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Biology and Ecology of Dioryctria Ponderosae Dyar and Dioryctria Tumicolella Mutuura, Munroe and Ross

Mark A. Brohman
University of Nebraska-Lincoln

BIOLOGY AND ECOLOGY OF *DIORYCTRIA PONDEROSAE* DYAR AND *DIORYCTRIA TUMICOLELLA* MUTUURA, MUNROE AND ROSS

by

Mark A. Brohman

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BIOLOGY AND ECOLOGY OF *DIORYCTRIA PONDEROSAE* DYAR AND *DIORYCTRIA TUMICOLELLA* MUTUURA, MUNROE AND ROSS

Mark Allen Brohman, M.S.

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Advisor: Mark O. Harrell

The pine moths *Dioryctria ponderosae* Dyar, and *D. tumicolella* Mutuura, Munroe and Ross are serious pests of pine windbreaks, plantations, and landscape plantings in Nebraska. *D. ponderosae* adults are present from early May to early September. Peak capture of males in pheromone traps occurred around the first two weeks in June. Adults lived an average of 16.8 days and a maximum of 39 days when reared in the laboratory. *D. tumicolella* adults are present from late July through the end of September. Peak capture of males occurred around the third to fourth week in August. Adults reared from pupae in the laboratory lived an average of 7.8 days, with a maximum of 9 days. *D. tumicolella* was found to have an average wing length of 12.5 mm and *D. ponderosae* 11.5 mm.

In the Nebraska National Forest, ponderosa pine is the tree species most heavily infested by *D. ponderosae* and *D. tumicolella*, with Austrian and Scotch pines being affected to an intermediate degree, and jack pine is least infested. Pine moth pitch masses, which form at the entrances of the larval tunnels, are most common on

the northeast side of trees, followed by the northwest, southeast, and finally southwest side. Most pine moth infestation sites were found in the middle third of the trunk, followed by the top, and then the bottom portion. More pine moths were found on the trunk at points where branches occur than on other areas of the trunk or on the branches. Stressing or pruning ponderosa pines did not increase the number of pine moths infesting them. Bark thickness did seem to affect infestation levels, but it was unclear whether resin flow had a significant effect.

Three hymenopteran parasites were collected and identified from larvae and pupae of *D. ponderosae*, and four were identified from *D. tumicolella*. One spider and two ant species, or two forms of the same species, were observed preying or scavenging on *Dioryctria* spp. larvae.

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INTRODUCTION

Infestations of Dioryctria spp. pine moths have become very damaging to pines in Nebraska. The three Dioryctria spp. present are D. ponderosae Dyar and D. tumicolella Mutuura, Monroe and Ross in central and western Nebraska, and D. zimmermani (Grote) at the eastern edge of the state. The damage from the larvae tunneling just below the bark can result in girdling of branches or the trunk, allowing high wind or heavy snow to break them.

It was not until the early 1980's that the pine moths in Nebraska were identified as three species, and we developed a better understanding of their life histories. This study was conducted to gain additional information on the biology and ecology of the two central and western Nebraska species, D. ponderosae and D. tumicolella.

LITERATURE REVIEW

The *Dioryctria* species have proven to be difficult to identify and classify. Currently seven species groups of *Dioryctria* are defined by a combination of external characteristics and genitalial morphology (Mutuura and Munroe 1972). The two species of *Dioryctria* studied in this project are in two groups, *D. ponderosae* in the *ponderosae* group and *D. tumicolella* in the *zimmermani* group. *D. zimmermani*, the third species of pine moth in Nebraska, is also in the *zimmermani* group.

Taxonomy and Descriptions of Adults

The *zimmermani* group has been added to and revised several times since *D. zimmermani* was first reported in the United States in 1877 (Grote 1877). Heinrich (1956) reported *D. zimmermani* and *D. amatella* (Hulst) in eastern North America and *D. cambiicola* (Dyar) in the western U.S. Four new species, *D. contortella*, *D. monticolella*, *D. tumicolella*, and *D. banksiella*, all previously confused with *D. zimmermani* or *D. cambiicola*, were described later by Mutuura, Munroe, and Ross (1969). Schafer and Wood in 1977 described *D. taedae*, and Mutuura and Monroe in 1979 described *D. merkeli* and *D. yatesi*. Rose and Lindquist (1973) reported a new species of *Dioryctria* that was later named *D.*

resinosella Mutuura, a member of the zimmermani group (Mutuura 1982).

Genitalia have proven to be the most useful identification tool to separate the seven groups: sylvestrella, abietella, schuetzeela, auranticella, ponderosae, baumhoferi, and zimmermani (Mutuura and Munroe 1972). In the ponderosae, zimmermani and baumhoferi groups, the male genitalia have the lateral margin of the uncus strongly excavated sub-basally and the costa of the valve is prolonged apically into a sharp, tooth-like process (Mutuura and Munroe 1969). This is not found in the other four groups. The zimmermani and baumhoferi groups also have a distinct subapical spine on the distal margin of the sclerotized costal portion of the valve that is lacking in the ponderosae group. In the female genitalia of the baumhoferi, ponderosae and zimmermani groups, the sclerotized portion of the ductus bursae is substantially longer than the distance from the ostium to the tip of the ovipositor, whereas in other groups these are about the same length.

The ponderosae group resembles the zimmermani group in general external appearance. Adults of all three species in Nebraska are predominantly black and gray with a prominent "W"-shaped white line near the midpoint of the forewing.

The similarity of the species led to much confusion concerning the species present in Nebraska. Stein and Kennedy (1972) identified these insects in the northern Great Plains as D. tumicolella and D. zimmermani. Later Averill (1974) reported only D. zimmermani in Nebraska, and Ostrofsky and Harrington (1977) reported this species in 28 counties in the central and western portions of the state. Furniss and Carolin (1977) reported the species in Nebraska as D. ponderosae.

In October 1983, Akira Mutuura of the Biosystematics Research Center, Agriculture Canada, Ottawa, Ontario, Canada, identified D. ponderosae and D. tumicolella from specimens collected by Mark Harrell in the Nebraska National Forest. Mutuura also identified D. zimmermani from specimens collected in Douglas County by M. O. Harrell and J. A. Jones. Currently 38 counties in Nebraska have one or more species of Dioryctria pine moths (M. O. Harrell, J. A. Jones, and M. A. Brohman; unpublished data).

Descriptions of Larvae

Larvae of D. tumicolella are light to dark brownish red with an occasional greenish tint. They have six rows of small dark spots, each with a seta. When mature they have a head capsule width of 2.4 mm ± 0.21 (n = 72) and a length of ca. 25 mm (Harrell, Jones, and Brohman;

unpublished data). *D. ponderosae* larvae are predominatly creamy white with an occasional pinkish tint and with no prominent dark spots. Mature larvae have a head capsule width of 1.8 mm $\pm$ 0.26 (n = 64) and a length of ca. 22 mm. *D. zimmermani* larvae are usually brownish red and have small dark spots on the lateral and dorsal surfaces from which single setae emerge. All three species of larvae can vary in coloration. Brunner (1915) found a wide variety of larval colorations in *D. zimmermani*, ranging from dirty white through reddish yellow to a vivid green, presumably due to host differences. The larval head capsule in all three species is light to dark brown with black mandibles.

Life Histories

Harrell, Jones, and Brohman (unpublished data) also described the identification and life histories of the three *Dioryctria* species in Nebraska. *D. tumicolella* and *D. zimmermani* have one-year life cycles with adults present from late July through September. The first-instar larvae overwinter in a hibernacula under the bark scales. *D. ponderosae* has a life cycle ranging from 14 months to two years with adults present from May through September. The second, third, and fourth-instar larvae overwinter in tunnels within the inner bark.

In Michigan, Carlson and Butcher (1967) found caged

D. zimmermani laid eggs predominately on the main stem under the bark scales and in crevices at the base of lateral branches. They also found in the lab and field that D. zimmermani larvae do not move far after emerging from the egg and apparently do not feed until the following spring.

Predators and Parasites

Information on the predators and parasites of D. ponderosae and D. tumicolella has not been published, but reports of the natural enemies of some related Dioryctria are available. In most sections of the Rocky Mountains, the Rocky Mountain hairy woodpecker (Dryobates villosus monticola Anthony) feeds heavily on Dioryctria spp. larvae (Brunner 1915). Rennels (1960) stated that web-spinning and nonweb-spinning spiders might prey upon D. zimmermani adults. Patterson et al. (1983) observed a larva of Thanasimus undulatus (Klug) (Coleoptera: Cleridae) feeding on a D. resinosella pupa under bark scales in Maine. Ants, larvae of lacewings, and cockroaches have also been mentioned as possible predators (Rennels 1960).

Schaffner (1959) listed three hymenopteran parasites of D. zimmermani: Euderus cushmani (Crawford), Hyssopus thymus Girault, and Scambus hispae (Harr.). Larval parasites of D. zimmermani found by Rennels (1960) included: (Eulophidae) *Melittobia chalybii* (Ashm.), *Hyssopus rhyacioniae* Gahan, *Elachertus pini* Gahan; (Icheumonidae) *Calliephialtes comstocki* (Cress.); and (Eurytomidae) *Eurytoma pini* Bugbee. Neunzig et al. (1964) also reported *Hyssopus rhyacioniae* Gahan as a parasite reared from *D. zimmermani*.

Carlson and Butcher (1967) reported that parasitism could reach as high as 51% and 57%, as *D. zimmermani* larvae reached maturity. The parasites were predominately *Hyssopus rhyacioniae* Gahan and *Elachertus pini* Gahan. They found egg parasitism as high as 45%. *Trichogramma minutum* Riley was the most common parasite identified. Hainze and Benjamin (1983, 1985) found the following parasites of larval and pupal *D. resinosella*: *Exeristes comstockii* (Cresson), *Bracon rhyacioniae* (Muesebeck), *Hyssopus rhyacioniae* Gahan, *Eurytoma pini* Bugbee, *Coelichneumon dioryctriae* Rohwer, and several other parasites that could not be identified to species.

