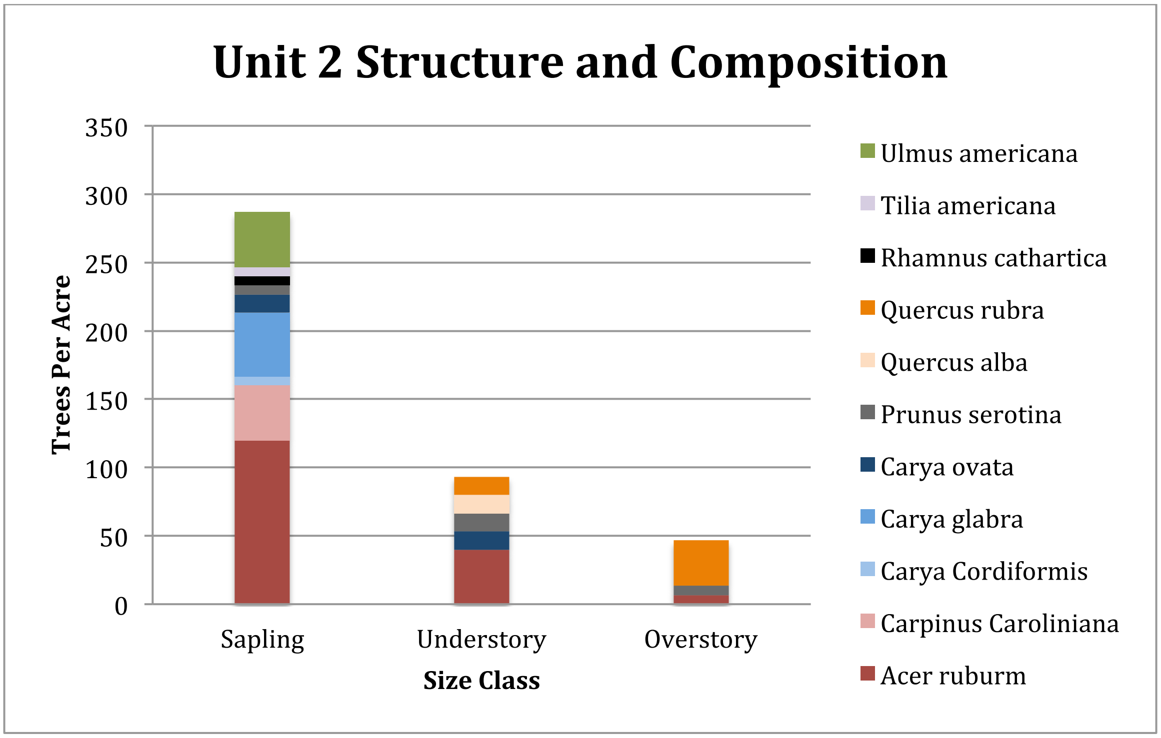
Unit 2: The Northeastern Stand



Unit 2 consists of 14.5 acres of oak-hickory forest along the remainder of the northern boundary of the property. It is bounded by the drainage channel on the west, fields to the south, and the property line again at its eastern extent. A small stream runs along the northern edge of the stand. This stand has been selectively harvested in the past, and is now over-crowded with low-quality, small-diameter stems. In general the groundcover in this unit is suppressed by the dense shade and the fungal community is dominated by generalist saprotrophs.

The soils in Unit 1 are: 3% Brookston loam in the northwest corner, 4% Conover loam along the northern edge, 30% Conover-Brookston loams in the northwest and south of the northern border, 1% Houghton muck in the southwest corner, 54% Wawasee loam with 2-6% slopes in the center and southeastern areas, 6% Wawasee loam with 6-12% slopes in the southwest, and 2% Wawasee loam with 12-18% slopes in the northwest.

This stand is overstocked. The basal area is 110 sq. ft/acre. This stand has 432 trees per acre with an average diameter at breast height of 4.6 inches. The merchantable volume of this stand is 148,459 board-feet using the International ¼-inch Rule.



The dominant canopy of trees larger than 12" dbh is 71% red maple, 14% black cherry, and 14% red maple. The subdominant canopy of trees between 4" and 12" dbh is dominated by red maple at 43%. Shagbark hickory, black cherry, white oak, and red oak make up 14% each. The sapling class is 42% red maple followed by 16% pignut hickory, 14% American elm, and 14% musclewood. White ash makes up 80% of the regenerating seedlings. The only other species with significant regeneration in the seedling class are the hickories, with 11% for shagbark, 4% for bitternut, and 2% for pignut.

The fungal community in unit 2 contains few mycorrhizal species. A large proportion of maple species and more recent disturbances may contribute to this trend. Notable edibles include honey mushrooms, aborted entoloma, pear-shaped puffballs, bricktop mushroom, and enoki. For more detailed information about the fungal community see the "Fungal Inventory" chapter.

Objectives for Unit 2

Because of the lower ecological quality of this stand the objectives for unit 2 prioritize opening the canopy, removing invasive shrubs before they become entrenched, and increasing the timber value of the unit.

1. Maintain oak species as at least 50% of the dominant canopy
2. Open the canopy and reduce basal area below 90 sq. ft/acre
3. Remove all invasive shrubs over 1" dbh

4. Increase canopy recruitment for subdominant black cherry

5. Reduce red maple to less than 25% of the sapling and understory classes

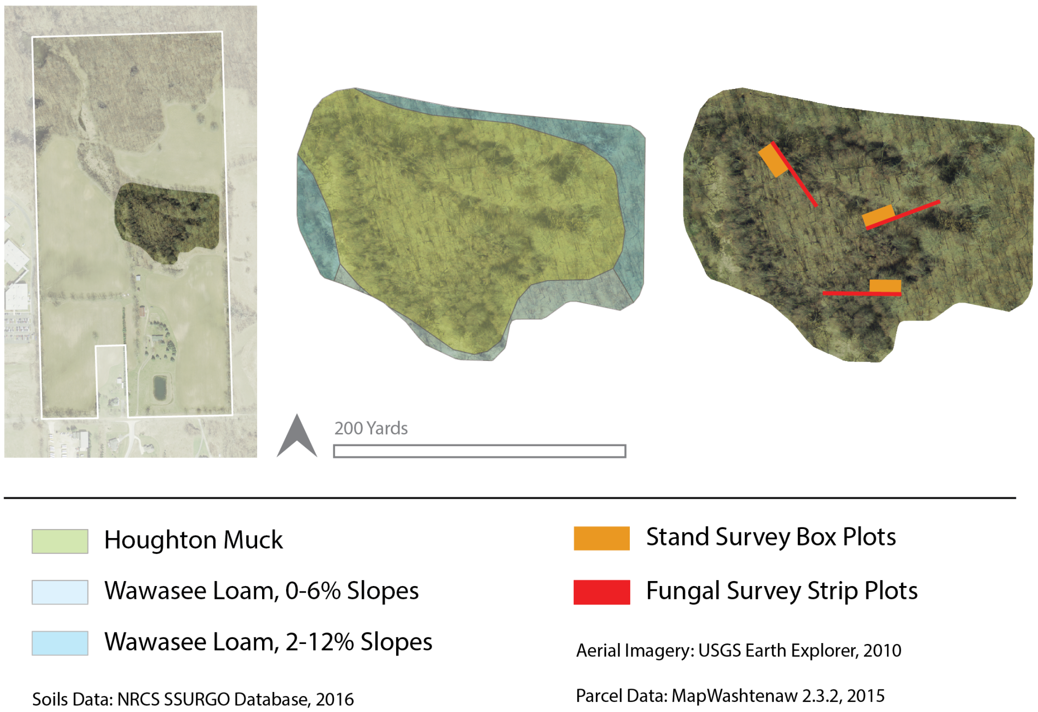
Recommendations

1. Select at least 25 crop trees per acre (about 365 in total)
    a. Select At least 50% oak, 30%black cherry, and 10% hickory
    b. Avoid trees that are very likely to succumb to disease like elms or ash
    c. Where enough trees cannot be found consider pruning marginal stems
2. Perform a crop tree release (see the "Crop Tree Release and Selecting Trees for Removal" chapter for more details) but retain release trees larger than 10" dbh for commercial thinnning in 15-20 years
3. Thin the residual basal area of large saplings and understory size trees until basal area is below 90 sq. ft/acre and there are about 350 trees per acre. Focus thinning on:
    a. Diseased trees
    b. Heavily suppressed trees
    c. Trees with misshapen or underdeveloped crowns
    d. Trees that could become hazards to people, property, or crop trees if damaged.
    e. Maple species
    f. Separating 4-6" dbh stems by around 10 feet
    g. Separating 6-10" dbh stems by around 15 feet
    h. Separating stems larger than 10"dbh by around 20 feet
4. Do not intensively harvest within 50m of the stream
5. When a harvest is scheduled:
    a. Harvest at least 2 acres at one time using a clearcut with seed trees
    b. If possible, thin the canopy by 40-60% between 5 and 10 years before harvest with either a commercial thinning or by deadening non-commercial trees during the dormant season with a weed torch
    c. Select 12-15 understory crop trees per acre that are around 40 to 60 years old, and preferably oak, to retain as seed trees
    d. Cage fresh oak stumps to protect sprouts
    e. Thin undesirable saplings from the harvested area with fire
    f. Cage at least 50 oak seedlings per acre if they are present
    g. Plant oak saplings if natural regeneration has not produced 50 dominant oak saplings within 5 years
6. Use a weed torch to burn off buckthorn seedlings and garlic mustard rosettes in the early spring
7. Evaluate the need for further release every 15 years

Rationale

Similar to stand 1, a crop tree release and thinning program will increase the growth rate, health, and resilience of the best trees in the stand. It will also promote a more open forest that is closer to historic conditions. In this case emphasis should be focused on trees with market potential. In some areas more crop trees may be available and in some areas fewer may be present. Consider pruning in areas where most trees are marginal. Even if harvest is not desired, improving the value of the stand will allow for business losses to be claimed on taxes when large trees fall. Smaller diameter trees harvested during release and thinning can also be fed into the mushroom business to offset the costs of forest stand improvement. It can also provide an emergency timber "bank" for occasional times when cash needs to be freed up.

Unit 3: The Central Stand

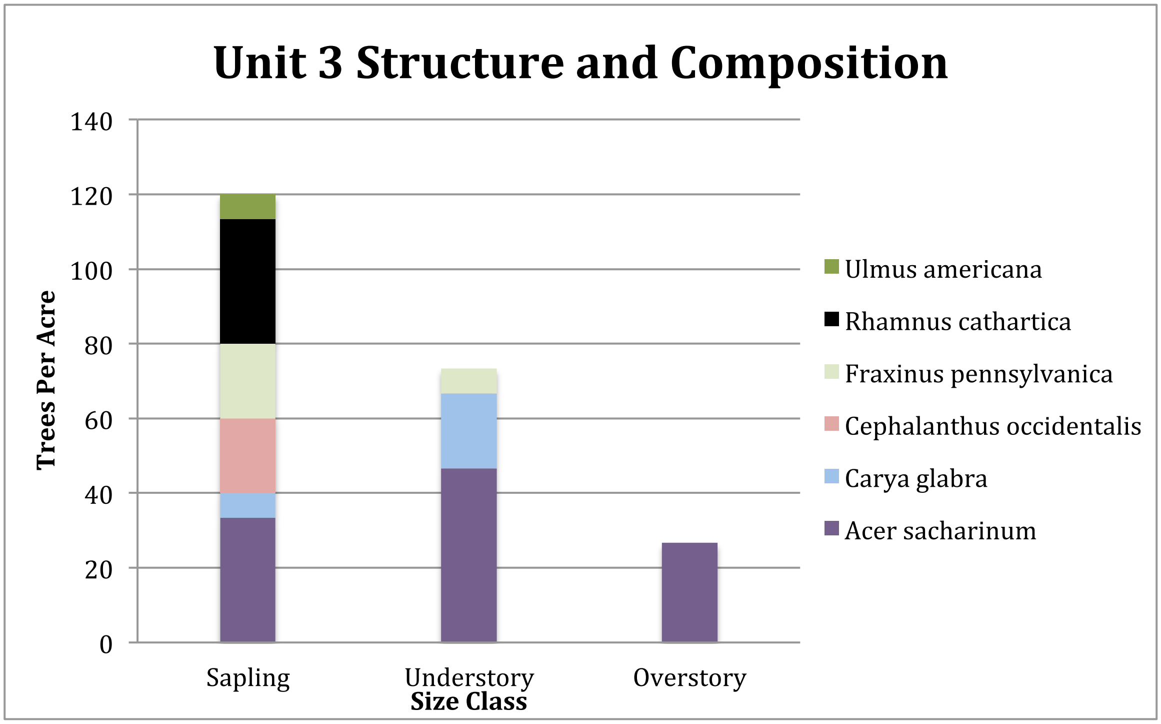


Unit 3 is a 6.0-acre hardwood swamp on muck soils that remain saturated for much of the year. It is bounded to the north and south by fields and on the east and west by two-track access lanes. This stand has a very unique groundcover and a high number of snags and deformed boles. There are higher numbers of invasive shrubs in and around this stand than the others. The fungal community of this stand includes several species with commercial potential.

The soils in Unit 3 are: 78% Houghton muck, 12% Wasasee loam with 2-6% slopes in the southern corners, and 10% Wawasee loam with 6-12% slopes along the northern, eastern, and western edges.

This stand is fully stocked. The basal area is 72 sq. ft/acre. This stand has 223 trees per acre with an average diameter at breast height of 5.7" inches. The merchantable volume of this stand is 37,433 board-feet using the International ¼-inch Rule.

The dominant canopy of trees larger than 12" dbh is nearly 100% silver maple. The subdominant canopy of trees between 4" and 12" dbh is dominated by 64% silver maple. Pignut hickory makes up 27% and green ash has maintained 7%. The sapling class is 28% silver maple and 28% common buckthorn. Buttonbush and green ash follow with 17% each. At 7% each pignut hickory and American elm make up the remainder of the sapling class. Silver maple makes up 48% of the seedling regeneration. Green ash makes up another 39% with white ash taking up the remaining 13%.



The fungal community in unit 2 is almost entirely saprophytic. This is probably due both to the hydric soils that remain saturated through the majority of the year and the dominance of the silver maples. Notable edible species include honey mushrooms, hen-of-the-woods, chicken-of-the-woods, rishi, and oyster mushroom. For more detailed information about the fungal community see the "Fungal Inventory" chapter.

Objectives for Unit 3

This stand is well stocked, but many of the trees are low-value and deformed. Higher value oaks and black walnuts can be found around the edges but are not dominant in this stand. Because of the muck soils and unique plant communities anything other than selective harvesting around the edges is not recommended.

1. Remove major hazard trees near the brushpile
2. Retain snags and den trees
3. Remove all invasive shrubs over 1" dbh
4. Create a ¼ acre area shaded year-round by conifers for a larger mushroom yard

Recommendations

1. Assess the safety of all trees within 25 meters of the brush pile
2. Carefully fell any trees that are identified as hazards or mark them for professional removal
3. Use a weed torch to burn off buckthorn and autumn olive shrubs during the dormant season
4. Plant conifer saplings or small trees over a ¼ acre patch along the southern edge of the swamp (about 100 trees)
    a. Prepare the site by clearing the understory
    b. White spruce, eastern white pine, and eastern hemlock are recommended
    c. Plant in a 10x10 foot grid underneath the current overstory
    d. Protect young trees from deer browse with fencing, cages, or tubes
5. After 20 years asses the need to release conifers by harvesting the overstory trees and thinning within the planting

Rationale

Unit three has only moderate commercial value throughout most of its area. Around the edges canopy release for high-quality trees could be considered, but the stocking density of the stand is already within the optimal range. The very wet soils on this site are also prone to damage from machinery and the herbaceous plant community below these trees might be impacted by over-zealous harvest. This site also receives drainage from the surrounding fields and the dredged channel to its northwest. Forest cover plays an important role in water filtration and percolation, which may be desirable on a farm with a mixed management history. For these reasons the only active management recommended in this stand is the removal of trees near more heavily utilized areas that might present a hazard to people or property.

Due to its proximity to the farm buildings, vehicle access, high moisture levels, and north-facing slope, the southern edge of stand 3 could make a very good site for a mushroom yard. Ideally a mushroom yard would be located under the year-round shade of a conifer overstory. The three species mentioned are all recommended for the Houghton muck soils, but eastern hemlock should produce the best shade. Because these are naturally slow-growing trees shade-cloth may be needed in the interim.

Unit 4: Field Edges and Oak Coppice Plantings

Most of the field edges were previously planted with black walnut trees. Many of these are diseased, misshapen, or damaged. The rest are not yet ready for harvest. These border plantings cover about 2.1 miles of field edges. Additionally, about a quarter acre of oak saplings were planted along Marshall Road in the southeastern corner of the property. Additional oaks were planted along some of the field edges.

Almost all of the field edges are located on Wawasee soils with 2-6% slopes. Some of the field edges in the northern part of the property sit on Wawasee soils with 6-12% or 12-18% slopes. The southeast corner of the property is composed of Spinks loamy sands.

Autumn olive is most prevalent on the property along these edges.

Objectives for Unit 4

Unit four has low conservation value, but is valuable as a windbreak and potentially as timber after several more decades. This area is a working component of the farm and warrants more intensive management than the forested stands.

1. Remove damaged, diseased, and low value trees from the field edges

2. Plant oaks that can be used as a sustainable source of logs for mushroom production

3. Create structural diversity, wildlife value, and mast production in the oak coppice plantings by using a "coppice with standards" system

Recommendations

1. Renovate the field edge plantings
    a. Salvage harvest damaged, diseased, and malformed trees
    b. Prune trees with undesirable branching
    c. Monitor stumps for sprouts and cage any that are desirable
2. Plant oaks in strips plots for future coppicing
    a. Plant 500-600 trees per acre (about 9x9 foot grid spacing)
    b. Plant in strips 2-4 rows wide with staggered centers (about 6.5 feet between rows)
    c. Alternate between blocks of several different oak species to prevent oak wilt from spreading through root grafts
    d. Alternate between species in the white oak and red oak groups
    e. Stagger planting and harvesting over about 20-30 years
3. Leave some residual stems during each coppice harvest to serve as larger "standard" trees
4. Cage or fence young trees and freshly coppiced stumps to prevent damage from deer

5. Eliminate invasive shrubs larger than 1" in diameter from the field edges

Rationale

As in the other units, diseased and badly damaged trees are liabilities to their neighbors as well as to people and property. Because black walnut is a highly desirable timber species, salvage cuts may provide some income depending on the quality of the individual trees and the status of the market. Income from these removals might be used to offset potential costs of professional pre-commercial thinning operations. Some trees may be able to be recovered through careful pruning. Others may sprout again from their stumps after removal. These sprouts should grow relatively quickly and may be good candidates to replace the removed trees.

Oak coppicing has been widely practiced in many parts of the world. However, recent outbreaks of oak wilt have decimated many old coppice forests. Oak wilt can spread quickly through root grafts between oak trees. This spread can be stopped with intensive interventions such as deep root pruning around infected trees and their neighbors if the outbreak is caught soon enough. Because oaks species only rarely graft between different species, plantings should alternate among 4-6 separate oak species. Rotate between members of the white oak and red oak groups to maximize this effect. Suggested species are pin oak, swamp oak, red oak, white oak, black oak, burr oak, and scarlet oak. The first four will be more competitive on lower, wetter sites. The last four are more appropriate for upland areas with better drainage.

When planting the oak coppice strips consider using them to add to or create within-field windbreaks and breaks along field edges. These strips will be easier to harvest and manage than block plantings, and provide better chances to manage oak wilt infections before they spread through entire blocks. This will especially be the case if occasional black walnuts and other trees break up the coppice plantings. Planting these strips as windbreaks also provides opportunities to enhance the production of other crops in neighboring fields. This is particularly true for crops that may be sensitive to cold or dry conditions that are exacerbated by the wind. Only harvest the coppice plantings during the dormant season so that wounds have a chance to heal before the risk of oak wilt infection increases in the spring and summer. When harvesting, leave scattered stems - called "standards" - to continue to grow and provide structural diversity and mast for wildlife.

