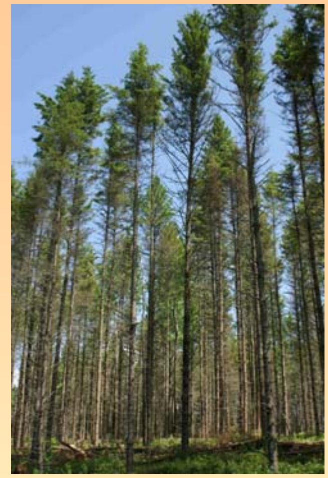
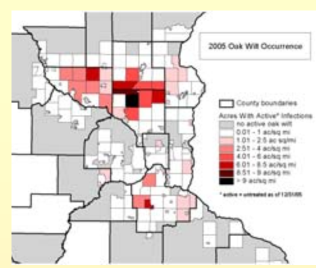
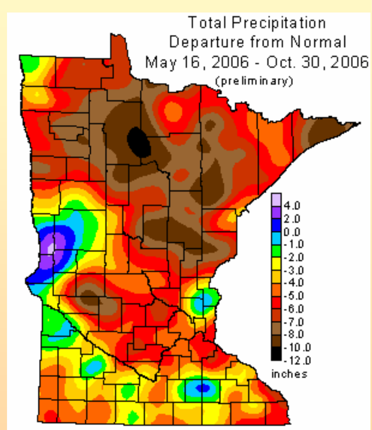
Minnesota Forest Health Annual Report

2006

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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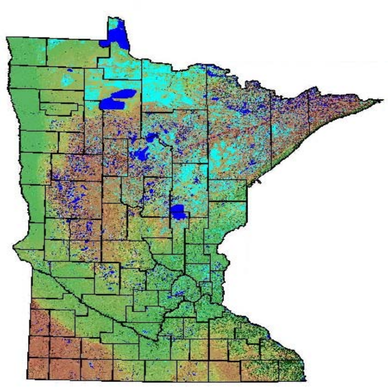

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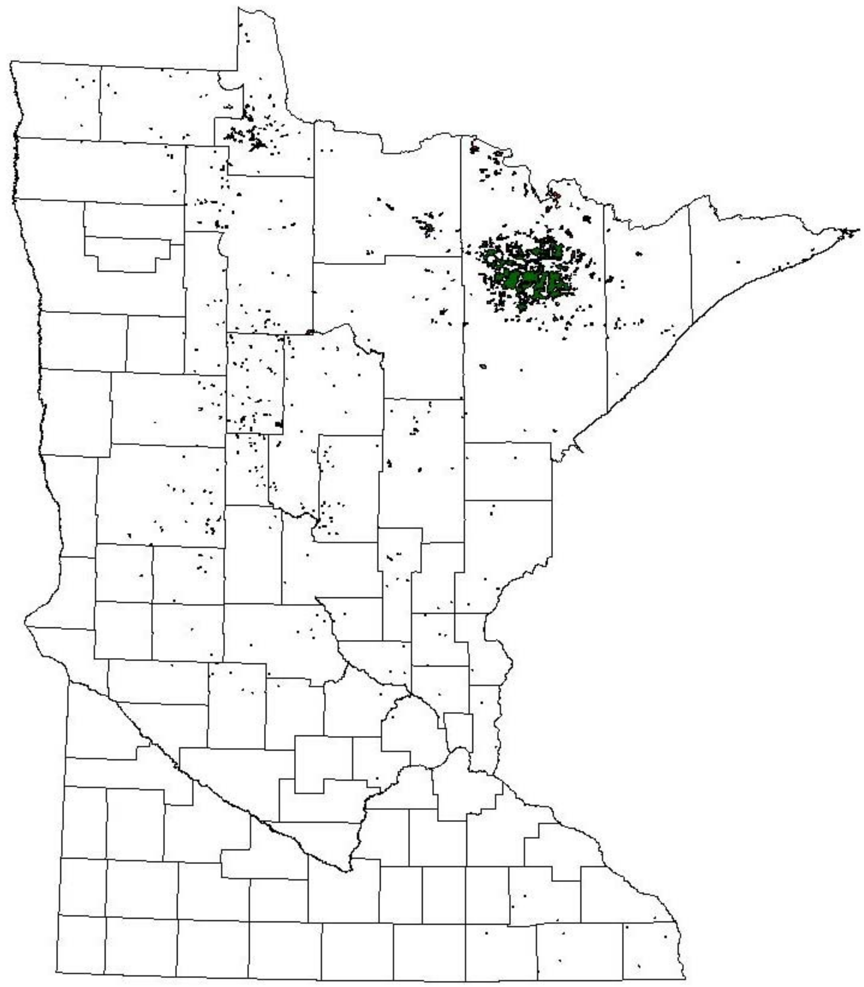
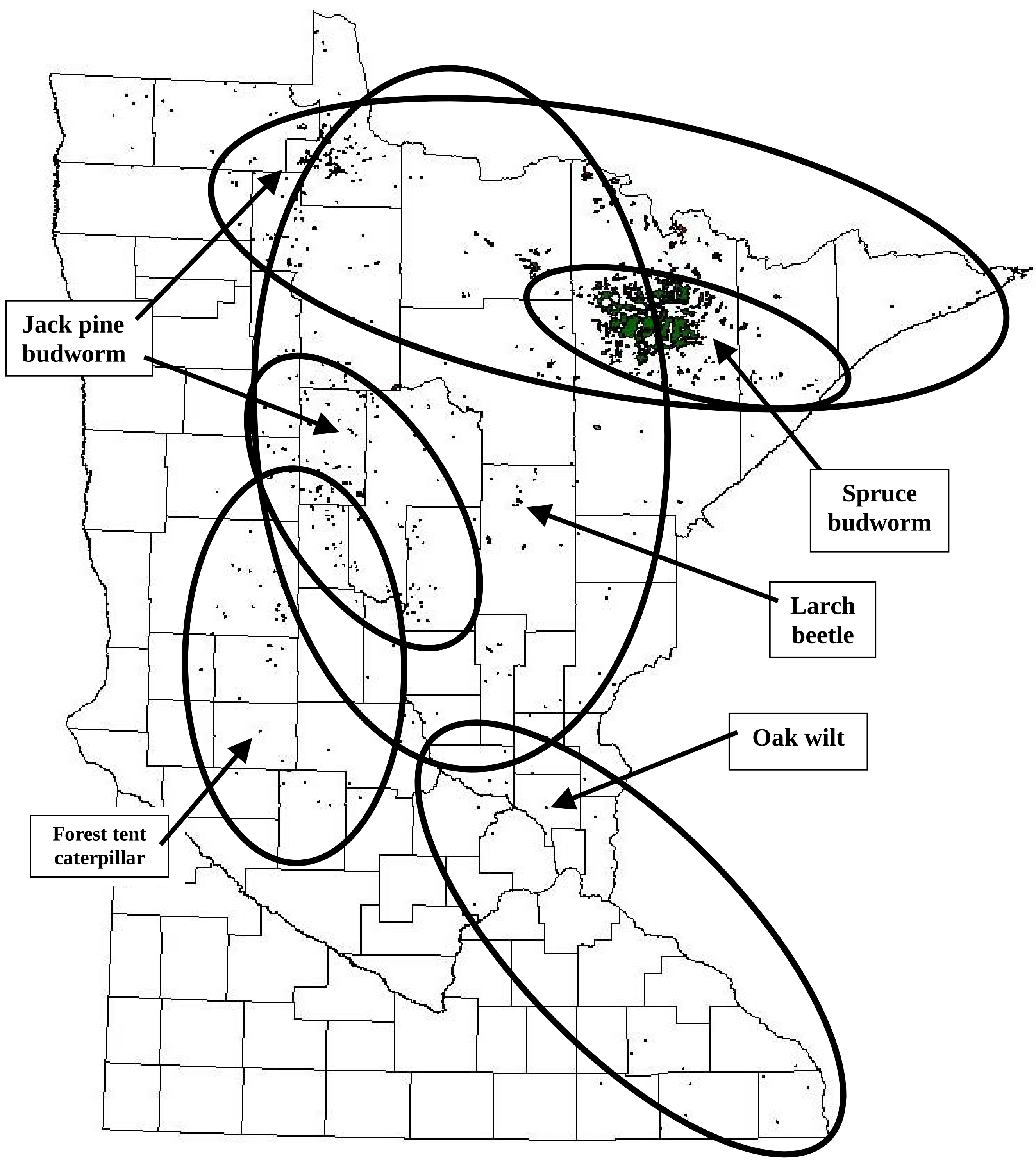
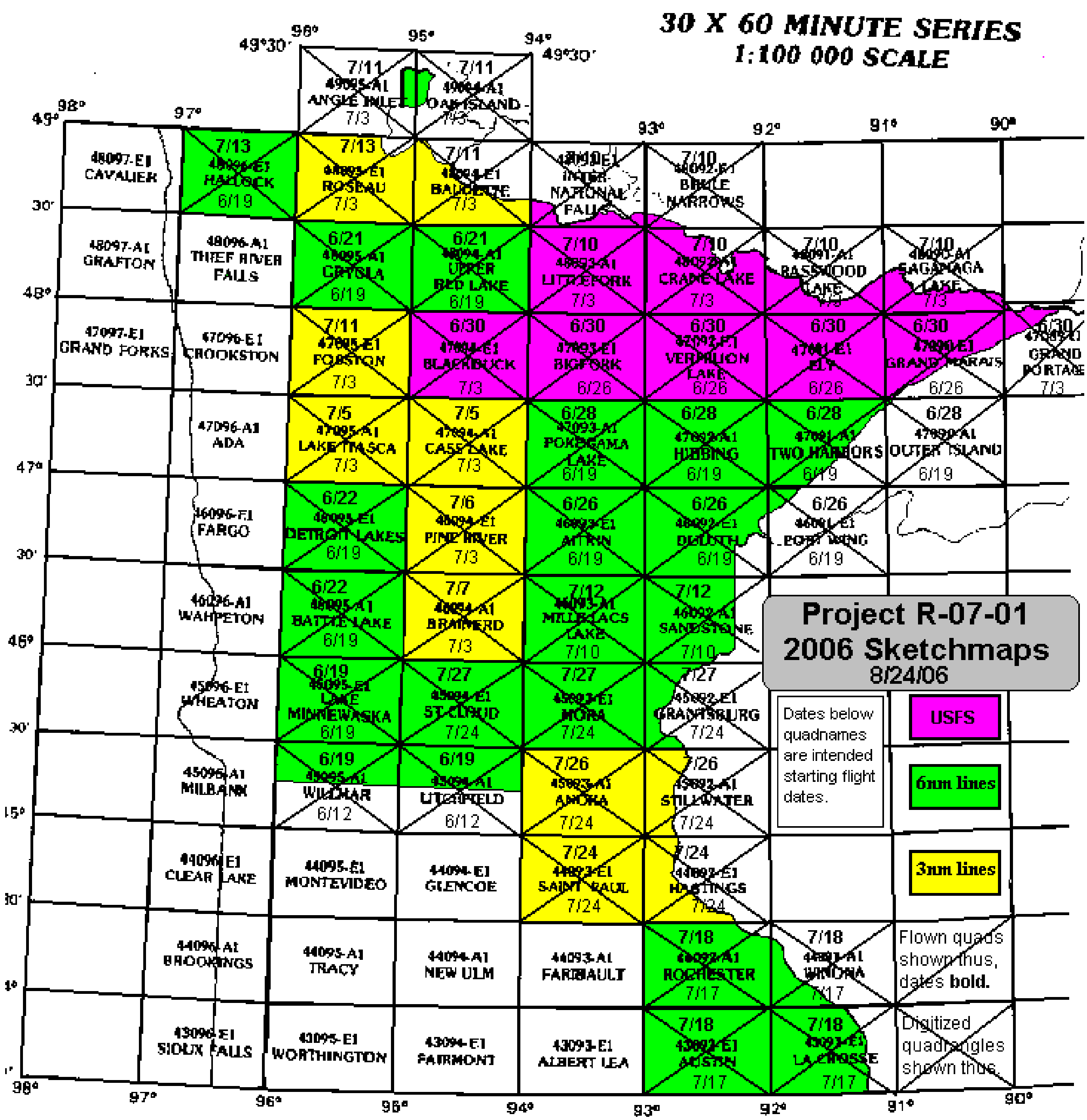
Aerial Survey 2006



Agent name	Number of polygons	Acres affected
Ash decline	8	662
Bark beetles	1	4
Dutch elm disease	66	357
Flooding	45	2083
Forest tent caterpillar	36	1982
Jack pine budworm	636	70790
Larch beetle	198	8927
Larch casebearer	62	6013
Large aspen tortrix	2	111
Oak wilt	1955	1462
Spruce budworm	247	287220
Unknown cause	557	16911
Wind damage	17	516

Aerial Survey 2006




30 X 60 MINUTE SERIES
1:100 000 SCALE
Project R-07-01
2006 Sketchmaps
8/24/06
Dates below quadnames are intended starting flight dates.
USFS
6nm lines
3nm lines
Flown quads shown thus, dates bold.
Digitized quadrangles shown thus.
CAVALIER
GRAFTON
GRAND FORKS
THIEF RIVER FALLS
CROOKSTON
ADA
FARGO
WAHPETON
WHEATON
MILBANK
CLEAR LAKE
BROOKINGS
SIOUX FALLS
ANGLE INLET
OAK ISLAND
HALLOCK
ROSEAU
CRYSTAL
UPPER RED LAKE
FOSSTON
BLACKDUCK
BIGFORK
LAKE ITASCA
CASS LAKE
DETROIT LAKES
PINE RIVER
BATTLE LAKE
BRAINERD
MILLE LACS LAKE
ST CLOUD
MORA
LITTLEFORK
CRANE LAKE
VERMILION LAKE
ELY
GRAND MARAIS
GRAND PORTAGE
POKEGAMA LAKE
HIBBING
TWO HARBORS
OUTER ISLAND
DULUTH
SANDSTONE
GRANTSBURG
STILLWATER
HASTINGS
ANOKA
SAINT PAUL
MONTEVIDEO
GLENCOE
TRACY
NEW ULM
FARIBAULT
ROCHESTER
WINONA
WORTHINGTON
FAIRMONT
ALBERT LEA
AUSTIN
LA CROSSE

INSECTS

Aspen blotch miner
Phyllonorycter tremuloidiella

Aspen blotch miners were very heavy on aspen through much of St Louis and Lake Counties. Crowns of some mature trees looked tan because of all the mines. In some locations, balsam poplar also had lots of blotch miners.

Bruce spanworm and Winter moth
Operophtera spp.

Entomologists from the University of Massachusetts at Amherst are attempting a worldwide survey of the winter moth and other species of *Operophtera* that are attracted to the same pheromone. These species include the winter moth, *O. brumata,* and the bruce spanworm, *O. bruceata,* and possibly others. The project will attempt to determine by genetic comparisons where our winter moths come from and the degree of relatedness of the species, and also the degree to which winter moth and the bruce spanworm are hybridizing. The winter moth is currently a serious pest to hardwood forests in New England.

Three traps were placed in the field in late November and early December, two in Olmsted County and one in Wabasha County. The Olmsted County traps caught 10 moths all identified in Amherst as bruce spanworm. The Entomologists there were happy to obtain samples from Minnesota.

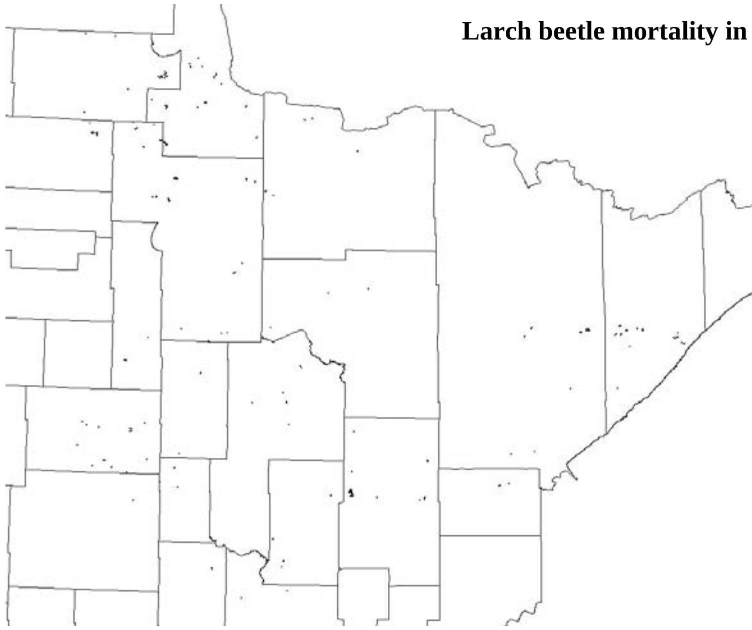
Douglas fir beetle
Dendroctonus pseudotsugae

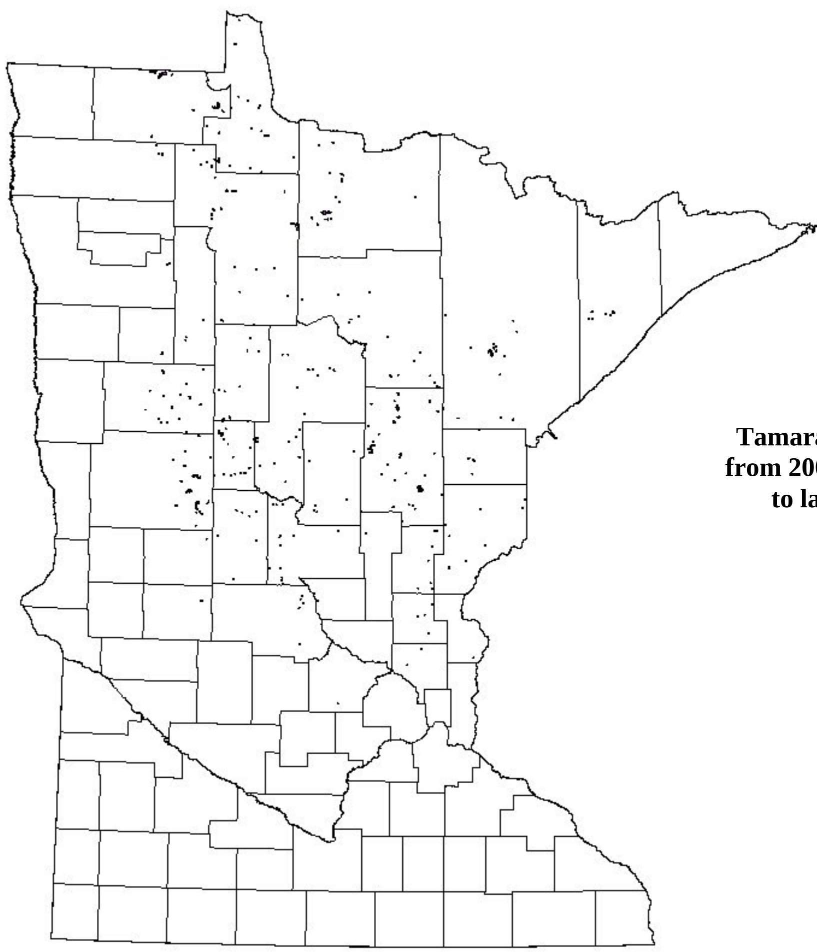
Trapping for Douglas-fir beetle has been done annually since they were first caught in Arbo Township, Itasca County in 2001. In 2006, 3 traps were placed on the Lonza site (formerly Larex) and 3 were placed in Arbo Township. All were baited with commercial Douglas-fir beetle baits. MN DNR provided baits for all 6 traps. MDA maintained the Lonza traps and MN DNR maintained the Arbo traps. Trap catches have not yet been sorted and identified.

Eastern larch beetle
Dendroctonus simplex

Eastern larch beetles continue to kill tamarack trees. Although only 8927 acres of mortality were mapped by aerial survey in 2006, mortality due to eastern larch continues to be very common and widespread. From 2001 through 2006, aerial surveyors mapped tamarack mortality on 53,734 acres in 911 stands. No consistent stress factor contributing to the current mortality by eastern larch beetle has been found. Trees from 40 to 160 years and older have been killed by the beetle. Mortality has occurred on upland as well as lowland sites and in pure stands as well as in mixed stands. Larch casebearer has been common during the same period of time that tamarack mortality has been occurring, but most stands with larch casebearer have not been experiencing mortality.

Larch beetle mortality in 2006



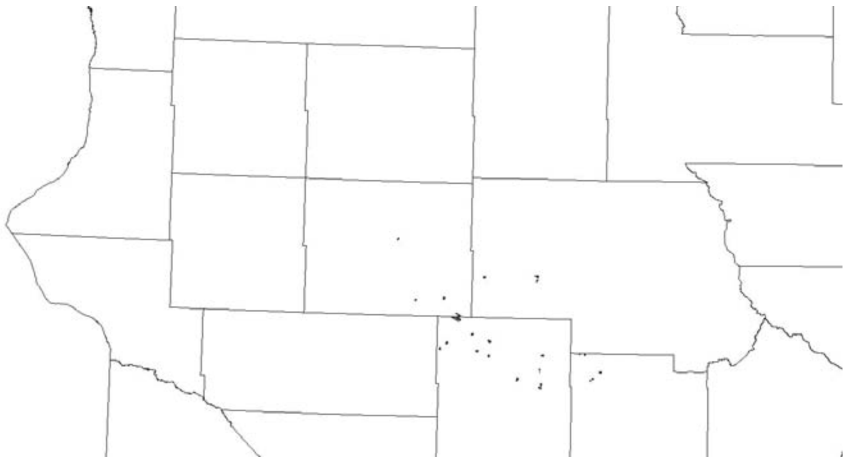


Tamarack mortality from 2000 to 2006 due to larch beetle

Forest tent caterpillar

Malacosoma disstria

Even though natural controls have caused the disappearance of forest tent caterpillars in most northern areas of our State, these defoliating insects were found in rather large numbers this year in northeastern Grant and northeastern Stearns Counties. These populations usually inhabit oak and basswood forests along lakeshores in the west-central counties. The population of forest tent caterpillars last peaked in northern Minnesota in 2002 but has had a fairly constant presence every year in the western lake country.



FTC defoliation in 2006.

Ips bark beetles

Ips spp.

A red pine stand in NE SW S16-T60N-R18W (47.68113, 92.63839) on the Laurentian Environmental Learning Center was precommercially thinned in October 2005. This site was planted to red pine but now has high density due to abundant volunteer red pine. A few of the cut trees were 3.5 to 4.5 inch DBH but most were smaller. Trees were completely cut off at the stump but were left in one piece with the branches attached. Basal area after thinning was 100 to 110 sq ft but, in a few spots, was still as high as 150 - 160 sq ft. Quite a few of the trees were left leaning in a partially up right position since they were hung up in the neighboring live trees. A ground fire burned through a part of the east end of the plantation in the spring of 2006.

Bark beetles infested the cut trees in 2006 resulting in a build up of bark beetles in the plantation. On August 10th, bark beetles were found to have attacked live standing trees on the east end of the plantation in the burned portion. A survey of the east end of the plantation found six standing infested trees. These were removed and disposed of while the current generation of beetles was still in the trees.

On Sept 14th, a more through survey of the plantation was conducted and it was found that many more standing trees had been attacked. In some bark beetle pockets, as many as 25 trees were killed. Attacked trees still had green needles even though bark beetles had consumed most of the cambium. Most of the bark beetles had already left the standing trees at this date and presumably had gone to overwintering sites in the duff. Since most of the bark beetles had already left the trees there was no point in cutting and removing the trees. This plantation will need to be watched closely next year especially if the drought continues.

The main lesson is that this plantation should have been thinned at a younger age to prevent the trees from becoming stressed from crowding. It also might have helped to cut the trees into2 to 3 foot lengths to speed drying.

A red pine plantation in Aitkin County in Sec 1 & 12 –T52N-R25W was thinned with a cut to length processor and forwarder starting on July 12th. Thinning continued into September. This was the second thinning. In some areas a fair amount of 8 to 10 inch fresh pine material was left behind due to forks or crooks in the stems. Some of larger material was up to 6 feet long. By July 27th, bark beetles had moved into this larger slash and were laying eggs. A few larvae were already present. On August 10th, a few new adults were present having completed a life cycle in a little less than a month. Most were still either pupae or larvae. Most of the bark beetle attack appears to have been in material 6 inches in diameter and larger but some beetles did attack slash down to 2 to 2.5 inches in diameter.

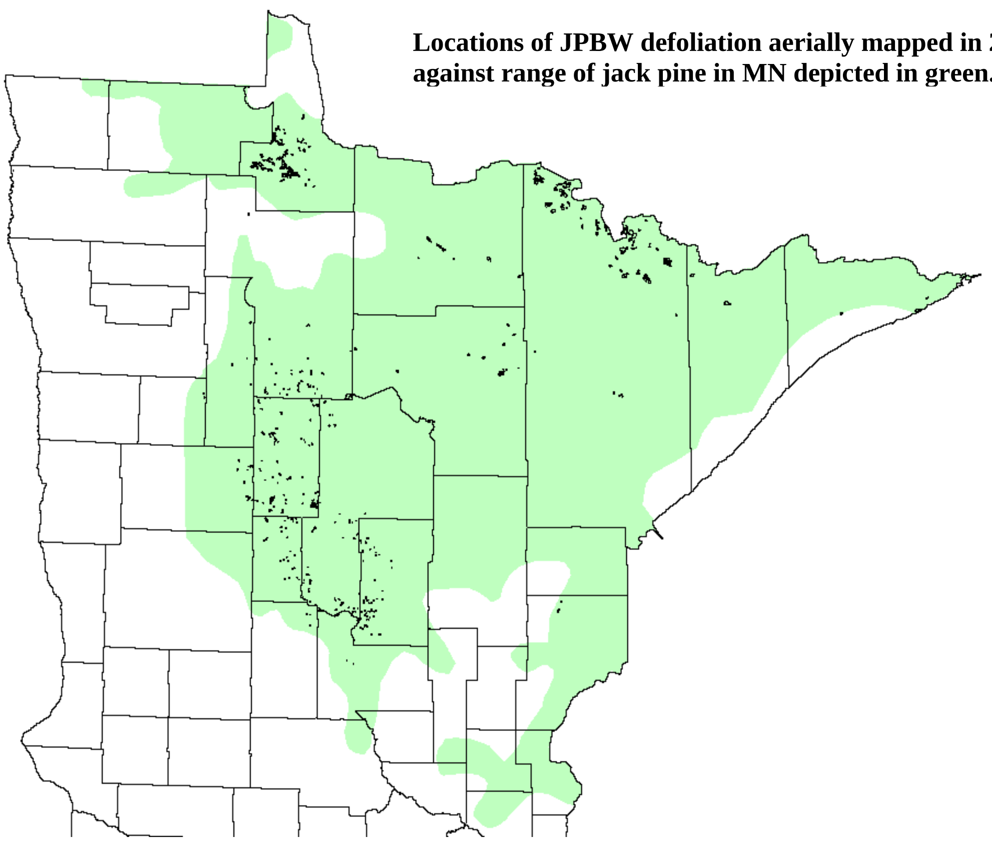
Red pine trap logs were placed in 4 locations in the plantation on Sept 9th to see whether bark beetles would still attack fresh material this late in the year. Trap logs were checked at the end of Sept and were peeled in early November. Only one bark beetle was found to have attacked one of the trap logs. This plantation is around 160 acres in size and thinning continued to about the end of October. A small study was conducted in this plantation looking at root injury as a result of the thinning. Quite a bit of root injury was evident varying from bark peeled off roots to broken and crushed roots. A study was also set up to monitor possible red turpentine beetle attack of trees with root injury. This can be found in the special studies section of the annual report.

In Region 1, the Region Forest Health Specialist suggested the foresters halt all thinning operations in red pine plantations due to the severity of the drought and the many flare-ups of bark beetles. This recommendation was made in mid-July and suggested that operations could re-start in September.

Jack pine budworm on jack pine

Choristoneura pinus

Jack pine budworm defoliation decreased to 19,400 acres; about a 4-fold decrease in acreage compared to last year. The patchy pollen cone crop this spring in the west-central counties was a significant factor in this population decrease. Unfortunately, that decrease was matched by a 51,390 acre increase in the northeastern counties and in Roseau and Lake of the Woods Counties. All-in-all, 70,790 acres were affected this year. The northern portion of our outbreak is probably associated with the current and severe outbreak in adjacent Canada between Kenora, Dryden and Fort Francis.



Locations of JPBW defoliation aerially mapped in 2006 against range of jack pine in MN depicted in green.

In the west-central counties, this is the fourth year of the outbreak and, typically, the "beginning of the end" of the budworm outbreak. There were indications this spring and summer of their imminent demise.

- During the early larval study, only a few plots had larvae on them and populations were very low.
- Pollen cones, necessary for survival of young larvae, were scarce. This indicates that the natural feedback mechanism in jack pine trees is handling the problem. Fewer pollen cones this year means less larvae next year, too.
- Egg mass studies predict declining populations for 2007 in Beltrami, Hubbard and Wadena Counties.
- Even though aggressive salvage and pre-salvage harvesting was used to mitigate the effects of prolonged defoliation, 250 acres of mortality were mapped in a single stand on county and private land in Hubbard County.

Last year, budworms caused 6,000 acres of defoliation in red pine stands in Beltrami, Hubbard, Wadena and Crow Wing Counties. This year, only 500 acres were defoliated, primarily near Park Rapids in Hubbard County. Early larval, pollen cone phenology and egg mass studies in red pines also found that populations are decreasing. For example, on the red pine impact study plots, the average number of egg masses per 36 inch branch dropped from 1.4 to 0.2, which indicates a decreasing population.

This is the third year of the jack pine budworm outbreak in Roseau and Lake of the Woods Counties. In 2004, each of the counties had less than 25 acres of mapped defoliation. Subsequently, no further defoliation occurred in Roseau County. In Lake of the Woods County during 2005, the defoliated area increased to 2263 acres and rose to 13,071 acres in 2006. Jack pine mortality was mapped on 130 acres in four stands in Beltrami Island State Forest. Egg mass surveys indicate that defoliation levels will be very low next year.

Jack pine budworm defoliated 37,496 acres of jack pine in the northeast Region in 2006. This is the first time jack pine budworm defoliation has been reported in this part of the state since an outbreak in 1982-1986. In the current outbreak, the largest area of defoliation is in northern St Louis County with smaller acreages defoliated in northeastern Itasca, central Koochiching, central St Louis and scattered stands in Lake and Cook Counties. Defoliation was mostly heavy in northeastern Itasca County and many of the affected stands are 65 years and older. Itasca County plans to cut most of their affected older stands in this area. In Koochiching County, on state administered lands, foresters plan is to monitor the outbreak and not to start any harvesting at this time. The affected stands in northern St Louis County are mostly within the Boundary Waters Canoe Area Wilderness and Voyageurs National Park where cutting is not allowed and so will only be monitored. Based on the previous outbreak, it is felt that in the northeastern part of the state overall impact will be minor. This could change however if the current drought continues adding significant stress to defoliated trees.

Jack pine budworm defoliation of jack pine in Itasca Co.

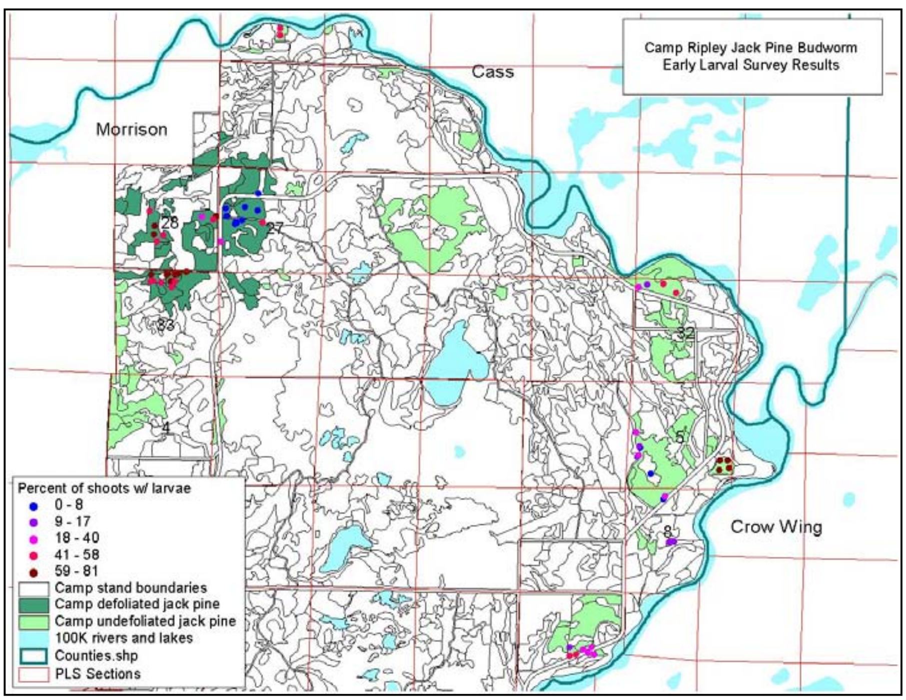
The previous outbreak in northeastern Minnesota started with light defoliation on about 2000 acres in 1984, expanded to approximately 2800 acres of generally light defoliation with scattered moderate and heavy defoliation in both 1983 and 1984. The outbreak in this area then collapsed and caused some top kill but little whole tree mortality. Considerable harvested occurred in mature and overmature stands as a result of the outbreak. In 1984, 150,000 acres of trace to light defoliation was mapped in northern St Louis, Lake and Cook counties along the Canadian, mostly in the Boundary Water Canoe Area Wilderness. This increased to approximately 200,000 acres of defoliation in 1985 with a slight increase in severity to mostly light-moderate. Scattered heavy defoliation was observed north and east of Ely in Lake County and near Gunflint Lake in Cook County. Top kill was observed in some stands north and east of Ely where trees were growing on shallow soils on rock outcrops. Populations collapsed and in 1986 slightly less than 14,000 acres of defoliation were mapped. Rainfall was well above normal in 1985 and may have contributed to the population collapse and also helped kept tree mortality to a minimum.

In the Central Region, two areas under state ownership were affected by the outbreak; these were the US Army Camp Ripley in Morrison County and General Andrews State Forest in Pine County. See map. A fall egg mass survey was conducted in both areas and the results suggested severe defoliation was likely in 2006, if JPBW populations survived the winter.

In Pine County, approximately 550 acres were defoliated east of Hwy 35. Because of the severity of damage in 2005 and because these stands were already scheduled for harvesting within the next few years, 173 acres were cut last winter and another 229 acres were marked to be cut this year. After an ecological evaluation, the decision was made to replant the cut stands with a combination of pine species. So this spring 39 acres were planted with a mixed ratio of 70:30 white and jack pine, and 134 acres were planted a mixed ration of 90:10 red and white pine.

In Camp Ripley, Army officials decided harvesting the most severely damaged stands was not an option because of the effect on the movement of military equipment and troops during training operations in the area. As a result, the decision was made to treat those stands at risk of damage with Btk, a biological insecticide – assuming sufficient numbers of JPBW survived the winter to warrant treatment. To help describe winter survival rates and likely summer defoliation, an early larval survey was completed in May. Based on a combination of survey results and Camp priorities, approximately 600 acres were treated with applications of the Btk product Foray 48B on June 3rd and June 8th.