Host selection

Rennels (1960), in an eight year study of *D. zimmermani* in Illinois, found Scotch pine (*Pinus sylvestris* L.) to be the most heavily infested of three pine species, with an infestation rate of 78.3%. Of the ponderosae pine (*P. ponderosae* Dougl. ex Laws) and jack pine (*P. banksiana* Lamb.) he examined, 27.5% and 5.9%

were infested, respectively. Based upon cardinal directions, he found no difference in the infestation sites on the trunk and attributed this to the long crowns that shaded the trunks, creating similar conditions on all sides. When looking at trees that had been heavily infested in the past and had poorly developed crowns, Rennels found that attacks on the trunk were more likely to occur on the sides exposed to intense radiation, west and south.

Carlson and Butcher (1967) found D. zimmermani to be distributed fairly uniformly over the main stem in the spring and early summer. In late summer, a higher percentage was found in middle whorls. Over the entire summer, May through August, they found 3% in the lower 1/5th of the tree, 11% in the next higher 1/5th, 38% in the next, 28% in the next, and 20% in the top 1/5th of the Scotch pines. However, Rennels (1960) reported that D. zimmermani were found in higher numbers in the zone of the tree from 6 to 15 feet in pines up to 25 feet in height. Brunner (1915) noted D. zimmermani infestations are very limited at the top and the base and, in mature trees, tend to be between 10 to 30 feet below the top. In second growth trees, infestations tend to be from about breast height up to 35 to 40 feet.

Brunner (1915) stated D. zimmermani attacks trees from a few inches to several feet in diameter, but it is the mature trees that provide the best food source while the smaller trees, up to a foot in diameter, suffer the most damage. Rennels (1959), as reported by Schuder (1960), noted _D. zimmermani_ required a minimum inner bark thickness of 0.15 inch.

Pine moths apparently prefer injured trees. Kellicott (1879) and Craighead (1950) both reported that the moth frequently attacks at points of injury. Brunner (1915) noted heavy infestation in trees with lightning scars. Rennels (1960) reported that removing live branches sometimes appears to increase the incidence of moth infestation. Wright et al. (1975) reported pruning increased infestation levels in Scotch pines. Schuder (1960) noted in a row of red pines injured by a sprayer that 64% were infested by _D. zimmermani_ while adjacent uninjured trees were not infested.

Numerous studies have been reported that have examined the effects of variables such as quantity and quality of resins produced by pines on the success of stem-boring forest pests. Smith (1985) reported that Mirov (1928) found western pine beetles were most destructive in areas where the resin flow of ponderosa pine was lowest. Smith reported that Callaham (1965) noted ponderosa pines at high risk of being attacked and killed by western pine beetle had the shortest period of resin flow. Smith also reported that Stark (1965) was unable to find a good association between oleoresin exudation pressure and success or failure of western pine beetle attacks on ponderosa pines. Vite and Wood (1961) reported primary resin flow may prevent successful bark beetle attack by pitching out the beetles. No studies of the effects of resin flow on host susceptibility to pine moths have been reported.

Control

Many researchers have tested insecticides for control of Dioryctria species. Keen (1938) originally noted some success in controlling D. ponderosae with orthodichlorobenzene, diluted 1 to 5 with water, with a small quantity of soap and linseed oil added. He also mentioned spraying with an oil solution of DDT when the eggs are hatching to control cambium-feeding twig and tip moths. Hand picking was noted by Keen (1938) as a possible means to control small valuable plantings that are isolated from sources of reinfestation.

Schuder (1960) recommended DDT, endrin, parathion, thimet, and malathion emulsions. Butcher and Carlson (1962) reported success controlling D. zimmermani with heavy stem-drenching applications in April of Shell SD-3562, phosphamidon, mexacarbate (Zectran), oxydemeton-methyl (metasystox-R), and phorate. They suggest the bark be wet thoroughly so that penetration of the toxicant to hibernacula or feeding site occurs and that a maximum insecticide residue can be present when the larvae are breaking dormancy or are entering the bark.

Harrell (1986a,b) determined that four insecticide treatments produced significantly fewer _D_. _tumicollela_ larvae per tree than the untreated control. The insecticide treatments were: drenching with acephate (Orthene 75S) at 0.35 oz/gal; dimethoate (Cygon 2E) at 0.67 oz/gal; acephate implants (Acecap 97) at 1 per 10cm spacing; and disulfoton (Di-Syston 15G) soil treatment at 2.5 oz/inch DBH.

Schuder (1960) reported _D_. _zimmermani_ did not appear to be attracted to light traps as he experimented over two summers with a variety of colors and trapped only one moth. Carlson and Butcher (1967) found caged adult _D_. _zimmermani_ attracted to incandescent light sources, but noted this to be construed as a point of escape from confinement and not natural attraction.

Neunzig et al. (1964) reported up to 50% mortality rates when heavy rains flooded the galleries of _D_. _zimmermani_ larvae.

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STUDY SITES

The main study area was the Nebraska National Forest, located in Thomas County in central Nebraska. The 90,000 acre forest of conifers, hardwoods and grasslands lies between the Middle Loup and Dismal Rivers. The soil type is 95% sand. Average annual rainfall is 21 inches (53.3 cm). The forest was planted in the early 1900's, and at its largest, covered approximately 30,000 acres. A large fire in 1965 destroyed most of the forest, and with some additional planting the forest now covers about 20,000 acres.

Two shelterbelts containing ponderosa and Austrian pines located 65 miles southwest of the Nebraska National forest were also used in this study. They were on the Harold G. Brohman Ranch in Custer County (T16N, R22W, Sec.21), 8 miles northeast of Callaway. The research was conducted during the summers of 1985-90.

CHAPTER 1: IDENTIFICATION, DISTRIBUTION, AND ADULT FLIGHT PERIOD

ABSTRACT

Two species of Dioryctria pine moths have been identified in central and western Nebraska: Dioryctria ponderosae Dyar and Dioryctria tumicolella Mutuura, Monroe and Ross. D. tumicolella has a one-year life cycle. Adults begin emerging generally around the last week in July. Peak capture of males in pheromone traps occurred around the third to fourth week in August. D. ponderosae has a life cycle that is generally two years in length. Adults begin emerging in early May. Peak capture of males in pheromone traps occurred around the first two weeks in June. In the laboratory, D. tumicolella adults lived an average of 16.8 days and a maximum of 39 days. D. ponderosae adults lived an average of 7.4 days and a maximum of 9 days. D. tumicolella was found to have an average wing length of 12.5 mm and D. ponderosae 11.5 mm.

INTRODUCTION

Dioryctria pine moths are serious pests of pines in Nebraska. At various times in previous years these insects have been believed to be D. zimmermani, D. ponderosae, the two species D. zimmermani and D. tumicolella, and the three species D. ponderosae, D.

tumicolella and D. zimmermani (Stein and Kennedy 1972; Averill 1974; Ostrofsky and Harrington 1977; Furniss and Carolin 1977; M. O. Harrell, personal communication). The lack of a clear understanding of which species and how many species are involved has made attempts to better understand and control these pests very difficult.

Harrell, Jones, Brohman (unpublished data) determined that D. tumicolella has a one year life cycle with adults present from late July through mid-September. They also determined that D. ponderosae in the same area has a life cycle ranging from 14 months to two years, with most adults present in June and July. The larvae of both species feed on conifers in the phloem of the branches and trunk.

Brunner (1915) believed that most moths that feed as larvae on internal tree tissues do not live more than 10 days and that most Dioryctria spp. adults live less than one week. He reported however, that one D. zimmermani adult lived as long as two weeks.

The study reported here was conducted to identify the species of Dioryctria pine moths in Nebraska, determine whether or not size differences in the larvae and adults could be used to identify the species, determine their distribution in the state, and determine adult longivity and flight period.

MATERIALS AND METHODS

Late instar larvae and pupae were collected, brought to the laboratory, and maintained in darkness at room temperature until adult emergence. Adult males were collected using Pherocon 1C traps baited with experimental pheromone blends as explained in Chapter 4. Mounted adults were sent for identification to two authorities on Dioryctria taxonomy: Akiro Mutuura, Biosystematics Research Center, Agriculture Canada, Ottawa, Ontario, Canada; and Herbert H. Neunzig, North Carolina State University, Raleigh, North Carolina. Distributions were established by collecting larvae in surveys, by pheromone trapping, and by examining past records.

To determine adult longivity, adults that emerged from pupae in the laboratory were placed in containers at room temperature with a 10% sugar water solution, and each was marked on the tip of the dorsal surface of their wings with a different color dot code of model paint. Longevity records were kept for 40 Dioryctria spp. adults. Wing lengths were recorded from 149 males caught in pheromone traps.

RESULTS AND DISCUSSION

In 1987 Mutuura identified specimens collected from the Nebraska National Forest and the Brohman Ranch as D.

ponderosae and specimens collected by M. O. Harrell and J. A. Jones at the eastern edge of the state as D. zimmermani. In 1988 Neunzig identified D. ponderosae collected at the Nebraska National Forest.

No new counties were added to the list of 38 counties in Nebraska previously known to have Dioryctria pine moths (Fig. 1). D. zimmermani is in Washington and Douglas Counties, in the extreme eastern edge of the state, while D. ponderosae and D. tumicolella are found in 4 and 36 counties, respectively, in the central and western portions of the state.

D. ponderosae adult males were detected in pheromone traps as early as May 14 and as late as September 6 (Fig. 2). The peak trapping period was the first two weeks of June. D. tumicolella adult males were detected as early as July 16 and as late as October 1. Their peak was generally the third to fourth week of August (Fig. 2). Male D. ponderosae and D. tumicolella caught in pheromone traps had average wing lengths of 11.5 mm ± 0.67 (mean ± SD, n=65) and 12.5 mm ± 1.13 (n=84), respectively.

One D. tumicolella adult collected from the Brohman Ranch in Custer county lived 39 days in the laboratory (Aug. 16 to Sept. 24, 1986); others lived from 9 to 21 days, and the average was 16.8 days (n = 22). D. tumicolella collected in Buffalo county had a longevity average of 7.8 days (n = 8) ranging from 5 to 9 days. *D. ponderosae* adults lived 5 to 9 days with an average of 7.4 days (n = 10). This indicates that the *D. tumicolella* adults can live considerably longer than the one to two weeks previously reported for most *Dioryctria* species but *D. ponderosae* may fall within the one to two week estimate.