Integrating Mushroom Production and Forest Stand Improvement

Bolts from Thinning

Any oak or hickory stems or limbs between about 4 and 6 inches in diameter that are removed in crop tree release or canopy thinning should be cut down into 3-4 foot lengths for use as shiitake mushroom bolts. Larger stems, up to about 10 inches in diameter, should be used as needed for bedlogs for other mushroom species or as shorter bolts used in stationary cold-weather shiitake stacks. Red maple can be used as well, although some report lower than desirable yield. Inoculate a dozen red maple bolts with a warm-weather shiitake strain to assess their productivity on this site. Each species of log will produce a subtly different mushroom, which may create opportunities for diversified marketing. Thin about two acres every year to ensure a steady supply of logs for the next two to three decades.

Bolts from Coppice

The coppice plantings will produce stems of suitable diameter for shiitake production after about 20-30 years. These stems will be very easy to access and harvest, increasing the efficiency of bolt production over the stems from the forest. In the meantime integrate these strips can be into existing nursery and farming operations as windbreaks that will moderate weather conditions and increase yields.

Inoculation of Stumps

Stumps and fresh snags over about 6 inches in diameter should be inoculated with spawn of a common and marketable species like hen-of-the-woods. This ought to increase the effectiveness of timber stand improvement because many commonly grown species are weak parasites that will help deaden stumps. Do not inoculate stumps that may re-sprout and produce desirable regeneration. Because stumps may take from several years to a decade to begin producing mushrooms inoculation methods should be as efficient as possible. Rather than painstakingly drilling holes for dowels consider making slashes with a chainsaw and packing them with sawdust spawn. The advantage to stump inoculation is that after stumps begin to produce they will continue to fruit for many years.

Chipping Slash and Infected Material

Small diameter slash and diseased material of any species can be chipped and inoculated. In the case of trees infected with oak wilt chip the wood during the dormant season immediately following infection. These chips can be inoculated with wine-cap mushrooms or used for sawdust spawn in more intensive operations. Inoculated mulch can be applied in orchards and garden settings in the place of normal hardwood mulch. If diseased trees are chipped make sure that that mulch is not used around trees the same genus until it has been aged for a year or so.

Spent Mushroom Substrates as an Organic Soil Amendment

Spent mulch, logs, and spawn material should be added to coppice plantings or returned to the forest as trail edges or brush piles for wildlife. Returning spent mushroom substrates to intensive plantings like the coppice strips is intended to help to slow the onset of coppice "fatigue" from repeated harvesting over time. This is because spent mushroom substrates add nutrients and organic matter to the soil as well as aiding in the breakdown of toxins in the soil.

Monitoring

A successful monitoring plan should ensure that the management plan is being correctly implemented, provide insight into the condition of the resource, and indicate the effectiveness of the plan at achieving its goals. Using these measures it should be possible to validate whether the assumptions of the current plan are accurate, or in need of revision.

- To ensure proper implementation of thinning, a simple basal area estimation should be made before and after each operation. The easiest way to do this is to use an inexpensive ten-factor angle gauge or prism. Otherwise a simple penny held exactly 24.75 inches away from ones face with a string can be used. Rotating in place count every tree that appears wider than the penny. Multiply the number of those trees by 10 to estimate the basal area of that spot. Repeat in two more positions in the thinned area.

- To monitor stand composition and structure repeat monitoring with 10x20m plots with nested milacres very fifteen years.

- To measure the efficacy of the crop tree selection and release follow a subset of 10% of the crop trees to verify increased growth rates and low overall mortality. For each tree in the set measure dbh every five years and record mortalities.

- Invasive plants will never be totally eliminated on the site but walk through every year in early spring to identify early leafing invasive plants. This is a good time to flame weed shrubs and second year rosettes of herbaceous invasives.

- Every summer in late July walk through the forest examining for signs of oak wilt and other major diseases. Mark infected trees for removal during the following winter.

- When planning a harvest create one milacre plot for each half-acre to be harvested in order to monitor regeneration. Record the regeneration five years before harvest, the summer following harvest, and five years following. Ideal regeneration will be on the order of at least 10,000 stems per acre following harvest.

Adaptive Management

Decisions about management should not be made once and followed dogmatically. Interventions should be made based on the actual, measured conditions of the site and reasonable expectations of how the intervention will change those conditions. Following an intervention further assessment should be carried out to determine if it was successful, or if further action is required.

- Use basal area data to evaluate whether thinning achieved the target basal area. If it did not then determine whether further thinning is necessary or desirable.

- Use crop tree data to verify that mortality is low and growth is high. If crop trees do not respond with higher growth rates in years following release then or if they are experiencing mortality rates higher than 5% over ten or twenty years then evaluate whether the release is helpful, or if other factors like pests or disease are to blame.

- Use nested plot data to evaluate whether oak is being maintained in the canopy and whether oak advance regeneration is improved by thinning and canopy release. If oaks are falling below their target levels and advance regeneration is sufficient, a harvest may be appropriate to renovate the stand. If oak advance regeneration is not occurring then more complex interventions may be required.

- Use milacre regeneration data to determine if oak advance regeneration is sufficient leading up to a harvest. If it is not, then a shelterwood thinning should be undertaken to reduce the canopy by 40-60%. If oaks are not regenerating following harvest, then a prescribed burn may be advisable. If there are only very few oak seedlings then tubing them may give them a competitive advantage over other, unprotected seedlings. If after five years there is very low oak regeneration then planting may be necessary to ensure their continued presence on the site. If oak regeneration is lower than desired, there may still be enough stems to select them as crop trees at a younger age where more trees (up to fifty or more) can be selected per acre. By selecting these trees their survival rates will be much higher than other trees in the surrounding forest, leading them to increase in relative dominance as they advance through the canopy classes.

Sample Workflow for the Next 20 Years

Year	Action	Monitoring	Decision
0-2017	• Select Crop Trees for Unit 1 • Plant Conifers in Unit 3	Crop Tree DBH	
1-2018	• Stand 1 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
2	• Stand 1 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
3	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
4	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
5	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion • Crop Tree DBH	Is the thinning sufficient?
6	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
7	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
8	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
9	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
10-2027	• Stand 1 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion • Crop Tree DBH	Is the thinning sufficient? Is CTR Effective?
11	• Stand 1 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
12	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
13	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
14	• Stand 2 CTR and Thinning	• Basal Area	Is the thinning

	(~2 acres) • Coppice Planting	Estimation • Disease and Invasion	sufficient?
15	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting • Commercial Thinning	• Basal Area Estimation • Disease and Invasion • Crop Tree DBH • Stand Composition and Structure	Is the thinning sufficient? Is CTR Effective? Is Oak Maintaining Dominance?
16	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
17	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
18	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
19	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion	Is the thinning sufficient?
20-2037	• Stand 2 CTR and Thinning (~2 acres) • Coppice Planting	• Basal Area Estimation • Disease and Invasion • Crop Tree DBH	Is the thinning sufficient? Is CTR Effective?
21	• Coppice Harvest		Is CTR Effective?

Sample Schedule for Timber Harvesting

Year	Action	Monitoring	Decision
-10 years	Plan Harvest	Evaluate Oak Regeneration	Is canopy thinning necessary for oak advance regeneration?
-5 years	Canopy Thinning	Evaluate Oak Regeneration	Is oak regenerating?
0 Years	Clearcut with shelterwood	Evaluate Oak Regeneration	Is oak regenerating?
+5 years	Cage oak seedlings Plant oak saplings if needed Burn if needed	Evaluate Oak Regeneration	Are there enough oak saplings to regenerate the stand?
+10 years	Cage oak seedlings Plant oak saplings if needed Burn if needed	Evaluate Oak Regeneration	Are there enough oak saplings to regenerate the stand?
+15 years	Select Crop Trees	Stand Structure and Composition	Can Oak Retain Dominance?

Fungal Inventory

Introduction

Fungi play an important role in forest ecosystems and have the potential to provide an additional source of income to forest owners interested in marketing non-timber forest products (NTFPs). In nature, fungi primarily fall into two functional groups. The first perform the critical function of decomposing organic material, breaking down difficult-to-digest plant material and returning its nutrients to the soil. The second form symbiotic associations with the roots of living plants. These fungi help the plant gather nutrients from the soil and help protect them from disease in exchange for access to sugars that the plants produce during photosynthesis.

Throughout history people have gone into the forest to gather edible and medicinal plants and fungi. In the US today these NTFPs support the livelihoods of many thousands of individuals and contribute to multi-million dollar markets for wildcrafted goods (Vaughan et al., 2013). Unfortunately forest management and NTFP harvest are only rarely coordinated. Forest farming is one strategy for intensifying the production of multiple forest products, including edible and medicinal mushrooms, alongside forest management. In many cases the strategy is to provide a near-term cash-flow from NTFPs to supplement the intermittent or far-distant future income provided by more traditional timber sales.

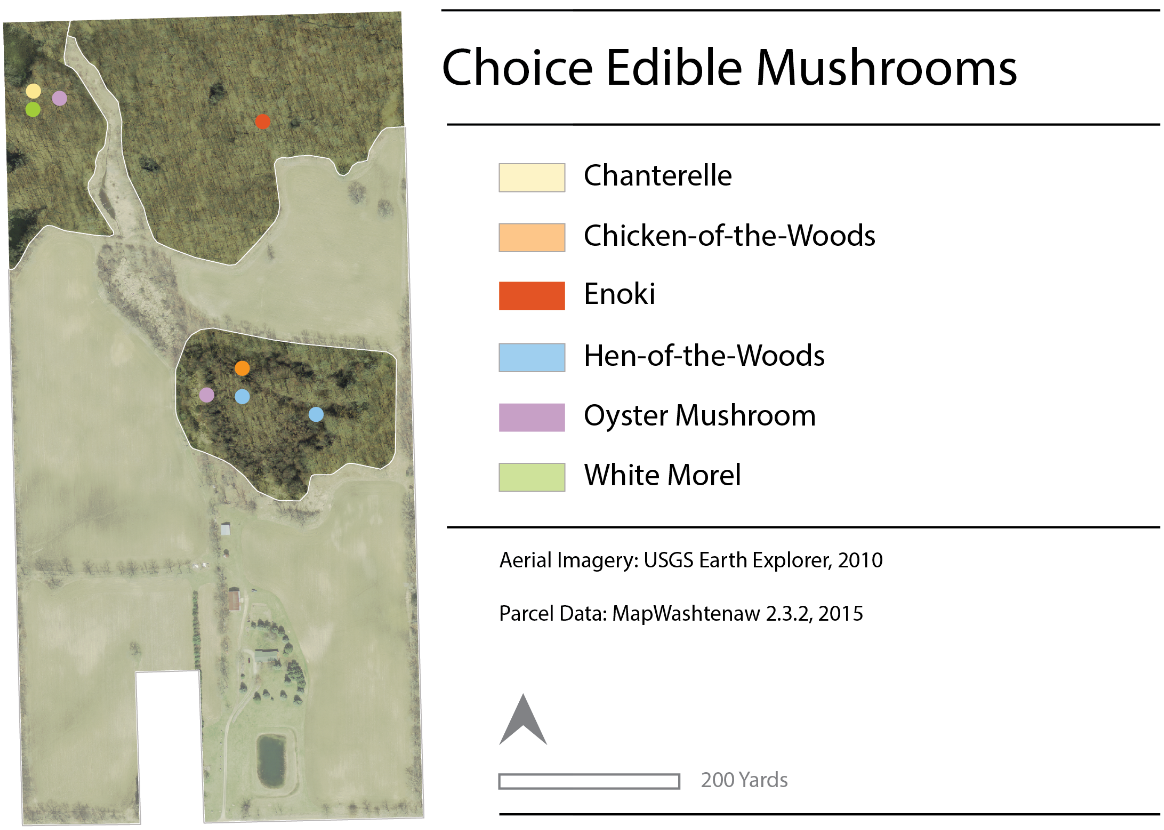
Forest farming mushrooms can include wildcrafting, extensive cultivation, and intensive cultivation strategies. Assessing the current fungal resources allows the farmer to locate marketable wild species, locate sources of local genotypes for intensive cultivation, and begin to schedule harvests throughout the year. It also helps to inform forest management in cases where species presence or absence provides valuable information about site conditions, or where the presence of a particularly valuable species might affect future management interventions.

Methods

The fungal inventory was conducted in each of the three forest stands following a modification of the methods presented by Pilz and Molina (1994). Three 2 by 50 meter (100 square meter) strip plots were located in each management unit following a random stratified design. Plots were oriented such that all major landscape positions were intersected. They were visited twice a month (every 2-3 weeks) From September, 2015 to November, 2015 and From May, 2016 to November, 2016. Within these plots all above-ground clusters of fruiting bodies with a maximum diameter greater than 1cm were identified and recorded. Unique species found outside of the plots were recorded as present in the stand, but no data was collected about the number of individual clusters. Species that could not be definitively identified in the field were photographed, collected, and identified in the lab following the keys in Kuo and Methven (2014), Miller and Miller (2006), and Barron (1999). Where gross morphology was inconclusive microscopic analysis of spore features was used to either identify to species or genus. Some mushrooms were only identified to genus when they were known to form complexes of closely related species (such as Russula) or were in particularly poor physical condition.

Summary

The fungal survey catalogued 79 unique species, including 11 ectomycorrhizal species, 67 saprotrophs, and 1 unidentified "Little Brown Mushroom." Twelve of these species were edible, with 6 of these being "choice" edibles. Unit 1 contained 50 species, of which 10 were ectomycorrhizal, 39, were saprotrophs and one was unidentified. Unit 2 contained 41 species, of which 4 were ectomycorrhizal and 37 saprotrophs. Unit 3 contained 39 species, all of which were saprotrophs.



Edible Species Locations and Fruiting Times

Species	Stands	May	June	July	August	Sept-ember	October
Armillaria gallica	NW,NE, C						
Auricularia auricula	NW,C						
Calvatia gigantea	NE						
Cantharellus cibarius	NW						
Entoloma abortivum	NW,NE						
Flammulina velutipes	NE						
Grifola frondosa	C						
Laetiporus sulferus	C						
Morchella esculentoides	NW						
Morganella pyriformis	NW,NE						
Pleurotus ostreatus	NW,C						
Polyporus squamosus	NW,NE, C						

Notes on Harvest and Management

Among mushroom harvesters there is a perennial debate about the potential to overharvest certain species. Because mushrooms are the fruiting bodies of underground fungal networks, harvest does not directly damage the fungi. But, it is thought that harvest might reduce the number of spores fungi are able to release and impede their ability to spread and reproduce. One interesting study in Switzerland found that over time harvesting mushrooms does not reduce future mushroom yields (Egli et al., 2006). However, they did find evidence that compaction due to increased foot traffic did slightly but significantly reduce yields over time. In general a single mushroom will produce millions, sometimes even trillions, of spores. Therefore, it is unlikely that harvesting will meaningfully affect spore dispersal.

Another concern is the effect that forest management practices like thinning, and harvesting might have on certain fungi. Many mushroom species thrive in very specific environments and any activity that alters the conditions of a forest is likely to produce some amount of change. In general, saprotrophic fungi, particularly the wood-rotting species, will react well to any activity that increases the amount of dead woody debris in a forest. Management that disturbs the soil or damages their hosts might suppress mycorrhizal fungi. Thinning has been shown to reduce the fruiting of chanterelle mushrooms in proportion to its intensity, taking over half a decade to rebound (Pilz et al., 2006). To avoid unnecessary degradation, management activities should be undertaken in the dormant season, preferably when the soil is frozen. Planning lighter interventions or spreading the disturbance over multiple years is recommended in areas with particularly valuable species.

Stand Inventory

Introduction

A forest stand inventory for the three stands was completed on August 4, 2016. The data collection followed the methods used by Hammett and Barnes (1968) in their study of Radrick Forest. Adopting these methods allowed for the collection of relevant stand metrics for inventory and evaluation. They also provided the ability to make direct comparisons to published descriptions of a high-quality old-growth oak-hickory forest in the same region and with a similar management history. This allowed for the use of Radrick Forest as a historical reference for analyzing the site and modeling the forest dynamics.

Methods

Three 10 by 20 meter (1/20 acre) plots were established in each of the three stands using a random-stratified approach that ensured that all major landscape positions were represented. Within these plots all trees greater than 1-inch diameter at breast height (dbh) were measured, identified, and recorded. The individuals were then sorted into three categories: dominant canopy (stems greater than or equal to 12" dbh) subdominant canopy (from 4" to 11.9" dbh), and understory (from 1" to 3.9" dbh). These categories roughly correspond to sawtimber, polewood, and sapling classes in more commercially oriented inventories. Within each plot, a nested quadrat of 0.5 by 8 meters (1 milacre) was established at a random corner. Within these plots tree regeneration was measured by recording all trees under 1 foot in height and all trees over one foot in height but less than 1 inch dbh.

Relative density was simply computed as the number of representatives of any species within a given class divided by the total number of individuals in that class. Basal area was calculated using standard methods found in Bettinger et al. (2009). Stand volume in board-feet was determined by estimating logs per tree as described by Quigley (1954) and utilizing his volume table following the International ¼-inch Rule. Stand area was determined using the Google Maps Area Calculator Tool (DaftLogic, 2007). These results were then evaluated using stocking guides for upland central hardwoods published by the University of Minnesota Extension (2009).

Soils data was collected from the Web Soil Survey app (Soil Survey Staff (2)), official soil series descriptions (Soil Survey Staff (1)), the Soil Survey of Marshall County, Indiana (NCSS, 1978), and the Soil Survey of Washtenaw County, Michigan (NCSS, 1977). Site class was evaluated with the methods described by Carvell and Perky (1997).

Summary of Results

Northwestern Unit

Area	5.1 Acres
Site Class	2
Basal Area	149
Trees per Acre	438
Average DBH	6.0 Inches
Stocking Density	Overstocked

	Stems per Acre			
Species	Seedling	Sapling	Subdominant	Dominant
Acer ruburm	2000	33	27	7
Carpinus Caroliniana	1333	27	0	0
Carya Cordiformis	2000	7	27	0
Carya glabra	2333	0	7	13
Carya ovata	1333	20	0	0
Fraxinus americana	4667	0	0	0
Prunus serotina	333	67	40	0
Quercus rubra	667	13	20	33
Rhamnus cathartica	2000	0	0	0
Tilia americana	1333	0	40	7
Ulmus americana	667	27	20	0
Total	**18667**	**193**	**180**	**60**

	Relative Density				Volume
Species	Understory	Subdominant	Dominant	Total	(board-feet)
Acer ruburm	0.17	0.15	0.11	0.15	4394
Carpinus Caroliniana	0.14	0.00	0.00	0.06	0
Carya Cordiformis	0.03	0.15	0.00	0.08	0
Carya glabra	0.00	0.04	0.22	0.05	17099
Carya ovata	0.10	0.00	0.00	0.05	0
Prunus serotina	0.34	0.22	0.00	0.25	0
Quercus rubra	0.07	0.11	0.56	0.15	43530
Tilia americana	0.00	0.22	0.11	0.11	7153
Ulmus americana	0.14	0.11	0.00	0.11	0
Total	1.00	1.00	1.00	1.00	**72175**

Northeastern Unit

Area	14.5 Acres
Site Class	2
Basal Area	110
Trees per Acre	432
Average DBH	4.9 Inches
Stocking Density	Overstocked

	Stems per Acre			
Species	Seedling	Sapling	Subdominant	Dominant
Acer ruburm	0	120	40	7
Carpinus Caroliniana	333	40	0	0
Carya Cordiformis	667	7	0	0
Carya glabra	333	47	0	0
Carya ovata	2000	13	13	0
Fraxinus americana	14000	0	0	0
Prunus serotina	0	7	13	7
Quercus alba	0	0	13	0
Quercus rubra	0	0	13	33
Rhamnus cathartica	333	7	0	0
Tilia americana	0	7	0	0
Ulmus americana	0	40	0	0
Total	**17667**	**287**	**93**	**47**

	Relative Density				Volume
Species	Understory	Subdominant	Dominant	Total	(board-feet)
Acer ruburm	0.42	0.43	0.14	0.39	12616
Carpinus Caroliniana	0.14	0.00	0.00	0.09	0
Carya Cordiformis	0.02	0.00	0.00	0.02	0
Carya glabra	0.16	0.00	0.00	0.11	0
Carya ovata	0.05	0.14	0.00	0.06	0
Prunus serotina	0.02	0.14	0.14	0.06	6650

Quercus alba	0.00	0.14	0.00	0.03	0
Quercus rubra	0.00	0.14	0.71	0.11	129192
Rhamnus cathartica	0.02	0.00	0.00	0.02	0
Tilia americana	0.02	0.00	0.00	0.02	0
Ulmus americana	0.14	0.00	0.00	0.09	0
Total	1.00	1.00	1.00	1.00	**148459**

Central Unit

Area	6.0 Acres
Site Class	1
Basal Area	72
Trees per Acre	223
Average DBH	5.7 Inches
Stocking Density	Fully Stocked

	Stems per Acre			
Species	Seedling	Sapling	Subdominant	Dominant
Acer sacharinum	5000	33	47	27
Carya glabra	0	7	20	0
Cephalanthus occidentalis	0	20	0	0
Fraxinus americana	1333	0	0	0
Fraxinus pennsylvanica	4000	20	7	0
Rhamnus cathartica	6001	33	0	0
Ulmus americana	0	7	0	0
Total	**16334**	**120**	**73**	**27**

	Relative Density				Volume
Species	Understory	Subdominant	Dominant	Total	(board-feet)
Acer sacharinum	0.28	0.64	1.00	0.48	37433
Carya glabra	0.06	0.27	0.00	0.12	0
Cephalanthus occidentalis	0.17	0.00	0.00	0.09	0
Fraxinus pennsylvanica	0.17	0.09	0.00	0.12	0

Rhamnus cathartica	0.28	0.00	0.00	0.15	0
Ulmus americana	0.06	0.00	0.00	0.03	0
Total	1.00	1.00	1.00	1.00	**37433**

Cost Benefit Analysis

Methods

Forest management is a long-term investment. In the Upper Midwest money and time spent on crop tree release and pre-commercial thinning may not see financial returns for many decades. Those approaching timber stand improvement as an investment may seek alternative short-term revenues to generate cash flow and offset the costs of early improvement activities. This cost-benefit analysis compares the returns of unthinned and thinned forests that are either integrated or not integrated with shiitake mushroom production.