The 2005 egg mass survey consisted of sampling 4 trees per plot, 2 mid-canopy branches per tree and a minimum of two plots per stand. The average number of egg masses found per 15" of needle bearing surface per plot was used to predict likely defoliation. Six stands within the defoliated area and two stands that had not been defoliated were sampled in November. Survey results suggested severe defoliation in 2006 was likely in four of the stands sampled. In May 2006, an early larval survey was completed to describe winter survival. The survey consisted of sampling five trees, 6 shoots each accessible from the ground for the presence/absence of JPBW larvae. Nine stands were sampled among those defoliated in 2005 and nine stands were sampled that had not been defoliated. Survey results suggested that winter survival rates were high and that several of the stands sampled were likely to be defoliated in 2006. See map.



In the oldest of the stands defoliated in 2005, substantial top kill was evident by the spring of 2006, along with some recent tree mortality. The current condition and age of these stands puts them at risk of further tree mortality and invasion by pine bark beetles - even without a second defoliation event. Little long-term damage was noticed in the younger defoliated stands.

During the larval survey, a rough estimate was made of pollen cone abundance on each plot. In the most severely defoliated stands, pollen cones were rare except among edge trees. Because pollen cones are critical for early larval survival, JPBW populations are expected to crash in those stands without cones. Stands with abundant pollen cones are at greater risk of defoliation and if they had been previously defoliated, they are also at risk of tree mortality. Stands not defoliated in 2005 are expected to see little to no long-term damage this year, unless previously stressed by advanced age.

Jack pine budworm can best be managed through cultural means. These include maintaining proper stand density, minimizing factors that favor abundant cone production and rotating the stand at approximately 45 yrs of age. Most of the jack pine stands in Camp Ripley are well beyond the 45-rotation age. They are also growing in mixed species and mixed age stands that tend to favor cone production. In those cases, DNR policy would favor regeneration cuts and replanting to maintain the jack pine component. Btk would only be used where a 2nd defoliation meant likely tree mortality and only then when harvesting wasn't feasible. However, land use on Camp Ripley limits stand management options.

Because of the need to maintain certain types of stand structure and minimize the risk of fire due to the use of explosive artillery, the Camp decided to treat a number of stands defoliated last year as well as some that have not yet been defoliated. Whether or not the treatments will succeed in maintaining the historical jack pine coverage desired by the Camp is yet to be seen. It may depend on bark beetle populations and future harvesting decisions.

Jack pine budworm on red pine

Choristoneura pinus

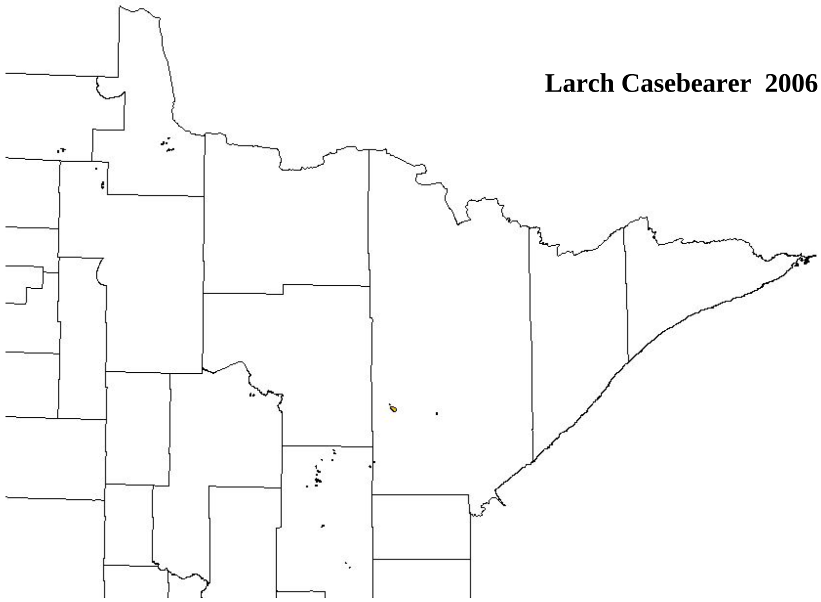
Last year, budworms caused 6,000 acres of defoliation in red pine stands in Beltrami, Hubbard, Wadena and Crow Wing Counties. This year, only 500 acres were defoliated, primarily near Park Rapids in Hubbard County. See photograph. Early larval, pollen cone phenology and egg mass studies in red pines also found that populations are decreasing. For example, on the red pine impact study plots, the average number of egg masses per 36 inch branch dropped from 1.4 to 0.2, which indicates a decreasing population.

The results of a two-year study documenting the impact of budworm defoliation on three red pine plantations can be found in the Special Projects section of the 2007 Annual Report.

Larch casebearer

Coleophora laricella

Larch casebearer continues to be active, mining tamarack needles and turning trees brown. Larch casebearer was mapped on 6013 acres in 2006. The duration and extent of the current outbreak is unusual. Prior to 2000, larch casebearers were seldom seen and required a careful and intentional search to find them, but since then, damage has been obvious enough to be mapped annually during the aerial survey. The amount of needle damage needs to be quite high before it becomes obvious and mappable using aerial survey. In some years, like 2000, the damage has been very widespread but light in many stands, 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 four to five years. So far no dieback or mortality has been associated with this damage.



Large aspen tortrix
Choristoneura conflictana

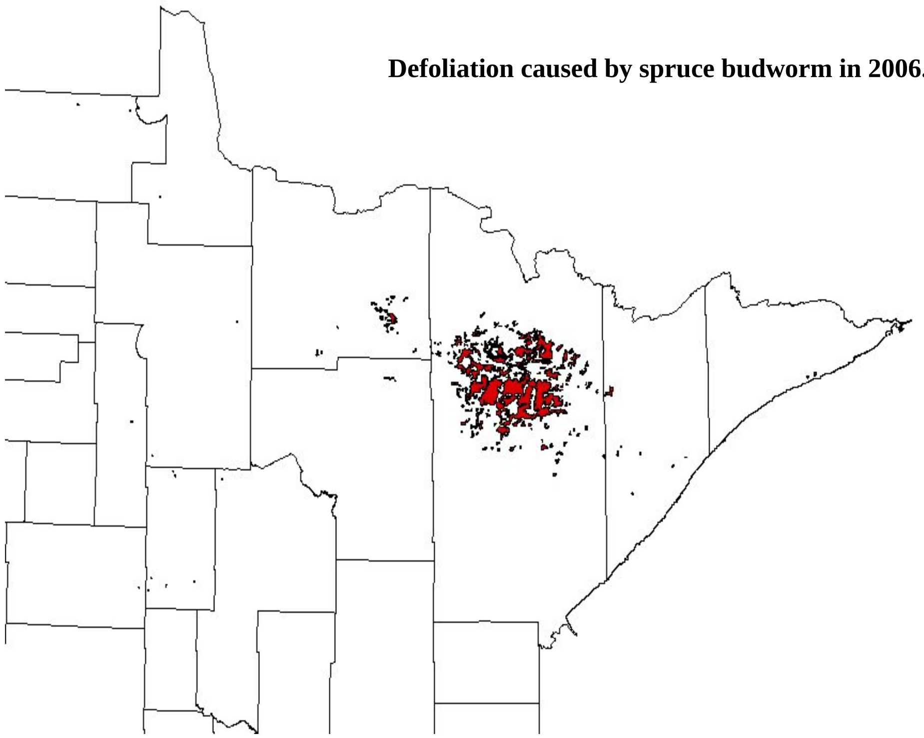
Large aspen tortrix was found on two sites along the north shore in Cook County totaling only 111 acres. Scattered areas of moderate to severe defoliation were reported in Ontario in the Kenora, Dryden and Red Lake districts. This may indicate a need to be on the watch for increased populations in Minnesota next year.

Oak twig pruner
Elaphidionoides spp.

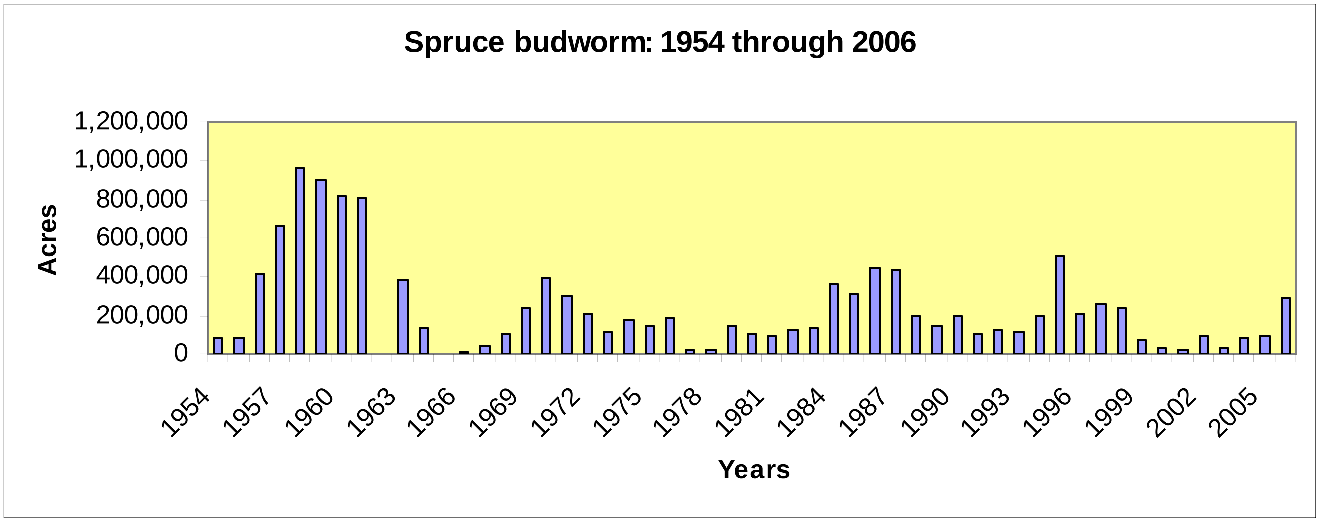
Oak twigs and branches littered the ground under oaks in yards in parts of the Northeast Region this summer. Reports came form Grand Rapids in Itasca County, Cloquet in Carlton County and Big Sandy Lake in Aitkin County. There are a number of different insects that cause this and the insects causing the damage this year were not identified to species. They feed in the twigs and branches weakening them. Wind eventually causes the branch to break off and fall to the ground. If you look at the end of the branches on the ground some of them look very ragged like you twisted a branch off the tree. In other cases the end of the branch is very smooth. If the branch has a smooth end to it, you can usually find a beetle larva by splitting the end of the branch open. This particular insect overwinters in the branch on the ground, so the recommendation is to pick up the branches and dispose of them. Don’t just throw them in the brush or tall grass at the edge of the lawn. These insects shouldn’t kill any trees but they can change the shape and appearance of the tree.

Spruce budworm
Choristoneura fumiferana

Spruce budworms defoliated trees on 287,220 acres this year. This was a large increase from the 92,500 acres defoliated in 2005. Budworm activity continues to be centered in northern St. Louis County with some defoliation also occurring in southeastern Koochiching County, northeastern Itasca County and central Lake County, as well as a number of scattered locations in other parts of the state. In addition to white spruce and balsam fir, budworm defoliation occurred on black spruce and tamarack on the west end of Lake Vermillion in northern St. Louis County.



In northeastern Minnesota, budworm defoliation has been noticeable and mapped continuously since 1954. See chart below. The chart shows two years with no acreages. Historic maps have not been found for these two years but historic newsletters indicate that spruce budworm defoliation was observed during those two years. There has been an average of 220,000 acres of defoliation mapped each year over this 53-year period.



Spruce spider mites

Oligonychus ununguis

Branch mortality and top kill was reported in many ornamental white spruce trees especially in and around Grand Rapids but reports were also received from Cloquet and Bemidji, as well. The cause appears to have been winter drying of needles in combination with spruce spider mite damage. All the homeowners claimed their spruce looked healthy during 2005 but then started changing color during the winter and early spring of 2006. Symptoms varied, but included fading or yellow needles, brown needles, dropping needles and often, dead buds on affected twigs. In some cases, the entire tree was affected, in other cases the top half of the tree or just one side of it was affected. On most sites examined, spruce spider mite eggs, old empty egg cases from the previous year and reddish brown overwintering eggs were quite abundant on damaged twigs and branches. It is likely that needles damaged by spruce spider mites in 2005 were more susceptible to winter drying and desiccation over the winter. On some of the trees the lower one or two feet of branches were healthy while the rest of the tree was affected or dead. The lower part of these trees were likely under snow cover during the winter and protected from the sun and drying winds. Most of the heavily damaged branches had dead buds. A few of the branches that appeared dead produced a couple adventitious buds but most did not. Many of the affected trees did not recover and have lost their aesthetics value especially those with dead tops.

Two-lined chestnut borer

Agrilus bilineatus

During 2001-2003, most of the red oaks within a ten mile radius of Grand Rapids died or died-back from two-lined chestnut borer attack which was instigated by simultaneous drought and forest tent caterpillar defoliation. Most oak experts say that oak regeneration depends primarily on regeneration already present and established in the stand at the time of the final harvest. Past experience with two-lined chestnut borer and forest tent caterpillar has shown that dead and dying oaks usually produce little or no stump sprouts. So, it seemed likely we would see few if any young oaks growing on most of these sites for the next rotation.

In examining some of these stands this fall, it was painfully obvious that most sites had little or no oak regeneration. However, on some of the sites, foresters are reporting oak regeneration a year or more after harvest. For example, in a stand east of Grand Rapids, oak regeneration this fall varies from a few hundred to 2000 seedlings per acre. Where seedlings were abundant, the stand was harvested in early 2006 when more than 80% of the red oaks were dead. Some of the oak seedlings looked as if they resulted from acorns sprouting this spring and are only about 9 to 10 inches tall with a tap root about ¼ inch in diameter. The remainder of the seedlings are up to two feet tall with tap roots between 3/8 and ½ inch in diameter and, so, must be a couple years old. The question now is whether or not they will survive deer browse and competition in order to provide the next generation of oaks on the site.

Wooly alder aphid

Paraprociphilus tessellates

Wooly alder aphid was abundant on silver maples in a number of locations in the Northeast Region including in Hibbing. There were lots of complaints of honeydew on cars, picnic tables and lawn furniture.

Diseases

Armillaria root disease

Armillaria sp. (likely *A. ostoyae*)

An Armillaria root disease pocket was examined with the tribal forester on the Bois Forte Reservation. A dozen pole to sawlog sized red pines had died and some of them had fallen down in past years. Many declining trees were present around the edge of the pocket. Mycelial fans of *Armillaria* were present on all the declining and dead trees examined. Abundant bark beetle emergence holes were evident on some of the fallen trees. A single red turpentine beetle pitch tube was found on one of the standing trees. It appears that bark beetles are playing a role in the decline and mortality of the trees but it was felt that *Armillaria* was likely the primary agent involved.

Brown cubical rot

Phaeolus schweinitzii

A root rot pocket was found in a white spruce windbreak in a backyard in Grand Rapids. The landowner had removed about a half dozen trees in the center of the pocket that had died a number of years ago. Additional dead and declining trees were present on both sides of the pocket in the windbreak. Fruiting bodies of *Phaeolus schweinitzii* were present on the ground near the base of a number of trees.

Diplodia shoot blight and collar rot

Diplodia pinea and D. scrobiculata

Four field studies and red pine management recommendations are described in the Special projects section of this report.

Hypoxylon dieback of bur oaks

Hypoxylon atropunctatum

Individual oaks stressed by drought or poor site conditions can develop a secondary canker disease caused by *Hypoxylon atropunctatum.* This fungus is distributed across the eastern US. In the southeastern counties of Minnesota, it is seen very infrequently on dying bur oaks and almost always found on trees growing under very stressful conditions. The fungus causes infections by entering through minor wounds and natural openings. The infected oaks start out looking like typical declining trees. After advanced symptoms of dieback and foliage chlorosis appear in the crown, black stromata are formed. These fungal fruiting bodies can be seen through splits in the outer bark. The black stromata are diagnostic for this disease. We have not observed any bur oaks recover from this disease.

Lirula needlecast of white spruce

Unlike other conifers, white spruce trees retain their needles for eight or more years and rely on them for food production all the years that they remain attached. So when spruce needles are shed prematurely, the growth and vigor of the tree can be diminished. A few pathogenic fungi (*Rhizosphaera, Chrysomyxa,* and *Lirula*) cause premature needle loss in white spruce. Needle loss and discoloration are particularly important for Christmas tree growers and homeowners.

Lirula macrospora causes needlecast of second year and older needles. Before being shed, these needles turn off-white, which is a stark contrast to the usual dark green color of the healthy needles. Linear, black fruiting bodies form along the length of the needle in the spring of the second year after infection and spores are release during July.

Moldy seedlings

Variety of fungi.

Every year the DNR plants three million seedlings. In some years, moldy seedlings are found when the shipping boxes are opened. There may be only one seedling affected or many of them. This year, some of the oak and walnut seedlings had mold on them. The University of MN cultured the fungi and found *Penicillium, Fusarium* and *Tricoderma* on the oak and *Penicillium* on the walnut.

Oak anthracnose

Apiognomonia quercinia

In July, homeowners in the Northeast Region began noticing brown dried out areas on white and bur oak leaves caused by anthracnose. Since the weather was quite dry this spring and summer this was not expected. However this does point out that fairly short periods of time of the right weather conditions are all that is needed for infection and can occur even in dry years.

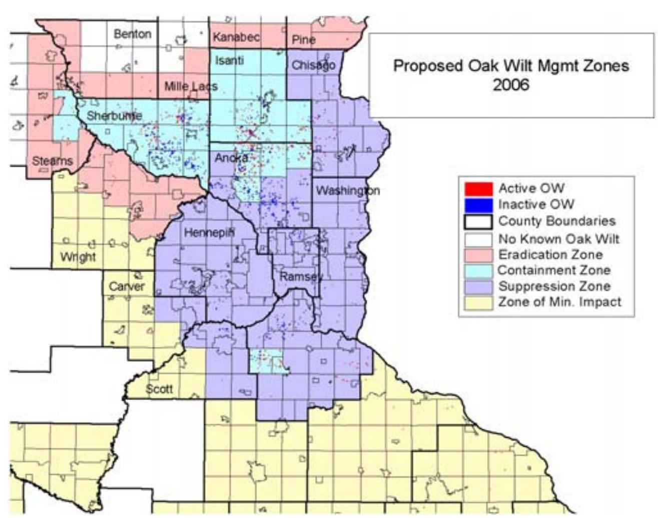
Oak wilt

Ceratocystis fagacearum

Based on the accomplishments reported in January 2006 by MN Releaf program participants, 922 infection pockets were treated in 2005 within the state suppression program. Of these 341 sites received vibratory plowing and 106 sites received fungicide injections. A total of 856 sites had potential spore producing trees removed. Based on forest cover data provided by Forestry Resource Assessment, these treatments protected 4,727 acres of bur oaks, 16,402 acres of northern pin oak and 11,715 acres of northern red oak.

An average of 1.5 infected acres per square mile is considered to be a level of disease manageable within the context of a local unit of government. In 263 of 289 or 91% of the civil divisions within the core area surveyed annually, disease incidence seems to be stable at or below that level (see map). Site conditions, state and federal assistance and active disease management have contributed to effective control in these communities.

In the remaining communities, past wind storms, abundant oak, high development pressures and a lack of infrastructure with which to implement effective disease management programs has led to an increase in disease. Within the area surveyed, disease incidence averaged 0.73 infected acres per square mile at the end of 2004 and increased to 0.84 by the end of 2005. An abundance of oak wilt in undeveloped areas where oak wilt is not generally managed is also contributing to the overall level of infection. In these rural areas, disease intensifies over time creating more and more satellite infections. As developing communities expand into these woodlands, they inherit a well-established problem that is difficult to address within the fledging community structure. The result is an overall increase in the state average disease incidence.



In response to increasing disease and decreasing funds, the DNR will be revising grant program guidelines for the fiscal year to begin July 2007. Four control zones were defined based on the level of disease incidence across the state (see map). Funding and the level of cost-share will be based on these zones. Within the eradication zone, an attempt will be made to identify and eradicate infection pockets for the purpose of keeping oak wilt out of portions of the state where it does not currently exist. Within the area of minimal impact, disease management will focus on silvicultural practices to limit future losses. In the containment and suppression zones, grant awards will be based on the ability of local units of government to implement a successful program. The two factors considered the most important in successful disease management are an ordinance under which sanitation of infected trees can be enforced and the presence of trained staff. Both of these will be required for future grant awards – assuming there are grant funds to be awarded.

Spruce needle rust

Chrysomyxa ledi and C. ledicola.

Spruce needle rust was observed in a number of locations such as roadside along Hwy 1 in northeastern Itasca County and on roadside spruce near Biwabik in St Louis County. Even though the spring and summer of 2006 were very dry, there were obviously periods of weather favorable for rust infection in some locations. Spruce needle rust was quite wide spread throughout the Northeast Region in 2005.

Tubakia leaf disease

Tubakia dryina

Across southern Minnesota, a late season leaf disease was seen on individual bur oaks. The fungus, *Tubakia dryina,* was identified as the main cause. This disease has been observed for many years but it seems to be increasing over the last few years. The disease symptoms can be very dramatic, as the entire tree turns brown except a few leaves in the very upper crown. See the photo in Chatfield, MN which was taken in late August. Defoliation can reach 90% in a few short weeks. Thus far, the defoliated bur oaks have been re-foliating the following year without causing dieback.

During late July and August, some bur oaks scattered throughout southern and southeastern Minnesota exhibited the following symptoms.

- Leaves with multiple leaf spots that eventually turn brown.
- Brown or curled leaves most commonly in the lower crown. The infection progresses from the lower crown into the upper crown.
- Whole tree crowns can become brown with curled leaves.

There is a great deal of variability between individual bur oaks in susceptibility to this disease. Affected trees will be adjacent to other bur oaks that are free of symptoms. This disease generally affects the same individual bur oaks each year. The affected oaks recover and produce new foliage the following spring, as we would generally expect for the consequences of a late season defoliator.

Hardwood trees on average can handle late season defoliation as the majority of the growing season has already taken place. However, several consecutive years of defoliation can eventually lead to long-term impacts. Stored food reserves can be depleted resulting in dieback or mortality by insect and diseases of secondary action. However, this has not been observed to date on bur oaks with repeated *Tubakia* infections. We will need to follow some of these trees to look for additional long-term impact.

Invasives & Exotics

(not established in Minnesota)

Firewood as a vector of invasive species

Expanding national and international trade and the movement of people across the United States has greatly increased the risk of invasive forest insects and diseases coming into Minnesota. Given the importance of state forest resources to local economies, plant and animal communities, and the quality of life for state residents, this is a major concern for the Minnesota DNR. Raw wood products or unfinished products with the bark left on have been involved in a number of introductions documented in the past. Past research and existing regulations focus on logs, solid wood packing material and wood pulp, but little attention had been paid to the movement of firewood, until recently.

Firewood is capable of moving a large number of forest pests. But the need to consider firewood movement has gained public attention only during this last year when a number of new infestations of the emerald ash borer (EAB) were traced back to recreational campers. As a result, Michigan, Ohio, Indiana, Wisconsin, and Canada have enacted new legislation to govern the movement of firewood into and within areas under their jurisdictions. There is considerable pressure for Minnesota to follow suit.

The movement of raw wood products is one of the primary means by which invasive insects and tree diseases are introduced into Minnesota. Expanding national and international trade, along with the rapid growth of national firewood suppliers and "big box" retailers, have increased the risk of disease and invasive insect introductions. Limiting the movement into Minnesota of raw wood products, including firewood, could decrease that risk.

Firewood can serve as a vehicle for a variety of forest insect and disease pests, including the fungi causing oak wilt and Dutch elm disease, wood stain fungi, gypsy moths, Sirex wood wasps, ambrosia beetles, bark beetles, and long-horned beetles. Although the movement of forest diseases and pests in firewood has been an ongoing concern, the approach of the emerald ash borer (EAB) has brought the issue to the forefront in Minnesota and nearby states.

The arrival of EAB in Minnesota is probably inevitable, but steps can be taken to delay introduction, primarily by limiting the importation of firewood from infested areas. Canada has banned the movement of all firewood (not just ash), with stiff penalties for knowingly moving firewood across the border. Michigan has banned the movement of all ash firewood. Previously, Wisconsin had launched a firewood information campaign, "If you bring it, burn it!" This year, the Wisconsin DNR dropped that particular message and has instead enacted a ban on all firewood originated from more than 50 miles away.

Minnesota campgrounds are one place where pests like gypsy moth and EAB can be introduced because of the transport of personal firewood supplies from infested areas. There are 637 campgrounds in Minnesota, 85 percent privately owned and 15 percent managed by DNR. As part of a one-day survey of 2005 state park campers:

- 56% of all campers brought their own firewood,
- 35% of out-of-state campers brought their own firewood.

Parks and Recreation Division reservation data indicates that about 14 percent of reservations come from out-of-state.

Visitors can also transfer personal firewood supplies long distances from other states during hunting, fishing, and other recreation trips. Nearly a quarter million nonresident hunting and angling licenses are sold in Minnesota each year. Recreation users in outdoor settings are often involved in several activities such as hiking, boating, camping, and ATV riding. Fire building may be a part of the recreation experience. It is likely that some of these out-of-state visitors are bringing firewood from home.

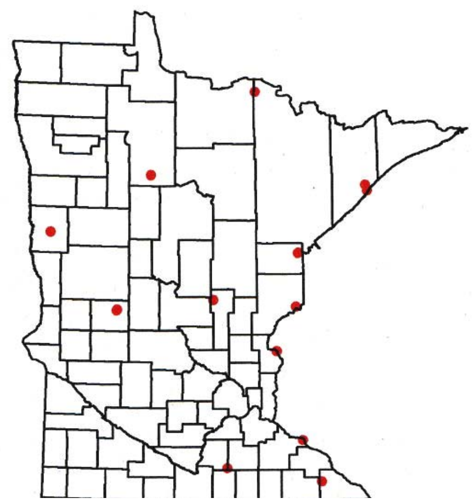
Limiting the movement of firewood into Minnesota will be challenging. The firewood business is diverse and dynamic, with small, medium, and large operations perpetually getting into and out of the firewood business. Larger commercial firewood businesses serve multi-state markets, with operators from as far away as Texas supplying firewood to national retailers and chain convenience stores.

To begin to describe the issues, the DNR Forestry Division and Minnesota Department of Agriculture have developed a list of Minnesota firewood processors. Preliminary efforts are underway to explore firewood pathways and educate industry representatives. The effort has recently been expanded to include commercial campgrounds. The DNR began a planning process this spring to address firewood coming onto DNR managed lands. The result of that effort to date is the review and possible revision of state statutes regarding forest pest prevention and management.

Emerald ash borer survey

Agrilus plenipennis

In cooperation with the Minnesota Department of Agriculture, the Forest Health Unit again participated in the early detection surveys for the Emerald Ash Borer (EAB). Twenty four ash trap trees were established on state land in fourteen state parks or state forest campgrounds. The trees that were peeled this fall showed no evidence of EAB. The remaining trees will stand through another growing season and will be peeled in the fall of 2007. At this time not all the trap trees may have been peeled, however to date nothing was found in the surveyed trees. We realize that our efforts are the proverbial ‘drop in the bucket’, however, one of our goal is to participate in the multi-agency detection surveys in Minnesota and in the Midwest.



Locations of DNR campgrounds where EAB trap tree surveys were conducted in 2006.

Gypsy moth survey

Lymantria dispar

The MN Department of Agriculture has proposed gypsy moth treatments this year across six different blocks, 5 in Cook County and one in Brooklyn Park in the metro area. The proposed treatments include four blocks totaling approximately 135,000 acres in Cook County to be treated with Disrupt II, a synthetic insect hormone that mimics the female sex attractant. If the treatments are approved, the other two blocks, approximately 2000 acres on the Grand Portage Indian Reservation and the small Brooklyn Park block, are to be treated with Btk, a biological insecticide approved for organic gardeners.

The treatments proposed are based on an assessment of the history of moth captures, local site conditions and treatment options covered in the Federal Environmental Impact Statement. Local environmental assessment and the final decision notices are under review. However, the DNR has already come out in support of the proposed treatments based on the potential environmental, social and economic costs associated with widespread gypsy moth infestations. We would like to delay gypsy moth establishment for as long as is feasible and we support the efforts of our sister agency toward that goal.

It is important to note that these proposals mark a decided change in the status of gypsy moth populations within the state from past years. Up until now, all of the treatments done have been relatively small (less than 2000 acres) and were carried out with the goal of eradicating small isolated populations located ahead of the expanding front of gypsy moth infestation. So the jump from the small infestations seen in the past to the 135,000 acres proposed for treatment in Cook County is a big one.

The size and distribution of the current population make it unlikely that it can be effectively eradicated. And actually the assumption that it will not be eradicated is consistent with the management goals of the National Slow-the-Spread (STS) program. Minnesota became an official member of the STS program in 2004, when Cook, Lake, Houston and Winona Counties were added to the STS action zone. The move signified how close the advancing front had moved to Minnesota and it represented a shift in management strategies, at least in those counties. While the state will continue to eradicate small populations where that is feasible, the goal of the STS program is to reduce (rather than eliminate) population peaks that threaten to coalesce and thus speed the rate at which the expanding front of infestation moves across the landscape. As such, eradication is not generally considered an STS objective. That is certainly true in this case, given the number of moths found in 2005 and the acreage involved in these proposed treatments.

Although, the gypsy moth is probably here to stay, it may be many years before quarantines are needed to prevent it's spread to other counties and even longer before local residents see any defoliation. However, that time frame is dependent on successful treatments to slow any population build up and on efforts to prevent any new introductions into the state. So continued diligence is needed by the MDA and her partner agencies.

2006 Gypsy Moth General Survey Program

Prepared by: Kimberly Thielen Cremers, Gypsy Moth Program Team Leader, MN Dept. of Agriculture

The Minnesota Department of Agriculture (MDA) was the lead agency during the 2006 gypsy moth detection survey program. Other cooperators, who set detection traps included the Three Rivers Park District (65 traps) in the Twin Cities metro area and the USDA FS (55 traps). Staff in the cooperative program set 19,039 delta traps across the state and 411 male moths were caught. In 2006, MDA hired a record high 47 seasonal staff. This group set and monitored 18,919 traps and covered 41 standard trapping routes.

The 2006 season marks Minnesota's third year as a formal member of the Slow the Spread (STS) Foundation. In 2004, Minnesota became a member of the STS Foundation when the STS action boundary moved into southeast Minnesota at the conclusion of the 2003 season, to include portions of Houston and Winona Counties. In the fall of 2004, due to increase in moth captures, 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 County. Then in 2005 and 2006 Minnesota felt some reprieve, the STS action boundary stayed constant in Cook and Lake County, but retreated a bit in SE Minnesota, dropping completely out of Wabasha County and only including a small portion of Winona County and all of Houston County.

For the 2006 trapping season, the state was divided into two distinctively different trapping regions, north and south, to account for the climatic differences within the state. The southern region began setting traps on June 5 and trap set was complete by July 7. The northern region's season was delayed by three weeks with trap set beginning on June 26 and ending on July 28. Traps remained in the field for five weeks in the south and 6 ½ weeks in the north. Trap removal for the south began on August 14 and was completed by August 31. Trap removal for the north began on September 14 and was completed by October 4.

Additional traps were set at state parks, mills, and nurseries within the standard trapping grid. Thirty-five of Minnesota's 72 state parks were within the standard trapping grid and received additional 1-2 traps each. Three moths were caught in state parks; all were on Minnesota's north shore. 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. Ten moths were caught at mill locations and 43 moths were caught at nurseries for the 2006 season. The ten moths caught at the mill locations were within the STS action area along the North Shore of Minnesota. Trap data surrounding the mill showed no correlation between the number of moths being caught and the activities of the mill operation rather the natural front of gypsy moth moving into that particular area. Trapping data surrounding the 43 nursery finds, on the other hand, did indicate some correlation with the activities of the nursery business.

Gypsy moth finds at Minnesota nurseries continues to be a problem. Thirty five percent of the 123 moths found in the southern one-half of the state were found at nursery operations. Ten nurseries in Minnesota accounted for the 43 moths found. Two of the 10 nurseries had greater than 10 moths captured at their place of business; one of the sites is under a Federal/State Compliance Agreement after alternate life stages (female moth and egg mass) were found during a follow up survey at the site. MDA continue to work with the industry to minimize their risks of transporting gypsy moth into the state.

Four mills (three pulp and one saw mill) and one nursery are under Federal/State 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. Thirty six 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.

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 123 of the total number of moths captured. See map. In the southeast (Houston, Winona, Olmsted, Wabasha Counties), an area, prior to 2005 that has had consistent increase in moth numbers in the past decade, only ten moths were caught. This is the second consecutive year with record low moth numbers in the SE. Prior to the 2005 season, the last time moth numbers were this low was in the early 1990's. Areas of concern in the central and southern part of the state, included one delimit site near Cambridge that had two traps with 11 moths, one standard detection trap in Hopkins that had five moths and a site near Shokopee that had one trap with three moths and an adjacent trap with a single moth. These sites will be delimited during the 2007 season.

The majority of the moths caught in Minnesota, 68%, were confined to the two far NE counties of the state (Lake and Cook). This was no surprise after a record 1,077 moths were caught in Cook County in 2005. There had been an increase in moth captures, from about 25-30 for the entire county since 2000, to 193 moths in 2004, then 1,077 moths in 2005. Moth numbers for Cook County are down with only 210 moths being captured. This decrease is associated with the 138,000 acres treated in Cook County during the 2006 season. Only three moths were caught within the treatment blocks however, moth numbers continue to climb in areas surrounding the blocks. Data is being evaluated at this time and MDA will be working closely with the agencies responsible for the management of lands within these areas to determine management strategies for 2007. It is likely that treatment proposals will be forthcoming.

General Treatment Program

2006 was a record breaking year for gypsy moth treatments in the state of Minnesota. Approximately 138,000 acres were treated in the state for gypsy moth. This is a drastic increase from the past five year's average of 760 acres annually. As the gypsy moth front moves closer to Minnesota treatment acreage is expected to increase to meet the overall statewide objective of decreasing natural spread rates of approximately 15 miles per year to less than 6 miles per year. Prior to the 2006 season, the cumulative total treated acreage was just over 4,700 acres (from 1980-2005). Majority of the historical acreage were within the Eradication phase of gypsy moth management. This year alone we surpassed the state's historical summation of acres by 29 times mainly resulting from the natural population front and the STS Action Area moving into Minnesota from the east.

Many challenges were met with this year's treatment program. Not only did Minnesota treat a historical high amount of acreage the treatment blocks were spaced out across two geographically separate counties; Cook and Hennepin (235 miles apart), two different management zones; Eradication and Slow the Spread, and crossed into multiple land jurisdictions; Indian Reservation, National Forests, state parks/forest, county, city, and private lands.

There were two Btk blocks and four mating disruption blocks across the state. One Btk block was within the Eradication zone in Hennepin County and the second Btk block and the four mating disruption blocks were in Cook County within the STS Action Area. There were three distinctly different application periods; mid-May, early-June, and late July due to the geographical distribution of the blocks and the treatment product utilized.

Two separate Environmental Assessments (EA) were completed with three separate decision notices (DN) one for Grand Portage Indian Reservation, one for Superior National Forest, and a third to cover all other lands-state, county, city, private,etc.

ERADICATION: (58 total acres)

Btk Treatments:
One site within the Twin Cities metropolitan received two applications of Btk, spaced seven days apart. In the fall of 2005 an egg mass was found within the treatment block. This was a small site of 58 acres, within Hennepin County in the city of Brooklyn Park. The site was highly urbanized and composed of several single family homes, a town home development, several apartment complexes and a city park. Treatments were conducted on May 16 and 23, 2006. Both applications were conducted by helicopter. An EA was not conducted at this site due to the fact the treatment was covered 100% by state funds, and was not required by state regulations.

