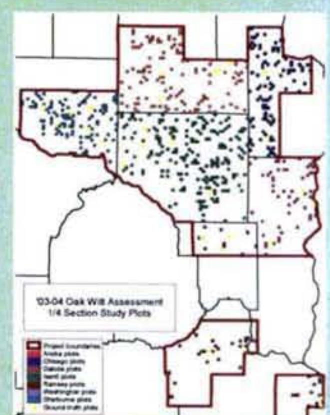
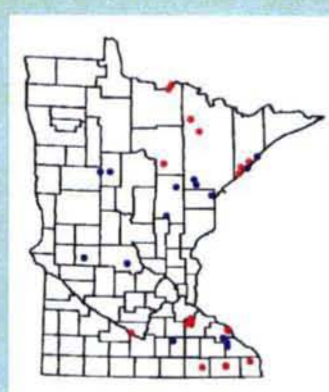
Jana's copy

Minnesota Forest Health Annual Report

2005

DNR – Forestry
Forest Health Unit





The forest resources of Minnesota

In Minnesota there are approximately 16.3 million acres of forested land, of which 14.9 million acres are classified as "timberland" or lands capable of producing timber. An additional 960,000 acres are not included in productive timberland due to their inclusion in the Boundary Waters Canoe Area Wilderness or other reserved land category. Forest land ownership is 46% private, 27% state, 14% county, 12% National Forest and 1% other federal ownership. (Source of data is the Minnesota 2001Eastwide Database provided by the USFS-NCFES.)

Two major industries depend on Minnesota's forested lands: forest industry and tourism. The forest industry is Minnesota's second largest manufacturing industry employing more than 55,000 people. The value of the forest products manufactured in Minnesota exceeds $7 billion and accounts for 16% of all manufacturing dollars generated in Minnesota. The tourism industry is Minnesota's second largest employer employing over 140,000 people and accounting for a payroll in excess of $3 billion. Gross receipts from tourism exceed $6 billion. Over 70% of people who took at least 1 spring or summer trip in Minnesota rated "observing natural scenery" as the most important activity of their trip.

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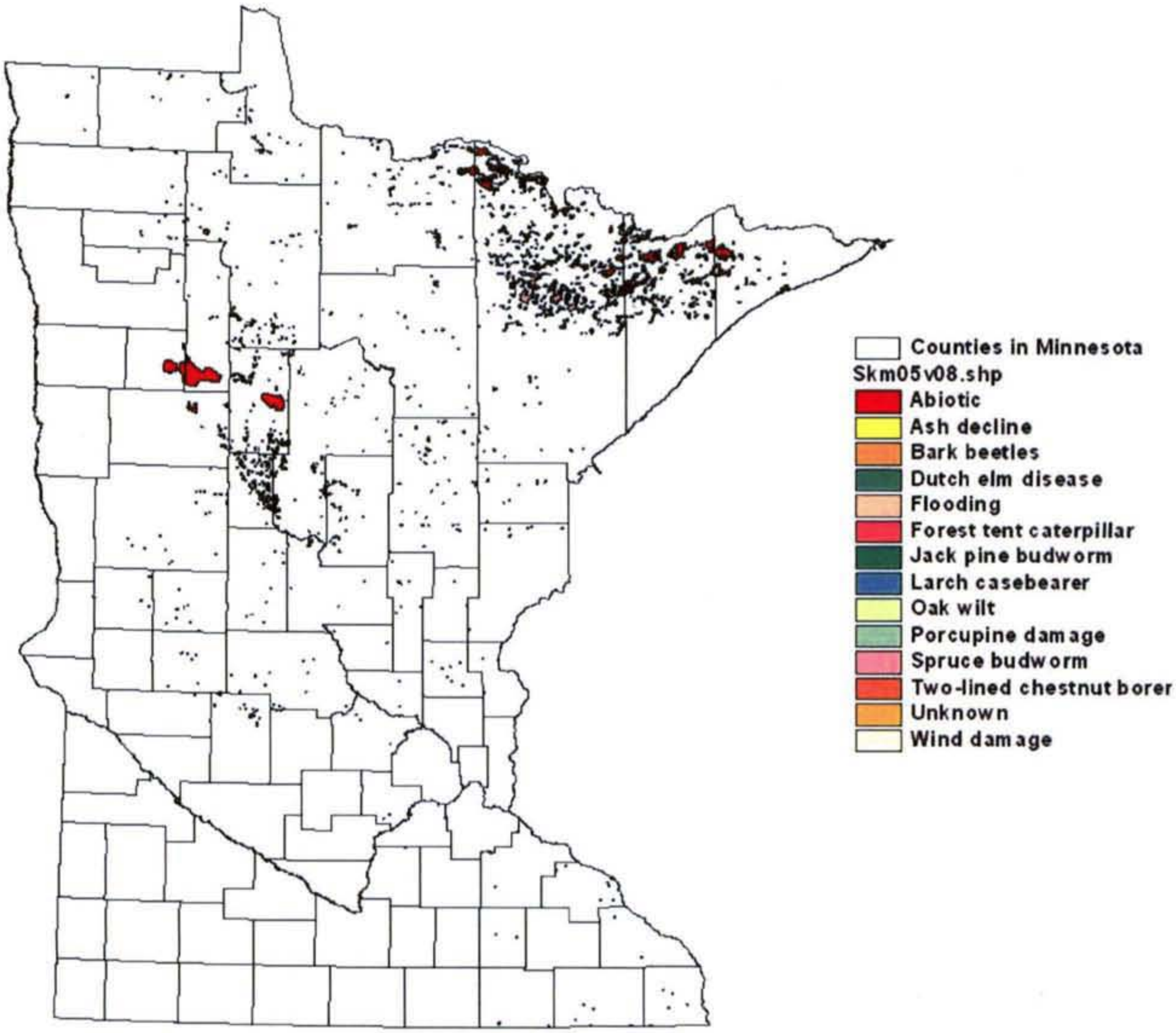
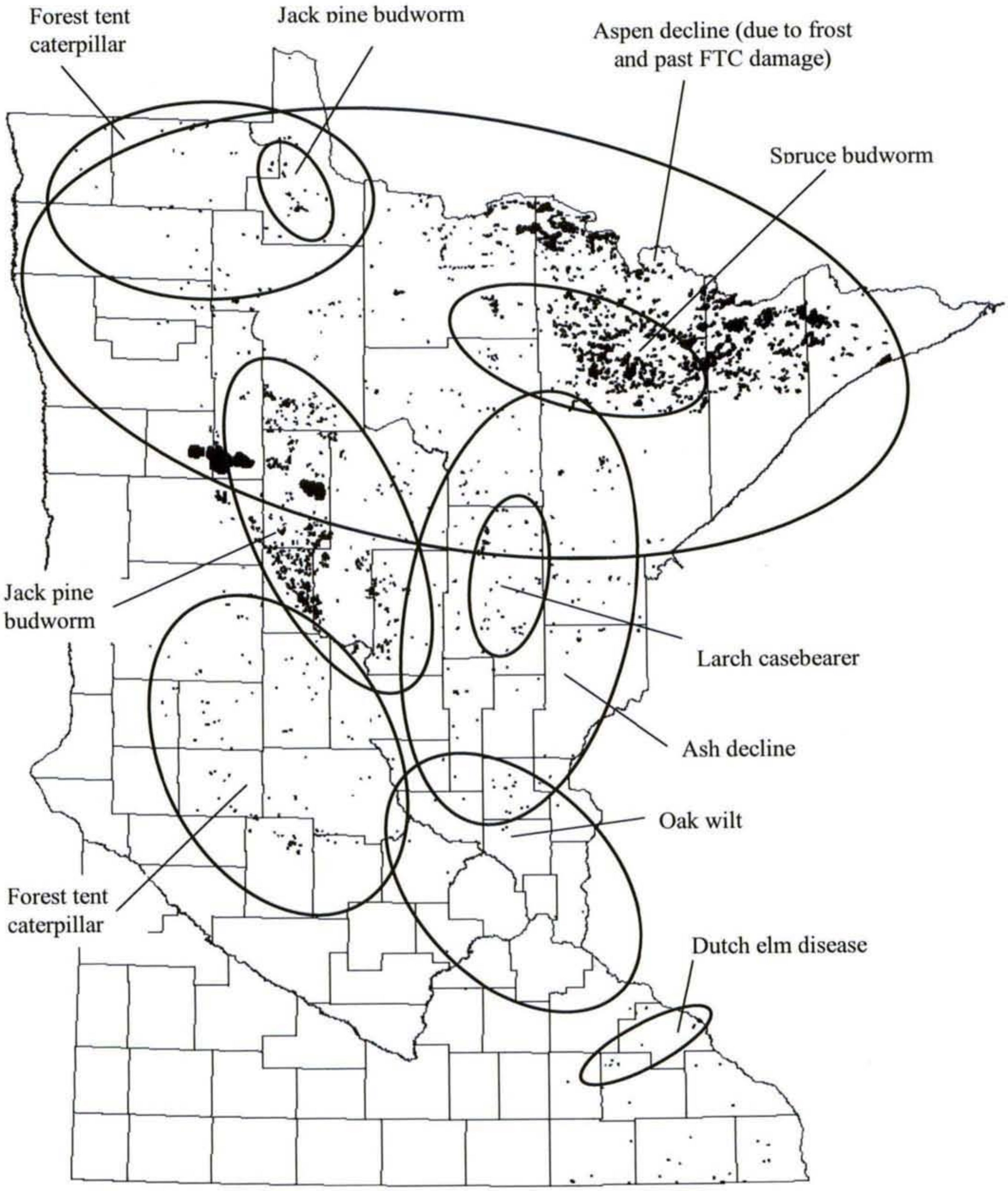
Aerial detection survey - 2005



Polygon and acreage totals from Aerial Survey 2005		
Agent name	**Number of polygons mapped**	**Total acreage of all polygons**
Aspen decline (due to spring frost and past forest tent caterpillar defoliation)	587	410,500
Ash decline	58	4,300
Dutch elm disease	12	560
Flooding	70	3,700
Forest tent caterpillar	109	9,800
Jack pine budworm	830	75,600
Larch beetle	187	11,000
Larch casebearer	52	4,600
Spruce budworm	192	92,500
Two-lined chestnut borer	11	770
Wind damage	91	3,400
Totals	**2199**	**616,730**

Aerial Survey - 2005



2005 Cheatsheet for Coding Damage Polygons

This sheet describes fields to be entered for 2005 damage polygons directly digitized from flight maps as ArcView shapefiles.

File Names: Successive versions of the sketchmapping shapefiles will be stored as skm05v01.xxx, skm05v02.xxx, etc.

Items coded: Arrange data fields in the following order and format:

Polygon ID: This consists of the name of the USGS 1:100,000 quadrangle on which the polygon is first delineated (even if it extends to other quadrangles), plus a 3-digit number: e.g. LakeItasca001, InternationalFalls125. Numbering starts at 001 in every quadrangle. Once assigned, this ID will not be changed unless the polygon must be divided. Character field, width 25.

Damage type code: Use severest type if more than one may apply. Flight map coding may indicate agent only; e.g. FTC = forest tent caterpillar = defoliation, or OW = oak wilt = mortality. Numeric field, width 2, no decimal.

Defoliation (D)	1	Topkill (Tk)	5
Mortality (M)	2	Branch breakage (Br)	6
Discoloration (Dc)	3	Stembreak/uproot (St)	7
Dieback (Db)	4	Branch flagging (Bf)	8

State severity code: Coding default is L unless otherwise specified. Character field, width 2.

Trace, 5%-25% affected	T	Moderate, 51%-75% affected	M
Light, 26%-50% affected	L	Heavy, > 75% affected	H

Federal severity code: Derived from state severity code. Numeric field, width 2, no decimal.

T, L	1	M, H	2

Pattern code: Coding default is 1 unless otherwise specified. Numeric field, width 2, no decimal.

Where host cover > 50%:		Where nonhost cover > 50%	
Cg = Contiguous	1	C = Continuous	3
P = Patchy	2	Sc = Scattered	4

Agent code: Following are common; see Aerial Survey Handbook for anything else. Coding default = Unknown (90000) where agent is not specified. Numeric field, width 6, no decimal.

Bark beetles (BB)	11000	Oak wilt (OW)	24021
Larch beetle (LB)	11010	Dutch elm disease (DED)	24022
Large aspen tortrix (LAT)	12037	Porcupine damage	41006
Spruce budworm (SBW)	12038	Flooding (F, Fl)	50004
Jack pine budworm (JPBW)	12041	Wildfire (WF)	50012
Larch casebearer (LCB)	12047	Wind damage (WD)	50013
Forest tent caterpillar (FTC)	12096	Winter injury (WI)	50014
Two-lined chestnut borer (TLCB)	15005	Herbicide damage (HD)	70001
Birch decline (BDb)	24005	Prescribed fire (PF)	70002
Ash decline (ADb)	24008	Unknown	90000

Agent Name: Common name of causal agent as given in Handbook. Character field, width 40.

Host code: Following are common; see Handbook for others. Use Hardwoods, Softwoods (= conifers) or Both if more than one species is involved. Numeric field, width 4, no decimal.

Hardwoods (Hw)	001		White pine	129
Softwoods (Sw)	002		Scotch pine	130
Both	003		White-cedar	241
Unknown	999	(Don't use unless necessary.)	Birch	370
Balsam Fir	012		Aspen	746
Tamarack	071		Balsam poplar	741
White spruce	094	(In plantations.)	Oaks	800
Black spruce	095	(In bogs.)	Willow	920
Jack pine	105		Basswood	950
Red pine	125		Elm	970

Host name: Common name of host as given in Handbook. Character field, width 40.

Acres: Calculate with Theme-Utilities > Calculate Area/Perimeter/Length in DNR Tools. Numeric field, width 16, 2 decimal places. Delete Area, Perfeet and Perimeter fields, retain Acres only.

Record of coding change

From: Quinn Chavez <qchavez@fs.fed.us>
To: "Mike Albers" <mike.albers@dnr.state.mn.us>, "Alan Jones" <alan.jones@dnr.state.mn.us>, "Jana Albers" <jana.albers@dnr.state.mn.us>, "David Heinzen" <david.heinzen@dnr.state.mn.us>, <bill.befort@dnr.state.mn.us>
Date: 1/25/2006 4:52:08 PM
Subject: Aspen with thin crowns and coding decision

We have confirmed that those polygons discussed are abiotic damage. In the national coding standard that Forest Health Monitoring uses I have changed the coding on those polygons as follows:

The damage causing agent code will remain DCA1 = 50000, 'abiotic', DAMAGE_TYPE1 is now '10', which is 'other damage' and in the NOTES field I have 'thin crowns, small leaves. Likely due to frost, drought and past forest tent caterpillar defoliation'.

Great job everyone. We should be updating the Viewer with final 2005 data for all of our states in the next couple of days.

Quinn Chavez
GIS Analyst
Northeastern Area
State & Private Forestry

INSECTS

Aspen blotch leaf miner

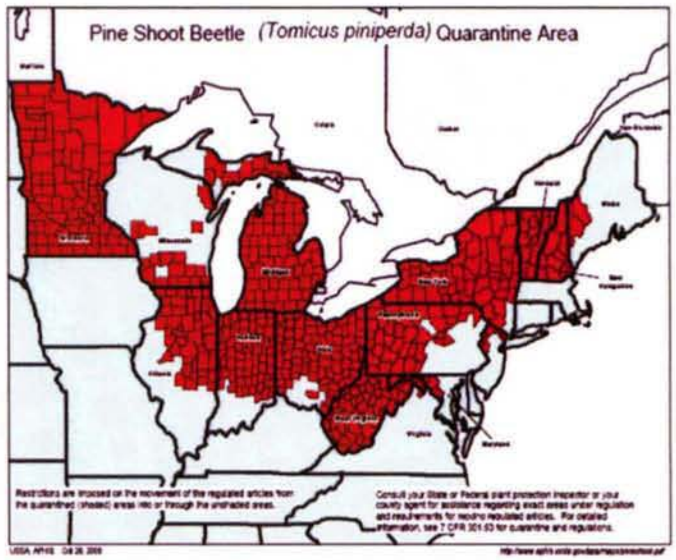
Phyllonorycter ontario

Leaf browning was very widespread and very heavy in northeastern counties during late summer.

Common pine shoot beetle

Tomicus piniperda

On September 16, 2005, a quarantine of <u>all counties</u> in Minnesota was established by the USDA for pine shoot beetles. Pine shoot beetles were caught in traps in Anoka, Dakota and Ramsey Counties in 2004. As a result Minnesota Department of Agriculture (MDA) established a state emergency quarantine for pine shoot beetle covering these 3 counties. MDA repealed the state quarantine of the three counties in Aug 2005, resulting in the USDA-APHIS establishing the federal, statewide quarantine.



The statewide quarantine regulates the interstate movement from Minnesota of pine trees and pine products with bark attached. For example all shipments of pine Christmas trees leaving Minnesota and going to non-quarantine areas must be certified free from pine shoot beetle. There are two ways to get a shipment certified. The first is to have a Plant Protection and Quarantine officer inspect the shipment and issue a certificate. The second way is for the grower or producer to attend an annual training and sign a compliance agreement.

A Eurasian bark beetle, the PSB feed inside new shoots, hollowing them out and killing the shoots. They breed under the bark and can build up in numbers under the right conditions They can feed on any pine, but prefer Scotch pine and only attack other pine when they are in mixed plantings with Scotch pine - and only then, when sanitation practices are lax. However, an outbreak can cause significant shoot damage, stunting and tree decline. An outbreak can also invite in other pests, such as the Ips pine bark beetle. They are considered a secondary beetle infesting recently cut, dying or severely stressed pine in the spring – hence the association with lax sanitation practices.

Young emerge in June and tunnel into the shoots of live trees. Each beetle may kill two to six shoots prior to moving to the base of a tree to over winter. The damaged shoots fade, brown and droop or break off at the base of the tunnel. These 'flags' are the most visible symptom of infestation. There may be several tunnels in one shoot and pitch tubes can occasionally found at the tunnel entry.

Potential impacts of pine shoot beetle

When PSB becomes established in Minnesota, we may hardly know it's even here or we may have significant impacts. We can make comparisons of impacts with native insects and with the exotics that are established in neighboring areas, but as exotic insects move into new areas, there is really no way to know for certain what their real impact will be. Here are some scenarios that illustrate how PSB impact might set Minnesota apart from the eastern states where it is rarely a concern.

1. Native bark beetles cause significant mortality losses during droughts in Minnesota compared to eastern states. The western counties of Minnesota are the western most edge of the native ranges of white, red and jack pines in the USA. Here it is dry, average annual rainfall is 20 inches, and even a modest drop in rainfall can precipitate a native bark beetle attack because trees are, in effect, growing in a prairie during the years of a drought.

Entomologists have shown that resins produced in healthy pine trees have the dual action of drowning-out and poisoning bark beetles. Yet, during comparable droughty weather, red pines in Minnesota are more readily attacked by native bark beetles than those in Wisconsin. Dr. Matthew Ayres, Dartmouth, found that, under normal rainfall conditions, resin flow in red pines was twice as high at Itasca State Park as it was at Eau Claire, Wisconsin. Under droughty conditions, Dr. Ayres speculates that this relationship would reverse. The resin defenses at Itasca would be compromised during droughts.

So, our red pines might inherently be more susceptible to exotic bark beetles during droughts because they are inherently more susceptible to native bark beetles.

2. PSB has a different timing of attack than native bark beetles. Pine shoot beetles fly and attack pines at least a month earlier than the native *Ips pini* . This might be important for jack pines because *Ips* bark beetles build up during jack pine budworm outbreaks. In this situation, if jack pine trees are defoliated by jack pine budworm and produce new shoots and needles, the next spring the pines may be able to recover some energy before being attacked by the native bark beetles. If instead, these trees are attacked by PSB before they produce new shoots and needles in the spring and before they have been able to recover from the stress of defoliation, they may suffer higher levels of mortality.

3. As the pine shoot beetle becomes established in Minnesota, they likely will displace some of the native bark beetles. Since PSB emerge one month earlier in the year, they will have used up the available habitat and produced their brood at the expense of the native bark beetles.

4. Many bark beetles carry blue-stain and other pathogenic fungi. Pine shoot beetles, like other bark beetles, carry fungi with them. The fungi they carry and their effects on pine trees have not been studied. It is conceivable that these fungi could cause problems with pine tree health.

5. Neighboring states find the most PSB problems in Scots pine growing in abandoned Christmas tree plantations. This is the situation where PSB finds its niche and then can build up and can spread into other species. Unfortunately there is no lack of unattended Scots pine plantations in Minnesota.

There are no simple answers when trying to predict what and how exotics will impact our trees, stands and ecosystems.

Douglas fir beetle

Dendroctonus pseudotsugae

Five Lindgren traps (16 funnel) were set in Arbo Township (Sec7-T56N-R25W) for Douglas-fir beetles. This is the site where Douglas-fir beetles were first caught in Itasca County. Each trap was baited with 1- ethanol pouch, 2 seudenol bubble caps, and 3 tubes of frontallin. Traps were set out on April 4, 2005, emptied once a week, and taken down on June 29' 2005. Preliminary sorting found no Douglas-fir beetles. Approximately 1680 eastern larch beetles were caught.

Minnesota Department of Agriculture set 5 Lingren funnel traps on or near the Larex plant in Cohasset, baited with commercial baits for Douglas-fir beetle. Preliminary sorting indicated that one Douglas-fir beetle was caught.

Eastern larch beetle

Dendroctonus simplex

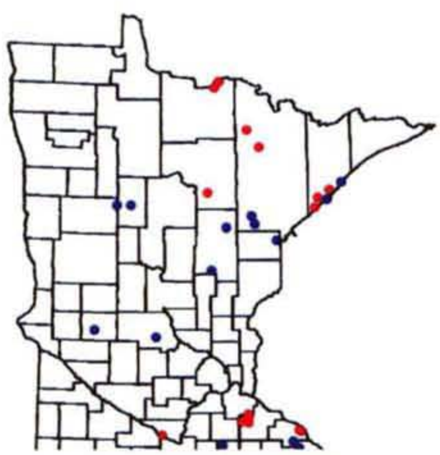
Mortality of tamarack was mapped on 11,593 acres in 193 stands throughout the range of tamarack. This acreage is an increase from those reported in 2004, but shouldn't necessarily be viewed as an indication that eastern larch beetle activity has increased. It always has been difficult to get an accurate picture of larch beetle activity from the air. Tamarack stands usually have a component of dead trees and these trees stand for a long time. Trying to map the change in the number of dead trees in these stands from year to year is difficult. However, we can say that larch beetle continues to be active and continues to kill trees although ground surveys suggest the populations of the beetle have declined at least in stands where they have been active for a number of years. The trend of the larch beetle population is unknown.

Emerald ash borer (not in MN)

Agrilus planipennis

In 2005 the DNR participated in the first early detection surveys for the Emerald ash borers. See map. The first survey was a visual survey of ash trees around several mill sites in cooperation with AHIS. The second was a trap tree survey following protocol established by the USDA Forest Service at several locations in both southern and northern Minnesota. No evidence was observed in either the visual mill survey or during the destructive sampling of trap trees. See map.

Six to ten years ago, an exotic wood-boring beetle arrived in southeastern Michigan, probably as a stow-away in wooden crates shipped from Asia. At some point, the emerald ash borers flew off to their favorite food, ash trees. Before the beetle was discovered in the summer of 2002, it had spread to at least six Michigan counties, one county in Ohio and across the river into Windsor, Canada. In its wake, it left ten million ash trees dead. Since 2002, additional locations in Michigan, Indiana and Maryland have been found. EAB has cost municipalities, property owners, nursery operators and forest product industries tens of millions of dollars.



EAB survey locations
(red- mill survey, blue- trap tree survey)

EAB is now firmly established in North America. This is a very aggressive beetle; virtually all ash trees growing in an area where the beetle is known to occur are at risk of dying. One of the efforts to contain the insect is a quarantine aimed at preventing EAB infested materials from moving out of areas in Michigan, Ohio and Indiana where EAB occurs. Under the quarantine, it is illegal to move ash trees, branches, untreated lumber, deciduous firewood and any other materials from these areas unless chipped to one inch or smaller. Additionally, the movement of all ash nursery stock is prohibited within, into, and from the entire Lower Peninsula.

What's at stake in Minnesota? Surprisingly, ash is the fifth most abundant species in our forests (FIA, 2001). The acreage of ash (1,218,000 acres) is comparable to that of oak or birch. At the national level, looking at the abundance of ash and what there is to loose, Minnesota ties for first place with Maine. In our urban forests, ash species and varieties commonly account for 10 to 35% of the trees planted.

In Minnesota, state and federal agencies are teamed up to detect and prevent the establishment of EAB. One of the tasks that will be accomplished this year is to monitor likely entry sites for the presence of EAB including ports of entry, state campgrounds, hardwood mills and tree nurseries.

Fall webworms

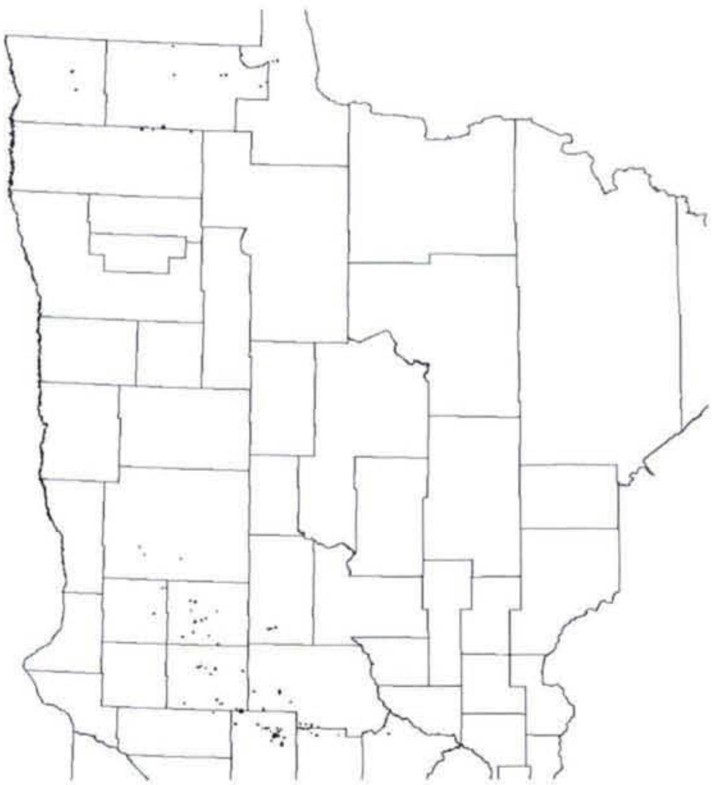
Hyphantria cunea

In late summer, colonies of fall webworms began to feed on dozens of tree and shrub species, particularly black walnut trees in southeastern counties. The first signs of activity by these caterpillars were the large silk webs and skeletonized leaves, both of which are considered to be unsightly, but are of little danger to the tree's health. This time of year the trees are preparing for dormancy so losing some leaves will have little affect on the tree. Periodically populations of the fall webworm increase and can become quite visible in forested areas across the southeast region. However, as their populations increase so do the populations of parasites and predators that always keep this native defoliator in control.

Forest tent caterpillar

Malacosoma disstria

Forest tent caterpillars caused 9,800 acres of defoliation in the western and northwestern counties, primarily in basswoods and oaks along lakeshores. Acreage has decreased slightly compared to last year and has intensified in the northwestern counties.

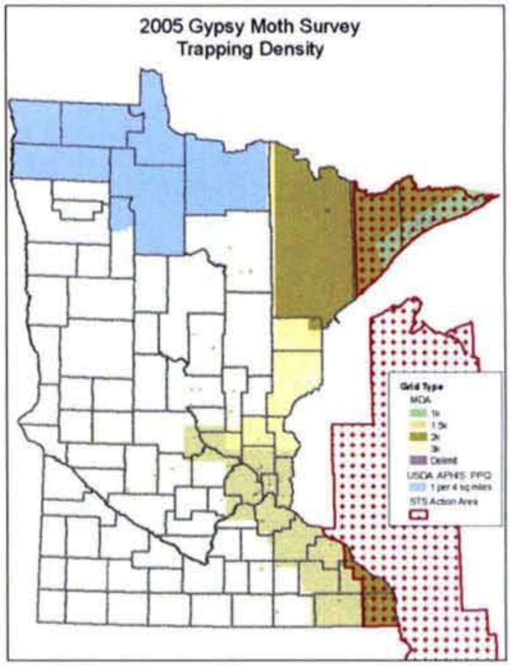


Gypsy moth: 2005 Gypsy Moth State Report

Prepared by Kimberly Thielen Cremers,
Gypsy Moth Program Coordinator,
Minnesota Dept. of Agriculture.

The statewide gypsy moth detection program is a cooperative effort among state and federal agencies. In 2001 a Gypsy Moth Strategic Plan was signed by the state Commissioners of Agriculture and Natural Resources, the State Health Plant Director USDA Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ), and the Field Representative from the USDA Forest Service (FS). The strategic plan describes the objectives and administrative structures necessary to manage the gypsy moth in Minnesota. It provides a mission statement, a framework for decision making, and outlines the strategies and mechanisms to implement the plan. On a bi-annual basis representatives from the four agencies and the University of Minnesota come together to discuss issues related to gypsy moth management. It is this cooperative effort that has built a strong gypsy moth program in the state of Minnesota.

2005 General survey program



The Minnesota Department of Agriculture (MDA) was the lead agency during the 2005 gypsy moth detection survey program. Other cooperators included USDA APHIS PPQ; USDA FS; Department of Natural Resources (DNR); and the Three Rivers Park District in the Twin Cities metro area. Staff in the cooperative program set 20,596 delta traps across the state, and 1,310 male moths were caught. This surpassed the 1998 record high of 953 moths.

In 2004, Minnesota became a member of the Slow the Spread (STS) Foundation when the STS action boundary moved into southeast Minnesota to include portions of Houston and Winona Counties. Due to increases in moth captures, in the fall of 2004 the action boundary was expanded into northeast Minnesota to include all of Cook and Lake Counties, and shifted westward in southeast Minnesota to include all of Houston, the majority of Winona and a small portion of Wabasha Counties. As a result, the program's protocol of trapping on available road systems within these areas shifted to trapping on a pre-determined grid laid across the landscape. We emphasized placing traps in grid target circles off available road systems. This change reduced trapper productivity due to the time needed to hike cross-country through extremely wooded terrain, but it did increase trap monitoring in very remote areas of northeast Minnesota.

Number of delta traps set	Agency
17,385	MDA
3,127 (18 AGM)	USDA-APHIS, PPQ
< 50	USDA-FS
84	Three Rivers Park District
Approx. 20, 596	**TOTAL**

As a result of the STS program moving into northeast Minnesota and to compensate for the reduction in traps placed per seasonal staff, MDA hired a record high 44 seasonal staff. This group set and monitored 17,385 traps, or 84.4 percent of all traps set in the state and covered 39 standard trapping routes. The state was divided into two distinctively different trapping regions: the south, which included the "road kill" sites and the northeast, which included the "hike-in" sites. (Hike-in was also conducted in the STS area in the far southeast but it was limited due to the extensive road network which allowed trappers to place traps within target circles without having to leave the road network). Each "road kill" route consisted of an average of 665 traps and the northeast "hike-in" routes averaged 236 traps each. In addition to the standard routes, MDA had five lead workers, setting an average of 120 traps of their own and overseeing five to nine trappers each. Other cooperators - Three Rivers Park District (84 traps), FS (<50 traps), and APHIS PPQ (3,127 traps) set approximately 3,271 traps or 16 percent of the traps set in the state.