Costs and revenues for shiitake mushroom production were taken from enterprise budgets presented in "Best Management Practices for Log-Based Shiitake Cultivation in the Northeastern United States"(UVM extension, 2013). To create their enterprise budgets they averaged the costs of 13 participating mushroom growing operations in the Northeast. These data were preferred over other published enterprise budgets because they contained more specific estimates of time and costs associated with each step of mushroom cultivation.

Thinning was simulated using crop tree release. Crop tree release costs were taken from Stringer et al. (1988). The higher range of costs was taken as a conservative estimate and projected into 2016 dollars. The benefits of improvement were estimated using changes in mortality rates from Miller et al. (2017) and the University of Tennessee Extension (2007). From these sources it was assumed that overall mortality rate of target species would be cut in half and that they would see a 33% increase in canopy recruitment. These were combined with a conservative estimate of increase in growth of timber volume by 25% annually over a baseline of 190 board-feet per year based on work by Ward (2008) and Creighton (2014). Because timber prices fluctuate widely year-to-year and species-to-species based on local and regional market trends the timber prices used were taken from University of Tennessee Extension's "Technical Guide to Tree Release in Hardwood Forests" (2007). A 50-year rotation length was assumed.

Integration between thinning and shiitake operations was accomplished by assuming that 50 shiitake logs per acre would be produced during crop tree release treatments. This is a reasonable conservative estimate because the average dbh is within the recommended range for shiitake logs, the stand is overstocked by over 100 stems per acre, and half the species in the subdominant class are suitable for the shiitake fungus. Two acres were released each year to supply 100 shiitake logs annually and this process was repeated every 15 years. The costs of crop tree release were included into the annual tree and log cutting and preparation labor for the shiitake mushrooms.

Results

Integrating the management of the forest and the shiitake log business increases the combined net present value (NPV) of the enterprises. At and interest rate of 5% the NPV of the integrated system is $1,832, or 3%, higher than leaving the forest unmanaged. Managing the forest without integrating it into the shiitake business increases NPV by only half a percent. Although integrated management does not increase annual cash flow, the value of the stand by the time it is harvested in year 50 is over $22,000 greater. This is due to the higher merchantable volume in the managed stand and the increase proportion of more-valuable timber species.

	NPV						
Interest Rate	4%	5%	6%	7%	8%	9%	10%
Integrated	$71,563.82	$55,955.82	$44,879.81	$36,820.79	$30,809.11	$26,215.24	$22,624.06
Not integrated	$68,579.57	$54,124.00	$43,750.18	$36,121.00	$30,373.68	$25,943.10	$22,453.26
Difference	$2,984.26	$1,831.82	$1,129.63	$699.78	$435.44	$272.14	$170.81
Increase in Value	104%	103%	103%	102%	101%	101%	101%

This improvement in stand value makes crop tree release a worthwhile investment on its own. At a cost of 85$ an acre it produces a 6% annual rate of return. If costs can be reduced through increased efficiency, low labor costs, or integration into another enterprise this rate of return can be increased.

Limitations

Although short-term returns for products like shiitake mushrooms are likely to be fairly realistic it is much more difficult to predict the outcomes of forestry investments. In fact, enterprise budgets for forestry activities are rarely published. While the costs for a mushroom cultivation business may be reasonably easy to estimate and the payoffs simple to project based on published estimates of per-log productivity forestry investments are not nearly so amenable to accurate prediction (University of Tennessee Extension, 2016). This is due to the larger number of species, the wide ranges of tree quality in extensively managed hardwood stands, variable growth rates, the variability and locality of timber markets, and variations in the intensities of different forestry treatments. At the same time non-tangible costs and benefits from aesthetic preferences and impacts on wildlife habitat are often important parts of forest ownership, but are not considered at all in an economic analysis of timber stand improvement.

Crop Tree Release Costs and Benefits

Summary

Rotation Length	Cost of CTR	Final Value			Returns above No Thinning Treatment		Rate of Return	
Years	Dollars	No Thinning	CTR	CTR+ Growth	CTR	CTR+ Growth	CTR	CTR+ Growth
50	$100.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	4%	6%
50	$85.00				$867.40		5%	6%

		$5,968.68	$6,836.08	$7,658.61		$1,689.94		
50	$80.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	5%	6%
50	$60.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	5%	7%
50	$40.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	6%	8%
50	$20.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	8%	9%
50	$10.00	$5,968.68	$6,836.08	$7,658.61	$867.40	$1,689.94	9%	11%

No Thinning

Year	0	1	2	3	4	5	6	50
Revenue	0	0	0	0	0	0	0	$5,968.67
Total Value	$3,946.45	$3,999.21	$4,051.38	$4,102.94	$4,153.93	$4,204.33	$4,254.16	$5,968.68
% oak	71%	71%	70%	70%	69%	69%	68%	50%
% other	29%	29%	30%	30%	31%	31%	32%	50%

Crop Tree Release (no additional growth)

Year	0	1	2	3	4	5	6	50
Revenue	0	0	0	0	0	0	0	$6,836.08
Total Value	$3,946.45	$4,010.91	$4,075.08	$4,138.96	$4,202.54	$4,265.84	$4,328.85	$6,836.08
% oak	71%	71%	71%	70%	70%	70%	70%	61%
% other	29%	29%	29%	30%	30%	30%	30%	39%

Crop Tree Release (25% increase in growth)

Year	0	1	2	3	4	5	6	50
Revenue	0	0	0	0	0	0	0	$7658.61
Total Value	$3,946.45	$4,029.18	$4,111.54	$4,193.52	$4,275.14	$4,356.39	$4,437.28	$7,658.61
% oak	71%	71%	71%	70%	70%	70%	70%	61%
% other	29%	29%	29%	30%	30%	30%	30%	39%

Shiitake Business Only

Shiitake Enterprise Budget

Year	0	1	2	3	4	5	6	50
Revenue	**$-**	**$1,236.79**	**$2,435.33**	**$3,595.61**	**$4,730.40**	**$4,730.40**	**$4,730.40**	**$4,730.40**
Logs Innoculated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Logs total	100.00	197.00	291.00	382.00	471.00	471.00	471.00	471.00
Fruiting Logs	-	97.00	191.00	282.00	371.00	371.00	371.00	371.00
Lbs/Log	-	1.04	1.04	1.04	1.04	1.04	1.04	1.04

Price/lb	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26
Variable Expenses	$1,519.00	$1,154.00	$1,357.00	$1,452.00	$1,647.00	$1,647.00	$1,647.00	$1,647.00
Tree Cutting								
Chainsaw	$364.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00
Chain	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Sharpening	$37.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Gasoline	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Inoculation								
Drill bit	$30.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Tool	$33.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00
Wax	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00
Grinder Parts	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Spawn	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00
Wax applicator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00
Harvesting and Sale								
Shade Cloth	$124.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00
Bags	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00
Gasoline	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00
Other								
Non-Durable	$71.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00
Durable	$65.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00
Labor								
Cost	$490.00	$678.00	$881.00	$976.00	$1,171.00	$1,171.00	$1,171.00	$1,171.00
Cutting Trees	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
Inoculation	30.70	30.70	30.70	30.70	30.70	30.70	30.70	30.70
Log Maint	6.2	4	4	4	4	4	4	4
Harvesting	0	7.5	14.7	18.1	25	25	25	25
Processing	0	3.8	7.5	9.2	12.8	12.8	12.8	12.8
Selling	0	9.7	19.1	23.5	32.5	32.5	32.5	32.5
Price/hr	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Gross Profit	$(1,519.00)	$82.79	$1,078.33	$2,143.61	$3,083.40	$3,083.40	$3,083.40	$3,083.40
Net Profit	**$(1,519.00)**	**$82.79**	**$1,078.33**	**$2,143.61**	**$3,083.40**	**$3,083.40**	**$3,083.40**	**$3,083.40**

Value of the Shiitake Enterprise

Interest Rate	4%	5%	6%	7%	8%	9%	10%
NPV	$56,869.87	$46,936.27	$39,317.70	$33,375.18	$28,665.10	$24,875.29	$21,783.03

MIRR							
6%	13.34%	13.34%	13.34%	13.34%	13.34%	13.34%	13.34%
8%	14.82%	14.82%	14.82%	14.82%	14.82%	14.82%	14.82%

No Integration

Enterprise Budgets

Year	0	1	2	3	4	5	6	50
Total Revenue	**$-**	**$1,236.79**	**$2,435.33**	**$3,595.61**	**$4,730.40**	**$4,730.40**	**$4,730.40**	**$91,276.19**
Forestry								
Revenue	$-	$-	$-	$-	$-	$-	$-	$86,545.79
Total Value	$57,224	$57,989	$58,745	$59,493	$60,232	$60,963	$61,685	$86,546
Value Oak	$52,703	$53,305	$53,896	$54,477	$55,046	$55,605	$56,154	$71,511
Value Other	$4,521	$4,683	$4,848	$5,016	$5,186	$5,357	$5,532	$15,035
Board ft	148459	151214	153969	156724	159479	162234	164989	286209
Oak bf	105406	106610	107793	108954	110093	111211	112308	143022
Others bf	43053	44603	46176	47770	49386	51023	52681	143187
%oak	71%	71%	70%	70%	69%	69%	68%	50%
%other	29%	29%	30%	30%	31%	31%	32%	50%
Shiitake								
Revenue	$-	$1,236.79	$2,435.33	$3,595.61	$4,730.40	$4,730.40	$4,730.40	$4,730.40
Logs Inoculated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Logs total	100.00	197.00	291.00	382.00	471.00	471.00	471.00	471.00
Fruiting Logs	-	97.00	191.00	282.00	371.00	371.00	371.00	371.00
Lbs/Log	-	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Price/lb	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26
Variable Expenses	$1,519.00	$1,154.00	$1,357.00	$1,452.00	$1,647.00	$1,647.00	$1,647.00	$1,647.00
Tree Cutting								
Chainsaw	$364.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00
Chain	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Sharpening	$37.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Gasoline	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Inoculation								
Drill bit	$30.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Tool	$33.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00
Wax	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00
Grinder	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00

Parts								
Spawn	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00
Wax apllicator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00
Harvesting and Sale								
Shade Cloth	$124.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00
Bags	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00
Gasoline	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00
Other								
Non-Durable	$71.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00
Durable	$65.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00
Labor								
Cost	$490.00	$678.00	$881.00	$976.00	$1,171.00	$1,171.00	$1,171.00	$1,171.00
Cutting Trees	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
Inoculation	30.70	30.70	30.70	30.70	30.70	30.70	30.70	30.70
Log Maint	6.2	4	4	4	4	4	4	4
Harvesting	0	7.5	14.7	18.1	25	25	25	25
Processing	0	3.8	7.5	9.2	12.8	12.8	12.8	12.8
Selling	0	9.7	19.1	23.5	32.5	32.5	32.5	32.5
Price/hr	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Gross Profit	$(1,519.00)	$82.79	$1,078.33	$2,143.61	$3,083.40	$3,083.40	$3,083.40	$89,629.19
Net Profit	**$(1,519.00)**	**$82.79**	**$1,078.33**	**$2,143.61**	**$3,083.40**	**$3,083.40**	**$3,083.40**	**$89,629.19**

Value of the Enterprises Combined

Interest Rate	4%	5%	6%	7%	8%	9%	10%
NPV	$68,579.57	$54,124.00	$43,750.18	$36,121.00	$30,373.68	$25,943.10	$22,453.26
MIRR							
6%	13.57%	13.57%	13.57%	13.57%	13.57%	13.57%	13.57%
8%	14.95%	14.95%	14.95%	14.95%	14.95%	14.95%	14.95%

Integrated Management

Enterprise Budgets

Year	0	1	2	3	4	5	6	50
Total Revenue	**$-**	**$1,236.79**	**$2,435.33**	**$3,595.61**	**$4,730.40**	**$4,730.40**	**$4,730.40**	**$113,332.70**
Forestry								
Revenue	$-	$-	$-	$-	$-	$-	$-	$108,602.30

Total Value	$57,224	$58,253	$59,282	$60,312	$61,344	$62,377	$63,414	$108,602
Value Oak	$52,703	$53,548	$54,393	$55,239	$56,088	$56,938	$57,792	$94,854
Value Other	$4,521	$4,705	$4,889	$5,073	$5,256	$5,439	$5,621	$13,749
Board ft	148459	151903	155347	158790	162234	165678	169122	320647
Oak bf	105406	107096	108786	110479	112175	113877	115585	189707
Others bf	43053	44807	46560	48311	50059	51801	53537	130939
%oak	71%	71%	70%	70%	69%	69%	68%	59%
%other	29%	29%	30%	30%	31%	31%	32%	41%
Shiitake								
Revenue	$-	$1,236.79	$2,435.33	$3,595.61	$4,730.40	$4,730.40	$4,730.40	$4,730.40
Logs Inoculated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Logs total	100.00	197.00	291.00	382.00	471.00	471.00	471.00	471.00
Fruiting Logs	-	97.00	191.00	282.00	371.00	371.00	371.00	371.00
Lbs/Log	-	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Price/lb	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26	$12.26
Variable Expenses	$1,519.00	$1,154.00	$1,357.00	$1,452.00	$1,647.00	$1,647.00	$1,647.00	$1,647.00
Tree Cutting								
Chainsaw	$364.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00	$73.00
Chain	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Sharpening	$37.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Gasoline	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Inoculation								
Drill bit	$30.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Tool	$33.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00
Wax	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00
Grinder Parts	$36.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00	$7.00
Spawn	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00	$110.00
Wax applicator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00
Harvesting and Sale								
Shade Cloth	$124.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00
Bags	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00	$21.00
Gasoline	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00
Other								
Non-Durable	$71.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00	$67.00
Durable	$65.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00
Labor								
Cost	$490.00	$678.00	$881.00	$976.00	$1,171.00	$1,171.00	$1,171.00	$1,171.00
Cutting Trees	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
Inoculation	30.70	30.70	30.70	30.70	30.70	30.70	30.70	30.70
Log Maint	6.2	4	4	4	4	4	4	4

Harvesting	0	7.5	14.7	18.1	25	25	25	25
Processing	0	3.8	7.5	9.2	12.8	12.8	12.8	12.8
Selling	0	9.7	19.1	23.5	32.5	32.5	32.5	32.5
Price/hr	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Forestry								
CTR	0	0	0	0	0	0	0	0
Gross Profit	$(1,519.00)	$82.79	$1,078.33	$2,143.61	$3,083.40	$3,083.40	$3,083.40	$111,685.70
Net Profit	**$(1,519.00)**	**$82.79**	**$1,078.33**	**$2,143.61**	**$3,083.40**	**$3,083.40**	**$3,083.40**	**$111,685.70**

Value of the Integrated Enterprises

Interest Rate	4%	5%	6%	7%	8%	9%	10%
NPV	$71,563.82	$55,955.82	$44,879.81	$36,820.79	$30,809.11	$26,215.24	$22,624.06
MIRR							
6%	13.63%	13.63%	13.63%	13.63%	13.63%	13.63%	13.63%
8%	14.98%	14.98%	14.98%	14.98%	14.98%	14.98%	14.98%

Model

Introduction

In order to inform decision-making and illustrate the potential management outcomes a simplified model of forest succession was developed. The model was based on the JABOWA-FORET type canopy gap model (Botkin et al., 1972a; Botkin et al., 1972b; Shugart and West, 1977). The model is not a predictor of exact future outcomes, but rather a tool that considers the life-history traits of the twelve species recorded during the stand survey and the general dynamics of their competition for light and soil resources. This was accomplished by considering nine species-specific growth parameters and two environmental variables. Because comparison between several sites with substantially different physical characteristics was not considered important for the purposes of this model, parameters and subroutines dealing with variable site conditions were dropped or simplified from previously published versions of the model.

Description of the Model and its Routines

The model was based on the core assumptions of Botkin et al. (1972b), modifications by Shugart and West (1977), with changes made in order to model drivers specific to the context of southern Michigan. The model operates as a self-contained unit in Microsoft Excel For Mac 2011, Version 14.7.1. The original models were run on IBM computers using data cards, and magnetic tape to input and store data. In order to manipulate the model into a form that could be run in a spreadsheet program, the subroutines were re-written as single lines of equations and copied into individual columns.

Each individual tree in the model is represented by a set 6 states each represented by column in the spreadsheet: its life-stage (net yet born, alive, recently deceased, and dead), whether it will be born in a given year, whether it will die in a given year, its diameter at breast height (dbh) in cm, its height in cm, and its leaf area in square meters. The values of each of these states were based on values provided in the Inputs, Parameters, and Birth spreadsheets. They were then used to calculate the next years values in the Parameters and Birth sheets. States were calculated in annual increments with each row of the model representing a single year.

Growth

Growth was based on a series of equations from Botkin et al. (1972). The height, H, of a tree of D dbh is determined as:

$$H = 137 + b_2D - b_3D^2$$

With:

$$b_2 = 2(H_{max}-137)/D_{max} \quad \text{and} \quad b_3 = (H_{max}-137)/D^2_{max}$$

Where H_{max} and D_{max} are species-specific parameters equivalent to the maximum height and diameter respectively reached by individuals of each species. The leaf area *L* of each tree with dbh *D* was calculated as:

$$L = C/15 \times D^b$$

Where C is a constant varying by tree tolerance type, and b is a constant with value 2.939 (Shugart and West, 1977). From the leaf area of each individual tree its light extinction was calculated using:

$$Q(h) = Q_0 \exp - k \int_h^\infty LA(h')d(h')$$

In which Q_0 is the full incident radiation (available light) at the top of the canopy; *Q(h)* is the radiation left at height *h*; k is a constant equaling 0.25; and the integral represents the sum of all leaf areas of each tree taller than height h. For practical purposes the sums of leaf areas were binned in in one-meter increments. The shading of each tree (*AL*) was then used to calculate the next year's growth reduction *r(AL)* via the two following equations.

For shade-tolerant species (Tc = 1 or 2):

$$r_s(AL) = 1 - \exp(-4.64(AL - 0.05))$$

For shade-intolerant species (Tc =3):

$$r_i(AL) = 2.24(1 - \exp(-1.136(AL - 0.08)))$$

Under optimal conditions *r(AL)* will equal 1.