To determine treatment success, the treatment block was trapped on a 250 meter grid density with the core surrounding the egg mass find at 3/acre. Four gypsy moths were caught during the 2006 season; three within the treatment block and a fourth just outside the treatment block within the delimit boundary. However, a second year of intensive trapping is needed to make certain the treatment was a success or failure.

SLOW THE SPREAD: (137,677 total acres)

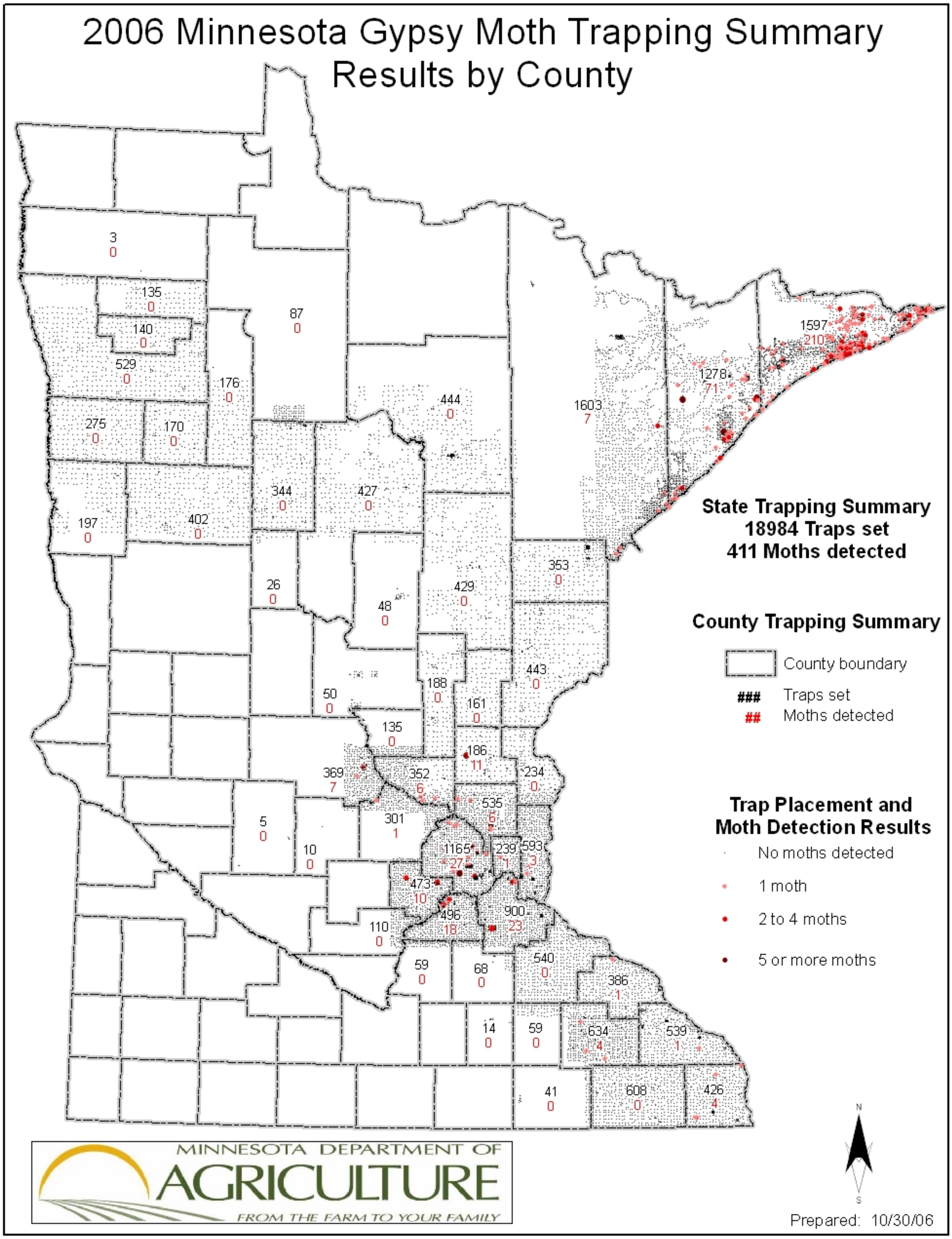
Btk Treatments:
One site in NE Minnesota, Cook County, within the STS Action Area received two applications of Btk, spaced 7-10 days apart. This was a 2,015 acre block within the Grand Portage Indian Reservation. This site was almost completely forest covered with no resident living within the block. There was one road that ran parallel to the bottom 1/3 of the block. Treatments were conducted on June 8 and 15, 2006. A separate EA and DN/Finding of No Significant Impacts was conducted and signed for this particular site. Funding for this project was covered 100% by STSF funding.

To determine treatment success, the treatment block was trapped on a 250 meter grid density. Thirty-three traps were set and only one gypsy moth was caught during the 2006 season. With only one moth being recovered it is likely that this treatment was successful, however, a second year of intensive trapping is needed.

Pheromone Flake Treatments:
135,662 acres were treated with pheromone flakes in 2006. The four Mating Disruption blocks in Cook County were the Shroeder Complex, 90,697 acres; Tom Lake, 35,797 acres; Farquhar Peak, 5,539 acres; and Kadunce River, 1,242 acres. Each block was treated utilizing the 6 grams of active ingredient per acre. Applications occurred on July 24, 25 & 26, 2006. Applications were moved up one week due to unseasonably warm conditions and the advancement in moth development in the Madeline Islands of WI. In just 2 ½ days all 135,662 acres were treated. Follow up trapping was conducted at the pheromone flake sites at a 2 km trap density and three moths were recovered within the Schroeder Complex block.

EGG MASS SURVEYS:

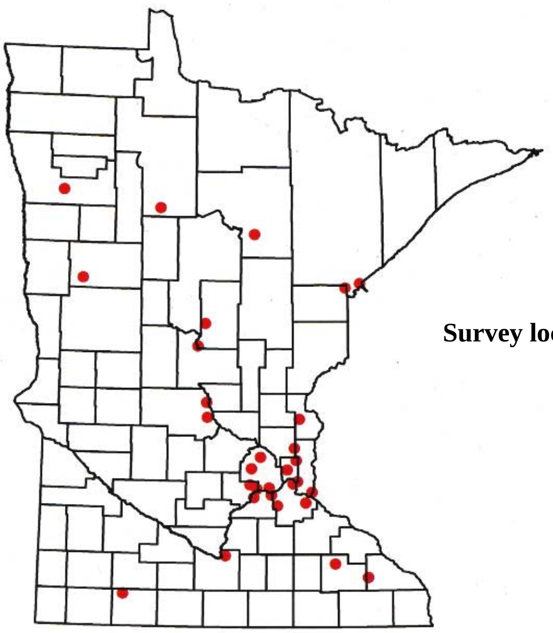
Several surveys were conducted in the fall of 2006, in response to relatively high numbers of moths trapped in several locations across the state. Only one site near the city of Cambridge (Spectacle Lake) warranted an egg mass survey. The survey was conducted on October 19, 2006 and no egg masses were found at the site. This site will receive intensive trapping during the 2007 season. In addition to the egg mass survey conducted in the Twin Cities metro area, several site surveys were conducted in Cook County surrounding several high find locations. No egg masses or alternate life stages were identified during this survey.


2006 Minnesota Gypsy Moth Trapping Summary
Results by County
State Trapping Summary
18984 Traps set
411 Moths detected
County Trapping Summary
County boundary
Traps set
Moths detected
Trap Placement and
Moth Detection Results
No moths detected
1 moth
2 to 4 moths
5 or more moths
MINNESOTA DEPARTMENT OF
AGRICULTURE
FROM THE FARM TO YOUR FAMILY
Prepared: 10/30/06

Sudden oak death pathogen survey

Phytophthora ramorum

For the third consecutive year, DNR of Forestry participated in the national *Phytophthora ramorum* survey. Field surveys were conducted adjacent to several major nurseries and in rural forested areas around the state. Thirty sites were surveyed in twenty-one Minnesota counties**.** Samples were collected from hosts known to be susceptible to *P.ramorum.* 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. Again, all were negative for *P. ramorum* by PCR testing.



Survey locations 2006 SOD Survey.

Abiotic agents

Ash decline

Ash decline continues to be a concern both because of the loss of the ash and because decline symptoms could hide or mask the emerald ash borer once it enters Minnesota. Ash decline and mortality was mapped by aerial survey on 27,000 acres in 2004, on 4322 acres in 2005 , an on an additional 662 acres in 2006. These reported acres may be just the tip of the iceberg since forest managers from many different agencies seem to feel that most of their black ash is in a state of decline. Site and weather conditions are still considered to be the primary factors that have stressed and /or killed the trees rather than any particular insects or pathogenic fungi. The significant drought that started in the spring of 2006 (and still continues) will hinder recovery and likely increase and intensify the decline.

Aspen mortality

In 2005, 587 pockets of aspen with thin foliage were mapped during the aerial survey in northern Minnesota totaling 410,500 acres. This was thought to have a number of causes including late spring frosts, and insect defoliation. But the most likely cause in northeastern Minnesota was thought to be stress from past years of forest tent caterpillar defoliation and drought. Drought returned in 2006 adding to the stress and it appeared that, at least in some cases, it had lead to tree mortality.

Scattered aspen mortality was seen along Hwy 135 north of Aurora, east of Ely along the Fernberg trail, and along Hwy 1 between Ely and Isabella. Mortality of paper birch was obvious along Hwy 1 between Ely and Isabella as well. Mortality appeared to be mostly where aspen was growing on top of rock ridges. This aspen mortality consisted of mostly individual trees and was apparently too light and scattered to be picked up on the aerial survey earlier this summer.

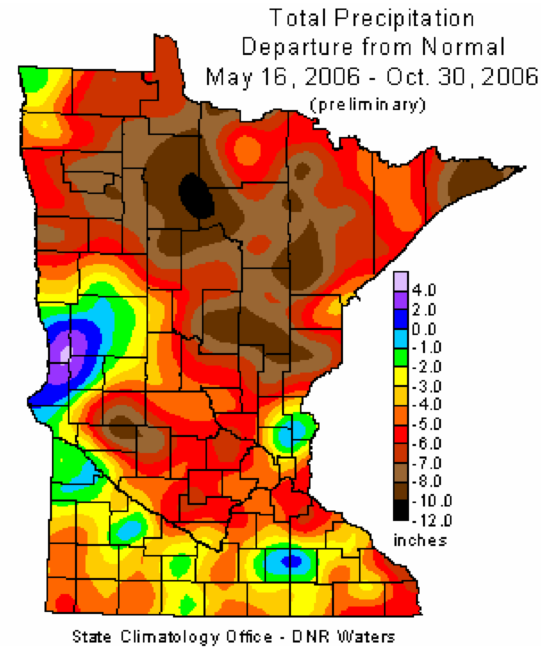
Drought

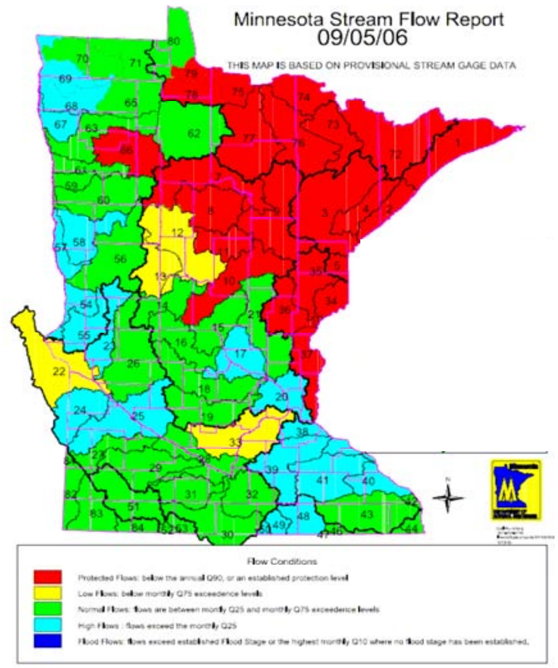
Even though the spring and summer were abnormally dry, leaves on most trees did not show symptoms of being under drought stress through most of the summer. Moving into August, however, symptoms of drought started to appear. Leaves on many species of hardwood trees in Cass County along Hwy 46 through the Chippewa National Forest were turning brown and crispy. The leaves on black ash were staying attached to the trees. This was also evident on the eastern end of the Iron Range where birch trees growing on ridge tops were turning brown and dropping their leaves.

It was very dry in the northern counties; here are some of the facts:

- Growing season precipitation levels were well short of the historical averages for much of the northern 2/3rds of Minnesota, deviating by more than 4 inches in most areas. See map on next page.
- Rainfall deficits exceeded 6 inches in many areas. This is the equivalent of receiving ZERO rainfall for the entire month of June and half of July. Deficits exceeded 10 inches in Blackduck Area.
- When compared to other years, this year's rainfall totals rank among the lowest ever recorded in northern counties.
- The USGS indicated that the stream discharge values for most streams and rivers ranked below the 25th percentile and, in many cases, they ranked below the 10th percentile. See map on next page.

(Thanks to Greg Spoden, State Climatology Office-DNR Waters, for the data, map and drought information.)





Heavy seed set on red maple and elm

Very heavy seed set occurred on red maple and elm in Itasca and St Louis Counties. As of June 13th, many of the red maple trees still had very small and sparse leaves.

Oak tatters

In 2006, oak tatters symptoms were found in Goodhue, Stearns and Sherburne Counties, as well as, in the Metro Area. Newly emerged leaves of oak trees have reduced inter-veinal tissues, which gives leaves a lacy or tattered appearance. From a distance trees may appear to be light in color or to lack leaves. The symptoms appear at the time of leaf emergence, generally in late May. In the landscape tatters is the most visible in early June as adjacent unaffected oaks develop healthy leaves. The oaks with tattered leaves appear lighter in color than oaks with unaffected leaves. The damage is often evenly distributed throughout the entire crown, but sometimes may be greater in the lower crown. It may affect all sizes and ages and whole stands of trees in woodlands or urban landscapes. Adjacent woodlands and trees may be unaffected. Within a few weeks, affected trees will produce a new flush of leaves that are free of the tatters symptoms. Oak tatters has affected primarily the white oak group, including white, bur, and swamp white. Trees in the red oak group are occasionally affected in Minnesota. Hackberry trees are rarely display symptoms of tatters.

Since oak tatters appear on newly expanding leaves, it seems to be caused by damage to leaf tissue inside the buds or to damage as the bud is expanding. Choloracetamide herbicides have been shown to produce tatters symptoms, but other factors have been suggested as potential causes. These include low temperature damage to buds or young leaves, insect damage, wind injury and desiccation. Some of the oak tatters observed in the Central Region this spring were in areas where herbicide damage was extremely unlikely.

Last year, an effort was made in southern Minnesota to link reports of tatters to possible herbicide drift from nearby cornfields. In two separate areas, where tatters symptoms did develop on oaks, mid-season investigations found that fields adjacent to the affected oaks received applications of Harness Xtra. In 2006, an oak tatters site in Goodhue County was field checked on May

30th. Apparently, on May 17th, the adjacent cornfields were sprayed with Keystone LA and Hornet, a combination that is the same as Harness Extra herbicide.

A single definitive cause of oak tatters symptoms has yet to be found. Perhaps, one or more of the aforementioned agents can cause tatters symptoms as oak leaves are expanding in the spring.

Tamarack turning brown

By late August and early September many tamaracks in northeastern Minnesota had turned brown. Some of the trees actually started turning brown in early August. In examining brown needles on these trees in September, no needle mining was found which ruled out the larch casebearer. Most of these brown trees appeared to be near road ditches. Trees farther into stands away from the roads appeared to be turning the more normal yellow with the typical timing, later in September. On the brown trees examined, some of the buds appeared to be green and healthy but many others were brown and dead. When bark was stripped off branches on these trees, the tissue appeared to be more tan in color with less green tissue than was found on more normal looking trees farther from the roads. Eastern larch beetles were not found in the lower trunk when trees were examined, however, trees were not cut down to look for the beetles higher on the trunks. In November, woodpeckers started stripping bark from the boles of some of these trees indicating that bark beetles were likely present higher in the trees. Drought is also suspected to be playing a role in this browning since many of them were near roads rather than farther into stands.

White spruce mortality and decline in plantations

Mortality and decline were observed in a number of plantations throughout northeastern Minnesota. Multiple factors seem to be involved including drought, defoliation, secondary organisms, etc. Needle loss due to spruce budworm or Rhizosphaera needlecast or, in some cases, a combination of both reduced growth and vigor. *Rhizosphaera* appears to have caused as much defoliation in some of the 30 year old and older plantations as spruce budworms have caused in others. Northern spruce engraver beetle, *Ips perturbatus,* was found in dead and declining trees in some plantations and a weevil, likely the small spruce weevil *Pissodes rotundatus*, was found in others. Armillaria root disease was easy to find on dead trees and might be playing a role as well. These plantations were affected by droughty weather in 2002 and 2003.

In addition to the pest problems, lack of timely management is likely part of the problem. Some of these plantations have been thinned and others have not. As white spruce plantations reach 30+ years of age, their growth slows, their vigor declines, and their live crown ratio can decline to as little as 25%. As their vigor declines, they pick up multiple pests that cause further stress and can lead to mortality. The thinned plantations showing problems were 30+ years old when thinned and have been slow to respond to the thinning. Mortality continues even five years after the thinning in some plantations. In order for white spruce to respond rapidly, thinning should occur while they have a good live crown ratio and before the trees have accumulated too many pests and stresses.

Phenology 2006

Date	Event	County
4/ 27	*Amelanchier* and sugar maples in full bloom. Aspen leaves > 1 inch long. E. of Walker.	Cass
4/ 28	Marsh marigolds are blooming. Aspen leaves < 1 inch long. Blackduck.	Itasca
5/ 1	White pine blister rust: aecial spores being shed. Whitefish Lake.	Crow Wing
5/ 2	*Amelanchier* starting to bloom. Jack pine candles are about 1 inch long. Also blooming: N. sweet coltsfoot, fly honeysuckle, prickly gooseberry, sugar maple, pin cherries. Leatherwood just done blooming. Grand Rapids.	Itasca
5/ 2	Red elderberry just beginning to bloom. Pine River.	Cass
5/ 2	Hundreds of red turpentine beetles “swarming” near log deck. Hoary puccoon is blooming. Badoura.	Hubbard
5/ 5	Snowed for 30 minutes today. *Amelanchier* in full bloom.	Hubbard
5/ 5	*Hepatica* starting to bloom. Grand Rapids.	Itasca
5/ 9	Bigtooth aspen leaves are emerging and are light sage green. Trembling aspen leaves still lime green. *Amelanchier* and marsh marigolds still blooming. North of Deer River.	Itasca
5/ 9	Violets blooming.	Lake of the Woods
5/ 10	Birch leaves emerging. Bur oak buds expanding, some tiny leaves visible. Starting to bloom: *Trilliums*, large-flowered bellwort, *Anemone* and wild strawberry. *Thalictrum* still in bud stage.	Cass and Hubbard
5/ 10	Jack pines have no male cones. Candles < 1 inch long. LaPorte.	Hubbard
5/ 16	Aspen seeds/ fluff is flying today.	Lake of the Woods, Beltrami, Marshall
5/ 17	Jack pine cone clusters very rare (< 1/1,000 shoots). Bur oaks are flowering. Hoary puccoon is till blooming. Eckles Tnshp.	Beltrami
5/ 25	Two mornings of sub-freezing temps last week. Oaks lost all of their new leaves.	Carlton
6/ 4	A few forest tent caterpillars were observed, only as singletons.	Beltrami, Hubbard
6/ 9	Blooming: blue flag iris, showy lady slippers and yellow lady slippers beginning.	Cass, Itasca
7/ 9	Jack pine budworm moths are flying in red pine study plot.	Southern Cass

Special Projects

Diplodia latency studies at State Nurseries

Final report on *Diplodia* latency studies in plantations

Final report on *Diplodia* shoot blight infections at Itasca State Park

Diplodia disease spread in restoration cut near Norris Camp

Red pine regeneration recommendations based on *Diplodia* studies

Firewood survey in North Shore state parks

Hickory mortality study

Jack pine budworm and ecological classification connections

Jack pine regeneration mortality in Wadena County

Red pine turpentine beetle study

White spruce cone pests

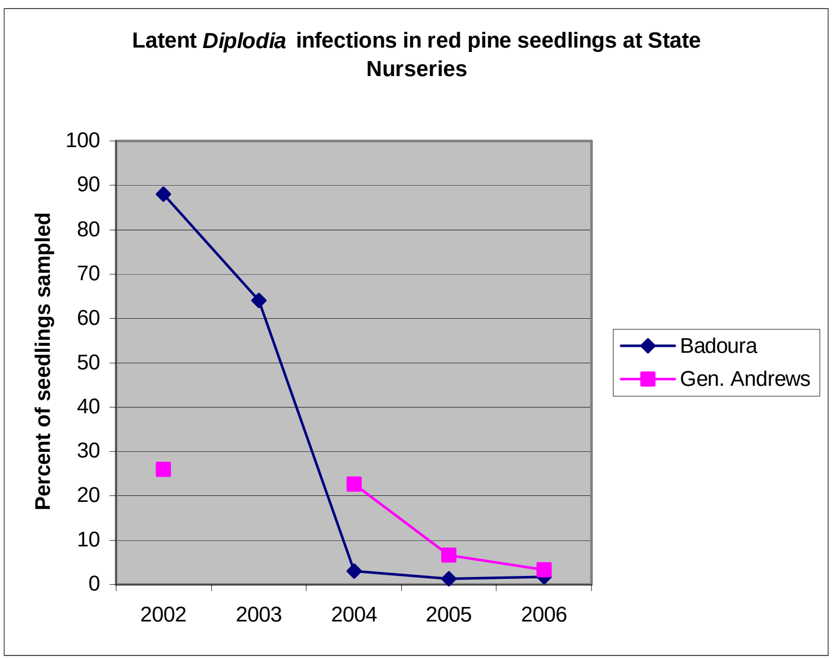
Diplodia latency studies of red pine nursery stock from State Nurseries

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 2006. All red pine seedlings were sampled in a systematic design and assayed by Dr. Stanosz's lab at the University of Wisconsin.

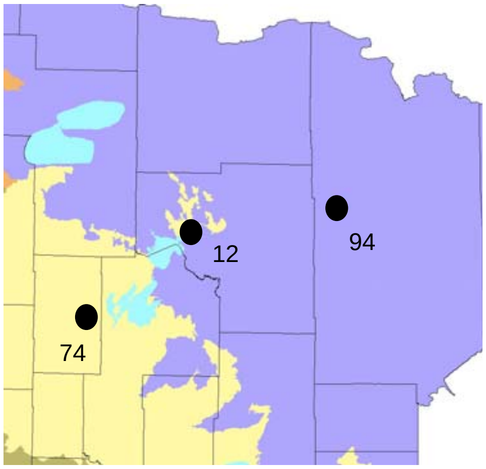
Results of *Diplodia* latency studies at State Nurseries in 2006

Location	Sample date	Seed-beds	Number of seedlings sampled	Number of latent infections found	Percent latent infections	Species determination	Notes
Badoura	Aug. 15	A8 (2-0)	120	0	1.67	Not done this year.	None.
		A9 (2-0)		1			
		A11 (2-0)		0			
		E10 (2-0)		0			
		E11 (2-0)		1			
Gen. Andrews	Aug. 16	F8 (2-0)	180	1	3.34		
		F9 (2-0)		3			
		D8 (3-0)		2			
		D9 (3-0)		0			

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. Seedlings were not sampled in 2003 at GASN. Windbreaks continue to be removed at GASN.



Diplodia latency studies: 2005 and 2006



At the outset of the two large *Diplodia* studies conducted from 2004 through 2006, we wanted to know:

1. How far and wide are *Diplodia* species distributed in red pines across northern Minnesota,
2. Are the amounts of overstory infections related to the amounts of symptomatic infections in the understory or adjacent plantations,
3. What is the total disease "load" in a plantation, given that *Diplodia* can cause symptomatic and latent infections, and,
4. Can any observable variable be used to predict total disease load or the amount of latent infections in a plantation.

A report, "Evaluating *Diplodia* species: shoot blight potential in overstory red and jack pine seedlings" covers the answers to questions 1 and 2 based on data gathered in 2004 from 100 sites. In 2005 and 2006, we answered questions 3 and 4 based on data gathered on 3 sites.

Methods and Materials

In 2004, 103 red pine sites were visited with the aim of determining inoculum levels (cone infection) in the overstory red pine stand, shoot blight incidence in plantation seedlings and the furthest distance that shoot blight could be found from the overstory edge. In 2005, three of these sites were selected based on the absence of confounding inoculum sources and the presence of shoot blight infections in the plantation in 2004. See map**.** Site 74 is the western-most site, April to August rainfall is 15.6 inches, and is found in the central floristic zone. Site 94 is the eastern-most site, April to August rainfall is 14.4 inches, and is found in the northern floristic zone. Site 12 is between these two, April to August rainfall is 14.6 inches, and is located in an area where central and northern floristic zones are intermingled. Sites 74 and 94 are separated by 98 miles.

Each site was visited in 2005 and revisited in 2006, two transects parallel to the overstory edge were established at varying distances based on the geography of the site. See Tables 1 and 2 below. Along each transect, a single, asymptomatic, current shoot was collected on the side of the tree facing the overstory. One shoot from fifty seedlings were taken along each transect. Each shoot was sealed in a plastic bag and kept in a cooler until being prepared for lab analysis at University of Wisconsin by Dr. Glen Stanosz. If a current shoot was blighted anywhere else on a sampled seedling, the seedling was tallied as a blighted seedling. In 2006, there were several insects and diseases causing shoot blight in the studied plantations. To estimate the amount of *Diplodia*-caused shoot blight in each plantation, blight transects were taken at 12, 62, 112, 162, 212 and 262 feet, and all shoot blight samples were collected. To be called *Diplodia* shoot blight, samples were verified by the presence of *Diplodia* spores in the lab. Pooled data from the first three blight transects were used to estimate the percentage of seedlings that had symptomatic *Diplodia* shoot blight in transect 1. Similarly, pooled data from the last three blight transects were used to estimate *Diplodia* shoot blight percents in transect 2.

Table 1. 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	14	6
74	Hubbard Co. S19-T142-R32	61 %	All *D. pinea*	66	132	51	52	7	8
94	St. Louis Co. S16-T60-R20	7 %	All *D. pinea*	116	248	50	50	5	3

Table 2. Latency study 2006: Location, cone infection and sampling information.									
Site	Location	Percent cone infection in 2006	*Diplodia* species recovered from seedlings	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	38	One was *D. scrobiculata* remainder were ***D. pinea.***	148	248	50	50	9	5
74	Hubbard Co. S19-T142-R32	58	All *D. pinea*	66	132	50	50	16	18
94	St. Louis Co. S16-T60-R20	8	All *D. pinea*	116	248	50	50	4	2

One hundred cones on the ground were collected in 2004 from the ground from each of the three red pine stands. 2006 was a poor cone production year, so only a few dozen cones were collected. In both years, each cone was determined to be either “infected” or “not infected” by *Diplodia* spp. by examining spores taken from fungal fruiting bodies.

Data was analyzed by use of linear regressions and regression trees are used to depict statistically significant relationships among variables.

Results and Discussion

Appendix 1 presents the data compiled for 2005 and 2006. For data analysis, each seedling in a transect was sorted into one of four categories: no infection found (clean), only latent infection found, only shoot blight infection found and both latent and shoot blight infections found. The total amount of shoot blight in a transect was determined by adding two categories, the percent of seedlings with only shoot blight and the percent of seedlings with both latent and shoot blight infections. Similarly, the amount of latent infections in a transect was determined by adding two categories, the percent of seedlings with only latent infections and the percent of seedlings with both latent and shoot blight infections. Total disease in a transect was determined by subtracting the percent of clean seedlings from 100%.

The percent of infected cones collected in 2004 was similar to the percentages found in 2006. See Table 3. Of the 184 cones that returned positive cultures, only one was identified as *Diplodia scrobiculata*, the remainder were *Diplodia pinea*.
There was a great deal of variability in the amount and type of Diplodia infections found in plantation seedlings. See Figure 1. The amount of latent infections always exceeded the amount of shoot blight infections in the same transect, and, in some instances, latent infections were found six times more frequently than shoot blight infections.

Table 3. Percent of *Diplodia* infected cones found on three sites in 2004 and in 2006.		
Site	**2004**	**2006**
12	45	38
74	61	58
94	7	8

The total disease load in seedlings was also variable, ranging from 0.6% to 92.2%. Where a low percentage of cones are infected, low levels of disease occur; where a high percentage of cones are infected, high levels of disease occur. In each year there was a significant relationship between infected cones and total disease. See Figure 2. The equations describing the relationship between cones and total disease load are not exactly the same for 2005 and 2006. Infection levels were much higher in 2005. Differences in rainfall might reasonably be invoked to account this. Since the spores are spread in raindrops, the year with higher rainfalls should experience a higher level of infections.

We wanted to determine if a measurable, site variable had a significant relationship with infection types and total amount of infections in the plantations. That way, we might be able to predict the amount of latent infections or the total disease load in the plantation. See Table 2. In 2005, there was a significant relationship between the percent of latent infections in each transect and the percent of infected cones. In 2006, it wasn’t significant. In 2006, there was a significant relationship between the percent of shoot blight infections in each transect and percent of infected cones. In 2005, it wasn’t significant. In 2006, there was a significant relationship between the percent of shoot blight and the percent of seedlings with any type of infection. In both years, there was a significant relationship between the percent of seedlings with both types of infection in each transect and the percent of infected cones. A fortuitous find because the Diplodia disease load can be predicted by the percent of infected cones on a site, whether or not a plantation currently exists there.

Table 4. P-values of linear regression equations for variables in 2005 and 2006. The relationship is significant when p< 0.05			
Independent variable (x)	Dependent variable (y)		
	Percent of seedlings with latent infections (totlatent)	Percent of seedlings with shoot blight (totblt)	Percent of seedlings with both types of infection (totdis)
2005			
Percent of infected cones	0.004	0.271	0.004
Percent of seedlings with shoot blight	0.419	-	0.250
2006			
Percent of infected cones	0.085	0.019	0.004
Percent of seedlings with shoot blight	0.071	-	0.031

In 2004, the percent of infected cones was significantly related to the amount of shoot blight infections (p = 0.008). (Latency and total disease percents were not determined in 2004.) From 2004 to 2006, there seems to be a pattern to the significance of percent cones infected to shoot blight infections and latent infections. In 2004 and 2006, the weather was dry during the summer; precipitation was less than 80% of normal as of August 1st . In 2005, the weather was near normal; precipitation was 80 to 110% of normal. When the weather is dry during the summer, shoot blight infections are significant and latent infections were not. When the weather is within the normal range, latent infections are significant and shoot blight infections are not. Rainfall seems to have an effect on significance of the type of infection that is expressed each year.

Using Classification and Regression Tree Analysis, both the amount of latent infections and the disease load in plantations can be roughly estimated from observable variables. In 2005 and 2006, the percent of latent infections can be split into two classes based on the observed levels of shoot blight in the plantation. See Figure 3. When the percent shoot blight is less than 12%, the amount of latent infections will also be low, averaging 10.8%. In 2005 and 2006, the total amount of disease in a plantation can be divided into two classes based on the percentage of infected cones found in an adjacent stand. See Figure 4. When the percent of infected cones is less than 45%, then the total amount of disease will be low, averaging 14.3%.

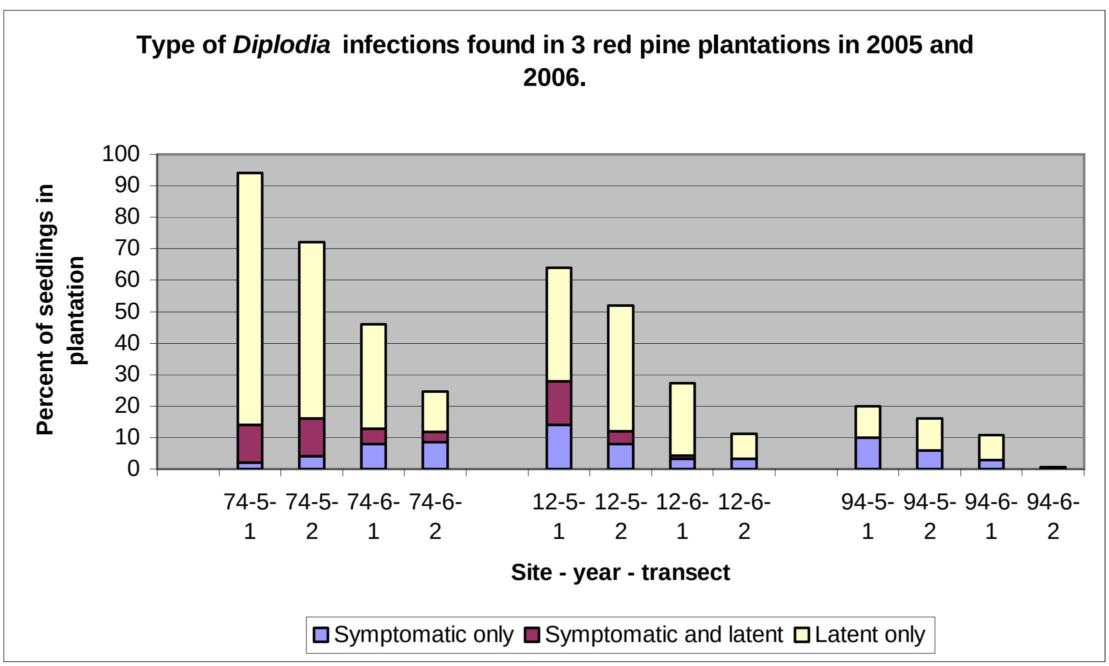


Figure 1.

Figure 2.

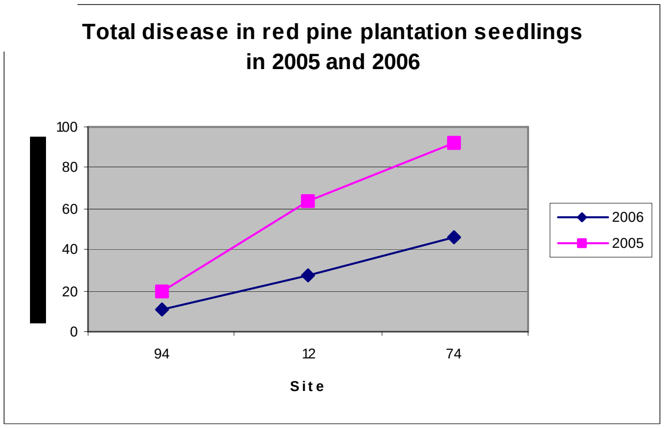


Figure 3.

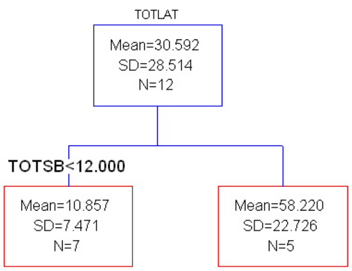
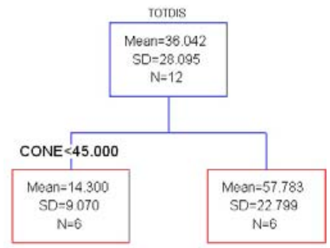


Figure 4.



