Insect and Disease Conditions in Bryce Canyon National Park Detected during August 1995

by
Dawn Hansen, Entomologist
Forest Health Protection
Ogden Field Office

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Abstract

Bryce Canyon National Park personnel were interested in establishing baseline information related to forest health. Forest Health Protection personnel conducted a systematic survey for forest insects, diseases and other abiotic damages throughout the forested areas of the Park and adjacent Dixie National Forest lands in August 1995. The major insect and disease agents found were Douglas-fir dwarf mistletoe, *Arceuthobium douglasii* Engelmann; western spruce budworm, *Choristoneura occidentalis* Freeman; Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins; and fir engraver beetle, *Scoyltus ventralis* LeConte. The implications of these insects and diseases and their role in prescribed fire management are discussed. Generally, it did not appear that the forest health conditions in Bryce Canyon National Park were much different than the Dixie National Forest lands adjacent to the Park. The potential of future bark beetle outbreaks and the continued spread of dwarf mistletoes, especially Douglas-fir dwarf mistletoe, are two forest health issues which Bryce Canyon National Park personnel can address in developing prescribed burn plans.

Introduction

In the spring of 1995, Bryce Canyon National Park personnel requested assistance in establishing a baseline for forest health from the Forest Health Protection, Ogden Field Office. Park personnel informed us in their request that:

> "Fire has been suppressed in the Park since the turn of the century. This has resulted in an un-natural forest condition including fuel buildup, alteration in species composition, and the presence of forest diseases. Recent field surveys indicate that a large percentage of trees in the south end of the Park (the mixed conifer area) are infected with mistletoe. Since commercial timber in Dixie National Forest is adjacent to the Park boundary, and there has been timber harvest adjacent which may mimic wildfire in the reduction of biomass, the presence of abnormal levels of forest diseases is of great concern, both to the park and the neighboring forest."

Park personnel were interested in incorporating information about the current levels of insect and disease to help in the design the future prescribed fire program. A prescribed fire program was initiated in the Park in 1990. After discussing their needs, a systematic survey was designed and conducted August 10 - 21, 1995 to sample forested areas for insect and disease activity both within the National Park and on adjacent portions of the Dixie National Forest.

Although Bryce Canyon National Park typically is thought of as a red rock canyon area with

spires, spindles, and sheer cliffs, the canyon rims are predominantly ponderosa pine, *Pinus ponderosae* Dougl. ex Laws, and mixed conifer forests. Elevation of the canyon rim varies from 6,600 to 9,100 feet. As elevation increases, Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco; white fir, *Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.; and other mixed conifers (such as Engelmann spruce, *Picea engelmanni* Parry ex Engelm.; limber pine, *Pinus flexilis* James; and Rocky Mountain juniper, *Juniperus scopulorum* Sarg.) become more predominant.

Historical Perspective

In reviewing our office records for the area, several historical references to Bryce Canyon National Park were found in accounts of insect and disease activity on the Dixie National Forest. The main forest insects influencing the Park were fir needle miner, *Epinotia meritana* Heinrich, defoliation in the late 1950's; mountain pine beetle, *Dendroctonus ponderosae* Hopkins, in the early 1970's; and fir needle miner defoliation again in 1976. See Appendix for more details.

Survey Objectives

There were three main survey objectives:

1) To determine the current status of forest insect and disease activity within Bryce Canyon National Park. This baseline information could be added to the Park's Geographic Information System (GIS) as a data layer.
2) To make a generalized comparison of the level of forest insect and disease activity within the Park compared to the Dixie National Forest lands adjacent to the Park.
3) To report any findings and their implications to the prescribed fire program of Bryce Canyon National Park.

Insect and Disease Biology

The following section will highlight the major insects and diseases which can be found in the forest types of Bryce Canyon National Park.

Bark Beetles: Bark beetles cause the most impacts of the forest insects in western coniferous forests (Furniss and Carolin 1980). They are small cylindrical beetles ranging in size from 2 to 8 mm long (Furniss and Carolin 1980). Except when adult beetles fly to attack new trees, their life cycles are completed under the bark of trees.

Bark beetles initiate an attack by chewing into the bark of the tree. The tree's major defense response is to pitch the beetle out the entrance hole with tree sap. Boring dust is created by the beetle as it chews its way in and along the inner bark (phloem) layer. If the tree can't pitch sufficient amounts of sap, the beetle is able to continue boring. As the beetle bores, it leaves a species-specific gallery pattern which identifies the type of bark beetle. The pitch

flow (or in some cases pitch tubes) and boring dust are two common visible signs of bark beetle attacks (Furniss and Carolin 1980).

Bark beetles tunnel within the tree phloem and lay eggs. After the eggs hatch, developing larvae mine the phloem, eventually girdling the tree. Bark beetles also introduce a blue stain fungus that blocks the tree's water-conducting vessels. As numerous bark beetles attack the same tree, the tree is overwhelmed and dies. Bark beetle populations are influenced by predators, primarily woodpeckers and other insects, parasites, and the availability of susceptible hosts as a food supply.

Typically, bark beetles are host specific. For example, Douglas-fir bark beetle, *Dendroctonus pseudotsugae* Hopkins, primarily attacks Douglas-fir trees. There are several native species of *Dendroctonus* which can be found in southern Utah including mountain pine beetle; Douglas-fir beetle; spruce beetle, *D. rufipennis* Kirby; fir engraver, *Scolytus ventralis* LeConte; and western pine beetle, *D. brevicomis* LeConte.

Mountain pine beetle aggressively attacks lodgepole pine, *Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. and ponderosa pine, but can attack other pine species. (For more detailed information on the biology of each bark beetle, see Appendix.) In ponderosa pine forest stands, low levels of mountain pine beetle attacks involve less than 5 trees per acre per year and occur in widely scattered single trees or small groups. As population levels increase and an outbreak begins, mortality increases to five to ten trees per acre (Sartwell and Stevens 1975). These outbreaks typically start in dense clumps of ponderosa pine which are often stressed from competition and in turn, more susceptible to beetle attack. Other stand factors which are common in mountain pine beetle outbreaks in ponderosa pine include: the presence of even-aged ponderosa pine of 8 to 12 inches in diameter at breast height (DBH, 4.5 feet above ground level), a high percentage of ponderosa pine in the area, and stand densities over 150 square feet of basal area (Sartwell and Stevens 1975). At the peak of a mountain pine beetle outbreak in ponderosa pine, mortality levels can range from 30 to 150 trees per acre (Sartwell 1971).

Douglas-fir beetle is a native bark beetle which infests Douglas-fir trees throughout their range. Typically, Douglas-fir beetle attacks trees weakened by drought or root disease, windthrown trees, snow-damaged or recently-fallen trees (Furniss and Orr 1978). When Douglas-fir beetles infest standing trees, they tend to attack larger, overmature trees. Mortality caused by Douglas-fir beetle is usually concentrated in pockets ranging in size from a few trees to hundreds (Weatherby and Thier 1993).

Spruce beetle can be a significant forest insect of mature spruce. The Dixie National Forest has experienced major losses to spruce beetle since 1991. Endemic spruce beetle populations are usually found in windthrown trees or trees stressed by root diseases. When beetle populations increase in downed trees, the emerging beetles will attack nearby standing trees if fresh down material is not available. Trees greater than 18 inches DBH and stand densities of

greater than 120 square feet per acre basal area are most susceptible to attack (Holsten et al. 1991).

Fir engraver beetles attack primarily white fir; grand fir, *Abies grandis* (Dougl.) Lindl.; red fir, *A. magnifica* A. Murr.; and occasionally subalpine fir, *A. lasiocarpa* (Hook.) Nutt.; Douglas-fir and Engelmann spruce. When fir engraver populations are at low levels, primarily small trees or the tops of larger trees are attacked. When the trees' resistance has been lowered by drought or other stresses, trees of any size are attacked and outbreaks can cause widespread mortality. The Intermountain Region (Utah, Nevada, western Wyoming, and southern Idaho) and much of the west has experienced high levels of fir mortality from 1991 to 1996 due to several factors including fir engraver beetles; western balsam bark beetles, *Dryocoetes confusus* Swaine; other bark beetles; disease pathogens; and environmental factors (Barbouletos et al. 1995, Gardner et al. 1996, Gardner et al. 1997).

Defoliators: Western spruce budworm, *Choristoneura occidentalis* Freeman, is the most widely distributed and destructive native defoliator in the western United States. Western spruce budworm attacks Douglas-fir, grand fir, white fir, subalpine fir, and occasionally spruces. The larval stage feeds on foliage and developing cones of host trees. Insect parasites, predators, and adverse weather conditions reduce populations levels and cause cyclic outbreaks (Fellin and Dewey 1982). Western spruce budworm defoliation reduces growth, kills tree tops and entire trees if defoliation occurs for several years.

Dwarf mistletoes: Dwarf mistletoes are parasitic, seed-bearing plants that depend on their hosts almost completely for water and nutrients (Hawksworth and Wiens 1996). Most western conifers have a host-specific dwarf mistletoe. Dwarf mistletoes can cause mortality and growth reduction in infected hosts, a decrease in the quantity, quality, and germination percentage of seeds produced, and lower timber quality. Heavily infected trees are more susceptible to attacks by insects, particularly bark beetles, other diseases, and are also more susceptible to environmental stresses such as drought.

Dwarf mistletoes cause branch swelling and brooming as they send hormones to the host plant which allow more nutrients and water to be sent to the area of the mistletoe. Dwarf mistletoe brooms, often called witches brooms, are a visible sign of this disease. (See Appendix for more details on the biology of dwarf mistletoes.)

Some of the most common types of dwarf mistletoes within the host types in Bryce Canyon National Park include Douglas-fir dwarf mistletoe, *Arceuthobium douglasii* Engelmann; southwestern dwarf mistletoe, *A. vaginatum* subsp. *cryptopodum* (Engelmann) Hawksworth & Wiens, which infects ponderosa pine; and limber pine dwarf mistletoe, *A. cyanocarpum* (A. Nelson ex Rydberg) Coulter & Nelson.

Limb Rust: Limb rust, *Peridermium filamentosum* Pk., is the most destructive rust of ponderosa and Jeffery pines. Limb rust is a systemic disease and is not restricted to a canker

or gall on the tree (Peterson 1966). Limb rust kills tree branches and slowly kills the entire tree. Rust spores infect needles and branches, which become red-brown or gray and die. Once the fungus grows into the tree bole from the infected branch, the tree slowly dies. It is estimated that the tree will die after the crown has 80 to 90 percent dieback (Mielke 1952). Limb rust weakens trees and they become more susceptible to other insects and diseases (U.S. Forest Service 1957).

Risk Rating Systems for Bark Beetles

The potential for bark beetle activity is present anytime suitable host is present. Risk rating systems are tools to help land managers determine the likelihood of a beetle outbreak and exist for various bark beetles (Bentz et al. 1993). For example, in the lodgepole pine host type, a risk rating system exists for mountain pine beetle (Amman et al. 1977). This risk rating system has been utilized and validated in several areas (Gillespie et al. 1990, Cameron et al. 1990, Vandygriff and Hansen 1992). Risk rating systems for other bark beetles are still being developed or have yet to be well validated.

