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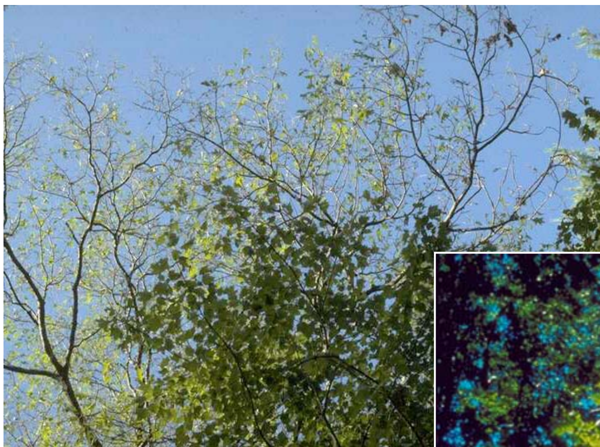
GYPSY MOTH SILVICULTURAL CONSIDERATIONS FOR MINNESOTA



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GYPSY MOTH SILVICULTURAL CONSIDERATIONS FOR MINNESOTA (2003)

TABLE OF CONTENTS **PAGE**

FIGURES **PAGE**

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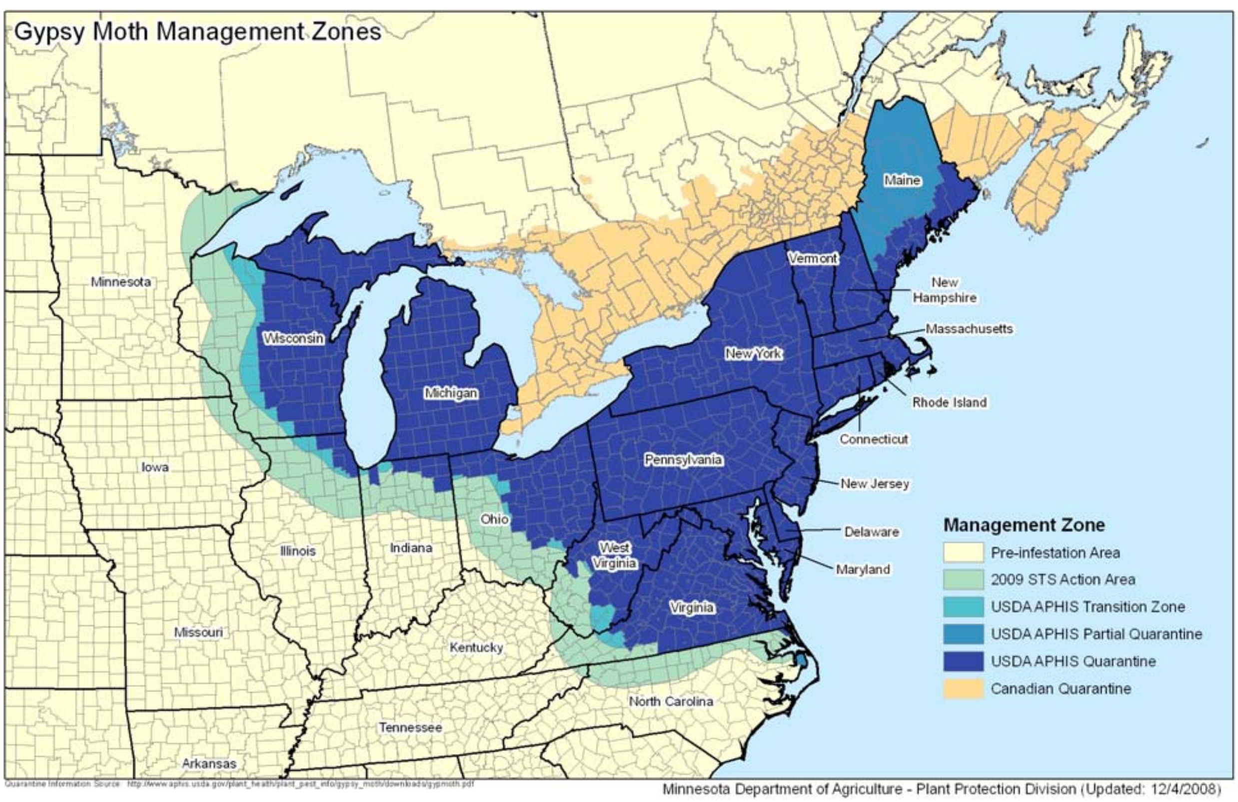
INTRODUCTION

Gypsy moths, *Lymantria dispar*, were introduced into North America almost 150 years ago near Boston, Massachusetts. By the 1990s, gypsy moths had spread throughout the northeast and Mid-Atlantic States into Michigan and Wisconsin (see Map 1). The Minnesota Department of Agriculture has been successfully detecting and eradicating spot infestations within Minnesota since 1969. However, it is just a matter of time, likely five to ten years, before gypsy moths become permanently established in the state (4).

In 2001, the Minnesota Department of Agriculture, Minnesota Department of Natural Resources (MNDNR), USDA Forest Service (USFS), USDA Animal and Plant Health Inspection Service (APHIS), and the University of Minnesota (UMN) published the "Strategic Plan for the Cooperative Management of Gypsy Moth in Minnesota". The strategic plan recognized silvicultural practices as a valuable set of tools in dealing with this exotic pest (4). Because trees are long-lived and slow growing, forest management practices are most effective when applied well in advance of gypsy moth defoliation. Land managers can minimize the ultimate impact of gypsy moth defoliation by starting now.

Map 1. Gypsy Moth Management Zones, 2008 (7)



INTENT OF THIS DOCUMENT

The goal of this document is to enhance urban and rural forest management in order to mitigate the long-term impacts associated with gypsy moth defoliation. The objective is to provide professional land managers with the tools needed to make sound gypsy moth management decisions within the context of normal silvicultural practices. In recognition of the fact that gypsy moth management is only one issue facing land managers, the intent is to present the information in a format that can be easily integrated into other management considerations.

Because the gypsy moth is not currently established in the state, this document focuses on the period prior to infestation. Because the time needed for forests to respond to any form of management is relatively long, we encourage land managers to incorporate gypsy moth considerations into their plans now. Recommended steps include:

1) Review the risk model for areas at risk of damage.
2) Update stand inventories in areas at high to moderately high risk.
3) Evaluate stand inventory data and prioritize stands that may benefit from active management with planning partners.
4) Incorporate gypsy moth considerations into scheduled management practices as budgets allow.

RISK OF DAMAGE

Gypsy moths produce two types of damage with the potential to affect land-use objectives; defoliation and tree mortality. Different factors influence whether or not a stand is at risk of defoliation or of tree mortality and different strategies are used to minimize the associated impacts. Stands highly susceptible to defoliation may suffer little mortality if they are growing under favorable conditions. Stands with a low susceptibility to defoliation, may suffer heavy mortality on the unusual occasion of being defoliated, if extenuating conditions place them at risk (15, 19, 33, 35). So understanding the distinction between susceptibility (to defoliation) and vulnerability (to mortality) is important in selecting appropriate management strategies.

Risk of Defoliation and Species Composition

The most important factor affecting the susceptibility to gypsy moth defoliation is the proportion of the stand comprised of gypsy moth’s preferred host species (1, 27, 37, 51). While many species of trees and shrubs are utilized as a food source, gypsy moth caterpillars prefer some species and avoid others. Stands dominated by oaks, aspen, birch, basswood, tamarack, or other preferred species are at a higher risk of defoliation because they are fed on by all caterpillar stages (see Table 1) (25, 50). Understory vegetation may also play a major role in making some stands more susceptible to the gypsy moth. Ticehurst and Yendol (67) report that most early instar gypsy moth larvae occur in the understory or on the forest floor in mixed oak forests.   In Minnesota, 53% of the forests are comprised of 50% or more of these preferred host species (5). Susceptible stands dominated by preferred host species experience more frequent and longer outbreaks, which produce higher levels of defoliation than do stands composed of avoided species such as ash and silver maple (1, 19, 38).