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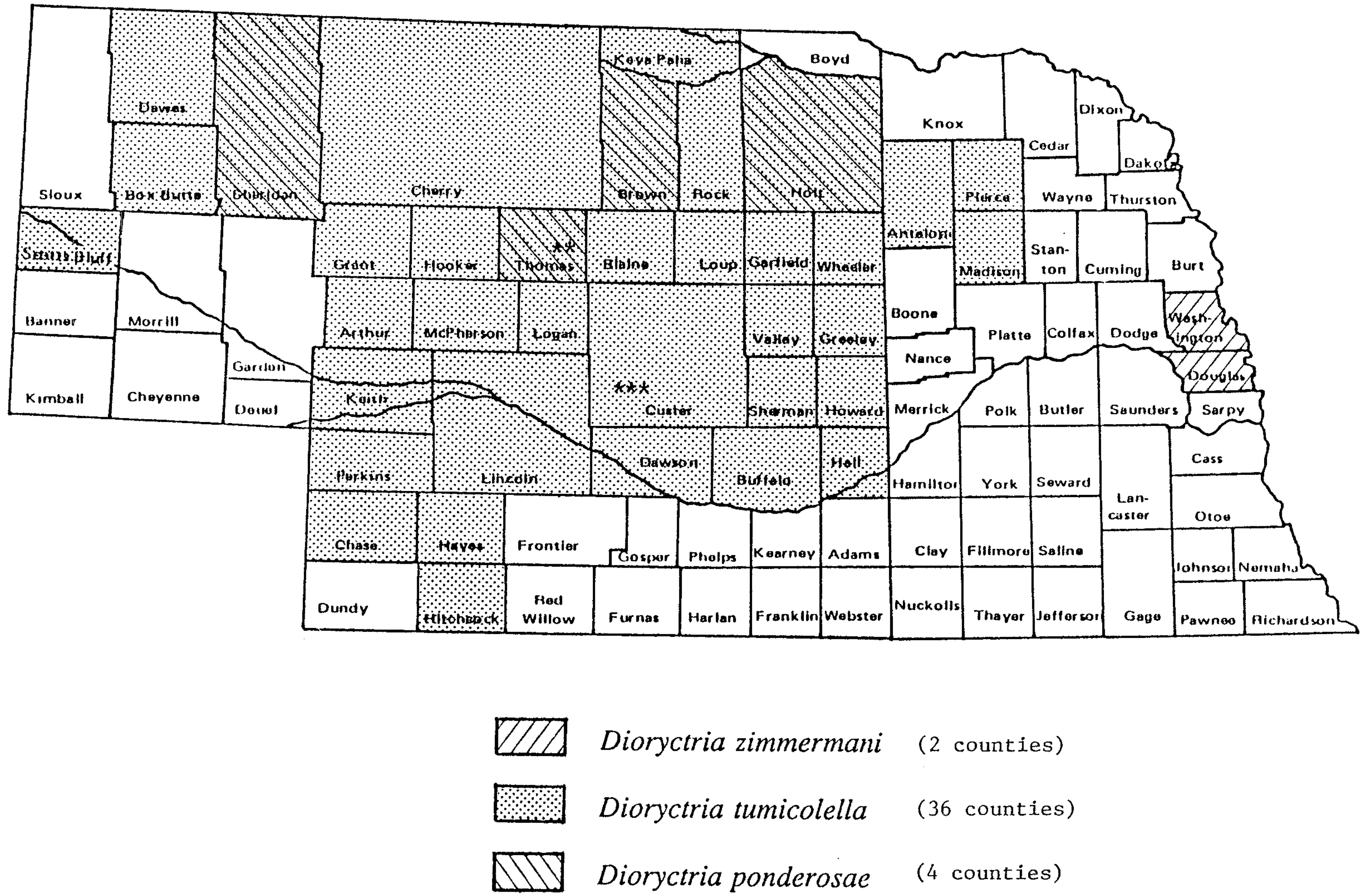
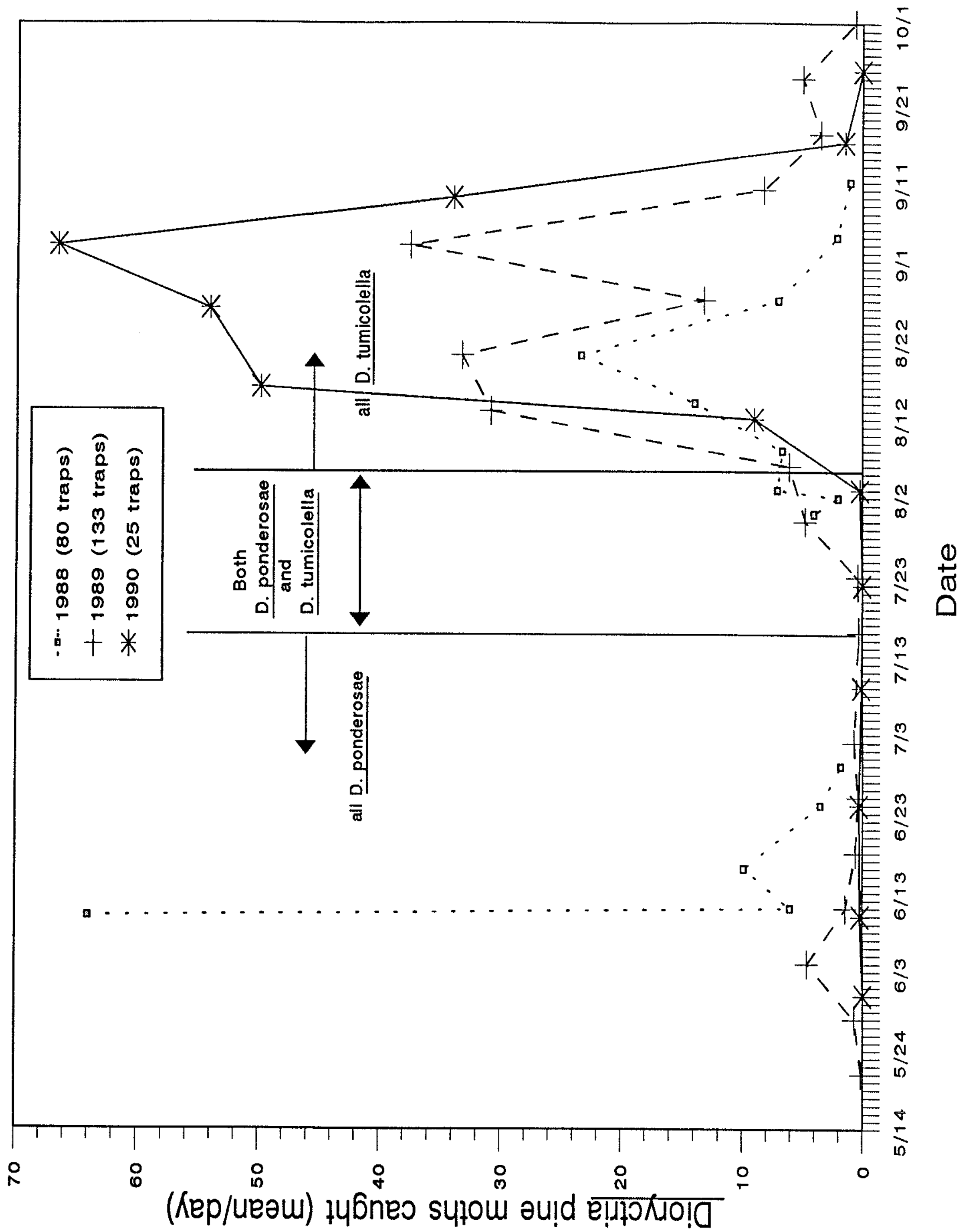


Figure 1. Known distributions by county of the Dioryctria spp. pine moth. ** Nebraska National Forest, *** Brohman Ranch.

Figure 2. Male Dioryctria pine moth flight periods as determined by pheromone traps.



CHAPTER 2: EFFECTS OF HOST CHARACTERISTICS ON DAMAGE AND INFESTATION LEVELS

ABSTRACT

In the Nebraska National Forest, ponderosa pine was the pine species most heavily infested by *D. ponderosae* and *D. tumicolella*. Austrian and Scotch pines were infested at intermediate levels, and jack pine was the least infested. *Dioryctria* spp. pine moths were found in higher numbers on the northeast side of ponderosa pines, followed by the northwest, then southeast, and finally southwest. They were found more frequently in the middle section of the trunk, followed by the top, and least frequently in the bottom portion. The pine moths were found in highest numbers on branch-trunk sites, followed by the trunk, and lowest on the branches.

Stressing or pruning ponderosa pines did not increase the number of pine moth infestations. Bark thickness did appear to significantly affect infestation levels, but it was unclear whether resin flow had an effect.

INTRODUCTION

The most damaging category of insect pests of trees are those feeding in the phloem, cambium or outer sapwood regions of the trunk. Such insects can destroy the tree's conductive tissue faster than the tree can replace it.

Stressed pines seem to be less resistant to insect invasion than unstressed pines (Minn. DNR 1987). Stress can interfere with normal tree metabolism and cause reduced synthesis of oleoresin and other insect-inhibiting chemicals as well as reduce the tree's ability to form wound periderm. Stress can come from a multitude of factors including: drought, old age, disease, crowding, past and current insect infestations, fire, pollution, logging, wildlife, and flooding.

As pine moth larvae feed in the bark, phloem, cambium and sapwood, they encounter nutrients and a variety of chemicals flowing from resin ducts and other cells that are cut by the feeding larvae. These resins and other chemicals can suffocate the larvae, kill them by poisoning them, or limit the nutrients available to the larvae by combining with the proteins and carbohydrates, making them indigestible.

Haack et al. (1984) found that average longevity, oviposition rate, and egg density were significantly greater for Ips calligraphus (Germar) females maintained in thick versus thin phloem of slash pine. Positive correlations between beetle production and phloem thickness have been found in several studies (Amman 1972; Amman and Pace 1976; Amman and Pasek 1986).