A risk rating system for the Douglas-fir beetle was developed by Ralph Thier, Entomologist, Forest Health Protection, Boise Field Office, which incorporated the following factors: the percent of Douglas-fir, the stand basal area, the average stand age, and the average DBH of Douglas-fir (Steele et al. 1996, See Appendix for details.). This risk rating system has only been validated in one geographical region in southern Idaho and performed well for predicting the probability of a Douglas-fir beetle infestation (Weatherby & Thier 1993).

An empirical risk rating system was developed for mountain pine beetle in ponderosa pine by John Anhold and Steve Munson, Entomologists, Forest Health Protection, Ogden Field Office which includes the following factors: stand basal area, average diameter of ponderosa pine; proportion of ponderosa pine in canopy, and the number of currently infested trees per acre (Dymerski & Anhold 1995). This rating system was used on the Dixie National Forest, Cedar City Ranger District for the Blue Springs/Reed Valley Analysis Area in 1995 and 1996 (Dymerski & Anhold 1995, See Appendix for details). In this analysis area, the risk rating seemed to predict areas of risk accurately (Anhold et al. 1997).

A risk rating system for mountain pine beetle and other pine bark beetles in southwestern ponderosa pine host types is currently being developed in a cooperative project by Forest Service Research and western Forest Health Protection offices. Field data has been collected in southern Utah (including several plots within Bryce Canyon National Park), northern Arizona, and southwestern Colorado. Statistical analysis is currently underway (Logan, personal communication).

There are currently no available risk rating systems for other bark beetles which could be found in this survey area such as fir engraver beetle, western pine beetle, and pine engraver beetles, *Ips* species.

Methods

Field Procedures

A systematic survey was designed to cover forest areas throughout the rim areas of the Park. Sample transects were spaced throughout the rim areas of the Park and on the Dixie National Forest (will be referred to as NFS lands) along the Park boundary. Figure 1 illustrates the placement of survey plots. Each sample transect had survey plots spaced 5 chains (1 chain = 66 feet) apart in order to provide a systematic sample. At each survey plot, an inventory was conducted using variable radius plots with a 20 basal area factor (BAF).

Data collected included:

- Tree species	-Insect Activity:	-Disease Activity:	-Abiotic Factors:
- Diameter at breast height	* Bark beetles	* Dwarf mistletoe rating	* Fire
	* Defoliators	* Stem decay	* Mechanical
- Age	* Other	* Foliage disease	* Lightning
		* Root disease	* Other

The survey codes used to note the presence or absence of insects and diseases were from the INDIDS program and Region 4 Regional Pest Codes (Bousfield 1980, Unpublished R4 Pest Codes). The 6-class dwarf mistletoe rating (DMR) system was used to quantify dwarf mistletoe levels on individual trees within the survey plots (Hawksworth 1977). Three trees were aged at every fifth plot, and growth measurements were determined to the nearest 1/20th of an inch for the past 10 years. Any unique situation about forest health conditions for a survey plot which was not captured in the field codes was recorded in the remarks section of the field forms.

During the survey, trees were recorded as dead if they had red or no needles. Trees which were currently infested by primary bark beetles were also considered to be dead. These species include mountain pine beetle, fir engraver beetle, and Douglas-fir beetle. Trees infested by secondary bark beetles such as red turpentine beetle, *Dendroctonus valens* LeConte, were considered to be live, since such attacks were usually limited to a small portion of the tree base.

Data Analysis

Field data were entered into Excel® spreadsheet software. For each survey plot, calculations were performed to determine forest type characteristics. Since survey plots are samples of the forest, a conversion to describe the forest on a per acre basis was necessary. The forest type characteristics determined were trees per acre (TPA), basal area per acre (BA), quadratic mean diameter (Dq), and percent species composition based on trees per acre and basal area per

acre. Basal area per acre, measured in square feet, is the cross section of the tree bole taken at breast height. This is a good measure of stand density since it includes the area in addition to the number of trees. The quadratic mean diameter is the diameter corresponding to the arithmetic mean tree basal area, and is the standard used to express the average tree diameter in a forest stand or survey (Husch et al. 1982).

For each species sampled, average total age and 10 year growth were determined.

To quantify aspects of forest health, the percentage of live and dead trees was determined for each species based on trees per acre and basal area per acre. For each plot, the percentage of trees affected by bark beetles, dwarf mistletoe, fire, and other damaging agents was calculated based on basal area per acre and trees per acre.

Dwarf mistletoe ratings were used to quantify the amount of dwarf mistletoe on live trees. The amount of dwarf mistletoe present in an area can be quantified in three ways: mean dwarf mistletoe intensity (DMI), mean DMR, and the percentage of host infected (incidence). Mean DMI is defined as the average DMR of only the infected trees (Hawksworth et al. 1995). Mean DMR is defined as the average rating for all host trees including both infected and uninfected. Determining the DMI and DMR ratings can help quantify how much dwarf mistletoe is present in the forest. The DMI and DMR ratings were determined for each plot with dwarf mistletoe-infected host.

Survey plots with live host type were risk rated for mountain pine beetle and Douglas-fir beetle, using the risk rating systems developed by Forest Health Protection personnel mentioned previously. Each susceptible plot was determined to have a low, moderate, or high rating.

A list of disturbance agents found on each survey plot was compiled. Comments not entered in data analysis were also compiled for all survey transects. (This detailed information will be on file with Bryce Canyon National Park and Forest Health Protection, Ogden Field Office.)

Survey plots were scanned into a Geographic Information System (GIS). The GIS used was an ARC-INFO (Version 7.0.4) workstation. Summary information, based on percentage of basal area affected, was compiled into one EXCEL worksheet and converted to a table for use with ARCVIEW. Summary maps were produced using ARCVIEW Version 5.0. Copies of ARC-INFO files were provided to Bryce Canyon National Park personnel for their future use in their GIS.

Since there were over 100 insect and disease codes used during the survey, it was necessary to group them into categories. The categories included bark beetles (mountain pine beetle in ponderosa pine, fir engraver beetle, Douglas-fir beetle, and other bark beetles), defoliation, other insects, dwarf mistletoes by host type, limb rust, root diseases, other diseases, and abiotic influences.

During the field collection phase of this survey, we concentrated efforts on surveying the Park; thus, conducted fewer plots on NFS lands. Statistical analysis comparing the Park to NFS lands was not conducted due to uneven sample sizes. Results for both the Park and NFS lands will be presented for general comparison.

Results

Vegetative Conditions

A total of 46 sample transects were surveyed; 35 transects were within the Park and 11 transects were outside the Park on NFS lands (Figure 1). Approximately 4000 trees were measured within a total of 697 survey plots; 539 plots and 3400 trees were within the Park and 178 plots and 600 trees were measured on NFS lands. In the Park, there were 27 plots which were treeless, while 28 plots on NFS lands were treeless.

Species composition: Species composition based on percent of the total basal area within the Park was predominantly ponderosa pine (46%), white fir (28%), and Douglas-fir (20%), with occasional Rocky Mountain juniper, limber pine, quaking aspen, *Populus tremuloides* (Michx.), bristlecone pine, *Pinus longaeva* D.K. Bailey, Engelmann spruce, and lodgepole pine present (< 5% each). The species composition was similar on NFS lands with ponderosa pine (44%) and white fir (35%) being the dominant species (Table 1). Most of the ponderosa pine was located in the northern portion of the Park, with more mixed conifers surveyed in the southern portion. GIS maps displaying the species composition at each survey plot are on file with Bryce Canyon National Park and Forest Health Protection, Ogden Field Office.

Forest type density: Considering only plots with trees, the basal area per acre ranged from 10 to 340 square feet within the Park and 10 to 280 square feet on NFS lands (Table 2). The average basal area per acre in the Park was 91 square feet and 64.5 square feet on NFS lands. Considering the average number of trees per acre, a similar trend was found with 138.6 trees per acre within the Park and 111.0 on NFS lands (Table 2). The average quadratic mean diameter was 13.73" in the Park and 12.26" on NFS lands (Table 2).

The average age was higher for trees sampled in the Park compared to those sampled on NFS lands (Table 3). The average age for ponderosa pine samples was 120 years old in the Park compared to 97 years old for NFS samples. The ten-year growth was higher on NFS lands with an average of 10/20ths versus 7/20ths on the Park sample.

The percentage of dead basal area per acre for all species was higher in the Park at 7.1 percent compared to 3.5 percent on NFS lands (Table 4). The predominant species found dead on survey plots in the Park was juniper (15.5%) and Douglas-fir (10.5%) on NFS lands.

Most of the juniper mortality appeared to have been caused by fire or bark beetles. Douglas-fir mortality recorded in the Park was frequently caused by Douglas-fir beetles. On NFS lands, the cause of Douglas-fir mortality was usually unknown.

Forest Health Conditions

Numerous insects, diseases and other agents of disturbance (fire, abiotic damages, etc.) were found during the survey (Table 5). Based on the percentage of basal area per acre, the most prevalent disturbance agents found inside the Park were Douglas-fir dwarf mistletoe, fire, abiotic damages, and western spruce budworm in that order of occurrence (Table 5). On NFS lands impacts from Douglas-fir dwarf mistletoe, abiotic damages, western spruce budworm, and limber pine dwarf mistletoe were most common. Disturbance agents found on each survey plot were summarized and an itemized list is on file with Bryce Canyon National Park and Forest Health Protection, Ogden Field Office.

Bark Beetles: Bark beetles have the potential to kill trees over wide areas and they were the main group of insects considered. There were several types of bark beetles found to be affecting trees. Some of the bark beetles currently infesting trees were: mountain pine beetle, Douglas-fir beetle, fir engraver beetle, red turpentine beetle, western pine beetle, and pine engraver beetles (Table 5). Evidence of red turpentine beetle, western pine beetle, pine engraver beetle and unknown beetle mortality were grouped as other bark beetles in conifer species in Table 5. The number of trees per acre and basal area per acre infested by all bark beetles was typically low (less than 5 percent). Roundheaded wood borers and flatheaded wood borers (Family Cerambycidae and Buprestidae) were recorded on numerous dead or dying trees, as they help with the decomposition and decay process. During the data analysis, it became evident that damage from borers was not recorded consistently among field crews, so the percentage of host affected by borers was not determined.

Most of the mountain pine beetle activity was found in the northern area of the Park associated with the ponderosa pine (Figure 2). As the species composition changed, other bark beetles were also detected. No more than 50 - 55 percent of the trees was affected by any bark beetle in any survey plot. In the southern portion of the survey, more mixed conifer forest types were present and consequently, evidence of fir engraver beetle and Douglas-fir beetle increased (Figure 3). At the time of this survey, there were no bark beetle outbreaks detected.

Other Insects: Western spruce budworm activity was primarily detected in the mixed conifer transects south of Natural Bridge. Both white fir and Douglas-fir had light defoliation. The percentage of host affected was slightly higher on NFS lands (Table 5). Several other insects were found including: Cooley spruce gall adelgid, *Adelges cooleyi* (Gill.), shoot damaging

insects, stem borers, and sucking insects. These insects were grouped into the other insect category in Table 5. The percentage of host affected by these insects was less than 1 percent in both the Park and on NFS lands.