Defoliation events will occur within five to 15 years of the initial infestation in a given area and most hardwoods will likely be defoliated at least once during this time frame as populations spread across the state (34). Subsequent outbreaks are generally less severe and depend on stand composition, site conditions that provide favorable gypsy moth habitat and weather (37, 40, 49). Some stands will be 100% defoliated on a regular basis and some will be completely avoided. Most stands, however, will fall somewhere between these two extremes, with patchy, cyclic defoliation after the initial outbreak.

Table 1. Gypsy Moth Host Preferences (33)

Category	**Overstory species**	**Understory species**
Preferred Species readily eaten by all caterpillar stages.	All oak, bigtooth and quaking aspen, basswood, paper and river birch, larch, mountain-ash, tamarack, willow and apple	Hawthorn, hazelnut, hop hornbeam, hornbeam, and serviceberry
Less preferred Species fed upon when preferred species are unavailable and by older caterpillar stages.	Yellow birch; box elder; butternut; black walnut; sweet and black cherry; eastern cottonwood; American, Siberian** and Chinese elm; hackberry; hickory; Norway**, red and sugar maples; all pine; all spruce; buckeye*, and pear*	Blueberries, pin cherry, chokecherry, sweet fern
Avoided Species that are rarely fed upon.	All ash, E. red cedar, balsam fir, silver maple, slippery elm, N. catalpa*, Kentucky coffeetree, horse chestnut*, sycamore*, black** and honey* locusts and red mulberry**	Dogwood, elderberry, grape, greenbrier, juniper, mountain and striped maple, raspberry, viburnum, and buckthorn**

* Commonly planted urban species. Use in woodlands is not recommended.
** Species that can be invasive. Gypsy moth defoliation may increase their competitive edge if left in a managed stand.

Note, all ash species are susceptible to the emerald ash borer (EAB). As a result, caution is needed when considering future stand composition. Scattered white ash trees growing in mixed uplands stands are the least likely of the ash to succumb to an EAB infestation.

Site Condition

Some stands that are otherwise susceptible may not be defoliated because they are not climatically suited for gypsy moth establishment and/or population build-up. Cold temperatures combined with winter drying can kill the eggs (52, 53). Winter mortality can keep populations low and limit or prevent defoliation, as seen in the upper peninsula of Michigan. However, egg masses survive well under snow, so population numbers can build during years of heavy snow cover (48, 64). Warm winter temperatures and high solar radiation can also have an effect on winter survival, killing eggs laid in sites exposed to the sun (54).

Sites with a history of severe defoliation are often characterized by frequent droughts, and low foliage biomass. Harsh growing conditions or a history of disturbance, such as grazing, storm damage or outbreaks of native pests, are also commonly associated with susceptible stands (1, 13, 40). Under mesic conditions, gypsy moth larvae commonly rest in the forest litter. Under xeric conditions, larvae spend most of their time in the trees (13). In the canopy, gypsy moths escape predation by hiding under bark flaps, in stem wounds, or other protected location (1, 56). Harsh sites often have a higher concentration of hiding places for the gypsy moth caterpillars along with limited habitat for predators like spiders, white-footed mice, and birds. Besides the distribution of preferred host species, weather and local site conditions are among the factors that determine the incidence and severity of defoliation events (22, 49).

Risk of Tree Mortality

Davidson et al (19) outlined a number of consistent relationships found between gypsy moth defoliation and tree mortality:

1. Preferred tree species are defoliated at higher rates and frequently suffer greater mortality than avoided species.
2. Tree mortality increases as the intensity, duration and frequency of defoliation increases.
3. Trees in the lower canopy (suppressed and intermediate crown classes) have a higher probability of being defoliated and dying, than trees in the upper canopy (dominants and co-dominants).
4. Physiological condition prior to defoliation directly influences the probability of mortality of individual trees. Those in good condition are less likely to die than those in poor condition.

These factors do not act independently; rather, it is their interaction that determines the outcome in the affected stands. Actual mortality in a given situation will depend on the duration and severity of defoliation, as well as the influence of local site and environmental conditions during the outbreak.

Intensity and Duration of Defoliation

As noted earlier, species composition is the primary factor determining the risk of defoliation.. The primary factor determining the risk of mortality is the intensity and duration of defoliation (1, 19, 35, 38). Light defoliation (less than 30%) usually causes little damage to trees. Trees with moderate defoliation (30% to 60%) may experience some growth loss, but are unlikely to die. When heavy defoliation occurs (greater than 60%), refoliation places a demand on the tree’s food reserves. The stress of refoliation can leave trees weakened and vulnerable to secondary pests, such as two-lined chestnut borer on oak and Armillaria root rot on all species. As the number of consecutive episodes of defoliation increases, the probability of tree mortality rises. Multiple stress events can have an additive effect and can result in significant loss of trees (1, 19, 58). For example, tree mortality in Michigan has been observed primarily in oak-dominated stands where gypsy moth defoliation coincided with late spring frosts or drought (72, 73).

Gypsy moth outbreaks commonly last one to five years in eastern North America. However, the initial outbreak in a newly infested area is generally longer and more severe (34). In eastern states, initial outbreaks resulted in mortality losses of 15% to 35% of the total basal area of defoliated stands (29). In Michigan, initial gypsy moth outbreaks lasted 2 to 4 years in oak-dominated forests and 1 year in aspen forests. Losses at the stand level among oak forest types ranged from 0% to 75% of the basal area with average losses of 6% to 10% across all forest types (73). Losses associated with later outbreaks are generally lower. After the initial outbreak, gypsy moths behave much like native pests with outbreaks occurring on a cyclic basis (1).

Among Minnesota tree species, those most at risk of damage include oak, aspen, paper birch, tamarack, and basswood (51). Among these, oak is the most likely to suffer noticeable levels of mortality that can impact community structure, wildlife habitat, and dependent industries (19, 35, 38).

Mortality rates among aspen are likely to be low (44, 54, 73). However, the high nutritional value of aspen leaves means caterpillars grow rapidly and are more likely to survive to adulthood (36, 45, 71). This allows gypsy moth populations to build rapidly. Fortunately, gypsy moth outbreaks among aspen stands are short lived. Trees are able to recover prior to the next defoliation event. In Michigan, outbreaks in stands dominated by oaks last two to four years, whereas outbreaks in aspen stands commonly collapse after one year of defoliation (72). The early collapse is thought to be associated with the rate of larval infection by the nucleopolyhedrosis virus (NPV), a common disease of gypsy moth (45). The low pH of oak leaves alters the toxicity of the NPV virus. Tannins, which are in higher concentrations in oak leaves than in aspen leaves, also seem to have an effect on the virus. The combination results in less disease resistance and shorter outbreaks among populations feeding on aspen.

The difference in nutritional value between aspen and oak may influence the frequency of defoliation in mixed or adjacent stands. Aspens may allow a rapid buildup of gypsy moth populations, while oaks sustain them. As a result, trees in mixed or adjacent stands may see repeat defoliation and increased mortality where they otherwise might not.

Minnesota has vast acreages of aspen, birch, oak, and basswood susceptible to both forest tent caterpillar (FTC) and gypsy moths (5). If gypsy moth and FTC outbreaks occur concurrently, the two insects may compete with each other for food. Because FTC emerges slightly ahead of the gypsy moth, FTC may limit gypsy moth population build up (54). If outbreaks occur consecutively, the prolonged stress may cause heavy mortality among all tree species involved.

While not normally a preferred host, white pine can be at risk of damage when grown under a susceptible overstory (30, 72). Where thinning isn't sufficient to reduce the risk of defoliation, the loss in value resulting from early harvest of a susceptible overstory may have to be weighed against the cost of protecting valuable understory pine.

Crown Condition and Class

The greatest single indicator of the likelihood of individual tree mortality is the physiological condition of the tree prior to defoliation (19, 27, 35). Crown condition is a highly visible indicator of a tree's level of stress and is therefore a good measure of its vulnerability to defoliation-related mortality. Mortality is highest among poor-crown trees, intermediate among fair-crowned trees, and lowest for trees in good condition (see Figure 1) (35).

