MCINTIRE-STENNIS #94 FINAL REPORT:

Black Bear Damage to Regenerating Conifers in Northwestern California

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ABSTRACT

Damage by black bear (*Ursus americanus*) to second-growth coniferous trees was examined on fourteen sites in coastal Humboldt County, CA. Four different coniferous species were damaged by bears; redwood (*Sequoia sempervirens*) was the species most often damaged. Redwood was damaged in significantly ($P < 0.05$) greater proportions than it was available on eight of 13 sites investigated. Bear damage ranged from 4.2 ± 2.2 to 72.5 ± 8.2 trees per hectare ($x \pm$ SE).

On six of seven sites, damaged redwoods had a significantly ($P < 0.05$) larger mean diameter at breast height (dbh) than did the nearest undamaged redwood tree. On nine of 13 sites, the dbh of damaged redwoods was significantly ($P < 0.05$) larger than the mean dbh of redwoods on the site. Significantly ($P < 0.05$) more damaged trees were observed near roads or trails than were expected (based on the forest as a whole). There was a significantly ($P < 0.05$) greater number of trees damaged in the 76–100% girdled category than were expected. Average annual increment of bear damage ranged from 0.3 to 23.5 trees per hectare. The mean annual increment of damage was 6.0 ± 2.2 trees per hectare ($x \pm$ SE).

The yield loss due to bear damage was estimated using a redwood growth simulation model. Percentage of yield lost ranged from 0.5% to 54.3%, with a mean percentage loss of 21.4% $\pm$ 5.0 ($x \pm$ SE).

Nine sites between the age of 59-61 were surveyed to ascertain the damage present on near-rotation age stands. The mean number of bear damaged trees per hectare was 15.9 $\pm$ 3.6 ($x \pm$ SE). On all nine sites, greater than 93% of all damaged trees were redwoods.

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INTRODUCTION

Black bear (*Ursus americanus*) depredation on redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*) has become an important issue in northwestern California. It has been reported that timber companies incur large losses from bear damage on coniferous tree species (Mullis 1986).

Bear damage has been defined as either partial girdling or complete girdling of a tree. Complete girdling results in the death of the tree, while partial girdling may cause reduced growth or increased infection with further decay and loss of wood production at harvest (Maser 1967; Mason and Adams 1987).

Bear depredation on trees has been reported since the 1950's (Glover 1955; Lauckhart 1955; Pierson 1966; Poelker and Hartwell 1973). Reports of bear damage to trees have been common in the Western U.S. (Glover 1955; Childs and Worthington 1955; Landenberger 1960; Radwan 1969; Poelker and Hartwell 1973), in the Eastern U.S. (Zeedyk 1956), in Canada (Molnar and McMinn 1960), and in Japan (Watanabe 1977; Furubayashi et al. 1980). In 1952, a study conducted in Humboldt County, CA, characterized age and size of the trees that were being damaged (Glover 1955). Several reports from Washington and Oregon (Resner 1953; Childs and

Worthington 1955; Lauckhart 1955; Pierson 1966; Maser 1967; Poelker and Hartwell 1973) have examined the extent of damage, or a few characteristics of those trees being damaged.

Several tree damage surveys have been made to investigate the extent and characteristics of this problem in California. A report by Fritz (1951) indicated that, in northern California, trees of pole size to about 76 cm diameter at breast height (dbh) and up to 25 years old had been damaged. This damage seemed to be centered in the Little River basin of Humboldt County, CA. Douglas-fir trees mixed in with redwoods were not being attacked, but both planted and naturally regenerating redwood trees were bear damaged.

Glover (1955) conducted a study in 1952 on the property of the Hammond Lumber Company in which he investigated a total of 1,469 damaged trees. Damaged trees were recorded in age classes of 5-10, 10-20, 20-30, 30-40, and 40-50 years. Damage tended to be heaviest in the 10-20 year old age group. The majority of the damage occurred in the combined 10-30 year old interval. Damaged trees were also put into one of eight five-cm dbh classes ranging from 10.2-15.2 cm up to 45.7 cm and greater. The combined 15.2-25.4 cm dbh group received the most damage. The study also found that 70% of the damaged trees were less than 1.8 m from another tree. The average number of trees damaged per hectare (ha) was 28.7 and the bears mostly damaged young redwoods. Only 9% of those trees damaged were Douglas-fir.