Dwarf mistletoes: The most predominant disease in our survey was dwarf mistletoe on Douglas-fir, with minor amounts found on ponderosa pine, white fir and limber pine (Table 5). Douglas-fir dwarf mistletoe was present on over 49 percent of the Douglas-fir in the Park (Table 5). The intensity of the Douglas-fir dwarf mistletoe was high in the plots where Douglas-fir was present with a DMI value of close to 4 in both the Park and on NFS lands (Table 7). It is helpful to note that the sample size from the NFS lands is small (18 trees) compared to the Park (130 trees). The Douglas-fir DMR values were also high (Table 7). An average stand DMR over 1.0 indicates heavy levels of dwarf mistletoe (Guyon, personal communication). Southwestern dwarf mistletoe was only present on 1.6 percent of the ponderosa pine and not considered to be a serious impact in this survey.

Light dwarf mistletoe infection was defined as less than 33 percent, medium for 34 - 65 percent, and high for over 65 percent (Guyon, personal communication). Much of the Douglas-fir dwarf mistletoe was at medium or high infection levels (Figures 4 & 5). For dwarf mistletoe in ponderosa pine, white fir, and limber pine less than 5 percent of the hosts was affected (Table 5).

Other Diseases: Four other categories of diseases were detected in this survey and all were at low levels. Limb rust in ponderosa pine was the most prevalent both in the Park and on NFS lands (but less than 2 percent) followed by canker and stem diseases, root diseases, and foliage diseases (Table 5). Diseases included in the category of canker and stem diseases are Indian paint fungus, *Echinodontium tinctorium* (E. & E.), Cytospora canker, stem canker, and heart rot/stem disease damage codes. Root disease category included *Annosus* root disease, *Phaeolus (Polyporus) schweinitzii* (Fr.) Pat., *Armillaria* root disease and a generic "root disease" damage code, where a specific agent could not be identified (Table 4). Since the percentage of host affected by these agents was so low, a spatial map was not included in this report, but is on file with Bryce Canyon National Park and Forest Health Protection, Ogden Field Office.

Abiotic Factors: Several categories of non-living disturbance agents were detected. Fire affected 16 percent of the trees in the Park and can be attributed to the prescribed fires conducted around the Visitor Center and Employee Housing Area in the northern portion of the Park since 1991. Weather damage (such as frost cracks, frost damage on needle tips, and evidence of lightning strikes), dead tops, multiple or forked tops, and mechanical damage were grouped as a category of abiotic damages. Approximately 10 percent of the trees in the Park and 8.7 percent of NFS lands were affected by these various influences. Animal damage

codes included evidence of porcupine feeding or sapsucker holes on tree boles. The other damages category included influences of suppression and a generic "other damaging agents" damage code.

Risk Ratings for Bark Beetles: For mountain pine beetle in ponderosa pine within the susceptible host plots in the Park, 89.4 percent are of moderate risk (Table 8). This compares to approximately 94.6 percent of moderate risk on NFS lands. For Douglas-fir beetle in the Park, 2.3 percent of the susceptible plots were low risk, 57.7 percent moderate risk and 40 percent high risk to future Douglas-fir beetle activity (Table 8). Of the plots sampled on NFS lands, 27.8 percent of the susceptible plots were low risk, 50 percent moderate risk, and 22.2 percent high risk (Table 8). (Detailed summaries of individual risk rating system results for each survey plot will be on file with Bryce Canyon National Park and Forest Health Protection, Ogden, Field Office.)

Discussion

Forest Characteristics

Comparing the basal area per acre found on survey plots in the Park to those from NFS lands, plots on NFS lands were less dense. This could be attributed to the logging and other management practices conducted on NFS lands. The lower densities on NFS lands may have in turn allowed for the higher growth rates sampled. It is very common for tree growth to reduce or slow down as their forest stand growing conditions become more dense causing more competition for available water and nutrients (Daniel et al. 1979).

Forest Health Condition Issues

The two main groups of disturbance agents which have the potential to significantly influence the long-term forest health of Bryce Canyon National Park are bark beetles and dwarf mistletoes.

Implications of Bark Beetles: Although very few bark beetles were found in this survey, the risk rating results indicated the potential for future outbreaks of mountain pine beetle in ponderosa pine and Douglas-fir beetle in Douglas-fir is present. Areas of high or moderate risk should have a higher priority for vegetation management, depending on management objectives of the areas.

Results from risk rating systems should be combined with knowledge of conditions of the local area. Bark beetle populations on neighboring lands can increase the risk of an area to future bark beetle outbreaks. In addition, as the stand conditions for each host type change over time (becoming older with larger trees and often more dense), the risk of future bark beetle outbreaks will increase. Vegetation management of high risk stands (such as thinnings or reducing basal areas) could also reduce the risk to future bark beetle outbreaks.

Dwarf Mistletoe Implications: Douglas-fir dwarf mistletoe will increase mortality and reduce the longevity of the Douglas-fir type within the survey area. Mathiasen and others (1990) found that Douglas-fir mortality was three to four times higher in forest stands of severely infested Douglas-fir dwarf mistletoe. Severely infected Douglas-fir dwarf mistletoe trees were those with individual tree DMR values of greater than four (Mathiasen et al. 1990).

If the Douglas-fir component is infected with Douglas-fir dwarf mistletoe and the management objective is to maintain that vegetative type, an effort to reduce the level of Douglas-fir dwarf mistletoe would be beneficial.

Some of the management tools for the reduction of dwarf mistletoes include the following:

1) Use silviculture treatments to harvest the infected stand. Areas which are harvested should have minimal edges, since any residuals still infected with dwarf mistletoe could spread seeds to susceptible hosts regenerating within 33 feet.
2) Remove infected trees and improve tree growth by thinning.
3) Change stand composition to non-susceptible hosts.
4) Remove infected residuals from logged or burned stands.

(Guyon and DeBlander 1991).

Implications of Insects and Diseases with Respect to Fire Management

Prescribed fire may help to manage vegetation to reduce tree densities and reduce the susceptibility of areas to bark beetle attacks. Fire management specialists can provide the expertise to meet specific management objectives.

Influences of scorched trees: Since the effects of fire vary, it is important to consider its potential influences on the residual trees. When trees are stressed (whether it be by fire scorching, lack of moisture or other factors), bark beetles often attack. The interaction

between fire-scorched trees and bark beetle attack has been examined in several studies. After the Yellowstone fires of 1988, Amman and Ryan (1991) found that trees with more than 50 percent of basal girdling by fire were infested by bark beetles within two years following the fire. The main species examined in this study were Douglas-fir, lodgepole pine, Engelmann spruce and subalpine fir. A study conducted in northern Utah also found Douglas-fir bark beetles attacking large diameter Douglas-fir with 60-80 percent of the tree bole scorched by fire the previous year and 60-80 percent of the crown scorched by fire (Cunningham 1997).

In addition to scorched tree bole impacts, Furniss (1965) noted the incidence of bark beetle attack increasing with tree size and the degree of crown scorch due to fire. If trees were completely scorched or defoliated by the fire studied in southern Idaho, the trees often died from the fire and not bark beetle attack (Furniss 1965). Weatherby and others (1994) found that Douglas-fir trees with over 48 percent crown scorch had a higher chance of being attacked by Douglas-fir beetle (Weatherby, personal communication). These studies suggest that minimizing fire scorch on susceptible trees would in turn reduce the risk of bark beetle attacks following a fire.

Dwarf mistletoe and fire interactions: Fires, whether wild or prescribed, can either inhibit or encourage dwarf mistletoes depending primarily on the intensity and size of the fire (Alexander & Hawksworth 1975). Jones (1974) found that relatively complete burns could aid in sanitizing the stand from dwarf mistletoe, since trees would regenerate faster than the spread of dwarf mistletoe from surrounding dwarf mistletoe-infected trees. A recent study in New Mexico has been examining the effects of prescribed fire on dwarf mistletoe-infected ponderosa pine (Conklin, personal communication). In an area that had burned, crown scorch appeared to have killed at least 80 percent of the mistletoe plants on over one-third of the residual live trees. The fire also sanitized approximately 20 percent of the residual live trees. However, a partial burn which leaves scattered dwarf mistletoe-infected trees, allows the dwarf mistletoe to spread to the new regeneration, if it is susceptible to the dwarf mistletoe (Kimmey & Mielke 1959, Graham 1960, Hawksworth 1969, Muir 1970).

Some of the symptoms caused by dwarf mistletoes such as witches' brooms, spike (or dead) tops, and tree mortality, tend to increase the rate of fire spread, intensity, and flammability in dwarf mistletoe-infested stands (Roth 1966, Jones 1974). This is especially common in Douglas-fir dwarf mistletoe, since the branches with brooms produce approximately twice as many twigs as healthy branches (Tinnin and Knutson 1980). The large dense witches brooms caused by Douglas-fir dwarf mistletoe may also break off during snowstorms and increase the likelihood of "torch outs" during surface fires under Douglas-fir trees (Weir 1916). Since Douglas-fir dwarf mistletoe witches' brooms can be 2 to 3 feet in diameter, they easily carry flames. Flaming witches' brooms can cause spot fires as they catch on fire and fall to the ground or are carried in the convection column of fires (Alexander & Hawksworth 1975).

Studies conducted in the southwestern ponderosa pine type suggest that fire exclusion in the past in some areas has resulted in two storied stands (Alexander & Hawksworth 1975). This in turn results in faster spread of dwarf mistletoe, since dwarf mistletoe seeds can easily fall on younger, smaller trees growing under the overstory. Roth (1966) suggested that the frequent underburns in the ponderosa pine type may have burned any dwarf mistletoe resistant regeneration developing under the mature trees.

Summary/Conclusions

As a baseline for forest health conditions of Bryce Canyon, the results from this survey should help provide information to be used in future management decisions. As a general comparison of insect and disease activity levels, it does not appear that the conditions in Bryce Canyon National Park are much different than the NFS lands adjacent to the Park.

The potential of future bark beetle outbreaks and the continued spread of dwarf mistletoes, especially Douglas-fir dwarf mistletoe are the two forest health issues which should be addressed in developing future vegetation management and prescribed burn plans for Bryce Canyon National Park. The documentation of the spatial distribution of these major insect and disease conditions found in this survey should aid in future planning. Forest Health Protection personnel can offer site-specific input as specific prescribed burn plans are developed.

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Tables and Figures

Table 1. Species composition based on the percentage of total basal area (BA) and trees per acre (TPA).

	Bryce Canyon National Park		Dixie National Forest	
Species	**% BA**	**% TPA**	**% BA**	**% TPA**
Ponderosa pine	46.05	41.09	43.73	44.37
White fir	28.76	33.05	35.15	35.44
Douglas-fir	20.27	16.85	11.67	11.10
Juniper	2.38	4.40	1.74	4.19
Limber pine	1.58	2.82	3.48	3.28
Aspen	0.45	1.16	0.87	1.54
Lodgepole pine	0.25	0.45	0.87	1.54
Engelmann spruce	0.16	0.03	0.17	0.05
Bristlecone pine	0.10	0.15	0.17	0.03

Table 2. Comparison of stand characteristics for Bryce Canyon National Park and Dixie National Forest. Plots without trees were excluded.

Stand Characteristic	Bryce Canyon Natl Park	Dixie National Forest
Minimum basal area per acre	10.00	10.00
Maximum basal area per acre	340.00	280.00
Average basal area per acre	91.03	64.49
Minimum trees per acre	1.41	3.82
Maximum trees per acre	975.77	449.15
Average trees per acre	138.58	110.98
Number of plots surveyed	536	178
Number of plots with trees	509	150
Minimum quadratic mean diameter (Dq)	5.53	5.00
Maximum quadratic mean diameter (Dq)	37.00	34.00
Average quadratic mean diameter (Dq)	13.73	12.26

Table 3. Comparison of average ages and ten year growth measured for each species in Bryce Canyon National Park and Dixie National Forest.