Poor crowns = 50% or more of the main branches are dead; when foliage density, size, and coloration are subnormal; or when epicormic sprouting is heavy.

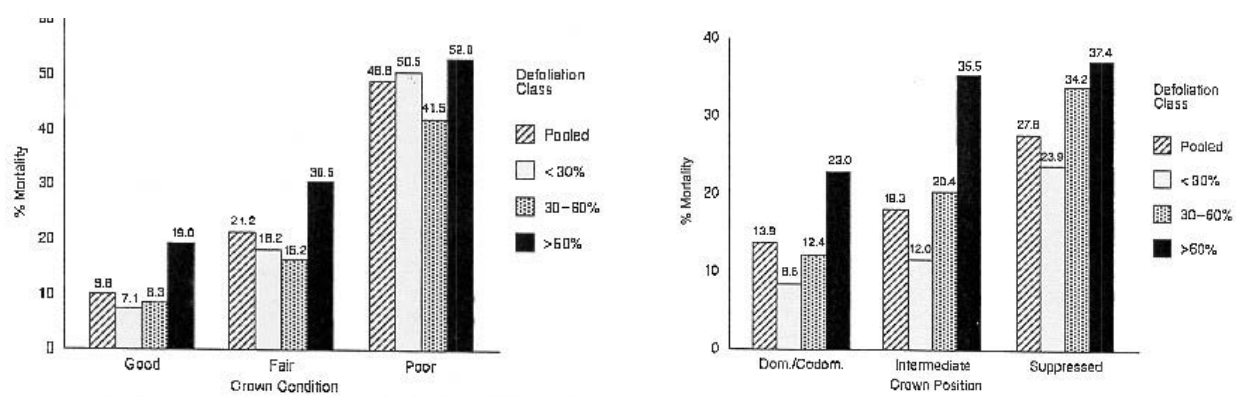
Fair crowns = 25% to 49% of the main branches are dead; when foliage density, size, and coloration is subnormal; or when there is some epicormic sprouting.

Good crowns = less than 25% of the main branches are dead; when foliage is healthy; and there is little or no epicormic sprouting.

Crown class has a similar correlation. As a general rule, intermediate and suppressed trees are more likely to die than dominant or codominant trees following defoliation. Small diameter trees and very large, overmature trees are also more likely to die than large, vigorous trees. In Michigan, most of the mortality has been in the suppressed- and intermediate-crown classes (72).

Even among the most susceptible species, dominant or codominant trees with crowns in good condition are likely to survive multi-year defoliation. On the other hand, a tree in an intermediate- or suppressed-crown class with a crown in fair to poor condition that has been defoliated is very likely to die, whether or not it is of a preferred host species (16, 35, 38).

Figure 1. Effect of crown condition and position on gypsy moth defoliation-related tree mortality (35).



Examples of crown conditions and their rating:

Poor Crown

Fair Crown

Good Crown

Poor Crown

Fair Crown

Good Crown

Site Suitability

The physical capacities and limitations of the site determine to what extent trees are able to maximize their reproductive, defensive, and competitive strategies. While trees may prefer specific growing conditions (which may or may not match where they are commonly found), ultimately trees will grow where they can effectively compete (58, 68, 69). Trees growing under conditions limiting their competitive ability are often predisposed to stress because they do not have the resources needed to maintain normal functions. Growth and reproductive rates tend to be lower and mortality rates higher under these conditions. The extent to which trees are growing on less than optimal sites is strongly correlated to the level of mortality seen after a defoliation event (1, 59).

Measuring site factors, how they interact and contribute to site productivity can be a daunting task. While site index is the most common method of estimating site quality, there are many methods to use, none of which can be effectively applied in all circumstances. Instead, land managers must use all the tools at their disposal (ecological land classification system and soil maps plus tree and site measurements, as well as their own expertise) to determine the suitability of a particular site for the species in question.

Other factors associated with the site that can affect the physiological condition of a tree include: past management history, recent weather and disturbance history, stand structure, status of competitors, density, age, and the presence or absence of pests (58). Recreation, grazing, past harvesting, and weather extremes can alter physical site characteristics (for instance, compacted soils) and alter the status of competitors (for instance, release maples in the understory). Even thinnings done to increase tree vigor can temporarily stress residual trees, leaving them susceptible to damage if they are exposed to another stress agent prior to full recovery. Recent stand history (i.e. two to five years prior to defoliation) is important and may increase mortality levels associated with a defoliation event.

Stand composition and structure as a function of physical site characteristics determine the competitive advantage each species has over others. Because the interaction of site characteristics and the species present are unique to each site, land managers must make management decisions on a site-by-site basis.

POTENTIAL IMPACTS IN MINNESOTA

To a great extent, forest cover will determine both the risk of damage and the likelihood of secondary impacts (1). For instance, wildlife impacts will depend on the frequency and severity of defoliation and the occurrence of associated tree mortality. Secondary impacts associated with defoliation alone include those that affect water quality, wildlife habitat, tourism, and human quality of life. Secondary impacts associated with tree mortality include those that affect wildlife habitat, forest industries, and property values (1, 26, 31, 33).

Risk Assessment

To assess the risk of tree morality following a defoliation event, a risk model was developed using guidelines established by Eiber, 1997 (20). The model incorporates forest cover, soil type, evapotranspiration shortfall and the probability of gypsy moth establishment in the following equation:

$$.65(A) + .20(B) + .15(C) - (D) = \text{the risk of tree mortality, where:}$$

A = GAP forest data (5) ranked by host preference

B = Atlas soil type (3) ranked by drought potential

C = drought stress calculated as Thornthwaite's evapotranspiration potential (10) minus 30 year average growing season precipitation (9).

D = probability of gypsy moth establishment (62) based on elevation and 30 year average temperatures.

The 30m resolution GAP data was created by MNDNR Forestry Resource Assessment using 1991 Landsat images and protocols outlined by the National GAP Program. The 100m resolution Soil Atlas data was obtained from the Minnesota Land Management Information Center (LMIC), as was the climate data. The Canadian Forest Service calculated the probability of gypsy moth establishment in Minnesota using Biosimm®. The resulting values were grouped into high, moderately high, moderate, or low risk categories and displayed in Map 2. For a listing of the rankings for each variable, see the appendix.