Poelker and Hartwell (1973) reported that bears in the Pacific northwest emerged from their den during early spring when there was a lack of abundant forage and thus experienced a period of weight loss for two to three months. Maser (1967) reported that the portion of the tree utilized for food was the spring growth of sapwood. Tree damage as a spring occurrence has been reported by several researchers (Fritz 1951; Resner 1953; Lauckhart 1955; Poelker and Hartwell 1973; Watanabe 1977). Maser (1967) reported that it was probable that individual bears developed a taste for sapwood, because not every bear damaged trees.

Two methods have been proposed to deal with the bear damage problem. The first is the removal of some of the bear population through sport hunting (Poelker and Parsons 1977) and the second is the use of a supplemental feeding program (Flowers 1986). The former, however, assumes all bears do damage and the latter assumes that tree damage is directly related to nutrition and energy for the bears.

The present study was designed with five objectives. The first was to document bear damage on several study sites in coastal Humboldt County, CA. Previous work (Fritz 1951; Glover 1955; and Landenberger 1960) documented bear damage at various times, each at only one site in Humboldt County. The second objective was to characterize damaged trees.

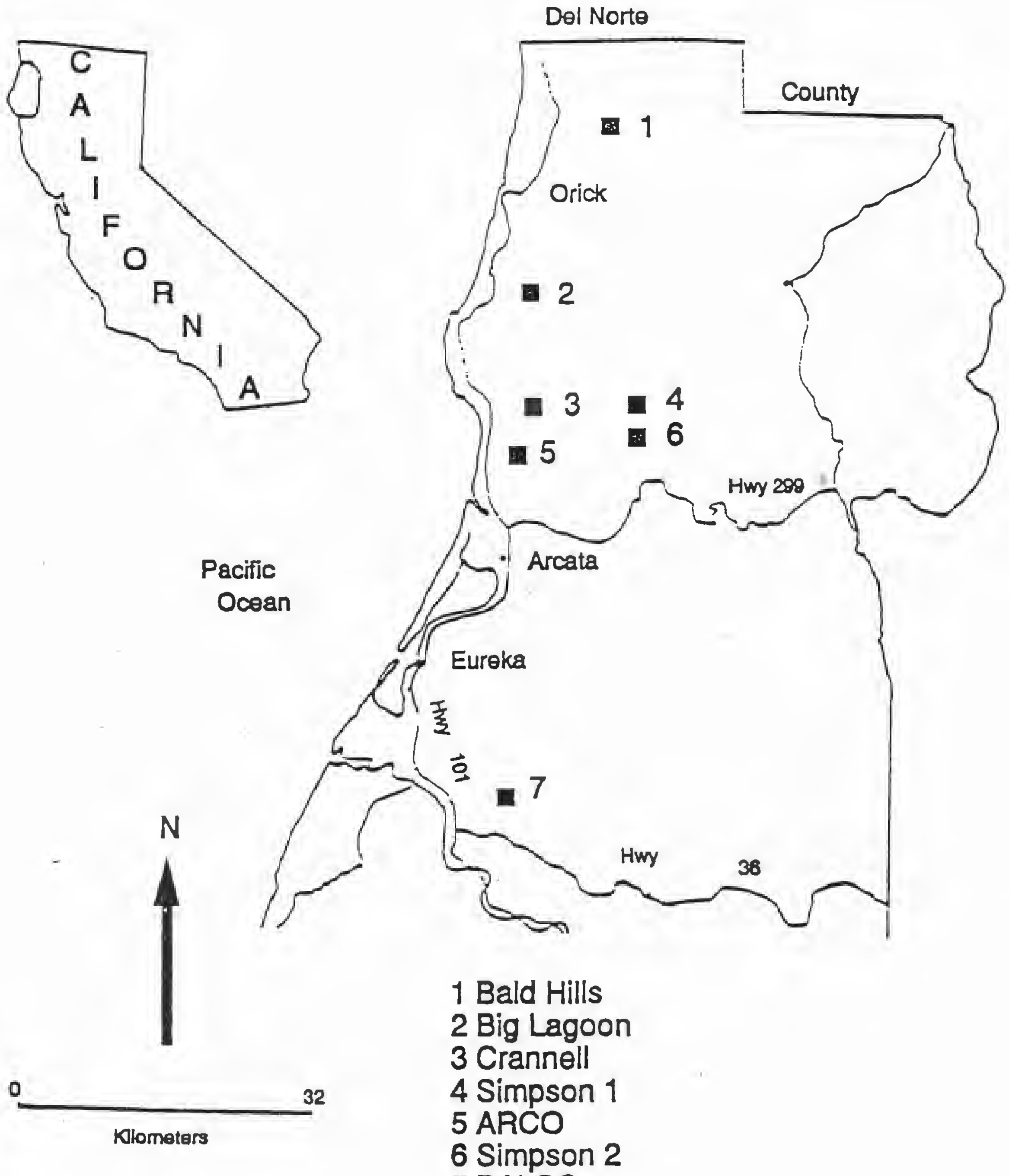
This was done to determine if damaged trees had similar characteristics. These characteristics were used in comparison with those characteristics measured in the studies conducted in Humboldt County during the 1950's. The third objective was to compare characteristics of bear-damaged trees with characteristics of nearby undamaged trees of the same species, as well as the average tree that comprised the site under investigation. This was done to determine if damaged trees differed from those trees not damaged. The fourth objective was to determine an estimate of actual yield loss attributable to bear damage. The fifth objective was to document the density of bear-damaged trees in stands that were at or near rotation age (59-61 years old).