Species	Bryce Canyon National Park				Dixie National Forest		
Total age (in years)	**n**	**Mini-mum**	**Maxi-mum**	**Aver-age**	**Mini-mum**	**Maxi-mum**	**Aver-age**
Ponderosa pine	192	7	247	120	48	143	97
White fir	63	8	206	128	99	117	110
Douglas-fir	64	7	155	120	53	146	93
Juniper	5	102	235	163	*	*	80
Limber pine	7	*	*	85	*	*	90
Engelmann spruce	1				*	*	150
10-year growth[1]	**n**	**Mini-mum**	**Maxi-mum**	**Aver-age**	**Mini-mum**	**Maxi-mum**	**Aver-age**
Ponderosa pine	74	3	14	7	5	13	10
White fir	37	2	9	6	4	11	7
Douglas-fir	8	4	10	7	9	21	13
Juniper	2	3	6	5	*	*	5
Limber pine	1				*	*	10
Engelmann spruce	1				*	*	11

n= Number of trees sampled. * Only one sample taken.

The following species were not sampled: aspen, lodgepole pine, and bristlecone pine.

[1]Measured in 20ths of an inch.

Table 4. Species mortality based on percent of basal area per acre for Bryce Canyon National Park and Dixie National Forest.

Species Mortality	Bryce Canyon Natl. Park	Dixie National Forest
Juniper	15.52	0.00
Douglas-fir	11.12	10.45
Ponderosa pine	7.03	1.99
White fir	4.13	3.65
Limber pine	2.60	0.00
All species	7.09	3.48

Table 5. Percentage of affected host based on basal area per acre by insect and disease category and species mortality.

Category	Bryce Canyon Natl. Park	Dixie National Forest
Mountain pine beetle in ponderosa pine	1.65	0.02
Fir engraver beetle in white fir	2.71	3.65
Douglas-fir beetle in Douglas-fir	3.03	0.00
Other bark beetles in conifer species	0.60	1.05
Western spruce budworm	3.24	5.40
Other insects	0.66	0.17
Douglas-fir dwarf mistletoe	49.65	44.78
Southwestern dwarf mistletoe in ponderosa pine	1.65	0.80
White fir dwarf mistletoe	0.64	0.46
Limber pine dwarf mistletoe	2.60	5.00
Root Disease	0.76	0.00
Limb rust in ponderosa pine	1.96	1.20
Canker & Stem Diseases	1.11	0.87
Foliage Diseases	0.04	0.17
Fire Effected	16.19	3.30
Abiotic Damages (weather, dead tops, mechanical)	10.35	8.71
Other Damages	1.31	0.00
Unknown Mortality	1.25	1.57
Animal Damages	0.37	0.00

Table 6. Insect and disease damaging agents found in survey.

Bark Beetles:

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins

Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins

Fir engraver beetle, *Scolytus ventralis* LeConte

Pine engraver beetles, *Ips* spp.

Red turpentine beetle, *Dendroctonus valens* LeConte

Western pine beetle, *Dendroctonus brevicomis* LeConte

Unidentified bark beetle-caused mortality

Other Insects:

Western spruce budworm defoliation, *Choristoneura occidentalis* Freeman

Defoliation by leaftiers or ponderosa pine needle miner, *Coleotechnites Moreonella* (Heinrich)

Other insects - includes shoot damaging insects, sucking insects, and Cooley spruce gall adelgid, *Adelges cooleyi* (Gill.)

Dwarf Mistletoes:

Douglas-fir dwarf mistletoe, *Arceuthobium douglasii* Engelm.

Southwestern dwarf mistletoe on ponderosa pine, *Arceuthobium vaginatum* subsp. *cryptopodum* Hawks. & Wiens

Limber pine dwarf mistletoe, *Arceuthobium cyanocarpum* Coulter & A. Nels.

White fir dwarf mistletoe, *Arceuthobium abietinum* f. sp. *coloris* Hawks. & Wiens

Other Diseases:

Limb rust, *Peridermium filamentosum* Pk.

Other rusts - includes western gall rust, *Endocronartium harknessii* (J. P. Moore) and fir broom rust, *Melampsorella caryophyllacearum* Schroet.

Canker and stem diseases - includes Indian paint fungus, *Echinodontium tinctorium* (E. & E.), Cytospora canker, stem canker, and heart rot/stem disease damage codes

Table 6 continued.

Root diseases - includes *Annosus* spp., *Phaeolus (Polyporus) schweinitzii* (Fr.) Pat, *Armillaria* spp., and generic "root disease" code, where a specific agent could not be identified

Foliage diseases

Abiotic Factors:

Fire-effected

Abiotic damages - includes weather influences (wind damage, winter damage, frost damage, lightning strikes), dead tops or multiple fork tops, and mechanical damage

Animal damage

Other damage - includes suppression effects and generic "other damage" code

Unknown mortality

Table 7. Comparison of dwarf mistletoe intensity (DMI) and dwarf mistletoe rating (DMR) values for Bryce Canyon National Park and Dixie National Forest survey plots with dwarf mistletoe.

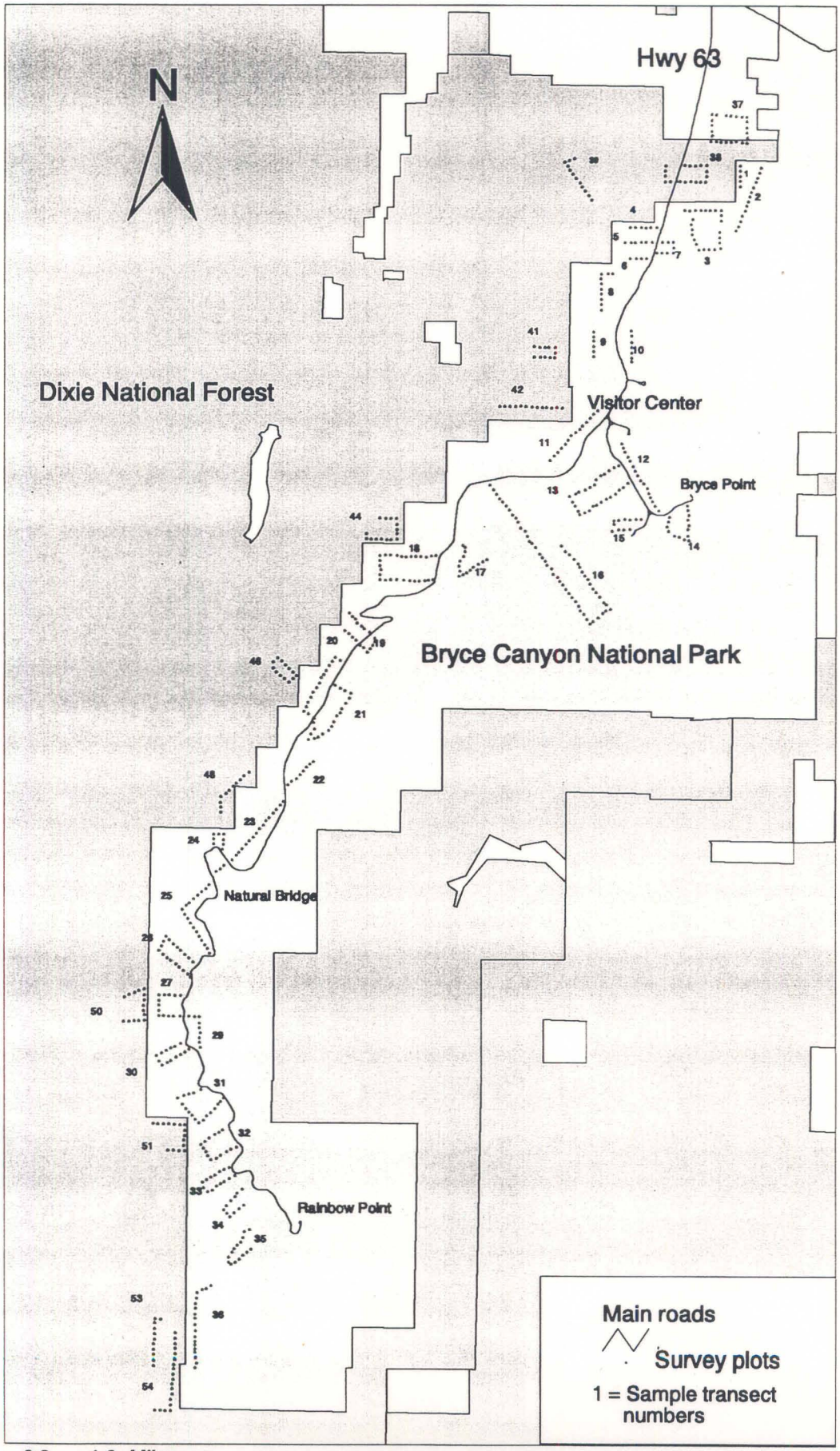
	Bryce Canyon National Park			Dixie National Forest		
Species	**DMI**	**DMR**	**n**	**DMI**	**DMR**	**n**
Douglas-fir	4.04	3.63	130	3.99	3.61	18
Ponderosa pine	2.84	2.28	16	4.50	3.00	2
White fir	4.20	1.19	5	0.00	0.00	0
Limber pine	1.00	0.50	1	4.00	4.00	1

DMI = Average dwarf mistletoe intensity, DMR = Average dwarf mistletoe rating
n = sample size

Table 8. Risk rating system results for mountain pine beetle in ponderosa pine and Douglas-fir beetle in Douglas-fir for Bryce Canyon National Park and Dixie National Forest susceptible survey plots.

	Bryce Canyon National Park		Dixie National Forest	
Risk ratings	Total number of susceptible survey plots	Percent of susceptible survey plots	Total number of susceptible survey plots	Percent of susceptible survey plots
Mountain pine beetle in ponderosa pine				
Low	32	7.5	5	4.5
Moderate	379	89.4	105	94.6
High	13	3.1	1	0.9
Total plots	424		111	
Douglas-fir beetle in Douglas-fir				
Low	5	2.3	10	27.8
Moderate	127	57.7	18	50
High	88	40	8	22.2
Total plots	220		36	

Figure 1. Bryce Canyon National Park forest health survey plots conducted August 1995.