Vite and Wood (1961) suggested primary resin flow may prevent successful bark beetle attack by pitching out the beetles. Different rates of resin flow could be a reason why some pine species are more susceptible than others. Smith (1985) reported that Mirov (1928) found western pine beetles were most destructive in areas where the resin flow of ponderosa pine was lowest. Smith reported that Callaham (1955) noted ponderosa pines at high risk of being attacked and killed by western pine beetle had the shortest period of resin flow. Smith, however, also reported that Stark (1965) was unable to find a good association between oleoresin exudation pressure and success or failure of western pine beetle attacks on ponderosa pines.

Harrell (1986c) found, of four pine species studied, ponderosa pine (*Pinus nigra* Laws.) had the greatest number of pitch masses per tree and the greatest amount of damage caused by *Dioryctria ponderosae* and *D. tumicolella*; jack pine (*P. banksiana* Lamb.) and Austrian pine (*P. nigra* Arnold.) had the lowest number of pitch masses per tree, and jack pine had the lowest damage rating of the four pines. Scotch pine (*P. sylvestris* L.) had an intermediate number of pitch masses per tree, and Scotch pine and Austria pine had intermediate degrees of damage. Rennels (1960) found Scotch pine to have an average *D. zimmermani* infestation of 78.3%, ponderosa pine of 27.5%, and jack pine of 5.9%

Harrell (1986) also suggested that trees growing on soils with low ability to retain water, such as sandy soils, are likely to have greater populations of pine moths than are trees growing on soils that have a higher ability to retain water, such as loams. This came from data that showed a significant negative linear relationship between infestation level and soil water holding capacity.

The study reported here was conducted to identify the host characteristics that affect the selection of the trees by *Dioryctria ponderosae* and *D. tumicolella*.

MATERIALS AND METHODS

Susceptibility of each of the four species of pines to *Dioryctria* pine moths was measured over a two year period. The number of infestaions was counted on 55 Austrian, 40 jack, 92 ponderosae, and 41 Scotch pines. The number of infestations per year and averages per species and per tree were calculated. To determine whether one side of the host tree was more likely to be attacked than another, the locations of pitch masses that form at openings of pine moth tunnels were recorded by cardinal direction. Ponderosa pines from 2.4 m to 9.7 m in height were examined. Each tree was divided into four quadrants: northwest, northeast, southwest and southeast. These quadrants were selected to determine whether locations of the larvae were related to the highest or lowest bark temperature (southwest and northeast quadrants, respectively) or the last sun of the day (northwest quadrant).

Inner bark and phloem thicknesses were measured from samples taken from Austrian, jack, ponderosa, and Scotch pines with a No. 2 cork borer (5.5 mm diameter). The inner bark thickness includes the phloem. Thicknesses were measured during June 1986 at a height of 125 cm on the northwest and southeast sides of the trees.

The volume of resin flow was measured on all four species of pines at a height of 110 cm on the southeast side of the tree at two and at four hours on June 14, 1986. A Kimble disposable glass pipette (1 ml in 1/100) was inserted 1.5 cm deep into holes made by the cork borer. The air temperature was 25° C, and the relative humidity was 70%.

To determine whether stressed trees are more likely to become infested with Dioryctria pine moths, a planting of 100 ponderosa pines was selected and all of the old and new Dioryctria infestation sites on the trees were counted. Any tree with two or fewer infestation sites, past or present, indicating a relatively uninfested tree, was used in the test tree group. Thirty-four test trees selected in this manner were then randomly selected for the stress and no-stress treatments. The 17 trees receiving the stress treatment had their trunks cut 2 cm deep, 1 mm in width at 30 cm above the ground on three sides with a bow saw.

In the spring of 1985, 109 ponderosa pines along a road in the Nebraska National Forest were pruned by USFS employees. The number of branches pruned varied from 0 to 18 per tree. The number of branches pruned and infestations in these trees was recorded during the summers of 1985, 1986, 1987, and 1988 to see if pruning (injury) would have an effect on infestation levels

RESULTS AND DISCUSSION

This study confirmed that ponderosa pine is the species in the Nebraska National Forest most heavily infested by D. ponderosae and D. tumicolella. Austrian and Scotch are intermediately affected and jack pine is the species least infested with D. ponderosae and D. tumicolella (Appendix A). Analysis of variance (ANOVA) procedures were performed using the SAS System (SAS Institute Inc.) and with number of insect infestations as a dependent variable there was a significant difference between the four species of pines and insect infestations (F value 7.78, PR>F 0.0001).

Of the 691 Dioryctria infestation sites in the ponderosa pines, 229 (33.1%) were in the northeast quadrant, 179 (25.9%) in the northwest, 161 (23.3%) in the southeast, and 122 (17.7%) in the southwest. These numbers are significantly different, using the chi-square test (x^2_{obs}= 7.8, $x^2_{3,.05}$= 34.2) from what would be expected if the infestations had occurred randomly. The pattern of infestations in the quadrants suggests that high temperatures may reduce the number of infestations in the more sun-facing sides of the tree. The southwest quadrant would be expected to be warmest since it receives the afternoon sun. The southeast quadrant being next, very close to the northwest quadrant which would be getting some afternoon sun. The coolest quadrant would be the northeast, which gets sun only in the early morning.

When examing the vertical distribution of Dioryctria spp. infestation sites in ponderosa pines, a significant difference between three vertical sections becomes apparent using the chi-square test (x^2_{obs} = 175.2, $x^2_{2,.05}$ = 6.0). Of the 691 infestation sites, 177 (25.6%) were in the top 1/3 of the tree, 360 (52.1%) in the middle 1/3 of the tree, and 154 (22.3%) in the lowest 1/3 of the tree. The infestation sites may be more numerous in the middle section of the tree because of a suitable inner bark thickness, abundance of branches, little movement of the site in heavy wind, shading, or other benefits.

Part of the reason for fewer insects in the lower part of the tree may be related to the fewer branches in this portion. Of the 691 infestation sites in the ponderosa pines, 371 (53.7%) were at branch-trunk intersections, 233 (33.7%) were on the trunk and 87 (12.6%) were on branches. These numbers are significantly different using the chi-square test (x^2_{obs} = 175.2, $x^2_{2,.05}$ = 6.0). The insects may be more numerous on the trunk and at the branch-trunk intersections because the trunk offers a thicker inner bark than the branches.

No significant difference using SAS ANOVA was found between numbers of new D. ponderosae and D. tumicolella infestations on stressed trees and control trees (Table 1 and Appendix B). The stressed trees may not have been stressed enough since they were girdled only on three sides, 1 mm in width and 2 cm deep. Another indication that none of the trees were stressed enough is the fact that all 17 stressed trees lived through the three years of this study, and the girdle marks were difficult to see just one year after the experiment started.

Pruning showed no significant effect using SAS ANOVA on infestation levels of D. ponderosae and D. tumicolella over non-pruned ponderosa pines over a three year period (Table 2 and Appendix C). The number of branches pruned also showed no significant effect on infestation levels using SAS ANOVA. There was no linear, quadratic, or cubic time effect of non-pruned to pruned trees over the three year time period using SAS ANOVA. In addition, no significant difference of resin flow rates on infestations was found using SAS ANOVA. Resin flow measured at two and four hours was significantly different between the four species of pines using SAS ANOVA (PR>F 0.0001, F = 18.72 and F = 18.07 respectively).

Principle component analysis indicates that pine moth infestation levels were shown to be significantly affected by inner bark thickness (slope = 0.7270, p = 0.0001). The trees with thicker inner bark had significantly more pine moths than those with thinner inner bark tissue. Ponderosa pine, the most heavily infested species, had the thickest inner bark. Jack pine, the least infested species, had the thinnest inner bark. Austrian and Scotch pines were both intermediate in inner bark thickness and infestation levels.

Phloem thickness on the northwest and southeast sides was significantly different between the four species of pines using SAS ANOVA (PR>F 0.0001, F = 15.76 and F = 13.63 respectively). Total inner bark on the northwest and southwest sides was significantly different between the four species of pines using SAS ANOVA (PR>F 0.0001, F = 21.80 and F = 21.35 respectively).

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Table 1. *Dioryctria* pine moth infestation levels in ponderosa pines artificially stressed by girdling at the Nebraska National Forest 1985 - 1988.

Treatment	No. of Trees	Number of Initial Infestations (mean ± SD) 1985	Number of New Infestations (mean ± SD) 1986	1987	1988
Girdled	17	0.5 ±0.61	0.6 ±0.84	0.3 ±0.46	0.8 ±0.62
Not Girdled	17	0.4 ±0.69	1.0 ±0.84	0.7 ±0.75	1.5 ±1.09

Table 2. *Dioryctria* pine moth infestation levels in pruned and non-pruned pine trees at the Nebraska National Forest 1985 - 1988.

Treatment	No. of Trees	Number of Initial Infestations (mean ± SD) 1985	Number of New Infestations (mean ± SD) 1986	1987	1988
Pruned	81	1.1 ±1.61	1.1 ±1.39	1.0 ±1.28	1.1 ±1.43
Non-pruned	28	1.5 ±1.47	1.4 ±1.83	1.3 ±1.32	1.3 ±1.79

CHAPTER 3: PARASITES AND PREDATORS

ABSTRACT

Five hymenopteran parasites were reared from *Dioryctria ponderosae* and *D. tumicolella* larvae and pupae collected in central Nebraska. *Bracon rhyacioniae* (Muesebeck) and *Exeristes comstockii* (Cresson) emerged from *D. ponderosae*; *Orgilus dioryctria* Gahan and *Chelonus* spp. emerged from *D. tumicolella*; and *Hyssopus novus* Girault emerged from both.

INTRODUCTION

Parasites and predators can play important roles in holding down populations of pest insects. Harrell (unpublished data) identified two parasites of *Dioryctria* pine moths in central Nebraska, *Hyssopus novus* on *D. ponderosae* and *Campoplex conocola* (Rohwer) on *D. tumicolella*. Six known parasites of *D. zimmermani* are: *Euderus cushmani* (Cwfd.), *Hyssopus thymus* Girault, and *Scambus hispae* (Harr.) (Schaffner 1959); *Hyssopus rhyacioniae* (Neunzig et al. 1964, Carlson and Butcher 1967); and *Elachertus pini* Gahan, and *Trichogramma minutum* Riley (Carlson and Butcher 1967). In Wisconsin Hainze and Benjamin (1983, 1985) reported five parasites of *D. resinosella*: *Exeristes comstockii* (Cresson), *Bracon rhyacioniae* (Muesebeck), *Hyssopus rhyacioniae* (Gahan), *Eurytoma pini* Bugbee, and

Coelichneumon dioryctriae Rohwer.