Appendix 1. Database: Percents of 4 infection types of *Diplodia* spp. on red pine seedlings, cone infections, 3 sites, each site has 2 transects, in 2005 and 2006.

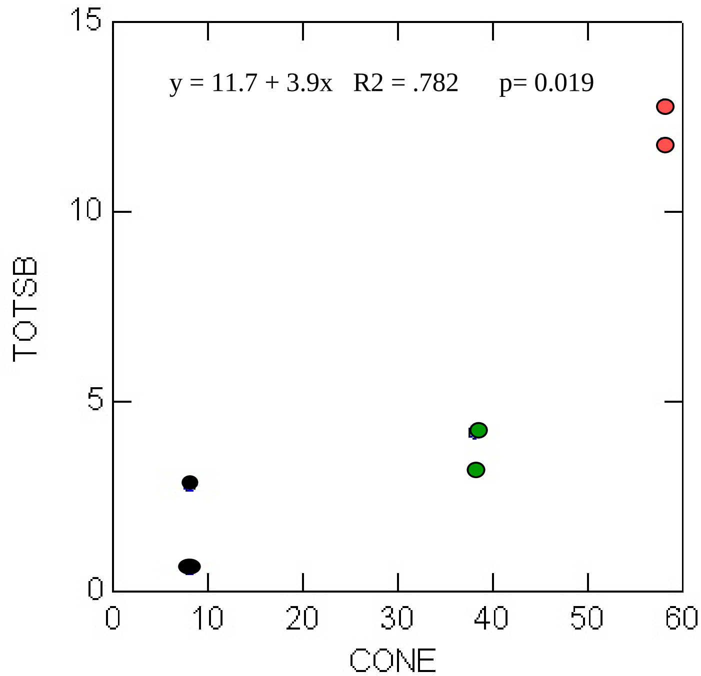
SITE$	CONE	SBLAT	LAT	SB	CLEAN	YEAR	SITEYRTR$	TOTLAT	TOTSB	TOTDIS
74.000	61	11.8	78.4	2	7.8	5	74-5-1	95	13.8	92.2
74.000	61	11.3	52.8	3.8	32.1	5	74-5-2	64.1	15.1	67.9
74.000	58	4.8	33.2	8	54	6	74-6-1	38	12.8	46
74.000	58	3.2	12.8	8.6	75.4	6	74-6-2	16	11.8	24.6
12.000	45	14	36	14	36	5	12-5-1	50	28	64
12.000	45	4	40	8	48	5	12-5-2	44	12	52
12.000	38	1	23	3.2	72.8	6	12-6-1	24	4.2	27.2
12.000	38	0	8	3.2	88.8	6	12-6-2	8	3.2	11.2
94.000	7	0	10	10	80	5	94-5-1	10	10	20
94.000	7	0	10	6	84	5	94-5-2	10	6	16
94.000	8	0	8	2.8	89.2	6	94-6-1	8	2.8	10.8
94.000	8	0	0	0.6	99.4	6	94-6-2	0	0.6	0.6

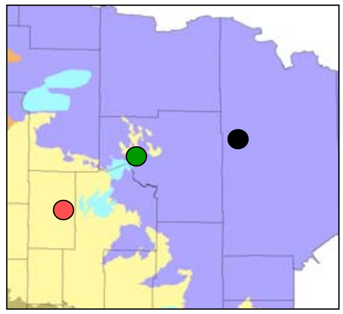
Appendix 2: 2006 data and analysis.

In 2006, there were several insects and diseases causing shoot blight in the studied plantations. To estimate the amount of *Diplodia*-caused shoot blight in each plantation, blight transects were taken at 12, 62, 112, 162, 212 and 262 feet, and all shoot blight samples were collected. To be called *Diplodia* shoot blight, samples were verified by the presence of *Diplodia* spores in the lab. Pooled data from the first three blight transects were used to estimate the amount of seedlings that had symptomatic *Diplodia* shoot blight in transect 1. Similarly, pooled data from the last three blight transects were used to estimate *Diplodia* shoot blight in transect 2.

2006 was a poor cone production year, so only a few dozen cones were collected from the ground from each of the three red pine stands. Each cone was determined to be either "infected" or "not infected" by *Diplodia* spp. by examining spores from fungal fruiting bodies.

A. The percent of infected cones can predict the amount of shoot blight in plantations seedlings (between 66 and 248 feet).





B. Based on the 2006 datat, significant relations were as follows:

a. The percent of cones infected by Diplodia can be used to predict the percent of
   11. seedlings with shoot blight
   12. seedlings with both shoot blight and latent infections
   13. seedlings without infections.

b. Unfortunately, the percent of infected cones did not predict the amount of latent infections as it did last year.

c. The percent of seedlings without infection can predict all three types of seedling infections.

Significant relationships as determined by linear regression in 2006			
	P value	R^2 value	Linear equation
X = percent of cones infected			
Percent of all seedlings with symptomatic shoot blight infections (See graph above in item 3.)	0.019	0.782	Y = 11.7 + 3.9x
Percent of all seedlings with shoot blight and latent infections	0.042	0.686	Y = 20.9 + 9.1x
Percent of all seedlings without any type of infection	0.048	0.664	Y = 126.0 – 1.1x
X = Percent of all seedlings without any type of infection			
Percent of all seedlings with latent infections	0.000	0.980	Y = 98.1 – 1.1x
Percent of all seedlings with shoot blight and latent infections	0.016	0.798	Y = 90.4 – 7.0x
Percent of all seedlings with symptomatic shoot blight infections	0.031	0.728	Y = 95.0 – 2.7x

Diplodia studies at Itasca State Park   2004 to 2006

Itasca State Park is having difficulty regenerating red pine in spite of excellent site preparation using prescribed fire on suitable sites with good seed sources. Questions remain regarding the influence of animal browse or shrub competition and environmental parameters such as duff depth and amount of light reaching the forest floor. Until 2004, no one had looked into the possibility that diseases could be having a deleterious influence on red pine regeneration. From recent studies and surveys elsewhere in Minnesota, we know that *Diplodia pinea* can have a huge effect on nursery seedlings and the success of outplanted seedlings due to its ability to cause latent infections. Internal water deficits, such as those caused by droughty weather, release latent infections to cause disease symptoms and seedling death.

Purpose:
To determine if live, containerized red pine seedlings could be used to "catch" *Diplodia* spores and produce disease symptoms by placing the seedlings under overstory red pine trees. This might indicate the presence and, perhaps, level of *Diplodia* inoculum in the stand. Fallen cones were also collected to provide another determination of the amount of inoculum in the stands.

Methods and materials:
In May of each year, containerized seedlings were placed in five red pine stands and one hardwood stand in Itasca State Park. There are no red pine seedlings or saplings in any of the stands. All of the red pine stands are classified as FDc34 in Minnesota's ecological classification scheme.

Blocks of containerized seedlings were produced in a greenhouse and had never been exposed to overstory pines, the predominant source of *Diplodia* inoculum. Two locations in each stand received a half- block containing approximately 90 seedlings. Seedlings were watered and monitored weekly then collected in mid-July. Overall, seedlings broke bud and grew 2 to 3 inches in height during that time and set new buds. The blocks of seedlings were stored in a sunny garage and watered for one more month. After that they were allowed to dry out, giving the latent infections an impetus to cause disease and produce fruiting structures.

Once the root mass had completely dried out, 50 seedlings were collected from each half block. Each seedling was examined using binocular scopes for the presence of classic shoot blight symptoms, internal stem and root collar symptoms, presence of *Diplodia* pycnidia and other damaging agents. For this report, seedlings that showed no external symptoms of *Diplodia* infection but did produce *Diplodia* fruiting bodies after being drought-stressed will be termed "latently" infected seedlings.

100 fallen red pine cones were collected in mid-November 2004 under the overstory red pines where the seedlings were set out earlier in the year. Efforts were made to collect the youngest, freshest cones. In the lab, each cone was visually inspected for the presence of *Diplodia* infections. Each cone was tallied as either infected or uninfected. Infections were verified by microscopic examination of the pycnidia and spores.

Results and discussion:
In all three years, a few containerized seedlings exposed to overstory red pine trees for eight weeks in the spring exhibited shoot blight symptoms of *Diplodia* infection. The amount of blighted seedlings averaged 9.8 %. See Table 1. Using in containerized seedlings, the presence of shoot blight can indicate that *Diplodia* is present in the red pine overstory.

Table 1. Percent symptomatic and asymptomatic *Diplodia* infections in containerized red pine seedlings from 2004 to 2006 and percent infected red pine cones in 2004.

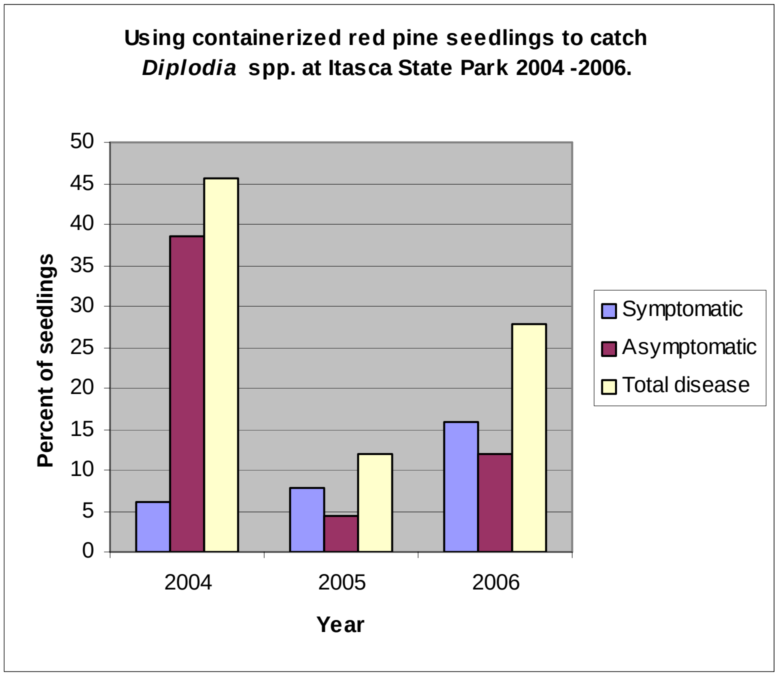
	Average	*SE Mean*	*Range*
Cones infected 2004	46.3	6.0	12 – 60
Asymptomatic 2004	38.5	6.3	13– 60
Asymptomatic 2005	4.3	0.8	2 – 8
Asymptomatic 2006	12.0	6.0	0 – 38
Symptomatic 2004	6.0	0.8	3 – 10
Symptomatic 2005	7.6	1.2	3 – 11
Symptomatic 2006	15.8	6.3	0 – 43
Total disease 2004	45.7	7.0	18 – 64
Total disease 2005	12.0	1.9	7 - 19
Total disease 2006	27.8	12.2	0 - 81

Latent stem infections in containerized seedlings will produce pycnidia when suitably drought-stressed. Between 2004 and 2006, the prevalence of latent infections varied widely and ranged from 0 to 60%. There was no significant relationship between the amount of shoot blight and the amount of latent infections in containerized seedlings.

In 2004, an average of 46% of the cones were infected by *Diplodia* and percent of infected cones ranged from 12-60%. During the first year of study, the amount of cone inoculum and the amount of latent infections found. Subsequently, there were not consistent relationships between the amount of cone inoculum and the amount of shoot blight or amount of latent infections. Based on this study, the percent of infected cones is not predictive of the total amount of disease in a stand but only shows a general trend.

The total amount of disease is defined as the sum of symptomatic and asymptomatic infections. See Figure 1. The total amounts of disease also varied widely yet, in all three years, there was a significant relationship between the total amount of disease and the amount of latent infections in the seedlings. Unfortunately, the amount of shoot blight infections was not significantly related to the total amount of disease so could not reliably predict it.

Fig. 1



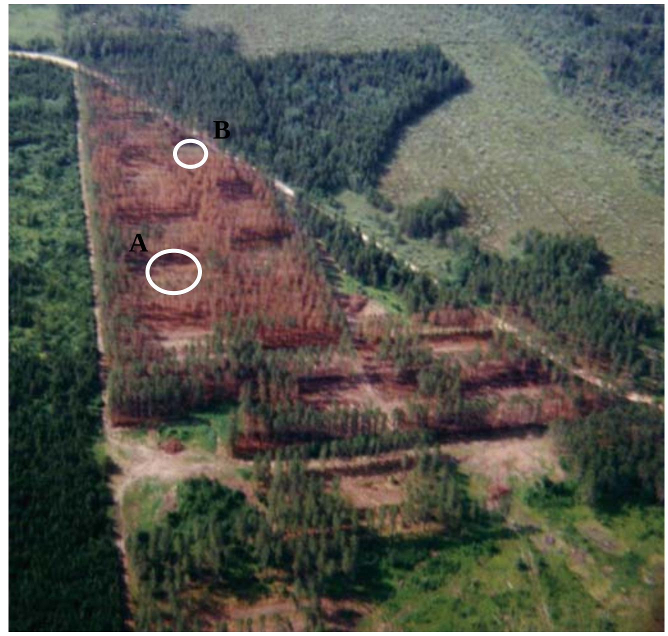
On a practical basis, the total amount of disease that developed in the containerized seedlings in only 9 weeks of exposure to the red pine overstory was large, ranging from 12 to 45%. Natural germlings and young seedlings would be more susceptible to succumbing from the accumulation of *Diplodia* infections from overstory trees than larger saplings and young trees.

Conclusions

1. Containerized red pine seedlings can be used to “catch” *Diplodia* spores in the spring and early summer. Both shoot blight and asymptomatic infections can be found in containerized seedlings.
2. Latent stem infections in containerized seedlings will produce pycnidia when suitably drought-stressed.
3. At Itasca State Park, shoot blight infections indicate that *Diplodia* inoculum is present in the overstory but shoot blight levels are not a predictor of disease potential of the overstory stand. This study shows that in natural systems latent infections are a more reliable indicator of the disease potential of the overstory stands than shoot blight.
4. *Diplodia* is an important disease of red pine and red pine seedlings in Itasca State Park. Natural regeneration of red pine seedlings in the understory of these mature red pine trees should be considered as having a very small chance of success.

Special thanks to Becky Marty, NR Specialist, and her seasonal staff at Itasca State Park.

Diplodia Study at Norris Camp 2006



From recent studies and surveys elsewhere in Minnesota, we know that *Diplodia pinea* can have a huge effect on nursery seedlings and the success of outplanted seedlings due to its ability to cause latent infections. Internal water deficits, such as those caused by droughty weather, release latent infections to cause disease symptoms and seedling death. At Itasca State Park, similar studies have shown that containerized red pine seedlings can be used to “catch” *Diplodia* inoculum from overstory red pine trees and that the level of cone infection is directly related to the amount of latent infections occurring in the containerized seedlings.

Palik and Zasada (2002) have proposed harvesting gaps of various sizes in older red pine plantations in order to add age, species and vertical structure complexities to the stand. They hypothesize that shoot blight will be more prevalent in small canopy gaps and less prevalent in large canopy gaps. A DNR study in 2004 and 2005 suggested that canopy gaps needed to be larger than 1 acre in size to prevent serious losses to *Diplodia* using this design.

A red pine stand in Lake of the Woods County was selected for a canopy gap study such as described by Palik and Zasada. In addition, Wildlife Managers opted to use prescribed fire in the spring of 2004 after the gaps were harvested. The study site is located in Beltrami Island State Forest, T159, R34W, SE ¼, Sec. 11. See photo.

Purpose:
To determine if canopy gap size influences the levels of *Diplodia* infection found inside the gaps. This study was an opportunity that presented itself in May and there were a couple of limitations: there were only two sizes of canopy gaps (0.5 ac and 0.15 ac) and there were a limited number of containerized seedlings available. DNR Wildlife Management -Norris Camp provided the opportunity for this study and watered seedlings weekly for the duration of the study.

Methods and materials:
On May 9th, containerized seedlings were placed in 2 canopy gaps. The radius of Circle A was 84’ and of Circle B was 47’. There were no red pine seedlings or saplings in either of the canopy gaps.

Blocks of containerized red pine seedlings were produced in a private greenhouse and had never been exposed to overstory pines, the predominant source of *Diplodia* inoculum. Three locations in each stand received two blocks containing approximately 200 seedlings. Locations were matrix = seedlings not in an opening and directly under several overstory trees; center = in the center of the circular gap; and, half-radius = seedlings stationed midway between the center and the edge of the circular opening. Seedlings were watered weekly and then collected on July 12th. Overall, seedlings broke bud and grew 2 to 3 inches in height during that time and set new buds.

On July 12th, the blocks of seedlings were stored in a sunny garage and watered for one more month. After that they were allowed to dry out, giving the latent infections an impetus to cause disease and produce fruiting structures.

Once the root mass had completely dried out, 50 seedlings were collected from each block. Each seedling was examined using binocular scopes for the presence of classic shoot blight symptoms, internal stem and root collar symptoms, presence of *Diplodia* pycnidia and other damaging agents. For this report, seedlings that showed internal symptoms of *Diplodia* infection after being drought-stressed will be termed “latently” infected seedlings.

50 (A) and 55 (B) fallen red pine cones were collected in mid-October under the overstory red pines where the seedlings were set out earlier in the year. Efforts were made to collect the youngest, freshest cones. In the lab, each cone was visually inspected for the presence of *Diplodia* infections. Each cone was tallied as either infected or uninfected. Infections were verified by microscopic examination of the pycnidia and spores.

Results and discussion:
After exposure to *Diplodia* inoculum for only nine weeks, the containerized seedlings in the center of the openings had high levels of infections, 10 to 15%. See Table 1 and Figure 1. Matrix infection levels were the highest, reflecting the high inoculum levels

directly under the overstory. There did not seem to be a difference in the amount of infection between Circle A and B in any infection type nor in the rate of inoculum decrease from the mid-points to the center of the openings. See Figure 2.

The radius of Circle A is 84 feet and the radius of Circle B is 47 feet. Results from the 2004 study predicts that, in Lake of the Woods County, openings should have a minimum radius of 112 feet in order to have the center of the opening free of *Diplodia* shoot blight. See Figure 3. Apparently, the radii of Circles A and B were not large enough for the 2006 growing season either. In fact, the radius of the opening should have been much larger than 112 feet in 2006 to reach a point of disease extinction. There are a few of explanations why 2004 shoot blight levels differed from 2006; in 2006, spores were spread further due to stronger winds and/ or the summer weather was more conducive to symptom expression and /or the air flow inside a circular opening has different wind flow patterns than in large plantations.

It seems that in gaps less than an acre in size, *Diplodia* shoot blight could take a toll on the red pine seedlings over a period of a few years.

Table 1. Number* of *Diplodia* infected seedlings after 9 weeks of exposure. Norris Camp. 2006**

	Infected seedlings with symptoms (shoot blight)				Infected seedlings without symptoms (latent)			
	Container 1		*Container 2*		*Container 1*		*Container 2*	
Circle A								
Center	8	2	5	3	6	0	4	3
Half-radius	1	2	9	6	1	1	2	6
Matrix	8	3	17	19	8	2	15	18
Circle B								
Center	6	4	2	3	6	3	1	3
Half-radius	8	6	2	3	8	1	2	3
Matrix	8	14	11	15	6	8	10	7

*   = Each cell represents 25 seedlings.
** = Infected seedlings had pycnidia on them.

Figure 1.

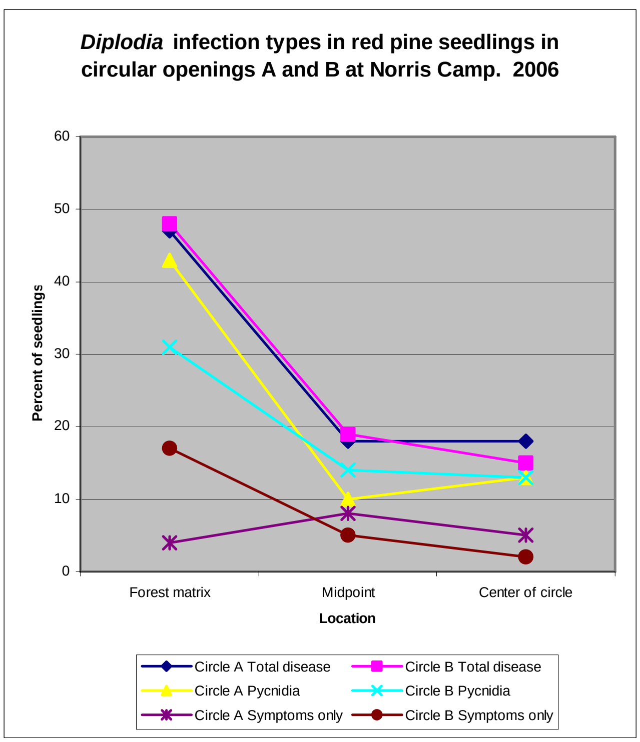


Figure 2.

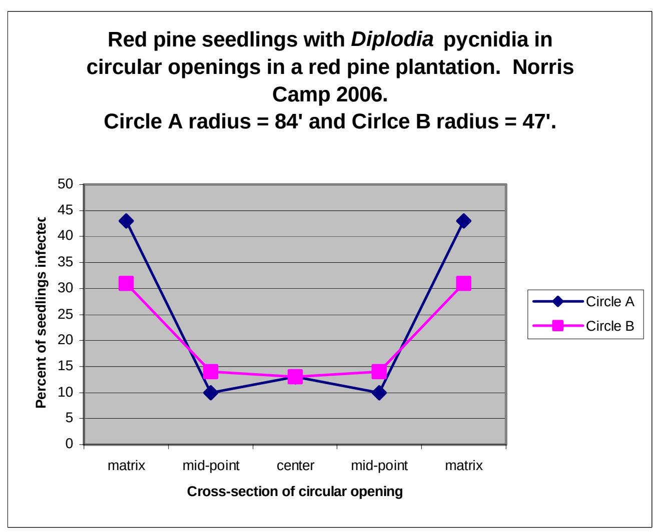
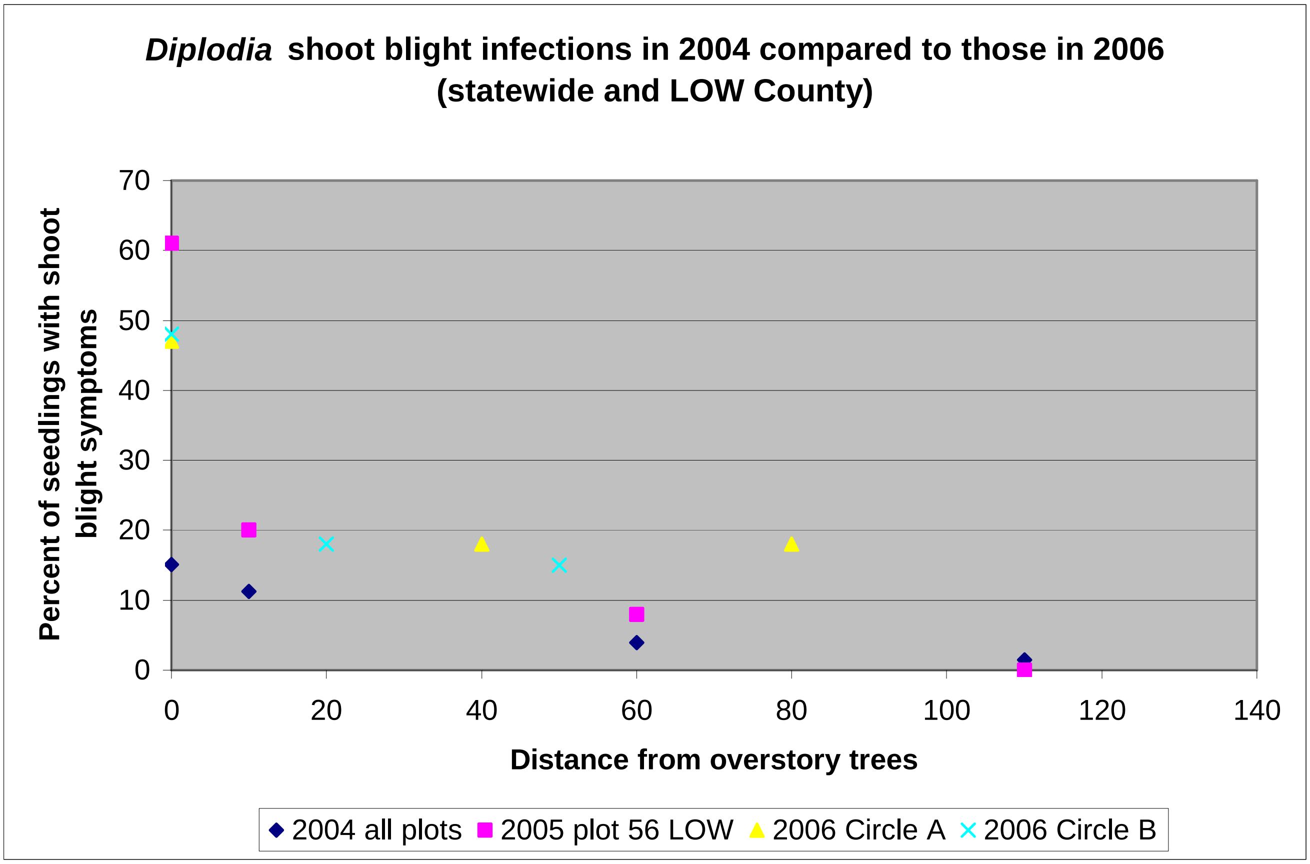


Figure 3.



Acknowledgements

I sincerely appreciate the efforts of Michael Broschart, DNR-Wildlife, for watering the seedlings each week for 10 weeks and Gretchen Mehmel, DNR-Wildlife, for the permission to do this study on Wildlife-administered land. Thank-you.

Red pine regeneration recommendation based on results of *Diplodia* studies from 2004-2006

Diplodia pinea is an invasive species in Minnesota. It is suspected that the fungus was introduced into Minnesota about 50 years ago. In the 1970's, *Diplodia* was noted as causing shoot blight, collar rot and seedling mortality in the nurseries. The application of fungicides curtailed disease in the nursery, or so we thought. During the 1980's and 1990's, losses occurred in young red pine plantations and were attributed to drought and poor treatment of the seedlings.
Losses became significant and that stimulated the practice of interplantings and attention to detail in shipping, handling and planting red pine seedlings. In the late 1990's, Stanosz found that the fungus could be found inside seedlings even though they were treated with fungicides. About 2000, Stanosz found that there could be *Diplodia* infections without symptoms, because the fungus is a "latent pathogen". The implication of these two discoveries was that our nursery seedlings could be harboring latent infections in spite of existing control measures. Surveys for *Diplodia* in the spring of 2003 showed we did have latent infections ranging from 20 to 88% latent infections in nursery stock. Latent infections were expressed during the summer drought of 2003 when 65% of the red pine seedlings died. Subsequent removals of red pine overstory trees in the nursery and other nursery management practices have reduced the occurrence of *Diplodia* spp. down to 1% in 2005 and 2006. Another implication of *Diplodia*'s ability to form latent infections is that natural and artificial regeneration can harbor latent infections if exposed to *Diplodia* inoculum. Questions still remained regarding the incidence and impact of *Diplodia* infections in natural and artificial red pine regeneration.

Several studies were aimed at answering the following questions:

5. How far and wide are *Diplodia* species distributed in red pine stands across northern Minnesota,
6. How far into a plantation will the disease spread from adjacent overstory pines,
7. Are the amounts of inoculum (percent of infected cones) in the overstory red pine trees related to the amounts of symptomatic infections in the understory or in adjacent plantations,
8. What is the total disease "load" in a plantation, given that *Diplodia* can cause symptomatic and latent infections,
9. What is the level of latent infections coming out of our state nurseries.

A report, "Evaluating *Diplodia* species: shoot blight potential in overstory red and jack pine seedlings" covers the answers to questions 1, 2 and 3 based on data gathered in 2004 from 92 sites. However, geographical gaps exist in the database. In 2005 and 2006, question 4 was answered based on lab analysis of asymptomatic shoots and field data gathered on 3 sites. Question 3 was also answered by data gathered on 8 sites at Itasca State Park over the three-year period. Each year, we sample seedlings from our Nurseries in order to determine the percent of latent infections for the next year's crop.

Results and recommendations are summarized from existing reports:

- *Diplodia* produces spores on red pine cones. Red pines produce cones periodically, every 5-6 years. Avoid planting and natural regeneration activities when mature cones are abundant and are still hanging in the tree crowns.
- On 89 of the 92 sites, *Diplodia* fruiting bodies were found on cones collected beneath overstory trees. The average number of cones infected on each site was 25%. *Diplodia pinea* was found on 93% of the sites and is ubiquitous in mature red pine overstories across northern Minnesota. *Diplodia scrobiculata* was found in cones on 28% of the 92 sites visited.

Natural regeneration in the understory

- *Diplodia* has the greatest impact on red pine seedlings growing in the understory below red pine overstory. In 2004, on 41 of the 92 sites (where blighted seedlings were found), the average incidence of current shoot blight was 15% in the understory, and, in the adjacent plantations, it was 5%.
- Although some red pine regeneration may be present, do not count on it surviving to create multi-storied or multi-aged red pine stands due to the accumulation of *Diplodia* infections that are eventually fatal. There may be a few exceptions, namely, sites where cone infection is very low (<3%) and none of the existing understory is blighted.
- Even in a poor year for dissemination of spores, *Diplodia* spores move 1 chain away from overstory trees. In good years, *Diplodia* spores can move up to 4 chains. Red pine shelterwoods and other gap regeneration methods are unlikely to be successful because *Diplodia* infections can cause high levels of mortality in natural regeneration since the openings are usually less than 2 or 3 chains in width.

Artificial regeneration in plantations

- *Diplodia*-caused mortality will be a factor in establishment until the plantation seedlings reach 10 feet in height. Impact will be most pronounced when the plantation is very young because losses of individual shoots or leaders can easily harm the tree.

- The incidence of *Diplodia* infections in plantations is usually limited to three chains from the overstory edge containing red pines. In most years, however, a one chain buffer strip would be sufficient to limit mortality losses.
- Avoid planting red pine adjacent to any red pine overstory that is older than 35 years. Always leave a 1 chain-wide buffer strip along the overstory edge wherever red pines occur. The buffer can be increased to 2 chains on sites where shoot blight is already known to be severe.
- Avoid leaving any live red pine trees on sites intended for artificial red pine regeneration. If some must be left as live trees, leave clumps of them and choose locations near to the plantation edge. This minimizes the area influenced by *Diplodia* infections. Note: BMP guidelines allow this practice.
- *Diplodia* causes latent infections that can be activated by drought or wounding. There can be 6 times more latent infections than shoot blight infections in a plantation. The amount of latent infections at 1-2 chains from the overstory edge is similar to the percent of infected cones in the red pine overstory.
- Rainfall seems to have an effect on the type of infection that is expressed each year. In 2004 and 2006, the weather was dry during the summer; precipitation was less than 80% of normal as of August 1st. In 2005, the weather was near normal; precipitation was 80 to 110% of normal. When the weather is dry during the summer, shoot blight infections are predominant and latent infections were subordinant. When the weather is within the normal range, latent infections are predominant and shoot blight infections are subordinant.
- Total disease load = shoot blight + latent infections. Total disease load in the first 2 chains of a plantation next to a red pine overstory is similar to the percent of cones infected by *Diplodia* in the overstory trees. This means that the total disease load can be predicted by the percent of infected cones in the nearby overstory, whether or not a plantation currently exists there.
- In 2005, with more favorable weather for infections, 92% of the seedlings were infected (shoot blight and/or latent infections) 1 chain away from the overstory on one of the three study sites.

Container stock

- Container stock can be used to detect and assess the inoculum (spore source) in the red pine overstory when mature cones are in the trees. Shoot blight infections are typically very low in number in container stock exposed to overstory trees, but latent infections are more abundant and can be determined by lab examination. It appears that the percent of infected cones in the overstory is significantly related to the amount of latent infections found in container stock exposed to the overstory for 8 weeks starting in late May. Using this detection technique would be helpful in situations where some type of red or jack pine regeneration is desired but no natural regeneration is present and cone infection is < 3%.

Nursery stock

- Since 2002, the removal of inoculum sources and the use of cultural and chemical methods have reduced the latency levels at Badoura Nursery from 88% to 2% (in 2007).

Firewood survey along the North Shore at State Parks

A firewood survey was conducted in 5 State Parks on the North Shore during the summer of 2005. Parks were conducted in St Croix, Gooseberry Falls, Split Rock Lighthouse, Jay Cooke and Judge Magney. The survey was conducted to determine how many people camping in state parks bring firewood with them into the parks. The survey was conducted by forestry and park staff who walked up to people present at camp sites and asked several questions.

NE Region Parks Firewood Survey, Summer 2005 — **Harley Hanson & Mike Albers 11/29/06**

Compiled data from all campers surveyed		MN camper data compared to all campers surveyed (by Park)		Out of State camper data compared to all campers surveyed (by Park)		MN camper data compared to all MN campers surveyed (by Park)		Out of State camper data compared to all Out of State campers surveyed (by Park)	
1. *Campers surveyed.*		1. *Campers from MN surveyed*		1. *Out of State campers surveyed*		1. *Campers from MN surveyed*		1. *Out of State campers surveyed*	
2. *Brought firewood into Park on this trip.*		2. *From MN and brought firewood into park on this trip*		2. *From Out of State and brought firewood into park on this trip*		2. *From MN and brought firewood into park on this trip*		2. From Out of State and brought firewood into park on this trip	
3. *Brought firewood into Park on this or previous trips.*		3. *From Minnesota and brought firewood into park on this or previous trips*		3. *From Out of State and brought firewood into park on this or previous trips*		3. *From Minnesota and brought firewood into park on this or previous trips*		3. *From Out of State and brought firewood into park on this or previous trips.*	
NUMBER	**PERCENT**	**NUMBER**	**PERCENT**	**NUMBER**	**PERCENT**	**NUMBER**	**PERCENT**	**NUMBER**	**PERCENT**
St Croix State Park Surveyed August 6, 2005 by R. Tiplady									
1. 39	39/39 = 100	33	33/39 = 84.6	6	6/39 = 15.4	33	33/33 = 100	6	6/6 = 100
2. 22	22/39 = 56.4	20	20/39 = 51.2	2	2/39 = 5.1	20	20/33 = 60.6	2	2/6 = 33.3
3. 27	27/39 = 69.2	23	23/39 = 58.9	4	4/39 = 10.2	23	23/33 = 69.6	4	4/6 = 66.6
Gooseberry Falls State Park Surveyed July 6, 2005 by H. Hanson									
1. 28	100	22	78.5	6	21.4	22	100	6	100
2. 15	53.5	14	63.6	1	3.5	14	63.6	1	16.6
3. 18	64.0	16	72.7	2	7.1	16	72.7	2	33.3
Split Rock Lighthouse State Park Surveyed August 16 & 18, 2005 by B. McDonald									
1. 24	100	22	91.6	2	8.3	22	100	2	100
2. 9	37.5	9	37.5	0	0	9	40.9	0	0
3. 10	41.6	10	41.6	0	0	10	45.4	0	0
Jay Cooke State Park Surveyed August 20, September 2 & 10, 2005 by J. Carlson and C. Catanzarite									
1. 51	100	51	100	0	0	51	100	0	0
2. 25	49	25	49.0	0	0	25	49.0	0	0
3. 33	64.7	33	64.7	0	0	33	64.7	0	0
Judge Magney State Park Surveyed August 20 & September 17, 2005 by D. Pelto									
1. 19	100	16	84.2	3	15.7	16	100	3	100
2. 19	100	16	84.2	3	15.7	16	100	3	100
3. 19	100	16	84.2	3	15.7	16	100	3	100
TOTALS and Percentages for all Parks in Survey									
1. 161	161/161 = 100	144	144/161 = 89.4	17	17/161 = 10.5	144	144/144 = 100	17	17/17 = 100
2. 90	90/161 = 55.9	84	84/161 = 52	6	6/161 = 3.7	84	84/144 = 58.3	6	6/17 = 35.2
3. 107	107/161 = 66.4	98	968161 = 60.8	9	9/161 = 5.5	98	98/144 = 68.0	9	9/17 = 52.9

Bitternut hickory mortality

Observations of hickory mortality have been made throughout the southeast region for the last twenty years. In fact, Dr. Eugene Smalley, from the University of Wisconsin, had described a new *Ceratocystis* species now named *C. smalleyi* in association with hickory bark beetle many years ago. He never published the taxonomy, however the US Forest Service did publish a Pest Alert on hickory mortality some time ago.