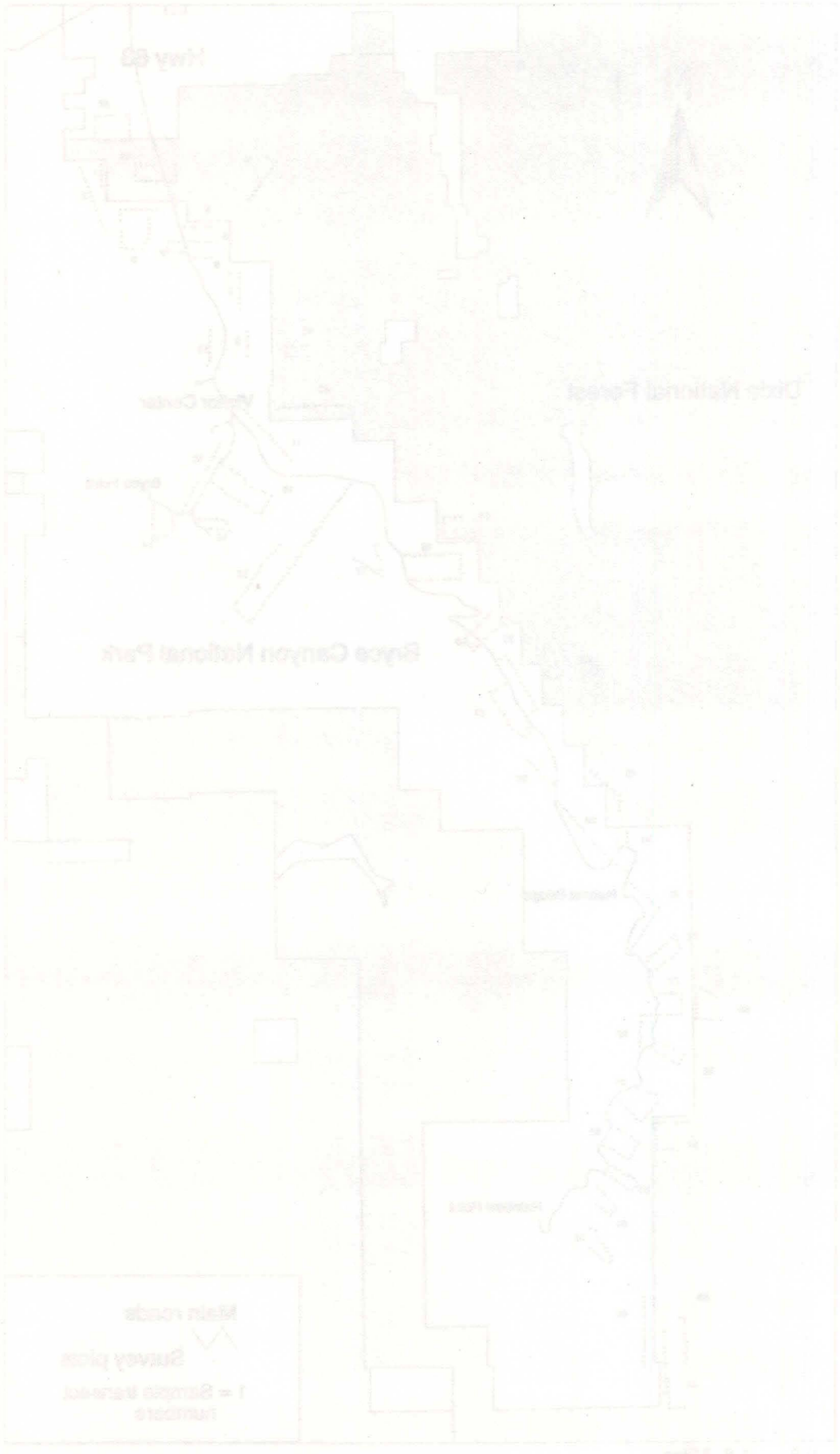
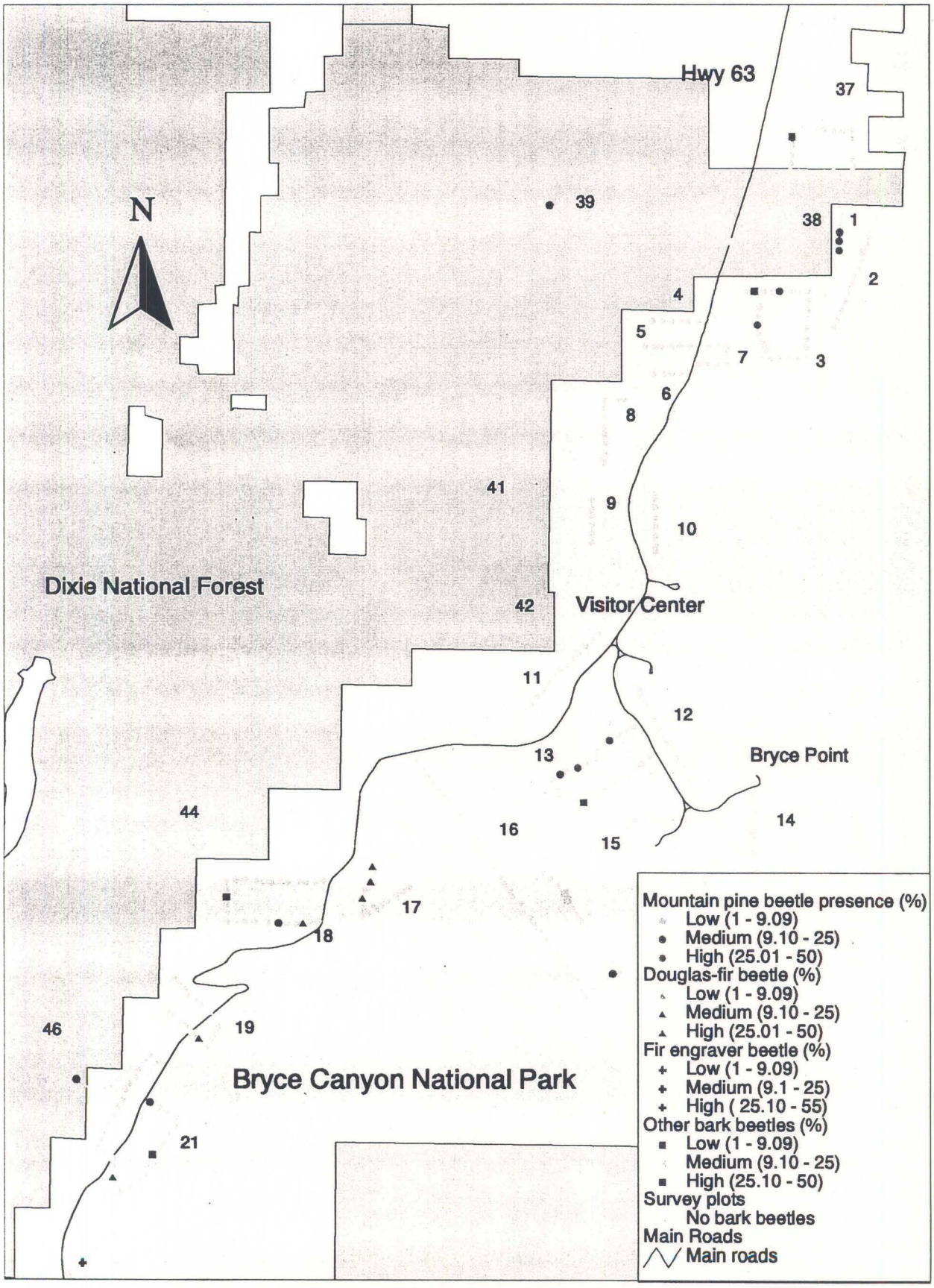


Figure 2. Percentage of host affected by bark beetles per plot in the northern survey portion.



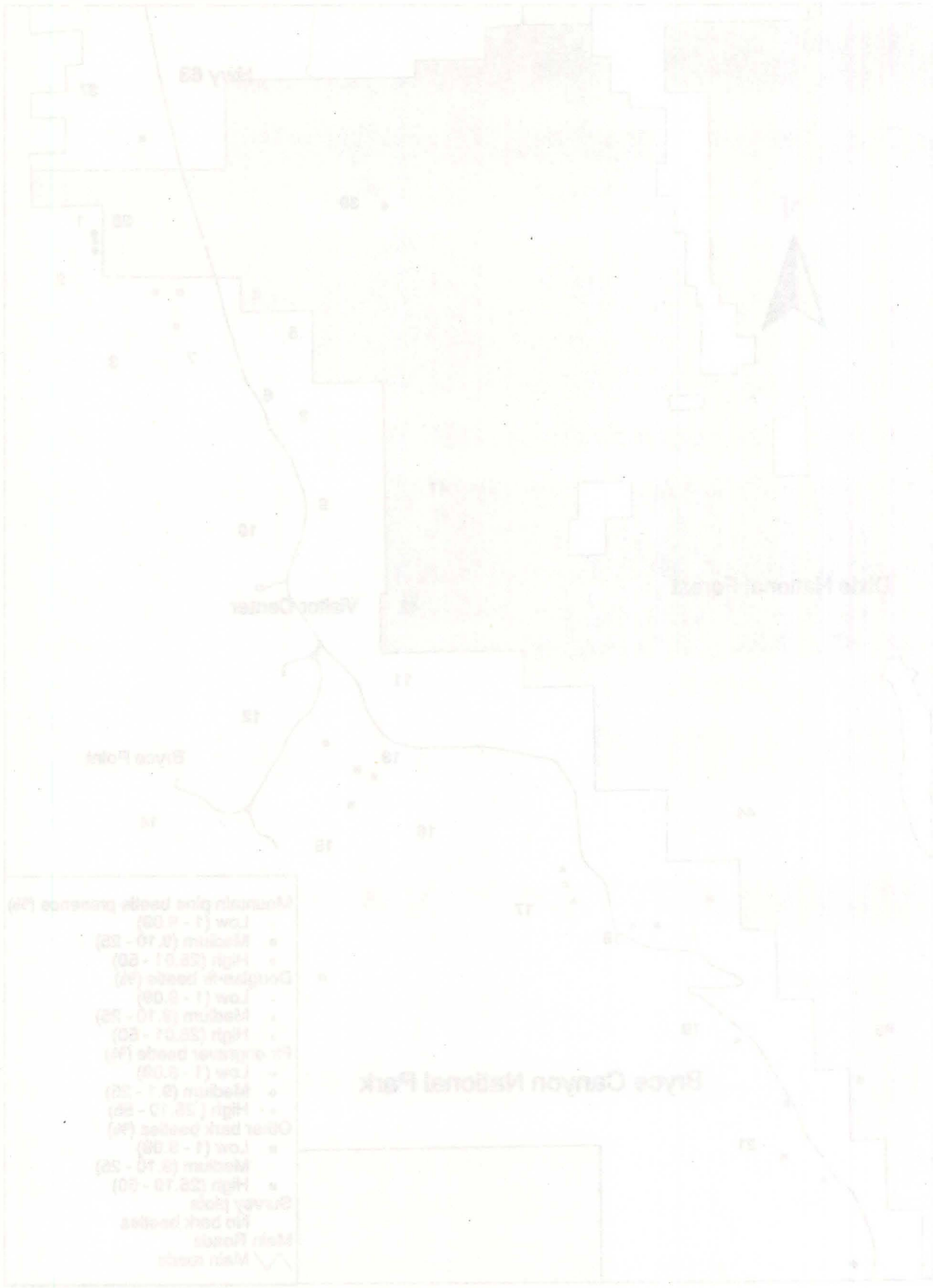
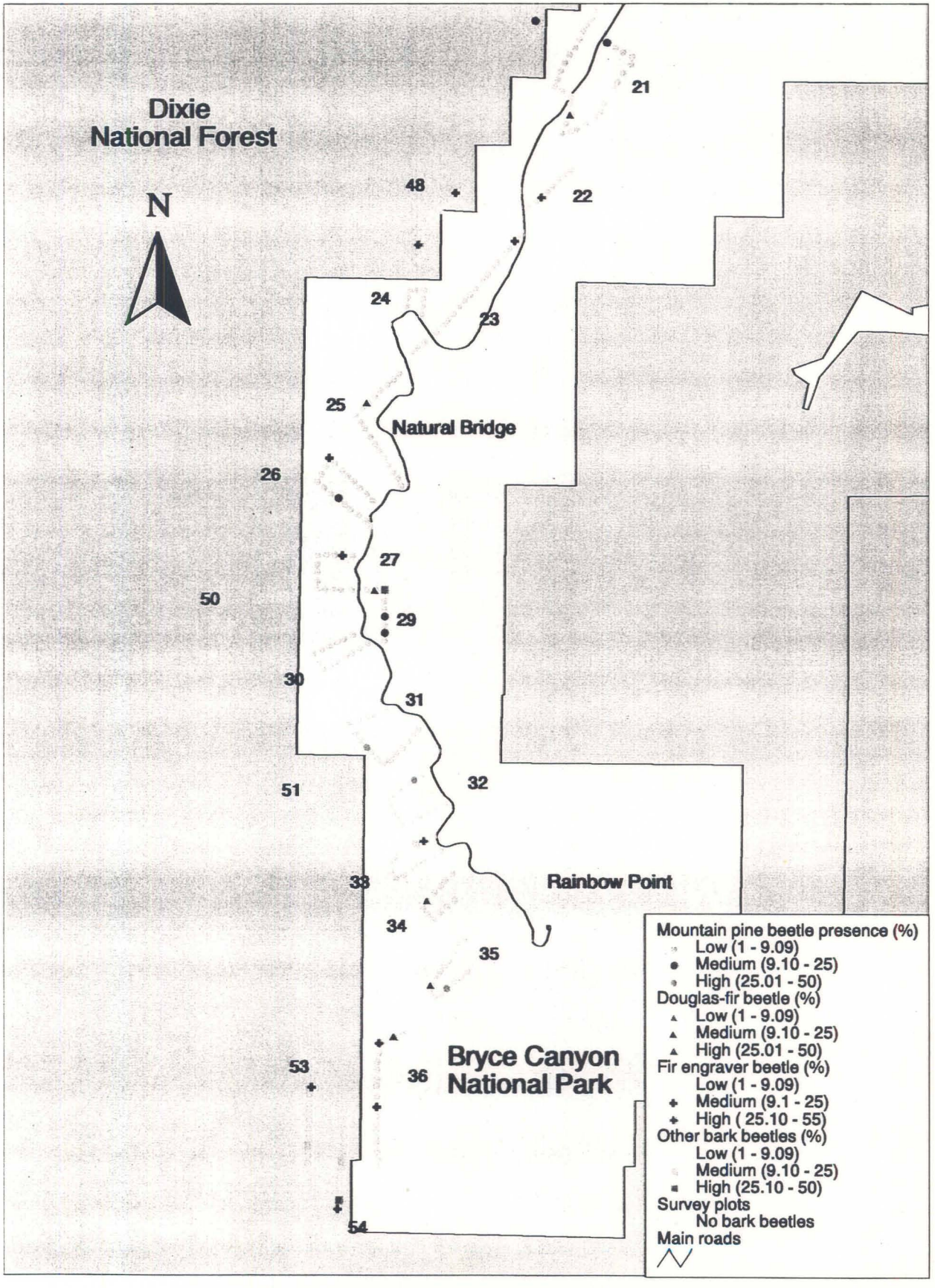