STUDY AREAS

Fourteen study sites were investigated in coastal Humboldt County, CA. During the first year of this study, five sites (ARCO, LP Big Lagoon, Simpson 1, Simpson 2, and PALCO) were chosen as the initial areas to be used for the duration of this investigation. The ARCO site was logged during 1989 making it unavailable for further investigation. Two new sites (LP Crannell and Simpson Bald Hills) were added to the study for the 1989 field season. Seven additional sites (LP Diamond Creek, LP Maple Creek, LP F-5, Elk River, Scout Camp, Klamath River 1, and Klamath River 2) were surveyed for bear damage during the 1990 field season. During 1991, nine sites were surveyed for bear damage, but not permanently marked. Therefore, a total of 23 sites were investigated for bear damage during the course of this study, 14 were permanently marked and all bear damaged trees tagged and 9 were surveyed on a one-time only basis.

The climate of this area is maritime with high humidity prevalent throughout the year. This area has distinct rainy and dry seasons. The dry season extends from May through September and morning fog followed by early afternoon clearing is representative of this period.

Temperatures are moderate throughout the year. During the months that this study was conducted, the average daily temperature ranged from 13.2^{0}C to a high of 15.2^{0}C (United States Department of Commerce 1988; United States Department of Commerce 1989). Rain in this area occurs during the period of October through April. While this study was conducted, the highest rainfall level in any single month was 6.93 cm which fell during May, 1988 (United States Department of Commerce 1988).



1 Bald Hills
2 Big Lagoon
3 Crannell
4 Simpson 1
5 ARCO
6 Simpson 2
7 PALCO

METHODS

Damaged tree characterization

The fixed-width transect technique of vegetative sampling was used to determine damage characteristics. Each study site was located on a 1:24000 topographic map and its area measured using a compensating polar planimeter. Transects were established, 402.3 m apart and parallel to each other on each study site. The transects followed a constant compass bearing which was chosen so that the transects were as perpendicular as possible to the contour of the land. Each transect was 20.2 m wide; therefore 5% of each site was included within the transects. Prior to the intensive fixed-width transect sampling, five random transects were established in order to test the proposed methods.

All transects intersected either a road or major drainage at the origin and end of the transect. This enabled the observer to know where the transect began and ended. The beginning of each transect was permanently marked with a steel stake and flagging. Flagging was also hung in trees as the transects were traversed. The transect was 10.1 m wide on both sides of a transect center line and all damaged trees were considered to be valid data trees.

Each damaged tree was tagged with a numbered aluminum tag and aluminum nails. Only those trees that could be clearly identified as bear-damaged were tagged (i.e. bear tooth marks must have been visible). All damaged trees on the initail seven sites were measured for the following variables: species, dbh, girdle percentage, girdle aspect, height to the first limb of the live crown, height to the beginning of the damage, distance to the nearest neighbor, distance to the nearest road or trail, year of damage, whether the tree was alone or in a clump, slope percentage, aspect, elevation, crown closure, and basal area. The first 10 variables described the actual damaged tree and the last five variables described the site where the damaged tree was growing.