Growth is also slowed by other-than-optimal temperatures and below-ground competition. To model the effects of temperature on growth the cooling degree days for the northern and southern range limits of each species were input as its $DEGD_{min}$ and $DEGD_{max}$ with a base temperature of 42°F. The species-specific reduction of growth, *T(DEGD),* was calculated by the parabolic function:

$$T(DEGD) = (4\,(DEGD - DEGD_{min})(DEGD_{max} - DEGD))\,/\,(DEGD_{max} - DEGD_{min})^2$$

This function has a maximum value of 1 and a minimum of 0 dependent on the annual growing degree days (*DEGD*). Root crowding and competition are simplified by the function:

$$S(BAR) = 1 - BAR/SOILQ$$

Where *BAR* is the total basal area of the stand, *SOILQ* is the maximum basal area measured for that site, and *S(BAR)* is the subsequent reduction of growth caused by

BAR approaching *SOILQ.* Within the model the basal area is calculated in square centimeters within a 10x10 meter plot.

These growth factors are combined in the final growth equation:

$$dD/dt = (GD\ (1 - DH/D_{max}H_{max}))/(274 + 3b_2D - 4b_3D^2) \times T(DEGD) \times S(BAR) \times r(AL)$$

Where *G* is the annual growth increment, determined manually so that each tree will approach 2/3 of its D_{max} by 1/2 of its maximum age (*AGMX*).

Birth

New saplings of 1.27cm dbh are introduced into the model through the BIRTH sheet. This could happen one of three ways: by direct introduction through 'planting' on the inputs sheet, through a stochastic annual birth process, or by means of simulated stump spouting in the year following the death of a tree. There are three available plantings on the input sheet. For each the number of saplings to be added and the year in which to add them may be specified. The annual birth process generates between 0 and 2 random integers between 1 and the maximum number of species in the model run. Each number generated is representative of a specific species based on its 'Rank' on the input sheet. If the species is eligible to reproduce in that year then a sapling is added for each time the species' rank is produced. Eligibility of reproduction is determined by whether the degree-days (*DEGD*) input for that year falls between the $DEGD_{min}$ and $DEGD_{max}$ for a given species, and whether the herbivore pressure input (between 0, none, and 3, high) results in that species being browsed. A palatability value was assigned to each species such that no species would be browed with no browse pressure (0) and all species but Rhamnus cathartica would be browsed under high browse pressure (4). If a species is eligible to reproduce and one of its individual trees with a dbh greater than *SPRTMN* died in the previous year then between 0 and *SPRTND* saplings are added based on a random integer. *SPRTMN* is the minimum sized tree that is capable of stump sprouting and *SPRTND* represents the maximum number of successful stump sprouts allowed for that species.

Death

Trees experienced death at a rate such that the probability of each tree reaching its *AGEMX* value is 2%, following the example of Botkin et al. (1972b). This was approximated by the equation:

$$E = 4.0 / AGEMX$$

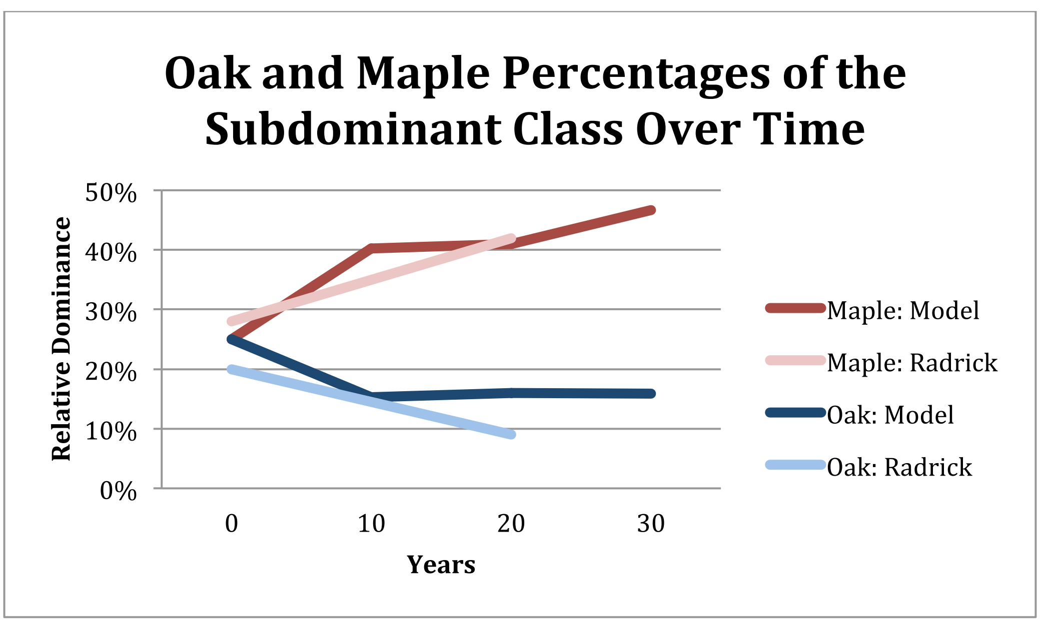
Where E is the probability of death in any given year. A tree whose annual growth in diameter has fallen below 0.01cm is subjected to an additional 0.368 probability of death. This results in a 1% chance of surviving ten years of extremely suppressed growth.

Parameterization

For species without previously documented $DEGD_{max}$ and $DEGD_{min}$ values, geographic ranges were determined by maps supplied by Hardin et al. (2001), Fowells (1965), and Kurylo et al. (2007). These ranges were then used in conjunction with the Degreedays.net web application (2017) to determine the average number of cooling degree days, base 42°F, for that location over the past five years (the longest average possible within the application). For each of the twelve species their maximum age, *AGEMX*, maximum diameter, D_{max}, and maximum height, H_{max}, were determined from species descriptions in Hardin et al. (2001), Fowells (1965), Barnes and Wagner (2004), and the USDA Fire Effects Information Sysetem (2017). *SPRTMN* and *SPRTND* were taken from Fowells (1965) via Shugart and West (1977) and personal experience. Where data were unclear or unavailable entries for closely related species were used as a baseline. Palatability was modified from Bradshaw and Waller (2016) and supplemented with descriptions in Fowells (1965) and the USDA Fire Effects Information Sysetem (2017).

Validation

In order to verify that this model could simulate the general stand dynamics of an Oak-Hickory forest in Southeast Michigan, a 10x10 meter plot representative of an average plot in Radrick Forest in 1968 was recreated in the model. The species composition and size class distributions followed descriptions by Hammitt and Barnes (1989). The major trends observed by Hammitt and Barnes between 1968 and 1988 were declining relative dominance of oak species in the subdominant class and increasing dominance of maple species in the same class. An average of 100 model runs was taken and compared to the changes in dominance in Radrick Forest.



	Maple species			Oak Species		
Model	Total RD	SubDom	Dom	Total RD	SubDom	Dom
Year 0	11%	25%	0%	73%	25%	100%
Year 10	12%	40%	0%	79%	15%	100%
Year 20	12%	41%	0%	78%	16%	100%
Year 30	12%	47%	2%	77%	16%	97%

Radrick	Total RD	SubDom	Dom	Total RD	SubDom	Dom
1968	33%	28%	0%	19%	20%	88%
1988	37%	42%	1%	14%	9%	82%

Overall stand dynamics were very similar in the model to those in Radrick forest. The average relative dominance of subdominant maples increased from 25% to 41% in the model compared to 28% to 42% in Radrick Forest. For oak species the average relative dominance in the subdominant class went from 25% to 16% in the model, closely following the trend from 20% to 9% in Radrick Forest.

The growth response to overstory release, crown release, and understory thinning were also simulated. These release cuts should all increase growth with overstory release increasing growth the most of the three, and understory thinning increasing growth the least. Overstory competition was simulated growing a 10-inch dbh and 20-inch dbh tree in the same plot. Release occurred in year 50 when the larger tree was removed from the model. Removal resulted in substantially increased understory growth, leading to 5.8 more inches of dbh growth by year 100. Crown release was simulated by growing three 10-inch for 50 years and removing two in year 50. The remaining tree grew by an additional 4.1-inches dbh by year 100. The understory release simulated a "thinning from below" or basal area reduction cut. This was simulated by growing 8 2-inch dbh trees bellow a 10-inch dbh tree for 50 years and then removing the smaller trees in year 50. This resulted in a smaller increase in growth than either of the other treatments with 1.6 additional inches of dbh gained by year 100 over unthinned plots.

Results and Discussion

A plot typical of the species composition and structure of Unit 2 was created and modeled for 100 years under 8 different scenarios:

1. No management (No Mgmt)
2. No management and low deer pressure (No Mgmt+LD)
3. Clear cut in year 50 (CC)
4. Clear cut in year 50 with low deer pressure (CC+LD)
5. Clear cut in year 50 with buckthorn removal in years 45 and 55 (CC+BC)
6. Clear cut in year 50 with buckthorn removal in years 45 and 55 and oak planting following harvest (CC+BC+QP)

7. Clear cut in year 50 with buckthorn removal in years 45 and 55, thinning in years 30 and 80, and oak planting following harvest (CC+BC+T+QP)
8. Clear cut in year 50 with buckthorn removal in years 45 and 55, thinning in years 30 and 80, and oak planting following harvest with low deer pressure (CC+BC+T+QP+LD)

Species	Buckthorn				Maples				Oaks			
Class	Under	Sub Dom	Dom	Total	Under	Sub Dom	Dom	Total	Under	Sub Dom	Dom	Total
No Mgmt	11%	10%	5%	8%	13%	26%	16%	18%	23%	17%	59%	46%
No Mgmt+LD	7%	9%	3%	6%	10%	21%	16%	17%	30%	23%	65%	47%
CC	13%	21%	33%	28%	8%	13%	23%	19%	17%	21%	0%	9%
CC+LD	9%	20%	26%	23%	7%	19%	16%	19%	24%	20%	0%	9%
CC+BC	13%	14%	24%	20%	10%	17%	29%	22%	17%	20%	0%	9%
CC+BC+QP	8%	8%	12%	10%	9%	11%	27%	20%	18%	47%	0%	21%
CC+BC+T+QP	13%	13%	0%	9%	10%	3%	45%	17%	17%	68%	0%	39%
CC+BC+T+QP+LD	10%	13%	0%	11%	8%	7%	40%	19%	21%	64%	0%	32%

Lower deer pressure did not have a consistent effect on species composition, likely due to the already random nature of sapling recruitment in the model. In general all scenarios followed a trend towards increased buckthorn dominance, fairly stable maple dominance, and declining oak dominance. The clearcut treatment substantially decreased oak dominance by year 100 to 9% and increased buckthorn dominance above 25%. Buckthorn control by removal five years before and after harvest was not sufficient to reduce buckthorn dominance and increase oak dominance by year 100. The addition of oak planting suppressed buckthorn encroachment and doubled oak dominance in year 100. Adding thinning treatments in years 30 and 80 did not provide further buckthorn suppression but nearly doubled oak dominance once more. Although none of the clearcut scenarios resulted in oak dominance of the overstory by the end of the model run, the CC+BC+T+QP scenario lead to 64% oak dominance of the subdominant class. This creates conditions where oaks are likely to be recruited into the overstory as the forest continues to mature following the stand-replacing harvest during year 50.

These scenarios highlight several important considerations for the management of oak-hickory forests. First, the historic conditions that allowed these forests to naturally regenerate true-to-type following stand-replacing disturbances are no longer present. Now forests will go through a prolonged phase of invasive dominance if these species are present in the seed or sapling banks. Oak species, which once would have dominated the young stands, are heavily repressed by these invasive species and forests may mature straight into more mesic types dominated by shade tolerant species. Second, targeted management interventions have the potential to dramatically reduce these impacts. Facilitating oak regeneration and selectively thinning can produce stands that are much more similar to historic conditions than "hands-off" management.

Limitations

Although a simple gap-canopy model can succeed in generally describing the successional processes of forest patches and species interactions, they rely on many simplifying assumptions. The first and most obvious of these is dimensionality. This class of model sidesteps a lot of complicated calculations by assuming that all trees are essentially growing at the same point in space and that their canopies extend throughout the area being represented. This fails to account for differences in competition based on distances between individuals, how light might travel through a complex, three dimensional canopy, and how these subtleties affect the conditions actually experienced by individuals. This model also does not account for complex ecological interactions such as facilitation, allelopathy, changes in decomposition rates due to differences in litter chemistry, or hydraulic modification. Limiting all belowground interactions to simply a maximum potential basal area is also a gross generalization that fails to account for any nutrient cycling or water dynamics, and the effects of sequential harvests on forest soil conditions. On a more basic level the simplified assumptions for growth and regeneration also create difficulties in calculating harvest volumes, and variations in regeneration success as conditions change.

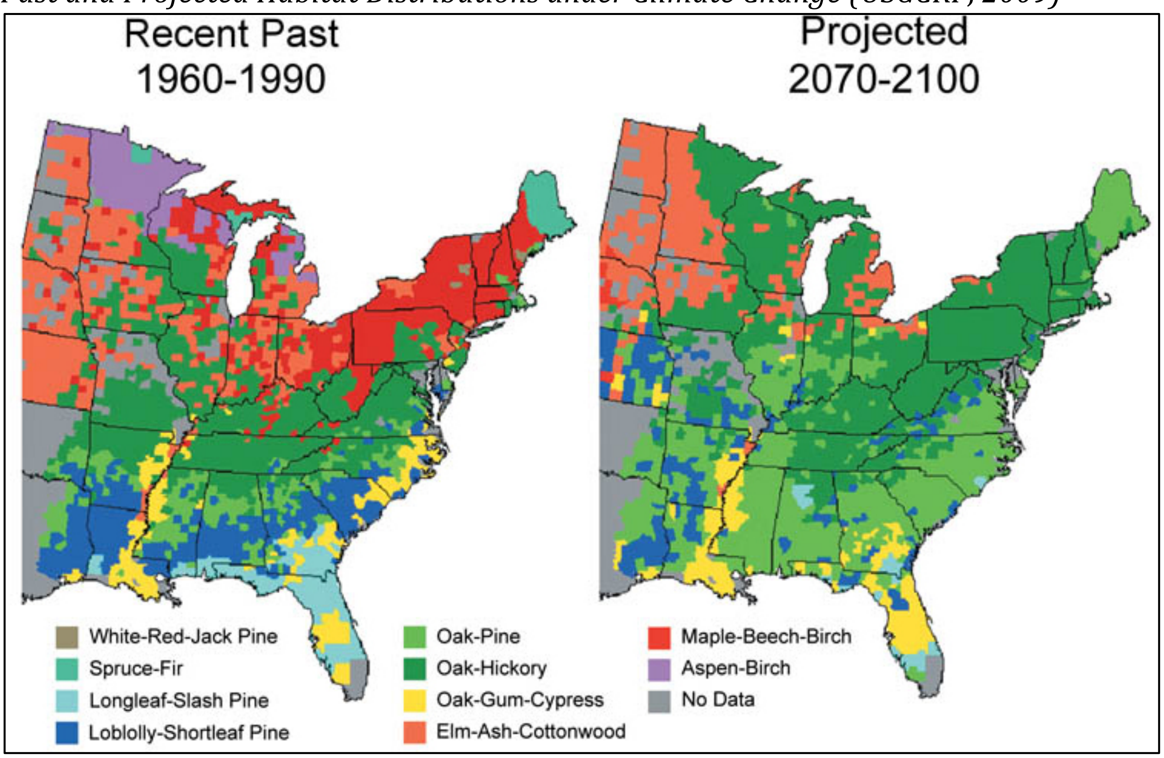
Clearly the results of this model have to be taken for what they are worth and not treated as a guaranteed outcome. The model's value lies in its ability to simply and clearly demonstrate how different management interventions can push a stand in different successional directions. This provides ecologically-based environmental hypotheses upon which adaptive management frameworks can be developed.

Oak-Dominated Forest Regeneration and Management

The Nature and Nurture Site

The timber stands along the northern property line are derived from the much larger expanses of historic oak-hickory forest that could be found on the farm and much of the surrounding county in the 1800s (Comer and Albert, 1997). In Michigan the oak-hickory community was typical of dry-mesic sites on sandy to loamy soils in the southern part of the Lower Peninsula (Kost et al., 2007). The canopy is most often dominated by one or several oak species, with white oak (*Quercus alba*) being most common, codominating with black oak (*Q. velutina*) on drier sites and red oak (*Q. rubra*) on more mesic soils and topographic positions. As the name of this forest type implies shagbark hickory (*Carya ovata*), pignut hickory (*C. glabra*), and bitternut hickory (*C. coriformis*) are frequent codominants. It is commonly postulated that, historically, relatively frequent low-intensity fires maintained lower tree densities, which helped to sustain oak advance regeneration. As fires were increasingly suppressed post European settlement the forest canopies closed and regeneration of the oak component was interrupted (MNFI, 2007). The results of the stand surveys suggest that most of these stands have maintained their characteristic oak-dominated overstory. However, over most of the area oak regeneration has been effectively halted, a trend that has been observed broadly throughout the Midwest (Goins et al., 2013; Knoot et al., 2015).

Past and Projected Habitat Distributions under Climate Change (USGCRP, 2009)



A trend away from oak-dominated forest types is not necessarily unprecedented, as southeast Michigan has historically contained a mixture of oak-hickory, beech-maple, and elm-ash-cottonwood forests. However, United States Global Change Research Program projections show a marked probability of future trends towards conditions that will favor oak-hickory types over the others in the region (USGCRP, 2009). Also noteworthy are diseases of beech, ash, and elm that make it unlikely that they will continue to dominate or co-dominate forests in the Midwest over the next century. It should also be considered that acorns represent a major food source for wildlife that cannot be replaced by the fruit of maple species (McShea et al., 2007). So, for the future conservation of both diverse forests and wildlife the continued maintenance of oaks on the landscape is essential.

Mesophication and Fire

In many oak-dominated forests the trend of increasingly poor oak recruitment is the result of "mesophication", a change in forest conditions due largely to the disruption of historic fire regimes (Nowacki and Abrams, 2008). It is widely accepted that time since stand establishment leads to decline of oak and rise of the more shade tolerant maple (Goebel and Hix, 1997). In particular, after an initial major disturbance oak recruitment all but halts and is followed by pulses of maple establishment (Hutchinson et al., 2008). Historically infrequent stand-replacing fire was the disturbance mechanism in these forests leading to stand replacement, with lower intensity fires thought to occur at intervals averaging around a decade. These natural and anthropogenic fires maintained the viability oak-dominated forest ecosystems (Abrams, 1992). Recently active fire suppression has coincided with a century in which droughts have been less intense and less frequent (McEway et al., 2011). This has resulted in the absence of conditions favorable to strong oak regeneration and recruitment, with fire-sensitive early-successional species dominating open areas, and shade tolerant species slowly replacing oaks in mature stands.

Herbivory and Seed Predation

Deer abundance may also be playing a role in the decline of oaks. Following overexploitation in the late 1800s, restrictions placed on hunting have now resulted in historically high populations of deer. In recent decades white-tailed deer (*Odocoileus virginianus*) have been shown to alter plant communities and make persistent changes to the structure of forests (Cote et al., 2004). Deer are now playing a keystone role in forests by limiting regeneration of important species, including oaks (Rooney and Waller, 2003). Deer-browse begins to affect the larger size-classes and eventually the composition of the forest canopy after several decades of impacted regeneration (Bradshaw and Waller, 2016).

Because deer seem to preferentially browse oak species over maple species (Strole and Anderson, 1992) attempts have been made to restore balance by reducing the size of the deer herd. Although some herd control efforts have quickly yielded positive results (Chollet et al., 2016), others have resulted in limited or substantially delayed benefits (Royo et al., 2010; Tanentzap et al., 2011). These results may be due to long-term depression of growth rates, depletion of seed sources, a legacy of alternate floral communities, or the preferential selection of browse by deer populations, even following reduction (Tanentzap et al., 2012). Furthermore, not all of the effects of reduced deer herbivory are necessarily positive (Webster et al., 2017), and in some cases deer may actually improve growth rates for established oaks (Lucas et al., 2013).