Several grid densities were utilized across the state to be consistent with APHIS PPQ trapping protocols and yet allow for a smooth transition into STS protocols and data collection during the 2005 survey season (see attached map). The STS action area was trapped on a two kilometer grid, with several areas of concern, particularly along the North Shore, receiving a higher density of traps. Areas outside the STS action area that were considered high-risk for the introduction and establishment of gypsy moth received traps on a 1500 meter grid - a similar density to the one trap per square mile (1/1) APHIS PPQ general detection density protocol. One exception was St. Louis County; due to its large area and limited road access, this county was trapped at a 2 km grid density rather than at a 1500 meter grid density. Areas are considered high risk for the introduction and establishment of gypsy moth based on human activity levels, preferred habitat for gypsy moth, and the advancing gypsy moth front from Wisconsin. The remainder of the state received traps at one trap per four square miles (1/4) or a three kilometer grid, which is on a four-year rotation, with approximately one-third of the state receiving traps annually. In addition to the standard trapping densities, areas which had moth catches in the past received intensive trapping to determine if a potential population exits. These trapping densities were: one trap per 250 meter, 16 traps per square mile, one trap per 500 meter, or one trap per one kilometer.

Moth counts	Type of trap
1,025	Standard detection (1500m, 2K, 3K, & 1 trap per 4 sq mile)
240	Delimit
17	Nursery
21	Random
5	Mill
2	Park
1,310	**TOTAL**

Additional traps were set at state parks, mills, and nurseries within the standard trapping grid. Twenty-three of Minnesota's 69 state parks were within the standard trapping grid and received additional 1-2 traps each. Two moths were caught in the state parks. Mills and nurseries were trapped according to the risk of gypsy moth introduction. Nurseries that are wholesale dealers, report stock sources from gypsy moth-quarantined areas, or have a history of pest problems, are considered high/moderate-risk, and each received between two and twelve traps this year. High-risk mills throughout the standard trapping grid also received two randomly placed traps. Mills are considered high-risk if it is known or likely that they have out-of-state sources and if they are within 60 miles of Wisconsin counties that trap fifty or more moths. There are 62 high-risk mills throughout Minnesota and 170 nurseries that are considered high/moderate-risk. Five moths were caught at mill locations and 17 moths were caught at nurseries for the 2005 season. No regulatory action is being taken at this time.

Four mills (three pulp and one saw mill) and one nursery are under Federal Compliance Agreements for gypsy moth in Minnesota. A Compliance Agreement is designed to decrease the risk of gypsy moth establishment in Minnesota while still allowing the mills and nursery to transport logs from gypsy moth-quarantined areas for milling or pulpwood, or in the case of the nursery, for bark mulch to utilize in a potting mixture. No gypsy moths were captured at these sites.

Trapping for Asian gypsy moth was conducted at the northern Minnesota seaport of Duluth. Eighteen traps were set around the port and traps were checked every two weeks throughout the season. One moth was caught and sent to OTIS Laboratories for DNA analysis. In fact, all Minnesota moths that were caught in St. Louis, Lake, or Cook Counties were sent to OTIS Laboratories for Asian gypsy moth DNA analysis. No Asian gypsy moths have been identified as of this time.

The FS provided funding to MDA to trap all other National Forest land and Bureau of Indian Affairs land within MDA's standard trapping grid. Superior National Forest, including the Boundary Waters Canoe Area Wilderness (BWCAW) was the only national forest, and Fond du Lac and Boise Forte were the only reservations that were within the state's standard detection grid, i.e. outside the STS Action Area, for the 2005 trapping season. Six hundred eighty-eight traps were set and five moths were caught on Superior National Forest lands within St. Louis County. Seventeen traps were set on Boise Forte Reservation, and 69 traps were set on Fond du Lac Reservation. No moths were caught at either of these two Reservations.

Moth numbers were down to record lows in the central and southeast parts of the state (St. Cloud to the Iowa border), accounting for only 58 of the total number of moths captured. In the southeast (Houston, Winona, Olmsted, Wabasha Counties), an area that has had a consistent increase in moth numbers in the past decade, only seven moths were caught.

It has been over 15 years since the trap catch numbers were this low in southeast Minnesota. One delimit site in Brooklyn Park had 13 moths that were caught in seven traps, accounting for 22% of the moths caught in this part of the state. An additional 29% (17 moths) were caught in nursery operations, indicating that gypsy moth life stages "hitch-hiking" on nursery stock continue to be a concern for Minnesota.

The big surprise for the 2005 season was the record number of moths in Cook County, the far northeastern county in Minnesota. Cook County alone surpassed the state record (953 moths) by catching the 1,068 of the 1,310 moths captured in the state for the 2005 season. There had been an increase in moth captures, from about 25-30 for the entire county since 2000, to 193 moths in 2004. The jump to over 1,000 moths this year is unexplainable. Treatment recommendations of over 229,000 acres are expected to be forth-coming. To date, Minnesota combined treated acreage is just over 4,500 acres. The majority of the land in Cook County is Superior National Forest, with several State Parks and an Indian Reservation. MDA will be working closely with these agencies to determine the best management strategy for this area.

General treatment program

In 2004, MDA conducted gypsy moth pheromone flake treatments at a 225 acre site (Rollingstone Site) in Winona County. Initial follow-up trapping indicates that this site has been eradicated; no moths were caught in 2004 or this past season (2005). However, a third year of monitoring is required to determine treatment success of a flake block.

In 2004, Minnesota also conducted a gypsy moth Btk ground eradication project at a 5 acre site in the Twin Cities Metropolitan area (Edina Site). After two consecutive years of follow-up trapping with no moth captures, this site is considered eradicated.

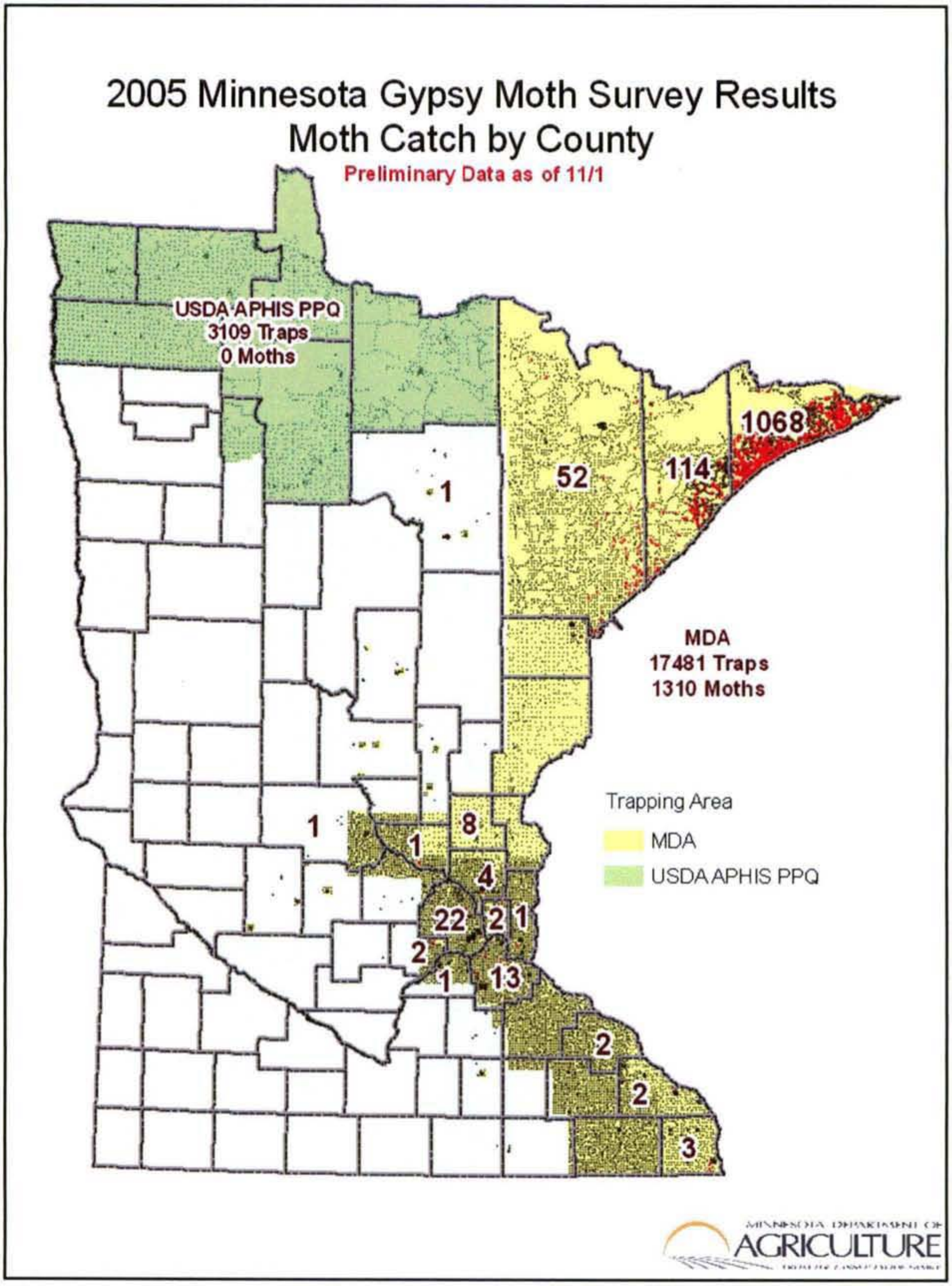
2005 Btk Treatments:

In the fall of 2004, MDA's seasonal survey program identified a gypsy moth infestation just 8 miles northeast of Tower, Minnesota in St. Louis County. In 2003, the site had been a standard detection trapping site (1 trap per four square miles) and two gypsy moths were caught in a single detection trap. In 2004, this site was trapped at a target density of 16 traps per square mile and 37 total moths were caught in five traps; one trap alone captured 28 moths. A follow-up egg mass survey was conducted on October 26, 2004 and two egg masses were identified. This was the northern-most gypsy moth infestation on record.

Due to the proximity of the moth captures to the BWCA and the finding of positive gypsy moth traps on the Superior National Forest, the FS was contacted to discuss treatment options. A 640 acre treatment block was proposed and encompassed federal, state, county, city and private lands. Superior National Forest land within the treatment block consisted of 44.2% and the remaining 55.8% was on state and private lands. Due to the mix of ownership it was decided that a joint Environmental Assessment (EA) would be conducted with two separate Decision Notices. An EA was conducted for the site and a public meeting was held in Tower on January 18, 2005. The proposal received a lot of support from local residents as well as environmental groups. In mid-April, the forest supervisors from both the Superior National Forest and FS State and Private Forestry signed off, giving the green light for treatments to proceed.

Btk treatments (Foray 48F) were conducted via fixed wing aircraft on both June 6 and June 16, 2005 at a rate of 30 Forestry Toxin Units (FTU) per acre. Two data loggers placed in the block as well as caged egg masses were utilized to determine treatment timing. A FS observation aircraft was utilized during treatments to assist in communication between the spray aircraft and the ground crew. Applications were conducted without any aircraft incidents.

Site Name	Acres	Product	Rate/acre	Application Equipment	Date of First Application	Date of Second Application	Cost/Acre
Tower	640	Foray 48F	30 FTU (80 oz.)	Airtractor 502B	June 6, 2005	June 16, 2005	$38,592 ($30.15/ acre)


2005 Minnesota Gypsy Moth Survey Results
Moth Catch by County
Preliminary Data as of 11/1
USDA APHIS PPQ
3109 Traps
0 Moths
MDA
17481 Traps
1310 Moths
1068
114
52
1
1
8
1
4
22
2
1
2
1
13
2
2
3
Trapping Area
MDA
USDA APHIS PPQ
MINNESOTA DEPARTMENT OF
AGRICULTURE

To determine treatment success, the treatment block was trapped on a 250 meter grid density, surrounded by an 8 mile area with a 500 meter grid density. No gypsy moths were caught during the 2005 season. However, a second year of intensive trapping is needed to make certain the treatment was a success.

2005 Pheromone Flake Treatment:
Minnesota did not have any flake treatments in 2005.

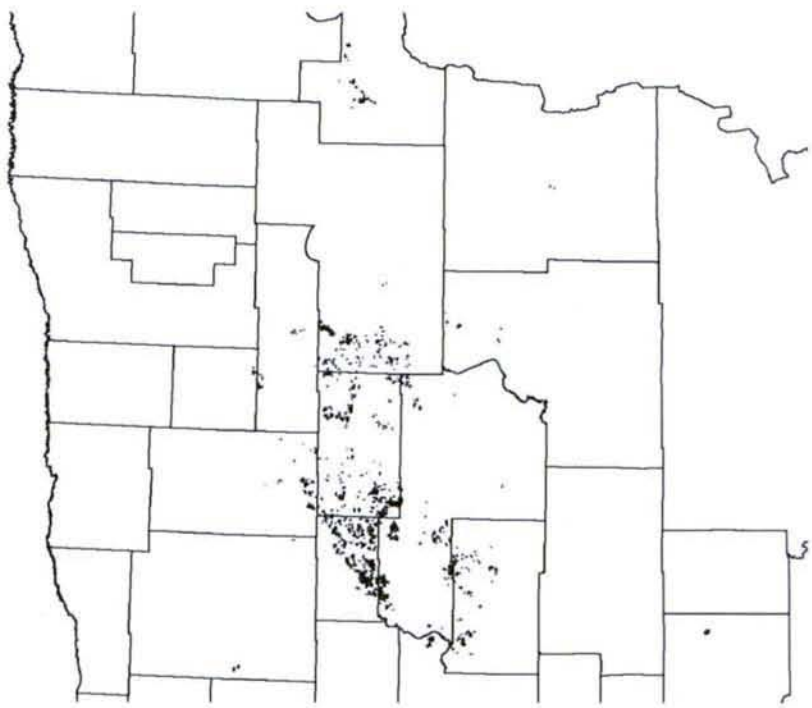
Egg mass surveys
Several surveys were conducted in the fall of 2005, in response to relatively high numbers of moths trapped in several locations across the state. Only one site within the Twin Cities metro area (Brooklyn Park) warranted an egg mass survey. The survey was conducted on September 19, 2005 and two egg masses (more likely, one egg mass in which the female was interrupted during egg laying) were found at the site. This site is being proposed for a 58 acre Btk treatment in the spring of 2006 to eradicate this isolated population.

In addition to the egg mass survey conducted in the Twin Cities metro area, several site surveys were conducted in Cook County surrounding several of the high find locations. No egg masses or alternate life stages were identified during this survey. However, this area is within the STS Action Area and treatments are being proposed on over 150,000 acres.

Jack pine budworm

Choristonerua pinus

75,600 acres were defoliated this year, almost doubling last year's total acreage. Within the existing outbreak area, stands that the budworms missed in the previous two years were found and defoliated this year. The outbreak also spread out in all directions, reaching jack pine stands in Lake of the Woods, Koochiching, Itasca, Pine, Morrison, Ottertail and Mahnomen Counties. See map. In Pine County, the defoliated acres (540) surround the Gen. Andrews State Nursery. Salvage harvesting operations continued this year, particularly in Beltrami, Hubbard and Wadena Counties, which have suffered two or three years of heavy defoliation with subsequent topkill and mortality.



Jack pine budworm survey: Fall 2004 and spring 2005			
County	Number of plots	Percent of stands with Heavy defoliation in 2004	Percent of stands predicted to have Heavy defoliation in 2005
Becker	2	100	0
Beltrami	13	54	38
Hubbard	14	77	7

600(+) ac

The bigger news is that the jack pine budworm outbreak has spread into red pine plantations!

Some red pine plantations from Brainerd to Bemidji were defoliated with affected stands having very high incidences of shoot infestation. The only other time damage to red pines has been documented was in the late 1950's. That outbreak on red pine was concurrent with an outbreak on jack pine during 1957 and 1958 and was limited in geographical extent to four populations near Bemidji, Pequot Lakes, Badoura and Cloquet. Unfortunately, there was no record of the number of acres defoliated. We do know that most of the affected red pines were adjacent to defoliated jack pine stands. Severe defoliation and subsequent topkill of red pines were documented on staminate-cone bearing trees only near Bemidji and Pequot Lakes.

The current outbreak is much more extensive and occurs in red pine plantations that are literally miles from the nearest jack pine stands. Many red pine plantations showed signs of heavy infestation. Two of these stands have been studied more thoroughly, a young stand near Baxter in Crow Wing Co. and an older stand north of Bemidji in Beltrami Co. In both stands, at least 93% of all the shoots had been defoliated to some extent, ranging from trace to severe, with the leader always suffering the heaviest defoliation. See table. On both sites, the terminal and lateral buds were well formed and plump indicating that tree vigor is high and that the red pines should be able to withstand defoliation in 2006. Egg mass counts were very high in the young stand and were low on the older stand while both stands had low levels of egg parasitism.

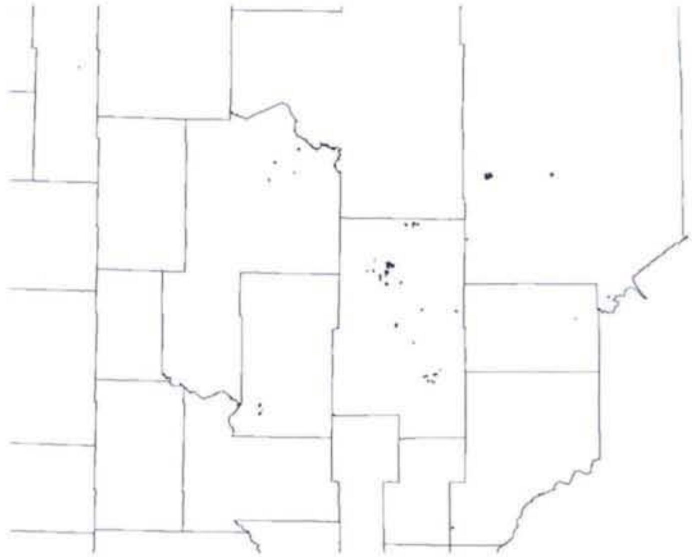
Examination of ten red pine trees for egg masses and impact of jack pine budworm after one year of defoliation.

	Egg masses			Terminal leader			Entire tree
	Ave. number of EM per 36' branch	Range of EM per branch	Percent parasitism of EM per branch	Percent with live bud in terminal	Percent '05 foliage remaining	Percent '04 foliage remaining	Percent bud infestation on all branches
Near Bemidji	2.1	0 - 9	23	100	27	31	78
Near Badoura	0.05	0 – 1	0	100	74	53	5
Near Baxter	16.7	7 - 34	32	90	25	10	93

wrong

Larch casebearer

Coleophora laricella

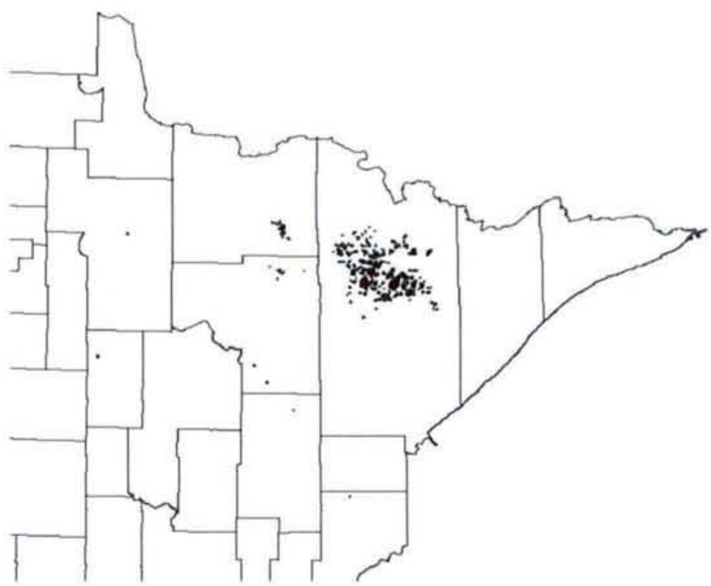


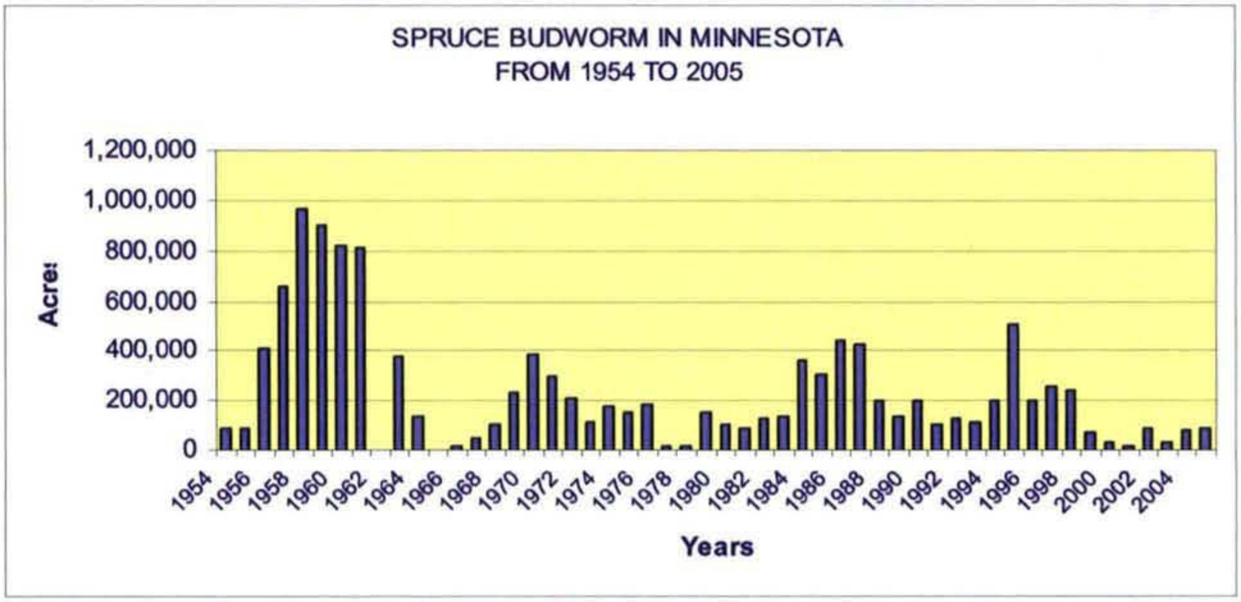
Larch casebearer continued to be active mining tamarack needles and turning trees brown last summer. Casebearer activity has been noticeable in the state every year since 2000. The amount of needle damage needs to be quite high before it becomes obvious and mappable using aerial survey. The amount of acres affected and the level of damage since 2000 is unusual. Prior to 2000, casebearer was seldom seen and required a careful and intentional search to find it but, since then, it has been obvious enough to be mapped during the aerial survey. In some years the damage has been very widespread but light in many stands as it was in 2000 while in other years it has been less widespread but more intense in individual stands. Casebearer damage has caused high levels of needle damage in some stands in Aitkin County for three to four years. So far, no dieback or mortality has been associated with this damage.

Spruce budworm

Choristoneura fumiferana

Defoliation increased to 92,500 acres, an increase of approximately 10,000 acres compared to last year. Budworm activity continues to be centered in northern St Louis County with minor acreage of defoliation also occurring in southeastern Koochiching County and northeastern Itasca County. A number of white spruce plantations were defoliated in widely scattered locations in other parts of the state. In northeastern counties, budworm defoliation has been noticeable and mapped pretty much continuously since 1954. See chart. You'll note that the chart shows two years with no acreages depicted. No historic maps have been found for these two years, but newsletters from that time period indicate that spruce budworm defoliation was observed in those years. There has been an average of 220,000 acres of defoliation mapped each year over this 55 year period.





White spruce plantations in the white spruce thinning study were ground surveyed in the fall of 2005 and spring of 2006, before bud break, for defoliation levels. Results are presented below:

Plantation name	Location	Defoliation
White spruce alley	S21-T64-R21, ST Louis	0 defoliation on all plots
Warba	S23-T54-R23 Itasca	0 defoliation on all plots
Power line	S36-T155-R25, Koochiching	0 defoliation on all plots
Johnson Landing	S28-T65-R26, Koochiching	0 defoliation on all plots
Plantation Road	S24-T149-R27, Itasca	0 defoliation on all plots
Larson Lake Salvage	S16-T61-R24, Itasca	50% defoliation on plots R1, T3 40% defoliation on plots R2, T1 30% defoliation on plots R3, R4, T4 20% defoliation on plots T2
Sam Welches Corner	S12-T147-R30, Beltrami	0 defoliation on all plots
White Township	S36-T57-R15, St Louis	0 defoliation on all plots
Smith Creek	S12-T53-R26, Itasca	70% defoliation on plots R1, T1 60% defoliation on plots T2, T3 50% defoliation on plots R2, R3
Aitkin County	S8-T52-R25, Aitkin	0 defoliation on plot R1 10% defoliation on plots R2, R3 20% defoliation on plot T1 40% defoliation on plot T2 50% defoliation on plot T3
Taconite Trail	S36-T60-R23, Itasca	0 defoliation on all plots

DISEASES

Diplodia and *Sirococcus* shoot blight

Diplodia pinea and *Sirococcus conigenus*

The wet weather during the spring has led to some heavy infections of shoot blights on understory and edge trees. There are a number of locations where just about every new shoot on understory and edge trees appeared to be infected.

Most of these infections are *Diplodia* (or *Sphaeropsis,* take your pick) but there is likely some *Sirococcus* mixed in as well. The spores of these fungi are rain splashed out of the overstory red pine onto the smaller trees. Sometimes, the *Diplodia* infection only kills the current shoot and then becomes latent (or inactive). However, if these infected trees later become drought stressed, the *Diplodia* can be reactivated and kill the trees.

Please see additional reports on *Diplodia* species in the Special Projects Section.

Oak anthracnose

Apiognomonia quercinia

Oak anthracnose is a common leaf disease caused by the fungus, *Apiognomonia quercinia.* Seen across Minnesota, the current anthracnose outbreak was the most spectacular witnessed here in 25 years. Not only were the conditions ideal for disease development (cool temperatures and periodic rains), but also there was an unusually long time (nearly a week) for initial infections to occur.

White oak and native bur oak are the most susceptible, although all species of oaks found in Minnesota can be infected. Fungal spores are rain splashed onto new growth in the spring from over wintering sites on the twig bark. The spores infect the young, immature leaves early in the season (this year, it was the last week of May) causing necrotic (brown/dead), deformed margins on the leaf tissue as well as necrotic, irregularly shaped spots. These spots and lesions tend to form along the veins or be confined by them. Usually, a distinct margin develops between the dead and healthy leaf tissue. Heavily infected leaves may appear misshapened and curled. The heaviest infections tend to be located in the lower portion of the tree crowns where the humidity is highest and leaves remain wet or dewy. As warmer and drier weather conditions occur, the threat of anthracnose infection decreases and the leaves produced during the summer are generally much freer of disease symptoms.

Oak wilt

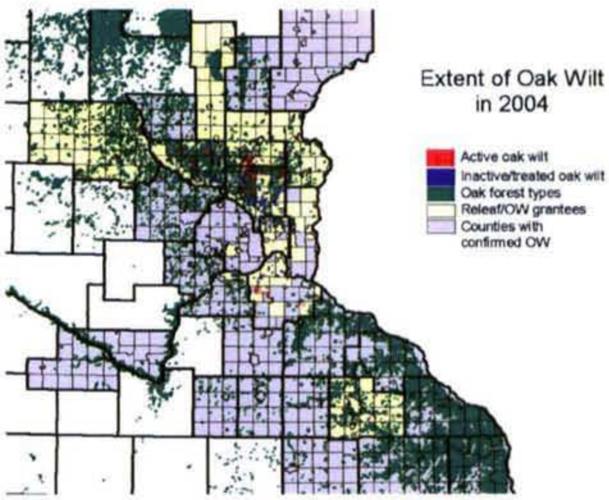
Ceratocystis fagacearum

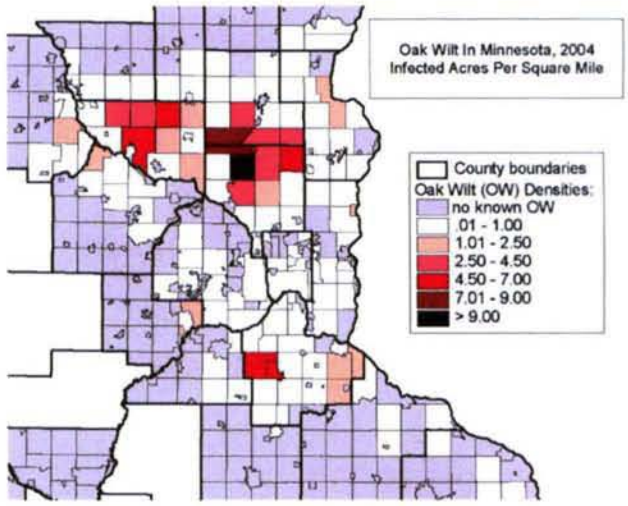
Suppression

Oak wilt suppression was funded through a federal pest suppression grant and administered through the MN Releaf Program. The MN Releaf program provides a combination of state and federal funding in the form of matching grants to local units of government for a wide-range of practices aimed at promoting ecosystem management.

In that context, 29 communities and 5 counties in the developing rural-urban interface received matching grants ranging from $2,000.00 to $65,000.00 for the upcoming treatment year. In the '04-05 treatment year, a total of 1114 individual oak wilt infection pockets covering 622 acres were treated during the '04-05 treatment season. Estimated treatment costs, averaged $939.28 per pocket or $1682.26 per acre, with 50% of those costs paid by participating landowners.

At the end of 2004, the density of active oak wilt infection pockets across MN Releaf grant recipients was calculated to be 1.71 infected acres per square mile, with individual communities ranging from 0 to 10.54 infected acres per square mile. That included a total of 3122 active pockets statewide (grant recipients only), covering 3616 infected acres. The average size for infection pockets still active at the end of the year was 1.13 acres per pocket.

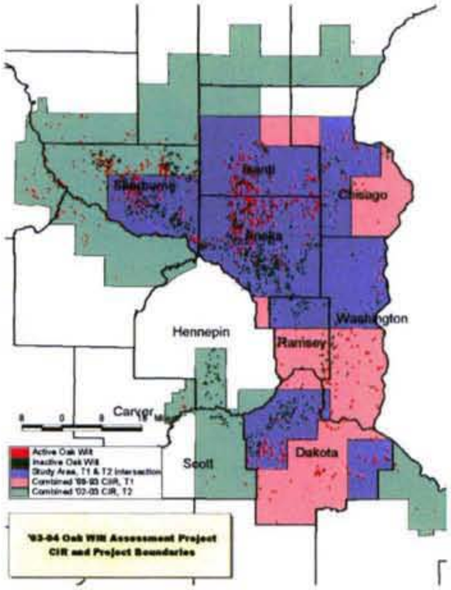


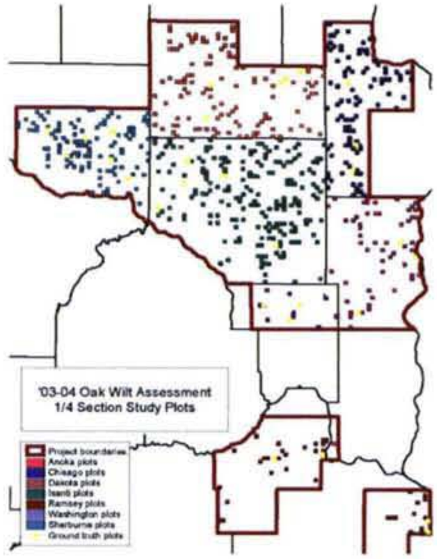


Assessment

An assessment project was launched in 2003 and completed during the '04-05 treatment season. Rectified color-infrared photography from two photos periods approximately ten years apart were used to describe the change in oak wilt occurrence and evaluate factors influencing that change across the study area. Four categories of community programs, soil texture and 12 categories of land use were evaluated using 640 randomly selected ¼ section plots (40 acres each). Change in population density was also evaluated but was not found to be correlated to the change in oak wilt. The other three factors were highly correlated to changes in disease incidence. The lack of active suppression activities (communities without an active program) and sandy soils were correlated to higher disease incidence. A significant reduction in disease incidence was correlated to communities with active programs.