Figure 3. Percentage of host affected by bark beetles per plot in the southern survey portion.



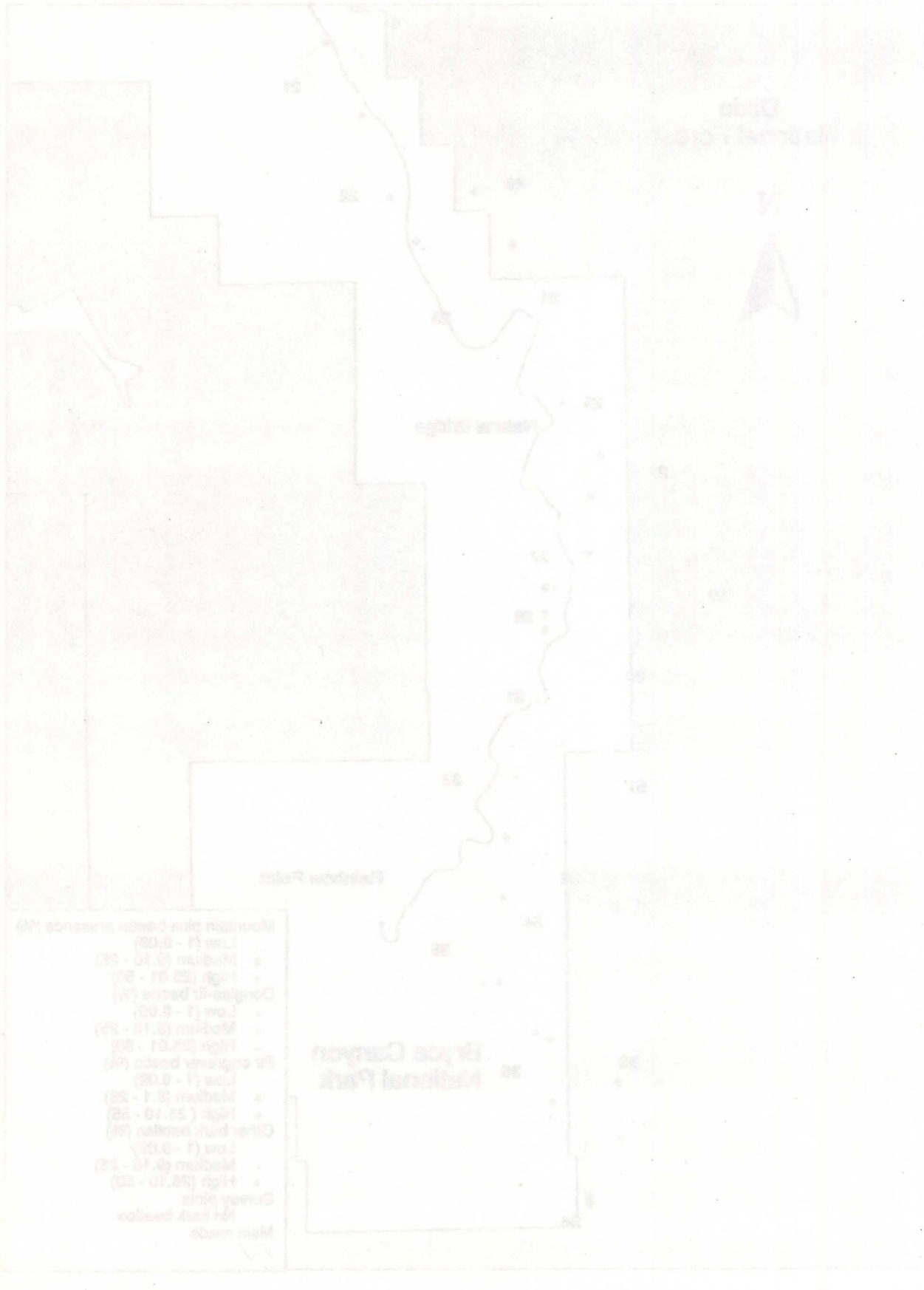
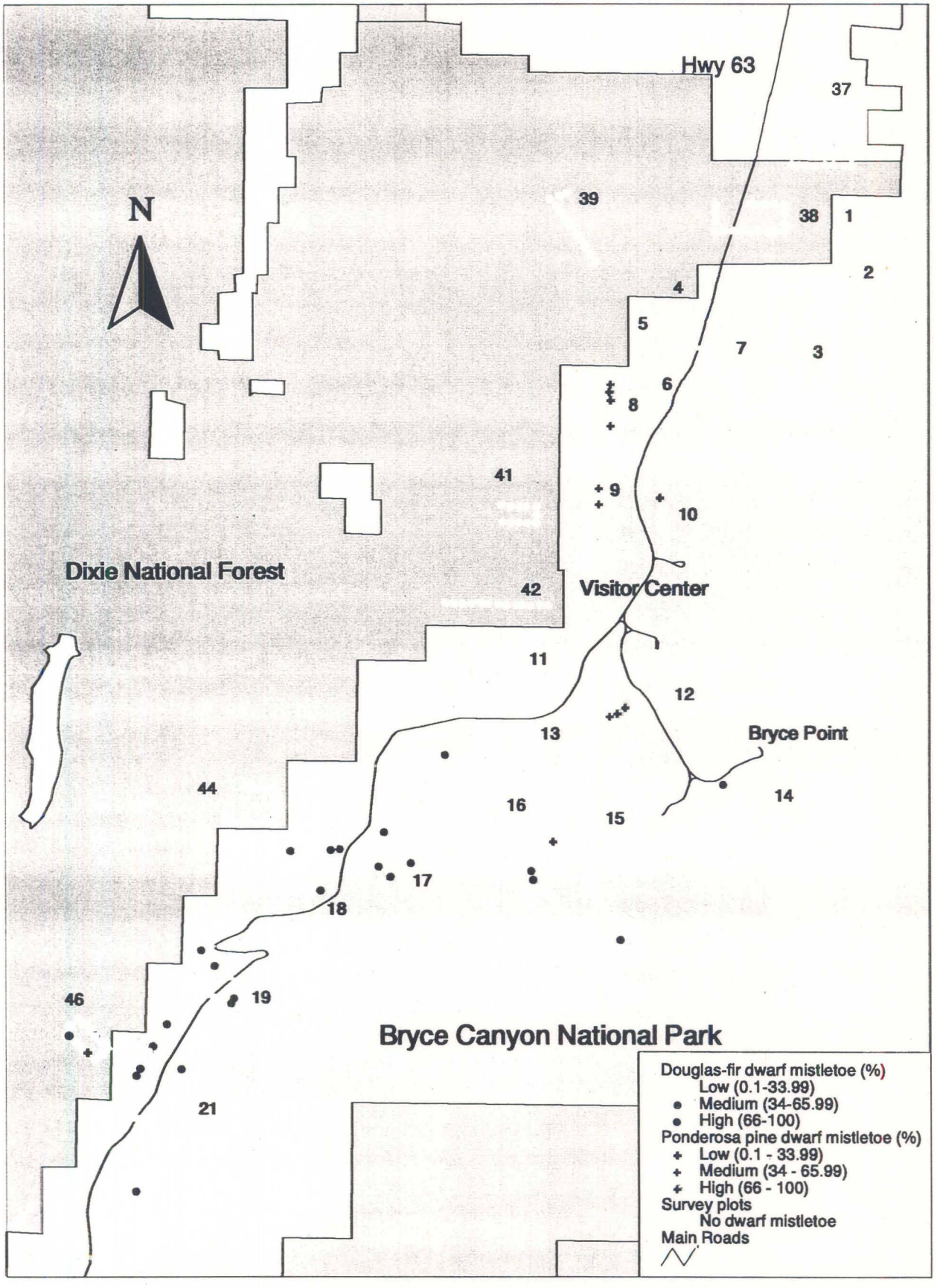


Figure 4. Percentage of host affected by dwarf mistletoes per plot in the northern survey portion.