Although deer have been accused of also consuming acorns before germination exclosure studies in Illinois have shown that acorn consumption by deer is not a likely cause of germination failure as mice can consume over 90% of acorns on the forest floor after deer and squirrels have been excluded(Haas and Heske, 2005). Squirrels may in fact be beneficial for oak recruitment, as squirrel-buried acorns germinated at higher rates and may be protected from mortality caused by disturbances such as fire (Haas and Heske, 2005). Other research has indicated that the effects of high deer populations on other vertebrates are generally minimal during years of high acorn production (McShea, 2000), reinforcing the notion that they are not major seed predators.

Legacy Effects

The slow decline of oak recruitment can lead to persistent legacy effects that make the restoration of historic species composition difficult. The transition to more shade tolerant maple species as the stand ages can result in denser canopies with fewer gaps (Goebel and Hix, 1997). Opening the canopy in the absence of fire results in conditions most favorable to early successional species such as yellow poplar (*Liriodendron tulipifera*) (Van Gundy et al., 2013). Even thin-barked maples can become resistant to the moderate intensity fires that result from controlled burning if they have grown large enough (Arthur et al., 2012). Over time the replacement of oak leaf-litter with that of maple species results in faster litter decomposition, less litter overall, decreases in plant available nitrogen, and reduced flammability of the litter layer (Nowacki and Abrams 2008, Alexander and Arthur 2014). When added to already lower populations with fewer seed-sources these effects make the recovery of oak recruitment challenging.

Past Extinctions

The loss of major keystone species such as the American chestnut (*Castanea dentata*) and the passenger pigeon (*Ectopistes migratorius*) may also have a role in changing the role of oaks (McEwan et al., 2011). Although difficult to quantify, the reliance of many small mammals on acorns might be related to the loss of the American chestnut and an increased pressure on oaks as the main mast-producing trees (McShea, 2000). Alternatively, the loss of the chestnut may have provided a niche in forest canopies that would have otherwise been unavailable to many oak species, resulting in greater oak prevalence than the historic norm. Again, work by Goins et al. (2013) and Knoot et al. (2015) indicates that this is not the case and that oaks in general have been in decline for well over a century.

The role of the Passenger pigeon is also difficult to fully quantify. Passenger pigeons are famous for travelling in massive flocks that followed major mast events. These flocks could contain hundreds of millions of birds so their mast consumption, their fecal deposits, and the physical damage caused by their roosting were almost certainly major drivers of forest disturbance (Ellisworth and McComb, 2003). It is speculated that fecal deposits could reach a half-meter in depth and cause the mortality of hundreds of kilometers of forest at a time. These dead trees and the fallen debris caused by feeding and roosting likely contributed fuel for wildfires and interacted with their frequency and severity. Recent genetic research has suggested that passenger pigeons experienced wildly fluctuating populations similar to "outbreak species" of insect pests adding further complexity to the historic size, severity, and frequency of their disturbances (Hung et al., 2014).

Management Strategies

Although many decades of foundational conservation and restoration dialogue centered on allowing "natural" processes to run their course in the inevitable march towards "climax communities" these approaches ignore the complex, dynamic structure of forest ecosystems and the potential for succession to follow multiple paths, some of which will not lead to desirable results (Christensen Jr., 2014). All forests can potentially be thought of as responsive ecosystems existing on a continuum from stand initiation, to stem exclusion, to understory reinitiation, to complex (old growth) stages (Johnson, 2004). The conditions of any particular stand are a combination of internally derived changes -like forest succession- and externally derived changes –like a stand-replacing forest fire. In the context of oak forests different combinations of biotic and abiotic drivers can result in anything from open savannahs, to rich oak-hickory stands, to dry oak-pine barrens. In the oak-hickory forests the tendency for oak species is to develop bell shaped size-class distributions over time, where they are overrepresented in larger classes and underrepresented in new growth (Stout, 1991). For this reason some level of disturbance is necessary for continued, long-term oak dominance. Focus on the conservation of mature forest has come at the cost of conserving other early-successional stages of forest development in North America, leaving these stages underrepresented on the landscape (King and Schlossberg, 2014)

Clear-cutting

Traditional timber stand management in the United States is an even-aged management system centered around periodic clear-cutting. In an oak-dominated hardwood setting management would typically follow a process such as that described by Roach and Gingrich (1968). An even-aged plan would generally allow for the removal of the entire overstory, natural regeneration from sprouts, seedlings, and germination, and periodic thinning cuts. The rotation would typically be longer than 80 years, so the payoff to this style of management could be many decades after committing to costs associated with pre-commercial thinning. These costs are eventually recovered through increased yields or mitigated with tax deductions or possible sales of the smaller stems (Miller, 1984). Thinning focuses on removing undesirable species, poorly formed or slow-growing individuals, and reducing the density of stems as the trees increase in diameter to allow for continued rapid growth. Although most economical at large scales, these methods can be scaled down to smaller woodlots, or to create many units on staggered rotations (and steady income). As the size of the stands clear-cut decrease the line between even-aged management and some uneven-aged treatments begins to blur.

Clear-cutting in many ways mimics the stand-replacing events that have sustained oak forests for thousands of years. Thinning may also promote healthier trees that are more resilient to disease pressures (Stout et al., 1995). However, this practice faces cultural resistance to harvesting large areas of forest, and tends to downplay habitat conservation goals in favor of economic outcomes. It also has failed to guarantee the regeneration of higher-value oak species. Desirable regeneration is characterized as at least 1000 seedlings over 2 feet tall per acre (Wisconsin DNR, 2009) and if this is not achieved then there may not be enough quality individuals to select from when thinning. Evidence indicates that clear-cutting stands already undergoing mesophication is not enough to restore oak regeneration and likely accelerates the loss of oak dominance (Gould et al., 2005). Research on standard intermediate thinning shows little promise in mitigating this decline with business as usual (Dwyer et al., 2007).

Burning

If removing fire from the landscape has hampered the regeneration of oak-hickory forests, then the re-introduction of periodic fires through controlled burns seems to be an obvious solution. However, the reintroduction of fire has produced mixed results (Arthur et al., 2012; McEwan et al., 2011). Although the historic importance of fire is rigorously documented, the drivers of “mesophication” are more complex than this single loss. Nevertheless, fire is probably required to help oak and hickory seedlings remain competitive while waiting for naturally proceeding gap dynamics to take place (Iverson et al., 2008; Hutchinson et al., 2005).

Historically, fires might have been highly variable in severity, scale, and frequency. Many forestry programs aim to restore the mean fire frequency of 5-12 years to oak-hickory forests in the Midwest by introducing low-intensity burns at regular intervals. In almost all cases intense flames are discouraged and fire reaching the canopy is prevented. These practices, while important for safety, do represent the interests of modern forest managers at least as much as they do the ecological role of fire in pre-settlement forests. While oak species tend to have thick bark, store resources underground and away from fire, and create a relatively flammable litter layer, they are also vulnerable to fire mortality in their juvenile stages. Small oaks can be top killed by fire and it may take 10-30 years of no fire for an oak sapling to grow large enough to survive additional fires (Arthur et al., 2012). So, although fire is useful for opening the canopy, reducing ground cover competition, and creating conditions favorable for oak regeneration it is also capable of halting the regeneration process.

Fire for oak seedling recruitment should be kept below rates of 5 per decade, and ideally vary in frequency and seasonality (Brewer, 2014). These initial burns are intended to prepare the seedbed, reduce understory competition, and increase canopy gaps. After recruitment has been established fire may have to be withheld for up-to several decades until oaks are nearly 15 cm dbh (Arthur et al., 2012). Stump sprouts may mature faster if conditions are right. In these years burning may be halted altogether and replaced by pre-commercial thinning as the major disturbance, or selected oaks can be protected by fire-breaks.

Deer Control

Even under ideal conditions oaks will not be able to compete with other species if they are preferentially browsed by deer. Browse control has been shown to be an important element that interacts with fire and canopy thinning treatments (Van Gundy et al., 2014). Unfortunately, herd reduction is not a realistic goal on an unfenced private parcel with high deer abundance on neighboring land. In cases where significant damage due to deer has been documented Deer Management Permits and Deer Damage Permits may be available from the State of Michigan, and could represent an additional source of capitol for landowners.

Deer reduction alone is not likely to be sufficient for the maintenance of an oak-hickory forest. Although woody regeneration has been shown to increase after deer population reductions (Jenkins et al, 2015), it is notable that none of the species regenerating were oaks. Other studies targeting specific communities have shown rather limited success (Royo et al., 2010; Tanentzap et al., 2011).

If the regeneration of oak species is low and deer browsing is a major concern, additional steps will have to be taken to protect seedling and sapling trees. Fencing off small areas and providing tree guards for vulnerable groups or individuals represents extra outlay of both labor and capitol, but may be the only way to maintain historic forest community structure alongside unprecedented deer abundance.

Shelterwood and Canopy Thinning

Another management intervention targeted at increasing oak regeneration is to increase light penetration to the forest floor through shelterwood cutting or canopy thinning. These are typically a two-step process with an initial harvest reducing cover to around 40-60% and a second harvesting cut 5-10 years later after advance regeneration has been established (Wisconsin DNR, 2009). In shelterwood the thinned species are often killed with herbicides and left to stand as snags, while canopy thinning is another commercial or pre-commercial thinning operation with the additional goal of improving regeneration.

Site conditions may also play an important role in how much the canopy must be opened and how effective it will be as a treatment. For oak regeneration on dry sites thinning should aim for increasing canopy openness above 8.5% and up to 19% and on moist sites further thinning may be necessary (Iverson et al., 2008). Loftis (1990) describes the results of a range of treatments across a gradient of site qualities, concluding that less productive sites require lower stand reductions than on high-quality sites.

Because shelterwood and canopy thinning treatments increase the amount of light reaching the forest floor, they create conditions where oak species with intermediate shade tolerance are favored over shade tolerant species such as maples. Unfortunately, thinning may result in conditions where fast growing, shade intolerant species can outcompete oaks. Brose (2011) examined the effects of several shelterwood treatments and concluded that although clear-cutting produced the greatest short-term oak survival the oaks were not dominant after year 8 in intermediate to mesic sites, giving way to competition. Therefore, facilitation of oak-hickory regeneration within mature forests requires both burning and canopy thinning in at least some cases (Holzmueller et al., 2014) and some studies have only found thinning effective when combined with at least two burns (Iverson et al., 2008).

Uneven-age Management

Due to issues resulting from even-aged management including regeneration failures, erosion and water quality concerns, and loss of increasingly scarce mature-forest habitats more sustainable alternatives have been sought after. Uneven-age management can range from retaining single trees in a clearcut to single-tree selection from a mature stand. Single-tree selection is typically favored in northern hardwood forests where there is an adequate component of high value species and regeneration of shade-tolerant species is in line with the ecology of the forest community (Leak et al., 2014).

Green tree retention cuts (GTR) are just modified clearcuts. In the case of GTR "lifeboat" trees are left to provide certain ecosystem functions. The trees left behind might be sources of seed for natural regeneration, provide inoculum for ectomycorrhizal fungi, become refugia for insects, small mammals or lichens (Rosenvald and Lohmus, 2008). Although promising there is a lack of data supporting this method in most forest types and for the longer time frames relevant to forest management.

An expansion on the GTR approach is two-aged management, sometimes called "shelterwood-with-reserves." Two-aged management creates two or more age cohorts growing together. One way to create these cohorts is to harvest most of the stand at the rotation age, leaving behind around 12-15 trees per acre. These trees should be about half as old as the rotation length. Regeneration from this point creates the new young cohort. Two-age management has been shown in at least one case to lead to satisfactory regeneration of oak species (Miller and Kochenderfer, 1998; Perkey et al., 1999) although further management may be needed to maintain this success (Miller et al., 2006).

Typically the intermediate approach of group or patch selection harvests are considered most appropriate to for oak-hickory forests (Wisconsin DNR, 2009). Group or patch selection favors the development of forest with diverse age classes through small clearcuts (removing everything), regeneration or release cuts (removing the canopy layers), or shelterwood cuts (to maintain certain species or sell a proportion of the mature stock). For initiating oak regeneration this might look like a targeted shelterwood removal from below followed by a release harvest of the overstory, or a group selection adjacent to oak seed trees (Leak et al, 2014). For trees with intermediate shade tolerance such as oaks the patch size is recommended to be a half-acre or larger or at least 150 ft in diameter (Wisconsin

DNR, 2009). After harvest the maintenance of these patches is treated much like a miniaturized clearcut, with intermittent release and thinning cuts. In fact, at smaller scales these patch selection cuts approach the adaptations of even aged management to smaller woodlots recommended by Roach and Gingritch (1968).

A variation on this approach is Variable Density Thinning (VDT). VDT explicity aims to restore or maintain structural heterogeneity in managed stands by thinning in "skips and gaps." This method combines group harvest approaches in the "gap" treatments with prescriptions for unthinned areas, or "skips." Intermediate thinning is undertaken throughout the remainder of the stand. This process is intended to speed the restoration of heterogeneous forest structures such as valuable structures or species skips, large trees in thinned areas, and early successional trees in the gaps (Stanturf et al., 2014). The main downside to this approach is that the focus on forest complexity dramatically increases management complexity while limiting opportunities for economic returns.

A general drawback to uneven-age management of oak forests is that oaks have historically performed well under even-age management conditions. Although uneven-age management may address other goals for the forest such as managing for aesthetics, recreation, wildlife habitat, and ecosystem services they may not successfully retain the desired species composition. A comparison of alternative harvesting methods in oak-hickory forests in the Ozarks found that the general response of oaks to single tree selections was poor, and that uneven aged management failed to improve oak regeneration over traditional clearcuting (Chen et al., 2015). On the other hand, oaks did not do significantly worse in the group selection treatment.

Coppice Management

Coppicing is an ancient technique of forest management that has been used around the world to produce small diameter timber for fiber and fuel. Common in Europe, it became the prevalent land cover of English lowlands in the early Middle Ages (Fuller and Warren, 1993). Trees were cut on rotations of 5-20 years - some for over 1,000 years - up until the 1800s, when the practice began to be abandoned. Present interest in coppicing in Britain is largely concerned with the conservation of wildlife that has become reliant on the habitats created by coppice management over the past millennia.

In coppiced stands trees might be cut on short-rotations for stick-sized material, simple coppices where all of the material was grown out for the same period, or two-storied coppices with "standards." The standards were trees, commonly oaks, which were left to grow for 3-8 coppice cycles and then harvested for larger building materials (Evans, 1992). Long-term coppicing represents large nutrient exports from a site and may result in declining soil fertility. Stands that become 'tired' after many regenerations may not be responsive to simple solutions such as fertilizer additions.

In cases where coppicing has been abandoned the coppice is considered "stored" as the trees grow to resemble a more mature forest (Evans, 1992). The larger trees resulting from this practice may be more susceptible to diseases and defects, and have significantly lower success in resprouting after harvest (Pyttel et al., 2013). As in North American oak forests exposure to deer herbivory results in greater mortality of young stems (Pyttel et al., 2013). One solution to this problem was "pollarding", a type of coppicing where the stems were harvested above the browse line, resulting in less vulnerability of the regeneration.

In Japan *Quercus acutissima*, *Q. crispula*, and *Q. serrata* were traditionally managed in coppice forests for firewood, charcoal, and shiitake bedlogs. Although abandoned in Japan around the 1960's, recent interest in biomass fuels has lead to renewed concern about their stand dynamics. In recent years Japanese oak wilt (*Raffaelea quercivora*) has caused high oak mortality in some species and created difficulty in regeneration (Nakajima and Ishida, 2014). Coppicing for traditional shiitake bedlogs is still common in some areas. Stem density in *Q. acutissima* stands managed for shiitake log production is typically between 1,000 and 1,500 stems per hectare on a 10-15 year rotation (Matsumoto et al., 1999).

Major Tree Pests and Diseases

Dutch Elm Disease (Adapted from USDA FS, 1998)

Dutch elm disease (DED) is a fungal infection of trees in the genus *Ulmus*. Of the two elm species native to Michigan, American elm (*U. Americana*) is highly susceptible while red elm (*U. rubra*) is sometimes somewhat resistant. Although no native ems are immune to Dutch elm disease some individuals have a higher tolerance and may survive infection. The fungi responsible for DED are *Ophiostoma ulmi* and *O. novo-ulmi*. DED spreads locally through root grafts and over land by native and introduced bark beetles, which are attracted to stressed, dying, or dead elms, where they lay their eggs. From here the fungus enters the vascular structure of the tree and prevents water movement to the crown

The first symptoms of DED are wilting and yellowing leaves, usually on the limb where it has been introduced by beetles or on the side of the crown where it entered through a root graft. Infected branches and stems will develop brown streaking in the sapwood. It is sometimes possible to save trees with DED by pruning the infected branches. Pruning is most effective when less than 5% of the crown is affected and all infected branches are cut 5 to 10 feet back from the last signs of streaking. Root pruning can be used to try to protect nearby neighbors.

Emerald Ash Borer (Adapted from Haak et al., 2015)

The emerald ash borer, *Agrilus panipennis*, is an East Asian jewel beetle discovered near Detroit in 2002. This insect pest causes morality to trees in the *Fraxinus* genus. Adults fly beginning in May or June and peaking in June to July. They eat the foliage of their host plant, mate and lay eggs in crevices or between layers of bark. Eggs hatch 7-18 days later and the larvae begin to tunnel through cambium, feeding on the inner bark and outer sapwood. From here the larvae grow and develop over then next year or two before emerging as adults. Infected trees usually die after 1-3 years of infestation. The infection leaves behind telltale larval galleries beneath the bark.

Treatment of emerald ash borer is not currently economical. Forest management guidelines focus on diversifying forest stands in preparation for a future in which ash is not a major component of the forest and to reduce the sites of infection as the borers spread. Most efforts are aimed at slowing the spread of the ash borer by studying its movement, creating quarantine zones, and restricting the transport of ash logs.

Oak Wilt (Adapted from USDA FS, 2011)

Oak wilt is an aggressive fungal disease that affects many species of oak (*Quercus* spp.). It is unknown whether oak wilt fungus (*Ceratocystis fagacearum*) is native to the Eastern United States or if it was introduced in the early 1900s. Either way it has become much more prevalent due to increased tree wounding in many areas. Oaks in the red oak group - those with pointed leaf tips - are the most vulnerable and may be killed within three weeks of infection. Recovery is possible but rare. White oaks – with rounded leaf tips- are more resistant and may persist for one or more years. Oak wilt spreads locally through root grafts between oaks of the same species. The infection spreads overland by spores carried on the bodies of nitidulid sap beetles. These beetles are attracted to wounded oak trees.

Infected trees exhibit rapid leaf discoloration and wilting, starting with a color shift in late June-early July. From here the crown wilts from the top downward and the leaves appear bronzed. Often leaves are cast as the infection progresses, displaying brown at the tips and margins and sometimes some remaining green at the leaf base and lower veins. Accurate diagnosis of oak wilt may require sending samples to a laboratory such as MSU Diagnostic Services.

To prevent oak wilt, avoid injuring healthy oak trees, particularly between April 15 and July 1 when conditions are most likely to be favorable to infection. Fresh wounds created in this period can be treated with tree paint to mitigate the risk of infection. Infected trees should be removed during the dormant season and then chipped, split, or dried to prevent spore production. Consider also removing neighboring trees of the same species. To prevent spread through root grafts trench around the infected tree with a plow or remove the stump. Do not move infected wood without properly treating it.

MSU Diagnostic Services

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East Lansing, MI 48824-6469

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pestid@msu.edu

Invasive Species

Autumn Olive (*Elaeagnus umbellata*)

Autumn olive is a highly invasive woody shrub that was brought to the United States from Asia in the early 1800s. For many years it was promoted as a beneficial plant for wildlife because many birds and small mammals enjoy its fruit. Autumn olive fixes nitrogen through a symbiosis with actinomycetes in the soil and so it has also been promoted for the restoration of highly disturbed and nutrient poor sites. This intentional planting has greatly increased its range in the US and aided its spread dramatically.