Because the sampling scheme was based on a minimum of 15% forest cover, a large number of plots fell in undeveloped rural woodlands. In these areas, the incidence of oak wilt was higher than in developing areas, and the rate of increase in disease incidence seemed to be higher. The high incidence in undeveloped areas may be associated with a number of severe windstorms that occurred during peak spore pad production over the ten-year study period. Besides the general loss of oak woodlands, the implication for the MN Releaf program is that as communities expand into these areas, they will be inheriting a substantial pest problem. Various options are being explored to address related issues.





Red pine pocket mortality

Complex of insects and root-inhabiting fungi

Although caused by a complex of North American species, red pine pocket mortality is relatively rare in Minnesota (MN). The story is quite different in Wisconsin (WI), where the syndrome is found scattered across the state . Over the last several years, a large number of infection pockets have been found in the Sand Dunes State Forest (SF), just outside of Zimmerman (Sherburne County). The relatively high concentration of pockets in the Sand Dunes stands in stark contrast with the relative lack of infection pockets elsewhere in MN. So the concern is why here and why now, and what do we do about it.

A Brief History

During stand inventories conducted in the late 1990's and early 2000's, a number of pockets of advancing tree mortality were discovered. After several field trips, DNR forest health staff members were unable to confirm the cause of the damage. Then in late 2004, wood samples with black staining resembling that associated with black stain root rot caused by *Leptographium wageneri* in Douglas fir and by *Leptographium procerum* in white pine were collected and cultured by the University of MN plant disease clinic (UMN). Based on fruiting structures and characteristics in culture, the UMN identified the fungus as *Leptographium*, most likely *procerum*.

The cultures were then sent to Glen Stanosz at the University of WI. He confirmed all four cultures sent to him (collected at one site on two different occasions) were related to the larger group of ophiostromoid fungi (those producing spores on coremia) in which *Leptographium* belong. The taxonomy of *Leptographium spp.* as a group is complex and not completely understood. But one of the four cultures seems to most closely resemble *Ophiostroma aureum* or a close relative of *L. terebrantis*. The identity of the other three fungi has not yet been confirmed, primarily because they are not responding to the same genetic trials – perhaps suggesting a different species. So the work continues.

Disease Symptoms

Red pine pocket mortality, as described in WI, is associated with a complex of organisms that include *L. terrebrantis* and *L. procerum*, pine bark beetles (*Ips pini*), red turpentine beetles, (*Dendroctonus valens*) and three species of root weevils. The symptoms include circular openings in red pine stands with dead trees in the center, scattered red trees along the edges and declining, thin-topped or chlorotic trees around the margins of the infection center. Signs of beetle infestation are common, but do not necessarily occur on all affected trees. These signs include frass, exit holes, pitch tubes, and galleries under the bark. Black stained wood is often found associated with red turpentine beetle pitch tubes. Staining may also be found in the root crown and main flare roots. Resin soaked wood may occur in close association with the staining.

Because the taxonomy of this group of fungi is not fully understood, neither is their epidemiology. As such, the age-old question of which came first, the chicken or the egg, has yet to be resolved. All of the insects involved can vector these fungi and spread them to other trees through their feeding and breeding habits. All of these insects are associated with weakened, dead or dying trees. Only under unusual circumstances, do they attack healthy, vigorously growing trees.

Leptographium spp. are capable of spreading from tree to tree through root grafts. However, although they are vascular-inhabiting organisms like the better-known fungi causing Dutch elm disease and oak wilt, *Leptographium spp.* are not considered aggressive pathogens. So one theory of how the disease complex is spread, is that some form of disturbance stresses some trees enough to invite in opportunistic pests – namely one or more of the insect vectors. If these insects are carrying *Leptographium* spores, the fungus is able to invade vascular tissue exposed at the feeding sites and a new infection pocket is begun. Once in a stand, the fungus can spread from tree to tree weakening those trees they invade. However, the fungus does not kill the trees. Instead, the stress caused by the *Leptographium* infection invites in more opportunistic insects. The bark beetles are then responsible for finishing off affected trees.

But with the nearest known infection pocket in WI, how were the pockets started in Sherburne County? Windstorms in the late 1990s had damaged a number of the stands. Many of the stands had also been thinned in the recent past. Drought had added additional stress and outbreaks of pine bark beetles have been an on-going issue. The affected stands are also between 35 and 50 yrs old, the range seen affected in WI. BUT the nearest known source of spores is in WI, and neither the beetles nor the weevils are capable of traveling that far by themselves.

That raises all kinds of questions. Are there more species involved than those documented in WI? Do they have different environmental needs and if so, did we just happened to find the right combination in the Sand Dunes SF? If so, what are those environmental needs and where else do they co-occur in MN? Are there other means of spread we aren't considering? Are there smaller pockets we just haven't located that are acting as a bridge between the larger red pine plantations? Or are plantings of other pine species providing that service? At this point, we don't know.

Disease Management

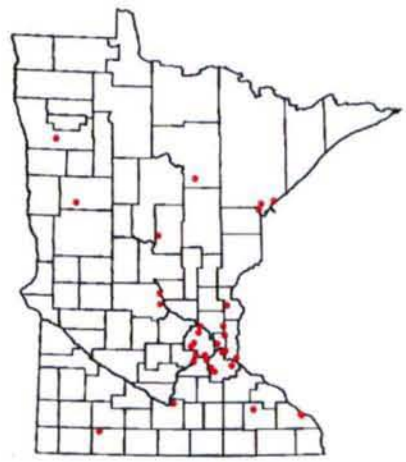
With so many questions, management is a guess. Two methods are being tried in WI in different parts of the state with varying degrees of success. With the thought in mind that disease spread is relatively slow and regular thinnings will capture most tree mortality, infection pockets are salvaged when they are discovered, by clear-cutting the pocket plus a buffer equal to one tree height in width. The buffer approximates the number of trees that would die between thinnings as a result of the infestation. The approach thus sacrifices some potential growth in order to utilize wood they might otherwise lose.

The other method is to combine vibratory plowing with a treat-to-the-line approach. Plows lines are placed 30-40' outside the infection pocket boundary and all pine inside that line are harvested. The distance chosen is based on field experience and apparent differences in the relative role of root weevils versus red pine turpentine beetles in different parts of the state. Weevils seem to play a greater role in the disease complex in those WI stands closest to the Sand Dunes SF.

The current plan
Given the lack of clear answers and the value of the affected stands in the Sand Dunes SF, a combination of treatments are planned as funding permits. In the most valuable stands, vibratory plowing will be combined with a cut buffer approach. This involves about ¼ of the known infection pockets. Four additional stands are more or less linear or are buffered by non-pine forest types, providing an opportunity for a trial. In the trial, half of each pocket will be plowed and the other half will receive a cut-buffer. Both halves will be monitored and the results compared. Several of the affected stands were cut and thinned in the recent past, so there are no active symptoms at this time. These stands will be monitored and any additional symptoms noted and mapped. The remaining stands are considered of too low a priority to treat and/or too young to thin. These will be monitored for continue spread of the disease complex and will serve as controls for our trial. In the meantime, we will be surveying other plantations in the area to make sure we aren't missing something. Then we watch and wait for word from those studying the taxonomy of this complex group of fungi.

Sudden oak death (not in MN)

In 2005 the Minnesota DNR Division of Forestry again participated in the national *Phytophthora ramorum* survey. Field surveys were conducted adjacent to several major state nurseries and in rural forested areas around the state. Twenty-six nursery sites and seven rural forested sites were surveyed in nineteen Minnesota counties. On sites, one hundred and thirty two transect surveys collected just over fifty suspect samples. Samples were collected from known P. ramorum host genera. The samples were processed at two labs, the Minnesota Department of Agriculture Lab in St. Paul, and the Forest Products Lab at Mississippi State, Mississippi. Twenty-eight samples were tested at the MDA lab in Minnesota and twenty-two were tested at the Mississippi lab. All were negative for P. ramorum by PCR. This was the second year of survey for P. ramorum.



SOD Survey locations

Spruce needle rust

Chrysomyxa ledi and *Chrysomyxa ledicola*

Traveling through the northern counties of Minnesota during the summer you couldn't help noticing the "flocked" spruce trees. Pint to tan-colored "flocking" was observed on white, black and blue spruce trees in stands and plantations and on Colorado blue spruce in yards and windbreaks. Many different patterns of infection were also noticed. In some areas, the entire stand is affected, other stands only a few are infected while most are not. The needles on these spruces are infected with a spruce needle rust fungus but it is usually not a cause for concern. The spruce needle rust fungi, *Chrysomyxa ledi* and *Chrysomyxa ledicola,* can look bad but aren't serious for most trees. However they can be tough on newly planted trees and Christmas trees. The rust is most common on blue spruce but infected large acreages of white and black spruces as well.

ABIOTICS

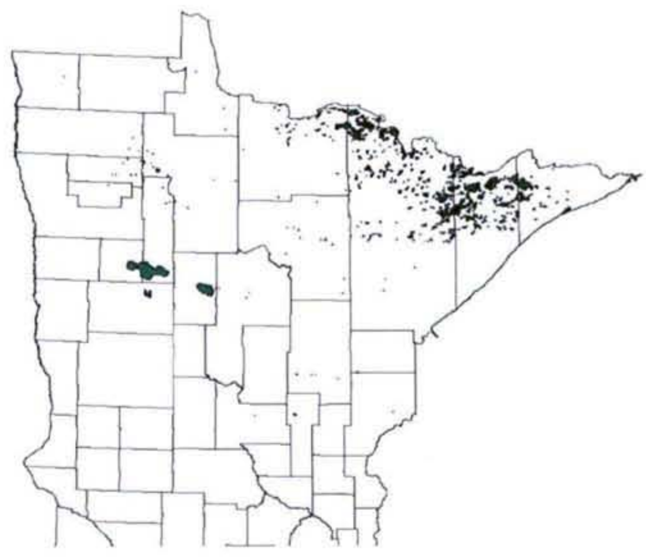
Ash decline

Unknown

Decline of black ash continues to be a concern both because of the loss of the ash but also because it could hide or mask the emerald ash borer. Surveys have found no emerald ash borer in the state. Aerial survey mapped 4322 acres in 58 stands scattered across the northern 2/3 of the state. This is a decrease from the 27,000 acres reported last year. Surveyors attempted to map the change from last year rather than map previous years of mortality. But again this is difficult to do and so it is hard to have a clear picture of a change in the condition of the black ash from last year. In stands examined on the ground it appeared that the problem did not continue to expand much if at all. At the same time trees with a lot of dieback did not appear to be showing much in the way of improvement either. Site and weather conditions are still considered to be the primary factors that stressed and killed the trees rather than any particular insects or fungi.

Aspen with thin crowns

Physiological response to defoliation and drought



There were 587 pockets of aspen with thin foliage throughout northern Minnesota this summer; acres totaled 410,500. The trees had leaves but the leaves were small being only the size of a nickel to a quarter. These trees often were the largest and oldest on the sites. This situation was not examined until late in the summer, making it somewhat difficult to make a positive determination of the cause. There appears to be a number of causes of this across the state. In most locations insects do not appear to have been involved. Some places had spring frosts at the time of aspen leaf break that killed portions of the tender new leaves and caused other trees to drop all their new leaves. In northeastern Minnesota another common cause appears to be stress from past years of forest tent caterpillar and drought. The affected trees are putting on little or no growth, and the shoot growth is abnormally short. No forest tent caterpillar was mapped in northeastern Minnesota but forest tent caterpillar cocoons were collected at a location near Johnson Lake in northern St Louis County, suggesting that low levels of the insect may still be active in at least a few locations in the northeast.

Aspen mortality and dieback was reported on 50,000 acres across northern MN last year. This was attributed to stress from forest tent caterpillar and drought. No mortality was reported this year but stands with trees showing the thin crowns need to be watched to see if they recover or start to experience mortality.

See Aerial survey section of this report for a change in coding due to this type of damage.

Oak tatters

Herbicide damage

Oak Tatters has been a condition that affects emerging oak leaves, causing them to appear lacy or tattered. It has been observed throughout the Midwestern United States, including Minnesota, Michigan, Wisconsin, Iowa, Illinois, Indiana, Ohio, and Missouri. It was first reported during the 1980's in Iowa, Indiana and Ohio, but has been observed sporadically for the last ten years in Minnesota and Wisconsin. The cause has eluded surveyors in all of those years.

In 2004, researchers in Illinois hypothesized that tatters on oaks was due to herbicide drift from applications onto corn and soybean fields. In controlled experiments two year old potted white oaks were exposed to varying concentrations of choloracetamide herbicide products, including Harness Xtra and Dual Magnum. Both products produced the tatters symptoms on the treated oaks. After 45 days following the treatments, the oaks produced new leaves free of the tatters symptoms, as they do in the field. The study indicates that drift of choloracetamide herbicides may be the cause of what has been at times large portions of the landscape affected by oak tatters.

This spring, in Minnesota, an effort was made to attempt to link reports of tatters to possible herbicide drift from nearby cornfields. As it happened, tatters was for the most part a non-event across the state. It seems that the phenology of the oaks did not coincide with the potential drift from applications of Choloracetamide herbicides applied to nearby cornfields. However, in two separate areas, tatters symptoms did develop on the oaks. Mid-season follow-up investigations found that, in both instances, fields adjacent to the affected oaks received applications of Harness Xtra. These herbicides are applied at the time of leaf emergence of the oaks and other affected species.

SPECIAL PROJECTS

Diplodia in nursery stock: No overstory trees, no disease

Until the late 1990's, the prevailing pathological dogma was that if shoot blight infections in the nursery seedbeds were absent, then there were no *Diplodia* infections of the seedlings. That belief was turned upside down by the work of Glen Stanosz's lab at the University of Wisconsin. Stanosz and co-workers found that there could be *Diplodia* infections without and symptoms, because *Diplodia* is a "latent pathogen".

In 2002, this arcane biological fact became all too apparent when 65% of the red pine seedlings in plantations died due to the effects of drought and latent *Diplodia* infections. Our best course of action was to eliminate the sources of infections in the Nurseries by removing the pine windbreaks. In the winters of '02-03 and '30-'04, Badoura Nursery removed 1250 cords of red pine windbreaks. Nursery managers also reinstituted fungicide spray regimes and regularly rogued seedbeds, among other actions. These removals would have an impact, but not immediately. Seedlings that were alive in 2002, prior to the removal of windbreaks, had already been exposed to *Diplodia* and some of them were already latently infected.

In 2003, a systematic survey of the entire 2-0 red pine crop was done. Dr. Stanosz's lab found averages of 40 to 71% latent infections in the red pine fields. So, the entire crop of two million seedlings at Badoura Nursery was rejected and destroyed. In 2004, we anticipated a drop in latent infection levels because most of these seedlings had emerged after the windbreaks were removed. Another systematic survey of the 2-0 red pine crop was done and we were delighted to find only 2.5 % latent infections in the nursery beds.

We continued to assay seedlings for the presence of latent infections and, in 2005, we found another decrease in latency levels. *Diplodia* infections are now down to 1.25%. What does this mean in terms of red pine seedling survival in new plantations? Recall that latent infections need to be activated by internal water deficits. So, if there is droughty weather or poor stock handling in 2006, only 1.25% of the seedlings might die due to latent *Diplodia* infections and it's likely that more than 98 % of the seedlings will live.

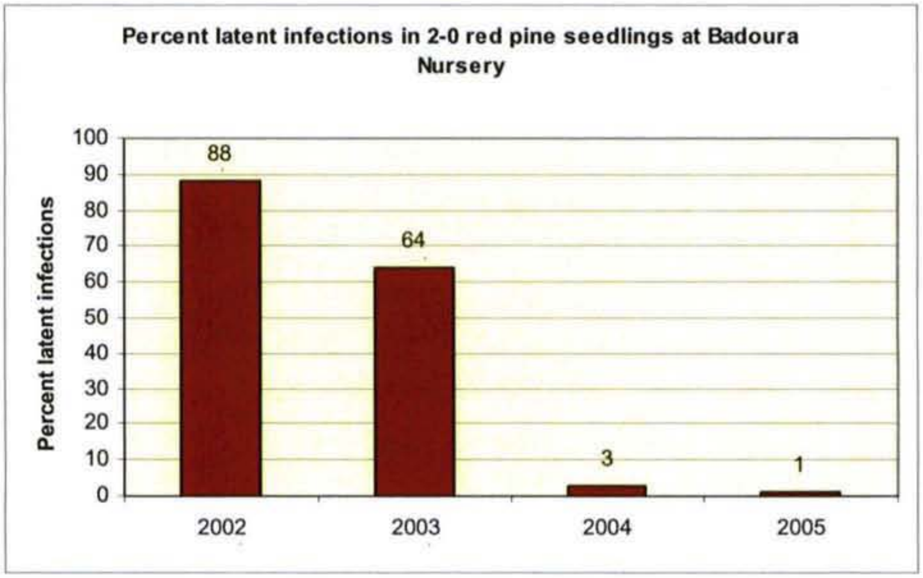
Data

In an effort to monitor the amount of latent *Diplodia* infections that occur in red pine seedlings produced by the State Nurseries, a survey was completed at Badoura Nursery and Gen. Andrews Nursery in 2005. All 2-0 red pine seedlings were sampled in a systematic design and were assayed for the presence of *Diplodia pinea* (formerly *Sphaeropsis sapinea* Strain A) and for *Diplodia scrobiculata* (formerly *Sphaeropsis sapinea* Strain B) by Dr. Stanosz's lab at the University of Wisconsin.

Results of *Diplodia* study at State Nurseries in 2005

Location	Sample date	Seed-bed	Number of seedlings sampled	Number of latent infections found	Percent latent infections	Species determination	Notes
Badoura	July 27	A7	15	0	1.25		
		E7	30	1		D. pinea	
		F12	35	0			
Gen. Andrews	July 28	B9	30	4	6.66	All *D. pinea*	
		D8	60	2		Both *D. pinea*	
		G2	15	0			
		G3	15	2		One *D pinea* and one *D. scrobiculata*	Also found *Siroccocus conigenus* on another seedling

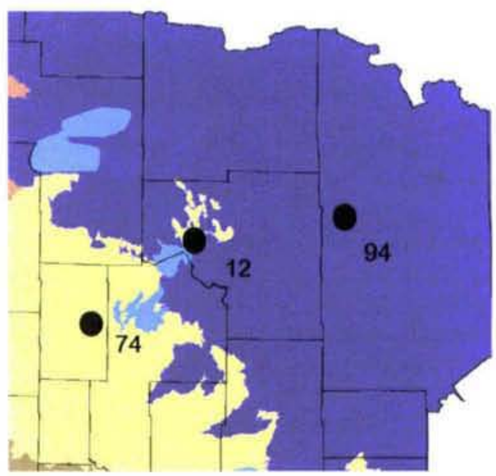
The amount of latent infections has decreased significantly at both nurseries since they've removed the overstory pines in the windbreaks. See figure below. Most of the removals were accomplished at Badoura during the winters of 2003 and 2004. In 2003, Badoura Nursery had 64% latent infections in the 2-0 red pine seedlings and this year, the 2-0's had 1.25% latent infections. In 2002, General Andrews Nursery had 26% latent infections in the 2-0 seedlings and by 2005, there were 6.7% latent infections. At Gen. Andrews, most of the overstory removals were accomplished recently and there is a lag time between removals and disease reductions because existing seedlings were exposed to Diplodia inoculum prior to overstory tree removals. At GASN, the incidence of latent infections is expected to decrease over the next two to three years.



Latent infections of *Diplodia pinea* in red pine plantations

Objective: To investigate the levels of latent infections in the seedling of three red pine plantations in the fall of 2005. Comparisons will be made between the levels of shoot blight and latent infections and the levels of cone infection and latency in seedlings.

Methods and materials: In 2004, 103 red pine sites were visited with the aim of determining inoculum levels (cone infection) in the adjacent overstory red pine stand and shoot blight incidence in red pine seedlings and the furthest distance that shoot blight could be found from the overstory edge. In 2005, three sites were selected based on the absence of confounding inoculum sources and the presence of shoot blight in the plantation in 2004. See map. Each site was revisited in 2005, two transects parallel to the overstory edge were established at varying distances based on the geography of the site. See table below. Along each transect, a single, asymptomatic, current shoot was collected on the side of the tree facing the overstory. Fifty samples were taken on each transect. If a current shoot was blighted anywhere else on the seedling, it was tallied as a blighted seedling. Each shoot was sealed in a plastic bag and kept in a cooler until opened for lab analysis at University of Wisconsin by Dr. Glen Stanosz.



In 2004, 100 cones were collected on the ground from each of the three red pine stands. In the Resource Assessment lab in Grand Rapids, each cone was determined to be either infected or not infected by examining spores from fruiting bodies. This determined the cone infection level in 2004. See table below. A subsample of ten infected cones from each site was assayed in Stanosz's lab to determine which species was present.

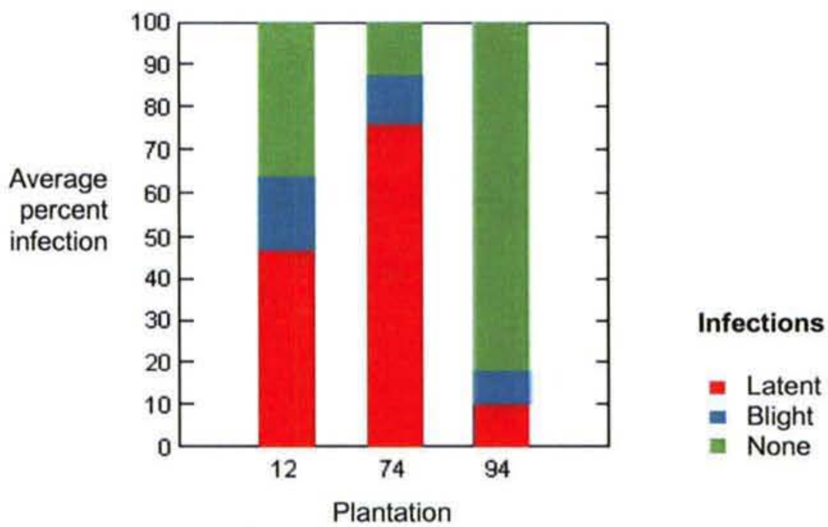
Latency study 2005: Location, cone infection and sampling information.									
Site	Location	Cone infection in 2004	*Diplodia* species recovered	Distance of transects from overstory edge		Number of seedlings sampled in transects		Number of blighted seedlings found in transects	
				First	Second	First	Second	First	Second
12	Itasca Co. S18-T147-R26	45 %	All D. pinea	148	248	50	50	12	5
74	Hubbard Co. S19-T142-R32	61 %	All *D. pinea*	66	132	51	53	4	8
94	St. Louis Co. S16-T60-R20	7 %	All *D. pinea*	116	248	50	50	5	3

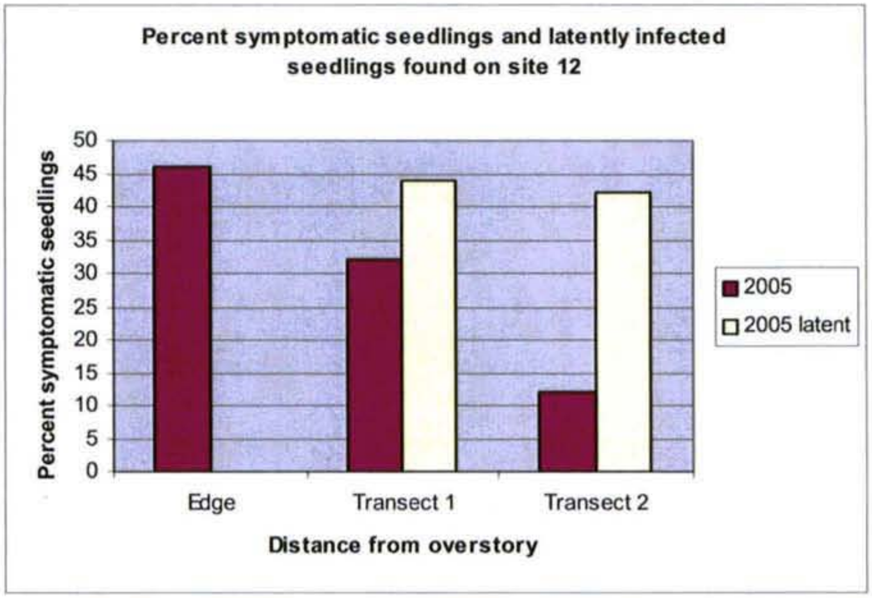
Results:

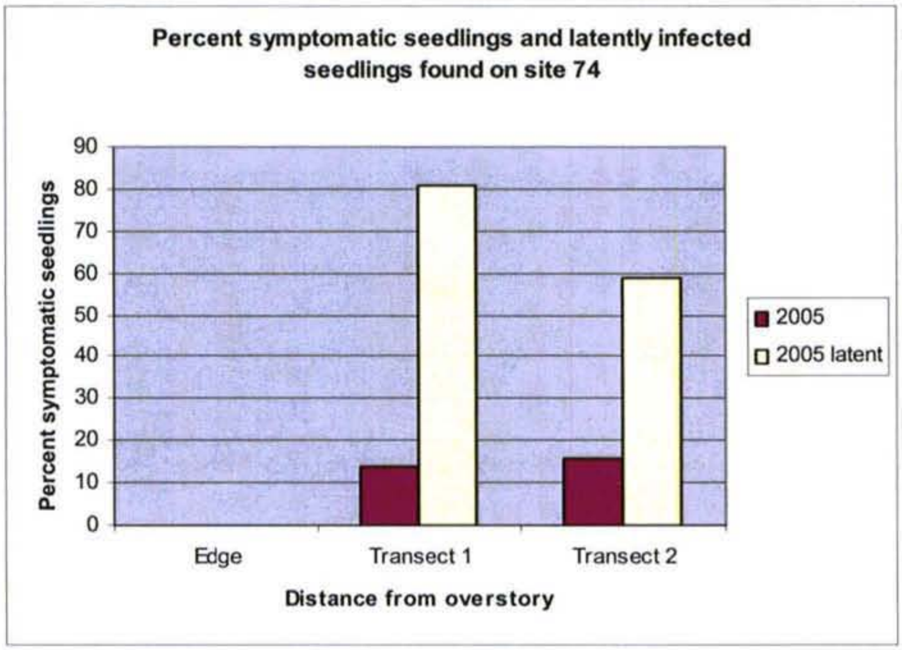
1. 102 of the 304 seedlings had latent infections caused by *Diplodia pinea*. See table below. There were no latent infections caused by *D. scrobiculata.*

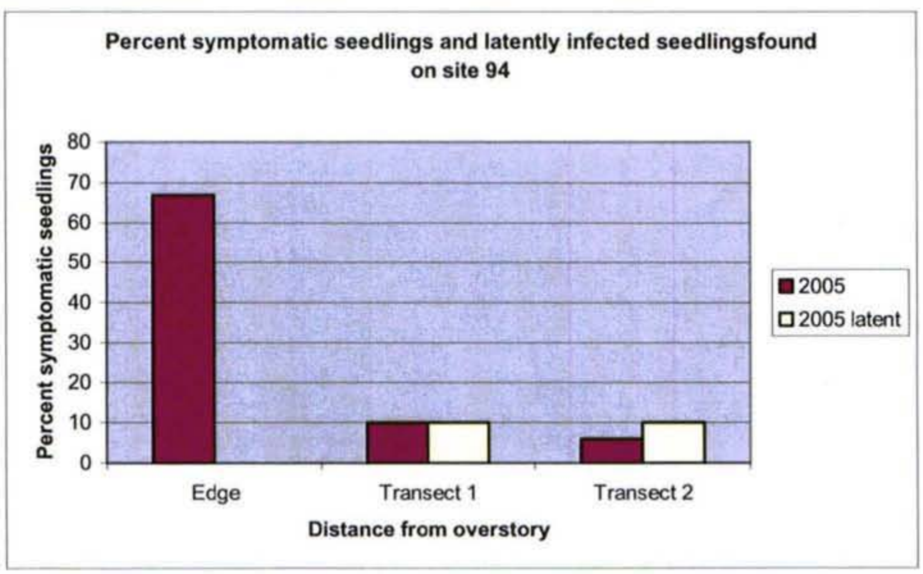
Incidence of shoot blight and latent infections in each transect					
Site	Transect	Combination of infection types			
		No shoot blight and No latent infections	No shoot blight and Latent infections	Shoot blight and No latent infections	Shoot blight and Latent infections
12	1	19	19	6	6
	2	24	21	4	1
74	1	5	41	0	4
	2	17	28	2	6
94	1	40	5	5	0
	2	42	5	3	0

2. In plantations, there is variability in the amount of shoot blight, latent infections and absence of infections. See figure below. The amount of latent infections in plantations is up to six times greater than the amount of shoot blight found.

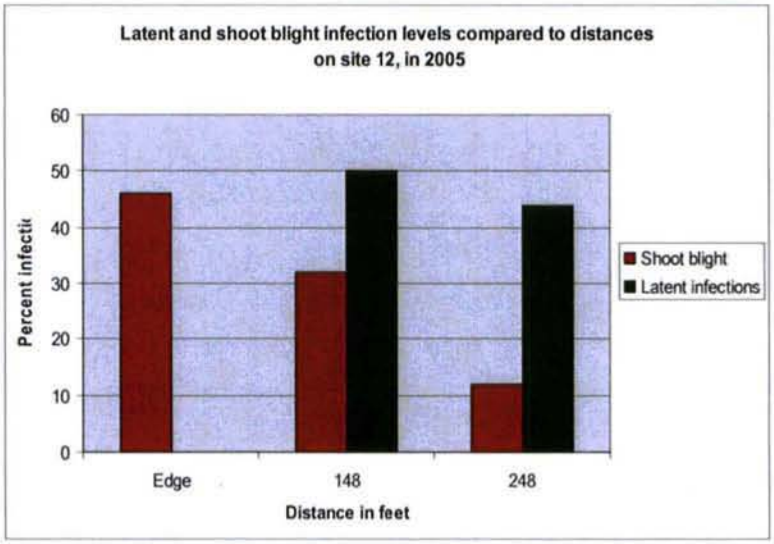



Percent symptomatic seedlings and latently infected seedlings found on site 12
Percent symptomatic seedlings
50
45
40
35
30
25
20
15
10
5
0
Edge
Transect 1
Transect 2
Distance from overstory
2005
2005 latent

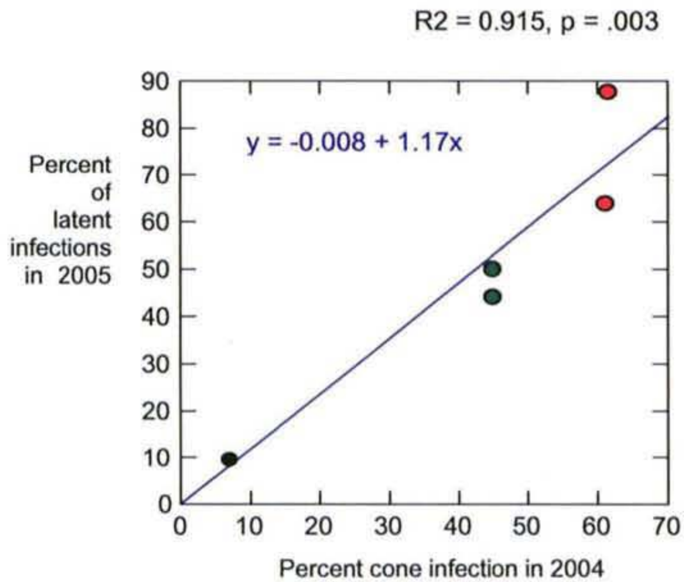

Percent symptomatic seedlings and latently infected seedlings found on site 74
Percent symptomatic seedlings
90
80
70
60
50
40
30
20
10
0
Edge
Transect 1
Transect 2
Distance from overstory
2005
2005 latent

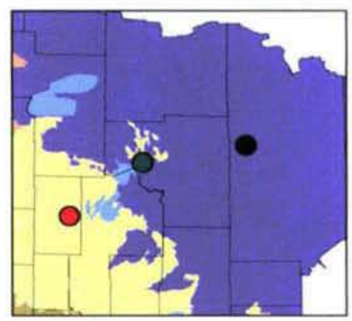

Percent symptomatic seedlings and latently infected seedlingsfound on site 94
Percent symptomatic seedlings
80
70
60
50
40
30
20
10
0
Edge
Transect 1
Transect 2
Distance from overstory
2005
2005 latent

3. In 2005, the distance from the overstory edge to the furthest shoot blight infection on site 12 was more than 248 feet as judged by the chart below. If the amount of latent infections decreases at about the same rate (has a similar slope), then the distance to the furthest latent infection would be much greater than 248 feet.