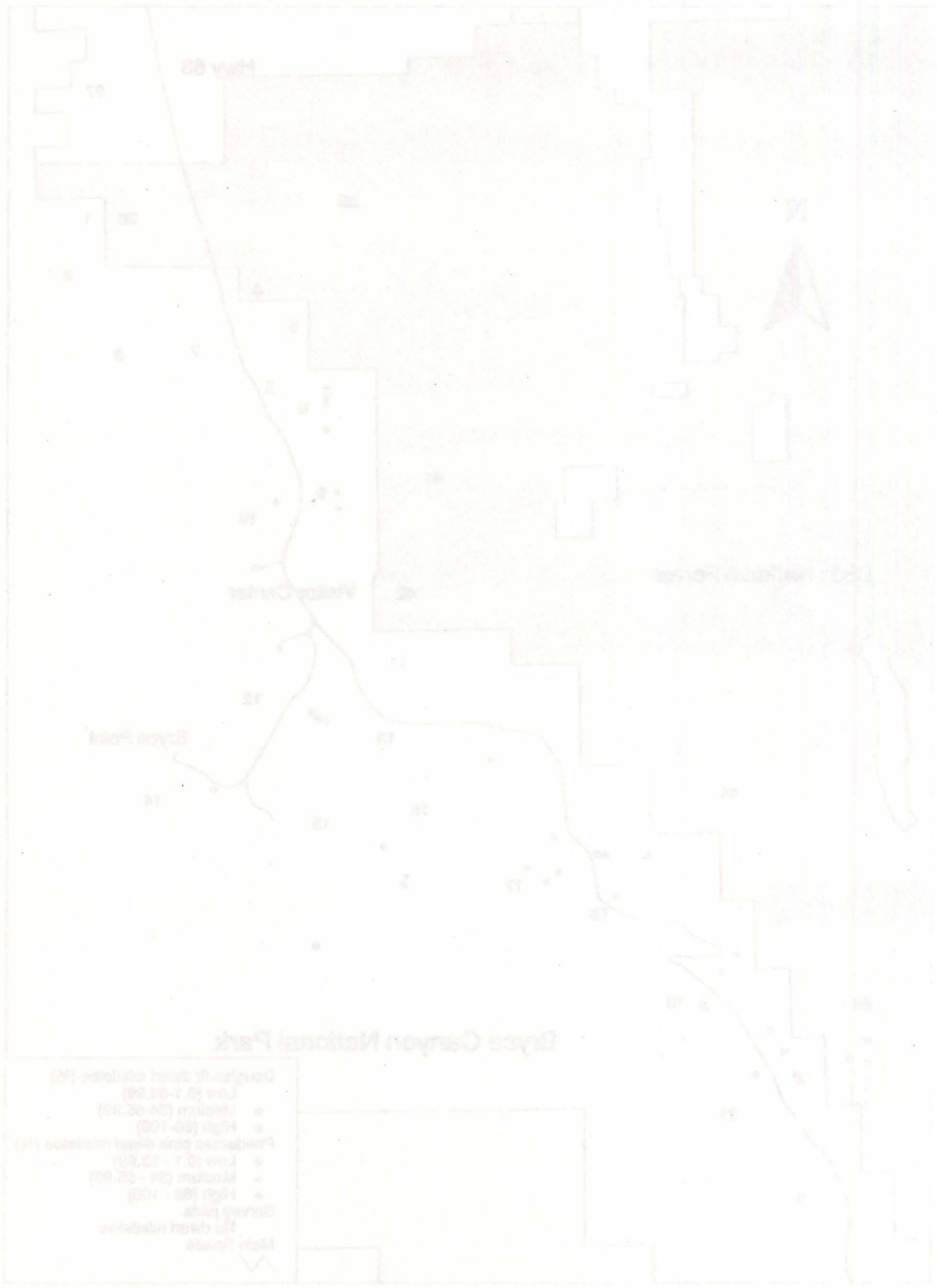
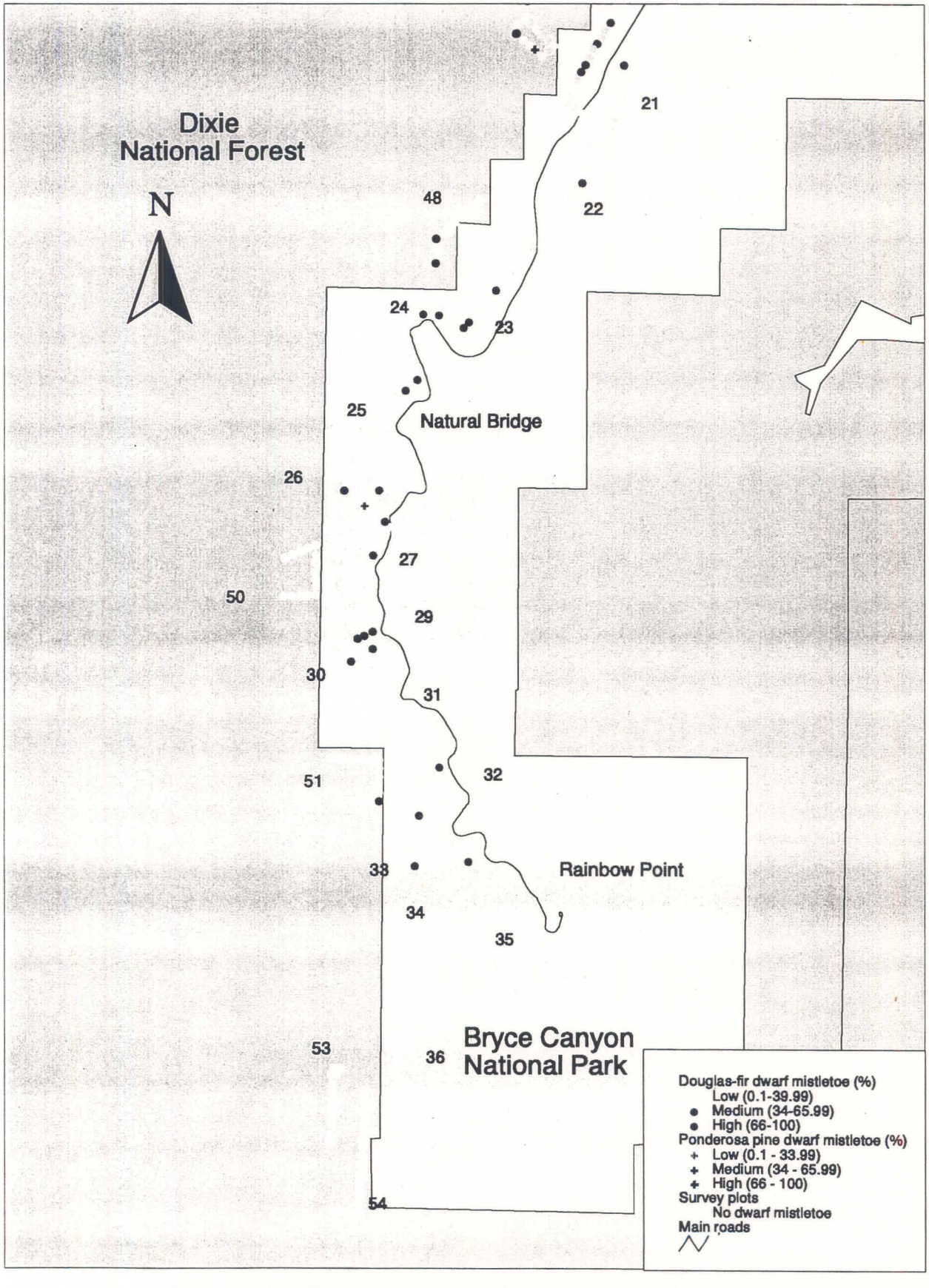
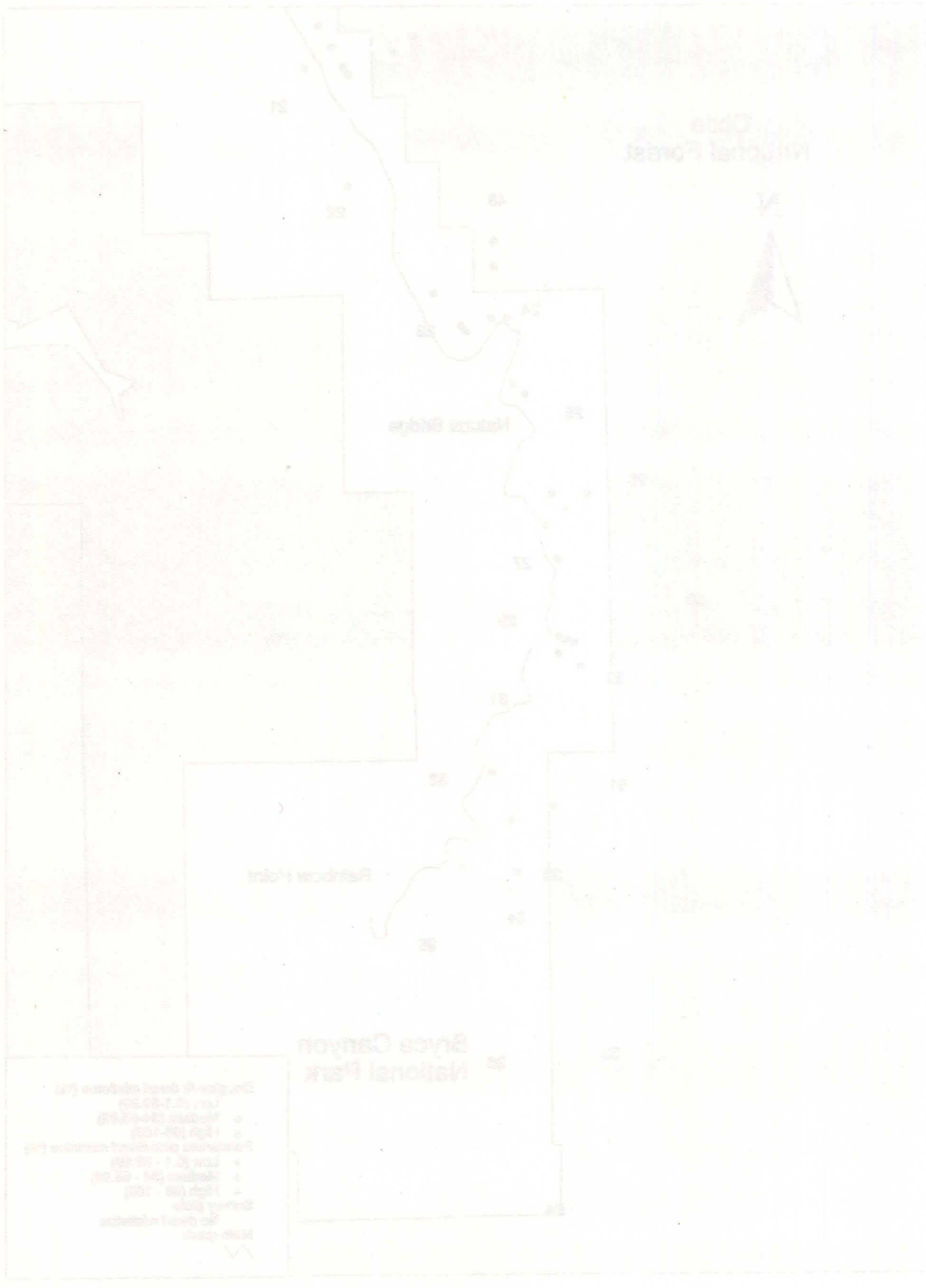


Figure 5. Percentage of host affected by dwarf mistletoes per plot in the southern survey portion.