Autumn olive can produce dense stands that directly displace native species and alter soil conditions through increasing nitrogen mineralization rates. Because it can tolerate very poor sites the communities most threatened are often those that are uncommon and highly adapted to those poor conditions. Young plants may be hand pulled and smaller stems may be repeatedly mowed to control autumn olive. Fire does not seem to have much effect because autumn olive resprouts after damage and its seeds respond well to post-fire conditions. For more information visit the Fire Effects Information System (USDA, 2017).

Common and Glossy Buckthorn (*Rhamnus cathartica* and *Frangula alnus*)

The buckthorns are a pair of tall shrubs or small trees that were brought from Europe as ornamental hedge plants. They can grow up to around 25 feet tall and resprout vigorously when wounded. Both buckthorns can grow in wet to upland habitats, although the common buckthorn thrives on drier sites while the glossy buckthorn is more aggressive on wet soils. Buckthorns spread when birds consume their seeds. The seeds contain laxative compounds, which help the birds to disperse them more effectively. Although birds eat their berries they are not palatable to major herbivores like deer.

Their sprawling tendency and thick canopy allow them to aggressively compete for space and light. Like some other invasive species the buckthorns leaf out early in the spring and retain their leaves well after most natives have lost theirs. When their leaves do fall they produce a nitrogen rich litter that decomposes quickly and decreases the ability of the litter layer to support fire, which many natives are adapted to. Smaller infestations can be pulled, burned, or repeatedly mowed. Larger plants are typically treated with herbicide because of their vigor when resprouting. Treating with a weed torch may be effective if the root crown is thoroughly cooked (Smallidge, 2014). For more information visit the Fire Effects Information System (USDA, 2017).

Garlic Mustard (*Alliaria petiolata*)

Garlic mustard is an invasive biennial herb that was originally brought from Europe and cultivated as an edible green. Today it is highly invasive across a wide range of habitats, although it tends toward forest understories. It can handle soils anywhere from periodically flooded to xeric. Although not necessary for invasion, it is helped along by disturbances, rapidly colonizing new sites in their wake.

Like many alliums, garlic mustard produces allelopathic chemicals that inhibit competitors and disrupt mycorrhizal networks in the soil. Deer also avoid grazing it, giving it a further competitive advantage over many native species. Control of garlic mustard is typically accomplished by pulling and composting the second year rosettes in the spring and early summer before their seed has set. Fire has mixed effects on garlic mustard but is generally considered to inhibit its invasion. For more information visit the Fire Effects Information System (USDA, 2017).

Japanese Barberry (*Berberis thunbergii*)

Japanese barberry is a perennial shrub that was brought from Japan as a replacement for the European barberry plant in ornamental hedges. The European barberry is an alternate host of wheat rust and was largely eradicated in the United States. In the Midwest it generally only achieves a low density but in some northern and northeastern forests it can form dense colonies that cover most of the forest floor. This density is achieved through vegetative reproduction via rhizomes, root sprouts, and layering.

Japanese barberry can become dense enough to choke out native vegetation and hamper tree regeneration. Over time barberry contributes to more acidic soils with higher net nitrification, and less overall organic matter. These conditions favor barberry over native species. Hand pulling, digging, or repeated burning are all viable options for reducing populations of Japanese barberry. For more information visit the Fire Effects Information System (USDA, 2017).

Japanese Hedge Parsley (*Torilis japonica*)

Japanese hedge parsley is an herbaceous biennial in the carrot family. It is a recent invader in southern Michigan with little currently published about its spread or impacts. Its "stick-tight" seeds adhere to clothing and fur, allowing it to spread rapidly into areas that have been otherwise unaffected. Control is currently attempted by pulling the second year rosettes before seed has set.

Multiflora Rose (*Rosa multiflora*)

Multiflora rose is a perennial shrub native to Japan. It was brought to the United States as a rootstock for ornamental roses and has since become a common invader of upland forests and fields. They are most commonly found on woodland edges in areas that have a history of agricultural use. Their seeds are bird dispersed so they can be found in small pockets over a wide variety of sites, but are not especially competitive in mature forests with little disturbance. Controlled fire will generally inhibit multiflora rose growth and invasion, although they are capable of resprouting. Like fire, mowing and cutting can be effective if repeated regularly over several years. For more information visit the Fire Effects Information System (USDA, 2017).

A Note on Invasions

What makes a species invasive is largely a matter of perspective. Many non-native species have "naturalized" in Michigan and the rest of the United States, but relatively few are considered invasive. These species will never be totally eradicated and will eventually find a place within our plant communities. Until that time it is important to consider the impacts that they are having on native biodiversity. These impacts go beyond simply crowding out a few wildflowers here and there. Invasive plants can seriously disrupt natural processes that maintain our native ecosystems and underpin the services that they provide. They can hamper or halt the regeneration of forests, make pastures unpalatable to livestock, and cost farmers time and money to control their spread in and around their fields. For this reason it is imperative to recognize which plants are having these effects and control their abundance whenever it is possible.

Crop Tree Release and Selecting Trees for Removal

Reasons to Thin and Release

Ecological

- Fast-growing, vigorous trees are more resilient to disturbance from pests, diseases, drought, or other sources
- The species composition of the stand can be managed to achieve wildlife and habitat goals
- Removing weak or diseased trees removes sources of inoculum from the forest, protecting the remaining trees
- Treatments can be used to create snags, standing dead trees, and coarse woody debris that are valuable wildlife resources

Cultural

- Treatments can be used to enhance species composition and habitat for desirable game species
- Opening up the forest floor or enhancing species composition can be used to achieve aesthetic goals
- Removing malformed trees near trails reduces the risk of damage to people or property

Financial

- Selecting fast-growing trees with straight stems of marketable species increases the future value of the woodlot
- Reducing competition from less competitive and less valuable trees increases the growth rate and future value of the stand
- Removing diseased and hazard trees decreases the risk of damage to valuable trees
- In older stands release treatments may be an opportunity to generate income

Selection Criteria For Crop Trees- Adapted from the Technical Guide to Crop Tree Release in Hardwood Forests (University of Tennessee Extension, 2007)

- A species suitable to the overarching ecological and commercial goals for the stand, such as mast for wild life, high value timber, or species diversity
- The tree's crown is in a dominant, co-dominant, or strong intermediate position in the stand, showing its capacity to benefit from release
- Its live crown ratio is at least 30% of the stem height, the crown shows little or no sign of dieback, and preferably is evenly distributed around the tree
- The bole is straight and the bark pattern is clear with no signs of defect or epicormic branching
- The tree is healthy and vigorous, with no low forks, signs of disease, or indicators of imminent mortality

- Any age is acceptable so long as it is expected to survive long enough to meet the objectives for the stand
- The tree is important for additional reasons such as aesthetic or emotional value, or expectation that it will provide important wildlife habitat

Selection Criteria For Release Trees

- It shows signs of disease or high sustained levels of pest infestation
- The tree is or could become a hazard tree, although if it is too hazardous removal should be postponed until harvests are made by professionals
- It is not a crop tree
- It is a species that is either not important or detrimental to achieving the stand management objectives
- Its crown is in contact and competition with the crown of a crop tree resulting in a low free to grow determination

Free-to-Grow Determination

Free-to-grow determination is a simple heuristic, or rule-of-thumb, that can be used by forest managers to determine which trees should be removed to release crop trees. The determination is made by simply dividing the crop tree into four hypothetical quadrants and seeing how many of them are free from competition from neighboring crowns (Perkey and Wilkins, 1994). A score of 4 would mean that all four quadrants of the tree were free to continue growing and filling in the canopy. A score of 0 indicates that the tree has no room to grow and will be stifled by competition. Because healthy crowns can expand by a foot or more in a year, crowns separated by less than two feet are not considered free. Trees with crowns below those of crop trees do not compete heavily with the crop trees and do not have to be removed in a release (University of Tennessee Extension, 2007). If the crowns of two crop trees are in contact with each other, simply manage them as if they were one tree.

Other Considerations for Crop Tree Management and Release

Crop tree management is a highly adaptable approach to timber stand management that sits between the "clearcut" and "selection cut" methods (Houston et al., 1995). Many private landowners and public land managers prefer to avoid clear-cutting for ecological and aesthetic reasons, but the selection cuts often recommended by foresters have the tendency to result in "high grading," where all of the valuable timber is removed and only low value and unhealthy trees remain. The crop tree approach focuses management on specific, desirable trees that sit within a relatively natural forest matrix. This allows for practices that increase the monetary value of the stand while simultaneously supporting important non-financial values.

Stand age, history, and objectives are important factors when determining how many crop trees to manage, which trees to manage for, and which trees to remove. In young stands with good regeneration selecting crop trees at younger ages can result in managing up to 70 good crop trees per acre. In a previously unmanaged stand perhaps only 20 or 30 trees will be selected (University of Tennessee Extension, 2007). This is perfectly acceptable because even though prior management may have increased the survival rate of valuable younger trees, the majority of the stands economic value may be represented by only a handful of trees of specific species. As the stand ages the growth response of crop trees to release will decline. In most cases worthwhile increases can still be made (Miller, 1997; Miller and Stringer, 2004). In older stands trees will also be more vulnerable to wind throw and other disturbances in the years immediately following release, so breaking the release into multiple treatments of no more than two quadrants at a time is prudent (University of Tennessee Extension, 2007).

The flexibility of crop tree approaches become even more apparent when it comes time to harvest the stand. When even-aged or group selection is preferred then the trees may simply be clearcut and regenerated using standard silvicultural practices. Where forest owners are resistant to clearcutting, crop tree selection can be used to initiate a two-aged forest that retains a portion of its mature structure even after harvest, while allowing for satisfactory regeneration (Miller and Kochenderfer, 1998; Perkey et al., 1999). If oak regeneration is a specific goal then the presence of crop and matrix trees creates an easier set of decisions around what trees may be used for a shelter wood treatment and which trunks to avoid burning too close to with prescribed fire. Where a landowner is not interested in larger harvests single-tree selections can be made from the valuable crop trees. In fact, where harvest is not the main objective, there is evidence to suggest that using targeted crown release can accelerate the development of large trees, snags, canopy gaps, and other elements of mature old-growth forests (Singer and Lorimer, 1997).

Recommended Further Reading

- Crop Tree Field Guide: Selecting and Managing Crop Trees in the Central Appalachians by Arlyn W. Perkey and Brenda L. Wilkins, 2001
- How to recognize Hazardous Defects in Trees by the USDA Forest Service, 2012
- Technical Guide to Crop Tree Release in Hardwood Forests by the University of Tennessee Extension, 2007
- Tree Crop Management in Eastern Hardwoods by Arlyn W. Perkey and Brenda L. Wilkins, 1994
- To Fell A Tree: A Complete Guide to Successful Tree Felling and Woodcutting Methods by Jeff Jepson, 2009

Strategies for Organic Forest Management

Why Organic Forestry?

In the United States organic production is most often associated with the USDA Organic certification for agricultural systems.

'The USDA organic regulations describe organic agriculture as the application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering. Organic producers use natural processes and materials when developing farming systems. These contribute to soil, crop and livestock nutrition, pest and weed management, attainment of production goals, and conservation of biological diversity."

– USDA National Organic Program, 2015

The reasons for implementing organic practices in agriculture are clear. Farms are often sites of intensive management including large amounts of tillage, cultivation, fertilization, and pesticide application. These practices have contributed to issues with soil and water contamination, erosion, and concerns about the safety of farm workers and the people eating the food that they produce.

It may surprise many to learn that modern forestry and ecological restoration also use significant amounts of pesticides, and sometimes even tillage, cultivation, and fertilization. These practices are usually justified in terms of how much labor is saved, how much additional land can be managed with these tools, how pernicious the plants being treated are thought to be, or even how infrequently they are expected to be used. They also represent a practical dilemma for people concerned about the long-term health of natural and human environments. Herbicide use comes with inherent health risks to applicators, and even careful applications can cause unintended ecological consequences due to drift, runoff, leaching, or translocation through root grafts with treated trees (University of Minnesota Extension, 2009). Even normal use can result in changes to soil chemistry and microbial communities that could make establishment of the desired species more difficult and pave the way for further plant invasions. For a thorough and well-referenced treatment of this subject, see the first chapter of Orion (2015).

Although there is no certification for organic forestry, organic management of a woodlot may be required for a farm business certified by the USDA or simply a personal preference. In either case these techniques should provide a helpful starting point for extending organic practices into the forest. If organic principals are not important to a forest manager, then it is still worth considering that adopting some of these techniques as part of an integrated pest management plan could help mitigate future financial and ecological losses.

Timing of Management Interventions

The first major management lever available is the timing of interventions. Forestry operations should be undertaken during the dormant season when most trees and herbaceous plants will have transferred many of their resources belowground. This should help encourage more vigorous resprouting for many temperate species, including oaks. Also consider scheduling any operations that require heavy machinery for times when the ground is frozen and preferably protected by a layer of snow to avoid unnecessary soil compaction and disruption that invasive species could take advantage of (University of Minnesota Extension, 2009). Limiting pruning and harvesting to these times also ensures that trees and stumps do not have open wounds during the times when certain diseases are most virulent. For this reason oaks should never be pruned from April through July, which is when oak wilt spores are most active.

Tree Release and Thinning

Healthy, vigorously growing trees that are not under unnecessary stress from competitive pressures will be more able to fend off pests and diseases and weather other disturbances. Release and thinning operations can also remove sources of inoculum such as weak, wounded, or already diseased trees. Diseased trees should be felled and removed at the earliest opportunity, even if left in place many common diseases that infect the bark layers of living trees will not persist long on dead stems.

Fencing

Deer fencing is probably a necessity for the regeneration of browse sensitive species. Plastic tree shelters increase moisture and carbon dioxide concentrations immediately surrounding young trees, increasing early growth rates. If snug to the ground they can also prevent rodent damage to the young bark. Wire tree shelters will stop deer and rabbit browse (University of Minnesota Extension, 2009). Shelters should be six feet tall and may be removed when the sapling is old enough to resist damage.

Girdling

Girdling is a useful tool for deadening trees that are competing with crop trees or targeted for thinning in shelterwood treatments. In traditional forestry it is usually combined with herbicide treatments to ensure the mortality of girdled trees. Using a chainsaw make two cuts encircling the tree. The cuts should be 1 inch deep and 3-6 inches apart from each other (University of Minnesota Extension, 2009). One drawback of this treatment is that chainsaw operation can be time consuming and many treated trees may resprout from the base. This may not be a problem in release treatments, but could be problematic if the species is undesirable or the treatment is meant to stimulate regeneration.

Flame Weeding

For stems that are too small for girdling flame weeding is often an effective replacement (Smallidge, 2014). To avoid risk of fire and increase effectiveness, only use flame weeding when the forest is too wet for the fire to escape. Winter is a good time for this. Steaming snow will help to cook the targeted individual while inhibiting wildfire. Train the flame on the base of the tree until it is well blackened all around its circumference. Check again in a year or two to treat any sprouts. Flame weeding can accomplish many of the same results as herbicide spraying with lower costs and in a way that simulates a natural disturbance. Consider using a ten-pound propane tank attached to a backpack for ease of transport and maneuvering in the woods.

Controlled Burning

Reintroduction of fire onto a landscape through controlled burns can be used to suppress or encourage specific species depending on their life history and the timing, duration, and intensity of the burn. Burning can suppress many woody and fire-sensitive species, while increasing germination of the seedbank and allowing fire-adapted native species to remain competitive (Schuler et al., 2009). However, care must be taken that burning does not reduce populations of native species of concern. Burning is useful for reducing populations of buckthorn saplings and smaller honeysuckle, especially if burned over multiple years (Anderson and Schwegman, 1971; Boudreau and Wilson, 1992). And, it can create opportunities for the local seed bank to express itself before any further treatments. Burning twice a decade can help to maintain herbaceous vegetation and oak recruitment (Burton et al., 2011). Additional burning may be desired intermittently to control the resprouting of invasive shrubs but should never exceed 5 fires per decade. Fire can also damage valuable individuals, so care should be taken to assure that crop trees and regenerating stems are protected from fire.

If burning is not possible at any time due to poor weather conditions we recommend using a weed torch as an alternative to burn small areas. These burns can be focused specifically on problem species and may also be effective in areas with many conservative species. As above, although the torches can be used at any time of year, only use them when the ground is wet and the risk of fire is low. Be wary of burning in stands with large snags, lots of downed wood, or other fuels that could allow a fire to grow out of control.

Controlled fire is a powerful ecological tool when applied appropriately. Historically fire played a critical role in many forest ecosystems and continuing that legacy can help us maintain those systems. Fire is also a blunt instrument, so its application in managing smaller areas for specific species may be rather limited. In oak-hickory and mixed-oak forests, fire intervals were probably greater than a century in many areas, despite higher frequencies in others. Many hydric and wet-mesic sites probably saw widespread fire only very rarely. The advantages of controlled burning should be weighed against risks to property and the cost of organizing or hiring a qualified burn crew. It is strongly recommended that landowners contact a certified burn boss to learn more about the costs, necessary conditions, and opportunities presented by controlled burns.

Outdoor Mushroom Cultivation Four Ways

Overview

Outdoor mushroom cultivation is a promising way to transform the costs of forest management activities like pre-commercial thinning and timber stand improvement into a profitable enterprise. Although forests in parts of Japan have historically been intensively managed for mushroom substrate production with short-rotation coppicing (Matsumoto et al., 1999), in North America mushroom substrates are typically derived as a secondary product of forestry or arboriculture. These sources can offer a rich supply of material of sizes perfect for mushroom growing. In general there are three steps that are likely to ensure the greatest success when integrating these activities in a woodlot.

First, have a plan for the forest. Having a long-range vision extending from the current conditions of the forest to a desired future will help to guard against hasty harvesting choices that may impact the forest over decades. Second, have a plan for mushroom inoculation. Even if mushroom growing is only a minor interest it will be much more successful if some basic legwork is done before hand. This includes selecting species or strains of fungi appropriate for the size and species of logs being inoculated, having the correct materials on hand on the day of inoculation, and having some idea when to expect and how to process a harvest. Finally, logs used for mushroom production should be used reasonably quickly with sources suggesting that for the most popular species logs should be inoculated within three to four weeks of felling (UVM Extension, 2013; Cotter, 2014). The reason for this is to avoid unnecessary competition with other wood-rotting fungi that could colonize the wood in the interim period. The single exception in this list is the wine-cap mushroom (*Stropharia rugoso-annulata*), which prefers woodchips that may be aged up to a year (Mudge and Gabriel, 2014).

Bolts and Bedlogs

Shiitake Bolt Production

<u>Overview:</u> Shiitake mushrooms (*Lentinula edodes*) has been cultivated for thousands of years in Japan and China. Their long history of use in traditional Asian cooking, flavor, documented nutritional qualities, and archetypical ‘toadstool’ form make them a relatively easy mushroom to market. Although the number of shiitake growers is rising, most report that the market is not saturated, with demand far outstripping current supply (Gabriel, 2015). Shiitake cultivation is also much better documented and studied in the United States than most other commercial mushrooms, excluding the standard button mushroom (*Agaricus bisporus*). Market analysis in 2008 showed a strong consumer preference for shiitake mushrooms that is unlikely to be completely vulnerable to replacement by other specialty mushrooms due to its cultural and nutritional ties (Gold et al., 2008). Although achieving very high volumes of production takes time, hard work, and experience, the traditional, low-tech methods of shiitake growing produce high-quality

mushrooms capable of consistently fetching top prices (Gabriel, 2013). These factors combine to make shiitake culture a good candidate for the cornerstone of a small-scale mushroom business and an excellent complement to active forest management.

Substrate: Some resources suggest that mushroom logs should come from the healthiest and straightest trees of only specific species. Evidence from North American growers suggests that low-grade logs of many different native genera are perfectly suitable for mushroom production (Gabriel, 2013). Oaks (*Quercus* spp.) are traditionally treated as the standard for shiitake mushroom production, although sugar maple (*Acer sachharum*) has been shown to consistently out produce oak logs in some trials (Bruhn et al., 2009). Other good producers are Ironwood (*Ostrya virginiana*), Musclewood (*Carpinus caroliniana*), and American beech (*Fagus grandifolia*). Less productive suitable species include birches (*Betula* spp.), Hickories (*Carya* spp.), and Red Maple (*A. rubrum*). These species produce quality mushrooms but may yield less than 50% of the other species in some cases (UVM Extension, 2013). Ash (*Fraxinus* spp.), elms (*Ulmus* spp.), evergreens, fruit trees, and soft hardwoods are not recommended as substrates.