4. The amount of cone infections (from the previous year) can predict the amount of latent infections occurring between 66 and 248 feet from the overstory edge.





5. Based on data from this study:
   a. The amount of shoot blight does not predict the amount of latent infection in adjacent planations.
   b. The amount of cone infection does not predict the amount of shoot blight.
   c. The amount of cone infection does predict the amount of latent infection.

So, percent of infected cones can be used to predict the amount of latent infections occurring between 66 and 248 feet from the overstory edge.

Evaluating *Diplodia* species:
Shoot blight potential in overstory red and jack pine trees.

By Jana Albers, Mike Albers and Dan Gilmore (Univ. of Minnesota)

Abstract

Current, unprecedented losses of pine seedlings in nurseries, young plantations and natural regeneration are attributed to a fungal disease, Diplodia shoot blight in Minnesota. This study addressed critical gaps in understanding and managing Diplodia shoot blight on red pine seedlings in plantations and in natural regeneration of multi-storied red pine stands. Site specific information on the occurrence and incidence of *Diplodia* species on 92 red pine sites in eight ecological subsections and on 28 jack pine sites in two ecological subsections is presented.

For this study, each red pine site consisted of a mature red pine stand paired with an adjacent red pine plantation. On 89 of the 92 sites, *Diplodia* fruiting bodies were found on red pine cones collected beneath overstory red pine trees and the average incidence of *Diplodia*-infected cones was 25.0%. *D. pinea* was recovered (Smith and Stanosz, 1999) from infected red pine cones on 93% of the sites across northern Minnesota. These results indicate that *Diplodia pinea* has successfully invaded red pine stands and has established itself in the cones.

Only the incidence of *Diplodia* species was studied on jack pine sites, where cones were clipped from trees. The average incidence of cone infection by *Diplodia* species was 12.3%. *D.scrobiculata* was recovered from infected cones on 100% of the sites. *D.pinea* was recovered from infected cones on 64% of the sites indicating that it has successfully invaded the cones in jack pine stands, too.

Diplodia pinea is a latent pathogen that is capable of causing symptomatic shoot blight infections and latent infections that can develop into shoot blight if activated by droughty conditions (Stanosz et al, 2001). In this study, only symptomatic shoot blight infections were used to assess the disease potential of the overstory. The incidence of latent infections was not assessed because of the scope of the study.

On the 41 sites, where blighted seedlings were found, the average incidence of shoot blight in the understories was 15.0% and, in the adjacent plantations, the average incidence of shoot blight was 4.7 %. The average furthest distance that blighted seedlings were found from the overstory edge was 62.6 feet. In 2005, seven sites were revisited and shoot blight incidence was determined. Average shoot blight infection in the understory and individual transects was seven times greater those found in 2004 in the same locations. So, in 2004, the impact of *Diplodia* shoot blight occurred predominantly in a 63 foot - wide strip along the overstory edge where less than 5% of the seedlings were blighted, whereas, in 2005, *Diplodia's* impact occurred in a 141 foot wide strip where 25% of the seedlings were blighted. In 2005, the distance to the furthest infected seedling ranged from 50 to 262 feet and averaged 141 feet. 2004 was a "modest" year for shoot blight expression compared to 2005. Observed ranges of shoot blight incidences in this study are typical of empirical observations made in Minnesota over the last two decades.

Analysis of site, ecological and geographical variables indicated that site variables can be used to describe the incidence of *Diplodia* shoot blight on red pine seedlings under or adjacent to a mature red pine stand. Based on Classification and Regression Tree analyses, five site variables can approximate the incidence of shoot blight on understory and plantation seedlings, and, the furthest distance to blighted seedlings in a plantation.

Guidelines are suggested so that a forest manager can select sites for natural or artificial red pine regeneration based on the observed and anticipated incidence of *Diplodia* shoot blight. The shoot blight potential of a proposed plantation should be determined if either live red pines have been retained inside the plantation, or, the plantation is adjacent to a mature red pine overstory. The shoot blight potential of an overstory should be routinely determined if red pine regeneration is desired. The shoot blight potential of canopy gaps should always be predicted prior to selecting gap size if red pine regeneration is desired.

This study primarily contains data from a single growing season, 2004, so further study is needed to verify the relationships among the site variables and the predicted levels of shoot blight in order to make these management recommendations more statistically robust.

Note: Two versions of the Annual Report - 2005 were made. One has the complete project report and the other has selected maps printed after this page. The full report is on the enclosed CD.

National insect and disease risk mapping

By Frank. J. Sapio and Frank. J. Krist Jr.
USDA Forest Service - Forest Health Protection
Forest Health Technology Enterprise Team
Fort Collins, Co.

The purpose of this effort is to develop a periodic five year strategic assessment of risk of tree mortality due to major insect and diseases. This project is the second in a series which uses the development of a geographic information system (GIS) database to identify the potential impact caused by both endemic and non-endemic forest pests.

While the earlier effort "Mapping Risk from Insect and Disease" (Lewis 2002) was truly a pioneering effort, the process documented below bears little resemblance to its parent effort. Different software, some of it custom, was used in this model. In addition, host data, GIS methods and even the definition of risk are significantly different in this "next generation" product.

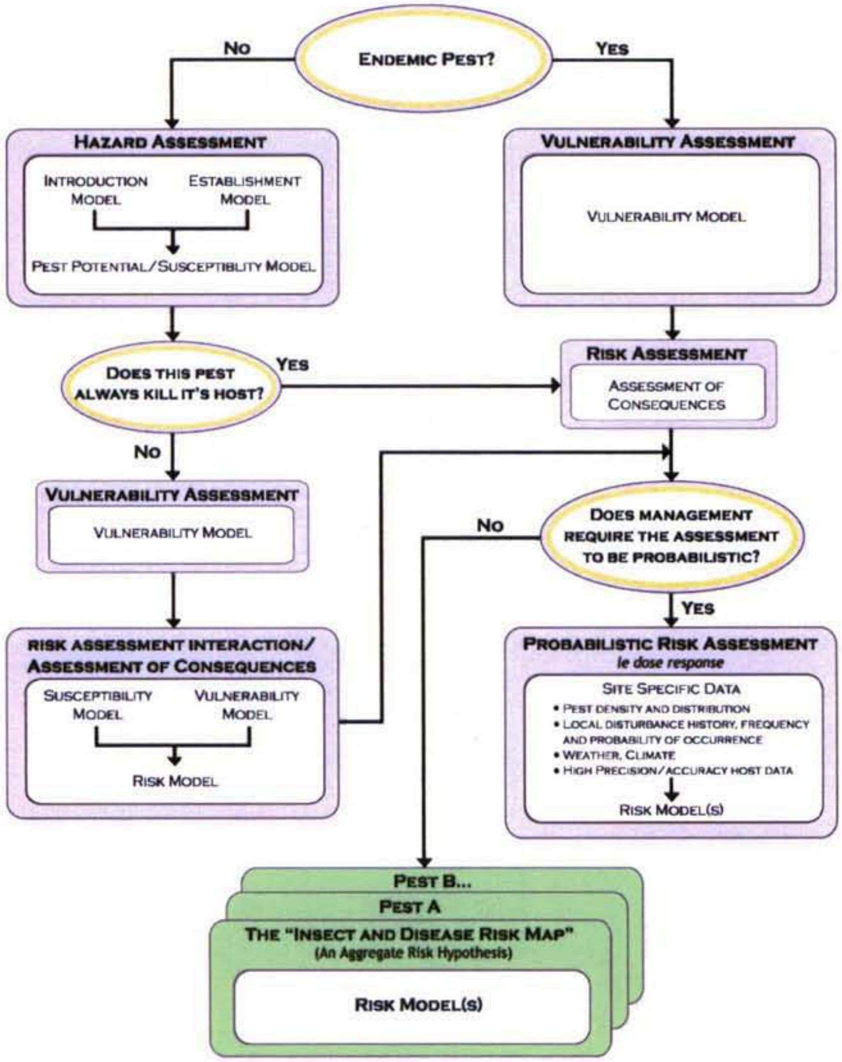
The risk mapping effort described in this paper was undertaken to provide Congress and USDA officials with a broad, national-level depiction of the risk of basal (BA) area loss due to tree mortality. The Risk Map Oversight Team definition of risk is as follows: The expectation that 25% or more of standing live volume greater than 1" DBH will die over the next 15 years, including normal background mortality.

This strategic product is not intended to predict local insect and disease outbreaks. It is intended to provide a strategic look across the entire nation using a well documented and completely transparent process. The map is built at a 1 kilometer spatial resolution. If a higher resolution view of the risk due to insects and diseases is required, we recommend that you contact a Regional Risk Map Team Lead who may be able to provide a local high resolution assessment of pest risk.

Version 3.0 of the 2006 National Insect and Disease Risk Map (NIDRM) is more than "just a map". It represents a collection and integration of over 189 individual risk models which use a consistent, repeatable and transparent process. We have focused on the development of a dynamic risk modeling process that can provide improved maps as models and data are updated and/or become available.

The creation of a national risk map was a collaborative process initiated by the Forest Health Protection (FHP) staff and delegated to the Forest Health Monitoring Program. Through the FHM Regions, entomologists and pathologists from all fifty states and FHP Regions were invited to take part in the process of creating the risk map. Those specialists who were able to dedicate time became part of the regional efforts for creating risk models. A Risk Map Oversight Team was formed to define products, provide general guidance and schedule activities. Regional Risk Mapping Teams were created with forest health and GIS participants from the Forest Service, state agencies and academia to oversee and assist in multi-criterion model development and to revise draft products. Starting in 2004, forest health experts met to develop descriptive models using group consensus and published information. In April 2005, GIS experts on the teams were trained by Frank Krist to convert text-based models into GIS-based processes. Forest health and GIS experts then met together at regional workshops to run models, review results, and make adjustments. The process culminated with a collective review of results during November by participants on the regional risk mapping teams. The Forest Health Monitoring Research Work Unit (Southern Research Station) was instrumental in the development of the host parameter data which drive individual models in the map. Actual data surfaces were prepared at the Forest Health Technology Enterprise Team (FHTET) for access by FS Regional and State cooperator staff. Model deficiencies and applicability were discussed and plans were drawn up to develop models where optimal data are limited or no published models exist.

Standard national data sets for total and individual species basal Area, quadratic mean diameter (QMD), stand density index (SDI) (Reineke 1933), percent host, PRISM® climate layers, soils and topography were developed specifically to support this work. The host data layers (BA, SDI, and QMD) are derived from models themselves, however, we did not invest in an effort to quantify the uncertainty surrounding them. We did develop a qualitative assessment of their accuracy and believe that they are adequate to conduct this national assessment.



Regional risk mapping teams constructed a series of multi-criteria risk models using ArcView 3.x, Spatial Analyst ModelBuilder and IDRISI 32 Geographic Information System (GIS) software (Eastman 1995, 1999). A five step process was designed to develop a standard National depiction of risk. They steps are:

1. Identify a list of pests (risk agents) and target host species. This is conducted by region with certain models constrained to select geographic areas.

2. Identify, rank, and weight criteria that determine the susceptibility and vulnerability to each risk agent; in some cases susceptibility to a pest approximates vulnerability and therefore results in tree mortality in the model. This would be true for pests such as the emerald ash borer and oak wilt. A series of standard tools and documentation have been developed to aid in the collection of criteria and rank their relative importance.

3. Standardize risk agent criteria values and combine the resultant criteria maps using weighted overlays. Through a group process, participants assign a level of risk to values within GIS layers that represent criteria. This could be a highly iterative process, depending upon the level of documented knowledge and the familiarity with individual data layers and risk agents. Often relative weights are decided upon when viewing intermediate map products.

4. Convert modeled values for each risk agent to predicted Basal Area (BA) loss over a 15 year period. This is done for each forest species that occupies a pixel in the national data base. To convert values to BA loss, a "typical" maximum realizable mortality rate (MRM) is assigned to each risk agent. This is an estimation of mortality loss, expressed as a percent of BA loss, for the next 15 years, if all criteria are met in step three. The

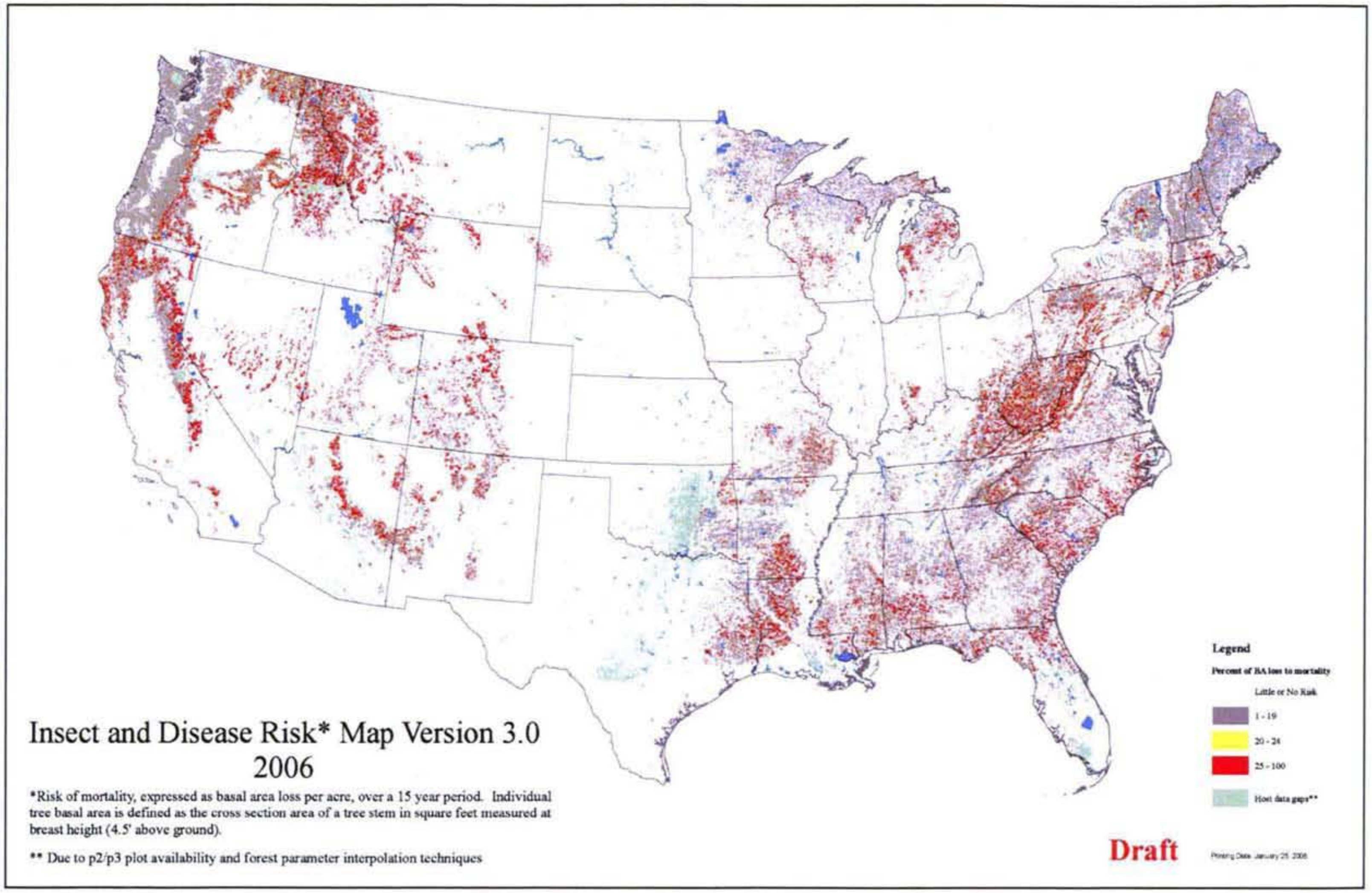
actual mortality rate varies depending upon the level of risk. For example, a high risk pixel may correspond to a mortality rate of 100% while pixels with medium risk would correspond to a mortality rate of 50%. Predicted BA loss is calculated by multiplying the mortality rate by the BA of each individual host species.

5. Identify pixels on a national base map that are at risk of encountering a 25% or greater loss of total basal area or volume in the next 15 years. This potentially dynamic threshold was set by the National Risk Map Oversight Team for the national risk product. Our product maintains the entire range of predicted BA loss and can be set at any output threshold. The maps found in appendices 6 and 7 are set to the Oversight Team's definition of risk that identifies mortality greater than 25 % of stand volume over a 15 year period.

Each of these five steps described require different participants. Steps 1 - 3 require participation from of forest health and GIS specialists while steps 4 - 5 primarily involve GIS specialists with little periodic input from forest health specialists until the models (maps) were produced. Therefore, in this National project, much of the workload fell on the local GIS specialists to collect information and build risk models.

http://www.fs.fed.us/foresthealth/technology/peer_review_nationalinsectanddisease_riskmap.shtml

This site will include all of the individual risk models including model documentation for 189 models (spreadsheets with available references), 189 risk maps, 189 risk contribution maps, host data and of course, a large format plot or print file, for the composite map. Upon request we can also provide a draft manuscript intended as a USDA Forest Service Report. We ask that you study the NIDRM process and its associated data surfaces in depth. Please contact regional risk mapping leads, oversight team members or the authors of this review guide to provide insight as to how we can improve this process. "You'll know 'em when you see 'em".


Insect and Disease Risk* Map Version 3.0
2006
*Risk of mortality, expressed as basal area loss per acre, over a 15 year period. Individual tree basal area is defined as the cross section area of a tree stem in square feet measured at breast height (4.5' above ground).
** Due to p2/p3 plot availability and forest parameter interpolation techniques
Legend
Percent of BA loss to mortality
Little or No Risk
1 - 19
20 - 24
25 - 100
Host data gaps**
Draft
Printing Date January 25, 2006

MINNESOTA DNR - FOREST HEALTH MANAGEMENT
FFY 2005 GRANT #: 05-DG-11244225-088
SURVEY and TECHNICAL ASSISTANCE
FOREST HEALTH MONITORING
EMERALD ASH BORER EARLY DETECTION SURVEY
SUDDEN OAK DEATH SURVEY

Progress Report: October 1, 2004 – September 30, 2005

Survey & Tech. Assistance: Pest and Host Evaluations			
Target		Accomp: 9/30/05	
Activity	Pest/Host	Acres	Trend
Evaluation	Forest tent caterpillar	Data being analyzed	
	Jack pine budworm	Data being analyzed	
	Spruce budworm	Data being analyzed	
	Larch beetle	Data being analyzed	
	Diplodia shoot blight	Data being analyzed	
	Black ash decline	Data being analyzed	

Survey & Tech. Assistance: Long Term Spruce Budworm Evaluation in White Spruce Plantations		
Activity	Target	Accomp: 9/30/05
# Full plot measurements	6	6
# Spruce budworm defoliation rating	11	11

Survey & Tech. Assistance: Incidence of *Diplodia* on Natural Regeneration at Itasca State Park		
Activity	Target	Accomp: 9/30/05
# Seedlings in study	1,200	1,200
# Seedlings in control to assay for latent infections	40	40
# Seedlings w/ visible Diplodia infections	1,160	1,160
Results		
Forty seedlings in the control block were assayed for latent infections. No latent infections were found. The 1,160 seedlings collected in the pine understory were collected and put in cold storage. These seedlings will be inspected during the winter of 2006.		

Survey & Tech. Assistance: Oak Wilt Management		
Activity	Target	Accomp: 9/30/05
# LUG's assisted for oak wilt control	25	25

Survey & Tech. Assistance: Outreach		
Activity	Target	Accomp: 9/30/05
# presentations or training events	30	29
# Forest Health Newsletters	4	3
# news releases	6	6
# brochures	4	0
# TV/radio opportunities	4	2
# requests for forest health assistance	400	Did not track
Co-authored: *Surveys for asymptomatic persistence of Sphaeropsis sapinea on or in stems of red pine seedlings from seven Great Lake region nurseries*. 2005. G.Stanosz, D.Smith, J.Albers. Forest Pathology 35:233-244.		

Survey & Tech. Assistance: Meeting Attendance	
Meeting	Accomp: 9/30/05
SPFO Cooperator's Meeting	Done
Western Insect and Disease Meeting	NO
North Central Forest Pest Workshop	Done
Gypsy Moth National Meeting	Done
Exotic Pest Workshop	Done
Risk Map Meeting	Done

Survey & Tech. Assistance: Forest Health Reports	
Report	Accomp: 9/30/05
Accomplishment and Expenditure Report (FS3400-5)	To be submitted

Forest Health Monitoring: Detection Surveys		
Activity	Target	Accomp: 9/30/05
General pest detection – million acres	12.0	13.0

Forest Health Monitoring: Detection Survey Results – FFY05	
Causal Agent	Acres
Data being analyzed	NA

Forest Health Monitoring: Information Management	
Activity	Accomp: 9/30/05
Pest detection surveys results provided on maps at 1:100,000 scale	To be done
Digital aerial survey maps provided to NA, SPFO by 12/15	To be done
Text and graphics for the annual state Forest health Highlights to NA, SPFO by 12/15	To be done

Forest Health Monitoring: Douglas-fir Beetle Detection Trapping		
Activity	Target	Accomp: 9/30/05
# of traps	5	10
Results		

No results available: trap catches have not been sorted

Forest Health Monitoring: Pine Shoot Borer Trapping		
Activity	Target	Accomp: 9/30/05
# of traps	20	0
Results		
Minnesota Department of Agriculture initially installed a trapping network and DNR assisted in the first scheduled trap monitoring. Trapping was eventually abandoned when the decision was made to extend the pine shoot borer quarantine statewide.		

Forest Health Monitoring: Oak Tatters Survey		
Activity	Target	Accomp: 9/30/05
# of plots	5	2
Results		
In 2005 tatters was for the most part a non-event across the state. It seems that the phenology of the oaks did not co-inside with the potential drift from applications of Choloracetamide herbicides applied to nearby cornfields. However, in two separate areas, one south of Kasson, MN and another near Austin, MN tatters symptoms did develop on the oaks. Mid-season follow-up investigations found that in both instances, fields adjacent to the affected oaks received applications of Harness Xtra. These herbicides are applied at the time of leaf emergence of the oaks and other affected species. Foliage sampling was not used.		

Forest Health Monitoring: Meeting Attendance	
Meeting	Accomp: 9/30/05
National Forest Health Monitoring Working Group	Done

Emerald Ash Borer Early Detection Survey		
Activity	Target	Accomp: 9/30/05
# of trap tree sites	15	17
# of trap trees	---	34
Results		
No results: trap trees were not felled by the end of September. In addition the environs around 15 wood using mills were inspected for ash dieback and dead ash. Either the sites had no ash close by or there was no evidence of EAB despite the declining and dead ash present around the mills.		

Sudden Oak Death Survey		
Activity	Target	Accomp: **FINAL**
# plots established & measured	30	33
Results		
See report following.		

Evaluating *Diplodia* species: Shoot blight potential in overstory red and jack pine

By
Jana Albers, MN - DNR
Mike Albers, MN - DNR
Dr. Dan Gilmore, Univ. of Minnesota

March 1, 2006

Evaluating *Diplodia* species: Shoot blight potential in overstory red and jack pine trees.

By Jana Albers, Mike Albers and Dan Gilmore

Abstract

Current, unprecedented losses of pine seedlings in nurseries, young plantations and natural regeneration are attributed to a fungal disease, Diplodia shoot blight in Minnesota. This study addressed critical gaps in understanding and managing Diplodia shoot blight on red pine seedlings in plantations and in natural regeneration of multi-storied red pine stands. Site specific information on the occurrence and incidence of *Diplodia* species on 92 red pine sites in eight ecological subsections and on 28 jack pine sites in two ecological subsections is presented.

For this study, each red pine site consisted of a mature red pine stand paired with an adjacent red pine plantation. On 89 of the 92 sites, *Diplodia* fruiting bodies were found on red pine cones collected beneath overstory red pine trees and the average incidence of *Diplodia*-infected cones was 25.0%. *D. pinea* was recovered (Smith and Stanosz, 1999) from infected red pine cones on 93% of the sites across northern Minnesota. These results indicate that *Diplodia pinea* has successfully invaded red pine stands and has established itself in the cones.

Only the incidence of *Diplodia* species was studied on jack pine sites, where cones were clipped from trees. The average incidence of cone infection by *Diplodia* species was 12.3%. *D.scrobiculata* was recovered from infected cones on 100% of the sites. *D.pinea* was recovered from infected cones on 64% of the sites indicating that it has successfully invaded the cones in jack pine stands, too.

Diplodia pinea is a latent pathogen that is capable of causing symptomatic shoot blight infections and latent infections that can develop into shoot blight if activated by droughty conditions (Stanosz et al, 2001). In this study, only symptomatic shoot blight infections were used to assess the disease potential of the overstory. The incidence of latent infections was not assessed because of the scope of the study.

On the 41 sites where blighted seedlings were found, the average incidence of shoot blight in the understories was 15.0% and, in the adjacent plantations, the average incidence of shoot blight was 4.7 %. The average furthest distance that blighted seedlings were found from the overstory edge was 62.6 feet. So, in plantations, the impact of *Diplodia* shoot blight usually occurs in a 63 foot - wide strip along the overstory edge where less than 5% of the seedlings are blighted. Since, the entire understory is affected by an infected overstory and the level of shoot blight is commonly three times greater in the seedlings, we conclude that the impact of *Diplodia* shoot blight in plantations is usually minor in comparison to its impact in understories.

Analysis of site, ecological and geographical variables indicated that site variables can be used to describe the incidence of *Diplodia* shoot blight on red pine seedlings under or adjacent to a mature red pine stand. Based on Classification and Regression Tree analyses, five site variables can approximate the incidence of shoot blight on understory and plantation seedlings, and, the furthest distance to blighted seedlings in a plantation.

Guidelines are suggested so that a forest manager can select sites for natural or artificial red pine regeneration based on the observed and anticipated incidence of *Diplodia* shoot blight. The shoot blight potential of a proposed plantation should be determined if either live red pines have been retained inside the plantation, or, the plantation is adjacent to a mature red pine overstory. The shoot blight potential of an overstory should be routinely determined if red pine regeneration is desired. The shoot blight potential of canopy gaps should always be predicted prior to selecting gap size if red pine regeneration is desired.

This study primarily contains data from a single growing season, 2004, so further study is needed to verify the relationships among the site variables and the predicted levels of shoot blight in order to make these management recommendations more statistically robust.

Background

Coniferous trees are critical components of eastern woodlands, which provide economic value, aesthetic beauty, recreational opportunities, wildlife habitat, water protection, and biodiversity. Approximately twelve million acres of forests in the eastern US are categorized as the red/white/jack pine cover type. Among diseases affecting red and jack pines is *Diplodia* shoot blight and canker, caused by *Diplodia pinea*. The disease occurs worldwide and causes damage in exotic pine plantations in New Zealand, Australia, and South Africa (Wingfield et al, 2001). The most common symptoms of *Diplodia pinea* in mature pines are shoot blight and death of lower branches and the disease only rarely causes tree mortality (Sinclair and Lyon, 2005). The fungus causes shoot blight and cankers on saplings and pole-sized pines and, mortality occurs when most of the shoots are blighted or a canker girdles the stem. On pine seedlings, *Diplodia* causes shoot blight and collar rot which commonly kill the seedlings (Gilmore and Palik, 2006). Although long recognized, the disease was not noted as cause of severe damage in the north central United States until the mid-1970s (Palmer et al, 1988). Epidemics were subsequently reported affecting red and jack pines in nurseries (Stanosz et al, 2005) and plantations (Stanosz and Cummings-Carlson, 1996).

Diplodia pinea exhibits latency in needle, bark and cone tissues of pine hosts (Blodgett et al, 1997a). *D. pinea* is able to infect and persist in host tissues without causing symptoms until a shift in host physiology releases the fungus to cause disease and disease symptoms (Blodgett et al, 1997a). Stanosz et al, (2001) demonstrated that water stress is the physiological trigger that releases *Diplodia pinea* from a quiescent state to an active state. Whether seedlings become blighted and die from accumulated infections depends on moist weather suitable for infection (Blodgett et al, 1997a) and droughty weather severe enough to activate those infections (Stanosz et al, 2001).

Diplodia epidemics appear to be related to substantial rainfall deficits (Stanosz and Cummings-Carlson, 1996) and damage has always associated with severe drought (Nichols and Ostry, 1990; Stanosz and Cummings-Carlson, 1996; Stanosz et al, 2005). The latest example of this in Minnesota is a *Diplodia* collar rot epidemic in red pine seedlings that occurred during a severe drought during the spring and summer of 2002. Once the seedlings were planted, rain did not fall again for six weeks. Losses of other conifer species averaged 15% while losses of red pine averaged 65%. Examination of seedlings from 27 plantations showed that 98% of the dead red pine seedlings had *Diplodia* fruiting bodies on them (Albers, unpublished data). In 2003, a systematic survey of nursery stock showed the asymptomatic persistence of *Diplodia* in 64% of the two million 2-0 seedlings at Badoura Nursery (Stanosz et al, 2005).

Coincident with severe damage in Lake States has been recognition of variation within the pathogen, and confirmation of the biological significance of these differences. Palmer et al. (1987) recognized two morphological groups among isolates identified as *Diplodia pinea* from MI, MN, and WI. Two distinct groups, referred to as A and B, now have been confirmed on the basis of independent molecular genetic markers including isozymes, RAPDs, ITS sequences, and microsatellite fingerprints (Stanosz et al. 1999, Zhou and Stanosz 2001, Zhou et al. 2001). Isolates in group A appear to be highly genetically similar and isolates from the Lake States are not differentiable from those from other parts of the world. Inoculation of shoot tips in greenhouse trials reveal that these A group isolates are highly aggressive on red and jack pine (Blodgett and Stanosz 1997a) and several other conifers (Blodgett and Stanosz 1997b). B group isolates, while not aggressive on red pine shoots, were able to cause disease of jack pines. Recently, DeWet et al (2003) have separated the two morphological groups into two species; A = *Diplodia pinea* and B = *Diplodia scrobiculata*. Burgess et al (2004) found strong geographic isolation between populations of *D. scrobiculata* in North America.

The presence of infected overstory red pines limits the success of both artificial and natural regeneration (Palmer et al, 1988). Under optimal conditions for disease development, such as in conifer nurseries, blighted seedlings can be found more than 1000 feet from the inoculum source (Palmer et al, 1988). Empirical evidence has shown that the impact of this disease is variable across northern Minnesota (FH Reports, 1976 to 2004), reflecting both differences in overstory infection and in epidemiological conditions on those sites. Since the early 1980s, blighted red pine seedlings and saplings have died or remained stagnant on many sites, the inoculum being derived from cone and shoot infections in nearby or overstory red pines. Trends toward uneven-aged management of red pine (Ostry et al, 1998; Gilmore and Palik, 2006) and the paucity of natural jack pine regeneration (FH Report, 1999) have renewed concerns over the impact of *Diplodia* on pine seedling vigor and survival.

At present, we have no field method to evaluate the incidence and severity of *Diplodia* in mature red pine stands, much less to evaluate disease potential in adjacent plantations. By developing a method to evaluate *Diplodia* at the stand level, foresters could evaluate sites prior to planting and avoid losses by preventing lethal infections. More importantly, sites where inoculum levels are absent or low would be well suited to natural regeneration and the development of multi-storied red pine stands.