In 2006, the US Forest Service, in cooperation with the states of MN, Iowa, and WI, has begun surveys to begin looking at the causes of hickory mortality. In the field, symptomatic trees will exhibit crown dieback and small chlorotic foliage. Many of the affected bitternut hickories have indications of cankers on the stems. Examinations under the bark of these cankers reveal brown discolored lesions of varying sizes. At the center of most of these lesions is one single entrance hole that appears to be made by a species of ambrosia beetle, yet to be identified. The upper crowns of felled trees have entrance holes and plenty of activity from the hickory bark beetle *Scolytus quadrispinosus*. On occasion Phomopsis galls are found on branches and main stems. From the US Forest Service lab, cultures are finding isolates of *Ceratocystis* fungi. Additionally they are finding "*Fusarium*-like" isolates, and "*Sporothrix*-like" isolates. They plan to work with these fungi to see if they can be identified down to species.

In the recent past a species of *Ceratocystis*, *C. carya* was associated with a "canker-wilt" disease on hickory in Iowa. It causes wilting, but is not a true vascular wilt pathogen in that it doesn't clog the xylem, but instead colonizes parenchyma tissue. It has been particularly associated with wounds and may be brought in by ambrosia beetles. *Ceratocystis smalleyi* is very closely related to *C. carya*, but has some distinct morphological characteristics and is associated with the hickory bark beetle, *Scolytus quadrispinosus*. *C. smalleyi* may also play a significant role in hickory mortality as it may have some adaptations related to its association with the bark beetles that are unique. These species are considered to be wound colonizers. Either the bark beetles are coming into the trees followed by ambrosia beetles bringing in the fungi or the reverse happens.

Plans for the 2007 field season include continued sampling and expansion of the surveys to additional sites. What needs to be done is to see symptomatic trees early in the season, fell and check high up in the crowns to see if the bark beetles are getting in there first. For landowners with hickory mortality, we advise continued management selecting against hickory. It is not known if sanitation would be of benefit to reduce mortality in nearby unaffected hickory.

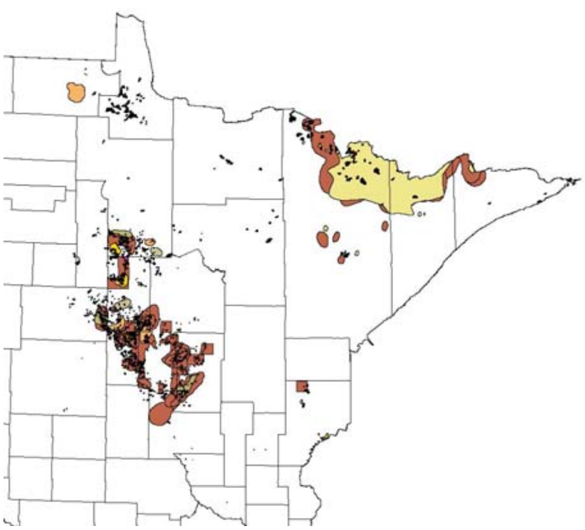
Jack pine budworm: A case for ECS floristic regions

Jack pine budworm defoliation is splashed across the aerial survey maps of western and northern counties this year to the tune of 70,790 acres. See Aerial Survey map. In the west-central counties, jack pine budworm outbreaks typically occur at 6 to 12 year intervals, last for 2 to 4 years and can cause significant mortality. Since 1954, six outbreaks have occurred in this region. Outbreaks in northern/ eastern counties occur at 20 or more year intervals, last for 1 to 2 years and cause little or no mortality. Since 1954, two outbreaks have occurred in this region. See map 1. The historic frequency and duration of outbreaks can be split into two groups that seem to reflect the distribution of central (FDc) and northern (FDn) floristic regions of the Fire Dependent communities. See map 2.

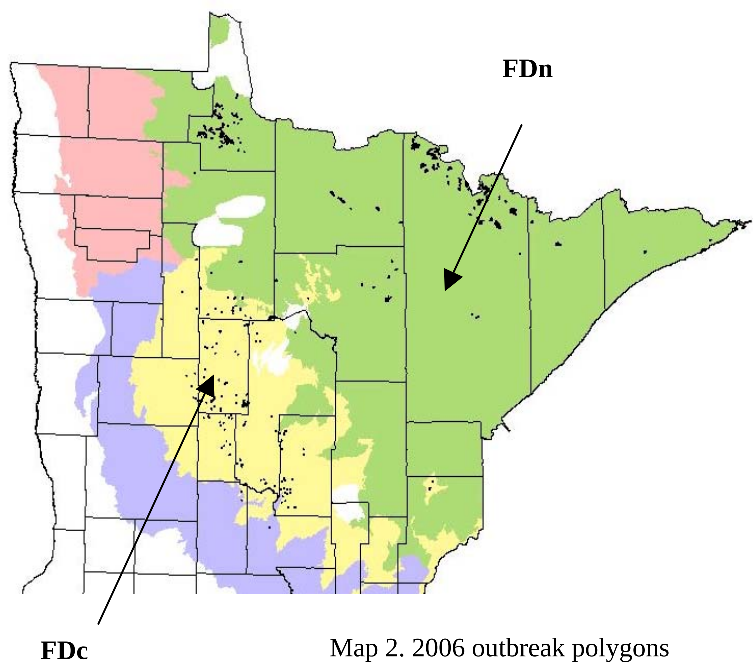
Jack pine characteristics are different between the two floristic regions. Most jack pines in central floristic communities grow on sites that were formerly prairies as little as 1,500 years ago. These communities are “woodlands” where trees are more widely spaced than in the northern floristic region. These communities evolved with frequent, light fires in between catastrophic fires. Consequently, the jack pines have a shorter life span and very few serotinous cones. Natural jack pine stands appear to have regenerated over a period of about 30 years with several cohorts of seedlings contributing to the stands. In contrast, jack pines in FDn communities grow on sites that have been pine forests for 5,500 to 10,000 years. These communities evolved with fire intervals almost two times as long as FDc communities. Consequently, the jack pines have a longer life, more serotinous cones and denser “forest” spacing. Natural jack pine stands usually regenerate in a singe cohort after a catastrophic fire that stimulates the serotinous cones to shed seed.

Another difference between the two floristic regions lies in the fact that spruce budworm, a closely related species, is a constant inhabitant of the northern floristic region and is only a rare inhabitant of the central floristic region. In the northern floristic region, a large spruce budworm population has been existence every year since 1954 and probably many decades before that. Jack pine budworms and spruce budworms share most of the same parasites and predators. In the northern floristic region, robust populations of budworm parasites and predators are maintained and this may help keep the jack pine budworm population below outbreak level in most years and prevent serious damage when the population does increase.

So, whether the impact from jack pine budworm populations is based on the growth characteristics of the stands, on the levels of parasites and predators or on both, it appears that the northern/ central floristic region split can be used to differentiate management of jack pine in Minnesota. In central floristic region communities, jack pine rotation age should be set lower (45 to 55 years) to prevent serious losses due to jack pine budworm. Foresters should recognize that natural regeneration occurs at a slow pace and may take up to 30 years on some sites after harvest and that stands will not be as fully stocked because these are “woodland” communities. In contrast, for northern floristic region communities, jack pine rotation ages can be set higher and based upon stem decay and natural stand breakup rather than on the infrequent occurrence of budworm outbreaks. Natural regeneration from serotinous cones is likely to occur quickly and thickly after a fire or a well-timed harvest.



Map 1. Outbreak polygons superimposed in each other. Outbreaks from 1954 to 2006.

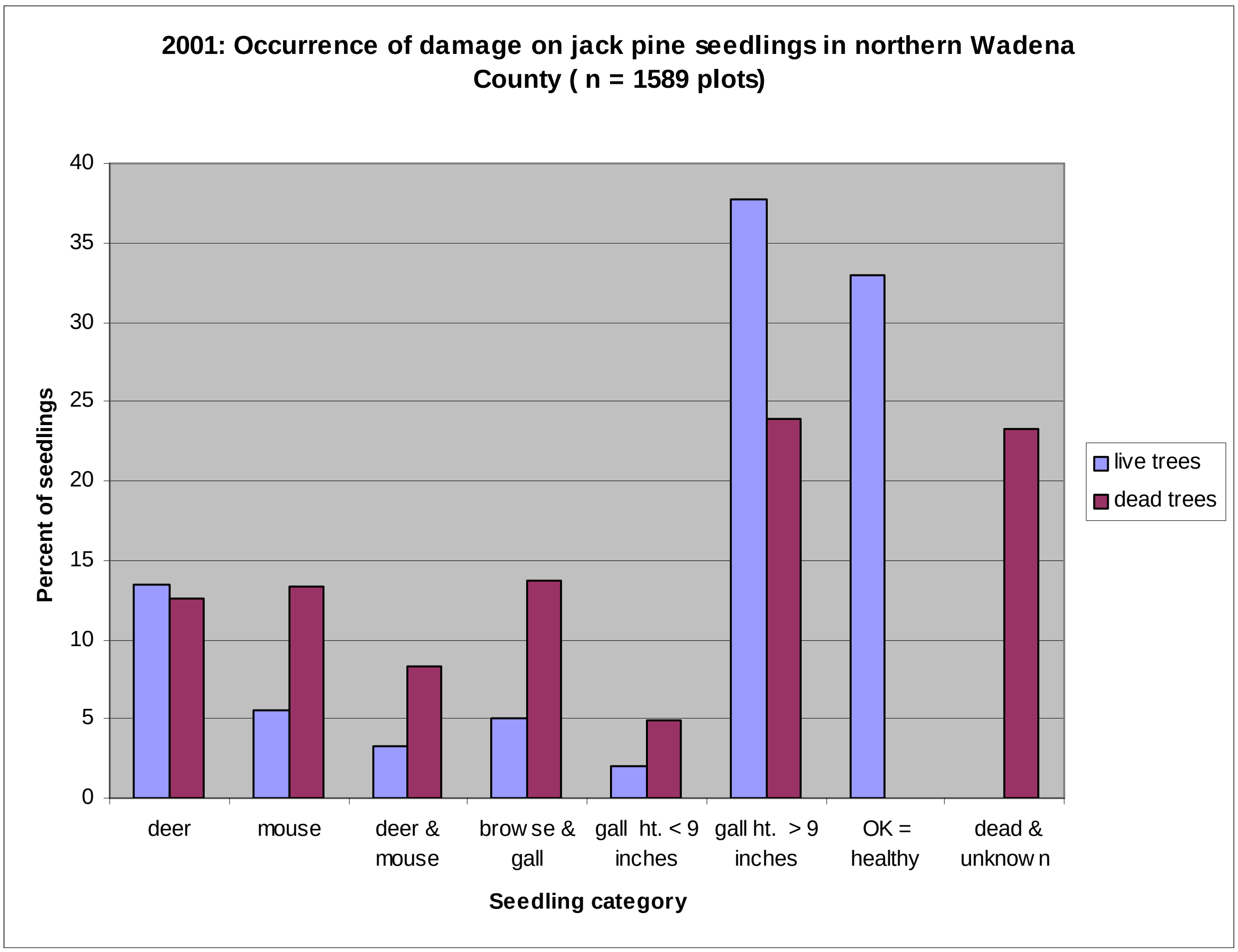


Map 2. 2006 outbreak polygons on ECS map.

Jack pine seedling mortality in Wadena County during 2001

Site data from the 2001 study of jack pine regeneration in Wadena County was analyzed by Dr. Daniel Gilmore, Univ. Minnesota. Here are the results:

agent	live percent	std error	dead percent	std error
deer	13.503	0.889	12.577	1.435
mouse	5.56	0.592	13.355	1.515
deer & mouse	3.3	0.473	8.274	1.184
browse & gall	4.971	0.565	13.695	1.509
gall ht. < 9 inches	1.977	0.337	4.919	0.976
gall ht. > 9 inches	37.72	1.225	23.942	1.884
OK = healthy	32.968	1.166		
dead & unknown			23.237	1.894



Root injury and possible red turpentine beetle attack study

A red pine plantation in Aitkin County (Sec 1 & 12 –T52N-R25W, 7.25 miles east of Hill City) was thinned with a cut to length processor and forwarder starting about July 12th. Thinning continued into September. This was the second thinning of approximately 50 year old, 160 acre red and white pine plantations. Soil excavations revealed root injury on trees along main haul roads as well as along some of the trails where the forwarder and processor had traveled. Soils on this site are loamy very fine sand and are not very vulnerable to compaction. The forwarder had tracks on while operating in the stand. The forwarder was large being able to haul up to 10 cords of wood in a load. The summer of 2006 was very dry, well below normal.


Red pine root excavated to show root injury along main haul road.


White pine root excavated to show injury along processor and forwarder trail. White paint has been sprayed on the root in the picture to the right in order to show portions of the root where logging equipment injured or removed bark.

Red turpentine beetle study - There are over 1.5 miles of main haul road inside the plantation. This main haul road has been traveled multiple times by thinning equipment as well as semi-trailers hauling wood out of the plantation. Tire tracks average about 6 inches deep. Many trees stems are within 2 feet of the main haul roads and some as little as 1 foot from the main haul roads. Considerable root injury was found on some of these trees with many broken and crushed roots and bark peeled off roots.

Because of the root injury found on this site there is concern that injured trees may suffer root rot and bark beetle attack. Bark beetle attack could include Ips attack on the main bole or red turpentine beetle attack of the root collar area. This study was primarily set up to see whether trees whose roots were injured during thinning are attacked more by red turpentine beetles than trees whose roots suffered less or no damage. The study was set up in November 2006.

The study is intended to compare red turpentine beetle attack on trees following thinning in 3 groups of trees with different levels of root injury:

1. Trees immediately adjacent to main haul roads – most severe root injury
2. Trees immediately adjacent to skid trails – moderate root injury
3. Trees without evidence of equipment traffic adjacent to them in this thinning – i.e. no root injury. These trees will serve as the control since there is no unthinned portion of the plantation to serve as a control.

1. Trees immediately adjacent to main haul roads – most severe root injury November 7, 2006

Main haul road runs in an east-northeast direction. On November 7, 2006,fifty trees were marked on the southern side of this road and another fifty were marked on the northern side of the road. Tree one is closest to the landing on the southern side of the haul road and is marked in blue tube paint with a 1. Every 10th tree is numbered with blue tube paint 10, 20, 20 etc up to 50. Trees in the study between these numbered trees were marked with either a dot of blue tube paint or a 2-inch horizontal line of blue tube paint at approximately breast height facing the road. The closest trees to the main haul road were chosen consecutively. At the time of marking the base of the tree was examined for signs of red turpentine attack. Signs of turpentine beetle were found only on one tree number 72. This tree had one pitch tube on the SW side and resin/frass pellets on the NE side. No other tree has any signs of turpentine beetle attack.

Tree 1: southwest end of main haul road. Blue tube paint 1 at breast height on north face to tree Location = 47.01436 N, 93.46416 W
Tree 51 is on the NE end of the haul road and is on the northern side of the road. It has the number 51 written in blue tube paint. Location = 47.01572N, 93.45811 W.

2. Trees immediately adjacent to skid trails. Moderate root injury is assumed to have occurred in this group of trees.

The processor and forwarder traveled immediately adjacent to one side of the trees in this group. It is assumed each piece of equipment made only one pass. The forwarder had tracks on but the processor did not. Marked 100 trees in the same manner as above with white tube paint on November 15, 2006 with Bob Tiplady and Ginger. The base of each trees in this group was examined for signs of red turpentine beetle. No signs of red turpentine beetle were found in this group of trees. These trees run parallel to the main haul road in 1 above but are to the southeast.

Tree 1 = 7 paces to the SE from tree one along the main haul road.
Tree location = N47.01427, W93.46334
Tree 25 = north east end of first row of trees in this group
Tree location = N47.01471, W93.46144
Tree 26 = SE of skid trail Tree location = N47.01481, W93.46149
Tree 50 = SW end of skid trail Tree location = N47.01411, W93.46328
Tree 51 Tree location = N47.01404, W93.46298
Tree 70 = NE end of this line of trees Tree location = N47.01448, W93.46159
Tree 90 location = N47.01410, W93.46284
Tree 91 = SW end of line of trees that started with tree 70
Tree Location = N47.01402, W93.46304
Tree 92 = SW of tree 91 Tree location = N47.01397, W93.46287
Tree 100 = NE of tree 92 Tree location = N47.01411, W93.46241

3. Trees in this group were screened from forwarder and processor traffic by a row of trees on either side. So the forwarder and processor did not pass immediately adjacent to these trees but passed one row of trees away on each side. These trees are thought to have suffered the least amount of root injury on this site and serve as controls for the study.

Marked 100 trees in same manner as described above with blue /or white tube paint. Tree 1 is approximately 40' north northwest of tree 95 (Group 1-most severe damage) along the main haul road. This set of trees runs approximately parallel to the main haul road. The base of all trees marked in this group were examined for signs of red turpentine beetle attack but none were found.

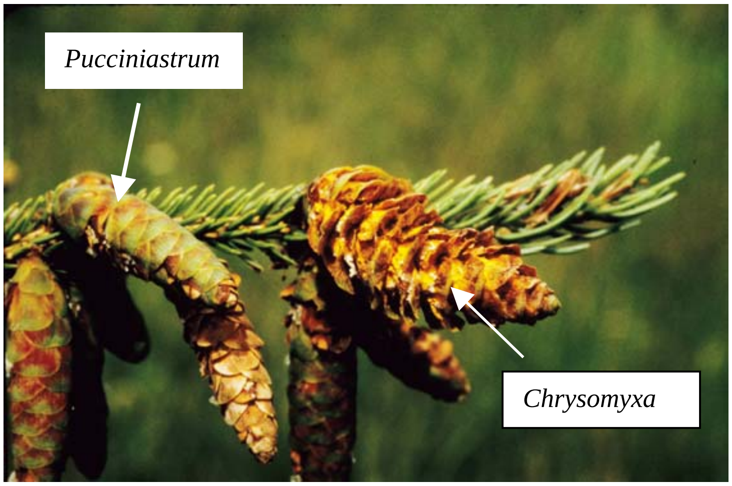
Tree 1 = blue paint Location = 47.01470 N, 93.46271 W.
Tree 17 gap – continue 150' along same row
Several gaps – continue along sane row to tree 50 at 47.01551 N, 93.45909 W,
To tree 68, move northwest to tree 69
Tree 69 is 30 ' to NW from tree 68 and is at 47.01567 N, 93.46020 W
Turn east at tree 85 and follow adjacent row back
Tree 86 is at location 47.01543 N, 93.45905 W,
Tree 95 is at 47.01539 N, 93.45963 W,
Tree 96 is at 47.01523 N, 93.45916 W,
Tree 100 is at 47.01561 N, 93.45927 W and is about 100 feet from the main haul road.

White spruce seed orchard cone pests

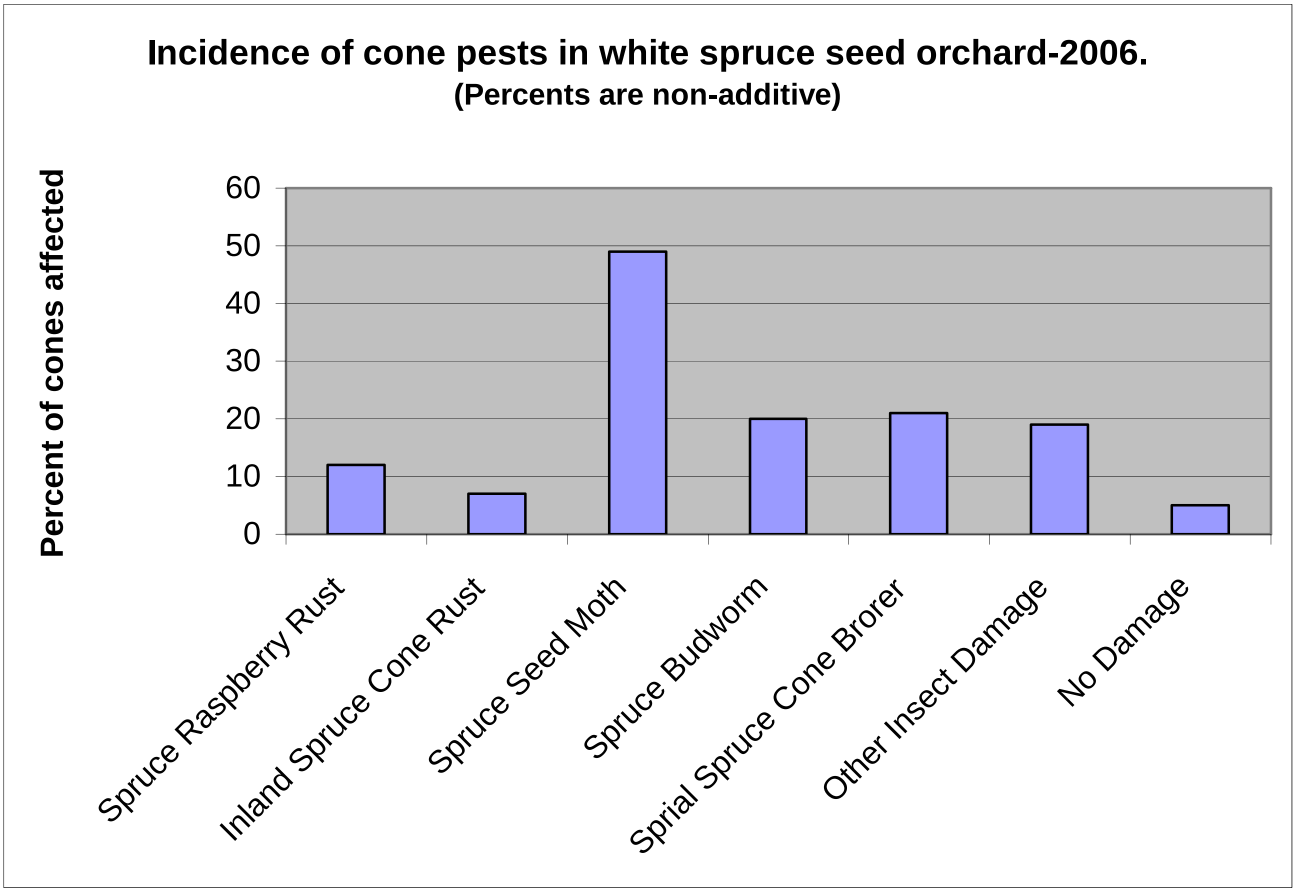
Insects and fungi damaged most cones in a grafted white spruce seed orchard in northeastern Minnesota. Two rusts and three insects caused most of the damage. The list below shows the percent of cones damaged by each of the pests.

American Spruce raspberry rust = 12% of the cones
Inland spruce cone rust = 7%
Spruce seed moth = 49%
Spruce budworm = 20%
Spiral spruce cone borer = 21%
Other insect damaged cones = 19%. A few of these cones were damaged by spruce seed midge and a few others were damaged by coneworms, likely *Dioryctria abietivorella* which has been found in this seed orchard in the past. This survey was conducted a bit late in the season making it impossible to identify the insects that had damaged many of the cones in this group.
No damage = 5% of the cones

These percentages are not additive since many of the cones were damaged by more than one insect or rust.



Overall 19% of the cones had rust, and 87% had insect damage and 5% showed no damage.



Spruce raspberry rust = *Pucciniastrum americanum*
Inland spruce cone rust = *Chrysomyxa pirolata*
Spruce seed moth = *Cydia strobilella* – formerly *Laspeyrisia youngana*
Spruce budworm = *Choristoneura fumiferana*
Spiral spruce cone borer = *Strobilomyia neanthracina* formerly *Hylemya anthracina*
Spruce seed midge = *Mayetiola carpophaga*
Fir coneworm = *Dioryctria abietivorella*

In order to identify insects that damaged the inside of the cone and the seed the cones were cut in half longitudinally and examined. These cones were rated as 'good' if 50% or more of the seeds cut through in this process looked healthy. Cones were rated as 'no good' if less than 50 % of the seeds were healthy. Fourteen percent of the cones were rated as good and 86% were rated as no good. Most of the cones rated as no good had 3 or less healthy looking seeds.

In 2006, 57.6 bushels of cones were picked and 43.3 pounds of seeds were extracted for a yield of 12 oz per bushel.

Spruce seed moth larva and damage

Papers and Publications

Bark beetle study on Anoka Sand Plains

Bark beetle study in recently burned red pine plantation

Impacts of drought and bark beetles on the Anoka Sand Plains

By Matthew P. Ayres[1], Bruce D. Ayres[2], Mike Peltier, and Jana Albers

Executive Summary

Red pine, the state tree of Minnesota, was an important element of pre-settlement forests, and a significant timber species during the early 20th century. Red pine has been widely propagated since the late 1950s and has proven its value in terms of growth, pest resistance, soil conservation, wildlife, biodiversity, aesthetics, recreation, and timber value. Also, it facilitates a silvicultural system with regular selective harvests over a long rotation time, which allows for growing economic returns to landowners and the forest products industry while simultaneously favoring forested landscapes that include more large trees and old-growth stands than the region has known since the early 1900s. Because it is only now that the first rotation of plantings are maturing into forests, land managers have surprisingly limited experience on which to base management decisions. For example, there is limited ability to know when, or where, there will be consequential mortality of adult trees from drought and bark beetles, and what, if anything, can be done to mitigate the undesirable impacts. Motivated by the most recent drought, we conducted studies to address the following questions: (1) Why is red pine mortality associated with drought and bark beetles more common in the Anoka plains of east central Minnesota than in nearby, apparently similar, forests; e.g., the Colfax region of west central Wisconsin? (2) Are there predictable patterns in tree mortality within a region that are related to soil type? (3) Do bark beetle infestations tend to become self-perpetuating eruptions following a drought?

The Anoka Plains and the Colfax region, separated by ~ 90 miles, both contain extensive red pine forests that experience similar climates and grow on sandy soils derived from glacial outwash. The Anoka Plains have received an average of 6% less annual precipitation, which seems inadequate by itself to explain the history of recurrent droughts and forest disturbance. However, analyses of river discharge data indicated that the sandy soils of Anoka are different enough from the loamy sands of Colfax to strongly affect the probability of droughts. In ~20 years since 1930, the median weekly discharge rate from rivers that drain the Anoka plains have dropped below 30% of the long-term average. This compares to only 1 year that rivers draining the Colfax region have been so low. Droughts in 2000, 1988-89, 1976, 1964, and the 1930s were plainly evident in the river discharge data, which suggests that real-time, online, discharge data provided by the USGS can be used to recognize droughts at the time when tree water stress is maximal. The recent drought at Anoka apparently reached its nadir in October of 2000. Some tree deaths became evident the following winter. More extensive tree mortality during the next two growing seasons was apparently due to an epidemic of the bark beetle, *Ips pini*, that was triggered by the drought. Regional differences in the rates of red pine growth and mortality are so large that optimal silvicultural practices (e.g., harvest schedules) must be different, but we know of no regionally customized guidelines that are presently available to land owners and forest managers.

Results supported the hypothesis that populations of *I. pini* are normally regulated at endemic levels by resource limitations, but can switch to an epidemic state following a resource pulse from drought-killed trees. Endemic populations of *I. pini* may function chiefly as scavengers of trees that are dying for other reasons, while epidemic populations seem to escape resource limitations by attacking, killing, and reproducing within healthy trees. Under this model, bark beetles amplify climatic effects into self-perpetuating episodes of forest disturbance. Direct death of trees from drought may be less important than drought as a factor that triggers state changes of bark beetles from endemic to epidemic. Pest systems with multiple equilibria are ideal candidates for cost-effective control, because occasional intervention can drive eruptions back to endemic levels where they will tend to be maintained by natural regulatory forces. In the case of *I. pini*, it is relatively cheap and easy to monitor local populations with pheromone-baited funnel traps to identify potential eruptions before they occur (our sampling suggested an action threshold of 500 *I. pini* / stand) to our knowledge, this was the first test for eruptive population dynamics in *I. pini*. Conclusions should be regarded as tentative, but indicate the possibility for cost-effective mitigation of forest disturbance in regions such as the Anoka Plains. We suggest that a plan be developed and implemented to evaluate different possible strategies for pest monitoring and control. This could probably be done in a way that: (1) permits validation or refinement of bark beetle population models; (2) tests for possible undesirable side effects, e.g. removal of natural controls by predators; and, (3) provides immediate reductions in tree mortality from beetles.

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Introduction

At the time of European settlement, red pines (*Pinus resinosa*) were a dominant element of forests throughout the western Great Lakes region, especially in the sandy soils derived from glacial outwash (Curtis 1959, Bonnicksen 2000). Red pine and white pine (*P. strobus*) largely supported the early timber industry in this region (Walker 1998), which in turn shaped the economic and cultural development of northern Minnesota and Wisconsin (Fries 1951, Swanholm 1978, Birk 1999). Accordingly, red pine is the state tree of Minnesota. Virtually all of the mature red and white pine forests were logged by the 1930s and the associated forest products industry waned. However, red pine has been widely propagated since the late 1950s and has proven itself to be an excellent silvicultural option in that it: (1) grows well even on sites that are barely arable without irrigation; (2) resists pests and pathogens that often exert severe impacts on white pine stands (e.g., white pine weevils, blister rust, and deer browsing); (3) contributes to soil conservation, protecting the most vulnerable soil types from erosion by water (roots and duff layer) and wind (year round foliage), often stabilizing sites previously eroded by bad agricultural practices; (4) is a native species that generates wildlife habitat and promotes biodiversity; (5) produces forests with broad human appeal for aesthetics and recreation; (6) generates logs with good value and high demand; and (7) facilitates a silvicultural system with regular selective cuttings but a long rotation time, which allows for growing economic returns to landowners and the forest products industry while simultaneously favoring forested landscapes that includes more large trees and old-growth stands than the region has known since the early 1900s.

Thus red pine forests have returned to Minnesota and Wisconsin, and grow in size and value with each year. As red pine regeneration programs of the 1950s and 1960s have begun producing merchantable timber, red pine has already replaced depleted stocks of jack pine and spruce to become the major source of softwood fiber for the Lake States long established paper industry, and has re-energized the softwood lumber industry, reversing a near century of decline. In Minnesota, red pine forests accounted for 382 million acres in 2001 (compared to 71 million acres of white pine), up from 247 million acres in 1977 (Minnesota Forest Resources Information Cooperative 2003). Similarly, a 1996 forest inventory in Wisconsin reported 988 million cubic feet of red pine compared to 929 million cubic feet of white pine (Wisconsin Department of Natural Resources 1996).

The value of forest industry shipments in WI during 1996 was $19.7 billion (compared to $8.4 billion in 1982). Furthermore, the percentage of sawtimber volume in highest quality classifications (grades 1 and 2) increased from 28% in 1983 to 40% in 1996. As the size and value of these forests grows, so grows the importance of their management.

Since it is only now that the first rotation of plantings are maturing into 2nd growth forests, which are destined to one day become our only old growth, foresters and landowners have surprisingly limited experience on which to base some important management decisions. For example, there is little basis for knowing when or where there will be consequential mortality of adult trees from drought and bark beetles. If some soil types or regions have predictably higher mortality rates for trees, the expected half life for a cohort of trees will be reduced, which, among other things, influences the successional trajectory of a forest managed for wildlife, and changes the optimum harvest schedule of a forest managed for economic returns. There is also little basis for evaluating the costs and benefits of pest control efforts in mature stands of red pine.

One of the most significant pests of mature pines in the Great Lakes region is the pine engraver beetle, *Ips pini* (Schenk and Benjamin 1969, Sartwell et al. 1971, Geiszler et al. 1984, Klepzig et al. 1991, Rasmussen et al. 1996, Kegley et al. 1997, Ayres et al. 1999, Santoro et al. 2001). *I. pini* is regarded by many forest entomologists as an occasionally eruptive species (Berryman 1987) that normally has little impact on healthy trees, but which can produce sustained outbreaks when environmental conditions such as a drought or windthrow allow the development of large populations that then become self-sustaining through continued successful mass-attacks on otherwise healthy trees. Such populations are excellent candidates for cost-effective control because occasional efforts can suppress eruptions back to low (endemic) populations levels where they then tend to be regulated by natural forces. Based on this theoretical principle, rather extensive control programs (mass-trapping) were conducted in the Sand Dunes State Forest following the drought of 1988-89 and in Itasca State Park following the windstorms of 1996-97. However, the underlying theory has not been tested for *I. pini*. If it does not hold, then bark beetle control efforts such as mass-trapping or sanitation logging would have less benefit, no benefit, or even make matters worse by delaying the onset of natural controls from predators

Objectives

We conducted studies during 2002 to address the following questions:

1. Why is tree mortality associated with bark beetles more common in the Anoka plains than in superficially similar regions, e.g., west central Wisconsin?
2. Are there predictable patterns in tree mortality within a region that are related to soil type?
3. Do bark beetle infestations tend to become self-perpetuating eruptions following a drought?

Background for Objective 1: Why regional differences?

The Anoka Plains of east central Minnesota, including Sand Dunes State Forest in Sherburne Co., contains significant stands of red pine that generally grow well but have a history of bark beetle outbreaks coincident with droughts (e.g., 1976, 1988-89, and 2000-01). The Colfax region of nearby west central Wisconsin also contains extensive stands of red pine that are comparable in age and structure to those in MN. However, tree mortality from bark beetles or drought is very rare in the Colfax region. In 15 years of studying bark beetles in red pine forests, we have only witnessed very occasional instances of individual trees that might have died from drought or bark beetles, and we have never observed the simultaneous infestation of multiple live trees. Most foresters and landowners in the Colfax regionunderstandably ignore bark beetles in their management. These two regions have similar sandy soils derived in part or whole from glacial outwash and are near enough (90 miles) that one would expect similar temperatures and precipitation (Fig. 3). We compared these regions with respect to historical patterns in precipitation to test whether climatic patterns could account for the apparent differences in tree mortality from droughts and bark beetles. We also compared soil characteristics and river discharge patterns to test the alternative hypothesis that patterns are due to soils and drainage rather than climate. Finally, we compared regions with respect to site index for red pines and interannual variation in diameter growth to test whether trees on the Anoka Plains are more water limited for any reason.