Dbh was defined as the average stem diameter, outside bark, at a point 1.4 m above the ground. A steel diameter tape was used to accurately measure this parameter. Dbh was recorded to the nearest 0.1 cm.

Girdle percentage and girdle aspect were assessed for each tree. Percentage of girdle was recorded as degrees of arc damaged/360 degrees. Girdle percentage was put into one of four categories (1-25%, 26-50%, 51-75%, or 76-100%) for chi-square goodness-of-fit analysis. The mean azimuth of the girdle was determined, except for those trees that were 100% girdled, using a hand compass from the center of the damage arc.

Height to the first limb and height to the point of initial damage were determined with a clinometer and a calibrated pole. lope percentage readings were measured to the top and bottom of the pole and to the limb or point of damage. A simple ratio (Curtis and Bruce 1968) was then utilized to determine height:

$$h = \frac{(p)\ (\%\ \text{slope to damage} - \%\ \text{slope to tree base})}{(\%\ \text{slope to top of pole} - \%\ \text{slope to tree base})}$$

where h = height to first limb or to damage and p = height of pole. If the damage or limb was low, then the height was determined by hand using a 23 m logger's tape.

The logger's tape was also used to measure the distance to the nearest undamaged neighbor. Distances were recorded to the nearest 2.5 cm.

The year of damage was recorded, based on observations made at the site of the injury. Current year's damage was easily recognized, due to the white color of the area that had been stripped of bark. M. Alcorn (Louisiana Pacific, pers. comm.) has reported that following complete girdling, needles turn bright orange within 2 months to 3 years. Within 3 years after damage, needles begin to fall and the tree dies within 5 years. The bark around the area damaged may also be used to age the damage. The extent to which the bark has grown into the damaged area increases with time since damage.

Trees were also recorded as a single stem or as multiple stems/stump. Redwoods were the only damaged species that readily stump sprouted to form clumps of trees. A clump of trees was defined as two or more redwoods occurring as a result of a redwood stump.

The distance to the nearest road or trail was determined by use of a 23 m loggers tape or by ocular estimation. A trail was defined as at least 0.6 m wide. The distance was put into one of the following categories: 0-7.6 m, 7.7-15.2 m, 15.3-30.5 m, 30.6-76.2 m, 76.3-152.4 m, 152.5-304.8 m, or >304.8 m. For the chi-square goodness-of-fit analysis to test for random occurrence of damaged trees within each interval, data was put into one of four categories (0-30.5 m, 30.6-76.2 m, 76.3-152.4 m, 152.5-304.8 m).

Elevation was determined by barometric altimeter. Elevations were recorded in 15.2 m categories. Aspect was determined with a hand compass and slope percentage, with a clinometer.

Basal area was ascertained with a 1.85 m^2 factor basal area prism (Husch et al. 1982). Crown closure (canopy cover percentage) was determined by use of a spherical densiometer (Husch et al. 1982).

The nearest undamaged neighbor tree was measured for the following six variables: species, dbh, elevation, aspect, slope, basal area, and crown closure. These variables were measured using the same methods as described for the damaged tree measurements. Species of trees not found damaged and trees with a smaller dbh than the smallest damaged tree (10 cm) were not used as a nearest neighbor to enable justifiable comparisons to be made between damaged and undamaged trees. Thus, when such a tree was encountered, the nearest neighbor that met the restrictions was sampled.

Vegetation Sampling

Vegetation sampling was conducted at all study sites, except the ARCO site due to it being logged prior to the second year of study. Prior to sampling, the LP Big Lagoon study site was visited and a typical area was chosen to determine the species area curve for that particular site. A plot center was chosen, and then radii of 1.5, 3.0, 4.5, 6.1, 7.6, 9.1, and 10.7 m were established and the total cumulative number of species were recorded. When a plateau in number of species was reached, the corresponding radius was then selected for the size of the plots to be utilized. The LP Big Lagoon site reached a plateau between 7.6 and 10.7 m; therefore, a 0.04 ha plot size was utilized on all sites for the vegetation sampling. The previously established bear damage transects were used to establish the vegetation plots. The total length of the transect determined the distance that plot centers were separated from one another. Plot centers were at least 30.5 m apart, but not more than 213.4 m apart. A 30.5 m steel tape was trailed to measure the distance between plots. The distance separating plots was constant for any one transect.