Objectives

Current, unprecedented losses of pine seedlings in nurseries, young plantations and natural regeneration are attributed to *Diplodia pinea*. This project will address critical gaps in understanding and managing the invasive pathogen on red pine seedlings in plantations and in natural regeneration of multi-storied pine stands. Site specific information on the incidence and disease potential of 92 mature red pine stands in eight ecological subsections will be analyzed to accomplish the following:

- Create thematic maps to show the distribution and incidence of *Diplodia pinea* and *Diplodia scrobiculata* across northern Minnesota in red and jack pines,
- Develop a technique to evaluate shoot blight potential in red pine, and,
- Develop guidelines for natural and artificial regeneration of red pine under or adjacent to overstory pines.

Methods

Palmer et al (1988) suggest that red pine cones in windbreak trees are the primary source of inoculum in beds of 1-0 red pine seedlings in nurseries. In this study, we sought to set up an analogous situation using the red pine cones from mature red pine overstories as the source of inoculum and the young red pine seedlings and saplings in adjacent plantation as the susceptible hosts. We also studied the incidence of shoot blight in red pine regeneration underneath the overstory red pines, on sites where red pine regeneration could be found.

Site selection: To be considered a suitable site for this study, the site needed to have a mature red pine overstory, an adjacent red pine plantation that was from three to seven years old and 100 cones found on the ground during the site visit. Using the CSA Inventory shape files in ArcView v.3, several hundred potential red pine overstory/plantation pairs were identified on state, federal and county ownerships. The resulting pairs were projected onto 2003-2004 Farm Service Administration photography in order to further eliminate pairs where additional sources of inoculum might be found that would spread into the plantation. Sources included any other adjacent pine trees, any other adjacent pine overstories or the presence of pine residuals in the plantation. Also, sites were disqualified if the overstory/ plantation boundary was concave or convex. Ninety five sites were selected for site visits. All sites were visited between July 5 and October 20, 2004. GPS readings were taken in each overstory to create a GIS layer documenting the location of the sites. A reduction in the number of sites was made because three of the sites had no cones on the ground, so we could not assess the inoculum. The resulting 92 sites were located in eight Ecological Subsections found across northern Minnesota. See Map 1. (Note: all maps can be found in the Appendix.) This represents a complete sample of the existing sites in the surveyed area.

Understory data: The incidence of symptomatic *Diplodia* infections in the understory was determined inside a 66 foot wide strip along the overstory/ plantation boundary. All seedlings (0.5 to 5 feet tall) and all saplings (5.1 to 15 feet tall) were tallied as asymptomatic, blighted or dead. See Map 2. From each infected seedling or sapling, a blighted shoot was collected, bagged and frozen at 8 to 26 degrees F until they were examined. The occurrence, composition and relative densities of subcanopies were documented on sites where they were found. On 49 of the 92 sites, an ecological classification of the overstory stand was determined to the site level (Aaseng et al, 2003). See Table 1.

On each red pine site, 100 cones were collected from the forest floor under the overstory. In the lab, each cone was examined under a 10X Zeiss binocular scope. If black fruiting bodies were found on a cone, up to five samples of the fruiting bodies were examined for the presence of *Diplodia* spores under a 40X microscope. Based upon the presence or absence of *Diplodia* fruiting bodies, each cone was determined to be infected or to be not infected. For each site, the percent of infected cones was calculated. From each site, a subsample of ten infected cones was sent to the Stanosz lab for determination of *Diplodia* species. There, each cone was individually washed, the resulting rinsate was cultured and the DNA was extracted, amplified and identified to species with the appropriate primers (Smith and Stanosz, 1995; Smith and Stanosz, 2006). For each site, the percent recovery of each *Diplodia* species was determined.

Table 1. **Ecological classification of sites evaluated in this study** (n = 49)	
Classification	Number of sites
FDc23	1
FDc24	3
FDc34	12
FDn12	2
FDn32	2
FDn33	19
FDn43	9
MHn35	1

Plantation data: In the adjacent plantation, seedlings were inspected for the presence of shoot blight by walking transects parallel to the overstory. See Map 2. The first transect was 12 feet from the trunks of the overstory pines. In actuality, most of the seedlings in the first transect were under a branch of a nearby red pine tree. Both planted seedlings and natural regeneration, if present, were tallied. The second transect was 50 feet from the first transect. All subsequent transects were 50 feet from the preceding one. Survey crews tallied asymptomatic, blighted and dead seedlings along the transects. A single symptomatic shoot was taken from each blighted seedling and its location was documented by a GPS waypoint. Shoot samples were frozen until lab examination. Survey crews continued walking transects until two consecutive transects found zero blighted seedlings. The locations of all mature red and jack pine trees along the edges of plantations (edge trees) and inside plantations (interior trees) were documented as GPS waypoints.

850 symptomatic shoot samples from the understory and plantations were examined for the presence of *Diplodia* and *Sirococcus* symptoms and fruiting bodies. If shoot blight disease was suspected but no definitive fungal signs were found, the sample was tallied as "shoot blight". Samples were refrozen and sent to Stanosz's lab to determine the incidence of *Diplodia* species. These samples are still being processed.

The distance from the overstory edge to the furthest symptomatic seedling was determined by measuring the distance in ArcView using FSA photography and GPS waypoints.

In September and October of 2005, seven sites were revisited. Seedling infection and mortality in the understory and in the plantation were tallied as they were in 2004. No cones were collected.

Jack pine sites: Twenty-eight jack pine survey sites were selected following the methodology as described for red pine, except that a site was solely composed of a mature jack pine stand. See Map 3. A single GPS location was established on each site in order to create a GIS layer. One hundred cones clipped from ten mature trees were collected for determination of the incidence of *Diplodia* infection. All cone samples were examined for the presence of *Diplodia* fruiting bodies. The percentage of infected cones was documented for each survey site. Where *Diplodia* infected cones were found, 10 infected cones were subsampled and sent to the Stanosz lab. For each site, the percent recovery of each *Diplodia* species was determined.

Statistics: Descriptive statistics, two-sample t-tests, linear regression and general linear models were used to analyze the findings in this study. See Table 2.

Table 2. **Statistical methods used in this study.**	
Method	Purpose
Two-sample t-test	Compare the recovery of *D. scrobiculata* from red pine cones in two floristic regions.
	Compare the presence and absence of a subcanopy on the number of understory seedlings and percent of blighted seedlings.
	Compare two levels of cone infection to the incidence of shoot blight in understories and plantations.
	Compare the incidence of shoot blight on sites where *D. pinea* alone was recovered to sites where both *D. pinea* and *D. scrobiculata* were found.
General linear model	Determine whether the incidence of shoot blight was related to the distance from the overstory edge.
	Determine whether the incidence of shoot blight in 2004 was the same as in 2005.
Linear regression	Develop a correlation between the amount symptomatic infections and the total amount of infections in a study of containerized seedlings at Itasca State Park.
Descriptive statistics	All remaining analyses.

Classification and Regression Tree Analysis: Classification and regression trees analyses (SYSTAT 2004) were used to develop rules to identify conditions affecting levels of *Diplodia* shoot blight infection. Regression trees parallel regression modeling where the dependent variable is quantitative. Classification trees parallel discriminant analysis classification methods. A least squared loss function, which minimizes the sum of the squared deviation, was used in all analyses.

Results

Objective 1: Create thematic maps to show the distribution and incidence of *Diplodia* infection and the occurrence of *Diplodia pinea* and *D. scrobiculata* across northern Minnesota in red and jack pines.

Red pines

On red pines sites, the incidence of *Diplodia* infections in 2004 was described by cone, understory seedling and plantation seedling infections as follows.

On 89 of the 92 red pine sites, *Diplodia* fruiting bodies were found on cones collected beneath the overstory trees. The number of cones that were infected on each site ranged from 0 to 84; the average number of infected cones was 25.0 cones per site. Map 4 shows the distribution and incidence of *Diplodia* infection on cones on each site.

From sites with infected cones, *Diplodia* species were recovered in lab assays (Smith and Stanosz, 1995). Lab assays showed *Diplodia pinea* alone caused cone infections on 61 sites, *Diplodia scrobiculata* alone caused infection on one site, both species caused infection on 25 sites and neither species was recovered from infected cones on five sites. See Map 5. Map 6 shows the distribution and percent recovery of *Diplodia pinea.* The average percent recovery of *Diplodia pinea* was 59.7% from 86 sites. Map 7 shows the distribution and recovery of *Diplodia scrobiculata.* The average percent recovery of *D. scrobiculata* was 7.8% from 26 sites. *D. scrobiculata* was recovered from red pine cones in the central floristic region five times more frequently than in the northern floristic region. See Map 8 and Figure 1. *D. scrobiculata* was not recovered from cones that came from the 19 sites in the northern native plant community, FDn33.

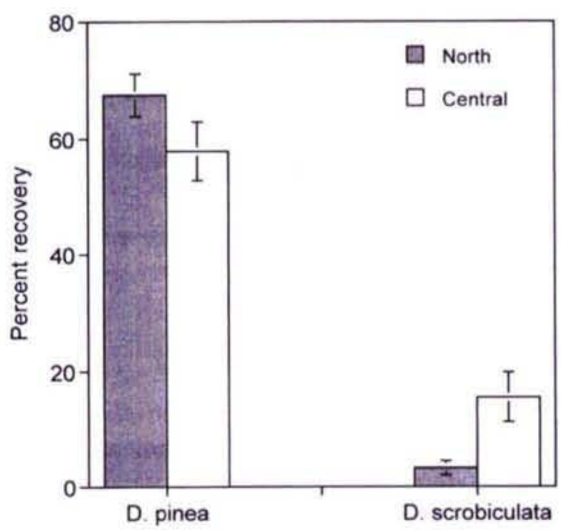


Figure 1. Comparison of the recovery of *D. pinea* and *D. scrobiculata* from infected red pine cones on 92 sites in either the northern or central floristic region. Two-sample t-test was used; for *D. pinea*, $p = 0.405$ and for *D. scrobiculata*, $p = 0.011$.

Blighted red pine seedlings were found in 39 plantations. Only two plantations had blighted seedlings found beyond the fourth transect. The total number of seedlings in the first four transects ranged from 3 to 534 on each site; the average was 89.9 seedlings per site. The incidence of shoot blight, tallied in the first four transects of each plantation, ranged from 0.2% to 35.0%. The average incidence of shoot blight was 5.0% of the seedlings. Map 9 shows the distribution and average incidence of shoot blight seedlings found in the first four transects of the plantations.

Red pine seedlings were present in the understory on 48 sites and no seedlings were present on 44 sites. See Figure 2. Where understory seedlings were present, only 17 sites had blighted seedlings. Where seedlings were found, the number of seedlings ranged from 1 to 407 seedlings per site; the average was 31.4 seedlings per site. Blighted seedlings were found on 17 sites and the incidence of shoot blight ranged from 4.0% to 100% of the seedlings; the average incidence of shoot blight was 36.4 % of the seedlings. Map 10 shows the distribution and incidence of *Diplodia* infection in seedlings found in the understory on each site.

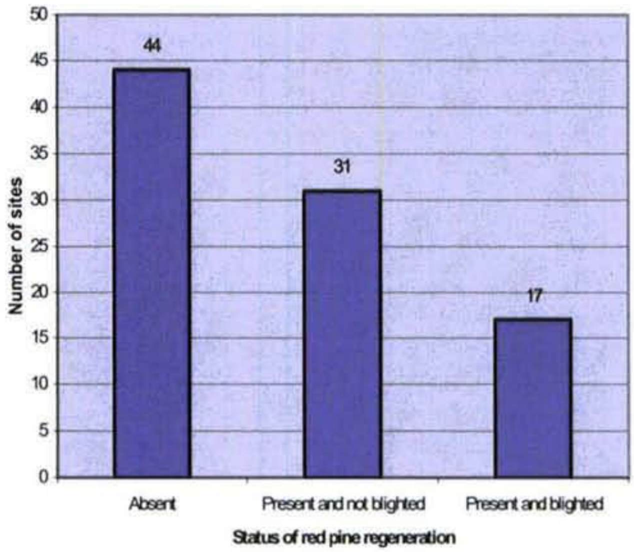


Figure 2. Occurrence of red pine regeneration and presence of shoot blight in understories.

Jack pines

On jack pine sites, the incidence of *Diplodia* infections in 2004 can be described by cone infections found on 28 sites. On 28 of the 28 sites, *Diplodia* fruiting bodies were found on cones collected from mid-crown branches of overstory trees. The number of cones that were infected on each site ranged from 1.9 to 41.0; the average number of infected cones was 12.3 per site. Map 11 shows the distribution and incidence of *Diplodia* infection on jack pine cones from each site. From infected cones collected on these sites, *Diplodia* species were recovered in lab assays (Smith and Stanosz, 1995). The average percent recovery of *Diplodia pinea* was 20.8%. Map 12 shows the distribution and percent recovery of *Diplodia pinea*. The average percent recovery of *D. scrobiculata* was 75.9%. Map 13 shows the distribution and recovery of *Diplodia scrobiculata*. Lab assays showed *Diplodia pinea* alone caused cone infections on 1 site, *Diplodia scrobiculata* alone caused infection on nine sites, both species caused infection on 17 sites and neither species was recovered from infected cones on one site. See Map 14.

Objective 2: Develop a technique to evaluate disease potential in red pine.

Incidence and severity of Diplodia shoot blight in understory and plantation seedlings

Diplodia infections caused shoot blight in red pine seedlings found in understories and plantation transects. In 2004, shoot blight was found in 41 of 92 plantations, and the average incidence of *Diplodia* shoot blight was determined. See Figure 3. The incidence of shoot blight in seedlings in the understory and first transect were not significantly different than each other but were significantly different than transect 2. The amount of shoot blight present in the remaining four transects was not significantly different from each other but were significantly different than the understory and the first two transects. The distance from the overstory edge to the furthest tallied occurrence of shoot blight ranged from 10 to 262 feet and averaged 63 feet.

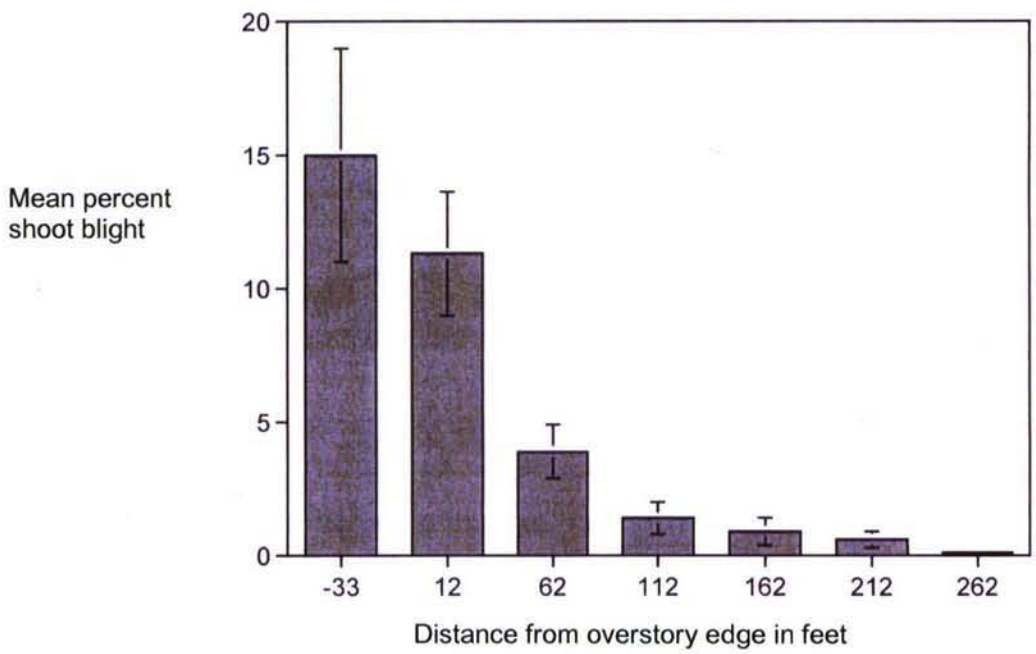


Figure 3. Percent *Diplodia* blighted seedlings found on 41 sites where the understory and/or the plantation had blighted seedlings. Overstory edge is at 0 feet. General linear model was used; $F = 8.609$ and $p= 0.0000$.

The incidence of dead seedlings was tallied in the understory and in each of the transects. Mortality in the understory ranged from 0 to 100% and averaged 5.2%. Mortality in transect 1, along the edge of the overstory, ranged from 0 to 34.7% of the seedlings and averaged 5.7%. Mortality in the first four transects ranged from 0 to 40% of the seedlings and averaged 7.6 %.

The presence of interior and edge trees was documented on 36 of the 92 sites. On 40% of the 36 sites, blighted seedlings were found along transects in close proximity to interior or edge trees. On the remaining sites, no infections were found in the plantation so the impact of interior and edge trees could not be assessed.

Subcanopies were present on 56 sites. See Table 3.

Table 3. **Density and composition of subcanopies found under red pine overstories.**			
Density		Composition	
Density rating	Number of sites	Species	Frequency of species occurring in subcanopy, %
No canopy	38	Balsam fir	31
Low	26	Oak species	20
Medium	25	Paper birch	13
High	11	White spruce	13
		Aspen	11
		Maple species	4
		White pine	4
		Red pine	2

Neither the total number of understory seedlings nor the incidence of blighted understory seedlings was significantly different on sites with or without subcanopies. See Table 4. On the sites in this study, there doesn't seem to be evidence that a subcanopy can reduce the number of red pine seedlings or reduce the amount of shoot blight in the understory.

Table 4. **Presence of red pine regeneration and incidence of shoot blight in red pine understories with and without a subcanopy.**			
	With subcanopy present (n=56)	Without a subcanopy (n=36)	Probability
Average number of seedlings/ saplings	18.8	12.4	0.537
Average percent shoot blight	5.4	8.9	0.399

In 2005, seven sites were revisited and shoot blight incidence was determined. The incidence of *Diplodia* shoot blight was much greater in 2005 compared to its incidence in the same plantations in 2004. See Figure 4. Average infection in 2005 in the understory and individual transects was seven times greater than averages found in 2004 in the same locations. In 2005, the distance to the furthest infected seedling ranged from 50 to 262 feet and averaged 141 feet. In comparison, 2004 was a "modest" year for shoot blight expression compared to 2005.

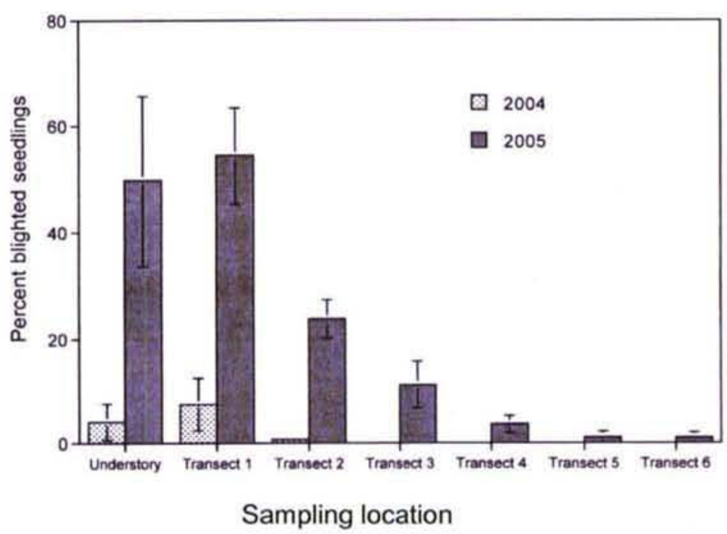


Figure 4. Comparison of the incidence of *Diplodia* shoot blight on 7 sites in 2004 to the incidence of shoot blight on the same sites in 2005. General linear model was used; $F = 6.764$ and $p = 0.000$.

Classification and Regression Tree Analysis (CART) is commonly used to detect statistically significant relationships between variables and create decision trees. Analyses did not find environmental, ecological or geographic variables to influence the infection of the cones and understory or plantation seedlings. Using CART analysis of all variables, we found five site variables that best described the success or failure of artificial regeneration in adjacent plantations and natural regeneration in the understory. The five site variables are:

- Percent of cones infected by *Diplodia*,
- Total number of seedlings in the understory,
- Percent infected seedlings in the understory,
- Percent infected seedlings in the first transect (along the edge of the overstory),
- Percent dead seedlings in the first transect.

CART associations found in this study can be used to infer shoot blight incidence on other red pine sites if the sites have similar population metrics to those in this study. See Table 5.

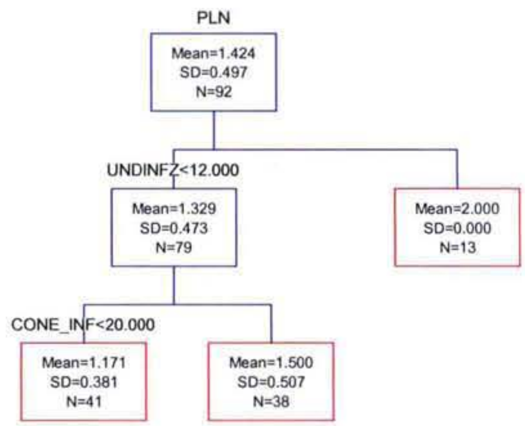
Table 5. **Population metrics for the 92 sites evaluated in this study.**

Description	Mean (SE of mean) Min. – Max.	Variable name in CART graphics
Percent of cones infected by *Diplodia*.	25.0 (2.1) 0 - 84	Cone_inf
Total number of seedlings and saplings in the understory.	16.4 (5.8) 0 - 407	Totnumbund
Percent of blighted seedlings in the understory.	6.7 (1.9) 0 - 100	Undinfz
Percent of dead seedlings in the understory.	5.2 (1.7) 0 - 100	Zdeadund
Percent of dead seedlings in transect 1 of the plantation, 12 feet from the overstory edge.	5.1 (1.2) 0 - 60	Trans 1
Percent of dead seedlings in transect 1.	5.7 (0.7) 0 - 35	Zdeadtrans
Percent of blighted seedlings in the first four transects of the plantation.	2.1 (0.5) 0 - 35	Plninfz
Number of feet from overstory edge that the furthest blighted seedling was found in a plantation.	62.6 (8.9) 10 - 262	Distance

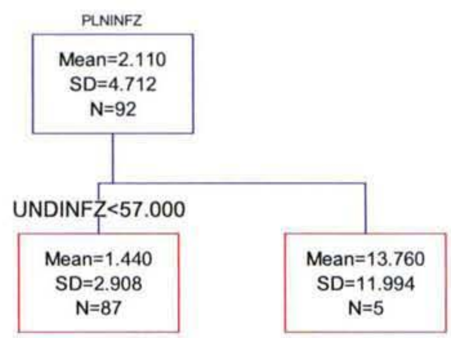
Artificial regeneration in plantations

From site information derived from all 92 sites, CART analysis found that four site variables can indicate the absence of *Diplodia* infection or the incidence of seedling infection in plantations. Similarly, three site variables can be used to predict the average furthest distance that symptomatic seedlings can be found from the overstory edge.

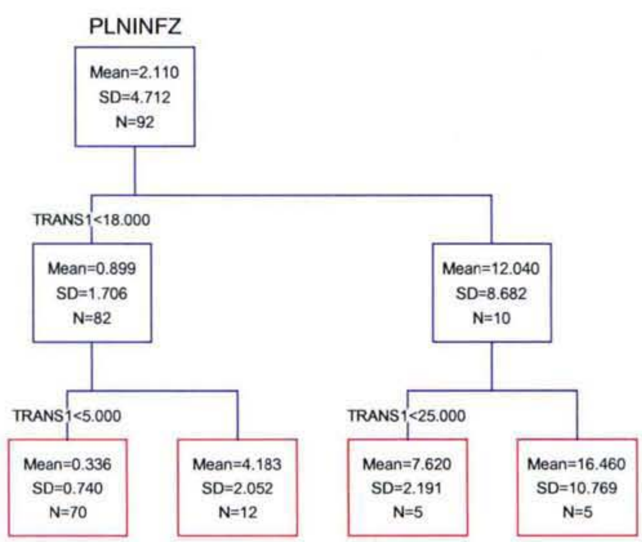
Two variables can be used to predict whether or not an existing or proposed plantation (pln) will have blighted seedlings due the proximity of an overstory. Using the percent of seedlings that are blighted in the understory (undinfz) and the percent of cones that are infected (cone inf), it is likely that the plantation will be either blighted (mean = 2.0) or not blighted (mean = 1.0). For example, if the understory infection is greater than 12 %, then it is very likely that the adjacent plantation will be infected.



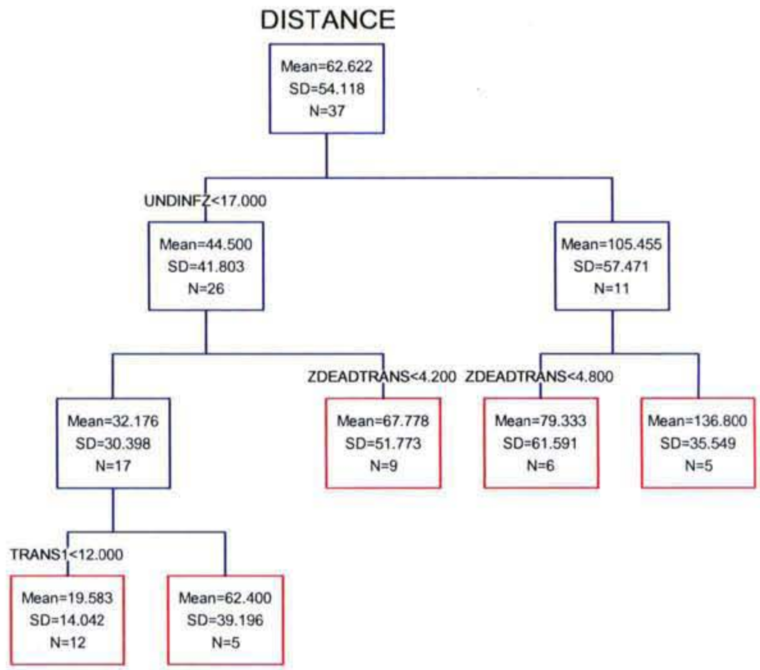
The percentage of symptomatic seedlings in the understory is an indicator of the percentage of blighted seedlings in plantation seedlings (plninfz). Plninfz describes the percent of blighted seedlings found in the first four transects of a plantation. The population can be split into two groups by using the percent infection of understory seedlings (undinfz). When the understory infection is less than 57%, then the mean infection of the plantation is 1.4%. When the understory infection is greater than or equal to 57%, then the mean infection of the plantation is 13.7%.



When understory seedlings are absent but blighted seedlings can be found along the edge of the overstory (trans1), the percent shoot blight in the plantation (plninfz) can be anticipated. For example, if the percentage of blighted seedlings along the edge of the overstory (trans 1) is more than 18 % but less than 25%, the mean shoot blight expected in that plantation would be 7.6 %.



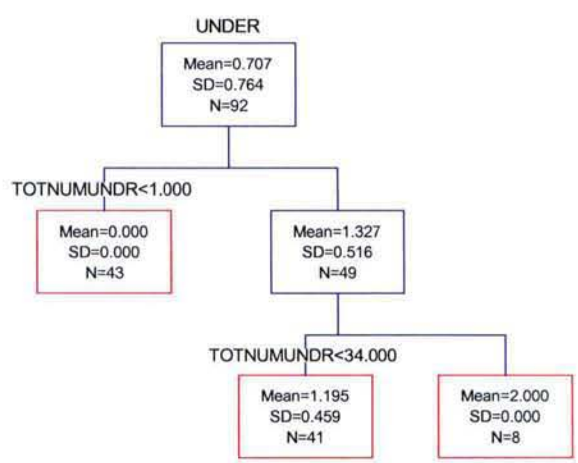
The furthest distance into a plantation that blighted seedlings can be found in existing or proposed plantations can be described by three variables; percent of blighted seedlings in the understory (undinfz), percent of dead seedlings along the overstory edge (zdeadtrans), and, percent of blighted seedlings along the edge of the overstory (trans1). The distances have been split into five groups representing five mean distances from the overstory edge; distances range 19 feet to 136 feet. For example, the average distance of 136 feet is indicated when there are more than 17 % blighted seedlings in the understory and more than 4.8 % dead seedlings along the overstory edge.



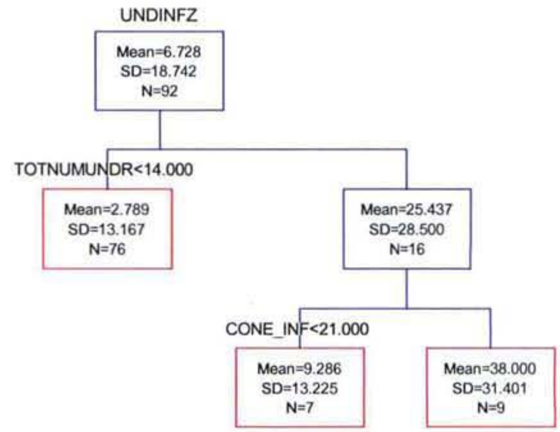
Natural regeneration in the understory

In this study, red pine seedlings and saplings were present in the understory on 48 of 92 sites and regeneration was absent on the remaining 44 sites. Where understory seedlings were present, only 17 sites had blighted seedlings. From site information derived from all 92 sites, CART analysis found that three site variables can be used to indicate the absence of *Diplodia* shoot blight or the incidence of shoot blight in understory seedlings.

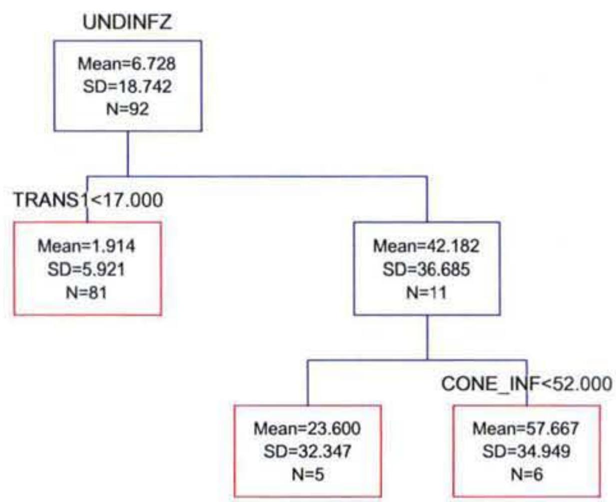
To determine whether the understory will be absent, present and not blighted or present and blighted, a simple tally of the total number of seedlings in the understory can be used to predict all three situations. Mean = 0 indicates that the understory is absent; mean = 1 indicates that the understory is present and not blighted; and, mean = 2 indicates that the understory is present and blighted. For example, infected seedlings are associated with sites when the total number of understory seedlings is 34 or greater.



Where red pine seedlings are present in the understory, a tally of the total number of red pine seedlings and the incidence of cone infection indicate the amount of blighted seedlings that could be found in the understory (undinfz). For example, a high level of understory shoot blight is associated with the presence of more than 14 seedlings in the understory and more than 21% of the cones being infected by *Diplodia*.



Even when the understory is absent, the amount of shoot blight in the understory can be anticipated. If cones and seedlings along the overstory edge can be found, a site may be categorized as having one of three levels of shoot blight in the understory. For example, if more than 17% of the seedlings along the edge of the overstory are blighted and cone infection is more than 52%, then the average infection in the understory would be catergorized as high.



Objective 3. Develop guidelines for artificial and natural regeneration of red pines under or adjacent to overstory red pines.