The most productive logs will be those with a high ratio of sapwood to heartwood resulting from vigorous tree growth (Mudge and Gabriel, 2014). Moisture content of shiitake logs is closely tied to yields (Tokimoto et al., 1998) so only logs with at least 90% of their surface covered in undamaged bark should be used. This practice will also help to prevent contamination of logs with competitor fungi, particularly during the spawn run phase. Trees should be felled in winter for the best yields (UVM Extension, 2014). Those cut in other seasons, especially late spring and summer, should be examined for bark slipping.

Logs are typically between 4 and 6 inches in diameter and 3-4 feet long. Larger lengths or widths may be used but the added weight can make management more difficult, especially where soaking is used to force fruiting. Logs inoculated with cold weather strains may be larger and heavier because they are less responsive to precipitation and soaking and more useful for season-extension (Bruhn et al., 2009; Mudge and Gabriel, 2014). Logs should be inoculated within 3-4 weeks of harvest for the greatest yields and less contamination.

Inoculation: Inoculation is achieved by drilling holes in the log, packing them with spawn (a living mushroom culture), and sealing the holes with wax. Other methods can be used but they may cause slower colonization, increased contamination, or inefficient use of spawn. Holes should be drilled in a diamond pattern all the way around the log and spaced between 4 and 6 inches apart (Cotter, 2014). The drill bit used should match the size of the plug/dowel spawn or spawn plunger being used. Hand drills can be used for this task but a corded angle grinder with a special bit attachment can speed the process up by nearly 10 times (Gabriel, 2013).

After spawn is packed into the holes they should be sealed with a food-grade wax. Cheese wax contains some petroleum, but is cheaper than beeswax and less prone to cracking under cold temperatures (Mudge and Gabriel, 2014). Wax cracking after the initial spawn run is unlikely to affect yield. Wax is melted in an inexpensive pot and brushed over the holes using a cheap paintbrush or dauber.

Spawn selection has been shown to have a very strong impact on future mushroom yields (Bratkovich, 1991; Bruhn et al, 2009). Bruhn et al. found that strains marketed as having a wide productive temperature range produced significantly more than warm weather or cold weather strains (2009). Warm weather strains might be more productive on softer hardwoods like red maple and cold weather strains can produce in the beginning and end of the season when it is too cold for other strains (UVM extension, 2013). Although dowel or plug types of spawn may be more convenient for inoculators, sawdust spawn has been shown to have substantially higher yields in multiple studies (Bratkovich, 1991; Bruhn et al, 2009).

Spawn Run: The spawn run is an incubation period where the mycelium of the shiitake fungi spreads and colonizes the entire log. After inoculation they may be stored in crib stacks, or leaned into A-frames, tepees, or hillside stacks (Mudge and Gabriel, 2014). The location of these stacks should be under 75-100 percent year-round shade and have high relative humidity. When shade is insufficient or intermittent, as in deciduous forest, shade cloth can be used as a supplement (UVM Extension, 2013). Management during this time period of 8 to 18 months is simply monitoring for contamination, and maintaining shade and moisture. Contaminated logs should be removed and if conditions become very dry logs can be doused with water or soaked for an hour to restore moisture.

Forcing or shocking: Most strains of shiitake are sensitive to precipitation and can be triggered to fruit by soaking logs in water. Although this increases management complexity and is heavy work, forcing shiitake logs can help regulate mushroom production so that reasonably predictable, consistent harvests can be made throughout the growing season. It is prudent to wait 14-17 months after inoculation before attempting to force production in order to ensure full colonization and secure the highest yields (UVM Extension, 2013).

Forcing can be accomplished by placing logs in large tubs such as stock tanks. The water used can be any temperature, although colder water will produce significantly higher yields (Bruhn and Mihail, 2009) with the magnitude of the increase proportional to the difference between water and air temperatures. Most guides suggest soaking for 24 hours (UVM Extension, 2012), but some research suggests that optimal soaking times may be vary by log with younger logs requiring fewer hours of soaking than older logs (Tokimoto et al., 1998). The same trial indicated that older logs produced greater yields after soaking when they received cuts to their ends to encourage water absorption. Shocked logs will begin to fruit in 3-5 days, be ready to harvest in 7-10 days, and then must be “rested” for 6-8 weeks before shocking again (UVM Extension, 2013).

Log Lifespan: Shiitake logs will be most productive in their second and third years (Bratkovich, 1991; Bruhn et al, 2009). After this yields will decline over the subsequent years. Forcing compresses the productive life of the shiitake logs and causes them to last for only 2-3 years, where a naturally fruiting log could be expected to last four or more seasons and produce the same lifetime yield (Mudge and Gabriel, 2014). For this reason forced fruiting may be most useful in cases where a grower is building a business around regular direct sales, and of little advantage if the mushrooms are being wholesaled.

Bedlog Production

Bedlog production provides a more moist and shaded microclimate that certain species require to fruit productively. The inoculation step is essentially the same, although many species will have fewer strains to choose from and may not be available in plugs or dowels. After inoculating the logs they should be set aside for 3-4 months for a brief spawn run before being partially buried in trenches or "rafts" (Cotter, 2014). Because these logs will not be moved larger logs can be used.

Trenching logs begins by excavating the log bed to a depth about half the diameter of the logs to be buried. Lay the logs tightly packed side-by-side in the trench and pack the space between logs with soil. Creating "rafts" is much the same except that no digging is required. Start with a thin layer of wood chips, straw, mulch, or soil, and then set the logs into this. After the logs are place, fill in the bed with additional substrate and build some up around the edges. After creating a bed thoroughly saturate it with water. Water again around the time that fruiting is expected. Log beds created in this way can be highly productive, but will only last for 2-3 years (Cotter, 2014).

Other species that can be grown with bolt or bedlogs

-*Flammulina velutipes* - These mushrooms are traditionally grown indoors with no light, producing a mushroom that looks nothing like wild-fruiting specimens. Outdoor cultivation is possible although yields will be low due to the narrow range of fruiting temperatures (Cotter, 2014). This is a species that can be found growing on elms in the wild and could be used to produce mushrooms from a variety of species not useful for shiitake production (Stamets, 2000). An additional caution in the cultivation of this species is that is is somewhat similar in appearance to deadly poisonous mushrooms in the genus *Gallerina*. Care should be taken to learn how to confidently identify both mushrooms to minimize the risk of making an unfortunate mistake.

-*Ganoderma lucidum* and closely related species - The *Ganoderma* genus includes several species of mushrooms that are used to make teas, tinctures, and traditional medicines. They are a good candidate for growth on less valuable maple species and can be expected to produce good yields, particularly with bedlog methods (Cotter, 2014).

-*Grifola frondosa* - *G. frondosa,* or hen-of-the-woods, is another mushroom that is commonly cultivated indoors. Unlike other mushrooms in this group, hen-of-the-woods will not fruit above ground. After inoculation let the logs colonize for 6-8 months and then bury it at least halfway and cover with woodchips, soil, and litter. Yields should be acceptable, although they will only fruit once per year (Cotter, 2014). One advantage to growing this species is that it is another one that has some name-recognition due to cultural associations.

-*Hypholoma sublateritium* – *H. sublateritium* is sold in Europe as the brick top mushroom, but is not often seen in US markets. It can be grown with very good results on buried logs, but care must be taken to be sure that the bed has not been contaminated by inedible wild natives of the same genus (Cotter, 2014). Stamets recommends growing *H. sublateritium* on oaks or similar hardwoods (2000).

-*Hypsizygus* mushrooms - Mushrooms in this genus look similar to oyster mushrooms (*Pleurotus ostreatus* and others). They can be grown on logs and produce large crops in outdoor settings (Cotter, 2014). Hardwoods unsuitable for shiitake logs such as elm could make good candidates for mushrooms in this genera as certain species are named for growing on elm trees (Elm oyster: *Hypsizygus ulmarius*).

-*Pholiota nameko* – the nameko mushroom is another commonly cultivated in Japan. They are dense and prolific fruiters in bedlog settings and logs will last 2-3 years (Cotter, 2014). This mushroom should perform well on softer hardwoods including birch (*Betula* sp.) and poplar (*Populus* sp.)(Stamets, 2000).

Totems

The totem method of mushroom production has the potential for great yields and is appropriate for some mushrooms species that prefer a greater volume of substrate than bolts. The drawback of this method is that the totems cannot be forced, and will only provide flushes of mushrooms during their normal fruiting times. While the basic form and function of the totem is straightforward, there are a couple of variations in how they are created. Each begins with fresh-cut logs 9 or more inches in diameter and at least 24 inches long.

For the first variation is in how the log is supported. The log may be partially sunk into the ground like a post. The end that is buried in the soil will help to regulate the moisture in the totem (Cotter, 2014). Otherwise the log can be set on the ground and stabilized by its own mass. The first method might be best for skinnier logs or in drier conditions. The second method is ideal when the log is very wide in proportion to its length.

The second major point of differentiation is how the log is inoculated. In one method notches are cut into the log with a chainsaw and filled with spawn. After the notch has been filled the piece of wood that was cut out is nailed back over the spawn to help hold it in place (Stamets, 2000). Another method is to make horizontal gashes in the log with a chainsaw and pack the gashes with spawn. In both cases the cuts should be arranged so that they ring the log at different heights in order to accelerate colonization (Cotter, 2014). A third method is to cut the log into foot long sections and stack them on top of each other. In this method spawn is layered between each disk of wood. To inoculate the bottom of the log, cardboard with spawn spread over it can be placed under the stack. For the top a two-inch tall disk is used to cap one final layer of spawn. This last disk prevents the spawn on top from drying out or being eaten by animals (Mudge and Gabriel, 2014).

To finish the totem, a large paper bag like those used for yard waste is used to protect the totem from sun, contain moisture, and protect the spawn while it inoculates. The back can be removed after the logs are glued in place by the spawn or allowed to deteriorate naturally. Because the totem is not easy to move site selection is very important. As before, heavy shade and protection from wind is ideal. A good Totem can produce for six years or more (Mudge and Gabriel, 2014).

Species that can be grown on totems
-*Herecium* species – *Herecium* mushrooms are well suited to totem cultivation. They have an excellent texture and subtle flavor that make them desirable for seasonal niche markets. Grace and Mudge achieved production of *Herecium* on par with forest cultivated shiitake (2015), although the general perception is that yields are low due to their limited fruiting window (Cotter, 2014). Cotter suggests partially burying the ends of logs to improve yields.

-*Laetiporus sulfureus* and close relatives – Known commonly as Chicken-of-the-woods, *Laetiporus* mushrooms are a relatively well recognized wild edible due to their striking orange coloration. Although there may be a ready market, *Laetiporus* is not a reliable producer in outdoor cultivation (Cotter, 2014). Additionally, a relatively large minority of people find that they cannot digest these mushrooms.

-*Pleurotus ostreatus* and close relatives – These mushrooms are typically lumped together as "oyster mushrooms" and can already be found in most upscale grocers. Oysters will grow on almost anything with cellulose and can be produced en mass very productively with a number of methods. Because of this it may not be worthwhile to produce them on logs. However, there is a ready market and they do fruit heavily when conditions are right so they may be worth growing. Oysters are also unique in that they will fruit prolifically from totems, wood chip beds, and bedlogs (Cotter, 2014). Outdoor growers should be aware that oyster mushrooms are quickly attacked by a number of insects and may need protective covering.

Wood Chips

Wood chips up to about a year old can be used in the cultivation of the wine-cap mushroom (*Stropharia rugoso-annulata*). Wood chip cultivation represents an opportunity to make use of large volumes of woody material that may be unusable for other methods due to size, shape, species, or damage in harvesting. Amending the wood chips with straw will help to maintain high moisture levels (Cotter, 2014), and has been shown to increase yields (Bruhn et al., 2010). Make beds simply by clearing litter and plant material from the bed site down to the bare soil. Then layer substrate and spawn until the bed is 6-8 inches thick (Mudge and Gabriel, 2014). Cotter suggests adding layers of cardboard on the bottom top and in between layers to protect spawn and create surfaces for mycelium to travel along (2014). A casing layer may also improve yields (Bruhn et al., 2010; Cotter, 2014). Finish by saturating the bed.

Beds will fruit several times a year for 2-4 years. Stamets recommends disturbing beds periodically and adding new organic matter so that the mycelium remains vigorous (2000). He also suggests using fully colonized beds to expand the culture and inoculate new beds by using 20% colonized chips to 80% new substrate in each new bed. This reduces the cost of commercial spawn and allows large beds to be created. Inoculated mulch may also be used fruit trees or in garden beds, with the fungi taking advantage of the partial shade for fruiting while providing plants with the benefits of a rapidly decomposing mulch.

Stumps and Shelterwood

Many of the wood rotting fungi can be used to inoculate stumps and recently killed shelter wood trees. As before, inoculation should follow harvest by no more than a month to provide the greatest odds of success. Stump inoculation is another way that active forestry can profitably interact with mushroom cultivation (Stamets, 2000). In practice stump inoculation is no more complicated than any of the other methods. Holes are drilled and filled with spawn all around the outer surface of the stump and a layer of spawn is spread around the outer ring of the cut face (Cotter, 2014). The drawback of this approach is that it may take several years for the stump to begin fruiting. However, once fruiting has begun, a stump may remain highly productive for a decade or longer. Stump inoculation is most beneficial for *Grifola frondosa*, *Laetiporus sulfureus, Pleurotus ostreatus, Flammulina velutipes,* and *Ganoderma* mushrooms (Cotter, 2014).

Limitations of Log-based Mushroom Cultivation

Log-based mushroom cultivation is low-tech, requires low initial investment, and can consistently produce top-quality mushrooms. These methods are most appropriate for small-scale producers who can fetch high prices for high-quality products through direct sales. If mushrooms are a main crop then log-based cultivation represents a large amount of heavy work in procuring, inoculating, and soaking bolts. At the commercial level much more income can be generated through more intensive techniques. Commercial production requires much greater investment in infrastructure and management, but offers greater control over yields and timing. If log-based mushroom cultivation is part of a business then financial goals should be set and a realistic evaluation of the local market should be weighed against the relative advantages and disadvantages of these techniques.

Recommended Further Reading

- Best management practices for log-based shiitake cultivation in the northeastern United States by the University of Vermont Extension, 2013

- Farming the Forest: an integrated permaculture approach to growing food and medicinals in temperate forests by Ken Mudge and Steve Gabriel, 2014
- Growing Gourmet and Medicinal Mushrooms, Third Edition by Paul Stamets, 2000
- Organic Mushroom Farming and Mycoremediation: simple to advanced techniques for indoor and outdoor cultivation by Tradd Cotter, 2014

Spent Mushroom Substrate as a Soil Amendment

After up to seven years of production a shiitake log will be spent. This spent log represents a waste product. In their native ecosystems white rot fungi break down lignin and cellulose in the host log through a variety of powerful enzymes (Vane et al., 2003). This results in the decomposition of the cell walls of the log and the eventual return of its component nutrients to the soil. Spent commercial mushroom substrates will be nutrient rich as well. This presents potential problems for the disposal of larger quantities of substrate. Gou et al. (2001) found that the effects of weathering on heaps of spent mushroom substrate from white button mushrooms (*Agaricus bisporus*) could be observed in the soil even at two meters of depth. Although this mushroom is grown on compost, the potential for leaching of nutrients is worth considering for any bulk substrate.

The same high nutrient content that makes the bulk disposal of spent substrate material problematic can also make it a useful aid in maintaining soil fertility. The carbon to nitrogen ratio of the spent substrate is significantly lower than that of the un-digested log and the enzymes produced by the shiitake fungus make the spent substrate attractive as an agricultural soil amendment (Phan and Sabaratnam, 2012; Vane et al., 2003). Applications of spent shiitake substrate to farmlands damaged by earthquakes in Japan have revealed that soil physical and biological properties were improved and crop yields were maintained (Kato et al., 2013). Another study in vineyard soils verified that applications of spent mushroom substrate increased the quantity of available inorganic nitrogen in the surface soil layer (Peregrina et al., 2012). Soil organic carbon was also significantly increased in the treated vineyard soils. Another Spanish study of the properties of soils amended with spent mushroom substrate showed that substrate amended soils had greater soil organic carbon, nitrogen, available phosphorus, and phosphatase, contributing to an overall improvement of soil fertility.

In contaminated soils, the enzymes from mushroom substrate have also been found to aid in the remediation of polycyclic aromatic hydrocarbons and resulted in significant increases in bacteria and fungi abundance (Li et al., 2012). Studies of applying spent mushroom substrates to vineyard soils in Spain have revealed that spent mushroom substrate acts successfully as a sorbent to reduce the risk of water contamination following fungicide applications (Herrero-Hernandez et al., 2011; Marin-Benito et al., 2012(1) Marin-Benito et al., 2012 (2)). The enzymes produced by the mushroom altered and enhanced the degradation of the fungicides while the substrate material itself absorbed and immobilized it.

In a small scale mushroom cultivation setting substrate materials could consist of compost, sawdust, straw, wood chips, bolts, or large totem logs. The finer materials could be incorporated into the soil with compost or mulch applications. The bulker bolts and logs will not break down so quickly but could be chipped or added along trail edges near perennial plantings where they will continue to break down and add nutrients to the soil slowly.