Brunner (1915) reported that the Rocky Mountain hairy woodpecker (Dryobates villosus monticola) feeds on Dioryctria spp. larvae. Rennels (1960) reported that spiders, ants, larvae of lace wings, and cockroaches are possible predators of Dioryctria spp. larvae, and Patterson et al. (1983) reported that the beetle larvae Thanasimus undulatus (Klug) (Coleoptera: Cleridae) as a predator of D. resinosella pupae. This study was conducted to identify predators and parasites of Dioryctria spp. pine moths in central Nebraska.

MATERIALS AND METHODS

Parasites were reared from larvae and pupae of Dioryctria ponderosae and D. tumicolella collected in the Nebraska National Forest, and the Brohman ranch, during the summers of 1985-1988 that appeared to be unhealthy or parasitized. The parasites were collected by keeping the suspected parasitized hosts in individual containers until the parasites emerged. Specimens of the parasites were sent to the USDA Systematic Entomology Laboratory, Plant Sciences Institute, Beltsville, Maryland for identification. These specimens have been deposited in the University of Nebraska-Lincoln entomology collection in Nebraska Hall and U.S.N.M. collections.

RESULTS AND DISCUSSION

Five species of hymenopteran parasites in three families were identified from D. ponderosae and D. tumicolella (Table 3). They were: Exeristes comstockii (Cresson), Bracon rhyacioniae (Muesebeck), Orgilus dioryctriae Gahan, Chelonus spp., and Hyssopus novus Girault.

Exeristes comstockii (Cresson) (Ichneumonidae) emerged from D. ponderosae collected in the Nebraska National Forest. E. comstockii has been reported in Nebraska from D. auranticella (Grote) (Pasek & Dix 1989) and had previously been reported from Quebec, south to Florida, and west to California and British Columbia (Krombein et al. 1979). Other known Dioryctria spp. hosts of E. comstockii are D. amatella (Hulst), D. clariolaris (Walker), D. disclusa Heinrich, and D. zimmermanni (Grote) (Krombein et al. 1979). It has not previously been reported from D. ponderosae.

Bracon rhyacioniae (Muesebeck) (Braconidae) emerged from a D. ponderosae collected in the Nebraska National Forest. B. rhyacioniae is reported from Quebec, west to Saskatchewan, N. Dakota, S. Dakota, Nebraska, Montana, Colorado, New Mexico, Arizona, Idaho, and California (Keen 1958, Krombein et al. 1979). The only Dioryctria spp. host previously reported was D. auranticella (Keen 1958, Krombein et. al. 1979).

Another braconid parasite, Orgilus dioryctriae Gahan, was collected from D. tumicolella in the Nebraska National Forest. This had previously been reported only from Colorado and California as a parasite of D. auranticella (Keen 1958, Krombein et al. 1979). Several braconid parasites, Chelonus spp., from D. tumicolella in the Nebraska National Forest could not be identified beyond genus because of revisions being made in the genus at this time.

Hyssopus novus Girault (Eulophidae) was recovered in the Nebraska National Forest from D. ponderosae and D. tumicolella and at the Brohman Ranch from D. tumicolella. This species was previously reported only in California, Idaho, New Mexico, Arizonia, and Colorado (Krombein et al. 1979, Schauff 1985). Reported Dioryctria spp. hosts are D. ponderosae, D. auranticella, and D. cambiicola (Krombein et al. 1979, Schauff 1985).

During this study, one unidentified spider was observed feeding on a Dioryctria spp. larvae. Also, two species of ants, or two forms of the same species, were observed in the Nebraska National Forest preying or scavenging on Dioryctria spp. larvae.

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Table 1. Parasites reared from *D. ponderosae* and *D. tumicolella* from the Nebraska National Forest, Thomas Co., Nebr. .

Family Laboratory	Species	Host	Emergence Date
Braconidae	*Bracon rhyacioniae* (Muesebeck)	*D. ponderosae*	28 June 1986
	Orgilus dioryctriae Gahan	*D. tumicolella*	1 August 1985
	Chelonus sp.	*D. tumicolella*	1 August 1985
Eulophidae	*Hyssopus novus* Girault	*D. ponderosae*	15 June 1987
			12 July 1987
		D. tumicolella	15 August 1987
		unknown	3 August 1985
		unknown	6 August 1986
			18 July 1987
Ichneumonidae	*Exeristes comstockii* (Cresson)	*D. ponderosae*	28 June 1986

1 Identifications provided by Systematic Entomology Laboratory, USDA-ARS. Braconidae, P. M. Marsh; Eulophidae, M. E. Schauff; Ichneumonidae, R. W. Carlson.
2 Collected at the Brohman Ranch, near Callaway, Custer Co., Nebr.
3 Host was either *D. ponderosae* or *D. tumicolella*, host larvae was decayed beyond positive identification.
4 This represents the collection date and the exact emergence date is unknown.

CHAPTER 4: IDENTIFICATION OF SEX PHEROMONES

ABSTRACT

Female sex pheromone blends for Dioryctria spp. pine moths were synthesized in Canada and tested in the field in this study. After three years of field trials, the following pheromone components and ratios were the most successful in attracting D. ponderosae adult males: (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) 10 ug/lure and 100 ug/lure; (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + Hexadecanyl-1-0-acetate (16:OAc) 100:40 ug/lure; and (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + (Z)-9-Hexadecenol (Z-9-16:OH) 100:10 ug/lure. In July, August and September, when D. tumicolella was the most abundant species flying, the following pheromone components and ratios were the most successful: (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + (Z)-11-Hexadecenyl-1-0-acetate (Z-11-16:OAc) 100:2 and 100:5 ug/lure; (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + (Z)-11-Hexadecenyl-1-0-acetate (Z-11-16:OAc) + (E)-9-Hexadecenyl-1-0-acetate (E-9-16:OAc) 100:5:2 ug/lure; (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + (Z)-11-Hexadecenyl-1-0-acetate (Z-11-16:OAc) + (Z)-9-Dodecenyl acetate (Z-9-12:OAc) 100:5:5 ug/lure and 100:5:15 ug/lure; and (Z)-9-Hexadecenyl-1-0-acetate (Z-9-16:OAc) + Tetradecenol 14:OH + (Z)-9-Dodecenyl acetate (Z-9-12:OAc) + (Z)-11-Hexadecenyl-1-0-acetate (Z-11-16:OAc) 100:100:5:5 ug/lure.

INTRODUCTION

Pheromone trapping has become a widely accepted means of obtaining distribution and population estimates for many species of insects, especially the lepidopterans. Sex pheromones have been identified for Dioryctria disclusa Heinrich ((Z)-9-tetradecenyl acetate (Z9-14:Ac)) (Meyer et al. 1982); D. abietella Schiff ((Z,E)-9,11-tetradecadienyl acetate (Z,E-9,11-14:Ac)) (Lofstedt et al. 1983); D. clarioralis (Walker) (Z-9-14:Ac and (E)-9-tetradecenyl acetate (E-9-14:Ac)) (Meyer et al. 1984); and D. amatella (Hulst) (Z-11-16:Ac) (Meyer et al. 1986).

Brewer and Deshon (1983) conducted screening trials in 1982 and found pheromones that had some attractiveness to Dioryctria spp. pitch mass borers in the Denver, Colo., area. They used 14 separate pheromones, which were not listed in the study, in baited sticky traps placed in two locations in the crowns of pinyon pines. One trap was located in the upper branches, 14 - 16 ft. above the ground, and the second was located 3.5 - 4 ft above ground. The data indicated that, in early summer, a substantially greater number of moths were attracted to traps placed in lower areas of the tree than those at higher positions and just the opposite occurred after early August. Brewer and Deshon concluded they were dealing with two different species that had different adult emergence periods and different height preferences. The study reported here was conducted to obtain synthesized sex pheromones of Dioryctria ponderosae and D. tumicolella.

METHODS AND MATERIALS

Dioryctria ponderosae and D. tumicolella pupae were field collected during the summers of 1987, 1988, 1989, and 1990 in the Nebraska National Forest and sent to Gary Grant, Canadian Forest Service, Forest Pest Management Institute, Sault Ste. Marie, Ontario, Canada; and Keith Slessor, Dept. of Chemistry, Simon Fraser University, Burnaby, British Columbia, Canada. Grant and Slessor excised the terminal abdominal segments, including the sex pheromone gland, from females only a few days old. The procedures used to extract and analyze the pheromones were from Struble and Richards (1983), Gilespie et al. (1984), Grant (1971), and Grant et al. (1972 and 1987). From the analyses, candidate compounds and blends were developed for testing.

Field tests using the developed sex pheromone compounds supplied by Slessor and Grant were conducted during the summers of 1988, 1989, and 1990 in the Nebraska National Forest, Thomas County. Pherocon 1C traps (Sandoz Ltd., Basel, Switzerland) baited with test pheromone blends on rubber septa were hung 30 cm from the trunk on a branch at a height of 1.5 - 2.0 m on the northwest side of the tree. The traps for each test were arranged among the trees in a linear fashion 20 to 30 m apart.

Ten test sites in stands of Pinus ponderosa, ca. 6 to 20 m tall, were selected in 1988. Fourteen pheromone blends (A,B,C,D,E,F,H,P,Q,R,T,U,V, and Z) with two controls were tested (Tables 4 and 5). Seven blends and one control were tested per site. The traps were put out for D. ponderosae on June 8th and collected on June 29th. This procedure was repeated on July 30 to September 9 for D. tumicolella.

Three sites were used during the 1989 trapping season (Tables 6 and 7). The first set of five pheromones (G,H,I,J, and K) were replicated five times, randomly assigned, and placed in 25 trees at the first site. Traps were put out May 21, replaced on July 30, and picked up October 1. The second and third sets, each containing the pheromones A,B,C,D,E,F,G, and H, were replicated five times at each of the two remaining sites, randomly assigned, and placed in 40 trees at each of the two sites. Traps were put out May 21, replaced July 23, and picked up October 1.