Artificial regeneration in plantations

The distance that *Diplodia* inoculum can spread in nurseries to form shoot blight infections was documented in Minnesota (Palmer et al, 1988). In two years of study, the researchers found that the furthest distance that symptomatic infections could be found from the red pine inoculum source was 600 feet and 1000 feet, depending on the amount of rainfall and wind during the growing season. The maximum distance that *Diplodia* inoculum can spread into red pine plantations is not known. However, it would be reasonable to assume that there would be very few symptomatic *Diplodia* infections found in a plantation if mature red pine trees were more than 600 feet away from that plantation. In other words, mature red pine stands more 600 feet away from the plantation would not be considered as sources of inoculum. Where other mature stands of trees impede the dispersal of inoculum because of stand height and width, it would be reasonable to assume very few symptomatic infections would be found in a red pine plantation even if the red pine trees were less than 600 feet away.

When establishing new red pine plantations, the presence and proximity of inoculum sources must be considered.

- If red pine stands are more than 600 feet away or if they are within 600 feet but inoculum spread is blocked by other stands of trees, then it's unlikely that the seedlings will be blighted. New red pine plantations can be established without further consideration of *Diplodia* shoot blight.

- If a red pine stand is adjacent to the proposed plantation or is within 600 feet and inoculum may spread directly into the plantation, then it's likely that symptomatic *Diplodia* infections would be acquired by the plantation seedlings. In these situations, *Diplodia* shoot blight potential should be considered prior to establishing the plantation. Otherwise, the proximity of *Diplodia* inoculum may interfere with the successful establishment of a well-stocked red pine plantation along plantation edges where red pine overstories are located.

- If there are mature red pine trees along the edge of the plantation or inside the plantation, inoculum may spread directly down onto the planted seedlings and cause shoot blight. This study did not focus on the potential impact from these residual trees, but did find shoot blight in seedling along several transects that was caused by the interior trees. We recommend that the only situation where red pine plantations should be established is where there are very few residual red pines and they are clumped together near the plantation edge. Otherwise, the abundance and proximity of *Diplodia* inoculum may interfere with the successful establishment of a well-stocked red pine plantation.

Based on data from 2004, the shoot blight potential of proposed or existing plantations can be evaluated by determining four site variables and their conditions. See Table 6. For each plantation condition, a suggested action is recommended.

Table 6. **Steps for evaluating *Diplodia*'s shoot blight potential in proposed or existing red pine plantations.**

Situation / determine	**Variables to consider**	**Conditions**	**Suggested action**
Step 1. Determine if seedlings in the plantation are likely to become blighted by Diplodia based on source of inoculum and site characteristics.			
Residual red pines are located inside the plantation or are scattered along the plantation edge.	Location, number and distribution of residual trees.	There are very few residual red pines and they are clumped together near or on the plantation edge. Shoot blight potential is moderate.	The only situation where red pine plantations should be established when residual trees are present. Buffer* the trees, as described below.

<table>
<tr><td></td><td></td><td>Many residuals are present and they are well distributed.

Shoot blight potential is very high.</td><td>The presence and proximity of Diplodia inoculum may interfere with the successful establishment of a red pine plantation.

Plant alternate (non-host) species or remove residuals.</td></tr>
<tr><td rowspan="2">An adjacent red pine overstory is present along one or more edges of the plantation.</td><td rowspan="2">Percent of blighted seedlings in the understory.

Percent of cones infected.

When understory is absent, use percent of blighted seedlings along the overstory edge.</td><td>Plantation edges are unlikely to be blighted if:

Understory blight is <12% and cone infection is <20%.

When understory is absent, percent of blight is <5% along the overstory edge.

Shoot blight potential is low.</td><td>Establish plantation without regard to buffering overstory.</td></tr>
<tr><td>Otherwise, plantation edges are likely to have blighted seedlings.

Shoot blight potential is moderate to high.</td><td>Establish plantation with buffers along edges of overstories. See below to determine buffer width.</td></tr>
<tr><td colspan="4">Step 2. Determine how severe shoot blight could be in the plantation near the overstory edges.</td></tr>
<tr><td rowspan="2">Determine shoot blight potential and necessity for buffer.</td><td rowspan="2">Percent of blighted seedlings in the understory.

If understory absent, use percent blighted seedlings along the overstory edge.</td><td>If understory blight is < 57%, then blight level in plantation will be low.

If understory absent and blighted seedlings <18%, then blight level in plantation will be low.

Shoot blight potential is low.</td><td>Establish plantation without regard to buffering overstory.</td></tr>
<tr><td>Otherwise, it is very likely that seedlings will become blighted.

Shoot blight potential is moderate to high.</td><td>Establish plantation with buffers along edge of overstory and around interior and edge trees. See below to determine buffer width.</td></tr>
<tr><td colspan="4">Step 3. Determine how far away from the overstory that red pine seedlings can be planted so that they have minimal impact from Diplodia shoot blight.</td></tr>
</table>

Determine buffer width.	Percent of blighted understory seedlings. Percent dead seedlings along the overstory edge. Percent infected seedlings along the overstory edge	If understory blight < 17%, the percent of dead seedlings along the stand edge is >4.2 and the percent blighted seedlings along the stand edge is <12%, the buffer width should be 20 feet.	Creation of a buffer would not be necessary adjacent to the overstory.
		If understory blight < 17% and the percent of dead seedlings along the stand edge is <4.2 , the buffer width should be 67 feet.	Create a 1 chain buffer along the overstory edge. In the buffer, plant alternate species or encourage natural regeneration of non-pine species.
		If understory infection > 17% and the percent of dead seedlings along the overstory edge is > 4.8, then the buffer width should be 136 feet.	Create a 2.5 chain buffer along the overstory edge. In the buffer, plant alternate species or encourage natural regeneration of non-pine species.
Step 4. Determine if planting red pine seedlings on this location should be avoided due to the severity of shoot blight and the shape of the plantation.			
Location of red pine overstories relative to the buffer width	Shape of plantation Buffer width	Shape of plantation is narrow or sinuous (Example: if plantation is less than 5 chains wide and buffer width needed is 2.5 chains.)	The presence and proximity of *Diplodia* inoculum will likely interfere with the successful establishment of a red pine plantation. Plant alternate (non-host) species.

* = A buffer is a narrow strip of the plantation that separates the adjacent overstory from the rest of the plantation.

Natural regeneration of red pine under red pine overstories

Ostry et al (2002) suggested that forest managers avoid attempts to regenerate red pine seedlings under a red pine overstory where *Diplodia* inoculum is present. In this study, we found that *Diplodia* inoculum was present in cones on 89 of the 92 sites, yet, red pine regeneration was present on 48 of the 92 sites. On 31 of those sites, the seedlings were not blighted. The fact that 31 sites had non-blighted regeneration indicates the possibility that there might be some conditions, like very low inoculum levels or an environment not conducive to disease expression, that would allow regeneration survival.

The surest strategy to establish red pine seedlings is to attempt regeneration only on sites that lack *Diplodia* inoculum in the overstory. In this study, only 3 of 92 sites lacked *Diplodia* inoculum in collected cones. Another strategy would be to attempt regeneration where cone inoculum levels are extremely low. On eleven sites in this study, where incidence of infected cones was from 0 to 3 %, an average of 1.4% of the seedlings were blighted in the understory and no blighted seedlings were found in adjacent plantations. See Figure 5 and Map 15.

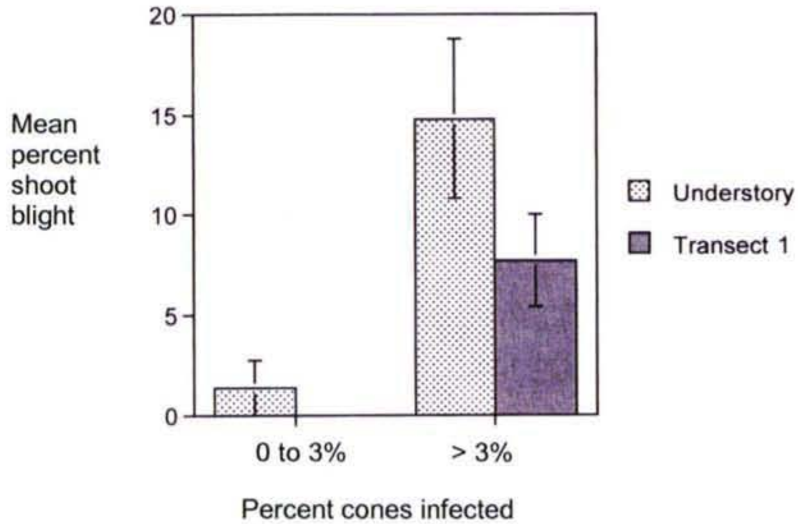


Figure 5 On 48 sites where understory seedlings were present, the incidence of shoot blight in the understory and transect 1 is compared to the incidence of cone infection in those locations. Where 0 to 3% of the cones are infected, mean shoot blight is 1.4% in the understory and is 0.0% in transect 1. Two-sample t-test was used.; p = .003.

When counting on natural regeneration to establish a two-storied red pine stand, the overstory's shoot blight potential should always be evaluated. Based on the 2004 data, the shoot blight potential can be evaluated by determining three site variables. See Table 7. For each overstory condition, a suggested action is recommended.

Table 7. **Steps for evaluating *Diplodia*'s shoot blight potential in red pine seedlings growing under a mature, red pine overstory.**

Status of regeneration	Variables to consider	Conditions	Suggested action
Step 1. Determine presence and shoot blight status of existing red pine regeneration, if any.			
	Presence of seedlings Occurrence of shoot blight on understory seedlings	All seedlings are non-blighted, or, Some seedlings are blighted, or, Seedlings are absent.	Step 2.
Step 2. Determine if red pine regeneration is likely to become blighted by Diplodia based on site characteristics.			
If only non-blighted red pine seedlings/ saplings can be found in the understory.	Percent of cones infected	If cone infection is < 3%, shoot blight potential is low.	Take action only if number of seedlings/ saplings is insufficient according to silvicultural guidelines for the site.
		If cone infection is > 3%, shoot blight potential is moderate.	Take action only if number of seedlings/ saplings is insufficient according to silvicultural guidelines for the site. Periodic waves of high infection or chronic low infection may take its toll on the regeneration.

Some blighted red pine seedlings can be found in the understory.	Incidence of blighted seedlings. Or Total number of seedlings in the understory.	If blighted seedlings < 5%, then shoot blight potential is considered to be moderate. Or If the total number of seedlings is > 14 and percent of cone infected is <21%, then the regeneration is likely to be blighted.	Non-blighted red pine regeneration exists in understory but is likely to suffer periodic losses due to the presence of latent *Diplodia* infections. This site is not likely to produce regeneration that will grow into pole-sized trees.
		If blighted seedlings > 5%, then disease potential is considered to be high. Or If the total number of seedlings is > 14 and percent of cone infected is > 21%, then the regeneration is very likely to be blighted.	Do not count on natural red pine regeneration on this site. Do no further work to attempt red pine regeneration on this site. Periodic waves of high infection or chronic low infection will take its toll on the any existing regeneration.
Red pine seedlings are absent from the understory.	Percent of blighted seedlings found along the overstory edge.	If the percent of blighted seedlings along the overstory edge is <17%, then shoot blight potential is low.	Other site conditions are precluding regeneration. Increase light, decrease shrub competition and/or decrease depth of duff to increase regeneration counts over time. If natural or artificial regeneration is attempted, be aware that periodic waves of high infection or latent infections may take its toll on the regeneration.
		If the percent of blighted seedlings along the overstory edge is > 17%, then shoot blight potential is high.	*Diplodia* is likely to be the causing the lack of red pine regeneration. Do no further work to attempt red pine regeneration on this site.

Discussion

Diplodia pinea is thought to be an invasive, aggressive species that is not native to the Lake States (Wingfield et al, 2001) and *Diplodia scrobiculata* is thought to be a jack pine pathogen that is native to the Lake States (Stanosz et al, 1999). On 89 of the 92 red pine sites in this study, *Diplodia* fruiting bodies were found on cones collected beneath overstory trees and the average occurrence of *Diplodia*-infected cones was 25.0%. See Table 8. *D. pinea* was recovered (Smith and Stanosz, 1999) from infected red pine cones on 93% of the sites across northern Minnesota and was average recovery from infected cones was 59.7%. *D.pinea* was recovered from infected red pine cones 7.6 times more frequently than the native species, *D.scrobiculata,* was recovered. These results indicate that *Diplodia pinea* has successfully invaded red pine stands across Minnesota and has established itself in the cones.

In the Chippewa Plains (CP) and Pine Moraines and Outwash Plains (PM) Subsections, where jack pine was historically abundant and still is currently abundant, *D.scrobiculata* was recovered two times more frequently from red pine cones than it from red pine cones was collected elsewhere in the state.

Jack pine cones were only collected in the Chippewa Plains and Pine Moraines and Outwash Plains Subsections where the average incidence of infection by *Diplodia* species was 12.3%. See Table 8. *D.scrobiculata* was recovered from infected cones on 100% of the sites while *D.pinea* was recovered from infected cones on 64% of the sites. *D.scrobiculata* was recovered from 75.9% of the infected jack pine cones and *D.pinea* was recovered from 20.8% of them. *D. pinea* has invaded two thirds of the jack pine sites that were studied but has a lower cone occupancy level than *D. scrobiculata*.

Table 8. **Average incidence and recovery of *Diplodia* spp. on red and jack pine cones found statewide, and, in the Chippewa Plains (CP) and Pine Moraines and Outwash Plains (PM) Subsections.**

	Average incidence of infected cones found on each site	Average recovery of *Diplodia* species from ten infected cones per site		Number of sites where *Diplodia* species were recovered from infected cones	
	Diplodia spp.	*D. pinea*	*D.scrobiculata*	*D. pinea*	*D.scrobiculata*
Red pine cones					
All Subsections	25.0 %	59.7 %	7.8 %	86/92 sites	26/ 92 sites
CP and PM Subsections	25.7 %	56.2 %	15.9 %	33 /34 sites	14 /33 sites
Jack pine cones					
CP and PM Subsections	12.3 %	20.8 %	75.9 %	18/28 sites	28/ 28 sites

Diplodia pinea is a latent pathogen that is capable of causing symptomatic shoot blight infections and latent infections that can develop into shoot blight if activated by droughty conditions (Stanosz et al, 2001). In this study, only symptomatic shoot blight infections were used to assess the disease potential of the overstory. The incidence of latent infections was not assessed because of the scope of the study.

As expected, the amount of shoot blight was greater in seedlings growing directly below the overstory than it was in seedlings growing in the adjacent plantation. On 41 sites where blighted seedlings were found, the average incidence of shoot blight in the understories was 15.0 % and, in the adjacent plantations, was 4.7 %. The average furthest distance that blighted seedlings were found from the overstory edge was 62.6 feet. So, in plantations, the impact of *Diplodia* shoot blight usually occurs in a 63 foot - wide strip along the overstory edge where less than 5% of the seedlings are blighted. In contrast to plantations, the entire understory is affected by an infected overstory and the level of shoot blight is commonly three times greater. Based on these findings, we suggest that the impact of *Diplodia* shoot blight in plantations is minor compared to its impact in understories.

Either *D. pinea* alone or both *D. pinea* and *D. scrobiculata* were recovered from infected red pine cones on 86 sites. Where both *Diplodia* species were present, the percentages of shoot blight infection found in understories, along overstory edges and in plantations were significantly less than on sites where only *D. pinea* was recovered. See Figure 7. This effect does not appear to be caused by differences in the amount of *D.pinea* present in the cones since the total amount of infected cones on the two types of sites was not significantly different and the percentage of *D. pinea* recovered from infected cones were not significantly different. Looking at the same recovery data on the same sites from a geographical perspective showed that none of the shoot blight percentages were different in the CP or PM Subsections compared to the remainder of the area. It is intriguing to consider that the presence of *D. scrobiculata* in the cones might mitigate the impact of *D. pinea* shoot blight on red pine seedlings.

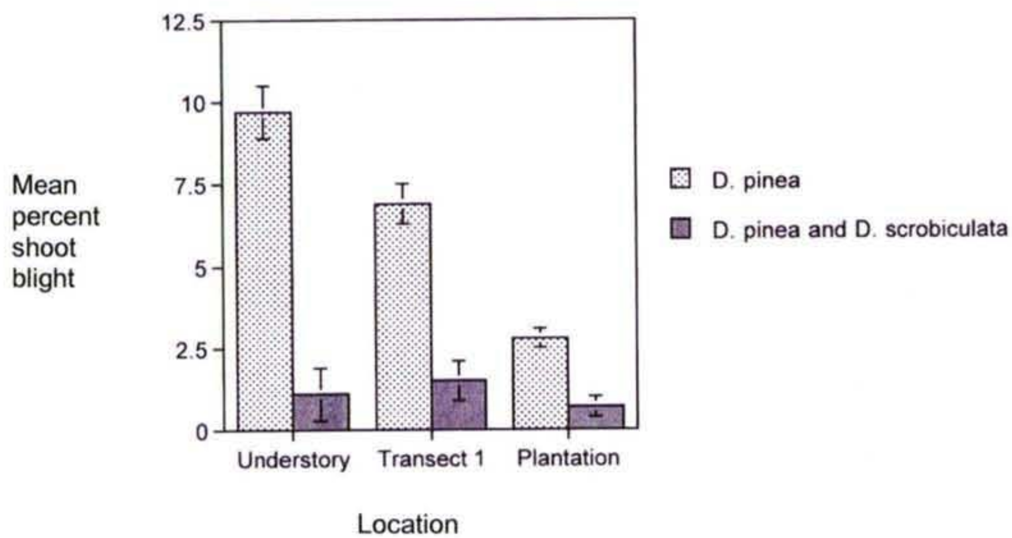


Figure 6. On 86 sites, *D. pinea* and/ or *D. scrobiculata* were recovered from infected cones. Shoot blight levels on 61 sites where *D. pinea* alone was recovered are compared to 25 sites where both *D. pinea* and *D. scrobiculata* were recovered. The comparisons are all significantly different. Two-sample t-tests were used; for understory $F = 33.34$ and $p = 0.0000$, for transect 1 $F = 16.70$ and $p = 0.0000$, and, for plantation $F = 13.99$ and $p = 0.0000$.

Analysis of site, ecological and geographical variables indicated that site variables can be used to classify the incidence of *Diplodia* shoot blight on red pine seedlings under or adjacent to a mature red pine stand. Five variables can predict the incidence of shoot blight on understory and plantation seedlings, even in the absence of understory or plantation seedlings. See Table 10. Site variables can predict the shoot blight potentials of other red pine stands when the population metrics are similar to those in this study. A forest manager can select sites for natural or artificial red pine regeneration based on the observed and anticipated incidence of *Diplodia* shoot blight on them.

Table 9. **Five site variables can be used to predict the incidence of shoot blight on red pine seedlings growing adjacent to or under a mature red pine overstory.**

Variable	Plantation	Understory
Percent of cones infected	X	
Percent of understory seedlings infected	X	X
Total number of seedlings in the understory		X
Percent blighted seedlings along the stand edge (in transect 1)	X	X
Percent dead seedlings along the stand edge	X	

When establishing new red pine plantations, the presence and proximity of inoculum sources should be considered.

- If mature red pine stands are more than 600 feet away, or, if they are within 600 feet but inoculum spread is blocked by other stands of trees, then it's unlikely that the seedlings will be blighted. New red pine plantations can be established without further consideration of *Diplodia* shoot blight.
- If a red pine stand is adjacent to the proposed plantation or it is within 600 feet and inoculum may spread directly onto the plantation, then it's likely that the seedlings will be blighted. If residual red pine trees exist on the proposed plantation site, then it's likely that the seedlings will be blighted.

In the last situation, *Diplodia*'s shoot blight potential should be considered prior to establishing new plantations.

Three variables, percent of infected understory seedlings, percent of dead seedlings along the overstory edge and presence of interior and edge trees, are sufficient to determine the shoot blight potential of a new plantation. See Table 6. On sites where shoot blight potential is low, artificial regeneration will succeed without the creation of buffer (area not planted to red pine) along the edge of a new plantation. On sites where shoot blight potential is moderate or high, a buffer along the edge of the new plantation should be created. Buffer width can be calculated and is based on the average furthest distance that blighted seedlings can be found from the overstory edge. The buffer strip may be planted with alternate species or left to regenerate aspen or other tree species on its own. Most red pine plantations in Minnesota have mature red pine stands along two or more edges and, if shoot blight potential is moderate or high, the proposed plantations would need buffers along all the overstory edges.

Plantations that are narrow or sinuous and surrounded by mature red pine stands may not be suitable for red pine regeneration if the shoot blight potential is high. For example, if the plantation width is less than five chains and buffers of 2.5 chains are recommended, the impact of Diplodia shoot blight is likely to interfere with plantation stocking. Similarly, the use of shelterwood cuts in existing red pine plantations are not likely to be successful unless the distances between groups of overstory trees is significantly more than twice the distance that blighted seedlings can be found from the overstory edge.

On sites where interior and edge trees are present, shoot blight potential will be a function of the number and location of the trees and the distance that inoculum can spread on that site. Based on data from 2004, the average furthest distance that blighted seedlings can be found from an inoculum source is 63 feet. Given this scenario, a single mature red pine tree will spread inoculum on 0.3 acres in the plantation. We recommend that the only situation where red pine plantations should be established is where there are very few residual red pines and they are clumped together near the plantation edge. Otherwise, the abundance and proximity of *Diplodia* inoculum may interfere with the establishment of a well-stocked red pine plantation.

The presence of infected overstory red pines limits the success of both artificial and natural regeneration (Palmer et al, 1988). Currently, trends toward uneven-aged management of red pine (Ostry et al, 1998) have renewed concerns over the impact of *Diplodia* on pine seedling vigor and survival. Ostry et al (2002) suggests that the surest way to establish red pine seedlings under a red pine overstory is to attempt regeneration only on sites that lack *Diplodia* inoculum in the overstory. In this study, only 3 of the 92 sites lacked *Diplodia* inoculum. Yet, red pine regeneration was present on 48 of the 92 sites and, on 31 of those sites, the seedlings were not blighted. The fact that 48 of the sites had viable regeneration indicates the possibility that there might be some conditions, like very low inoculum levels or an environment not conducive to infection, that allow the survival of red pine seedlings and saplings in the understory. Another possibility is that some of the seedlings were latently infected (Stanosz et al, 1997) and did not express disease symptoms because the environment was not conducive to disease activation.

As discussed earlier, the impact of *Diplodia pinea* was most pronounced on seedlings directly under a mature red pine overstory. When counting on natural regeneration to establish a two-storied red pine stand, we recommend evaluating the overstory's shoot blight potential. The shoot blight potential of a mature red pine stand can be evaluated by determining three variables, the percent of infected cones, the total number of seedlings in the understory and the percent of infected seedlings in the understory. If the understory is absent, the percent of infected seedlings found along the overstory edge can also be determined.

Most forest managers are willing to invest time and money on sites where understory establishment and survival are most reliable. Based on this study, we recommend that forest managers rely on regeneration in the understory in two, very limited, situations:

- Sites where non-blighted seedlings and saplings already exist and percent of cone infection is very low, from 0 to 3%. These sites would be most suitable for natural or artificial regeneration of red pine.
- Sites where non-blighted seedlings and saplings already exist and percent cone infection is relatively low, from 4 to 20%. These sites may also be suitable for red pine regeneration. However, periodic waves of high infection or chronic low infection may take its toll on the regeneration. Additionally, the presence of latent infections may increase the inoculum load in the regeneration and thus increase the likelihood of succumbing to the disease.

Palik and Zasada (2002) have proposed harvesting gaps of various sizes in red pine overstories in order to add age, species and vertical structure complexity to the stand. They hypothesize that shoot blight will be more prevalent in small canopy gaps and less prevalent in large canopy gaps. To relate this study to their hypothesis, consider defining a canopy gap as essentially a circular plantation surrounded by an adjacent overstory of red pines. The critical difference between a canopy gap and a plantation is that a canopy gap has inoculum spreading into its center from all directions. The incidence of shoot blight in the gap and the distance shoot blight will be found from the edge of the gap can be determined as if it was a plantation. For example, consider creating three canopy gaps with radii of 63 feet, 126 feet and 189 feet. Use a distance of 63 feet, the average distance that shoot blight spread into a plantation in 2004. See Figure 8. In the smallest gap, shoot blight can found all the way into the center of the gap, potentially causing losses in the entire gap. In the mid-sized gap, shoot blight can found 63 feet into the gap leaving 25% of the area with unaffected seedlings. In the large gap, shoot blight can found 63 feet into the gap from the edge leaving 44 % of the area with unaffected seedlings. As the gap size increases, more area in the center contains non-blighted seedlings.

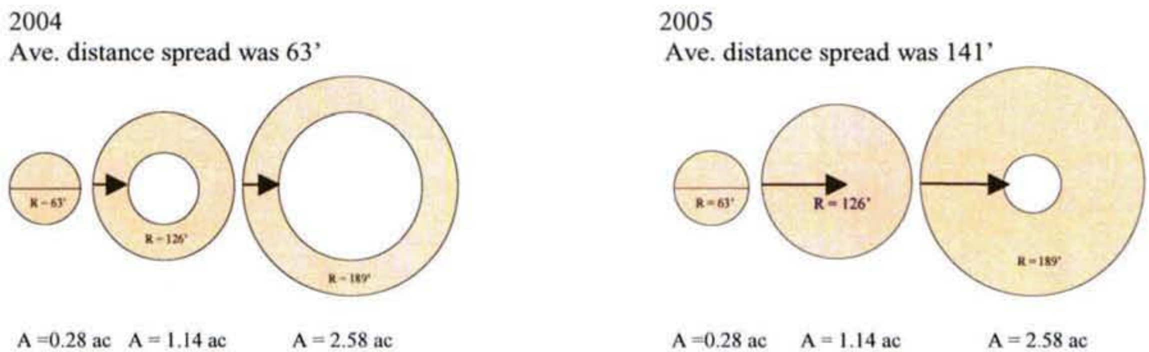


Figure 7. Circles represent canopy gaps. The distance that shoot blight could be found from the edge of the gap can be determined as if the gap was a plantation surrounded by an overstory stand.

However, 2004 was a very low year for shoot blight expression and spread compared to 2005. In 2005, the average distance shoot blight spread was 141 feet. Given that distance, shoot blight can be found all the way to the centers of the two smaller gaps and in the largest gap, only 6% of the area is free from shoot blight. So, during a low year for infection, like 2004, shoot blight will occur in 75 % of the 126' radius gap but would occur in100% of the gap during a high year for infection, like 2005. It seems that, unless gaps are much larger than an acre in size, *Diplodia* shoot blight could take a toll on the red pine seedlings growing inside the gaps over a period of a few years. The latest Manager's Handbook for Red Pine in the North Central Region (Gilmore and Palik, 2006) suggests that where *Diplodia* shoot blight is a concern, canopy gaps should be regenerated by planting jack or white pines, not red pines.

For the most part, this study contains data from a single growing season, so further study is needed to verify the relationships among the site variables and the predicted levels of shoot blight in order to make these management recommendations more statistically robust.

Future studies

The DNR Forest Health Unit and Resource Assessment Unit are interested in:

- Repeating measurements on a subset of these red pine sites in order to make the management recommendations more robust,
- Extending this type of survey work into additional areas that were not adequately covered in 2004, and,
- Investigating the level of latent infections in understory and plantation seedlings in order to determine their role in seedling survival.

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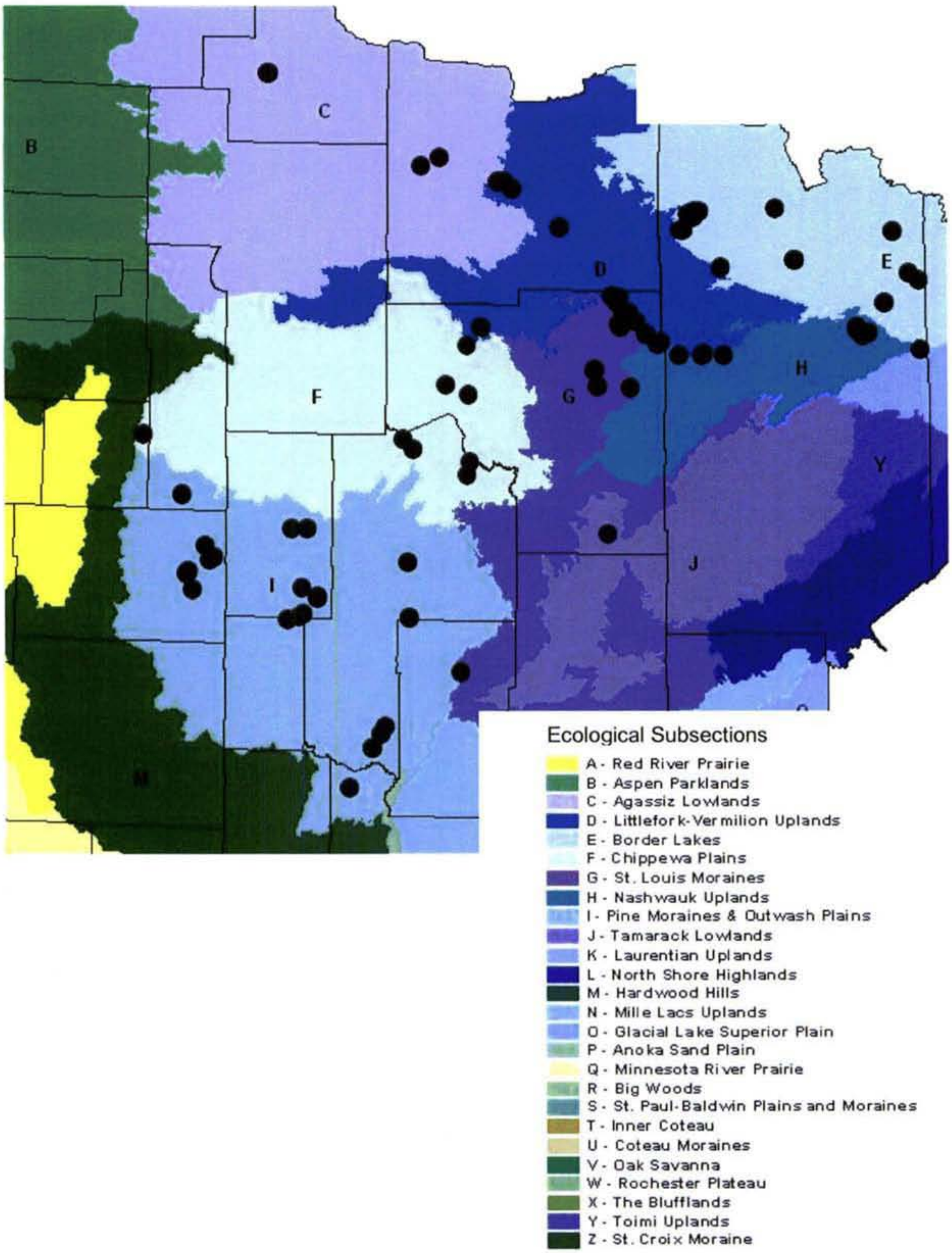
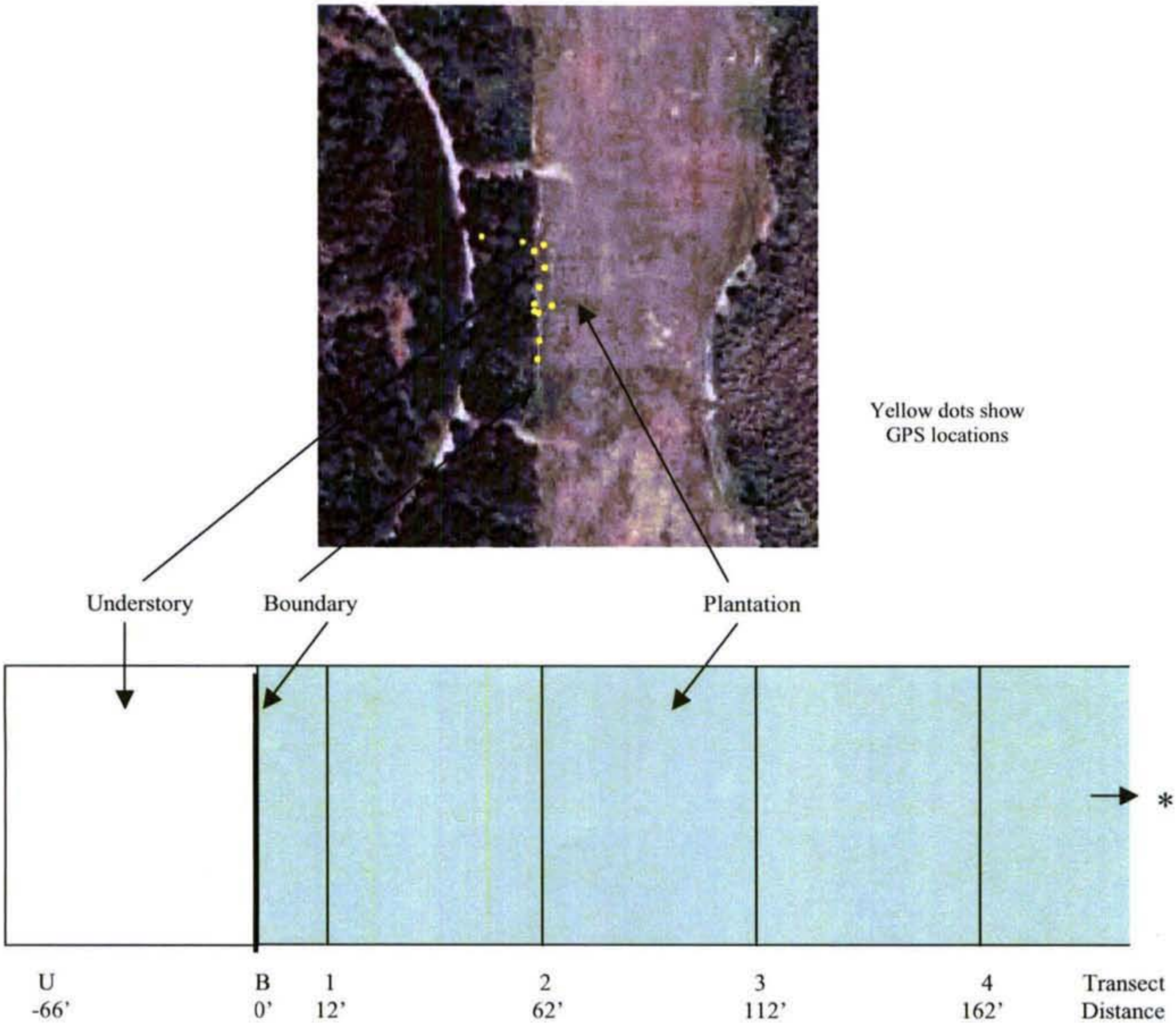
Appendix

Maps:

Map 1. Location of 92 red pine sites in eight Ecological Subsections in Minnesota.