Appendix

Historical Background of Insect and Disease Occurrences in Bryce Canyon National Park

1955: Fir needle miner, *Epinotia meritana* Heinrich, was active in white fir on 10,000 acres of Bryce Canyon Park and the Dixie National Forest.

1957: Approximately 10,000 acres of white fir were heavily defoliated by fir needle miner in Bryce Canyon Park and the Dixie National Forest. Four thousand acres were sprayed with an oil solution of malathion. The stand was in a weakened condition and susceptible to attack by fir engraver beetles.

1969: Mountain pine beetle infestation in ponderosa pine extended from Bryce Canyon National Park west into the East Fork of the Sevier River. There were approximately one-half dead trees per acre which approximated the 1968 level.

1970: Widely scattered ponderosa pine mortality, caused by the mountain pine beetle, continued in Bryce Canyon National Park and the Dixie National Forest.

Excerpt from August 12, 1970 report:

"Biologically, the mountain pine beetle situation in the East Fork of the Sevier River drainage is shared by both the Forest and Bryce Canyon National Park. As previously reported, individual and scattered patches of ponderosa pine die annually due to beetle attacks. A 1969 October survey showed an attack density of approximately one-half tree per acre, which approximates the 1968 infestation level."

1971: Scattered ponderosa pine mortality, caused by the mountain pine beetle, continued on the Forest and in Bryce Canyon National Park.

Excerpt from December 1971 report:

"The present mountain pine beetle, *Dendroctonus ponderosae* Hopkins, outbreak in Bryce Canyon National Park and the East Fork of the Sevier River, Dixie National Forest, Utah began in 1966. Annual aerial survey records show that the infestation increased from 1967 through 1969, especially on and around the Whiteman Bench area. In 1970, the outbreak decreased in intensity, but widely scattered mortality was detected over a larger area. The infestation decreased in extent and intensity in 1971. A decreasing trend is expected again

in 1972."

1972: The mountain pine beetle infestation adjacent to Bryce Canyon National Park continued to decline; however, scattered tree killing was detected throughout the ponderosa pine type in the Park and in the East Fork of the Sevier River on the Dixie National Forest.

1973: The persistent mountain pine beetle infestation in Bryce Canyon National Park on the Forest declined as expected.

1975: The serious mountain pine beetle outbreak on ponderosa pine in Bryce Canyon National Park, and the East Fork of the Sevier continued to decline.

1976: Light to heavy defoliation, by white fir needle miner, of white fir occurred over approximately 3,400 acres in several locations adjacent to Bryce Canyon National Park along the East Fork of the Sevier River.

No further mention of insect and disease activity in Bryce Canyon National Park in reports after 1976.

Biology of Various Insects and Diseases

Mountain pine beetle

Mountain pine beetle attacks and kills many species of pine; predominantly lodgepole, ponderosa, sugar, *Pinus lambertiana,* and western white pine, *Pinus monticola.* The lower 15 feet of the tree trunk is attacked in mid-summer by adult beetles (Amman et al. 1989). Trees can be mass attacked by numerous beetles and die within one year.

The female beetles attack the tree first. After they have successfully bored into the inner bark, they emit a chemical messenger, or pheromone, to attract males for mating and more females to aid in the mass attack. After mating occurs, eggs are laid in niches along the sides of a main gallery the female chews. Eggs hatch in 10 to 14 days. Larvae develop and feed on the inner bark, creating galleries and disrupting the flow of water and nutrients to the tree. Larvae overwinter and complete their development the next spring and summer. Mature larvae will excavate an area to pupate in at the end of their galleries. By July, the pupae develop into adult beetles which emerge and attack new trees.

Evidence of mountain pine beetle attack includes the presence of pitch tubes and boring dust. Pitch tubes are the tree's defense response to the beetle boring into the tree. When low numbers of beetles attack a tree, the tree can often produce enough resin to "pitch out" the beetles as they bore into the tree and the tree is not killed (Amman et al. 1989).

Douglas-fir beetle

Douglas-fir beetles overwinter as mature larvae and adults under the bark. Overwintering adults generally emerge and attack trees from April to June. The mature beetles will emerge and fly to attack new trees as soon as maximum air temperatures reach 65° to 70° F for several days in a row (McMullen and Atkins 1962). Overwintering larvae feed in the spring, pupate and emerge as adults in July and August. Douglas-fir beetles are strong flyers and have been observed to fly from 15 to 30 miles (in a laboratory setting) (Furniss et al. 1982, Lejeune et al. 1961). However, it is believed that Douglas-fir beetles will not fly farther than necessary to infest host material, typically less than one mile (Lejeune et al. 1961).

After adults bore into new host material, mating occurs and eggs are laid in a gallery which runs parallel to the wood grain. Galleries are packed with boring dust or frass as the female bores upward and lays eggs. Eggs hatch in 1 to 3 weeks. Larvae grow and develop through four stages, before pupating and emerging as adults, approximately 1 year after initial attack (Furniss and Orr 1978).

Initial evidence of Douglas-fir beetle infestation is pitch streamers or excessive sap oozing from the tree bole. When the beetles successfully infest the tree, tan- to brown colored boring dust is evident in the bark crevices. Woodpeckers will feed heavily on the larvae and commonly peck much of the bark off Douglas-fir infested trees. The year following attack, the trees will begin to discolor, turning from green to yellowish-green, then to red by the late summer.

Douglas-fir beetles often mass attack a tree in such high numbers, the tree will be killed. Occasionally, only a few beetles will attack a portion of the tree bole. This is called a strip attack. Healthy trees which are strip attacked can survive provided they are not attacked by additional beetles the following year.

Spruce beetle

Spruce beetle is a significant pest of mature spruce. It generally requires 2 years to complete their life cycle, but with different environmental conditions the life cycle can vary from 1 to 3 years. Adults have a primary flight period attacking hosts in May and June as the snow melts (Furniss and Carolin 1980). Occasionally some of the parent beetles can reemerge in the summer and lay more eggs. These late season eggs develop over the next 2 years and emerge in the late summer. Thus, a secondary flight period of adult beetles can occur anytime from May to October. Females bore through the outer bark into the phloem where they lay their eggs. Most of the eggs hatch by August. The larvae feed and overwinter and a year later most begin to pupate. During the second year of the life cycle before overwintering some beetles emerge and rebore into the tree base and overwinter. Two years after initial attack the beetles emerge and attack new trees.

The first sign of a current spruce beetle-infested tree is the reddish-brown boring dust or frass from entrance holes in bark crevices and around the base of the tree. There also may be masses of pitch at the entrance holes in bark crevices and around the base of the tree. Some trees may be attacked on one side of the bole creating a "strip attack". Trees strip attacked often survive. During the fall and winter following an attack, trees are usually debarked by woodpeckers feeding on larvae. Trees will begin to discolor during the second summer following attack, dropping most of their needles shortly after needle discoloration occurs.

Fir engraver beetle

Adult fir engraver beetles fly and attack trees mainly in July and August. If the first beetles are able to successfully bore into the tree without being pitched out, they emit an attractant luring other fir engraver beetles. After the adult beetles have bored under the bark of the tree, they mate and lay eggs along a horizontal gallery which they construct. This gallery is perpendicular to the grain of the wood, unlike most other bark beetles which construct egg

galleries parallel to the wood grain. These horizontal galleries are useful in identifying fir engraver (Ferrell 1991).

Approximately two weeks after the eggs are laid, larvae begin mining up and down the tree perpendicular to the horizontal gallery. The larvae continue to develop and overwinter as mature larvae. This feeding by the larvae on the inner bark and cambium layer disrupts the flow of water and nutrients in the tree, eventually causing tree death. After larvae overwinter, they begin feeding in the spring for a short period before constructing pupal chambers. The larvae pupate within these chambers developing into adult beetles within two weeks. Adult beetles, which are shiny black, 1/8th of an inch long, and have a characteristic "sawed off" rear end, emerge to attack new trees during the summer.

Branch flagging (or dead branches) is the first visible sign of fir engraver attack. The fir engraver habitually infest tops and scattered patches of cambium, causing branch and crown mortality from the top down. Mass attacks on a tree may cause top-kill or tree mortality within one summer. Often, streams of clear pitch flow from the entrance holes down the bole of the trees. After trees are killed by fir engraver, tree foliage turns yellow and then red over a three to six month period.

Dwarf mistletoe biology

Dwarf mistletoes are seed-bearing parasitic, dioecious plants that depend on their hosts almost completely for their water and nutrients. Dwarf mistletoes have narrow host ranges, usually infecting only a few species. Typically, they cause significant impacts on only one primary host.

Spread of dwarf mistletoe occurs in late summer to early fall when water pressure builds inside the mature fruits and seeds of the seed-bearing fruit are expelled 17 to 50 feet. The average horizontal distance of seed flight is between 17 and 30 feet. Infection of trees through the bark on needle-bearing shoots occurs within a few months after dispersal. Trees infected with dwarf mistletoe have swollen branches at the point of infection. Aerial shoots appear between 3 to 6 years after infection. As the dwarf mistletoe grows, it sends hormones into the host tree causing more growth in the infected area, resulting in excessive branching or witches brooms.

Spread of dwarf mistletoe in host stands is a function of stand age, density, and site index. Spread rates average 1 to 2 feet a year through a single-storied (even-aged) stand. Spread is most efficient and rapid from an infected overstory to an understory and slowest through even-aged stands (Hawksworth and Johnson 1989).

Site Risk Rating for
Mountain Pine Beetle in Ponderosa Pine

1) Determine the following stand conditions: stand basal area, average DBH for ponderosa pine, proportion of ponderosa pine (PP) in canopy, and number of currently infested trees per acre.

2) Using the following table and the above stand characteristics total the corresponding rating values enclosed in parentheses.

Stand Basal Area	Average DBH for PP	Proportion of PP in canopy	Number of Currently Infested TPA
< 80 (1)	<6" (1)	<50 (1)	<3 (1)
80-120 (2)	6-12 (2)	50-65 (2)	3-10 (2)
>120 (3)	>12 (3)	>65 (3)	>10 (3)

3) Using the totaled rating values to determine potential outbreak rating:

Total Rating Value	Potential Outbreak Rating
1 - 5	Low
6 - 9	Moderate
10 - 12	High

From Dymerski and Anhold 1995.

Risk Rating System for Douglas-fir Beetle

Stand Basal Area	Percent of live Douglas-fir > 9" DBH	Average Stand Age	Average DBH of Douglas-fir > 9"
> 250 (1.5)	> 50 (3.0)	> 120 (3.0)	> 14" (3.0)
120 - 250 (1.0)	25 - 50 (2.0)	80 - 120 (2.0)	10 - 14" (2.0)
< 120 (0.5)	<25 (1.0)	< 80 (1.0)	< 10" (1.0)

For each stand, the above factors are evaluated and numbers in parentheses are summed to determine overall risk rating.

Low risk = 0 - 4, Moderate risk = 5 - 7, High risk = 8 - 11

From Steele et al. 1996, Weatherby and Thier 1993.