Two sites were used during the 1990 trapping season (Tables 8 and 9). The first set of pheromones (P,Q,R,S, and T) with control traps (c) were replicated ten times, randomly assigned, and placed in 50 trees. The second set of pheromones (J,K,L,M, and P) were replicated four times, randomly assigned, and placed in 20 trees. Both sets of pheromone traps were put out August 4. On August, all traps were moved one location (to the next trap station) to eliminate individual tree effect and traps were picked up September 25.

To determine how far male Dioryctria spp. would fly from pine trees to the pheromone lures, pheromone traps baited with (Z)-9-hexadecenyl-1-0-acetate (Z9-16:OAc), the most highly attractive pheromone known at the time, were placed at several distances from the trees in grasslands adjacent to and upwind from the forest. During the summer of 1989, eight traps were placed on steel stakes at a height of 1 m and at intervals of 50 m along the edge of the trees, and at distances from the nearest trees of 50 m, 100 m, 150 m, and 200 m. Traps were monitored every week from May 28 to September 17, and the pheromone was replaced on July 30.

RESULTS AND DISCUSSION

In the 1988 experiments, Dioryctria ponderosae pine moths were attracted to pheromones A, B, C, D, P, Q, R, V, and Z, with little or no response to E, F, H, G (control), S (control), T, and U (Table 5). D. tumicolella, and the few D. ponderosae that fly in late summer, were attracted most to A, B, C, D, F, Q, R, T, V, and Z, with little or no response to E, G (control), H, P, S (control), and U.

In 1989, very few D. ponderosae adults were caught in any of the pheromone traps (Table 7). D. tumicolella adults were attracted most to pheromones G and H, and to A, B, D, E and F in moderate numbers. In the 1990 experiments, again very few D. ponderosae adults were caught with any of the pheromones, but P, Q, R, S, T, K, L, and P were successful in attracting D. tumicolella (Table 9).

From the trapping data the following pheromone components and ratios were the most attractive for D. ponderosae: Z-9-16:OAc 10 ug/lure and 100 ug/lure; Z-9-16:OAc + 16:OAc 100:40 ug/lure; and Z-9-16:OAc + Z-9-16:OH 100:10 ug/lure. In July, August and September when D. tumicolella is the most abundant species flying, the following pheromone components and ratios are the most successful: Z-9-16:OAc + Z-11-16:OAc 100:2 and 100:5 ug/lure;Z-9-16:OAc + Z-11-16:OH + E-9-16:OAc 100:5:2 ug/lure; Z-9-16:OAc + Z-11-16:OAc + Z-9-12:OAc 100:5:5 ug/lure and 100:5:15 ug/lure; and Z-9-16:OAc + 14:OH + Z-9-12:OAc + Z-11-16:OAc 100:100:5:5 ug/lure.

The experiment to see how far Dioryctria males would travel into the open was not successful. Only one male D. ponderosae was caught early in June at a distance of 100 m from the pine trees. This may prove that a male can fly at least 100 m, but we do not know if he was attracted from 100 m by the pheromone or whether by chance he came closer to the pheromone trap and then was attracted to the pheromone from less than 100 m. The wind may have blown him or he may have made a series of short flights.

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Table 1. Test pheromone mixtures for _Dioryctria_ pine moths in the Nebraska National Forest, 1988-90.

Code	Coumpound	ug ratio
	1988	
A&O	Z-9-16:OAc + 16:OAc	100:40
B&V	Z-9-16:OAc	10
C&Z	Z-9-16:OAc + Z-9-16:OH	100:10
D&R	Z-9-16:OAc	100
E&P	Z-9-14:OAc	100
F	Z-9-16:OAc + Z-9-16:OH	10:1
G&S	Control	Blank
H&U	Z-11-16:OAc	100
T	Z-9-16:OAc + 16:OAc	10:4
	1989	
A	Z-9-16:OAc	100
B	Z-9-16:OAc + 16:OAc	100:400
C	Z-9-16:OAc + Z-9-16:OH	100:1
D	Z-9-16:OAc + Z-9-16:OH	100:10
E	Z-9-16:OAc + Z-9-16:OH	100:30
F	Z-9-16:OAc + Z-9-16:OH + 16:OAc	100:10:40
G	Z-9-16:OAc + Z-11-16:OAc	100:5
H1	Z-9-16:OAc + Z-11-16:OAc	100:25
H2	Z-9-16:OAc + E-9-16:OAc	100:5
I	Z-9-16:OAc + Z-9-14:OAc	100:5
J	Z-9-14:OAc + Z-9-16:OAc	100:5
K	Z-9-14:OAc	100
	1990	
P	Z-9-16:OAc + Z-11-16:OAc	100:5
Q	Z-9-16:OAc + Z-11-16:OAc + E-9-16:OAc	100:5:2
R	Z-9-16:OAc + Z-11-16:OAc + Z-9-12:OAc	100:5:5
S	Z-9-16:OAc + Z-9-12:OAc + Z-11-16:OAc	100:15:5
T	Z-9-16:OAc + 14:OH + Z-11-16:OAc + Z-9-12:OAc	100:100:5:5
J	Z-9-16:OAc	100
K	Z-9-16:OAc + Z-11-16:OAc	100:2
L	Z-9-16:OAc + Z-11-16:OAc	100:10
M	Z-9-16:OAc + Z-11-16:OAc	100:20

14:OH	Tetradecenol
16:OAc	Hexadecanyl-1-0-acetate
Z-9-12:OAc	(Z)-9-Dodecenyl acetate
Z-9-14:OAc	(Z)-9-Tetradecenyl-1-0-acetate
Z-9-16:OAc	(Z)-9-Hexadecenyl-1-0-acetate
Z-9-16:OH	(Z)-9-Hexadecenol
E-9-16:OAc	(E)-9-Hexadecenyl-1-0-acetate
Z-11-16:OAc	(Z)-11-Hexadecenyl-1-0-acetate

Table 2. Test Mixture results for <u>Dioryctria</u> pine moths in the Nebraska National Forest 1988.

Experiment 1 and 2. Traps put out June 8, and picked up June 29. Traps were monitored each week.

Experiment 1

Lure	Replicates 1	2	3	4	5	Total
A	15	2	1	2	0	20
B	12	0	2	0	0	14
C	6	1	0	1	4	12
D	4	0	16	1	2	23
E	0	3	1	0	0	4
F	1	0	0	0	0	1
G*	0	0	0	0	0	0
H	0	0	0	0	0	0

Experiment 2

Lure	Replicates 1	2	3	4	5	Total
P	12	3	1	0	0	16
Q	11	4	10	4	8	37
R	18	15	0	1	0	34
S*	0	0	0	0	1	1
T	1	0	0	1	0	2
U	1	0	0	0	0	1
V	13	0	14	0	1	28
Z	4	8	12	0	3	27

Experiment 3 and 4. Traps put out July 30, and picked up September 11. Traps were monitored each week.

Experiment 3

Lure	Replicates 1	2	3	4	5	Total
A	15	10	3	8	1	37
B	7	0	4	1	2	14
C	9	9	3	6	7	34
D	9	8	8	13	8	46
E	0	1	0	0	0	1
F	19	0	1	7	10	37
G*	0	0	1	0	1	2
H	1	0	0	0	0	1

Experiment 4

Lure	Replicates 1	2	3	4	5	Total
P	0	0	0	0	0	0
Q	17	12	1	1	2	33
R	21	15	11	10	10	67
S*	0	0	0	0	0	0
T	6	0	0	11	1	18
U	1	0	0	0	0	1
V	2	2	2	7	2	15
Z	10	8	6	3	9	36

* is a blank pheromone, a control.

Table 3. Test Mixture results for <u>Dioryctria</u> pine moths in the Nebraska National Forest 1989.

Experiment 1. Set 1. Traps put out May 21, traps and pheromones replaced July 30, and traps picked up on October 1. Traps were monitored each week.

	May 21 - July 30						July 30 - October 1					
	Replicates						Replicates					
Lure	1	2	3	4	5	Total	1	2	3	4	5	Total
A	0	0	0	1	0	1	4	10	5	0	5	24
B	0	0	0	0	0	0	5	1	4	4	3	17
C	2	0	0	0	0	2	0	0	0	1	3	4
D	0	0	0	0	0	0	3	9	10	5	1	28
E	1	1	1	0	0	3	3	9	10	1	9	37
F	0	1	1	0	0	2	4	5	5	5	9	28
G	0	1	0	0	0	1	14	31	20	43	31	139
H1	0	0	0	0	1	1	4	8	17	2	4	35

Set 2. Traps put out May 21, traps and pheromones replaced July 23, and traps picked up on October 1. Traps were monitored each week.

	May 21 - July 30						July 30 - October 1					
	Replicates						Replicates					
Lure	1	2	3	4	5	Total	1	2	3	4	5	Total
A	1	3	1	0	0	5	8	13	1	0	1	23
B	1	0	0	2	0	3	1	6	7	8	3	25
D	2	1	0	0	1	4	15	7	1	1	4	28
E	0	1	0	0	0	1	9	5	1	3	2	20
F	1	3	0	3	2	9	11	15	13	13	14	66
G	0	1	4	0	1	6	30	30	98	4	20	182
H1	0	1	0	0	0	1	10	10	6	17	2	45

Experiment 2. Traps put out May 21, replaced with new traps and pheromones on July 30, and picked up October 1. Traps were monitored each week.

	May 21 - July 30						July 30 - October 1					
	Replicates						Replicates					
Lure	1	2	3	4	5	Total	1	2	3	4	5	Total
G	2	1	0	0	2	5	35	30	9	21	23	118
H2	1	0	0	0	1	2	3	0	6	1	9	19
I	0	0	0	0	0	0	0	0	1	0	0	1
J	1	0	0	0	0	1	0	0	0	1	0	1
K	0	0	0	0	0	0	0	0	1	0	0	1

Table 4. Test Mixture results for <u>Dioryctria</u> pine moths in the Nebraska National Forest 1990.

Experiment 1. Traps put out August 4, and picked up September 25. Traps were monitored each week.