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Fungal Inventory Raw Data

Species	count	type	Edible	Choice	plot	area	month	day	year
Xylaria polymorpha		sap			1	nw	September	22	2015
Scleroderma areolatum		ecto			1	nw	September	22	2015
Marasmius sullivantii		sap			1	nw	September	22	2015
Scleroderma areolatum		ecto			1	nw	September	22	2015
Schizophyllum commune		sap				nw	September	22	2015
Russula sp		ecto				nw	September	22	2015
Stereum ostrea		sap				nw	September	22	2015
Gerronema strombodes		sap				nw	September	22	2015
Schizophyllum commune		sap			2	nw	September	22	2015
Daldinia concentrica		sap			2	nw	September	22	2015
Sarcoscypha austriaca		sap			2	nw	September	22	2015
Scleroderma areolatum		ecto			2	nw	September	22	2015
Mycena luteopallens	5	sap			2	nw	September	22	2015
Inocybe sp		ecto			2	nw	September	22	2015
Russula sp		ecto			2	nw	September	22	2015
Mycena luteopallens		sap			2	nw	September	22	2015
Polyporus badius		sap				nw	September	22	2015
Pleurotus ostreatus		sap	y	c		nw	September	22	2015
Polyporus radicatus		sap				nw	September	22	2015
Schizophyllum commune		sap			3	nw	September	22	2015
Inocybe sp		ecto			3	nw	September	22	2015
Mycena luteopallens		sap			3	nw	September	22	2015
Boletus campestris		ecto				ne	September	22	2015
Schizophyllum commune		sap				ne	September	22	2015
Ischnoderma resinosum		sap				ne	September	22	2015
Trametes versicolor		sap			4	ne	September	22	2015
Mycena luteopallens	2	sap			4	ne	September	22	2015
Stereum ostrea		sap			4	ne	September	22	2015
Trametes pubescens		sap			4	ne	September	22	2015
Trichaptum biforme		sap				ne	September	22	2015
Polyporus alveolaris		sap				ne	September	22	2015
Inocybe sp		ecto			5	ne	September	22	2015
Phellinus gilvus		sap			5	ne	September	22	2015

Trametes pubescens		sap			5	ne	September	22	2015
Pluteus cervinus		sap				ne	September	22	2015
Daldinia concentrica		sap				ne	September	22	2015
Phellinus gilvus		sap				ne	September	22	2015
Polyporus varius		sap				ne	September	22	2015
Mycena luteopallens	3	sap			6	ne	September	22	2015
Omphalotus illudens		sap				ne	September	22	2015
Ganoderma curtisii		sap				c	September	22	2015
Gloeoporus dichrous		sap				c	September	22	2015
Postia caesia		sap				c	September	22	2015
Stereum ostrea		sap				c	September	22	2015
Grifola frondosa		sap	y	c		c	September	22	2015
Lenzites betulina		sap				c	September	22	2015
Mycena inclinata		sap				c	September	22	2015
Phellinus gilvus		sap				c	September	22	2015
Stereum ostrea	2	sap			9	c	September	22	2015
Phellinus gilvus		sap			9	c	September	22	2015
Mycena luteopallens		sap			9	c	September	22	2015
Trichaptum biforme		sap			9	c	September	22	2015
Plicaturopsis crispa		sap			9	c	September	22	2015
Trichaptum biforme		sap			9	c	September	22	2015
Bisporella citrina		sap				c	September	22	2015
Conocybe aurea		sap				c	September	22	2015
Mycena luteopallens		sap			8	c	September	22	2015
Phellinus gilvus		sap			8	c	September	22	2015
Stereum ostrea		sap			8	c	September	22	2015
Mycena luteopallens		sap			8	c	September	22	2015
Mycena luteopallens		sap			9	c	September	22	2015
Phellinus gilvus		sap			8	c	September	22	2015
Stereum ostrea		sap			7	c	September	22	2015
Mycena luteopallens		sap			7	c	September	22	2015
Phellinus gilvus	2	sap			7	c	September	22	2015
Crepidotus applanatus		sap			7	c	September	22	2015
Schizophyllum commune		sap			7	c	September	22	2015
Coprinopsis lagopus		sap			7	c	September	22	2015
Schizophyllum commune		sap			1	nw	October	11	2015
Armillaria gallica		sap	y		1	nw	October	11	2015
Mycena luteopallens		sap			2	nw	October	11	2015

Armillaria gallica	2	sap	y	3	nw	October	11	2015
Bisporella citrina		sap		3	nw	October	11	2015
Pholiota limonella		sap			nw	October	11	2015
Mycena inclinata		sap			ne	October	11	2015
Entoloma abortivum		sap		4	ne	October	11	2015
Polyporus squamosus		sap	y	4	ne	October	11	2015
Phlebia tremellosa		sap		4	ne	October	11	2015
Polyporus brumalis		sap		4	ne	October	11	2015
Galerina marginata		sap			ne	October	11	2015
Mycena inclinata		sap			ne	October	11	2015
Schizophyllum commune		sap		5	ne	October	11	2015
Polyporus alveolaris		sap		5	ne	October	11	2015
Phellinus gilvus		sap		5	ne	October	11	2015
Entoloma abortivum		sap	y	6	ne	October	11	2015
Phlebia tremellosa		sap		6	ne	October	11	2015
Camarops petersii		sap		6	ne	October	11	2015
Panellus stipticus		sap			ne	October	11	2015
Bisporella citrina		sap			ne	October	11	2015
Morganella pyriformis		sap	y		ne	October	11	2015
Armillaria gallica		sap	y	7	c	October	11	2015
Schizophyllum commune		sap		7	c	October	11	2015
Mycena luteopallens		sap		7	c	October	11	2015
Mycena inclinata		sap		7	c	October	11	2015
Xeromphalina tenuipes		sap		7	c	October	11	2015
Marasmius sullivantii		sap		7	c	October	11	2015
Pholiota limonella		sap			c	October	11	2015
Chlorophyllum rhacodes		sap			c	October	11	2015
Galerina marginata		sap		8	c	October	11	2015
Xeromphalina tenuipes		sap		8	c	October	11	2015
Pluteus sp		sap		8	c	October	11	2015
Armillaria gallica		sap	y	8	c	October	11	2015
Tyromyces chioneus		sap			c	October	11	2015
Marasmius rotula		sap		8	c	October	11	2015
Ganoderma applanatum		sap			c	October	11	2015
Galerina marginata	?	sap		9	c	October	11	2015
Omphalotus illudens		sap			c	October	11	2015

Bisporella citrina		sap				c	October	11	2015
Xeromphalina tenuipes		sap				c	October	11	2015
Mycena inclinata		sap				c	October	11	2015
Mycena luteopallens		sap			2	nw	October	31	2015
Trametes pubescens	"whit e"	sap				nw	October	31	2015
Marasmius rotula		sap			3	nw	October	31	2015
Galerina marginata		sap			4	ne	October	31	2015
Pluteus petasatus		sap			4	ne	October	31	2015
Panellus stipticus		sap				ne	October	31	2015
Pluteus cervinus		sap				c	October	31	2015
Lenzites betulina		sap				c	October	31	2015
Hypoxylon multiforme		sap				c	October	31	2015
Xeromphalina tenuipes		sap				c	October	31	2015
Galerina marginata		sap			8	c	October	31	2015
Panellus serotinus		sap			8	c	October	31	2015
Panellus stipticus		sap			8	c	October	31	2015
Polyporus alveolaris		sap				nw	May	19	2016
Polyporus squamosus		sap	y			nw	May	19	2016
Morchella esculentoides		ecto	y	c		nw	May	19	2016
Polyporus squamosus		sap	y			ne	May	19	2016
Polyporus squamosus		sap	y			c	May	49	2016
Dacrymyces palmatus		sap			1	nw	June	17	2016
Auricularia auricula		sap			1	nw	June	17	2016
Marasmius rotula		sap			1	nw	June	17	2016
Marasmius sullivantii		sap			1	nw	June	17	2016
Schizophyllum commune		sap			1	nw	June	17	2016
Sarcoscypha occidentalis		sap			2	nw	June	17	2016
Inonotus dryadeus		sap				ne	June	17	2016
Pluteus cervinus		sap				ne	June	17	2016
Schizophyllum commune		sap				ne	June	17	2016
Flammulaster erinaceella		sap				c	June	17	2016
Inocybe sp		ecto			1	nw	July	11	2016
Tarzetta cupularis		ecto			1	nw	July	11	2016
Russula sp		ecto			2	nw	July	11	2016

Polyporus alveolaris		sap			3	nw	July	11	2016
Xerula megalospora		sap				nw	July	11	2016
Polyporus varius		sap				ne	July	11	2016
Mycena inclinata		sap				ne	July	11	2016
Omphalotus illudens		sap				ne	July	11	2016
Polyporus squamosus		sap	y			c	July	11	2016
Auricularia auricula		sap				c	July	11	2016
Cantharellus cibarius		ecto	y	c		nw	July	26	2016
Crepidotus applanatus		sap			2	nw	July	26	2016
Scleroderma areolatum		ecto				nw	July	26	2016
Fugilo septica		sap			4	ne	July	26	2016
Scleroderma areolatum		ecto				ne	July	26	2016
Polyporus varius	2	sap			1	nw	August	6	2016
Russula sp		ecto			1	nw	August	6	2016
Crepidotus applanatus	2	sap			2	nw	August	6	2016
trametes versicolor		sap				nw	August	6	2016
Cantharellus cibarius		ecto	y	c	3	nw	August	6	2016
Crepidotus applanatus		sap			3	nw	August	6	2016
Crepidotus applanatus		sap			4	ne	August	6	2016
Pluteus cervinus		sap			6	ne	August	6	2016
Phellinus gilvus		sap			6	ne	August	6	2016
Crepidotus applanatus		sap			9	c	August	6	2016
Crepidotus applanatus	5	sap			8	c	August	6	2016
LBM					1	nw	August	22	2016
Crepidotus applanatus		sap			1	nw	August	22	2016
Inocybe sp		ecto			1	nw	August	22	2016
Laccaria sp		ecto			1	nw	August	22	2016
phlebia tremellosa		sap			1	nw	August	22	2016
Polyporus varius		sap			1	nw	August	22	2016
Lycoperdon nigrescens		sap			1	nw	August	22	2016
Schizophyllum commune		sap			2	nw	August	22	2016
Stereum ostrea		sap			2	nw	August	22	2016
Lepiota cristata	3	sap			2	nw	August	22	2016
Crepidotus applanatus		sap			2	nw	August	22	2016

Lycoperdon nigrescens		sap			2	nw	August	22	2016
Gyroporous castaneus		sap			2	nw	August	22	2016
Russula virescens		ecto				nw	August	22	2016
Panellus stipticus		sap				nw	August	22	2016
Abortiporus biennis		sap				nw	August	22	2016
Crepidotus applanatus		sap			3	nw	August	22	2016
Mycena inclinata		sap			3	nw	August	22	2016
Boletus campestris	4	ecto			3	nw	August	22	2016
Marasmius rotula		sap			3	nw	August	22	2016
Crepidotus applanatus	2	sap			4	ne	August	22	2016
Boletus campestris		ecto			4	ne	August	22	2016
Ganoderma applanatum		sap			9	c	August	22	2016
Marasmius rotula		sap			8	c	August	22	2016
Polyporus varius		sap			7	c	August	22	2016
Schizophyllum commune	2	sap			2	nw	September	15	2016
Inocybe sp	4	ecto			2	nw	September	15	2016
Tyromyces chioneus		sap			3	nw	September	15	2016
Polyporus alveolaris		sap			3	nw	September	15	2016
Russula virescens		ecto				nw	September	15	2016
Megacollybia rodmanii		sap				nw	September	15	2016
Conocybe aurea		sap				nw	September	15	2016
Trichaptum biforme		sap				nw	September	15	2016
Polyporus varius		sap			4	ne	September	15	2016
Sarcoscypha occidentalis		sap			4	ne	September	15	2016
Stereum ostrea		sap			4	ne	September	15	2016
Boletus campestris		ecto			4	ne	September	15	2016
Gymnopilus luteus		sap			8	c	September	15	2016
Polyporus varius		sap			7	c	September	15	2016
Abortiporus biennis		sap			7	c	September	15	2016
Laetiporus sulferus		sap	y	c	7	c	September	15	2016
Phellinus gilvus		sap				c	September	15	2016
Conocybe aurea		sap				c	September	15	2016
Abortiporus biennis		sap				c	September	15	2016
Pholiota limonella		sap				c	September	15	2016
Gymnopilus luteus		sap				c	September	15	2016
Lenzites betulina		sap				c	September	15	2016
Tyromyces		sap				c	September	15	2016

chioneus								
Crepidotus applanatus		sap			c	September	15	2016
Stereum ostrea		sap		1	nw	September	30	2016
Mycena luteopallens	14	sap		1	nw	September	30	2016
Marasmius sullivantii		sap		1	nw	September	30	2016
Panellus stipticus	3	sap		1	nw	September	30	2016
Phlebia tremellosa		sap		1	nw	September	30	2016
Marasmius sullivantii	2	sap		1	nw	September	30	2016
Mycena inclinata		sap		2	nw	September	30	2016
Mycena luteopallens	11	sap		2	nw	September	30	2016
Stereum ostrea		sap		2	nw	September	30	2016
Schizophyllum commune		sap		2	nw	September	30	2016
Marasmius rotula		sap		2	nw	September	30	2016
Mycena luteopallens	2	sap		3	nw	September	30	2016
Mycena inclinata		sap		3	nw	September	30	2016
Marasmius rotula		sap			ne	September	30	2016
Tyromyces chioneus		sap			ne	September	30	2016
Morganella pyriformis		sap	y		ne	September	30	2016
Mycena luteopallens	46	sap		4	ne	September	30	2016
Marasmius sullivantii		sap		4	ne	September	30	2016
Marasmius rotula		sap		4	ne	September	30	2016
Entoloma abortivum	4	sap	y	4	ne	September	30	2016
Schizophyllum commune	2	sap		4	ne	September	30	2016
Panellus stipticus	3	sap		4	ne	September	30	2016
Mycena luteopallens	62	sap		5	ne	September	30	2016
Marasmius sullivantii		sap		5	ne	September	30	2016
Mycena inclinata		sap			ne	September	30	2016
Mycena luteopallens	4	sap		6	ne	September	30	2016
Marasmius sullivantii		sap		6	ne	September	30	2016
Polyporus varius		sap		6	ne	September	30	2016
Entoloma abortivum		sap	y	6	ne	September	30	2016
Lycoperdon nigrescens		sap		6	ne	September	30	2016
Mycena luteopallens	5	sap		9	c	September	30	2016
Mycena luteopallens	8	sap		8	c	September	30	2016
Lepiota cristata		sap		1	nw	October	16	2016
Armillaria gallica	5	sap	y	1	nw	October	16	2016

Cortinarius iodes		ecto			2	nw	October	16	2016
Mycena luteopallens	5	sap			2	nw	October	16	2016
Armillaria gallica	8	sap	y		2	nw	October	16	2016
Entoloma abortivum		sap	y		2	nw	October	16	2016
Marasmius sullivantii	2	sap			3	nw	October	16	2016
Mycena luteopallens	5	sap			3	nw	October	16	2016
Armillaria gallica	8	sap	y		3	nw	October	16	2016
Entoloma abortivum	4	sap	y		3	nw	October	16	2016
Cortinarius iodes		sap			3	nw	October	16	2016
Morganella pyriformis		sap	y			nw	October	16	2016
Pluteus cervinus		sap				nw	October	16	2016
Calvatia gigantea		sap	y			ne	October	16	2016
Armillaria gallica		sap	y			ne	October	16	2016
Hypholoma sublateritum		sap				ne	October	16	2016
Armillaria gallica	2	sap	y		4	ne	October	16	2016
Entoloma abortivum	4	sap	y		4	ne	October	16	2016
Mycena luteopallens	5	sap			4	ne	October	16	2016
Panellus stipticus		sap			4	ne	October	16	2016
Stereum ostrea		sap			4	ne	October	16	2016
Flammulina velutipes		sap	y	c		ne	October	16	2016
Mycena luteopallens	77	sap			5	ne	October	16	2016
Mycena inclinata	2	sap			5	ne	October	16	2016
Morganella pyriformis		sap	y			ne	October	16	2016
Entoloma abortivum		sap	y		6	ne	October	16	2016
Pholiota limonella		sap				c	October	16	2016
Mycena luteopallens	2	sap			9	c	October	16	2016
Marasmius sullivantii		sap			8	c	October	16	2016
Mycena inclinata		sap			8	c	October	16	2016
Galerina marginata	2	sap			8	c	October	16	2016
Armillaria gallica	9	sap	y		7	c	October	16	2016
Galerina marginata	4	sap			7	c	October	16	2016
Mycena inclinata		sap			7	c	October	16	2016
Xeromphalina tenuipes		sap			7	c	October	16	2016
Phellinus gilvus		sap			7	c	October	16	2016
Phellinus gilvus	2	sap			3	nw	October	30	2016
Bisporella citrina		sap			3	nw	October	30	2016
Entoloma abortivum		sap	y			nw	October	30	2016

Schizophyllum commune		sap		5	ne	October	30	2016
Trametes pubescens		sap		5	ne	October	30	2016
Mycena luteopallens	6	sap		5	ne	October	30	2016
Marasmius sullivantii		sap		5	ne	October	30	2016
Mycena inclinata	4	sap		5	ne	October	30	2016
Trametes versicolor		sap		5	ne	October	30	2016
Marasmius sullivantii		sap		6	ne	October	30	2016
Marasmius sullivantii		sap		6	ne	October	30	2016
Phellinus gilvus		sap		6	ne	October	30	2016
Russula brevipes		ecto			ne	October	30	2016
Bisporella citrina		sap		9	c	October	30	2016
Pluteus cervinus		sap			c	October	30	2016
Lenzites betulina		sap			c	October	30	2016
Mycena inclinata		sap		8	c	October	30	2016
Galerina marginata	2	sap		8	c	October	30	2016
Galerina marginata	4	sap		7	c	October	30	2016
Auricularia auricula		sap		7	c	October	30	2016
Pleurotus ostreatus		sap	y		c	October	30	2016
Panellus serotinus		sap			ne	November	17	2016

Stand Inventory Raw Data

Plot	Location	Notes	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12
1	nw		Prunus	Prunus serotina	2.5	2.6	3	2	6	1.8	3.3	2	4.5	4.5		
1	nw		Ulmus	Ulmus americana	3	2.4	4.3	4.6	2							
1	nw		Quercus	Quercus rubra	2.8	19	6	21.4								
1	nw		Carva	Carva ovata	2.4	2.8	2									
1	nw		Carva	Carva cordiformis	5.2	11.3	6.2	7.7								
1	nw		Tilia	Tilia americana	4.7	4.3										
2	nw		Acer	Acer rubrum	3.1	6.3	6.2	14.1								
2	nw		Tilia	Tilia americana	6.4											
2	nw		Carva	Carva glabra	12.9	21.6										
2	nw		Quercus	Quercus rubra	17	6.4	15.6	3.8								
2	nw		Ulmus	Ulmus americana	1.9	6.3										
2	nw		Prunus	Prunus serotina	9											
3	nw		Prunus	Prunus serotina	2.7	5	5.7	2.2	2.4							
3	nw		Carpinus	Carpinus	2.7	1	1.6	1.7								
3	nw		Quercus	Quercus rubra	15.7	9.7										
3	nw		Tilia	Tilia americana	4.4	8.4	10.9	15.4								
3	nw		Carva	Carva glabra	8.3											
3	nw		Carva	Carva cordiformis	1.6											
3	nw		Acer	Acer rubrum	1	1.4	4	6.5	3.5	1.5						
4	ne		Quercus	Quercus rubra	8.5	11.9	19.5	17.2								
4	ne		Quercus	Quercus alba	8.3	6.2										
4	ne		Carpinus	Carpinus	1.3	1.8	2.4	3.5	1.3	1.3						
4	ne		Carva	Carva glabra	1	1.3	1.8	2.4	3.5	1.3	1.3					
4	ne		Carva	Carva cordiformis	3.4											
4	ne		Ulmus	Ulmus americana	2.7	3.2										
4	ne		Acer	Acer rubrum	5.6	2.7	3.3	2.8	1.8	1.8	4.2					
4	ne		Rhamnus	Rhamnus	2.3											
5	ne		Acer	Acer rubrum	1	1.5	1.2	3.8	1.8	2.4	1.3	1.1	1.6	1	1.7	3.5
5	ne		Prunus	Prunus serotina	12											
5	ne		Ulmus	Ulmus americana	2.7	2.4	2.8									
5	ne		Tilia	Tilia americana	3.6											
5	ne		Quercus	Quercus rubra	13	15.5										
5	ne		Carva	Carva ovata	10.2											
6	ne		Quercus	Quercus rubra	21.4											
6	ne		Ulmus	Ulmus americana	1											
6	ne		Carva	Carva ovata	1.9	7.8	3.6									
6	ne		Prunus	Prunus serotina	6.4	3.6	6									
6	ne		Acer	Acer rubrum	5.4	3	7	11.2	14.1	6.4						
7	c		Acer	Acer sacharinum	18.1	14.5	6	4.7	15	5	4.9	10.3				
8	c	Verified ID	Fraxinus	Fraxinus	1.3	3.2	4.3	2.5								
8	c		Cephalant	Cephalanthus	2.4	1.4	1.9									
8	c		Ulmus	Ulmus americana	2.2											
8	c		Rhamnus	Rhamnus	1.9	1.4	1.5	2.4	2.1							
9	c		Acer	Acer sacharinum	2.3	3.8	2.9	2.1	2.5	11.	21.	9.8				
9	c		Carva	Carva glabra	8	6.7	8.4	2.7								

Plot	Location	Notes	Species	Under 1'	Over 1'
1	nw		Fraxinus americana	5	1
1	nw		Carya cordiformis	4	
1	nw		Carya glabra	4	
1	nw		Carya ovata	4	
1	nw		Rhamnus cathartica	2	
2	nw		Acer rubrum	2	
2	nw		Carya cordiformis		1
2	nw		Carya glabra	2	
2	nw		Fraxinus americana	1	3
2	nw		Quercus rubra	2	
2	nw		Tilia americana		1
2	nw		Ulmus americana	2	
2	nw		Rhamnus cathartica	4	
3	nw		Acer rubrum	4	
3	nw		Carpinus caroliniana	4	
3	nw		Carya cordiformis	1	
3	nw		Carya glabra	1	
3	nw		Fraxinus americana	4	
3	nw		Prunus serotina	1	
3	nw		Tilia americana	3	
4	ne		Carpinus caroliniana	1	
4	ne		Carya glabra		1
4	ne		Fraxinus americana	12	7
4	ne		Rhamnus cathartica	1	
5	ne		NONE		
6	ne		Fraxinus americana	17	6
6	ne		Carya cordiformis		2
6	ne		Carya ovata	6	
7	c		Acer sacharinum	5	
8	c		Acer sacharinum	10	
8	c		Fraxinus pennsylvanica		12
9	c		Fraxinus americana	3	1