Background for Objective 2: Site-specific patterns in tree growth and mortality?
Sites that are generally suitable for red pine in the Anoka Plains include some soils with banding, which tends to slow the drainage of soil water out of the rooting zone, and other soils that lack banding. Soils with banding appear to support higher tree growth on average, presumably because of increased access to water, but may also increase susceptibility to drought. This could be because root systems on banded soils are shallower, due to generally higher water availability in the upper soil zones and increased mortality of those roots that extend into deeper zones subject to water saturation that limits oxygen supply. Trees with such root systems may be more susceptible to drought during dry years when water becomes depleted in the upper soil zones. Thus, red pines growing on soils with low site index (reflecting average growth) may develop deeper root systems that make them better able to survive droughts. One alternative hypothesis is that average growth is positively correlated with drought tolerance, including resistance to bark beetles. We tested these hypotheses by measuring tree growth, and tree mortality associated with a recent drought, across a range of soil types near Sand Dunes State Forest in MN. We also measured soil water profiles within each site.

Background for Objective 3: Are *I. pini* populations eruptive on the Anoka Plains?
During July 2001, more than 50 patches of red pine mortality were detected in Sherburne and Isanti Counties during aerial surveys by Minnesota Forest Health personnel. This was thought to be the result of a drought during 2000, which had ended by 2002. The eruption hypothesis assumes that populations are regulated around one of two equilibria, at endemic or epidemic levels (Fig. 1). Under this model, populations can undergo a state change from endemic to epidemic if some exogenous factor (e.g., a drought that kills some trees and produces a pulse of high quality food resources) permits populations to exceed an escape threshold beyond which further resource limitations are relaxed because they are able to employ mass-attacks to kill additional trees. In the case of bark beetles, resource limitations that regulate populations around the endemic equilibrium are expected to produce a pattern of increasing colonization density in suitable host material (fresh logs and recently killed trees) with increasing abundance of colonizing adults within the forest stand. When local abundance of colonizing adults exceed the hypothetical escape threshold, colonization density in logs is predicted to decline as some adults participate in attacks of nearby live trees. We tested these predictions (Fig. 2) with studies of multiple infestations in and around the Sand Dunes State Forest, a putative epidemic population, and multiple stands of red pine on the Colfax Plains, a putative endemic population.

Methods Objective 1: Regional comparison of precipitation, soils, river discharge, and tree growth
We identified 10 weather stations within about 50 km of our study sites near Anoka, MN (Fig. 5) and Colfax, WI (Fig. 6). Monthly climate records since 1940 were downloaded for each site from the National Oceanic and Atmospheric Association (NOAA 2003). We calculated annual growing season precipitation for each site as the total from 1 October of the previous year through 30 September of the growing year. We calculated indices of summer and winter temperatures as average daily temperate for June-August and December-February, respectively.

We identified two United States Geological Service gaging stations in each region with on-line, long term records of daily discharge rates: Elk River near Big Lake, MN (USGS 2003a), Rum River near St. Francis, MN (USGS 2003b), Red Cedar River at Menomonie, WI (USGS 2003c), Hay River at Wheeler, WI (USGS 2003d). The location of these gaging stations is indicated on Figs. 5-6, and, in higher resolution, at the USGS web sites in the bibliography. We downloaded the full history of daily discharge rates for each station, which went back to 1930 in most cases. Daily discharge rates showed frequent brief surges that corresponded to precipitation events, but also indicated a tendency to return towards a moving baseline that reflects the rate of groundwater input and might be interpretable as a measure of regional soil water availability for trees. We estimated this moving baseline for each station for each week of the data record (as the median of 7 daily records). The weekly interval was selected as being a time period that is physiologically relevant to trees; i.e., a week of severe water deficits would be expected to evoke drought stress in trees. To look for drought signals over the full 70 year record, we calculated the annual minimum of median weekly discharge for each station and plotted the time series and frequency distributions. These data were compared against historical reports of droughts in both regions. Weekly discharge rates were plotted for 3-4 year intervals that encompassed putative droughts at Anoka. We also plotted the frequency distributions of median weekly discharge rates (n ~ 3600 weekly values for each site).

We used USDA soil surveys for Sherburne County, MN and Dunn County, WI to compare the attributes of the soils supporting the red pine stands that we studied. We calculated site indices for red pine at a sample of 30-50 year-old red pine stands in each region (see below). We extracted increment bores from red pines in both regions, including a sample of 60-100 year-old trees, to test for regional differences in the effects of water availability on annual diameter growth.

Objective 2: Site specific patterns in tree growth and mortality

We selected 8 red pine stands near Sand Dunes State Forest to include a spectrum of soil types and a range of tree mortality following the drought of 2000 (Fig. 3). We also chose 5 sites near Colfax, WI (separated by 1 - 10 km) that included a spectrum of soil types in this region. At each site, we measured tree heights with a laser hypsometer, diameter at breast height of 5 trees / site, and basal area with an English BAF 10 prism (3 measurements / site). We extracted and mounted increment cores at 1 m height from 3 trees at each site. Site index was calculated from age and height following Lundgren and Dolid (1970). On 2327 August, 2002, we collected one soil core from each site (3/4" diameter to 90 cm depth). Cores were sectioned into 14 cm lengths, weighed immediately, then dried and re-weighed to obtain water content as percent mass. At the same time, we surveyed 6001000 trees at each site to estimate percent mortality during 2000, 2001, and 2002. Trees with no needles produced during the last year, and few dead needles still remaining on the tree, were judged to have died during 2000. Those with no live foliage, but holding needles produced during 2001 were judged to have died during 2001, and those with red foliage and current beetle attacks were classified as dead in 2002. These categories seemed to be quite discrete.

Objective 3: Test for eruptive behavior in populations of *Ips pini*

We used 12-unit Lindgren funnel traps to estimate the abundance of *Ips* bark beetles at each study site during the early summer flight period in 2002 (4 weeks of sampling from 26 May to 25 June). This sampling was timed to capture beetles that had successfully overwintered and were destined to reproduce during the summer. At each site, we deployed an array of four funnel traps, configured as an approximate square of ~ 20 x 20 m. Two traps per site were baited with the pheromone signal of *Ips pini*, ipsdienol + Lanierone, one was baited with the pheromone signal of *I. grandicollis*, ipsenol, and one was baited with the pheromone signal of I. *perroti*, ipsenol and ipsdienol (Ayres et al. 2001). Pheromone lures were bubblecaps purchased from PheroTech: elution rates of 0.2 mg / d for ipsdienol (racemic) and ipsenol, and 0.01 mg / d for Lanierone. Traps were emptied weekly and, at the same time, lures were rotated among traps to guard against spurious effects from trap position. Later, trap captures were counted and identified.

At each site, we also measured beetle colonization densities in logs. In late May, two trees were felled at each site, and 5, 50-cm long logs were removed from the mid-bole of each tree. At this time, 5 logs (2 or 3 from each source tree) were spread over each site (one log near each funnel trap, and one in the center of the trapping area). The other five logs were covered with a tarp, to prevent beetle colonization, until 15-20 July, when they were placed in the same locations as the first set of logs to provide a resource for colonization by the 2^{nd} generation of *I. pini*. At this time, the first set of logs were consolidated and covered with a tarp to prevent further colonization by beetles. On 22-27 August, we measured the colonization density by *Ips* of each trap log. We carefully removed a 40 x 22 cm section of bark from the upper surface of each log and counted the number of oviposition galleries, each representing one adult female that entered the log and began laying eggs. For each site, we calculated average experienced attack density, *ExpAD*, as:

$$ExpAD = \frac{\sum_{i=1}^{i\max} n_i \left(\frac{n_i}{area_i} \right)}{\sum_{i=1}^{i\max} n_i} \qquad \text{Eq 1}$$

where *I* = index for each log within a site, *imax* = the number of logs within a site, *nI* = number of attacking females per log, and *areaI* = dm^2 of area sampled within each log. This calculates the density experienced by an average ovipositing female within each site, which is more appropriate than the average density per log for estimating effects of intraspecific competition on population growth rate. It turned out that by the time of our measurements in late August, the logs colonized during June were too damaged by wood borers and other phloem-feeding insects to measure *Ips* colonization densities.

Hence, our subsequent analyses were restricted to logs colonized after 15 July. When we examined the logs in late August, we collected samples of adult *Ips* from the trap logs for identification. Not all of these have been examined yet, but it appeared that most, or all, were *I. pini*, which is as expected since the *I. pini* always has multiple generations per year in this region, while *I. grandicollis* and *I. perroti* typically just have a single generation (Ayres et al. 2001).

Results and Discussion

Objective 1a: Regional comparison of precipitation and temperature
Since 1940, annual precipitation near Anoka averaged about 6% less, with slightly greater inter-annual variation, than near Colfax: average mean ± average SD = 29.5 ± 6.3 inches / year vs 31.9 ± 5.5 inches / year (Table 1). Average summer temperatures were slightly warmer near Anoka (68.7 vs. 67.7 °F) and average winter temperatures were slightly cooler (14.5 vs. 15.3 °F) (Table 1). Neither Table 1 nor Fig. 7 indicated that the Anoka sand plains near Sand Dunes State Forest receive less precipitation than areas 20-30 miles further north, south, east, or west. Stations at Santiago and Elk River, about 10 miles north and south, respectively, of Sand Dunes State Forest (Fig. 5), have received annual precipitation that is representative for the broader area (Table 1, Fig. 7). In general, there was little variation in annual precipitation among sites within a region. The time series of annual precipitation since 1930 showed clear inter-annual variation in both regions, and some of the historical droughts were evident in the Anoka time series (Fig. 7); e.g., precipitation lows during 1976, 1987-88, and 2000 correspond to times of drought as evidenced by tree mortality and, sometimes, peat fires. Droughts reported in 1980-81 and 1965 were less evident in the Anoka precipitation data, and the extended drought of the mid 1930s ("Dust Bowl") was not very conspicuous. The precipitation time series for Colfax (Fig. 7, lower) was qualitatively similar to that of Anoka. In Fig. 7, there appear to be fewer years at Colfax vs. Anoka that stand out as having conspicuously lower precipitation. On the other hand, comparison of frequency distributions (Fig. 8) indicate that the interannual variation in precipitation was quite similar between regions. In general, interannual precipitation patterns were well correlated between the regions; i.e., dry years in Anoka also tended to be dry years in Colfax (Fig. 9).

Objective 1b: Regional comparison of river discharge
River discharge data showed very clear signals of all the reported droughts near Anoka (Fig. 10). Interannual variation in minimum weekly discharge rates were highly correlated between Rum River and Elk River, indicating that minimum weekly discharge is primarily driven by regional climatic patterns, rather than local land use, or local precipitation events. In both watersheds, an empirical drought threshold of < 30% of the long term average in weekly discharge rates did a good job of identifying drought years - better than precipitation patterns (compare Fig. 10 and Fig. 7). Discharge data from two rivers near Colfax area also showed high correlation across years (Fig. 11). The dry years of 1988-89 and the Dust Bowl were evident in the Colfax rivers, but, in contrast to the Anoka Plains, the annual minimum in weekly discharge rates never dropped below 30% of the long term average. This is consistent with the historical rarity of tree mortality from drought in the Colfax region. The frequency distributions of minimum annual discharge from the Anoka Plains differed from those of the Colfax region in tending to be skewed to the left (Fig. 12); i.e., a larger proportion of the years had low minium discharge rates in the Anoka Plains than near Colfax. The regional differences were even more pronounced in the frequency distributions of weekly discharge rates (Fig. 13). The variance in weekly discharge was dramatically higher in the Anoka Plains than near Colfax: coefficient of variation (SD / mean) = 1.23 and 1.31 for Elk and Rum Rivers vs. 0.67 and 0.83 for Red Cedar and Hay Rivers. Thus, weekly discharge in the Anoka Plains frequently dropped below the empirical drought threshold of 30% of the average while this has almost never happened in the Colfax region (Fig. 13). Note that there were strong regional differences in discharge variability even though precipitation variability was quite similar (compare Figs. 8 and 13).

Discharge data also permitted higher resolution in identifying the timing of historical droughts (Fig. 14). For example, discharge data indicate that the recent drought reached its nadir in October-November of 2000 (Fig. 14, upper), which is consistent with observations of dead and dying trees during aerial surveys in the winter of 2000-2001. Discharge rates remained above the drought threshold during 2001 and were well above average during 2002. Discharge data indicate that the drought of the late 1980s extended through two summers, 1988-89, and followed record highs during the summer of 1986 (Fig. 14, 2nd panel), which might have exacerbated the effects by producing root mortality in saturated soils. The drought of 1976 reached its nadir in September of 1976 (Fig. 14, 3rd panel), and the drought reported from the mid 1960s appears to have reached its nadir in August of 1964 (Fig. 14, lower panel).

Objective 1c: Regional comparison of soils
Our study sites spanned four mapped soil types within each region (Table 2). Both regions include sandy soils, derived from glacial outwash, that are characterized as having excessive permeability, limited available water capacity, and low fertility. However, the pine-bearing soils of the Anoka Plains are almost exclusively glacial outwash while the Colfax region

also includes sandstone residuum derived from the sandstone that was only 30-60 cm below the surface of two study sites. There are two separate glacial histories in the Colfax lobe of the Central Plain in Wisconsin. The entire landscape was thought to be glaciated only once, covered by the farthest reach of the first Wisconsinian glacial advance, the Altonian (30,000-50,000 YBP). It was very thin in the Colfax area, and thirty thousand years later, the till left behind is only inches deep on the upland areas that were not covered and reshuffled by the outwash of a later glacial advance, the Woodfordian (ca 10,000 YBP), which stopped ~ 30 km north of our study sites (Paull and Paull 1977). Now the region includes numerous sandstone ridges (20-60 m high) covered by shallow soils (18-60 cm) made up of weathered Altonian residuum, plus loess and decayed sandstone. The soils between the ridges, especially near rivers that drained the Northern Highlands, contains extensive sandy glacial outwash of the Woodfordian glacier (Laberge 1994). Thus, soils of the Colfax region, although tending to be sandy throughout, have two different histories, and somewhat different characteristics: tending to be relatively deep, outwash sands in the lowlands, versus shallow loams, underlain by sandstone, on the ridges. The two soils commingle and intergrade throughout the region.

The Anoka soils are classified as fine sand, loamy fine sand, or fine sandy loam. While the Colfax soils are loamy sand or loam. This suggests larger particle size and more rapid drainage through the Anoka soils compared to Colfax, which is consistent with the pattern of more variable river discharge rates from Anoka (Fig. 12), and more frequent drought (Figs. 10 vs. 11), even though precipitation is only 6% lower and no more variable (Fig. 8). Based on the soil survey data, the regions also differ in that Anoka soils tend to be more acidic and have lower available water capacity (Table 2). Somewhat surprisingly, the soil survey data revealed no differences in permeability or percentage of soil passing through sieves of four different size classes.

Objective 1d: Regional comparison of tree growth

The regional differences in red pine growth were larger than we guessed *a priori*. In Anoka, stands that were 45 - 55 years old were 52 - 66 feet tall and 7.7 10.9 inches diameter, while in Colfax, the stands were 4 - 15 years younger, but the trees were larger: 67 - 72 feet tall and 8.6 - 11.0 inches in diameter (Table 3). We calculated the average site indices (expected height at 50 years) to be 60 vs 84 feet at Anoka vs. Colfax. By comparison, site indices calculated for similarly aged red pine stands near Itasca State Park in western MN averaged 58 ft (Ayres et al. 1999).

We have not yet completed analyses of historical growth patterns based on tree rings, but visual inspection of the cores suggests that diameter growth on the Anoka Plains was somewhat lower on average, and much more variable between years, than in the Colfax region. We hypothesize that climatic effects on red pine growth will be weak or absent near Colfax, but strong, and related to droughts as quantified by river discharge, near Anoka.

Objective 2: Site specific patterns in soil moisture profiles, tree-growth, and tree mortality

Tree mortality associated with the 2000 drought on the Anoka Plains ranged from 6 to 122 trees / 1000 (Table 3). There was no obvious association between site-specific tree growth and tree mortality. Anoka sites with the highest tree mortality (4 and 6) had the lowest and highest site indices (Table 3). Neither were there clear associations between mapped soil types and tree growth or tree mortality (Table 3). Soil type 1258 fs included one site with low growth and high mortality and another with high growth and low mortality. Three sites on soil type 158A fs also included a broad range of site indices and tree mortality. Two sites on soil 1256 lfs had low site indices and moderate tree mortality. Further tests will be possible after the analysis of growth rings. The original hypothesis predicts that sites with the highest average growth tend to have high interannual variance in growth, and relatively high rates of tree mortality. Ideally, tests for relationships between tree growth, soil, and tree mortality would begin by selecting study sites at random with respect with tree mortality, which was not the case here (because tests for eruptive population dynamics - Objective 3 - were stronger with sites deliberately chosen to span a range of beetle abundance and tree mortality).

Soil moisture profiles showed evidence of perched water in some sites at Anoka but not others (Fig. 15). In 7 of 8 sites at Anoka, soil moisture at most depths, at the time of our sampling was about 5% by mass. In site 2, soil moisture increased from 5% at 60 cm to 12% at 85 cm. In site 5, soil moisture was elevated to near 10% at 18 cm, and to 17% at 78 cm. The fine sandy loam at site 10 had substantially higher water content, averaging about 10%, with higher amounts in the upper 10 cm, and declining amounts below 70 cm (Fig. 15). The sites that showed evidence of perched water (2, 5, and 10) had site indices that were average or below average (56, 61, and 53 ft; Table 3). Soil moisture profiles varied somewhat within mapped soil types (Fig. 15). Inferences from the soil moisture measurements were constrained because we had no replication within sites or across dates. Thus we cannot judge whether measurements are representative for the stands, even on the day of measurements. However, it appears that more such sampling would be feasible and permit a rigorous test of the hypothesis that red pines growing in banded soils tend to have higher growth on average, but are also more susceptibility to drought.

Soil moisture in the two loamy sands at Colfax also tended to be about 5% (Fig. 16). Chamnis North showed evidence of some perched water at about 50 cm and 85 cm. At Dickinson, soil water jumped to > 10% near 62 cm depth. The two loam soils, which lay only 30 60 cm above sandstone, had conspicuously higher soil moisture of ~ 10%. Calculated site indices were very constant among 4 sites (80 - 84 ft) and somewhat higher (89 ft) on one of the sites with PdB loamy sand.

Objective 3a: Abundance, species composition, and pheromone preferences of the bark beetle community
As expected, *I. pini* were more abundant in the Anoka Plains compared to the Colfax region (Table 4). With the same trapping protocol, captures of *I. pini* from late May to late June (the flight time of the overwintering generation) averaged about 8-fold higher in Anoka vs. Colfax (826 / site vs. 111 / site; Table 4). *I. grandicollis* were also more abundant in Anoka, but less so (only about 50% higher). Surprisingly, *I. perroti* were actually less abundant in Anoka than Colfax (Table 4). The two most abundant predators, *Thanasimus dubius* (Coleoptera: Cleridae) and *Playtsoma cylindrica* (Coleoptera: Histeridae) were both about 7-fold more abundant in Anoka than Colfax. The abundance of predators relative to prey, (*T. dubius* + *P. cylindrica*) / total *Ips*, was about 2.5x higher in Anoka compared to Colfax. This is consistent with the hypothesis that these specialist predators increase in their abundance after a year or two of high prey abundance. Presumably, this generates some negative feedback (with a delay) on the population growth rates of bark beetles (as has been reported for some other bark beetle systems; Turchin et al. 1999). It is not known whether or not this negative feedback is sufficient to eventually drive bark beetle populations back to an endemic equilibrium, or whether it is merely sufficient to regulate abundance around an epidemic equilibrium (see Fig. 1)

Bark beetle pheromone preferences in both regions matched those reported in earlier studies conducted near Colfax, WI and Itasca State Park, MN (Table 5): 95 -96% of *I. pini* were captured in traps baited with ipsdienol + Lanierone; and 73 - 94% of *I. grandicollis* were captured in traps baited with ipsenol by itself. The two most abundant predators were captured with all three pheromone signals, but were most attracted to the signal that is produced and preferred by *I. perroti* (ipsenol + ipsdienol). This suggests a hypothesis for why *I. perroti* were relatively rare in the forests where *I. pini* were very abundant.

Objective 3b: Test for eruptive behavior in populations of *Ips pini*
As expected, beetle-attacked trees were common in the Anoka Plains and very rare in the Colfax region: average tree mortality rates during the three years from 2000-2002 were 15.8 vs. 0.5 tree deaths per 1000 trees per year for Anoka and Colfax, respectively (Table 3). Across 8 red pine stands on the Anoka Plains, average tree deaths per 1000 were 6.4 in 2000, 24.7 in 2001, and 6.9 in 2002. In all but one Anoka site, tree deaths peaked in 2001. Tree attacks during 2002 were positively related to abundance of *I. pini* during early summer (Fig. 17, upper). There was a suggestion of a threshold for tree attacks, as predicted by the theoretical model for eruptive population dynamics (Fig. 2, upper). Tree attacks became relatively common when early summer trap captures of *I. pini* exceeded about 500 per two traps per month (Fig. 17, upper).

Colonization densities of logs by *I. pini* were also higher in Anoka than Colfax: mean experienced density ± SE = 2.5 ± 0.1 vs. 1.1 ± 0.2 ovipositing females / dm^2, respectively (Table 2). Across all 13 red pine stands that were studied, the density of *I. pini* in logs colonized during August was related to trap captures of overwintering *I. pini* adults during June (Table 2). However, this relationship was nonlinear, with a peak when trap captures were intermediate (Fig. 17, lower). There was strong statistical support for the nonlinearity of this relationships (AIC for 2^{nd} order polynomial vs. linear model = 5.57). The form of this relationship, and the match between a threshold for tree attacks and the peak in colonization density, were as predicted by the theoretical model for eruptive population dynamics (compare Figs. 2 and 17). The support for this model, although based on only a single year of data, is strengthened by the fact that the test involved rather specific predictions about the interrelations among three independent variables (local abundance as measured by trap captures, colonization densities in logs, and the number of live trees attacked during the summer). Presumably, beetle colonization densities in logs started to decline after trap captures exceeded about 800 because some beetles were participating in successful attacks of live trees, which increased the resource base for ovipositing females, and eased competition for phloem. Results suggest that the escape threshold for *I. pini* (Nescape in Fig. 1) is at 600 - 800 captures per two funnel traps per month.

Conclusions Regional differences in tree growth, tree mortality, and beetle outbreaks
Tree mortality rates are clearly much higher on the Anoka Plains than areas within 90 miles that experience similar climates and have similar sandy soils. This was obvious not only from the counts of mortality events during the last 3 years, but also from dramatic differences between the regions in the numbers of downed trees from earlier deaths; such logs were abundant throughout pine stands in the Anoka Plains but were rare or absent in pine stands near Colfax. The differences in tree mortality are difficult to explain based on the modest (6%) difference in average annual precipitation. Apparently there is a strong effect from the Anoka Plains being made up of soils that drain more rapidly than those near Colfax. Still, the direct effects on red pine forests of lower and more variable soil water would probably be modest were it not for the presence of bark beetles that can apparently be triggered by drought episodes to switch from endemic populations that rarely kill trees to epidemic populations that commonly kill trees. Thus the explanation for differences between red pine forests near Anoka and Colfax appear to involve strong interactions between climate, soils, and beetle population dynamics. The regional difference in tree mortality rates is surely enough to influence optimal harvest schedules, and is also surely enough to

warrant careful consideration of bark beetle management on the Anoka Plains, even while forest managers near Colfax can generally ignore them without consequence.

With constant annual mortality rates of 0.5 / 1000, such as we observed at Colfax, and other things being equal, a red pine stand would experience 48 deaths / 1000 trees over 100 years. Since 1930, there appear to have been about six significant droughts on the Anoka Plains. We estimated that the 2001 drought resulted in mortality of 15.8 trees / 1000. If there is one drought per 12 years that results in the death of 15.8 trees / 1000, on top of a background annual mortality rate of 0.5 / 1000, a red pine stand would experience 175 deaths / 1000 trees over 100 years. These calculations are very simplistic. In particular, they fail to account for: (1) the risks of catastrophic losses associated with droughts more severe than that of 2001; (2) mortality risks associated with fire, blowdown, fungal pathogens, and ice damage; (3) potential for minimizing risks through selective harvesting. Nonetheless, these calculations suggest that there would be value in developing more sophisticated projections to aid in the development of long term management plans for red pine stands that account for regional differences in tree growth and mortality rates on timber yield and stand structure over 50 - 100 year time frames. Our sense is that it is realistic to manage red pine stands near Colfax for a time frame of >100 years, while reasonable rotation times for red pine stands near Anoka may be substantially less. These calculations also suggest that the expected lifespan for red pine stands near Anoka may be extremely sensitive to consideration of bark beetle risks in site selection and management.

In addition to modifying red pine management strategies on the Anoka plains, it may make sense to consider other tree species for future reforestation. Because tree/bark beetle interactions can be quite species-specific, and because tree species differ in moisture requirements and drought response, planting other conifers instead of red pine, may make sense. Mixed species plantings in some areas have shown promise for managing pest/tree interactions, and offer the additional benefit of providing a more diverse ecosystem. Our work offers no insight as to the suitability of alternate tree species, but could help establish parameters for comparisons.

Application of USGS hydrological discharge data

Analyses of river discharge data suggest that there would be value in monitoring USGS discharge data to recognize potential droughts in the early stages and implement appropriate, cost-effective responses (e.g., minimizing log decks that could permit buildups of bark beetles, and conducting aerial and ground surveys for early signs of tree deaths and beetle activity). This would also facilitate studies of tree water status and resin defenses during the time of presumed maximal water deficits. Such studies are needed to understand how drought influences the defenses of trees that would survive in the absence of beetles. Available data suggest that resin defenses of pines are actually increased by moderate water deficits (Reeve et al. 1995, Ayres et al. 1999, Lombardero et al. 2000), but patterns at Anoka are also consistent with the alternative hypothesis that drought stress compromises tree defenses. Resolution of these competing hypotheses will aid in understanding how beetle control efforts and stand management can mitigate risks of tree mortality.

USGS river discharge data may have broader applicability for: (1) objectively identifying regions that are generally susceptible to consequential droughts; and (2) monitoring entire states for local or regional droughts. This broader applicability depends upon the unvalidated proposition that patterns identified here based on four rivers in two county-sized regions can be extended to a broader spatial scale. However, it would cheap and easy to begin evaluating the generality of, for example, the 30% drought threshold suggested here. Among other benefits, results would likely enhance our ability to anticipate the consequences for forests of changes in temperature and precipitation that have already occurred and are likely to accelerate (U.S. Global Change Research Program 2000). We can expect climate changes to continue to alter patterns of soil water availability in Minnesota, and the effects on forests, whether positive or negative, are likely to be the largest and most immediate in regions like the Anoka. Plains.

Correlations within a region between local soil types, average tree growth, and stand susceptibility to droughts

We were unable to resolve what, if any, are the patterns between local soil types, tree growth, and stand susceptibility to drought and beetles. However, the question is important and deserves further study. We suggest that a subsequent study include replicate pine stands selected at random from within different mapped soil types. Within these stands, one could measure: (1) soil moisture profiles as in Figs. 15-16, replicated within each stand and across the season; (2) tree mortality via surveys for dead trees and downed logs; (3) historical patterns in height and diameter growth; and (4) depth of roots. Results would aid forest managers and landowners in selecting sites for red pine propagation, and customizing management of red pine stands for site-specific characters (e.g., harvesting schedules, tree selection during harvesting, pest monitoring, and pest control).

Implications for understanding effects of climate on tree mortality and beetle populations

Results indicate that there are potential benefits to monitoring populations and treating those that have exceeded the escape threshold that separates endemic populations from eruptions. Apparently, climate and beetles interact to determine tree mortality rates and forest disturbance regimes. Direct death of trees from drought may be less important than drought as a factor that triggers state changes of bark beetles from endemic to epidemic. If it were otherwise, the impacts of beetles would be restricted to times when trees are dying, or have compromised defenses, as a result of climatic stress. As it appears to be, beetle mortality may continue for years after a drought abates. Potential control strategies for *Ips* in red pine forests include mass-trapping with pheromone-baited funnel traps, deployment and destruction of trap logs, and aggressive sanitation. In our judgement, it remains to be established that these control strategies can be effective and practical for pine systems in Minnesota, but if *I. pini* populations tend to have endemic and epidemic states (Fig. 1), there is potential value in pest control. The correlation among stands between trap captures in early summer and tree attacks during the summer, suggests that control might be effective at the stand level (not necessarily requiring expensive regional efforts). We recommend that a plan be devised for implementing pest control efforts in some stands that are above the estimated escape threshold (Fig. 17) and leaving other such stands as controls. This would permit the evaluation of different possible control strategies, the continued testing and refinement of models to predict bark beetle population dynamics, careful assessment of possible undesirable side effects (e.g., removal of natural controls by predators) and, hopefully, the mitigation of expensive beetle impacts within treated stands.

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Table 1. Comparison of annual precipitation (since 1940) and mean temperatures near Anoka, MN and Colfax, WI

				Annual precipitation (inches/yr, Oct-Sept)		Summer temp. (° F, June-Aug)		Winter temp. (° F, Dec- Feb)	
Region	Site	Years		Average	SD[a]	Average	SD[a]	Average	SD[a]
Anoka, MN	Santiago***	41		30.9	6.6	68.3	1.8	14.5	4.8
Anoka, MN	Elk River***	49		29.1	5.8				
Anoka, MN	Buffalo	40		29.1	6.1	69.8	2.0	15.5	4.2
Anoka, MN	Cambridge	54		28.6	5.6	68.0	2.3	13.7	4.0
Anoka, MN	Cedar	36		31.7	6.7	69.0	1.7	15.7	4.2
Anoka, MN	Collegeville	57		28.4	6.7	69.3	1.8	14.6	4.4
Anoka, MN	Maple Plain	43		29.6	5.3	69.5	2.3	15.1	4.1
Anoka, MN	Milaca	55		29.0	6.7	67.9	2.0	14.0	4.3
Anoka, MN	St. Cloud	53		27.2	5.9	67.8	1.7	13.0	4.2
Anoka, MN	St. Francis	30		31.0	7.1				
		Mean	**=**	**29.5**	**6.3**	**68.7**	**2.0**	**14.5**	**4.3**
		SD[b]	=	1.4	0.6	0.8	0.2	0.9	0.2
Colfax, WI	Bloomer***	56		31.3	5.8	68.4	2.1	15.8	4.0
Colfax, WI	Menomonie***	59		30.4	5.4	69.7	1.9	17.9	4.0
Colfax, WI	Amery	61		30.9	5.7	67.9	1.8	14.1	4.2
Colfax, WI	Baldwin	49		31.4	5.5				
Colfax, WI	CedarFalls	51		32.9	5.9				
Colfax, WI	Eau Claire	53		31.0	5.1	68.7	1.7	15.7	4.2
Colfax, WI	Holcombe	60		32.1	5.2	67.3	2.1	15.7	4.5
Colfax, WI	Mondovi	49		32.1	5.9	69.5	1.9	17.9	4.5
Colfax, WI	Rice Lake	49		31.9	5.1	67.3	1.9	14.3	4.1
Colfax, WI	Ridgeland	49		32.5	5.5	67.0	1.8	14.2	4.3
Colfax, WI	Spring Valley	37		31.3	5.6				
Colfax, WI	Weyerhauser	55		32.7	6.0	66.1	1.9	14.9	3.8
		Mean	**=**	**31.9**	**5.5**	**67.7**	**1.9**	**15.3**	**4.2**
		SD[b]	=	0.7	0.3	1.2	0.1	1.4	0.2

*** = closest station to study sites

SD[a] = standard deviation among years

SD[b] = standard deviation among sites

Table 2. Summary of soil types in red pine stands near Anoka, MN and Colfax, WI (based on soil surveys for Sherburne Co, MN and Dunn Co, WI). One additional soil was represented among the studied pine stands at Anoka (Scandia fine sandy loam at Site 10).

	Anoka soils represented in sampling			Colfax soils represented in sampling			
Soil map symbol	158	1258	1256	PfA	PbB	EmB	UnB
Soil name	Zimmerman fine sand	Zimmerman fine sand, thick solum	Cantlin loamy fine sand	Plainfield loamy sand	Plainbo Loamy sand	Elkmound loam	Urne-Norden loam
Family or higher taxonomic class	Mixed, frigid Argic Udipsamments	Mixed, frigid Argic Udipsamments	Mixed, frigid Typic Udipsamments	Mixed mesic, Typic Udipsamments	Mixed frigid, Typic Udipsamments	Loamy, mixed, mesic, Lithic Dystrochrepts	Coarse-loamy, mixed, mesic, Dystric Eutrochrepts
Landform	Outwash plains	Outwash plains	Outwash plains	Outwash plains, stream terraces	Base of steep slopes	Sandstone mantle	Upland ridgetops
Parent material	Glacial outwash	Glacial outwash	Glacial outwash	Glacial outwash	Glacial outwash	Sandstone residuum	Sandstone residuum
Cropland considerations	Excessive permeability; limited available water capacity	Excessive permeability; limited available water capacity	Excessive permeability; limited available water capacity; acid soil	Excessive permeability; limited available water capacity, low fertility	Excessive permeability; limited available water capacity, low fertility	Shallow soils subject to erosion and drought,low available water, moderate permeability, medium fertility	Moderate permeability and fertility, medium water capacity
Depth to mottling or banding	banded at 5-6 feet	banded at 6.6 feet +	No bands, mottled at 4 feet				
pH	5.1 - 6.5	5.1 - 6.5	5.0 - 6.0	6.1 - 7.3	6.7 - 7.3	6.1 - 6.5	5.6 - 7.3
Permeability (in / hr)	6 - 20	6 - 20	6 - 20	6.3 - 20	6.3 - 20	0.63 - 2.0	0.63 - 2.0
Available water capacity (in / in)	0.07 - 0.09	0.07 - 0.09	0.10 - 0.12	0.08 - 0.12	0.08 - 0.12	0.18 - 0.22	0.18 - 0.22
Percentage passing sieve #4	95 - 100	95 - 100	100	95 - 100	95 - 100	90 - 100	
Percentage passing sieve #10	95 - 100	95 - 100	100	85 - 95	85 - 95	80 - 90	80 - 90
Percentage passing sieve #40	10 - 20	10 - 20	50 - 75				
Percentage passing sieve #200	15 - 20		50 - 75	20 - 25	20 - 25	55 - 65	55 - 65
Extent of the soil (% acres in county)	58	7	6	8	7.5	1.1	27
Water table depth (ft)*	> 6	>6	3.5 - 6	>5	>5	>5	>5

* "Seasonal high" in Colfax soil survey

Table 3. Stand characteristics, beetle captures in pheromone-baited funnel traps, *Ips* colonization densities in traps logs, and beetle-attacked trees in red pine stands near Anoka, MN and Colfax, WI.