	Replicates										
Lure	1	2	3	4	5	6	7	8	9	10	Total
P	29	22	24	39	22	22	59	18	10	31	276
Q	12	13	24	25	32	8	51	75	12	33	285
R	29	25	26	22	9	30	47	30	23	18	259
S	11	31	11	15	17	9	26	14	16	33	183
T	16	34	25	25	19	13	62	43	49	27	313
Control	1	1	0	1	0	0	1	0	0	0	4

Experiment 2. Traps put out August 4, and picked up September 25. Traps were monitored each week.

	Replicates				
Lure	1	2	3	4	Total
J	1	2	2	4	9
K	25	35	15	15	90
L	11	11	10	7	39
M	2	3	0	1	6
P	41	19	25	7	92

CONCLUSIONS

It is now established that *Dioryctria ponderosae*, *D. tumicolella*, and *D. zimmermani* pine moths are present in Nebraska. *D. ponderosae* is found in four central Nebraska counties and has a life cycle ranging from 14 months to two years. *D. tumicolella* has been found in 36 counties in central Nebraska.

Three hymenopteran parasites of *D. ponderosae* were identified and four from *D. tumicolella*. It was confirmed that in the Nebraska National Forest, ponderosa pine tends to be the most heavily infested with *Dioryctria* pine moths of the pine species, with Austrian and Scotch pines affected intermediately, and jack pine being the least infested.

This study also revealed that the pine moths were found in higher numbers on the northeast side of ponderosa pines, followed by the northwest, then southeast, and finally southwest. They were found more frequently in the middle section of the tree, followed by the top, and least frequently in the bottom portion. The pine moths were found in highest numbers on the branch-trunk sites, followed by the trunk, and the lowest on the branches.

Stressing or pruning ponderosa pine trees did not increase the number of pine moth infestations. Resin flows and bark thicknesses did seem to affect infestation levels. Pheromones were developed during this study that had excellent results in attracting male moths.

FURTHER RESEARCH NEEDED

Distribution maps for the *Dioryctria* spp. need to be developed for the entire state of Nebraska, and life cycles need to be examined more intensively. Distributions for *D. ponderosae* and *D. tumicolella* could be established with pheromone traps since they have proved to work very well in this study.

Cross sections at points of attack of heavily infested trees could be taken and used to reconstruct past population trends, which could then be related to past weather conditions. Additional natural enemies could be identified by continuing to collect and identify parasites, and monitoring any predators of larvae and adults. Tree spacings and infestation levels could be compared to see if tree density is related to infestation levels.

Additional research is needed in the use of pupal characteristics and setal patterns of larvae of *Dioryctria* spp. to identify *Dioryctria* spp. immatures. An artificial medium for rearing larvae could be developed so that more studies could be completed in the laboratory.

Appendix A. Resin flows, phloem and inner bark thicknesses, and infestations for Austrian pines at the Nebraska National Forest 1986.

1*	2*	3*	4*	5*	6*	7*	8*	9*	10*
1A	6.0	3.4	0.10	0.25	1.0	1.0	3.0	6.0	3
2A	8.0	3.1	0.08	0.19	1.0	1.0	4.0	3.0	1
3A	6.0	3.1	0.12	0.34	1.0	1.0	3.5	4.5	0
4A	11.0	4.3	0.00	0.04	1.0	1.0	4.5	4.0	2
5A	9.0	3.7	0.00	0.04	1.0	1.0	4.0	4.5	3
6A	7.5	3.4	0.07	0.22	1.0	1.0	3.5	4.5	2
7A	13.0	5.5	0.16	0.41	1.0	1.5	3.0	4.5	0
8A	7.0	4.0	0.17	0.40	1.0	0.5	3.0	2.5	2
9A	8.5	3.4	0.11	0.32	1.0	1.0	3.0	5.0	2
10A	7.0	4.0	0.07	0.17	1.0	1.0	3.0	3.0	1
11A	7.0	3.4	0.10	0.31	1.0	0.5	4.0	2.5	0
12A	11.5	5.8	0.16	0.43	1.0	0.5	4.0	4.0	1
13A	9.0	4.3	0.19	0.50	0.5	1.0	3.0	3.0	0
14A	7.0	3.4	0.09	0.22	1.0	1.0	3.0	4.5	2
15A	10.0	3.4	0.00	0.04	1.0	1.0	2.5	3.5	2
16A	11.5	5.2	0.00	0.04	1.0	1.0	4.0	5.0	1
17A	8.0	3.4	0.31	0.83	1.5	1.0	4.0	5.0	3
18A	8.0	3.7	0.07	0.21	1.0	1.0	3.0	3.0	0
19A	9.5	5.5	0.10	0.30	1.0	1.5	2.5	4.0	3
20A	9.0	4.0	0.02	0.06	1.0	1.0	3.0	3.0	0
21A	7.0	3.7	0.05	0.19	1.0	1.0	2.5	4.5	2
22A	8.0	4.6	0.13	0.36	1.0	1.0	3.5	4.0	3
23A	7.0	3.4	0.04	0.14	1.0	1.0	3.0	4.0	0
24A	11.5	5.5	0.12	0.30	1.0	1.0	3.5	5.0	2
25A	7.5	4.0	0.11	0.23	1.0	1.0	5.0	5.0	3
column means			0.10	0.26	1.0	0.98	3.4	4.1	1.5

1* Tree identification number.
2* DBH in cm.
3* Height in m.
4* Resin flow at 2 hours in 1/1000 ml.
5* Resin flow at 4 hours in 1/1000 ml.
6* Phloem thickness in mm, NW side at 125 cm.
7* Phloem thickness in mm, SE side at 125 cm.
8* Inner bark thickness in mm, NW side at 125 cm.
9* Inner bark thickness in mm, SE side at 125 cm.
10* Number of _Dioryctria_ pine moth infestations.

Appendix A cont. Resin flows, phloem and inner bark thicknesses, and infestations for Scotch pines at the Nebraska National Forest 1986.

1*	2*	3*	4*	5*	6*	7*	8*	9*	10*
26S	10.5	4.3	0.38	0.70	1.0	1.0	3.0	3.0	2
27S	10.0	4.9	0.40	0.71	1.0	1.0	3.0	2.5	2
28S	5.5	2.7	0.54	0.98	0.5	1.0	3.5	3.5	0
29S	9.5	4.3	0.37	0.80	1.0	1.0	2.5	3.5	0
30S	11.0	4.6	1.60	1.60	1.0	1.0	2.5	3.0	0
31S	9.0	5.5	0.51	1.01	1.0	1.5	4.0	4.0	6
32S	11.0	5.8	0.34	0.61	0.5	1.0	2.5	3.5	2
33S	10.0	5.5	0.37	0.79	0.5	0.5	2.0	1.5	2
34S	10.5	5.8	0.42	0.96	0.5	1.0	2.5	3.5	2
35S	7.0	4.3	0.35	0.80	0.5	1.0	4.0	3.5	0
36S	5.5	2.4	0.11	0.15	0.5	1.0	2.5	3.5	0
37S	11.0	5.2	0.00	0.00	1.5	1.5	5.5	5.5	4
38S	9.0	2.4	0.20	0.30	1.0	1.5	4.0	3.5	4
39S	12.0	6.1	0.12	0.26	0.5	0.5	4.0	3.5	2
40S	9.0	5.2	0.70	1.45	0.5	0.5	3.5	3.5	3
41S	11.0	7.6	0.43	0.84	0.5	1.0	3.0	3.5	2
42S	8.0	4.0	0.27	0.56	0.5	1.0	2.5	2.5	0
43S	8.0	5.5	1.20	1.60	0.5	0.5	3.0	3.0	0
44S	15.0	7.0	0.66	1.39	1.0	0.5	2.0	3.5	0
45S	13.0	4.3	0.75	1.60	0.5	1.0	2.5	3.5	2
46S	7.5	4.3	0.15	0.31	1.0	1.0	3.5	3.0	2
47S	7.0	3.7	0.15	0.30	1.0	1.0	3.5	4.5	3
48S	10.5	5.8	0.45	0.88	0.5	1.0	3.5	3.5	0
49S	11.5	7.0	0.40	0.79	0.5	1.0	3.5	3.5	1
50S	13.0	6.7	0.87	1.60	1.0	0.5	2.5	3.0	2
column mean			0.47	0.84	0.74	0.94	3.1	3.4	1.6

1* Tree identification number.
2* DBH in cm.
3* Height in m.
4* Resin flow at 2 hours in 1/1000 ml.
5* Resin flow at 4 hours in 1/1000 ml.
6* Phloem thickness in mm, NW side at 125 cm.
7* Phloem thickness in mm, SE side at 125 cm.
8* Inner bark thickness in mm, NW side at 125 cm.
9* Inner bark thickness in mm, SE side at 125 cm.
10* Number of <u>Dioryctria</u> pine moth infestations.

Appendix A cont. Resin flows, phloem and inner bark thicknesses, and infestations for ponderosa pines at the Nebraska National Forest 1986.