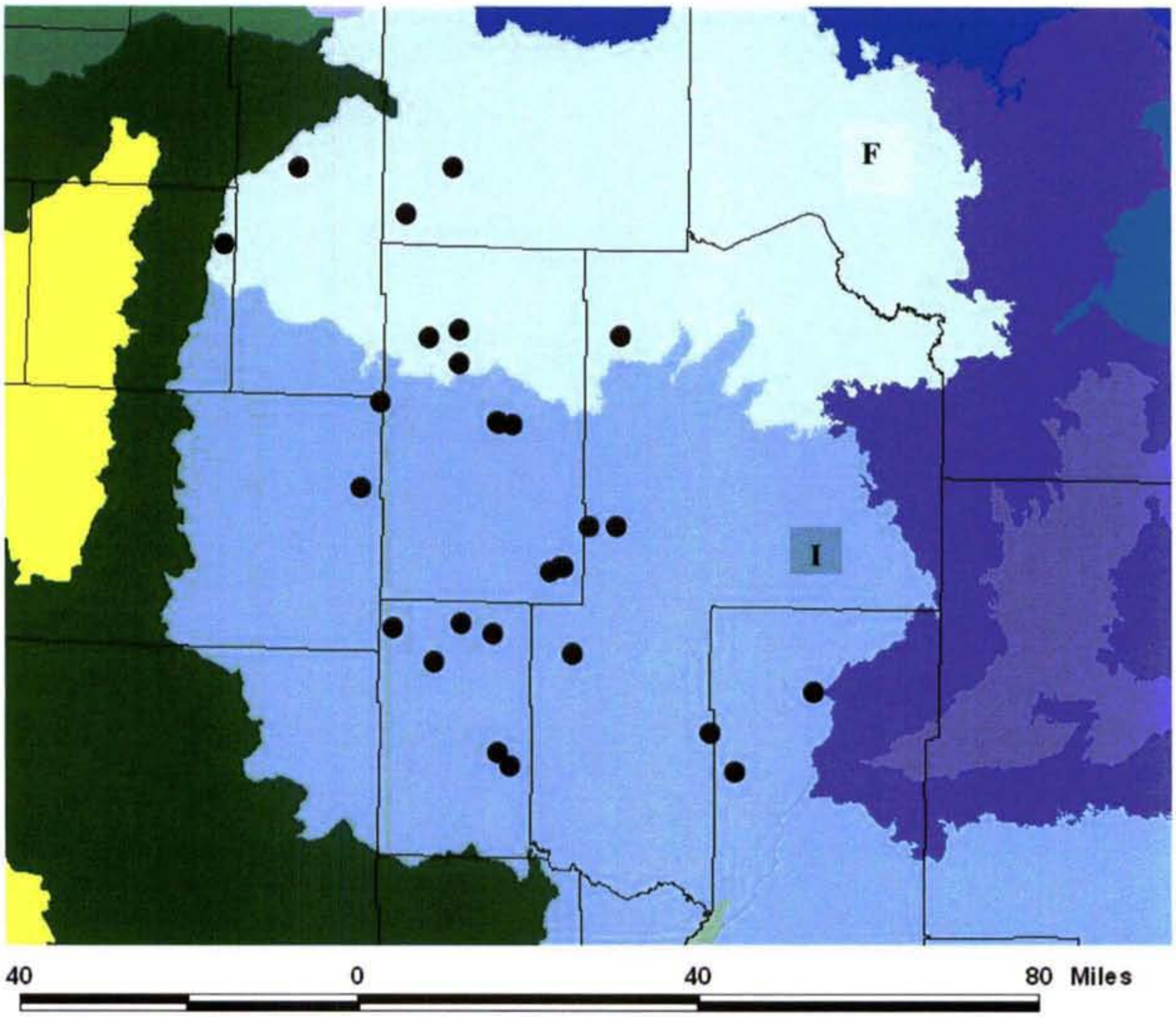
Map 2. Study site design and list of samples taken from red pine sites



* = Field crews continued creating transects in a plantation until they found two consecutive transects without blighted seedlings.

Samples and data collected from the understory and the plantation on red pine sites	
Data collected 4 GPS locations Subcanopy density and composition Seedlings (Non-blighted, blighted, dead) Saplings (Non-blighted, blighted, dead)	Data collected GPS locations of all blighted seedlings GPS locations of all interior and edge trees Number of seedlings (Non-blighted, blighted, dead) in each transect
Sampled 100 cones collected on the ground Blighted shoots from each blighted seedling or sapling	Sampled Blighted shoots from each blighted seedling

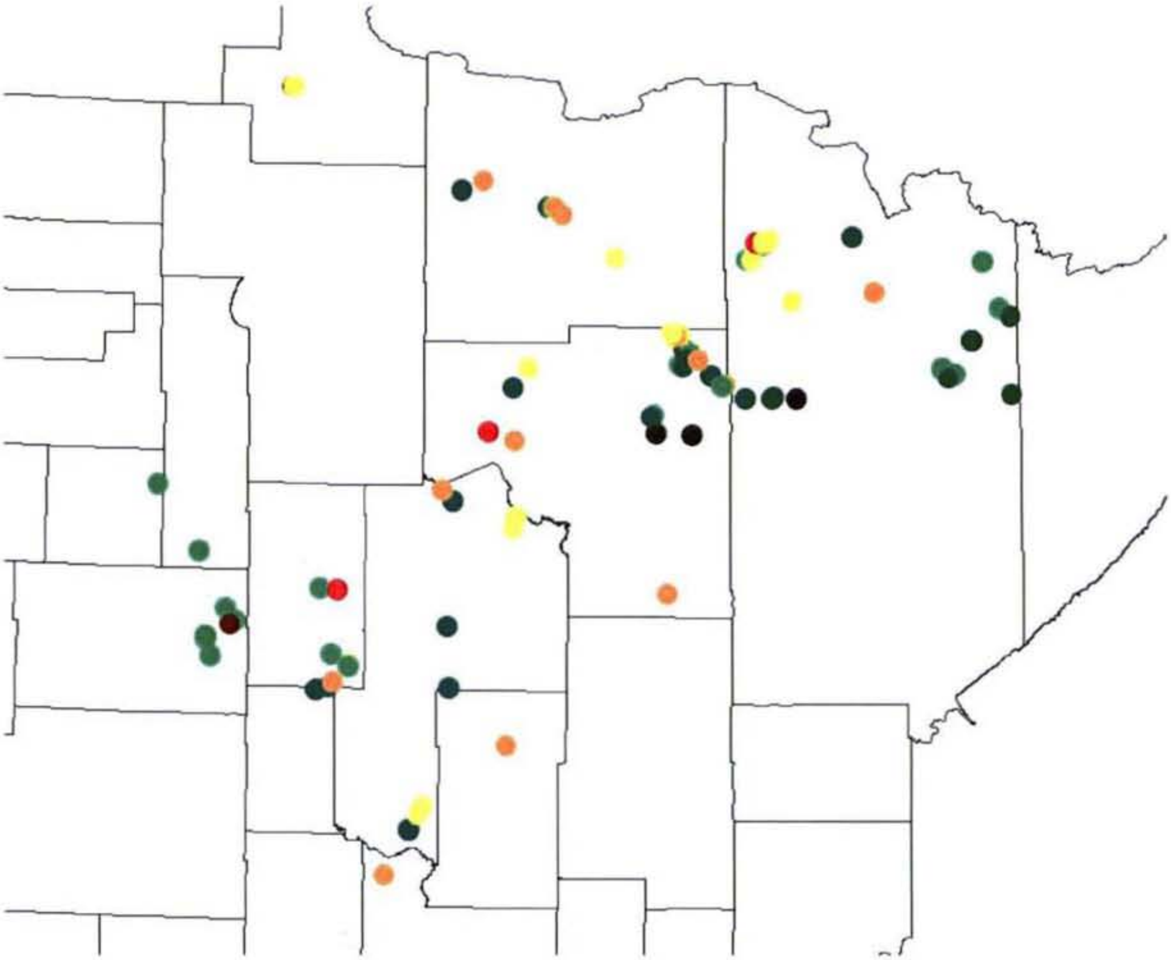
Map 3. Location of 28 jack pine sites in two Ecological Subsections.

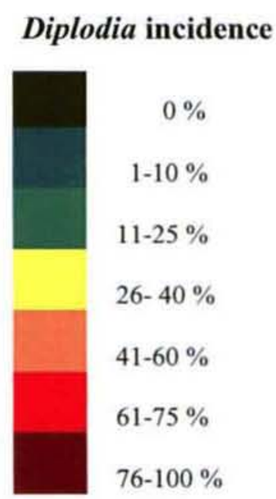


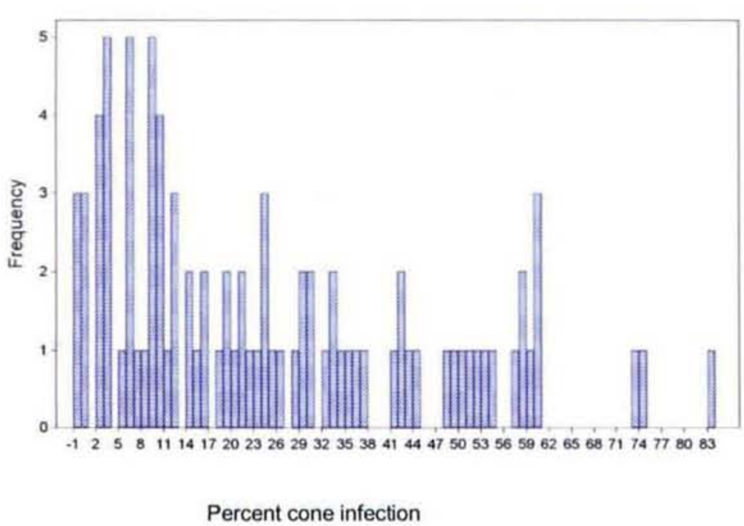
Ecological Subsections

F = Chippewa Plains
I = Pine Moraines and Outwash Plains

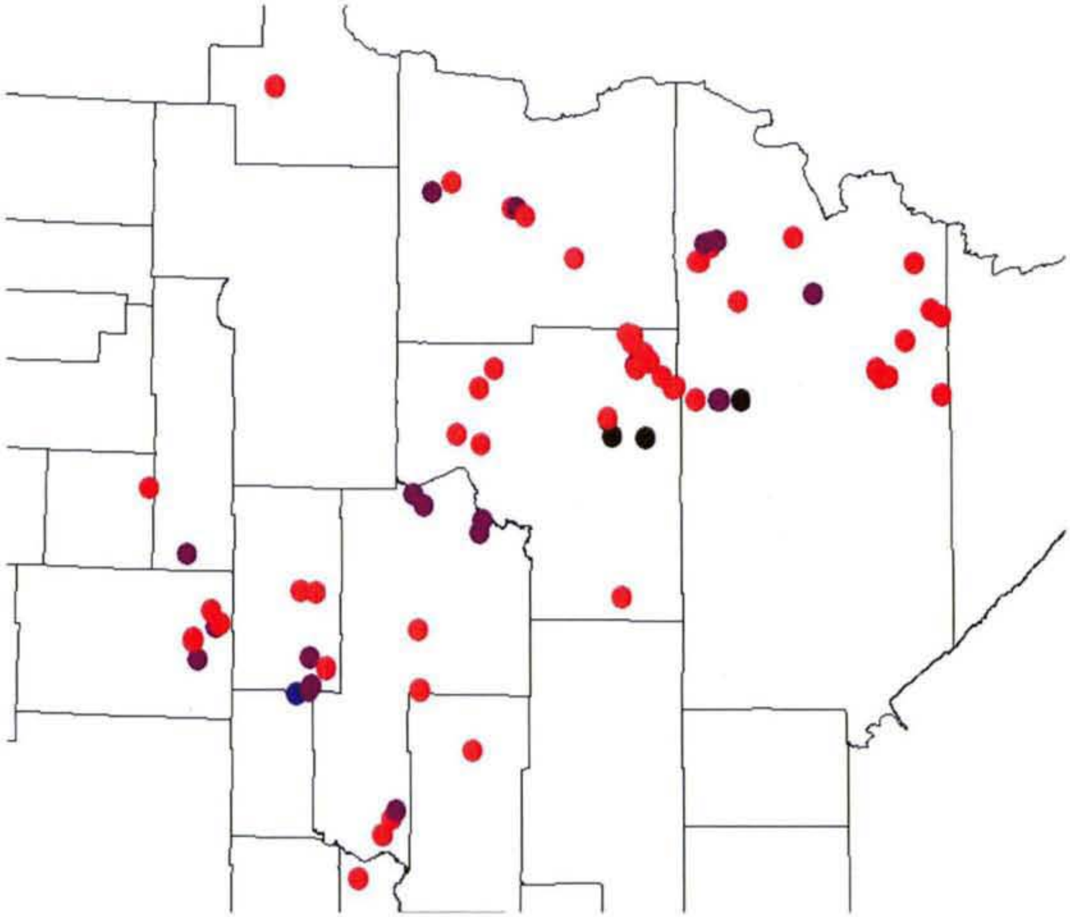
Map 4. Incidence of *Diplodia* species on 100 red pine cones per site.

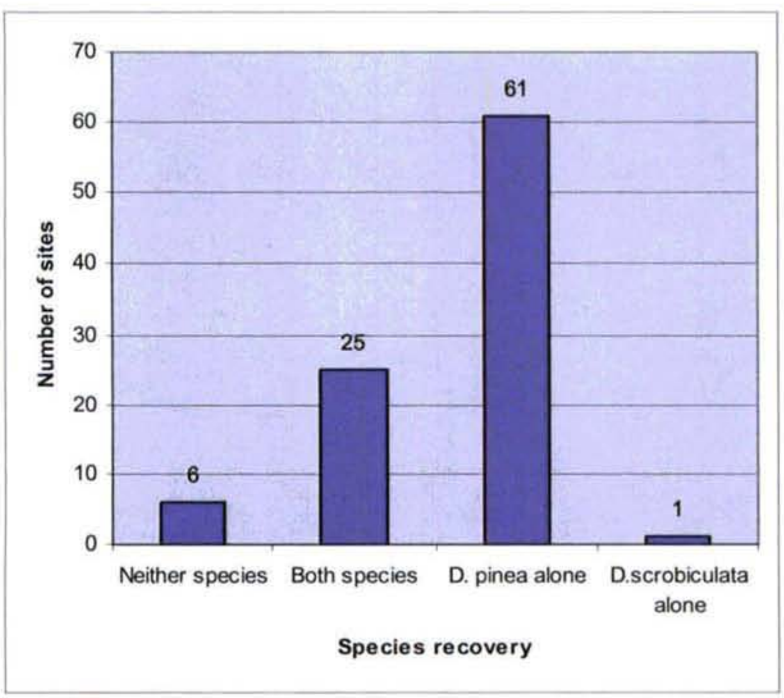






Map 5. Co- occurrence of *Diplodia* species based on recovery from 10 infected red pine cones per site.

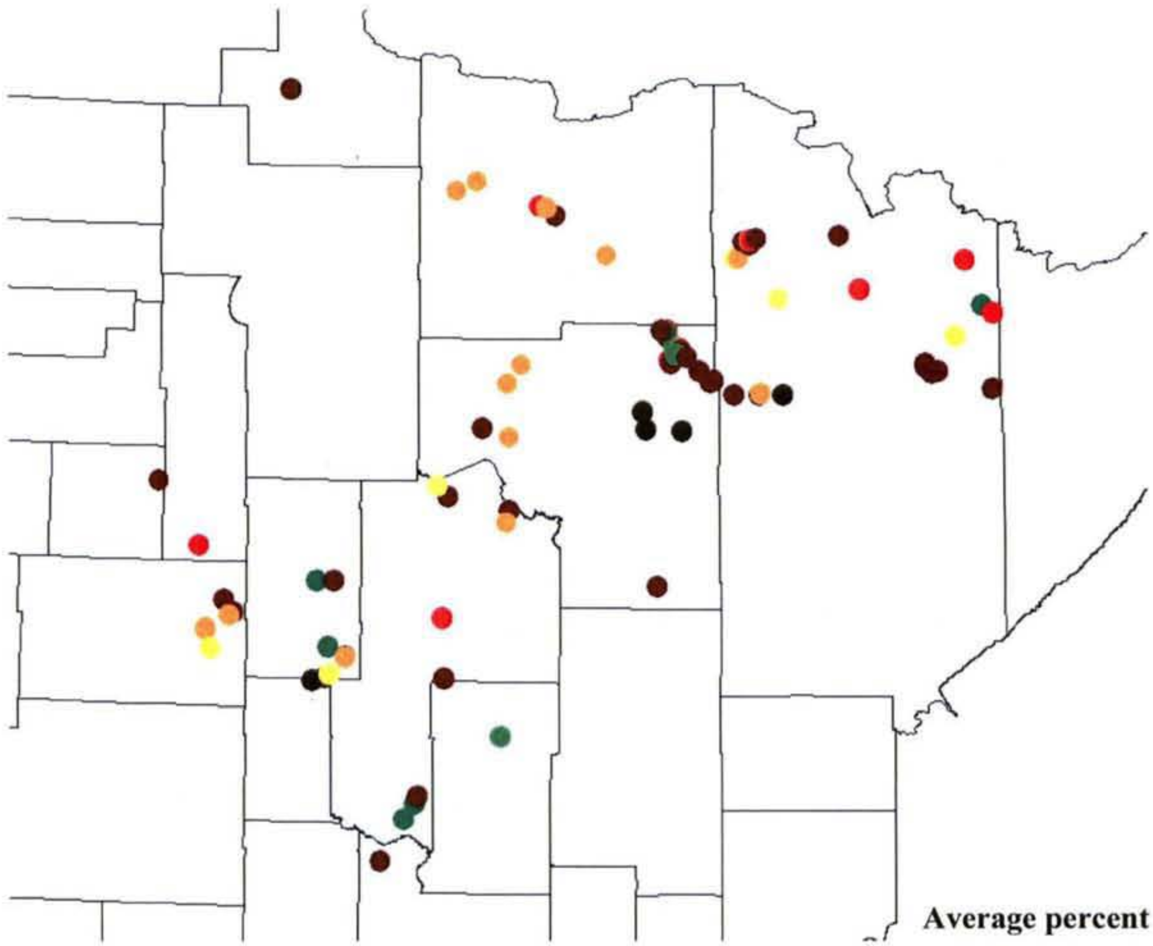


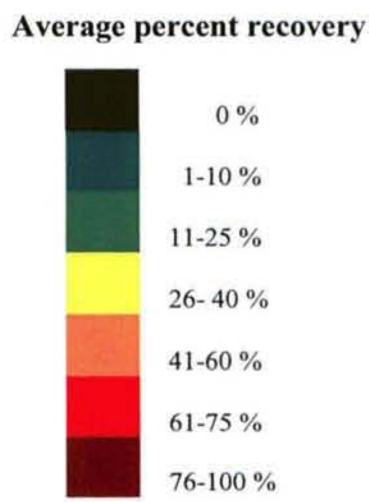


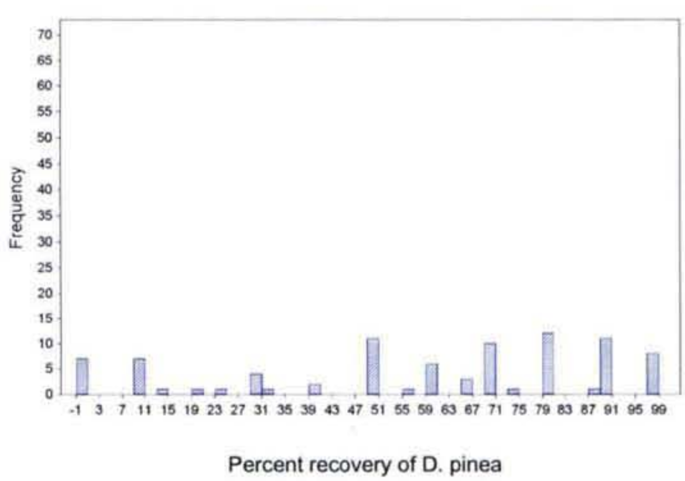
Presence of *Diplodia* species

- Neither species
- Both species
- D. pinea alone
- D. scrobiculata alone

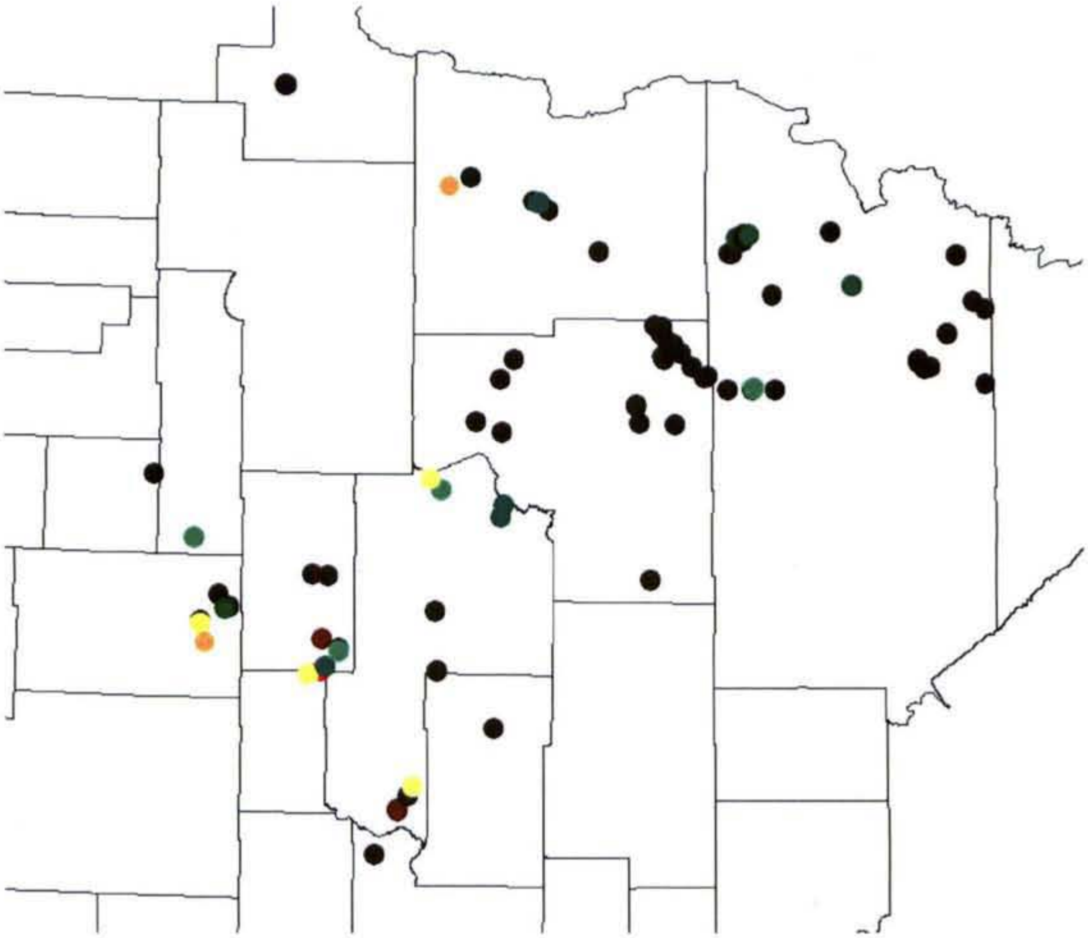
Map 6. Average percent recovery of *Diplodia pinea* from 10 infected red pine cones per site.

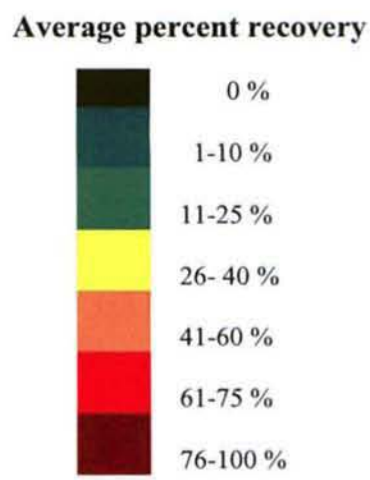


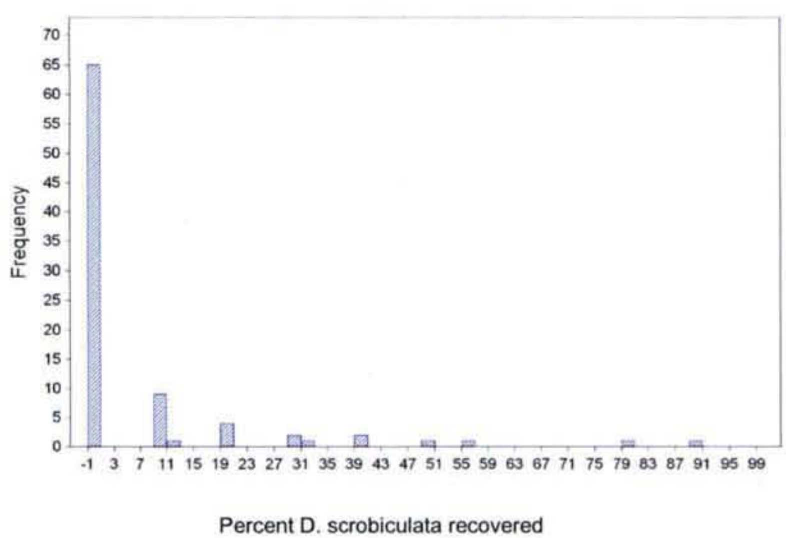




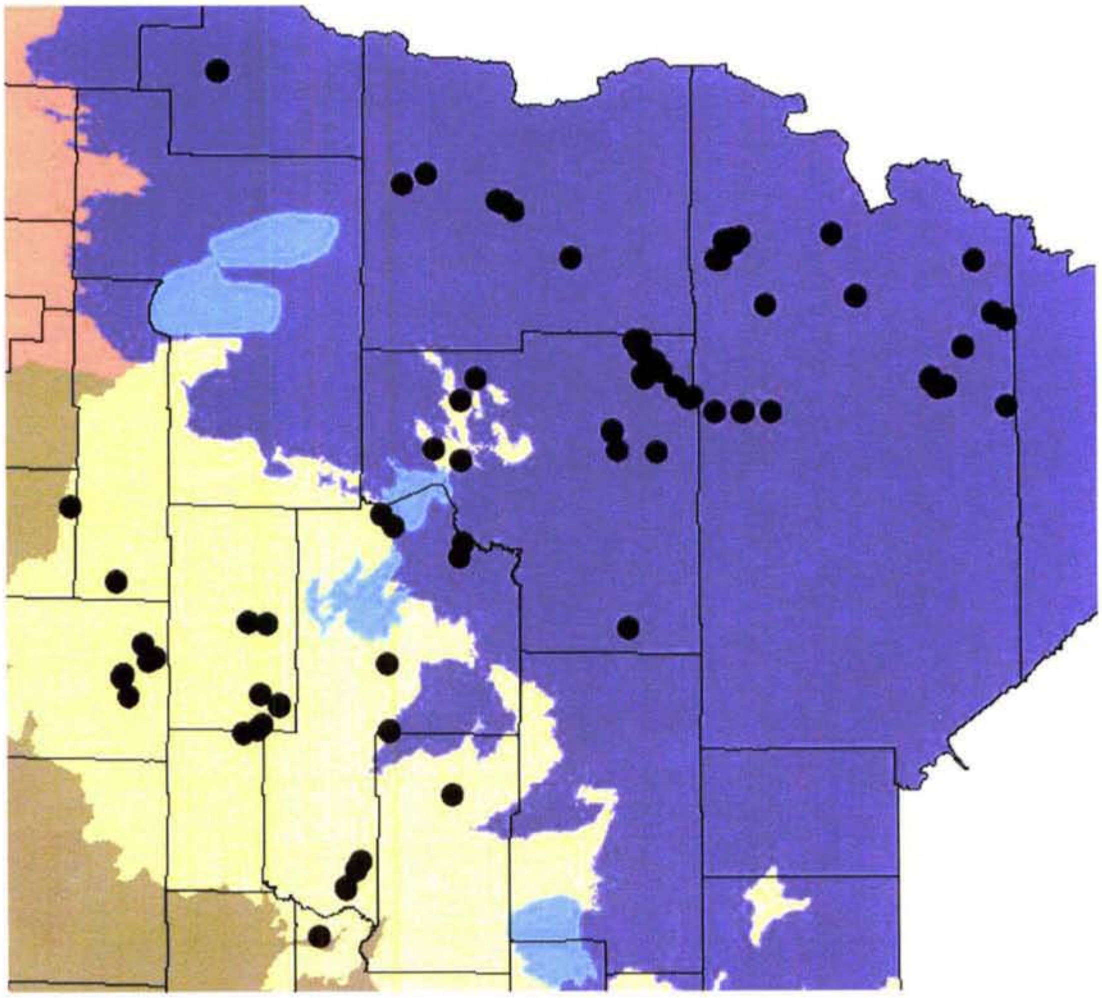
Map 7. Average percent recovery of *Diplodia scrobiculata*







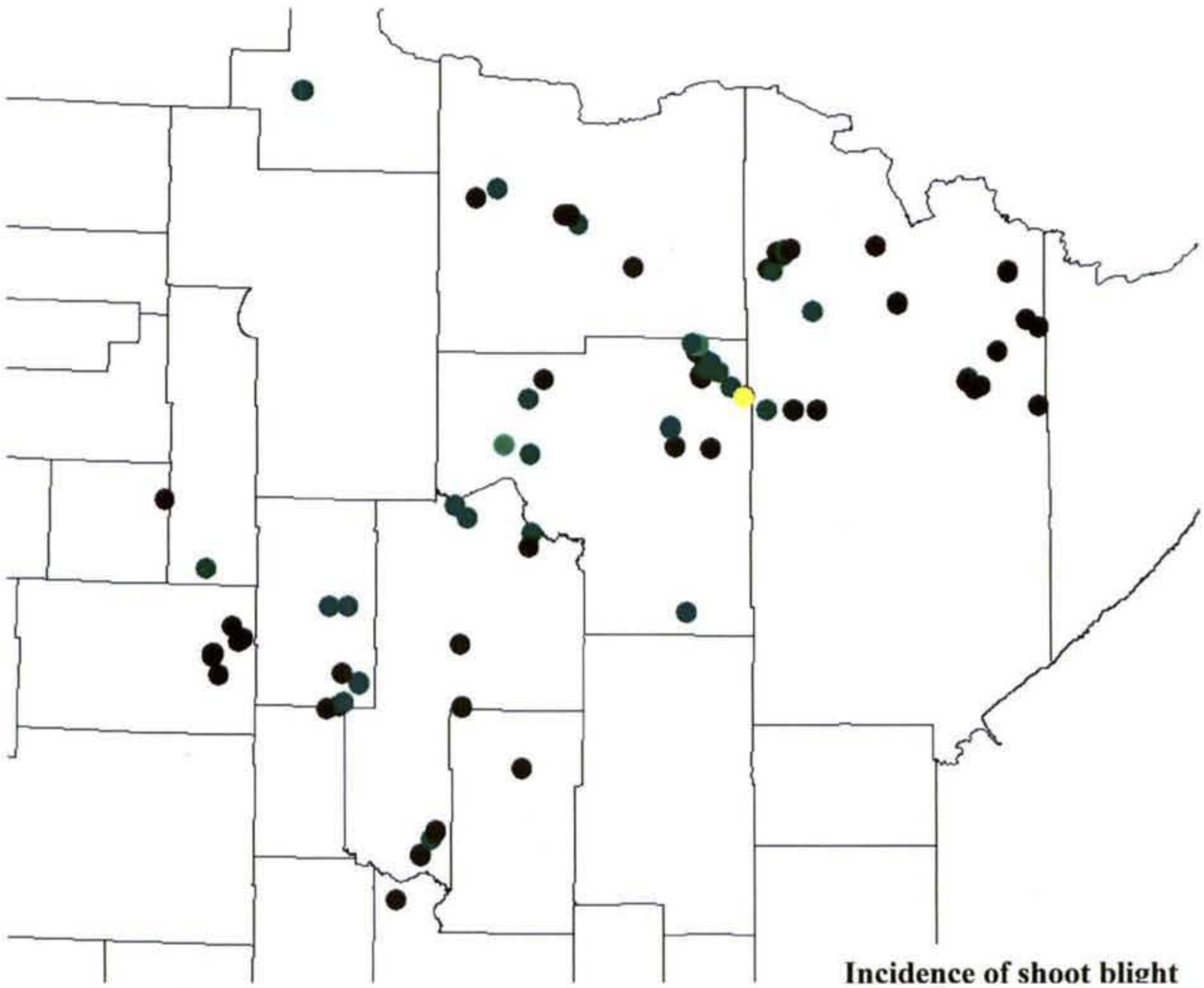
Map 8. Location of red pine plots in the northern and central floristic regions of the Ecological Classification System.