Forest Impacts

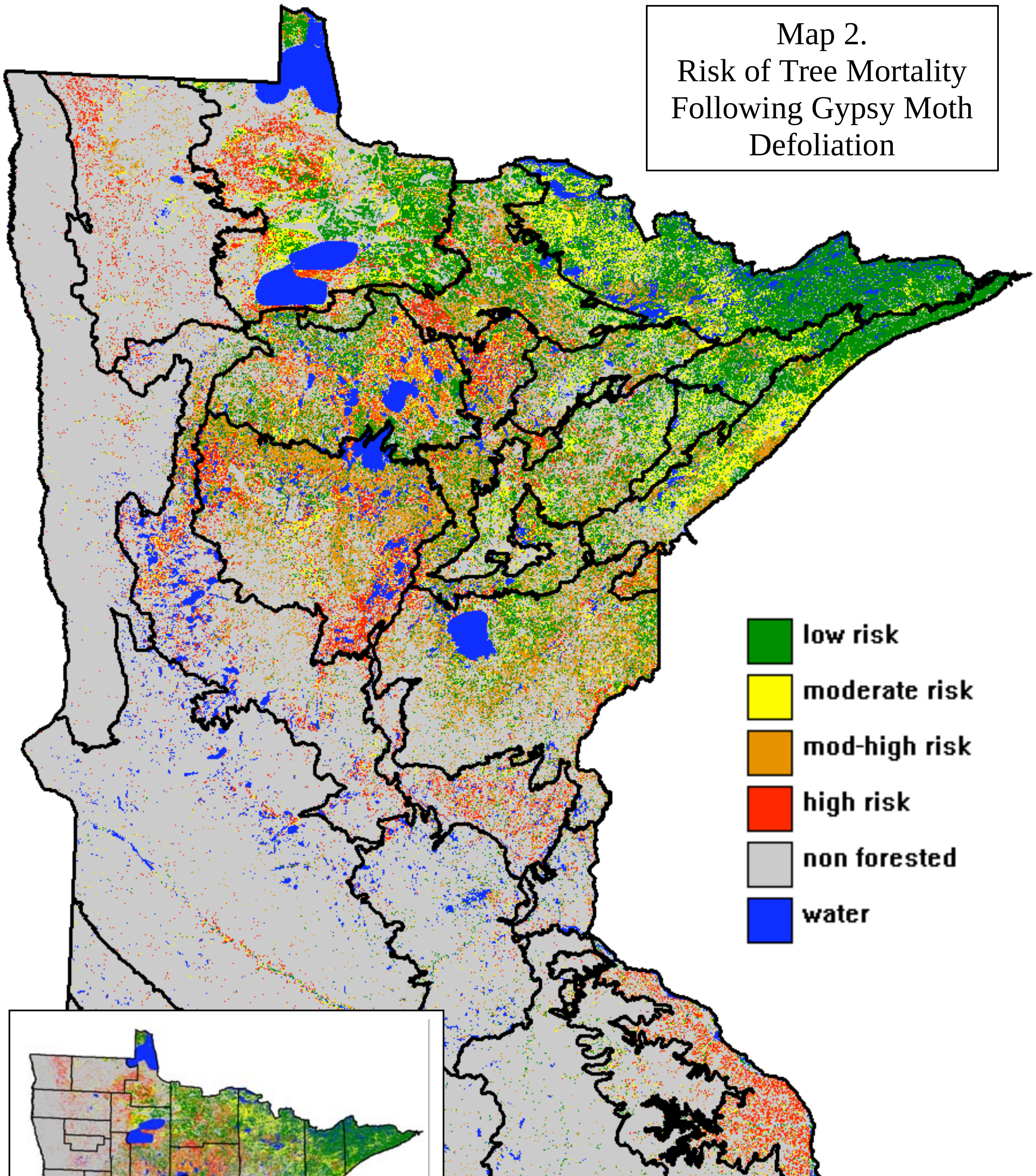
While high-risk stands occur in a scattered pattern across the state, the highest concentrations of stands at high to moderately high risk of mortality occur in a broad C-shaped band from southeast Minn., through the Twin Cities area and then west and north through the center of the state.

In the southeast, stands are commonly even-aged and dominated by oak. White and northern red oaks are found on the moist sites, while bur and pin oaks are found on the drier sites. The topography limits management options, so gypsy moth defoliation may shift species composition toward the current understory species, i.e., maple on the moist sites and shrub or grasslands on the drier sites. Local wildlife dependent on the oaks may suffer as a result of these population shifts.

Northern red oak and pin oak dominate most of the hardwood stands in the Twin Cities area, where oak wilt, buckthorn, and development pressures limit both growing conditions and the management options. Oak decline is already common on the Anoka Sand Plains after the last several drought events, so significant mortality may be a problem once the gypsy moth arrives.

Along the transition between prairie and forest ecosystems, intermittent drought and harsh growing conditions place oak-dominated stands at high risk of mortality. A heavy pine component may lessen defoliation in some forest stands, but without active management, oak dominated stands may convert to other cover types, such as prairie grasslands and savannas. In northern Minnesota, the lowland conifers are at little risk of gypsy moth-related damage. However, the abundance of aspen throughout this region

Map 2.
Risk of Tree Mortality
Following Gypsy Moth
Defoliation



With Subsection Boundaries
See the discussion of
subsections under separate
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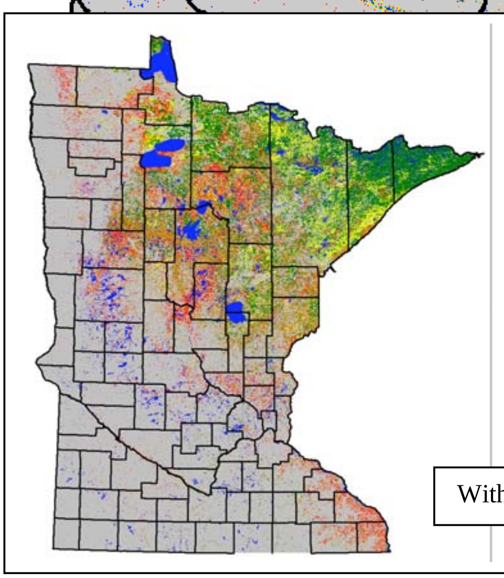

With County Boundaries

will support large populations of gypsy moths. Defoliation events are likely to be spectacular but are not likely to cause much tree mortality, unless FTC outbreaks and/or drought compound gypsy moth-related stress.

In northeast Minnesota, the probability of establishment drops dramatically greatly lowering the risk of defoliation-related tree mortality. However, gypsy moths are able to survive and reproduce under these temperatures as demonstrated by populations in Canada and the Upper Peninsula of Michigan. Along the north shore, many of the birch at their pathological rotation age and have already begun to decline. If the area sees several years in a row of mild temperatures that allow gypsy moth populations to build, the risk of defoliation and subsequent tree mortality goes up. In that case, it may be difficult to maintain these stands because the shallow rocky soils limit species other than birch and the tourist industry limits management options.

In east-central Minnesota, forested sites are more moist with fine-textured soils. As a result, they support diverse northern hardwoods that are less susceptible to defoliation. Because of the range of management options, silvicultural practices may be useful to limit future tree loss. However, defoliation will still likely be significant and affect the tourist industry.

Wildlife Impacts

Gypsy moth infestation in Minnesota has the potential to both harm and benefit wildlife habitat and species (12, 24, 60, 66). The degree of impact is dependent on the timing and extent of defoliation, and whether or not defoliation results in significant tree mortality. There may also be some impacts to wildlife arising from silvicultural efforts to prepare for potential moth infestation.

Many bird species may see short-term benefits from the dramatically increased food supply, increasing survival rates and fledging success (63). Cuckoos, which quickly adapt to intensive feeding on moth larvae, may increase in number. Mammals such as black bears, mice, and shrews are also likely to take advantage of moth larvae as a food source. Moth eggs may be used for food by wintering insectivorous bird species such as chickadees and woodpeckers (17). On the other hand, defoliation can reduce mast production among the oaks (32) so may affect bird and mammal populations dependent on acorns.

Oak (all species), aspen, basswood, and all hawthorn, hazel, and alder species provide important wildlife food, nesting sites, or cover. Significant mortality of these species can lead to long-term loss of valuable habitat. Tree mortality can benefit some species by creating additional snags with cavity potential and coarse woody debris as dying trees begin to fall (12, 63).

Opening the forest canopy, whether by defoliation alone or by defoliation followed by tree mortality, increases the amount of light reaching the forest floor and subsequent temperatures. Birds susceptible to heat stress may abandon nests. They may also see an increase in egg/juvenile mortality along with higher mortality of forest reptiles and amphibians. An open canopy may lead to increased predation of some bird species and their nests and an increase in the incidence of nest parasitism (12, 66). Conversely, opening the canopy can lead to a flush in growth of shrub, grass, and forb species that respond to increased light and temperature levels. This vegetative flush can be beneficial to many bird and mammal species that utilize them for food, nesting, and cover (11, 12, 16, 43). Increased light and temperature through the canopy may also lead to an increase in insect populations. This may be beneficial to species that utilize them for food, and to the young of species that have a critical need for insect food sources located within or near cover, such as turkeys (47) and ruffed grouse (14).

Water Quality Impacts

Gypsy moth, like other forest defoliators, can influence the quantity and quality of water resources as well as promote changes to the aquatic animal community. Whether these perturbations have serious consequences for Minnesota's water resources depends on the duration of the defoliation-induced change.