		Stand characteristics							Trap captures (per 4-trap array during June 2002)						*I. pini* in logs[d]	Attacked trees / 1000		
Region	Site	Soil.ID	Age.2002[a]	Age.2002[b]	Height(ft)	Site.Index[c]	DBH(in)	BasalArea	*I.pini*	*I.grand*	*I.perrot*	*T.dubius*	*P.cylind*	Ips/Predator	Attacks/dm2	2002	2001	2000
Anoka.MN	1	1256 lfs	49	52	63	61	10.1	107	624	346	33	430	452	1.1	2.11	7	60	0
Anoka.MN	2	1256 lfs	51	53	59	56	10.5	137	1096	206	3	221	95	4.1	2.88	3	10	7
Anoka.MN	4	1258 fs	57	51	52	51	8.7	230	606	252	12	244	217	1.9	3.48	7	84	31
Anoka.MN	5	158A fs	57	55	66	61	10.9	90	866	297	16	363	121	2.4	1.91	15	28	2
Anoka.MN	6	158A fs	48	43	66	75	8.2	180	1657	331	34	1443	304	1.2	1.20	24	52	24
Anoka.MN	8	158A fs	40	45	52	57	9.5	207	261	177	28	1123	143	0.4	2.45	0	10	0
Anoka.MN	9	1258 fs	45	46	64	68	7.7	183	733	269	205	721	216	1.3	2.10	3	3	0
Anoka.MN	10	Sp fsl	35		39	53	8.0	177	762	162	2	153	22	5.3	3.72	10	0	0
		Mean	**48**	**49**	**58**	**60**	**9.2**	**164**	**826**	**255**	**42**	**587**	**196**	**2.2**	**2.5**	**9**	**31**	**8**
		SE	**1.0**	**0.7**	**1.2**	**1.0**	**0.2**	**6**	**51**	**9**	**8**	**59**	**17**	**0.2**	**0.1**	**1**	**4**	**2**
Colfax.WI	ChamN	Pdb	39	39	72	89	10.6	183	62	156	56	65	34	2.8	1.44	0	0	0
Colfax.WI	ChamW	EmB	39	39	67	83	11.0	147	169	189	202	130	38	3.3	0.20	2	0	0
Colfax.WI	Dickin	PfA	43	42	72	83	10.2	133	139	145	176	68	25	4.9	2.29	1	5	0
Colfax.WI	ScoreN	PdB	42	41	68	80	10.1	160	69	86	8	45	10	3.0	0.30	0	0	0
Colfax.WI	ScoreS	UnB	42	41	71	84	8.6	230	118	242	224	110	37	4.0	1.52	0	0	0
		Mean	**41**	**40**	**70**	**84**	**10.1**	**171**	**111**	**164**	**133**	**84**	**29**	**3.6**	**1.1**	**1**	**1**	**0**
		SE	**0.4**	**0.3**	**0.5**	**0.6**	**0.2**	**8**	**9**	**11**	**19**	**7**	**2**	**0.2**	**0.2**	**0**	**0**	**0**

[a] Age based on planting records. Age.2002.b = age at 1 m (from cores) + 5. Site indices calculated from Age.2002.b

Table 4. Average captures per site (in 4 Lindgren funnel traps) of three species of *Ips* bark beetles and two species of bark beetle predators during early summer 2002 in 8 red pine stands on Anoka Plains, MN and 5 red pine stands near Colfax, WI.

~Mid-date	*Ips pini*		*Ips grandicollis*		*Ips perroti*		*Thanasimus dubius*		*Playtsoma cylindrica*	
of collection	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax
27-May		23		136		101		11		4
3-Jun	675	20	229	15	37	20	313	23	98	6
13-Jun	60	10	11	6	4	7	120	14	36	6
20-Jun	91	58	15	6	1	5	155	36	62	13
29-Jun		441*		6		40		30		17

* Presumed to be the 2nd generation.

Table 5. Percent of captures by species and region in Lindgren funnel traps baited with either of three sets of pheromone lures, designed to match the pheromone production of *I. pini* (ipsdienol + Lanierone), *I. grandicollis* (ipsenol), or *I. perroti* (ipsdienol + ipsenol). Bark beetle preferences in both regions matched expectations based on previous studies near Colfax and Itasca (Ayres et al. 1999, 2001). Both of the two most common predators responded to all pheromone signals, but were most attracted to ipsdienol + ipsenol. This, plus the generally high abundance of predators near Anoka, might explain the relative rarity of *I. perroti* near Anoka (Table 4).

Pheromone	*Ips pini*		*Ips grandicollis*		*Ips perroti*		*Thanasimus dubius*		*Playtsoma cylindrica*	
lure(s)	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax	Anoka	Colfax
Ipsdienol + L*	95	96	3	0	4	2	35	29	34	38
Ipsenol	2	0	73	94	0	0	24	23	19	12
Ipsdien. + Ipsenol	3	4	23	6	95	98	41	48	47	50

* Lanierone, = pheromone synergist of ipsdienol for *Ips pini*

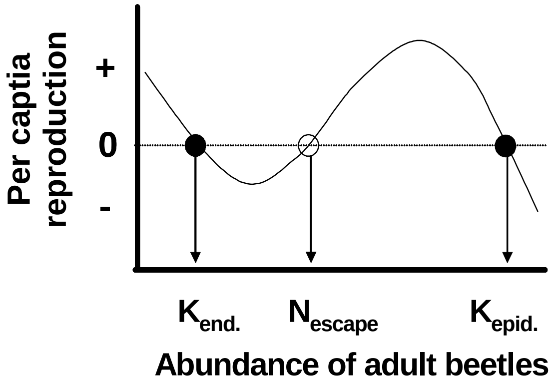

Fig. 1. Theoretical model of an eruptive forest insect. Per capita population growth rate is a complex function of abundance. When abundance is less than N_{escape}, populations tend to be regulated around an endemic equilibrium ($K_{endemic}$). However, if exogenous forces permit the population to exceed an unstable equilibrium or escape threshold (N_{escape}), populations will tend to grow to a much higher epidemic equilibrium ($K_{epidemic}$). We tested whether this model applies to the pine engraver beetle, *Ips pini*, by testing some predictions derived from this model (Fig. 2)

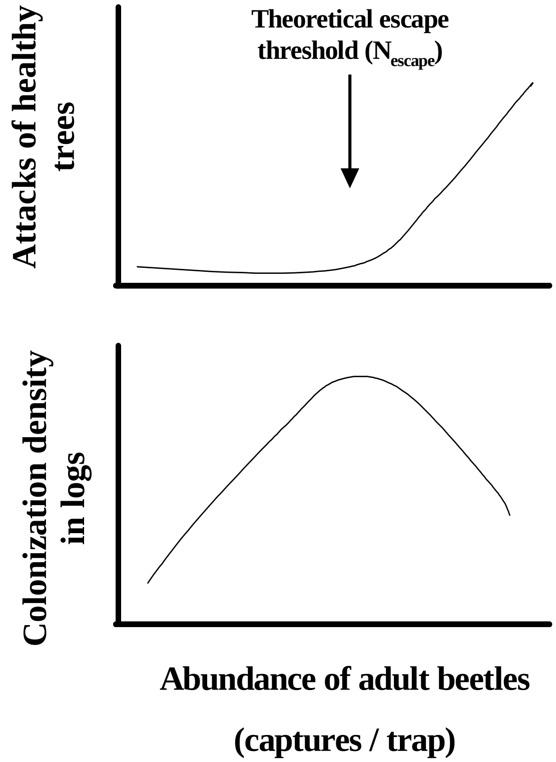

Fig. 2. Predictions derived from Fig. 1 for *Ips pini*. As local population abundance increases, the colonization density in logs (ovipositing females / dm^2) is predicted to increase (generating the initially negative relationship in Fig. 1 between adult density and per capita reproduction), until populations reach a threshold where they begin to attack live trees, at which point competition for food resources is theoretically alleviated and colonization density is predicted to decline.

The maps shown in Figures 3-6 are not reproduced here, but can be viewed online at:
http://www.dartmouth.edu/~mpayres/pubs/Anoka/

Fig. 3. Location of study sites on Anoka Plains, MN, and Colfax lobe Central Plains in WI.

Fig. 4. Location of seven red pine stands studied within Sand Dunes State Forest, MN. Site 10 (not shown) was 11.3 miles due east of site 3.

Fig. 5. Location of climate stations (highlighted waypoints) used for analysis of precipitation patterns on Anoka Plains, MN. Eight red pine study sites (1-10) are near center. Elk Weir and Rum Weir are USGS gaging stations used for analysis of hydrologic discharge patterns

Fig. 6. Location of climate stations used for analysis of precipitation patterns near Colfax, WI. Five red pine study sites are near center. Hay Weir and Red Weir are USGS gaging stations used for analysis of hydrologic discharge patterns.

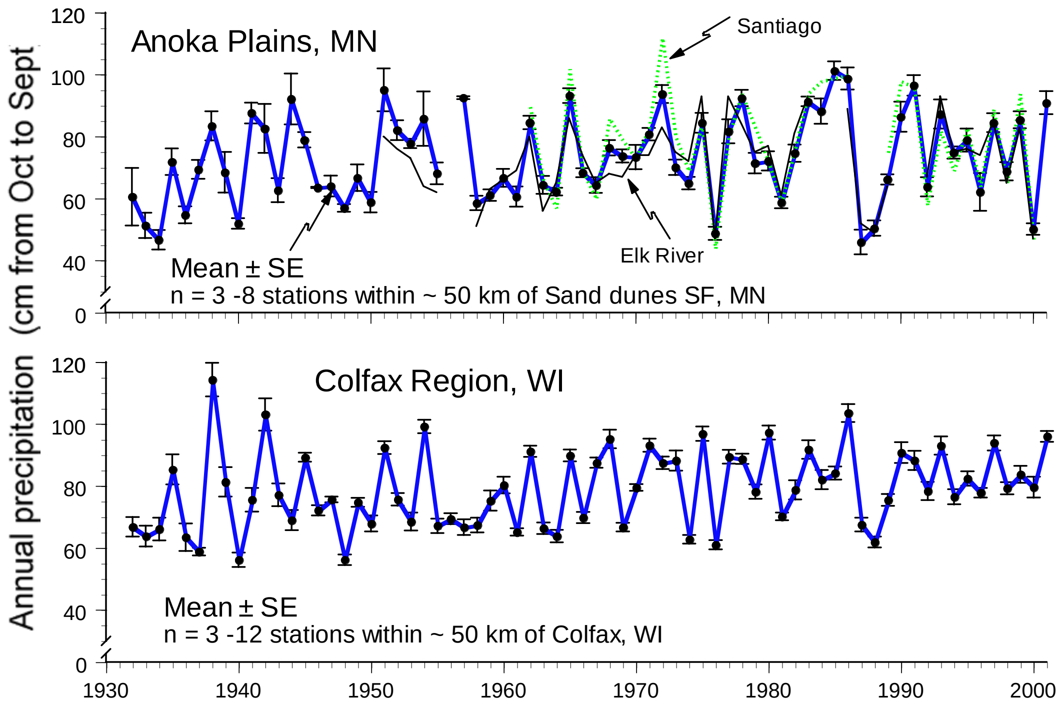

Fig. 7. Annual precipitation on the Anoka Plains and Colfax Plains since 1932. There was only minor variation among climate stations within the region (note small SEs and close tracking of data from Santiago and Elk River with regional data). See Figs. 5-6 for location of climate stations.

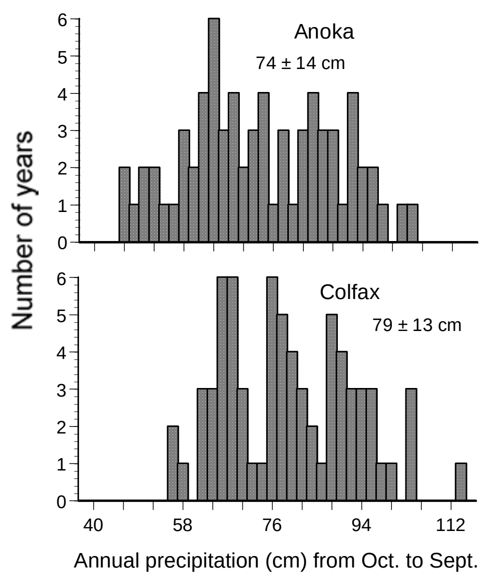

Fig. 8. Frequency distribution of annual precipitation since 1932 near Anoka, MN and Colfax, WI. Average precipitation was 5 cm / year lower near Anoka vs. Colfax (6%), but interannual variance was similar.

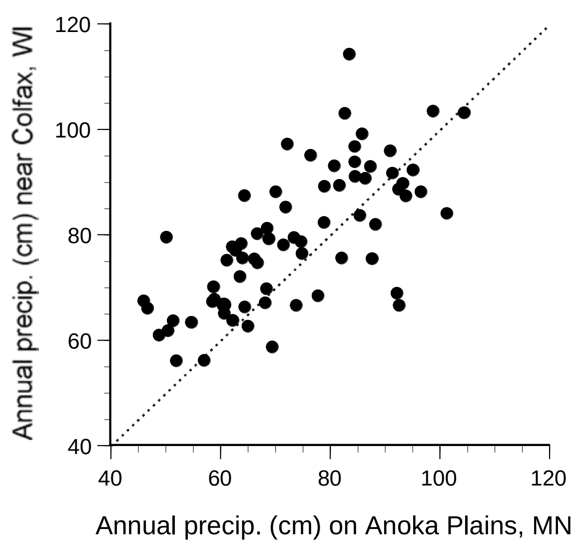

Fig. 9. Annual precipitation near Colfax, WI and Anoka, MN are well correlated (same data as in Figs. 7-8). In 50 of 69 years, annual precipitation was greater near Colfax vs. Anoka. The average difference was 5.9 cm / year.

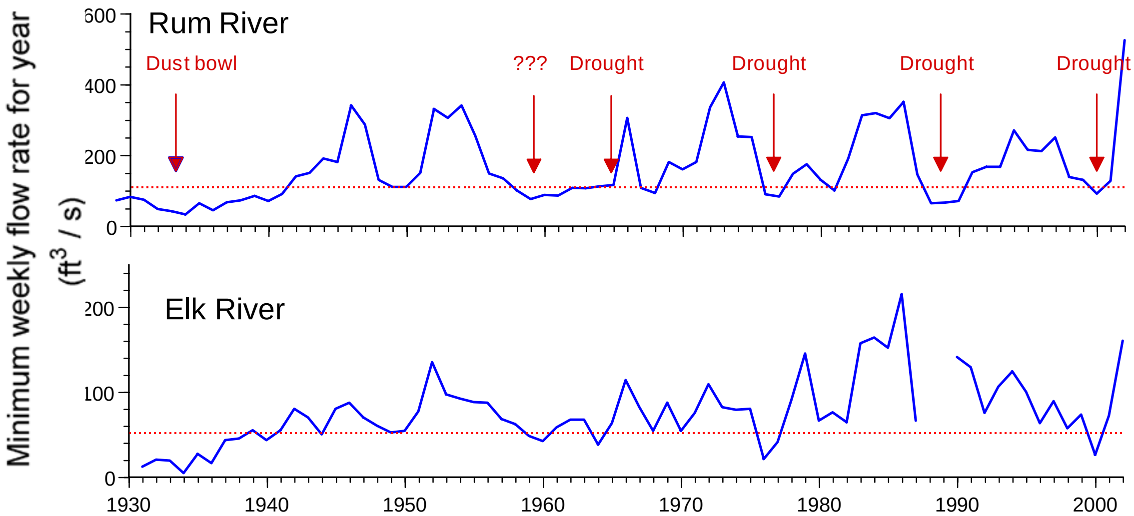

Fig. 10. Annual minimum of weekly discharge rates from two gaged rivers draining the Anoka Plains. Historical droughts at Sand Dunes State Forest (as reconstructed without reference to the discharge data) are indicated with arrows labelled "Drought". Based upon these data, we hypothesize that there was another drought in 1959-60. The dotted lines indicate an empirical drought threshold calculated as 30% of the longterm average in median weekly discharge rates (Fig. 13): 113 and 53 ft^3 / s for Rum and Elk Rivers, respectively. Note that the historic droughts are more evident in the discharge data than the precipitation data (Fig. 7), and that the discharge data are available online in real-time through the USGS. See Fig. 14 for close-ups of weekly discharge rates during droughts.

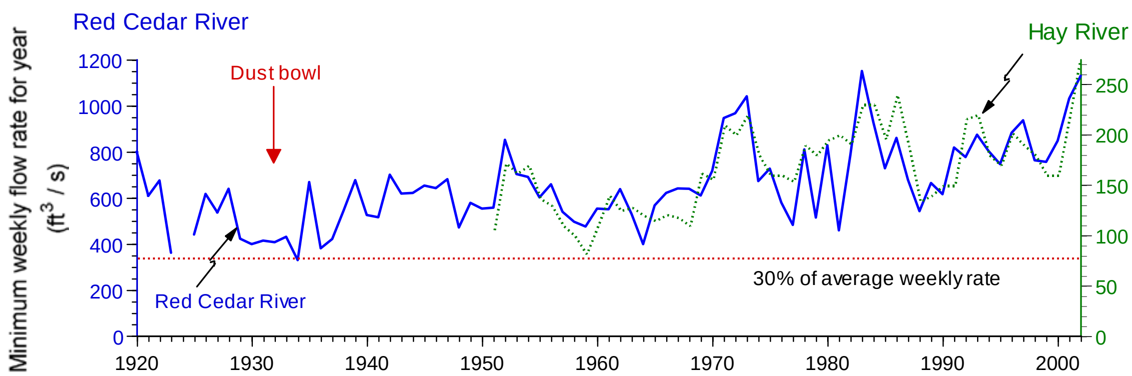

Fig. 11. Annual minimum of weekly discharge rates from two gaged rivers draining the Colfax lobe of the Central Plains in Wisconsin (see maps in Figs. 4 and 6). Unlike the Anoka Plains, river discharge rates near Colfax rarely drop below a putative drought threshold of 30% of the long term average. This is consistent with tree mortality from drought being common in Anoka and rare near Colfax. The lowest recorded discharge rates in the Colfax area were in 1934 during the Dust Bowl. Low precipitation during 1988-89 (Fig. 7) produced a noticeable dip in discharge rates, but did not approach the 30% threshold, and did not produce significant mortality in red pines. Based on these data, we hypothesize that low soil water in 1959 and 1964 had notable impacts on agricultural yields in the area.

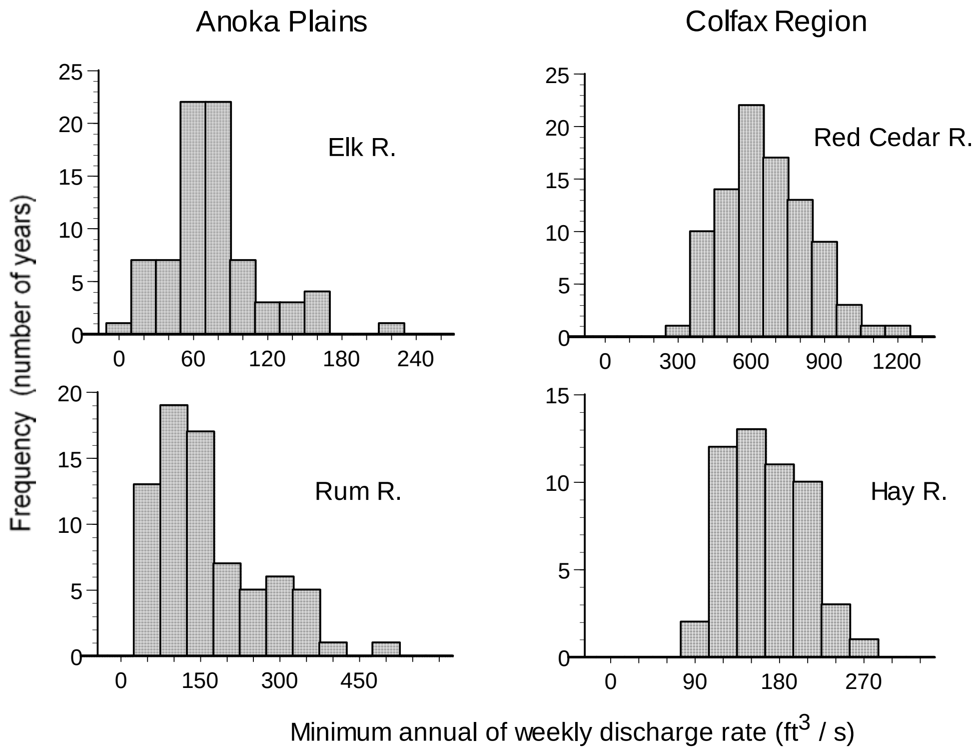

Fig. 12. Frequency distributions of annual minima in weekly discharge rates in two rivers draining the Anoka Plains (left) and the Colfax region (right). Note that there are relatively more years with low discharge in the Anoka Plains.

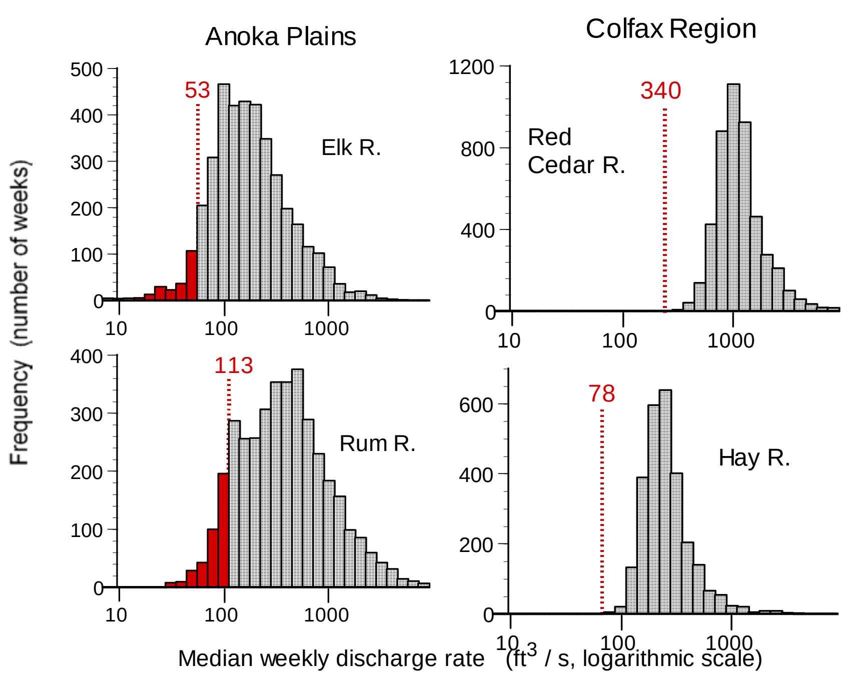

Fig. 13. Frequency distributions of weekly discharge rates in two rivers draining the Anoka Plains and Colfax region. Note markedly higher variance in rivers draining the Anoka Plains. Values of 53, 113, 340, and 78 indicate putative drought thresholds defined as 30% of the average (same as indicated in Figs. 10, 11, and 14).

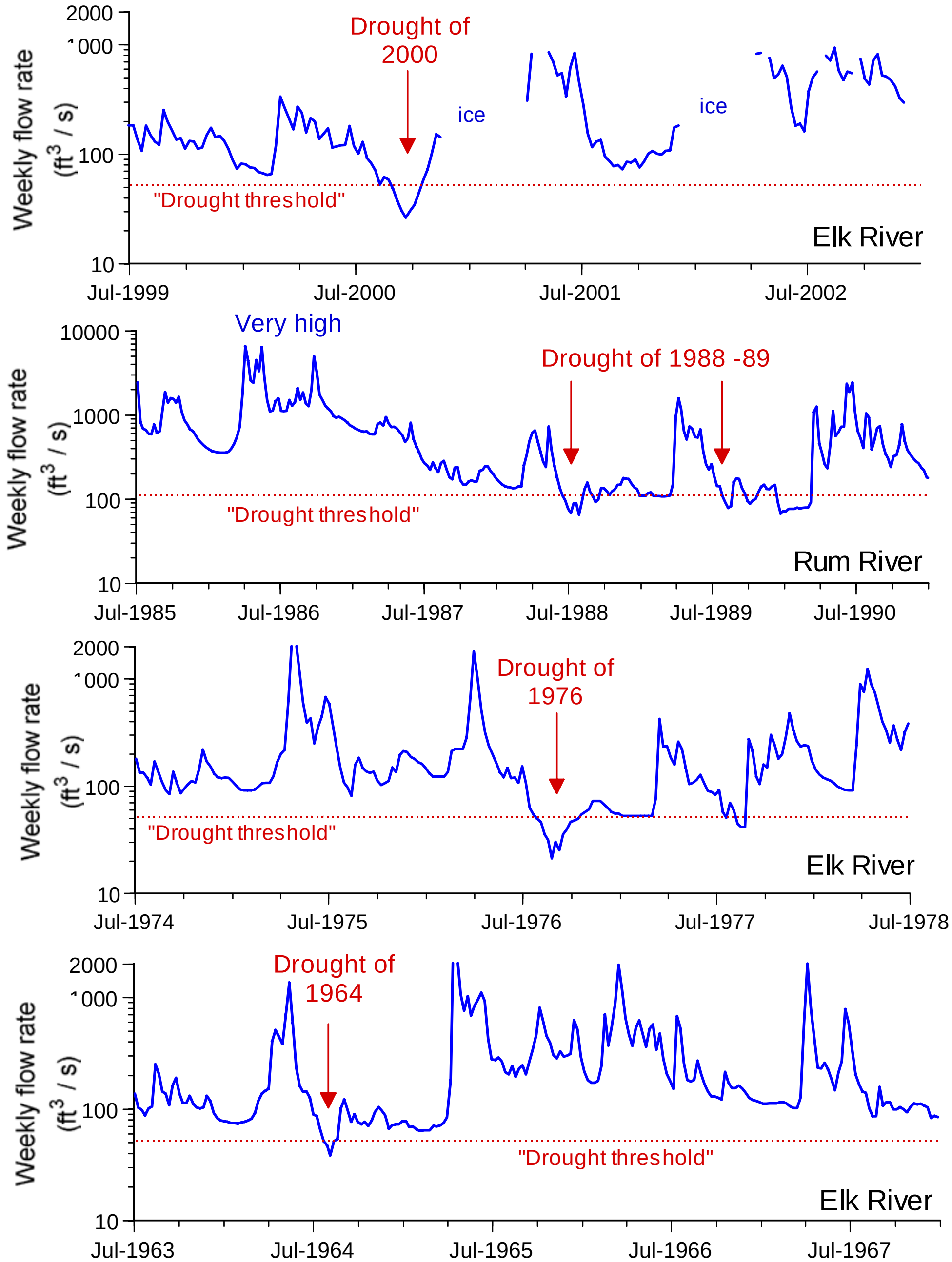

Fig. 14. Weekly discharge rates from the Anoka Plains before, during, and after droughts (in 2000, 1988-89, 1976, and 1964) that were recognized based on tree mortaility, beetle outbreaks, and peat fires. Note that a "drought threshold" defined as 30% of the long term weekly discharge rates seems to provide an objective and reasonably accurate metric for recognizing consequential droughts. This metric has particular value because discharge data are available on-line, in real time, which could permit the recognition of future droughts as they occur, before tree mortality, beetle outbreaks, and peat fires.

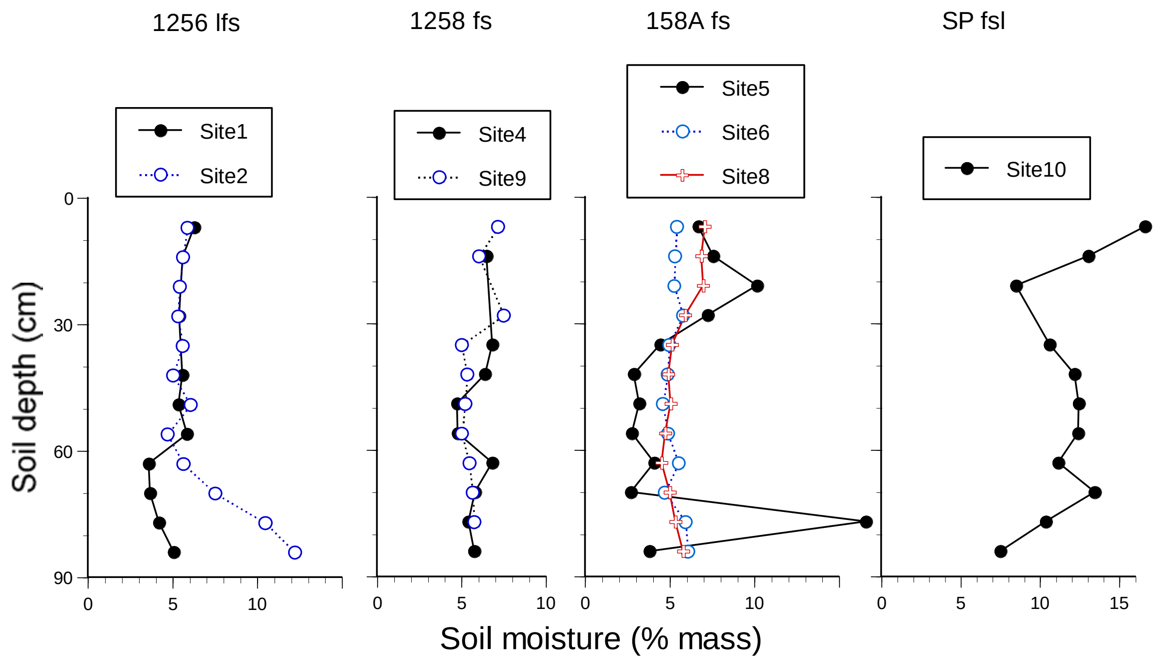

Fig. 15. Soil moisture vs. depth on 23-24 August 2002in 8 red pine stands on four soil types near Anoka, MN.

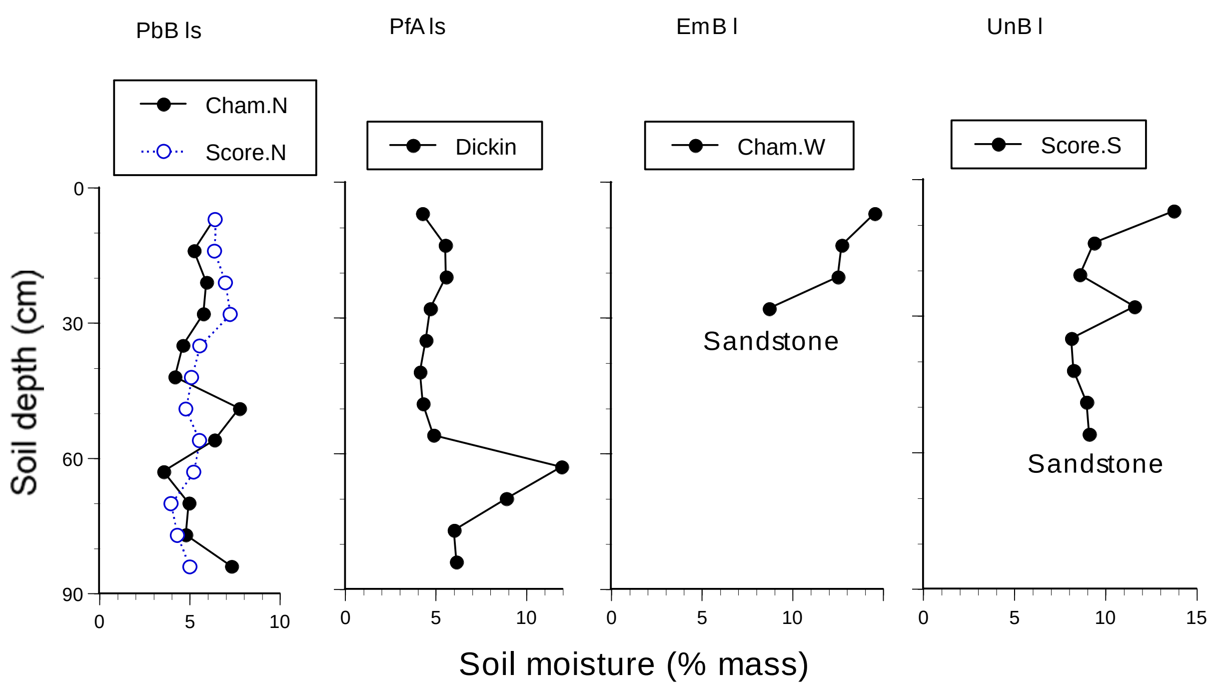

Fig. 16. Soil moisture vs. depth on 26-27 August 2002in 5 red pine stands on four soil types near Colfax, WI.

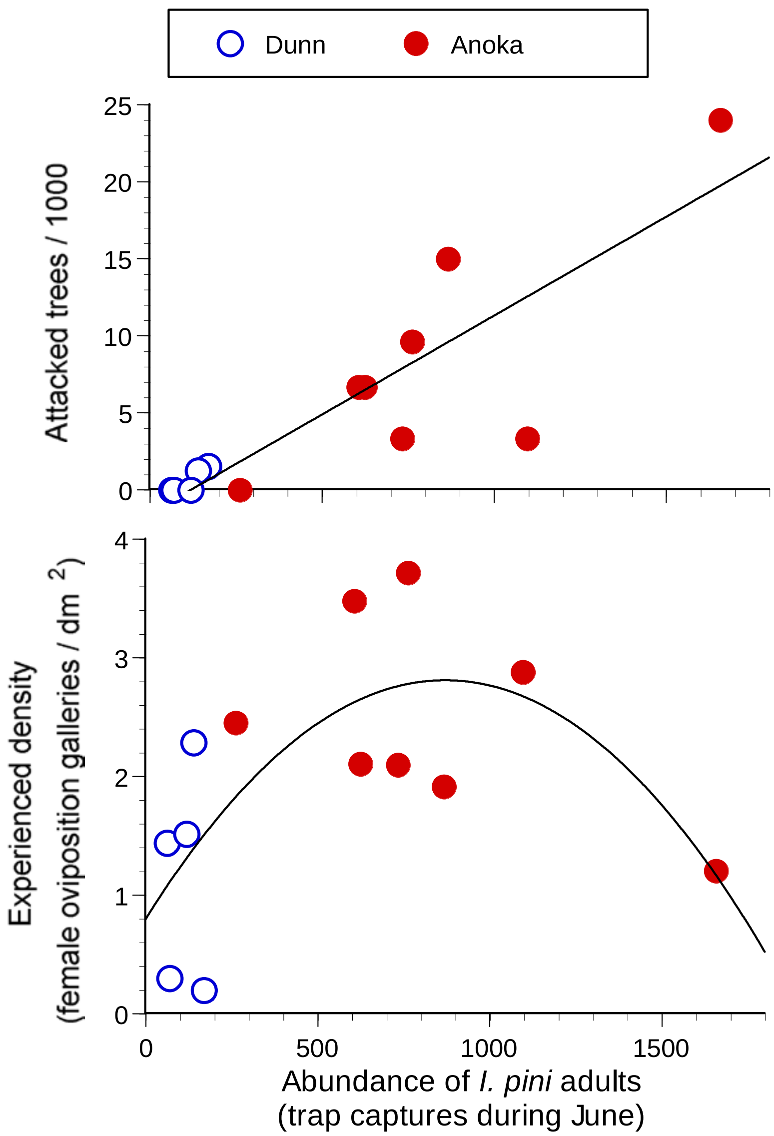

Fig. 17. Trees attacked by Ips pini during summer 2002 as a function of I. pini trap captures during early summer (upper) and I. pini colonization density in logs as a function of trap captures (lower). Best fit function for upper: $Y = -1.5 + 0.013 \cdot X$ ($P = 0.0002$). Best fit function for lower: $Y = 0.79 + 4.63\text{E-}3 \cdot X - 2.66\text{E-}6 \cdot X^2$ ($P = 0.035$ for full model, $P < 0.02$ for both coefficients). Compare these empirical data to theoretical predictions in Fig. 2 for an eruptive population (Fig. 1).

Beetle abundance in Burned and Unburned Red Pine Stands in Beltrami Island State Forest, MN

By Michael Broschart, Gretchen Mehmel and Scott Laudenslager, DNR-Wildlife

Introduction

Red pine (*Pinus resinosa*) is present in the Beltrami Island State Forest, MN as plantations and is also a component in old growth stands. Several species of pine bark beetles attack all pines in Minnesota but prefer red pines. Species of pine bark beetles that occur in Minnesota are *Ips pini*, *I. grandicollis*, *I. perroti*, and the red turpentine beetle, *Dentroctonus valens*.