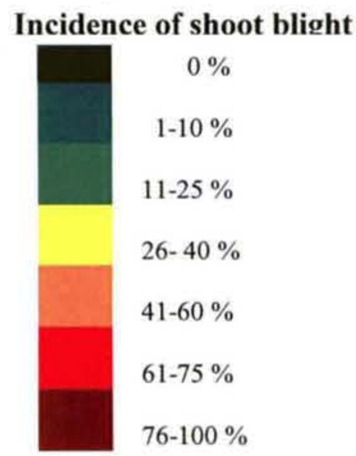


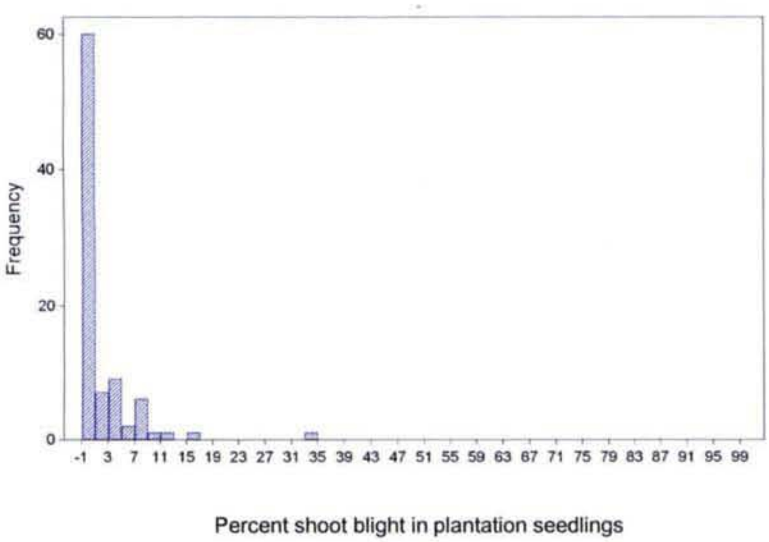
Floristic regions

- Central
- Northern
- Southern
- Western
- Lakes

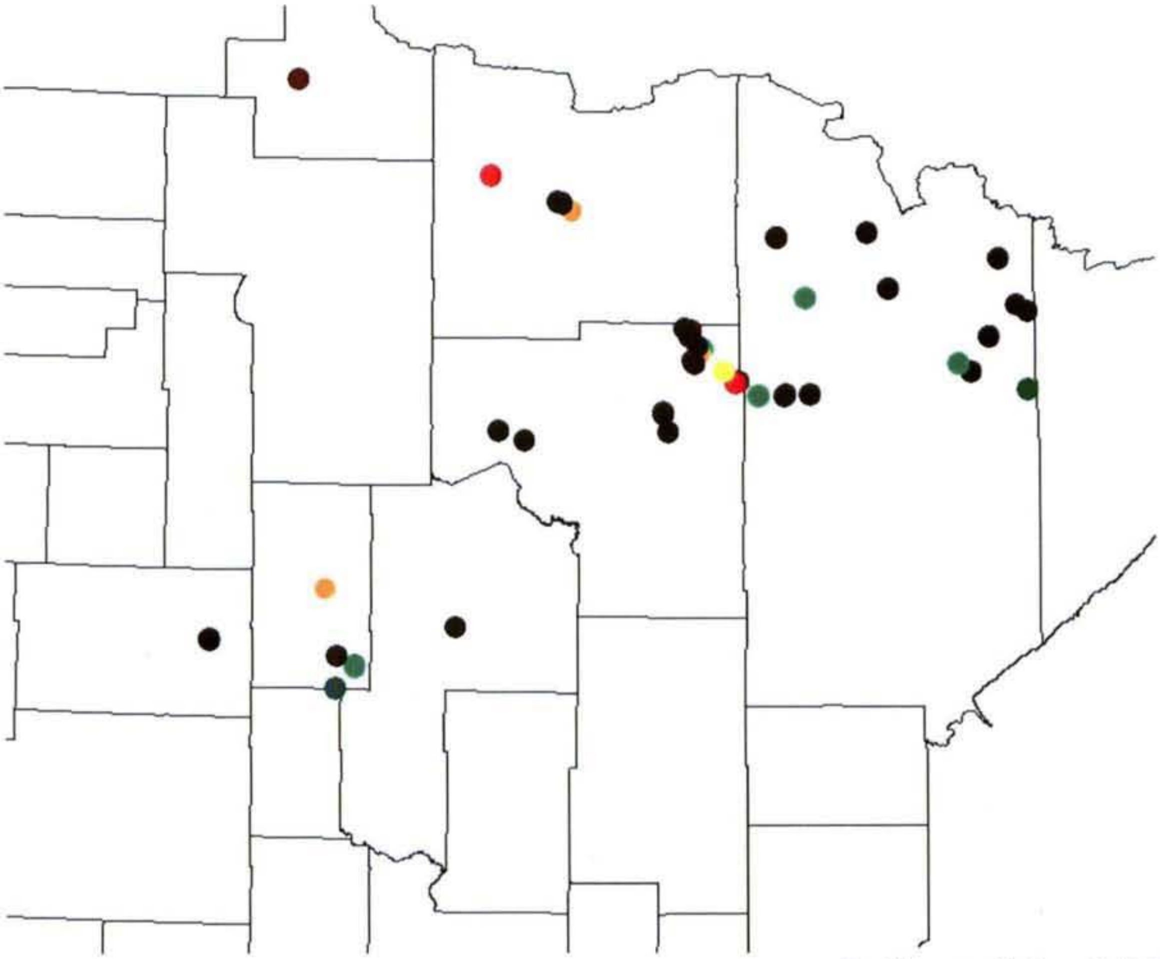
Map 9. Incidence of *Diplodia* shoot blight infection in red pine plantations.

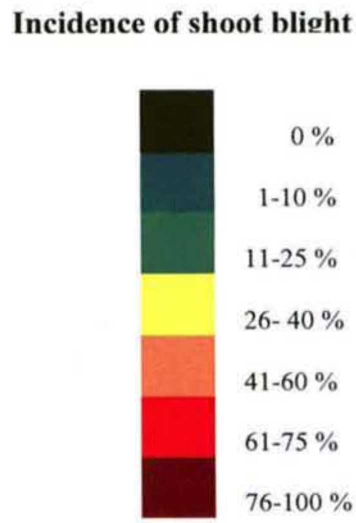


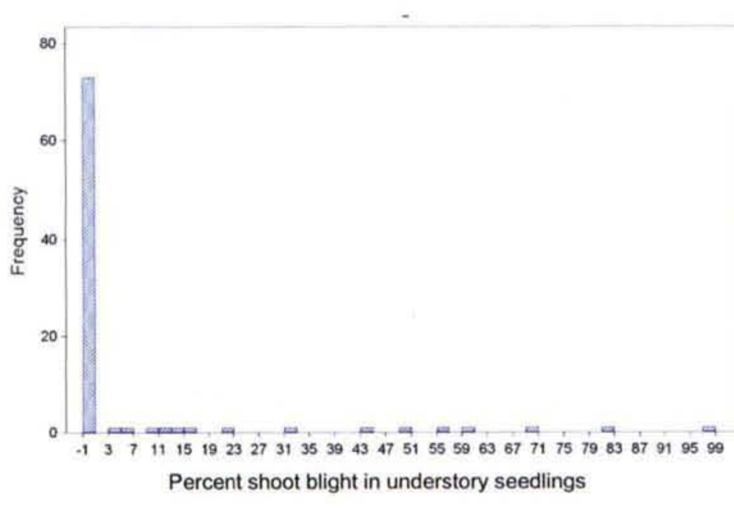




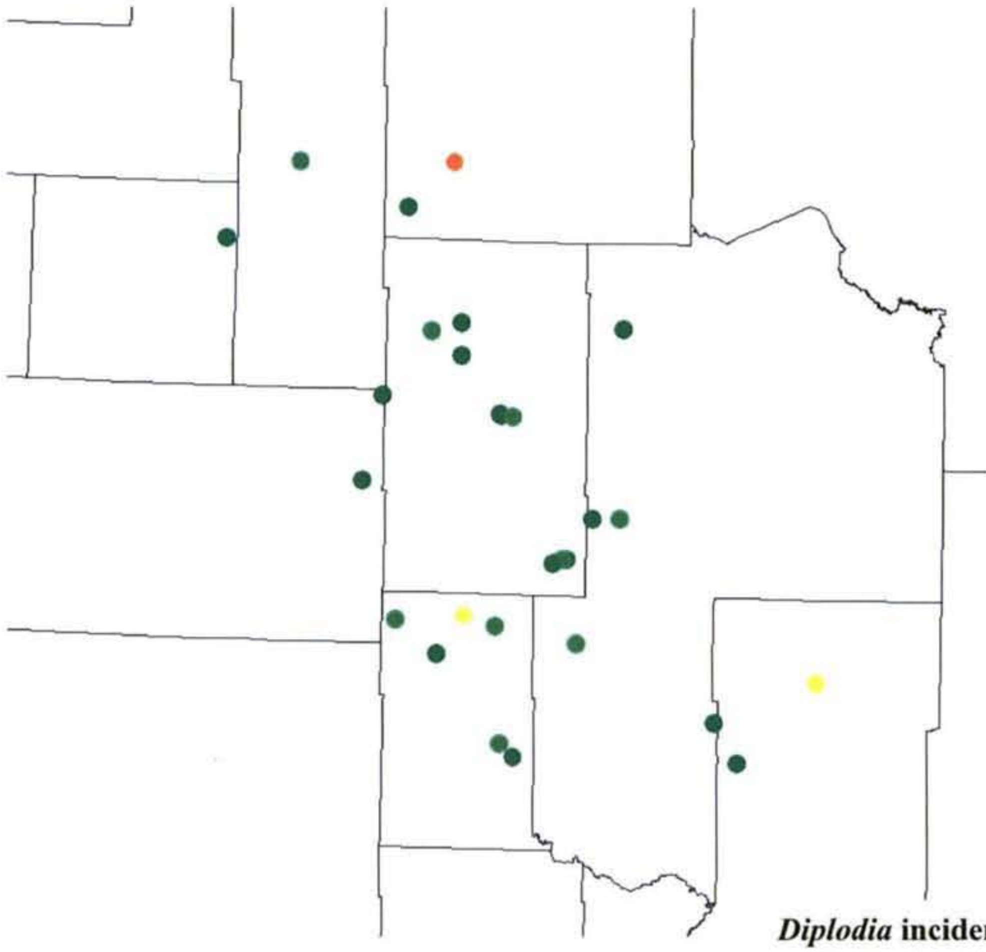
Map 10. Incidence of *Diplodia* shoot blight in red pine seedlings in the understory on 48 sites where the understory was present.

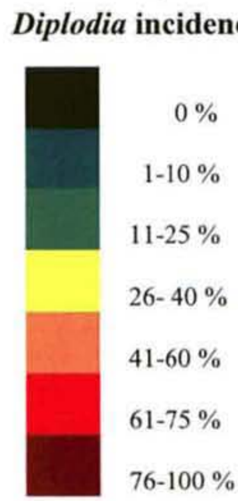


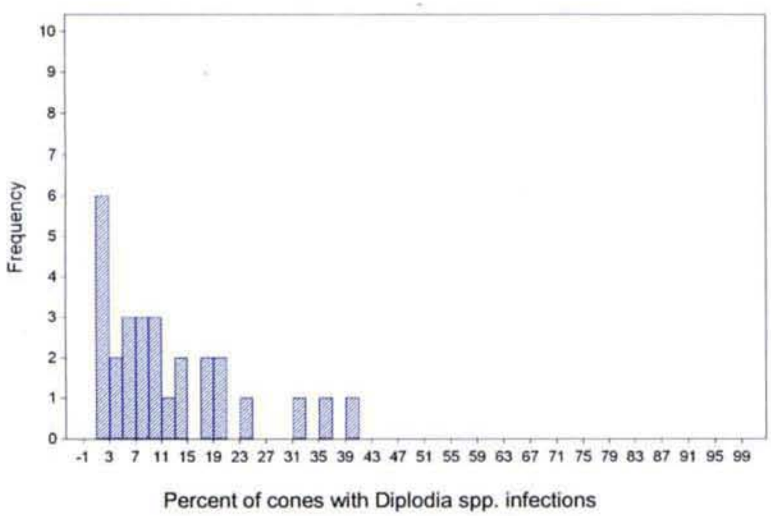




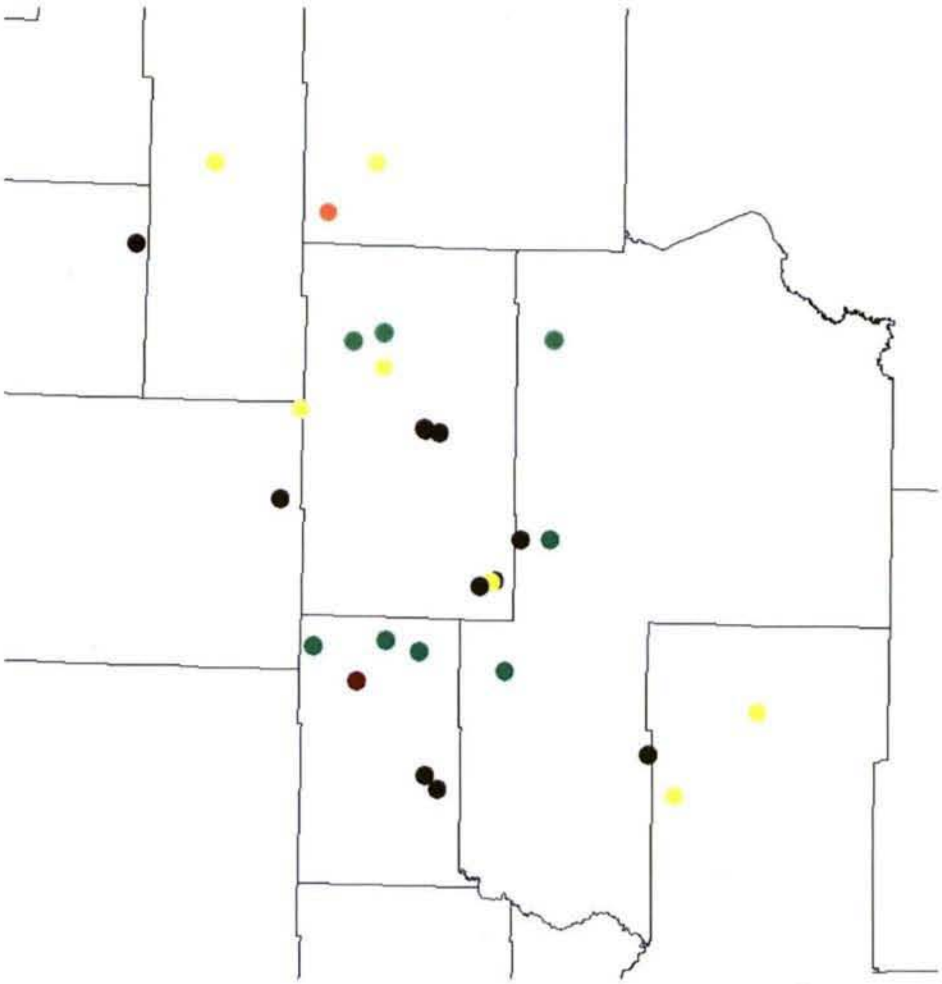
Map 11. Incidence of *Diplodia* species on 100 jack pine cones per site.

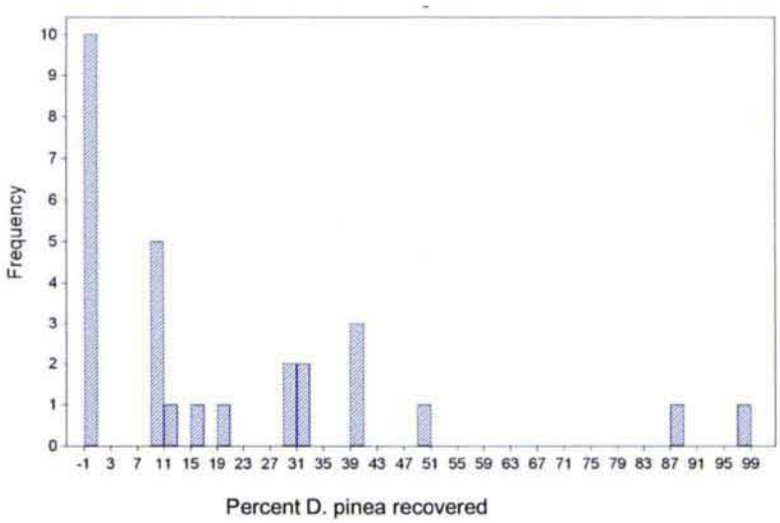


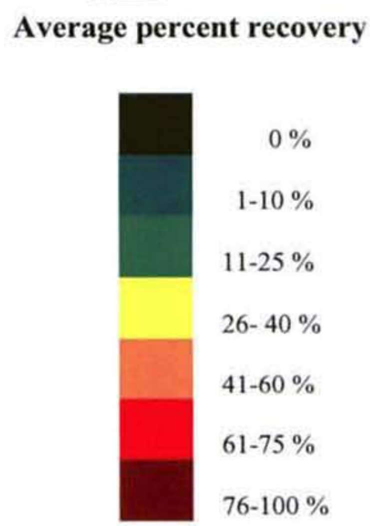




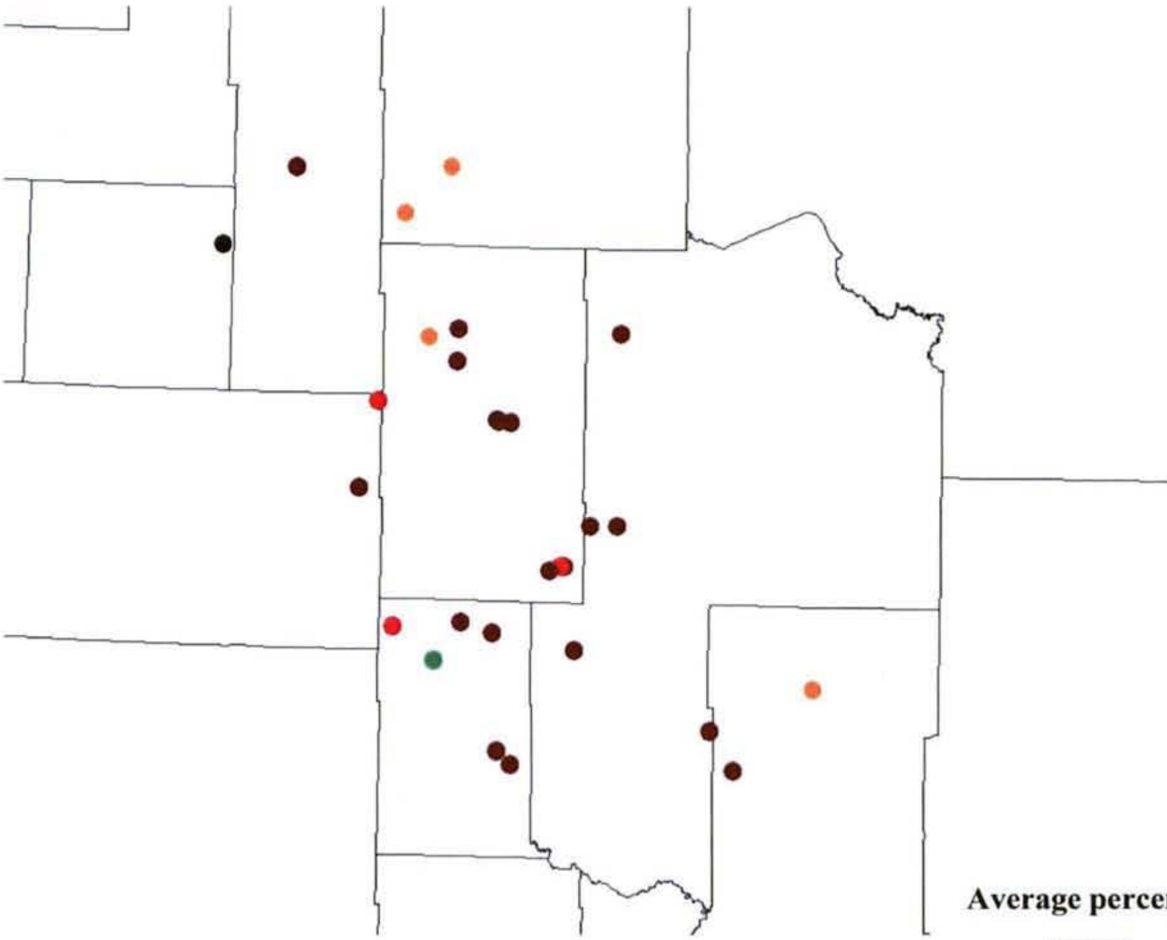
Map 12 . Average percent recovery of *Diplodia pinea* from ten infected jack pine cones per site.

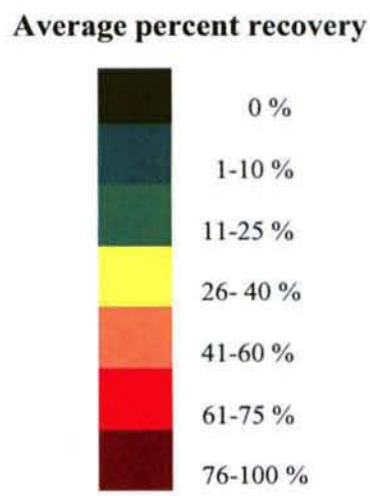


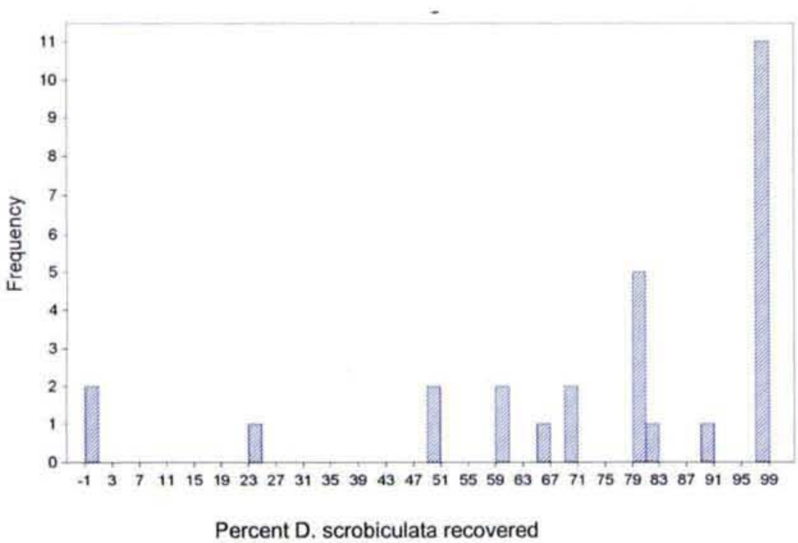




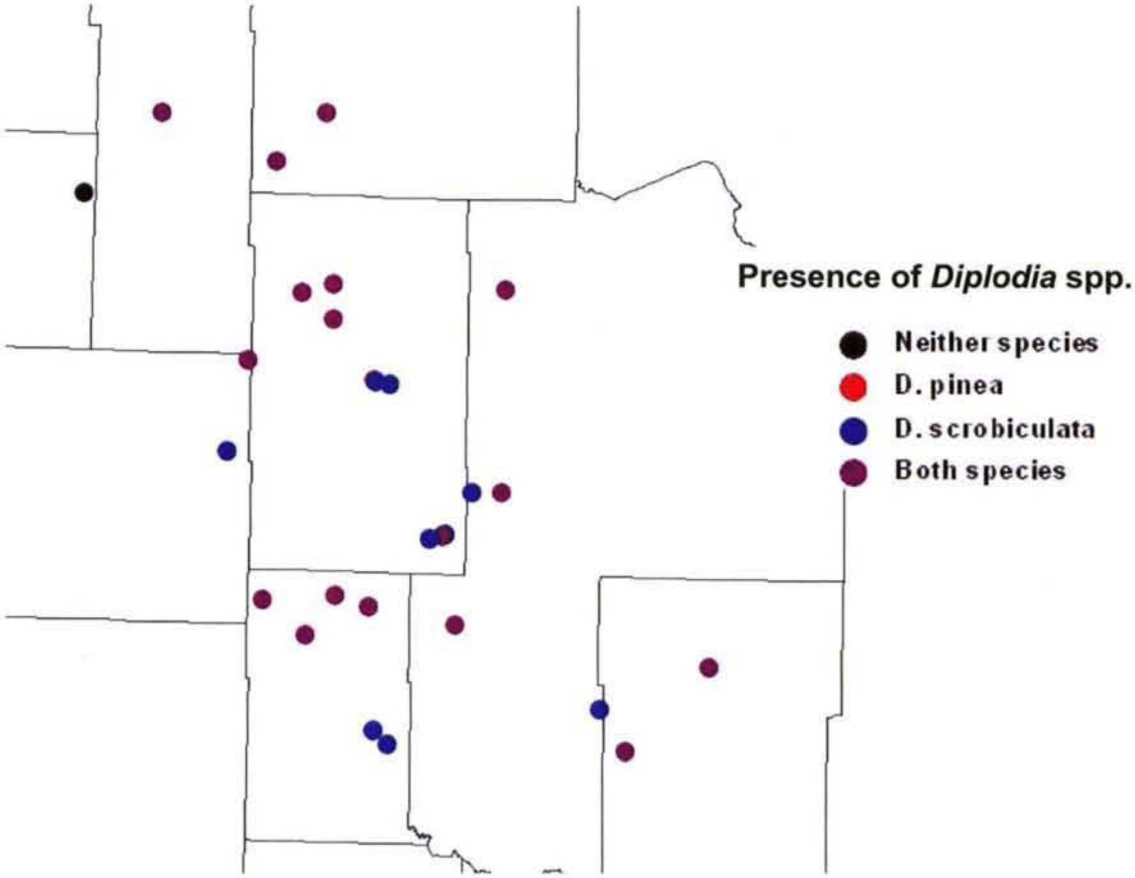
Map 13. Average percent recovery of *Diplodia scrobiculata* from ten infected jack pine cones per site.

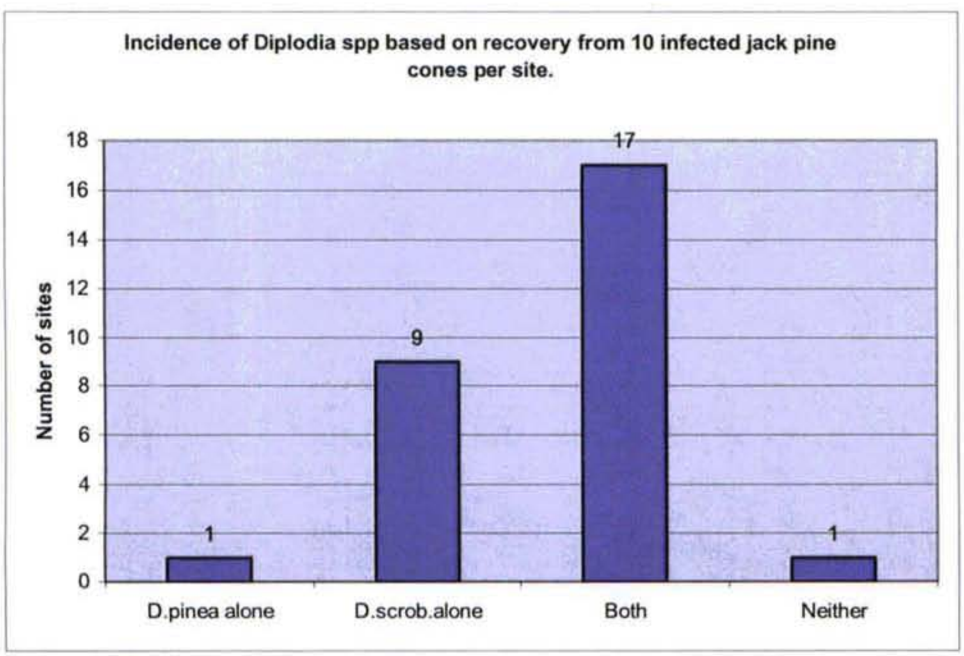






Map 14. Co- occurrence of *Diplodia* species based on recovery from ten infected jack pine cones per site.





Map 15. Red pine sites where the incidence of cone infection is less than four percent.