While Minnesota is renowned for lake resources, the state also hosts a number of valuable stream resources that are more likely to be impacted by defoliation. These streams contain diverse animal communities and complex food webs. Some streams harbor rare or endangered biota, while others include important recreational species such as trout. Trout streams are generally clustered into three regions of the state; southeast Minnesota in bluff country where trout streams cascade down to the Mississippi River floodplain, northeast Minnesota along Lake Superior and upper St. Croix River valley where trout populate many of the tributary streams, and central Minnesota where bold springs provide sufficient coldwater refuge for trout to survive during the warm summer months. Due to the complex interaction of stream communities, changes in any one component of the animal community can have rippling effects throughout the entire aquatic system. And undoubtedly, changes will be judged to be "beneficial" or "undesirable" depending on how recreationally important or ecologically sensitive species respond to these perturbations.

Reduction in the amount of foliage in a forest stand reduces the rate of evapotranspiration. Water that normally moves through the leaves of trees remains in the soil. Rainfall energy, normally dissipated by leaves, can result in increased runoff during periods of defoliation. This runoff can lead to increased turbidity, channel instability, and risk of flooding (62). With time, increases in herbaceous plants due to increased available light may increase soil water-holding capacity and help absorb rain impact.

Any changes in leaf deposition, volume or timing from riparian trees (whether from defoliation- induced forest community changes or active forest management) could disrupt stream productivity and cause shifts in the aquatic invertebrate community if occurring over a long period of time (57). The stream invertebrate community could shift from one specialized in shredding of leaf material to one specialized in filtering particulate matter or algae. Several studies have found relationships between riparian forest composition and stream productivity (8, 60, 65). Macro invertebrate abundance and diversity was influenced by the riparian forest type (i.e., deciduous or coniferous).

Stream corridors dominated by deciduous trees demonstrated higher macro-invertebrate production (from terrestrial and aquatic sources) than coniferous trees.

Extensive stand mortality can increase the amount of coarse woody debris in the riparian corridor. Coarse woody debris is recognized as an important habitat component in the littoral area of lakes and greatly enhances habitat complexity in streams. Woody debris provides a substrate for algae and aquatic insect fauna, which are the base of the aquatic food chain. Numerous fish species utilize woody debris for overhead cover in streams and spawning substrate in lake environments. Woody debris in the riparian zone also contributes wildlife benefits as loafing habitat for waterfowl, turtles, and small mammals.

Leaf bits and frass produced during larval feeding drop into streams causing the nutrient content, primarily nitrogen and phosphorus to increase (70). In karst groundwater recharge areas, these sources of pollution as well as contamination due to inappropriate application of pesticides, may severely impact sensitive fish, wildlife, and water resources. Turbidity as well as fecal streptococci and coliform counts can also increase in response to increased frass production (18). A study of water quality before and during gypsy moth defoliation events in an Appalachian stream watershed suggested that acidification could occur due to the large amount of nitrate entering the system (70). Nitrate, acting like sulfate in acid rain, can overwhelm the capacity of the watershed to neutralize it, resulting in a decrease in stream pH. The detrimental effect of stream acidification on aquatic communities is well documented in the scientific literature. Stream resources in northeastern Minnesota likely would be most vulnerable to acidification.

Stream water temperature can increase because of reduced cover and increased solar radiation. A reduction in the forest canopy and associated beneficial shading of streams can cause an elevation in stream temperature. This is particularly a concern for trout streams in central Minnesota that approach the upper thermal tolerance limit for trout.

Recreational Impacts

Losses in tourism are influenced by the perceived scenic beauty of forests and by the direct impact of gypsy moths in high-use areas. Light defoliation opens forest stands and increases flowering among understory plants. This tends to increase public appeal. However, heavy defoliation and the resultant tree mortality decreases both drive-by and in-the-woods appeal (23).

In high-use areas, losses in tourism occur primarily during May, June, and early July. This is when feeding caterpillars become such a nuisance that tourists either shorten their visits or completely avoid recreational, historical, and tourist facilities located in infested areas. For example, public use of the Allegheny National Forest in Pennsylvania (ck on that) declined 20% during periods of defoliation (28). Wood-lot owners in New Jersey reported they lost recreational use of their land for an average of 108 person-days annually (46). This is because of the downpour of caterpillar droppings, irritating effects of larval hairs and lack of appeal created by large numbers of caterpillars and defoliated trees.

An additional cost is the creation of a large number of hazardous trees in high-use and urban areas. Hazard trees combined with multiple targets (people, structures, and vehicles) greatly increase public liability. Associated management costs can be prohibitive particularly for government agencies and small communities dependent on the tourist trade.

GENERAL SILVICULTURAL CONSIDERATIONS

Based on the two types of damage, there are two silvicultural strategies in forest management that can help mitigate future damage due to gypsy moth defoliation. The first involves reducing the likelihood of defoliation by reducing the percent of preferred host species found in a stand. This strategy is appropriate where the importance of nonhost species can be increased, while still maintaining adequate stocking levels of important preferred host species. Doing so reduces the severity and frequency of gypsy moth population outbreaks, which in turn lessens the impact on recreation and aesthetic values. In stands with a 50% or more preferred host species composition, or in stands where site conditions or land use limit silvicultural options, diversifying the stand may not be an option.

The second strategy is to reduce the vulnerability to mortality associated with gypsy moth defoliation-related stress by increasing stand vigor. Generally, damaged and suppressed trees are removed. Crop trees are favored. Nonpreferred host species are encouraged where appropriate and healthy preferred host species are maintained as an important component of the stand.

An added tool is the use of biopesticides. It may be necessary to protect high-value stands or stand components under certain circumstances, even when silvicultural practices are being utilized. For instance, advanced oak regeneration or understory white pine growing under an overstory of oak may be at high risk if protective actions are not undertaken (30, 39). If the silvicultural options are limited due to site conditions or other factors, biopesticides may be the only means to limit damage to high-risk stands.

How and where these strategies apply depends on site-level risks and land use values that may be affected. Recreation managers may not be concerned with tree mortality, but may be very concerned about defoliation levels affecting tourism. While growth loses may be noticeable, timber production isn’t severely affected until tree mortality begins to reduce merchantable stand volumes. The management threshold for aesthetic and wildlife values tends to fall somewhere between tourism and timber needs (33). Once the risk of damage has been determined, these values provide the basis for determining which if any, silvicultural practices are appropriate for a particular stand.

Site-Level Silvicultural Considerations – Keep in mind what the risk of damage warrants and what site conditions allow. See the Tatum Guide, page 27.

To diversify stand composition:

- Where site conditions allow, use thinning or regeneration systems to increase the proportion of less-preferred and avoided tree species to 50% or more of stand stocking.   (However, avoid favoring ash in stands already dominated by ash due to their high susceptibility to EAB).
- When regenerating a stand using shelterwood systems, special protection of the understory may be warranted through the use of biopesticides. The overstory may support high gypsy moth populations and the resulting defoliation can kill young seedlings.
- When managing stands on severe sites, such as sandy outwash plains or dry ridges, focus on regeneration of more suitable species based on the native plant community present or consider a shift in cover type based on the appropriate Subsection Forest Resource Management Plan (SFRMP).
- Where underplanting is needed to maintain oak in the stand, plant a mix of 50% oak and 50% avoided tree species. Always plant species appropriate for the site.

Intermediate timber stand improvement techniques to improve health and vigor of existing stands:

- Thin the stand to increase the size and vigor of residual crowns, i.e., the best trees in the dominant and codominant crown classes.
- Reduce stocking to an appropriate level.
- Early in the rotation, thin stump sprouts of gypsy moth preferred tree species, such as oak, or birch, to one stem per stump.
- In order to ensure adequate advanced regeneration, harvest stands prior to the time at which sprout capabilities are likely to decline, based on the disturbance regime and the conditions found on that specific site.
- If there is insufficient advanced regeneration present, use a shelterwood harvest. Competing vegetation may need to be controlled and desirable seedlings may need to be protected to ensure regeneration of the stand.