1*	2*	3*	4*	5*	6*	7*	8*	9*	10*
1P	14.0	7.0	0.17	0.33	1.0	1.5	3.5	6.5	5
2P	13.0	5.8	0.00	0.00	1.5	1.5	5.0	4.5	7
3P	16.5	8.8	0.20	0.41	1.0	1.0	4.5	5.5	13
4P	14.0	6.4	0.12	0.23	1.0	2.0	5.5	6.0	10
5P	10.0	4.6	0.12	0.24	1.0	1.0	3.5	5.0	4
6P	8.0	4.3	0.22	0.50	1.5	1.5	4.5	5.5	2
7P	9.0	5.2	0.10	0.29	1.0	1.5	4.5	4.0	1
8P	9.5	7.3	0.00	0.03	1.5	1.0	3.5	3.5	2
9P	8.0	6.4	0.12	0.34	1.0	1.0	3.0	3.5	0
10P	10.0	6.7	0.00	0.05	1.0	1.0	5.0	3.5	0
11P	17.0	6.7	0.15	0.38	1.5	1.0	3.5	4.5	0
12P	7.5	3.4	0.03	0.08	1.0	1.0	4.0	3.0	2
13P	8.5	4.6	0.08	0.18	1.0	1.0	4.0	2.5	2
14P	9.0	4.6	0.20	0.51	1.0	1.0	3.0	3.5	0
15P	11.0	4.9	0.00	0.00	1.0	1.5	5.0	3.5	4
16P	9.0	4.3	0.37	0.83	1.5	1.5	4.5	5.0	5
17P	7.5	3.4	0.21	0.64	1.0	1.0	4.0	4.5	2
18P	10.0	5.2	0.00	0.06	1.0	1.0	5.0	4.0	4
19P	6.0	2.7	0.00	0.03	1.0	1.0	4.0	4.5	5
20P	5.5	3.4	0.12	0.32	1.0	1.0	3.5	3.5	2
21P	5.0	2.4	0.05	0.15	1.0	1.0	4.0	4.5	1
22P	8.5	4.3	0.05	0.04	1.0	1.0	5.5	4.0	4
23P	7.5	5.2	0.07	0.10	1.0	1.0	5.5	3.0	6
24P	6.0	2.7	0.25	0.42	0.5	0.5	4.5	2.0	3
25P	8.0	4.0	0.27	0.48	1.0	1.0	4.0	4.0	3
column mean			0.12	0.27	1.1	1.1	4.3	4.2	3.5

1* Tree identification number.
2* DBH in cm.
3* Height in m.
4* Resin flow at 2 hours in 1/1000 ml.
5* Resin flow at 4 hours in 1/1000 ml.
6* Phloem thickness in mm, NW side at 125 cm.
7* Phloem thickness in mm, SE side at 125 cm.
8* Inner bark thickness in mm, NW side at 125 cm.
9* Inner bark thickness in mm, SE side at 125 cm.
10* Number of <u>Dioryctria</u> pine moth infestations.

Appendix A cont. Resin flows, phloem and inner bark thicknesses, and infestations for jack pines at the Nebraska National Forest 1986.

1*	2*	3*	4*	5*	6*	7*	8*	9*	10*
26J	9.0	7.0	0.17	0.30	0.5	1.0	3.0	2.0	0
27J	8.0	6.7	0.17	0.29	0.5	0.5	3.0	2.0	0
28J	9.5	7.3	0.34	0.64	0.5	1.0	2.0	2.5	1
29J	13.0	7.9	0.15	0.32	1.0	1.0	4.5	3.5	0
30J	17.0	7.9	0.25	0.54	1.0	1.0	4.5	3.5	7
31J	15.0	7.9	0.00	0.02	1.0	1.0	4.0	3.0	8
32J	7.0	6.7	0.00	0.02	1.0	0.5	2.0	2.5	0
33J	12.0	7.9	0.57	1.23	1.0	0.5	3.0	3.0	0
34J	7.5	4.3	0.13	0.28	1.0	0.5	2.5	3.0	0
35J	11.5	6.7	0.29	0.65	1.0	1.0	2.0	2.5	1
36J	11.0	7.0	0.14	0.34	0.5	1.0	3.5	2.5	0
37J	8.5	6.4	0.38	0.85	0.5	0.5	2.0	2.0	0
38J	10.0	7.0	0.00	0.00	1.0	0.5	2.0	2.5	0
39J	10.0	7.0	0.24	0.42	0.5	0.5	2.0	2.5	0
40J	10.0	7.3	0.13	0.38	0.5	0.5	2.0	2.0	0
41J	11.0	5.5	0.30	0.83	0.5	0.5	2.5	2.5	0
42J	11.0	7.9	0.43	1.02	0.5	0.5	2.5	2.0	0
43J	14.0	7.9	0.15	0.39	1.0	0.5	2.5	3.0	0
44J	6.0	5.8	0.08	0.22	0.5	0.5	1.5	2.0	0
45J	12.5	7.9	0.02	0.05	0.5	0.5	2.0	2.0	0
46J	12.5	7.3	0.12	0.45	0.5	0.5	2.0	2.0	0
47J	14.0	7.9	0.06	0.18	1.0	0.5	2.5	2.0	0
48J	11.0	7.9	0.15	0.42	0.5	1.0	2.5	3.0	0
49J	9.5	7.9	0.14	0.30	0.5	0.5	2.5	2.5	0
50J	7.0	4.3	0.16	0.42	0.5	0.5	1.5	2.5	0
column mean			0.18	0.42	0.70	0.66	2.6	2.5	0.68

1* Tree identification number.
2* DBH in cm.
3* Height in m.
4* Resin flow at 2 hours in 1/1000 ml.
5* Resin flow at 4 hours in 1/1000 ml.
6* Phloem thickness in mm, NW side at 125 cm.
7* Phloem thickness in mm, SE side at 125 cm.
8* Inner bark thickness in mm, NW side at 125 cm.
9* Inner bark thickness in mm, SE side at 125 cm.
10* Number of <u>Dioryctria</u> pine moth infestations.

Appendix B. *Dioryctria* pine moth infestation levels in ponderosa pines artificially stressed by girdling in the Nebraska National Forest 1985 - 1988.

Tree #	Girdled Yes or No	Number of Initial Infestations 1985	Infestation Numbers 1986	1987	1988
7	Y	0	0	0	0
12	N	0	1	0	0
14	Y	1	0	0	1
21	N	0	2	1	2
26	Y	1	3	1	2
28	N	0	3	1	1
38	Y	0	0	0	0
40	N	0	1	0	0
44	Y	0	0	0	1
45	N	2	2	2	2
46	N	0	1	0	2
48	Y	1	1	1	2
49	Y	2	1	1	0
50	N	0	0	0	1
52	Y	0	1	0	0
53	N	0	0	0	0
55	Y	0	2	0	1
59	N	1	2	2	2
60	Y	1	0	0	1
62	N	1	1	1	2
64	Y	1	1	0	1
67	N	0	1	2	4
68	Y	0	0	1	1
70	N	0	0	0	3
74	Y	0	1	1	1
75	N	1	1	0	2
80	Y	0	0	0	0
86	N	0	0	0	0
90	Y	1	0	0	1
93	N	0	0	1	1
94	Y	0	0	0	1
98	N	0	1	1	2
99	Y	1	0	0	1
100	N	2	1	1	1

Appendix C. *Dioryctria* pine moth infestation levels in pruned and non-pruned ponderosa pine trees in the Nebraska National Forest 1985 - 1988.

tree #	number of branches pruned	initial insect infestations 1985	Numbers of insect Infestations 1986	1987	1988
1	4	2	2	1	2
2*	0	0	0	0	0
3	12	0	1	1	1
4	9	0	1	2	2
5	12	0	0	0	1
6*	0	1	2	2	2
7*	0	4	1	1	3
8	14	5	5	2	0
9	13	0	1	0	1
10*	0	4	1	1	0
11	13	0	0	0	0
12*	0	0	0	0	1
13	4	2	3	3	1
14*	0	2	2	0	1
15*	0	2	1	1	0
16	2	0	2	0	0
17	9	0	0	0	0
18*	0	0	0	1	0
19	5	0	2	0	0
20	6	1	0	2	2
21	8	4	2	2	1
22	12	0	0	0	0
23	2	0	0	0	0
24*	0	4	7	6	8
25	10	0	0	1	2
26	5	2	2	2	1
27	15	0	1	1	2
28	15	0	2	0	0
29	12	0	1	1	1
30	10	0	0	2	3
31	11	0	0	0	1
32	11	4	6	4	2
33*	0	2	6	4	2
34	8	2	3	2	1
35	8	1	2	1	3
36*	0	0	0	1	0
37*	0	0	0	1	0

*trees that were not pruned

Appendix C cont. Dioryctria pine moth infestation levels in pruned and non-pruned ponderosa pine trees in the Nebraska National Forest 1985 - 1988.

tree #	number of branches pruned	initial insect infestations 1985	Numbers of insect Infestations 1986	1987	1988
38*	0	1	0	2	1
39*	0	0	0	0	0
40	13	7	2	2	1
41	9	0	0	0	6
42	8	0	0	0	0
43	14	0	0	0	0
44	9	0	0	0	0
45	13	1	1	1	0
46	10	0	0	0	0
47	7	1	3	0	1
48	5	0	0	2	0
49	16	2	0	2	1
50	12	2	2	2	2
51*	0	3	3	2	2
52*	0	1	2	2	3
53	14	0	0	1	1
54	7	0	0	0	0
55*	0	1	0	2	3
56	8	1	2	1	1
57	12	0	0	0	0
58	9	0	0	2	0
59	12	5	1	2	2
60	12	1	2	1	1
61	10	0	0	0	0
62*	0	2	3	2	0
63	10	3	1	3	3
64*	0	1	4	2	2
65*	0	1	1	1	1
66*	0	5	3	1	1
67*	0	3	1	2	5
68	6	1	2	0	0
69	10	6	6	0	0
70	8	6	5	6	6
71	16	3	1	2	2
72	12	0	0	0	5
73	8	3	1	0	2
74	8	3	4	6	6

*trees that were not pruned

Appendix C cont. <u>Dioryctria</u> pine moth infestation levels in pruned and non-pruned ponderosa pine trees in the Nebraska National Forest 1985 - 1988.

tree #	number of branches pruned	initial insect infestations 1985	Numbers of insect Infestations 1986	1987	1988
75	7	3	3	3	2
76	3	2	1	1	0
77	9	1	1	0	0
78	8	0	1	0	0
79	6	1	1	3	1
80	8	0	1	1	0
81	12	1	0	0	0
82	15	0	0	0	1
83*	0	2	0	0	0
84*	0	0	0	0	0
85	8	0	0	0	2
86	11	0	0	0	0
87	9	0	1	2	1
88	14	1	0	0	0
89	9	0	0	0	0
90	10	0	0	0	1
91	9	0	1	0	1
92	13	0	0	0	1
93	18	2	1	2	2
94	13	2	1	1	1
95	10	0	1	1	2
96	9	3	3	2	5
97	12	0	0	0	0
98*	0	0	0	0	0
99*	0	2	1	0	1
100*	0	0	0	1	1
101*	0	0	0	0	0
102	7	1	0	0	0
103	13	0	0	0	1
104	10	1	0	0	0
105	8	0	1	1	1
106	10	0	0	0	0
107	11	1	0	0	1
108	10	1	1	0	0
109	16	1	1	0	0

*trees not pruned