Bark beetles are naturally occurring as endemic populations in red pine forests and normally have little impact on healthy trees. However, bark beetles can occasionally erupt to epidemic population levels when red pine trees are stressed by drought, disease, fire damage, or mechanical wounding and spread by attacking otherwise healthy trees. Bark beetles bore through the bark of the trees and form tunnels or galleries between the bark and the wood. Large infestations can cause tree mortality by introducing blue stain fungi that plugs the water conducting tissues thereby disrupting water flow. Healthy pine trees can usually resist endemic population levels by producing a copious flow of pitch (oleoresin), which physically prevents the bark beetles from entering the tree.

Pine bark beetle adults over winter in the ground and emerge in late-April. They bore into bark and form tunnels in the inner bark where they lay their eggs. The eggs hatch to larvae, change to pupae, and finally mature to adults. The new adults bore out of the bark and then search out other pine trees or even the same tree to bore into and start a new life cycle. There can be multiple generations of bark beetles each summer.

A prescribed fire was initiated in a red pine plantation to remove duff, recycle nutrients and expose mineral soil to prepare a seed bed for red pine, white pine (*Pinus strobus*), and jack pine (*Pinus banksiana*) seeds. This fire inadvertently resulted in some physiological stress to some of the red pine in the stand as well as some mortality. As a result of the fire damage stress to this red pine plantation, it was hypothesized that the pine bark beetle population would erupt to epidemic levels. The Red Lake WMA initiated a monitoring study to assess the extent of the bark beetle outbreak in the burned stand.

Study Site

The monitoring study was designed to compare the bark beetle abundance between the burned red pine plantation representing a hypothetical epidemic population and an unburned red pine plantation representing a hypothetical endemic population. The prescribed fire occurred in the burned stand in the spring of 2004 and the unburned stand was thinned in the fall of 2004. Though thinning of forest stands does result in some stress to residual trees, it was assumed the level of stress experienced by the red pine in the unburned stand was not to the degree that occurred in the burned stand. This was evidenced by the fact that there were 51 dead red pine trees at the burned site and only 3 observed in the unburned site. The study sites were located in Beltrami Island State Forest, Lake of the Woods County, MN. The burned stand was located in T159, R34W, SE ¼, Sec. 11 and the unburned stand was to the northwest in T159, R34W, NW ¼, Sec. 2 (Fig. 1). The 2 stands were 2.4 km (2400 meters) apart. This was beyond the 200-500 m (summer) and 1000 m (fall) dispersal distances recorded for bark beetles (Ayres, et al 1999, Turchin and Thoeny 1993). The burn and unburned area sampled was approximately 6 and 4 ha, respectively. The basal areas of the burned and unburned stands were 15 m^2/ha (65 ft^2/acre) and 21 m^2/ha (90 ft^2/acre), respectively.

Methods

We used 12- and 16-unit Lindgren Funnel Traps to sample bark beetle abundance in the 2 red pine plantations (Fig. 2). Sampling was conducted from May 4 through August 18, 2006. Two types of lures were used, the pheromone lure combination ispdienol and lanierone (produced and preferred by *I. pini*) and a karimone lure (terpene-like chemical released by pine trees that attracts *D. valens*)(Phero Tech Inc., Delta, BC, www.pherotech.com). There were 23 traps at each site, deployed in 5 arrays of 4 traps configured as a 20 x 20 m square and 1 array of 3 traps 20 m apart in an equilateral triangle. The arrays were staggered in a zigzag fashion throughout each site. Arrays were situated at variable distances apart (at least > 20 m) in order to distribute traps throughout the stand. The 2 lures were alternated between arrays so that there were 12 traps with the pheromone lure and 11 with the karimone lure. The lures were replaced after 8 weeks as lures become depleted with time. Traps were emptied weekly into zip lock plastic bags after first counting and releasing all checkered beetles (*Thanasimus dubius*), the most important specialist predator of *Ips* spp. Trap samples were frozen and later all *Ips* spp. and *D. valens* bark beetles were identified and counted. *Ips* bark beetles are difficult to differentiate to species and require an expert to identify so they were only classified to Genus in this study. However, since the pheromone lure was specific to *Ips pini*, we are assuming that was the species primarily captured. Relative abundances (total captures) were used for descriptive and statistical comparisons between the 2 sites since sampling efforts were equal. Absolute density (numbers/ha) was determined for *Ips* spp. for comparison between the sites. Absolute density was calculated based on an effective sampling area of 0.1 ha for each multifunnel trap (Turchin and Odendaal 1996). A Two-Sample *t* Test Assuming Unequal Variances was used to detect differences in bark beetles and checkered beetles between the burn and control sites. Statistical results were considered significant at $P \leq 0.10$ (two-tailed test) and all means were presented with standard error (SE).

Ips beetle colonization density was measured in the burn treatment area by placing 10 piles of trap logs 0.61-1.22 m (2-4 ft) long and > 7.62 cm (3 in) in diameter at random locations within the stand (Fig. 3). Piles were situated at least 30.5 m (100 ft) apart. Trap logs were placed in the stand on

April 3, 2006 and removed on May 18, 2006 before the first generation emerged. After removal, 20 logs (2 from each pile) were randomly selected, a 77.4 cm^2 (12 in^2) section of bark removed from each log and the number of oviposition galleries were counted (representing one adult female laying eggs in the log). The average experienced attack density was calculated using the formula as described in Ayres, et al (2003).

Results

Total captures of *Ips* spp., *D. valens*, and *T. dubius* in the burned site were 2318, 149, and 291, respectively. The unburned site had total captures of 4376 *Ips* spp., 424 *D. valens*, and 513 *T. dubius* (Fig. 4). Mean weekly captures of *Ips* spp. was 144.86 ± 43.09 (SE) and 273.50 ± 62.22 (SE) for the burned and unburned sites, respectively (Fig. 5). The weekly mean number of captures was significantly greater at the unburned site (t = 2.05, P = 0.10). The mean weekly density of Ips bark beetles at the burn and unburned areas was 62.89 ± 18.73 (SE) and 118.91 ± 27.05 (SE), respectively (Fig. 6). Bark beetle density was greater at the unburned site (t = 1.70, P = 0.10).

Monthly total captures and density of *Ips* spp. was almost 2x greater in the unburned stand than the burned stand (Fig. 7). Total captures in May and June in the burned site was 1065 captures and 997 captures, respectively. Total captures at the unburned site was 1879 captures in May and 1574 captures in June. The mean monthly total captures between the burned (579.50 ± 262.04 (SE)) and unburned (1094.00 ± 392.33 (SE)) sites were not different (t = 2.02, P = 0.33). The density of *Ips* spp. during May and June was 463.04/ha and 433.48/ha, respectively in the burned stand and 816.96/ha and 684.35/ha, respectively in the unburned stand (Fig. 8). No difference in mean monthly density between burned (251.96 ± 113.93(SE)) and unburned (475.65 ± 170.58 (SE)) was detected (t = 2.02, P = 0.33).

Monthly totals just considering the 12 traps/site with the *I. pini* pheromone lure were 891 and 968 during May and June, respectively in the burned site. Total captures at the unburned site was 1811 captures in May and 1569 captures in June. The density of *Ips* spp., based on the area sampled by the 12 pheromone lure traps, during May and June was 742.50/ha and 806.67/ha, respectively in the burned stand and 1509.17/ha and 1307.50/ha, respectively in the unburned stand.

The mean weekly number of *D. valens* captures in the burned and unburned areas were 9.31 ± 6.12 (SE) and 26.50 ± 18.46 (SE), respectively. There was no significant difference in the abundance of *D. valens* between the burned and unburned stands (t = 1.73, P = 0.39). The mean weekly abundance for *T. dubius* between the burned and unburned stands was 18.19 ± 4.35 (SE) and 32.06 ± 4.90 (SE), respectively. The bark beetle predator *T. dubius* was more abundant in the unburned stand than the burned stand (t = 1.70, P = 0.04). The total captures of *T. dubius* during June were 190 in the burned stand and 259 in the unburned stand. The prey/predator ratio in the burn site was 9.36 ± 2.76 (SE) and was not different from 8.98 ± 1.81 (SE) in the unburned stand (t = 1.71, P = 0.91).

The abundance of *Ips* spp. peaked during the summer sampling period in mid-May to early-June and again in late-June to early-July in both the burned and unburned sites (Fig. 9). The burned and unburned areas showed similar patterns in abundance of *D. valens*, with numbers peaking in mid-May and declining precipitously to low levels through the remainder of the summer (Fig. 10). Captures of the specialist predator *T. dubius* was greatest during June and declined gradually during the summer to the lowest levels in mid-August in both the burned and unburned areas (Fig. 11).

Colonization densities of logs by *Ips* spp. was 10.93 ovipositing females/dm^2 for 20 logs sampled in May from the burned stand. This parameter represents the density experienced by an average ovipositing female within a site and estimates the effects of intraspecific competition on population growth rate (Ayres et al., 2003).

Discussion

Ayres et al. (2003) suggested an eruption hypothesis that assumes bark beetle populations are regulated around equilibria at either endemic or epidemic levels. Endemic bark beetle populations are normally regulated by resource limitations and primarily function as scavengers of trees that are dying due to other causes and generally do not cause mortality to healthy trees. Some exogenous factors such as drought, fire damage, disease or wind throw can cause stress among numerous red pines within a stand whereby their defenses against bark beetles are reduced. This may allow bark beetles populations to erupt to epidemic levels resulting in mass attacks on otherwise healthy trees, thereby killing the trees.

It was hypothesized in this study that the burned stand represented the location of an epidemic bark beetle population due to the numerous stressed, dying trees resulting from an excessively hot prescribed burn. It would be expected that a large bark beetle population would develop in this stand. Conversely, the unburned stand with supposedly less stressed trees would support a lower endemic population of bark beetles. Unexpectedly, *Ips* bark beetles were 2x more abundant in the unburned stand than in the burned stand. Mean weekly numbers and density of *Ips* spp. were significantly greater in the unburned stand than the burned stand. Mean monthly captures and density was also greater in the unburned stand though the difference was not significant. The sample size was too small to detect monthly differences, as well as lacking replication in space and time. It may require a larger sample size of monthly averages over several years at numerous locations to detect any statistical differences between the populations. Lack of significant statistical differences does not necessarily mean the data lack biological importance (Tacha et al. 1982, Cherry 1998). The graphical evidence indicating twice the abundance in the unburned stand versus the burned stand may be an important consideration from a management perspective. The greater bark beetle abundance in the unburned stand may be due to the higher basal area of this stand. Turchin and Thoeny (1993) found that bark beetles tended to aggregate in dense pine stands. The abundance of *D. valens* was also greater in the unburned stand though the difference in mean weekly captures was not statistically significant.

The abundance data may have been confounded by other factors that occurred in the study sites. The removal of the trap logs may have reduced the bark beetle population in the burned stand later in the summer. Since the population peaks were synchronous in both the burned and unburned stands early in the summer season, the trap logs may not have influenced trap captures. By removing the trap logs, you are effectively reducing the first generation of bark beetles (eggs and larvae produced by overwintering populations) and not necessarily the overwintering adults. So numbers of adult bark beetles in May and June in the burned stand may be representative of the bark beetle population in this stand. Conversely, bark beetle populations in the unburned stand may have been larger then expected due to improper sanitation practices after a thinning operation. A total of 16 slash piles with boles > 5 cm (2 in) dbh were randomly scattered throughout this stand. Numerous bark beetle entrance and exit holes were observed in these slash logs. MN DNR Division of Forestry guidelines recommend removing all slash > 5 cm dbh from thinned stands in order to remove resources that can be favorable to the build up of bark beetle populations (MN DNR 1989, MN DNR 2000). Irrespective of these factors, comparison of the difference in bark beetle abundance between the 2 stands does not indicate epidemic population levels in the burned stand.

The timing of disturbance may have influenced the differences in abundance between the 2 stands. The fire occurred in the spring of 2004 so the bark beetle population had 2 growing seasons to buildup and decline to the present levels. The unburned stand was thinned in the fall of 2004 giving the bark beetle population only 1 growing season to buildup and decline. The shorter time frame since initial disturbance may have resulted in higher population levels relative to the burned stand. It is not known what the population levels were in the unburned and burned stands after the thinning and fire disturbances, respectively. It is uncertain whether the populations reached epidemic levels in either stand. There certainly would have been resources available in both stands to support a bark beetle outbreak. Whether bark beetle abundance has been increasing or decreasing to current levels since the disturbance is open to question.

An additional factor influencing bark beetle numbers may have been the decrease in rainfall the past 3 years that may be resulting in further stress to the trees and leaving them vulnerable to bark beetle attack. Growing season rainfall totals (April-September) for 2004, 2005, and 2006 were 66.85 cm (26.32 in), 52.27 cm (20.58 in), and 30.99 cm (12.20 in), respectively. The lack of precipitation may be influencing current bark beetle population levels in both stands and compounding the affects of past disturbances.

The pheromone lure ipsdienol + lanierone used in this study is specific to *I. pini* while *I. grandicollis* and *I. perroti* each have their own specific pheromone signal (Ayres et al. 1999, Ayres et al. 2001, Ayres et al. 2003). Though there can be some attraction to heterospecific signals, for the most part each species was most attracted to the pheromone signal produced by that species (Ayres et al. 2001). Ninety-six percent of the *Ips* spp. were captured in the ipsdienol + lanierone traps. In addition, data indicate 2 population peaks during the summer (Fig. 9). *I. pini* usually has multiple generations while *I. grandicollis* and *I. perroti* typically have a single generation (Ayres et al. 1999, Ayres et al. 2001). For comparison with other studies, we assume that *I. pini* was the species primarily captured in this study.

Ayres et al. (2003) compared 8 drought stressed red pine stands with extensive tree mortality due to an epidemic of *I. pini* (Anoka, MN study area) with 5 red pine stands not experiencing drought stress or tree mortality with *I. pini* at supposedly endemic population levels (Colfax, WI study area). They found trap captures of *I. pini* during the June sampling period averaged about 8x higher in the drought stressed area versus the area with healthy, unstressed trees.

In Itasca State Park, MN, abundance of *I. pini* was 4-5 times higher in wind throw areas of old growth red pine forests than it was in undisturbed old growth or near wind throw areas (Ayres et al. 1999).

Another study in Itasca State Park, MN compared *Ips*. spp abundance before and after a prescribed burn in old growth red pine forests (Santoro et al. 2001). They found higher abundance of *I. pini* in fire-damaged sites in May, 1 month following the fire. Thereafter *I. pini* abundance fell below that of unburned sites during mid-summer and was similar to unburned sites by September. *I. grandicollis* and *I. perroti* abundances were similar in burned and unburned sites throughout the summer.

These studies all reported greater abundances of *Ips* in the red pine stands experiencing some type of stress. Data from our study indicate the opposite results with *Ips* captures 2x higher in the unstressed, healthy red pine stand versus the fire-stressed stand.

The drought stressed red pine stands in the Ayres et al. (2003) study experienced epidemic levels of *I. pini*, with mean captures during June of 826/site (range 261-1657/site). If we assume that I. pini was the species captured in our traps, the total captures during May and June in both the burned and unburned sites exceeded 826 bark beetles/month (Fig. 7). However, sampling intensity was not comparable between the 2 studies. Ayres et al. (2003) deployed an array of 4 traps at each site with 2 traps per site baited with *I. pini* pheromone and one each baited with *I. grandicollis* and *I. perroti* pheromone. Our study deployed 23 traps/site with 12 traps/site baited with *I. pini* pheromone and 11 traps/site with karimone. The pheromone baited traps caught 96% of the *Ips* spp. counted. Due to these factors, comparison of relative abundances can be deceiving.

The effective sampling area for the multifunnel trap was determined to be 0.1 ha (Turchin and Odendaal 1996). This makes the effective sampling area of each site in the Ayres et al (2003) study as 0.2 ha/site (2 traps x 0.01 ha). In our study area the effective sampling area/site was either 2.3 ha (23 traps x 0.10 ha) or 1.2 ha if you consider only the 12 pheromone baited traps. Our bark beetle abundance appeared larger because we sampled a larger area/site.

Using the absolute population density parameter can facilitate comparison of the *I. pini* abundance between our study and the Ayres study. In this way we can determine if the *I. pini* population in our study has reached epidemic levels. Ayres et al. (2003) determined that *I. pini* had reached eruptive population levels at 600-800 captures/2traps/month. They called this the escape threshold that separated endemic from epidemic populations. This equates to 3000-4000 captures/ha/month absolute densities. Captures in the burned stand during May and June were only slightly over 400/ha and between 700 and 800 captures/ha in the unburned stand if you consider the area sampled by 23 traps. Considering just the area sampled by the 12 traps/site with the pheromone lure, the density of bark beetles in May and June were 742.50/ha and 806.67/ha in the burned stand and 1509.17/ha and 1307.50/ha in the unburned stand. Based on this data, bark beetle densities in both the burned and unburned sites were well below the escape threshold and can be considered endemic.

Ayres et al. (2003) reported a mean colonization density of trap logs by *I. pini* of 2.5 ovipositing females/dm^2 in the stands experiencing bark beetle eruptions. This parameter is a measure of intraspecific competition. They postulated that colonization densities decline in trap logs after trap captures exceed 800 because bark beetles are attacking live trees. In our study, the colonization density in the burned stand was 10.93 ovipositing females/dm^2. This high density in trap logs may indicate increased competition for resources since the bark beetles were not able to successfully attack live trees and the dead trees were no longer suitable habitat.

Studies have documented increases in abundance of *T. dubius* in drought-stressed and burned sites in response to greater abundances of bark beetles (Santoro et al. 2001, Ayres et al. 2003). We found *T. dubius* more abundant in the unburned stand where the bark beetle population was also greater. The prey/predator ratio did not differ between the burned and unburned sites. This indicates that predator numbers responded similarly to prey abundance between the 2 sites, even though predators were more abundant in the unburned stand. The predators responded in proportion to the prey numbers at each site. Bark beetles populations may be maintained at endemic levels by natural regulatory forces such as predator populations and resource limitations (Ayres et al. 2003). Ayres et al (1999) suggest that *T. dubius* predation may limit *I. pini* populations. The abundance of *T. dubius* in both the burned and unburned sites in our study may have generated some negative feedback on the growth rates of the bark beetle populations. In this way bark beetle populations may have been maintained at endemic levels as indicated in our study sites.

Seasonal patterns in the abundance of bark beetles and their chief predator were similar to those found in other areas, with early-summer and mid summer peaks of bark beetles and an early-summer peak of predators with gradual decline thereafter (Ayres et al. 1999, Ayres et al. 2001). There was an unexpected precipitous decline in bark beetles trapped during the week of 5/18/2006 (Fig. 9). This was probably due to a cold and rainy period since the last collection date. The total rainfall was 1.17 cm (0.46 in) and the mean maximum temperature was 13.33 ^{0} C (56 ^{0} F) the previous week. Prior to the 5/11/2006 collection date the total rainfall was 0.58 cm (0.23 in) and mean maximum temperature was 16.57 ^{0} C (61.82 ^{0} F).

Conclusions and Recommendations

There was obvious tree mortality in the red pine stand where the prescribed burn was conducted. Defoliation occurred in some of the red pines not as a result of canopy fire but due to the excessive heat of the fire. Most of the needles turned green after the fire, indicating that complete burning of the inner bark did not occur. However, these trees did eventually die. Red pine survival following a fire depends on the type and degree of fire injuries, initial tree vigor, and the post fire influence of insects, disease, and weather. Tree mortality after the 1988 Yellowstone fires was attributed to a combination of delayed effect fire injury, bark beetle infestation, and unidentified causes (Rasmussen et al. 1996). Since there are no data on the initial extent of bark beetle infestation on the fire-injured trees, we cannot assume that all the tree mortality observed in the burned stand was the result of bark beetle attacks. Based on current bark beetle abundance in the burned stand, there is no indication that bark beetle populations switched from endemic to epidemic levels due to a resource pulse following the prescribed fire. We can therefore assume that bark beetle infestations of live, healthy trees were minimal and probably resulted in little or no mortality to vigorous trees. Also, any bark beetle population increases were confined to the burned stand and did not spill over into adjacent stands or into the forest as a whole.

We suggest that if there is a concern regarding the potential damage to red pine stands by bark beetle infestations, several control strategies on a stand level may be appropriate. Deployment, removal, and subsequent destruction of trap logs can be successful in reducing bark beetle populations, especially where there are already resource limitations. Aggressive sanitation practices involving removing all fresh slash > 7.6 cm in diameter (3 in) produced after harvest or thinning operations should be standard operating procedure since this is ideal bark beetle habitat.

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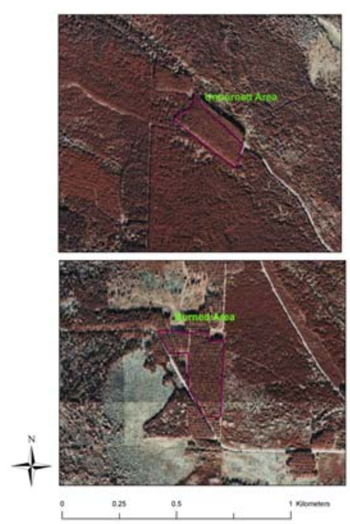

Fig. 1. Pine bark beetle study sites in Beltrami Island State Forest, MN

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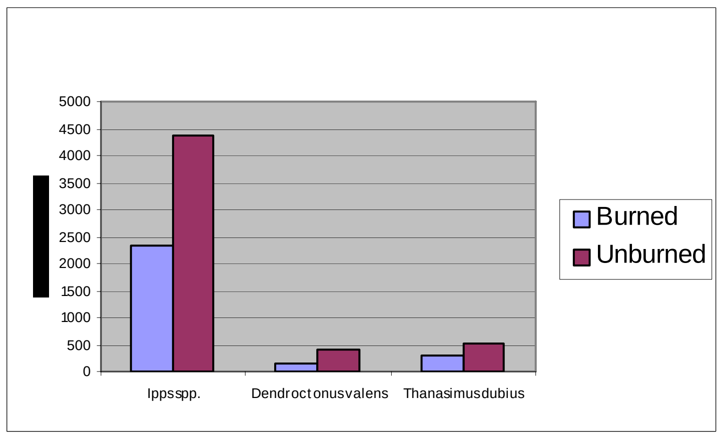
Fig. 2. Lindgren Funnel Traps used to capture pine bark beetles.

Fig. 3. Trap logs placed in burned stand from April 3-May 18, 2006.



Feg.4.Total number of bark beetle and predator captures, May-August, 2006.

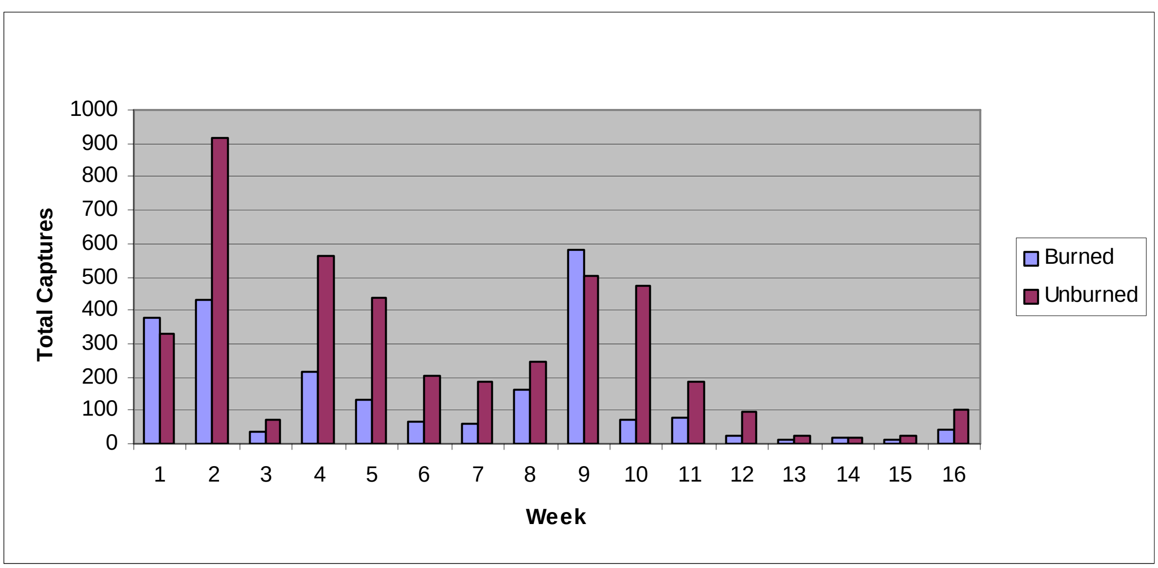


Fig. 5. Total number of *Ips* spp. captures by weeks sampled.

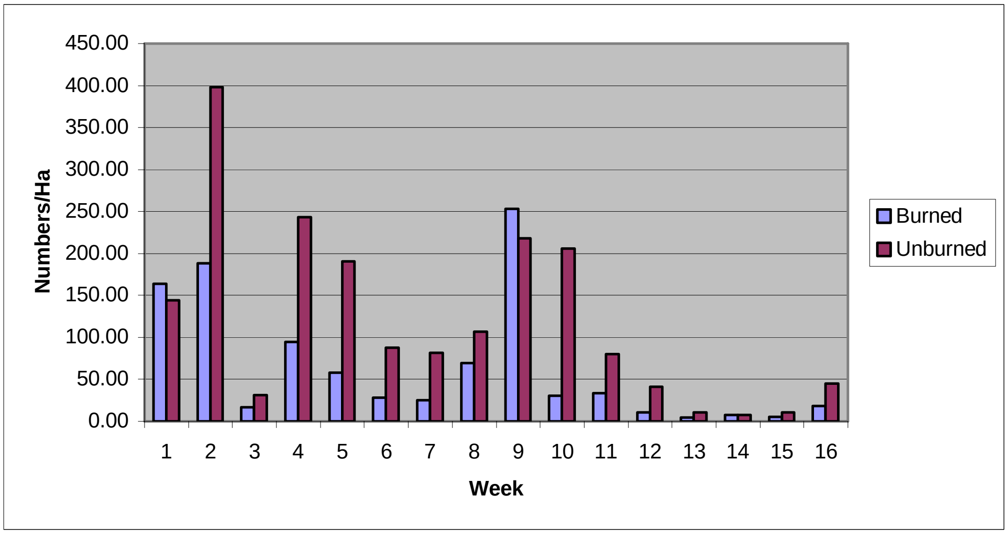


Fig. 6. Absolute density of *Ips* spp. by week.

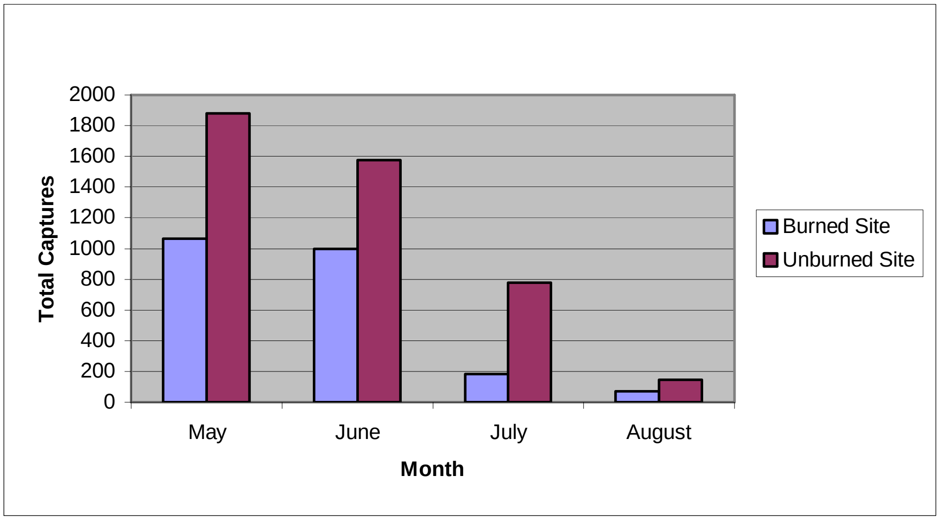


Fig. 7. Total captures of *Ips* spp. by month.

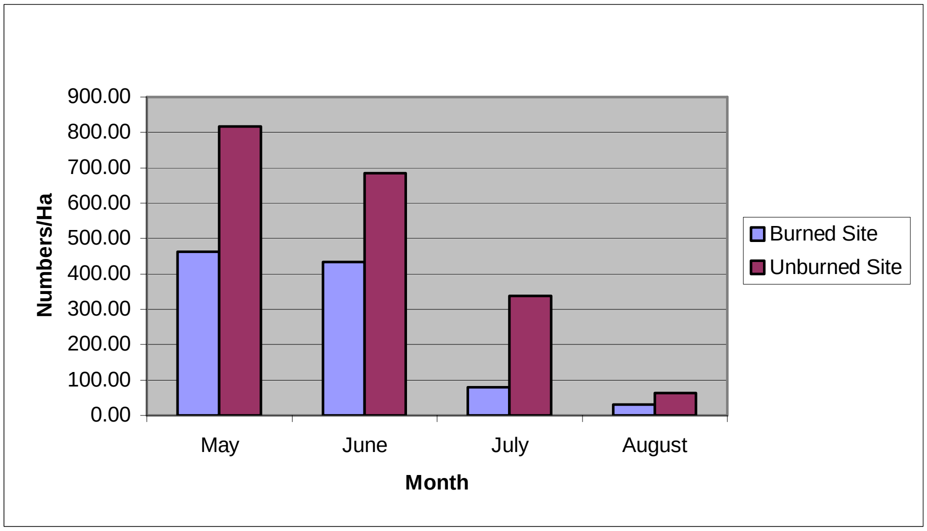


Fig. 8. Monthly density of *Ips* spp.

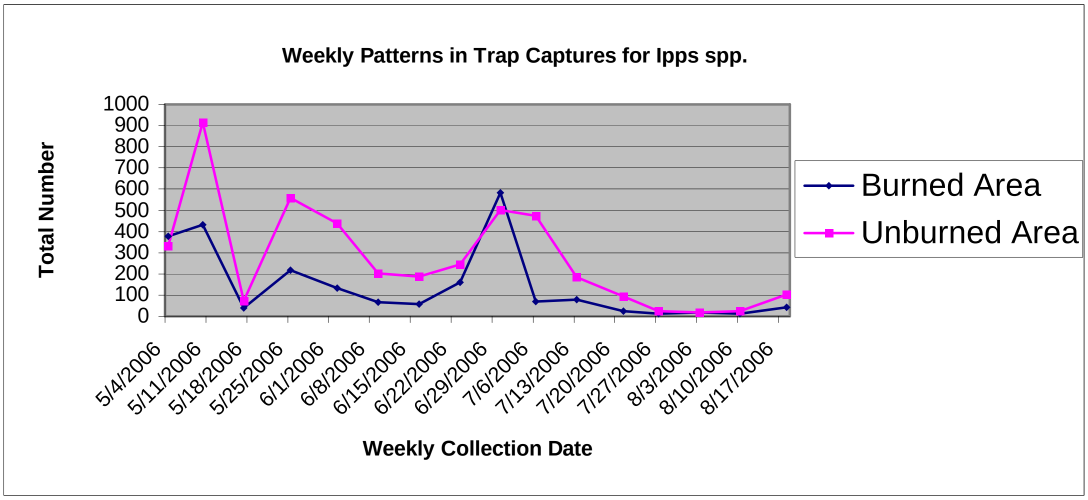


Fig. 9. Seasonal patterns in trap captures of *Ips* bark beetles.

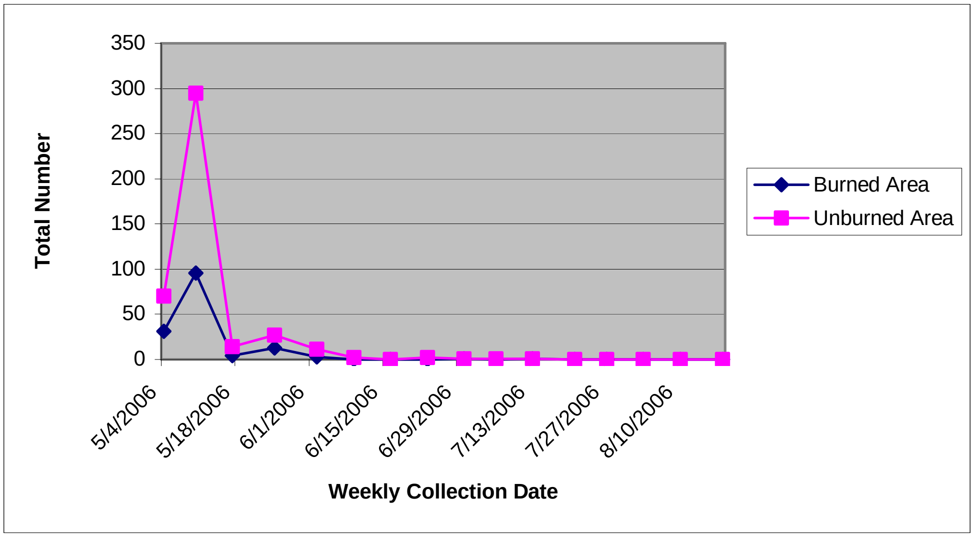


Fig. 10. Seasonal patterns in trap captures of *D. valens*.

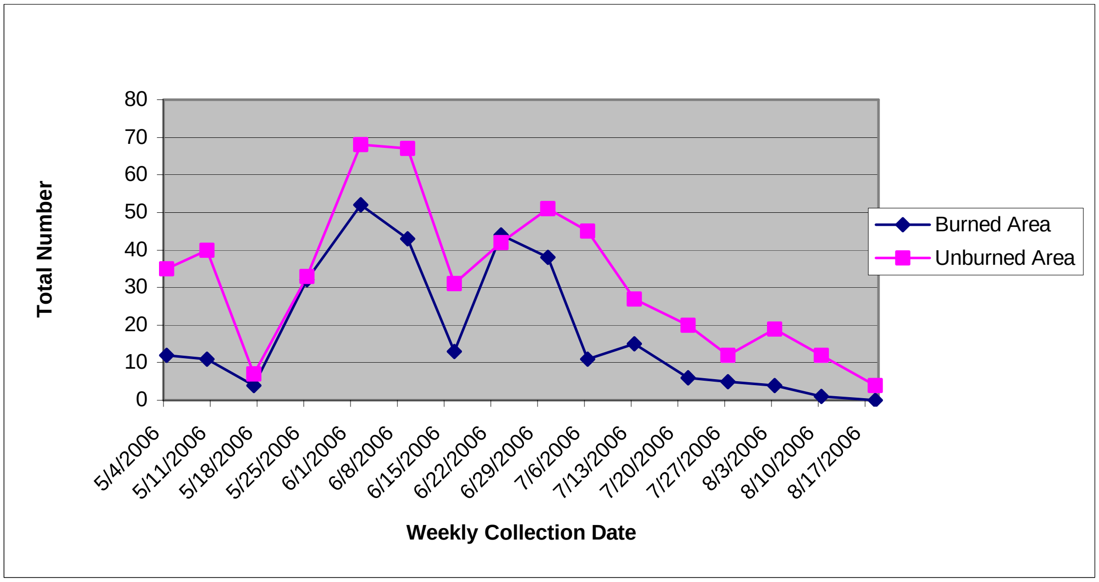


Fig. 11. Seasonal patterns in trap captures of *T. dubius*, chief bark beetle predator.