To maintain stand structure and composition for multiple benefits:

- Where healthy individuals are present, retain large-diameter, preferred-host species as seed and timber sources and for wildlife habitat.
- Where appropriate, provide wildlife habitat in nearby moderate- to low-risk stands.
- Although the creation and retention of coarse woody debris can enhance gypsy moth habitat by providing larval hiding places, the gypsy moth is not yet established in Minnesota. Until the moth becomes permanently established in Minn., follow site-level guidelines for the volume of snags, culls, and coarse woody debris. At that time, remove larval hiding places in high-risk stands.

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APPENDIX

GYPSY MOTH DAMAGE RISK MODEL

Model Equation: .65(A) + .20(B) + .15(C) – (D) = risk model of tree mortality following defoliation

where:

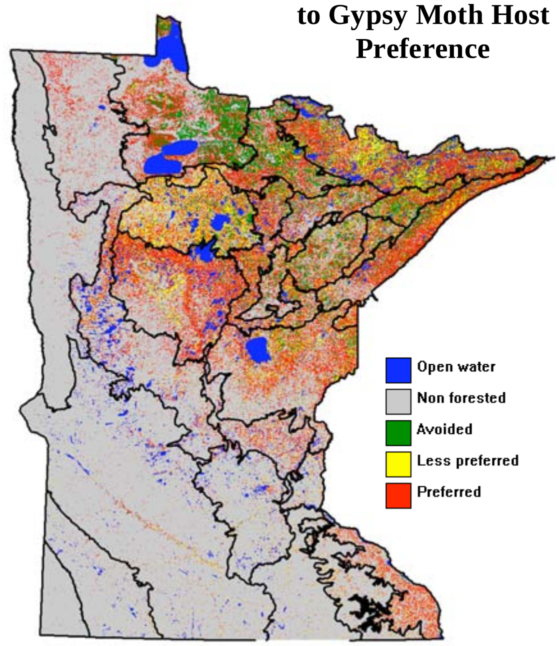
A = Forest cover ranked by gypsy moth host preference (MNDNR, GAP, 1995)
B = Soil type ranked by moisture holding capacity (Eiber, 1997)
C = Calculated evapotranspiration potential (Thornthwaite, 1979) minus 30 yr. average growing season precipitation
D = Probability of gypsy moth establishment, based on elevation and 30 yr. average temperatures (Regniere, 2002)

Data Layers:

I Forest cover, 30 meter resolution

Preferred Species:
Aspen/White Birch mix
Oak
Bur/White Oak mix
Red Oak
Northern Pin Oak
Tamarack
Less Preferred Species
Jack Pine
Red/White Pine
Red Pine
White Pine/mix
Jack Pine-Deciduous mix
Red/White Pine-Deciduous mix
Upland Coniferous mix
Upland Deciduous mix
Upland Coniferous/Deciduous mix
Cottonwood
Maple/Basswood mix
Avoided Species
Black Ash
Silver Maple
Black Spruce
White Spruce

Risk of Defoliation Due to Gypsy Moth Host Preference



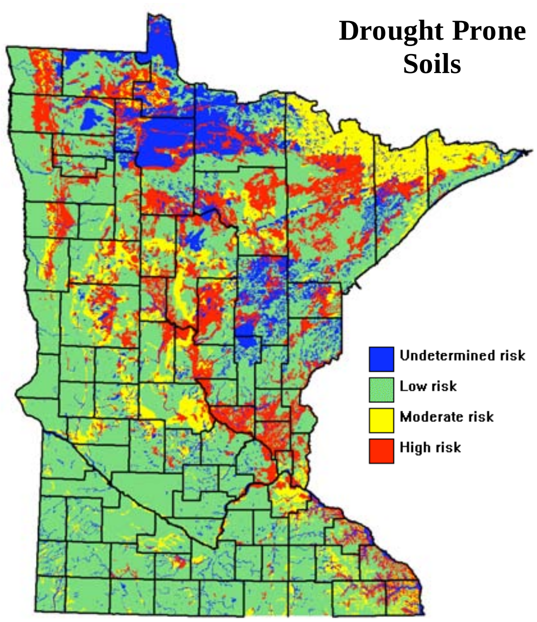
Spruce/Fir-Deciduous mix
Avoided Species cont.
Balsam Fir/mix
Red Cedar
Red Cedar-Deciduous mix
Northern White Cedar
Lowland Deciduous mix
Lowland Deciduous/Coniferous mix

II Soil type = Soil Atlas reclassed.

Where 1st column = sub soil &
2nd column = top soil
And C = clay
L = loam
R = rock
S = sand
X = mixed sandy loam
Y = mixed silty clay

Where 3rd column = drainage
And P = poorly drained
W = well drained

Where 4th column = color
And D = dark



L = light

Soil type rankings are:

Undetermined or no Potential
- AAAA (Alluvial)
- HHHH (Water)
- MDMD (Mines or dumps)
- MMMM (Marsh)
- RBRB (Raised bogs)

Low Damage Potential
- APAP (Acid peat)
- BPBP (Peat bog)
- CCPD
- CLPD
- CLPL
- CCPL
- CCWD
- CCWL
- LCPD
- LCPL
- LCWD
- LCWL
- LLPD
- LLPL
- LLWD
- LLWL
- LPLP (Peat over loam)
- NPNP (Non-acid peat)
- Peat

- SLPL
- SPSP (Peat over sand)
- YLPD
- YLWD
- YLWL

Moderate Damage Potential
- CSPL
- LSPD
- LSPL
- RCWL
- RLPD
- RLWD
- RLWL
- SLWD
- SLWL
- SLPD
- SSPL
- SSPD
- XCWL
- XLWD
- XLWL

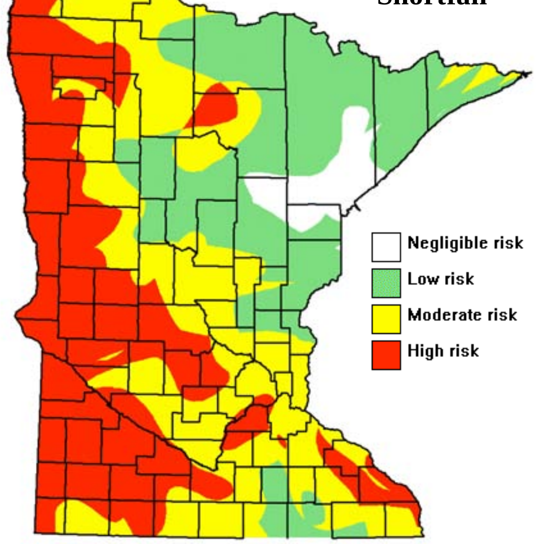
High Damage Potential
- CLWD

CLWL
CSWL
LSWD
LSWL
Rock
RSWD
RSWL
SSWL
SSRR (Steep rock)
SSWD

III Climate stress = Thornthwaite mean evapotranspiration potential minus 30 year ave. growing season precipitation, reclassed:

0-2” shortfall = negligible stress
3-4” shortfall = low stress
5-6” shortfall = moderate stress
7” & greater = high stress

Drought Risk Due to Evapotranspiration Shortfall



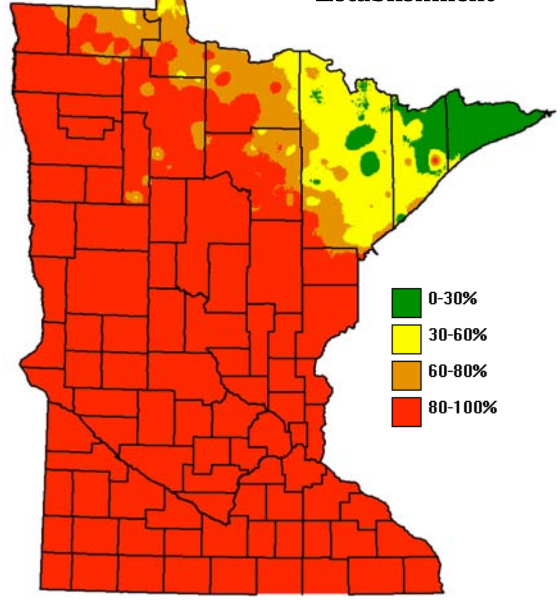
IV Probability of establishment, Canadian model reclassed:

0-30% probability = low risk (given a value of 2)

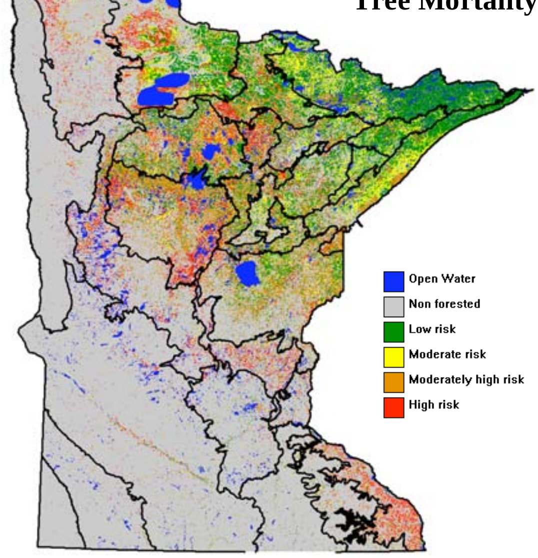
30-60% probability = moderate risk (given a value of 1)

60-100% probability = high risk (two categories grouped, given a value of 0)

Percent Probability of Gypsy Moth Establishment



Final Model: Risk of Defoliation-Related Tree Mortality



Gypsy Moth Silvicultural Considerations for Minnesota
TATUM GUIDE

Gypsy moths produce two types of damage with the potential to affect land-use objectives, defoliation and tree mortality. Different factors influence whether or not a stand is at risk of defoliation or of tree mortality, and different strategies are used to minimize their impacts. Understanding the distinction between susceptibility to defoliation and vulnerability to mortality is important in the selection of appropriate management strategies. Species composition is the primary factor determining the risk of defoliation (see Table 1). Stands dominated by preferred host species are likely to experience more frequent and longer outbreaks during which they are defoliated more severely than stands dominated by less preferred and avoided species. The primary factors determining the risk of mortality are the intensity and duration of defoliation and the condition of individual trees prior to defoliation. Condition is a function of site quality, competition and past history. Trees growing on less than optimal sites are at more risk of damage. Disturbed sites are also at more risk of damage. A thorough understanding of stand composition, stand history, and site-specific growing conditions is necessary for appropriate gypsy moth management.

There are two silvicultural strategies in forest management that can help mitigate future damage due to gypsy moth defoliation. The first involves reducing the likelihood of defoliation by reducing the percent of preferred host species found in a stand. This strategy is appropriate where the importance of nonpreferred host species can be increased, while still maintaining adequate stocking levels of important preferred host species. Doing so reduces the severity and frequency of gypsy moth population outbreaks, which in turn lessens the impact on recreation and aesthetic values. In stands heavily dominated by preferred host species, or in stands where site conditions or land use limit silvicultural options, diversifying the stand may not be an option.

The second strategy is to reduce the vulnerability to mortality associated with gypsy moth defoliation-related stress by increasing stand vigor. In general, damaged and suppressed trees are removed. Crop trees are favored. Less preferred host species are encouraged where appropriate and healthy preferred host species are maintained as an important component of the stand.

How and where these strategies apply depends on site-level risks and the values and land use that may be affected. Recreation managers may not be concerned with tree mortality, but may be very concerned about defoliation levels affecting tourism. While growth loses may be noticeable, timber production isn’t severely affected until tree mortality begins to reduce merchantable stand volumes. The management threshold for aesthetic and wildlife values tends to fall somewhere between tourism and timber needs. Once the risk of damage has been determined, these values provide the basis for determining which if any, silvicultural practices are appropriate for a particular stand.

Steps for Gypsy Moth Management:

1. Review the risk model and determine which areas are at high to moderately high risk.
2. Determine which stands within those areas need an updated stand inventory.
3. Prioritize needed inventory work lacking or outdated and schedule as budgets allow.
4. Review the inventory data for all stands at high to moderately high risk and evaluate site and tree conditions.
5. Review land-use objectives, site-level guidelines, and desired future conditions.
6. Determine which species are best suited for each site.
7. Determine what adjustments need to be made in the composition and/or quality of each stand (see Table 2). For each stand answer:
    - Will defoliation alone impact land-use objectives? If so, how much can or can’t be tolerated?
    - Will tree mortality impact land-use objectives? If so, how much can or can’t be tolerated given site conditions?
8. Prioritize needed stand work and schedule as budgets allow.

Table 1. Gypsy Moth Host Preferences	Note: * ornamental species not normally used in woodland settings, ** invasive species	
Category	**Overstory Species**	**Understory Species**
Preferred Species readily eaten by all caterpillar stages	All oak, bigtooth and quaking aspen, basswood, paper and river birch, larch, mountain ash, tamarack, willow, red alder, and apple	Hawthorn, hazelnut, hop hornbeam, hornbeam, serviceberry, witch-hazel
Less preferred Species fed upon by older caterpillar stages	Yellow birch, box elder, butternut, black walnut, sweet and black cherry, eastern cottonwood, American, Siberian** and Chinese elm, hackberry, hickory, Norway**, red and sugar maples, pine, spruce, buckeye* and pear*	Blueberries, pin cherry, chokecherry, sweet fern
Avoided Species that are rarely fed upon	All ash, E. red cedar, balsam fir, silver maple, slippery elm, N. catalpa*, horse chestnut*, Kentucky coffeetree*, sycamore*, black** and honey locusts*, and red mulberry**	Dogwood, elderberry, grape, greenbrier, juniper, mountain and striped maple, raspberry, viburnum, and buckthorn**

Table 2. Silvicultural Practices Useful in Limiting Gypsy Moth Damage			
Practices	**To reduce defoliation**	**To reduce mortality**	**To maintain diversity**
Intermediate thinnings	• Reduce proportion of preferred host species to ≤ 50% • Reduce the proportion of aspen within oak stands • Thin sprout clumps to one or two sprouts • Enhance mouse habitat	• Harvest stands a minimum of two yrs after a stress event • Harvest stands three yrs prior to any defoliation event • Remove weak, suppressed, or damaged trees • Thin to a B stocking level or less • Remove aspen within bur oak savannas and goat prairies • Where consistent with desired future conditions, consider stand conversions to pine or native grass or shrub land	• Retain large-diameter healthy preferred host trees • Leave snags and large woody debris • If defoliation is imminent, protect white pine growing under susceptible host types • Provide wildlife habitat in adjacent less-susceptible stands
Pine releases	• Reduce proportion of preferred hosts (particularly aspen)	• Where feasible, locate away from high-risk stands • If defoliation is imminent, protect white pine growing under susceptible host types	• Maintain large-diameter, healthy preferred hosts (particularly oaks)
Regeneration cuts	• Where adjacent stands are comprised of predominately preferred host species, create openings >25 acres	• Harvest stands before sprout capabilities decline • Use a shelterwood harvest to ensure sufficient regeneration • Protect susceptible advanced regeneration if defoliation likely	• Leave snags and large woody debris • Provide wildlife habitat in adjacent less-susceptible stands where possible
Planting projects	• Plant a mixture of less-preferred or avoided species	• Protect susceptible understory stock if defoliation likely	• Plant a mix of species appropriate to the site, with up to 50% preferred host species

See the *DNR Silvicultural Tipsheet* for a brief overview of the potential risks. See the *Gypsy Moth Silvicultural Considerations for Minnesota, Aug 2003,* for a more thorough discussion of the risk of potential damage and areas of the state where moderate to high-risk stands occur.

Prepared by Minnesota Department of Natural Resources, USDA Forest Service, and University of Minnesota---August 2003

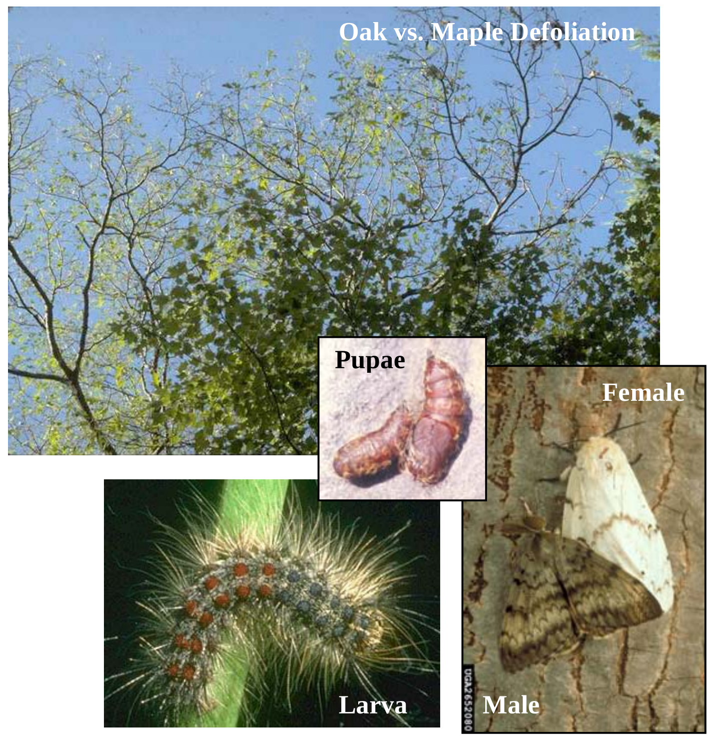
SILVICULTURE FIELD TIP
Field tested ideas.
Contact the author for further information.

Minnesota Department of Natural Resources
Division of Forestry

Field Tip No. 11 October 2003

MINIMIZING GYPSY MOTH DAMAGE

BY: Bill Barnacle, Silviculturist
Susan Burks, Forest Health Specialist



Gypsy moths are exotic, defoliating insects whose feeding can contribute to significant tree mortality. Currently, the moths are well established in eastern Wisconsin and are moving westward. The moth is not yet established in Minnesota largely because of the eradication efforts of the Minnesota Department of Agriculture. However, it is just a matter of time, perhaps five to ten years, before the moth becomes permanently established in Minnesota.

Landowners can minimize the impact of gypsy moth through active forest management. Because trees are long lived and slow growing, forest management practices are most effective when applied well in advance of gypsy moth defoliation. Forest managers are advised to begin now.

Once the moth becomes established, the most important factor affecting a forest's susceptibility to defoliation is the proportion of the forest made up of tree species that gypsy moth caterpillars prefer to eat (see table). Stands dominated by preferred species are defoliated at higher rates, more often, and for longer periods of time than stands composed of avoided species.

Site conditions and individual tree vigor play a role in how much tree mortality occurs after defoliation. Only a portion of those trees defoliated is at risk of mortality. A stand of trees that has a high proportion of preferred species and trees under stress or of low vigor, are at risk of significant mortality. Vulnerable sites are characterized by frequent droughts, slow growth and low amounts of foliage in the crowns. Ridge tops, and sites with shallow or overly dry sandy soils are examples of vulnerable sites.

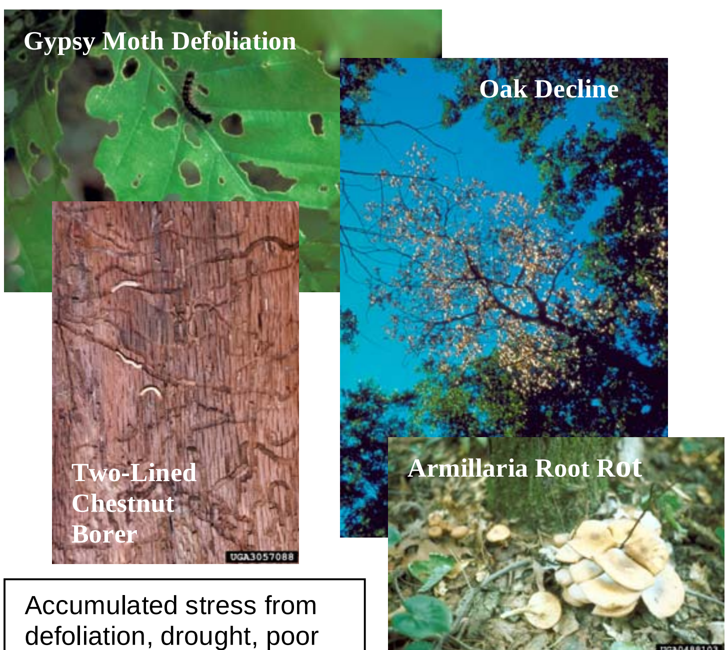
Table of Gypsy Moth Host Preference

Preferred:	Less preferred:	Avoided:
oak	yellow birch	ash
aspen	box elder	red cedar
basswood	walnut	balsam fir
paper birch	spruce	silver maple
tamarack	cottonwood	
	red and sugar maples	
	pine	

The greatest single indicator of the likelihood of tree mortality is a tree's physical condition at the time of defoliation. A tree with a full crown and only a few dead branches has a good chance of surviving defoliation.   A tree with a small crown and 50 percent or more dead branches has a poor chance of survival.

There is a similar correlation with a tree's crown class or its position in the canopy. A dominant tree that gets lots of sunlight has a good chance of survival. A suppressed tree that gets little direct sunlight has a poor chance of survival.

When gypsy moths become established in Minnesota and defoliate large areas, the repeated defoliation and tree mortality will likely shift susceptible stand composition away from oaks and other preferred species toward non-preferred species. On rich, good sites, species such as red maple, sugar maple and green ash may replace lost oaks. On drier, nutrient-poor sites, where seed sources occur, red and white pines may replace the oaks. In northern Minnesota, balsam fir will likely increase in number.



Accumulated stress from defoliation, drought, poor growing conditions and secondary pests contribute to tree mortality.

<u>What can you do to minimize the impact?</u>
There are two primary strategies in forest management that can help mitigate future damage due to gypsy moth defoliation. The first strategy involves reducing the likelihood of defoliation by reducing the percent of preferred host species through selective thinning. While reducing the component of preferred hosts won't prevent defoliation, it can lessen the severity and shorten insect outbreaks. The second strategy aims to reduce tree mortality following gypsy moth defoliation by increasing tree and stand vigor. This can also be done through thinning. Remove damaged and suppressed trees and encourage non-preferred species where appropriate. Maintain host stand diversity and healthy preferred host species as an important component of the stand.

- Make sure you have an up-to-date stand inventory before you begin. Effective gypsy moth management can only be done with a thorough understanding of the site and the stand on it.
- Determine if your forest stand is at moderately-high to high risk of damage.
- Determine if the likely damage levels have the potential to affect land-use objectives.
- Where appropriate, increase the component of less-preferred or avoided tree species. However, maintain existing healthy oak trees in your stand as a valuable wildlife resource.
- Consider thinning crowded stands or those with a history of stress and/or disturbance. Remove trees that are suppressed or have weak, thin crowns.
- Determine if your trees are "overmature." Old trees are more vulnerable to damage. Consider harvesting them - where that is appropriate.
- If you have hardwood stumps that have sprouted, remove all of the sprouts except one or two, where that's appropriate. A single sprout will develop a large, healthy crown less vulnerable to gypsy moth.
- When reforesting an area, plant a mixture of tree species with $\geq$ 50% avoided or less-preferred species. Avoid monocultures of any species.
- When planting trees, always match the tree species to the site. If you plant a tree where it doesn't belong, it will be stressed and vulnerable to mortality.
- When in doubt, check with a resource professional. They can help you determine the potential risk of damage and help you develop a management plan where that's needed.