At each study site, the characterization plots established on the first transect were used to determine the number of plots required to reach the desired accuracy. Each transect had to have at least four vegetation characterization plots. The sample size was determined by using a formula developed by Snedecor (1956). On the initial seven sites (except ARCO) the following information was recorded for each plot:

1. species of all trees that occurred in the plot (each tree considered a "plot tree");
2. dbh of all trees greater than 10.2 cm;
3. understory vegetation consisting of shrubs, ferns, grasses, and forbs;
4. percentage cover of each species of vegetation using the Daubenmire and Daubenmire (1968) method of estimating cover; and,
5. number of bear-damaged trees in the plot.

On the additional seven study sites, only numbers 1, 2, and 5 were collected.

Upon the completion of the vegetation sampling for a study site, the relative frequency of occurrence of all plant species encountered was calculated.

When field work was conducted by one researcher, all data were recorded in the field on a hand-held tape recorder. The tape recorded data were transcribed onto the data sheets. When a crew was conducting the field work, data were recorded directly onto the data sheets.

Data Analysis

Descriptive statistics and multiple range tests were calculated by use of the BMDP statistical software (University of California 1985). The BMDP software was also used to test for normality of the dbh data by the Shapiro and Wilk's W statistic. Levene's test for equal variances was utilized to check for homogeneity of variance. A one-way analysis of variance (ANOVA) was used to test the equality of the three tree-group dbh means. In the case of a significant F-statistic value for the ANOVA ($P < 0.05$), a Duncan's multiple range test was used to perform all possible comparisons. Where significant results of chi-square goodness-of-fit tests were detected, the chi-square analysis was subdivided (Zar 1984). This was done to determine if any category contributed a large amount to the size of the calculated chi-square value.

Chi-square contingency tables were used to test for significance between redwood trees damaged and redwood trees available and between redwood stump sprouts damaged and redwood stump sprouts available.

Chi-square goodness-of-fit tests were used to test for significance between number of trees observed and number of trees expected by chance in girdle percentage categories and between number of trees observed and number of trees expected by chance in the distance to road or trail categories. It was expected by chance occurrence that each of the four categories of girdle percentage would have an equal number of trees. The expected values for distance to road or trail were proportioned according to the size of the interval (e.g. the 152.5-304.8 m interval was expected to have twice as many trees in it as the 76.3-152.4 m interval).

Bear-Damaged Tree Density Estimation of Rotation-Aged Stands

During the 1991 field season nine study sites were randomly chosen to be used for bear-damaged tree density estimation in near rotation aged stands (59-61 years). Three sites were chosen on each of Louisiana-Pacific, Simpson Timber, and Pacific Lumber company lands. The sites were chosen at random and one non-repeatable (no permanent marking was established) transect was established on each site. All damaged trees were measured for the following variables: species, dbh, girdle percentage, and height to damage.

Analysis of Yield Loss Due to Bear Damage

The data collected during both the bear damaged tree surveys and the vegetation plot work was used in conjunction with the "CRYPTOS" software package (Wensel et al. 1988) to determine board foot loss due to bear damage.

The first step was to determine the total height and live crown ratio (LCR) for all trees occurring on each site. The age and fifty-year site index (for redwood) was provided for each site by the appropriate landowner. The vegetation plot data provided average dbh and trees per hectare (tph), by species, for each site. This information was input into the "GENR" (Krumland and Wensel 1988) program. The output was a list of hypothetical trees with dbh, total height, and LCR which were based on age, site index, average dbh, and tph. The program generates data for redwood, Douglas-fir, tanoak, and alder. This information was used, on a site specific basis, to generate regression equations to predict total height and LCR for all dbh's actually found on that site.

The next step was to determine the number of trees per dbh per hectare (i.e., per hectare expansion), based on the vegetation plot data. This was accomplished by recording the total number of trees for each dbh and dividing this number by the total number of hectares included in the vegetation plots for a particular site.

The "CRYPTOS" subprogram "ENTRY" was then used to input each stand description which included the following information: tree species, dbh, total height, LCR, and per hectare expansion. The stand description file could then be loaded into CRYPTOS for growth simulation. CRYPTOS was used to grow each stand to rotation age (59-61 years) and the gross board foot volume yield per hectare was generated.

The next step was to use the same stand description and "harvest" (remove) 100% girdled bear-damaged trees, then grow the stand to rotation age (59-61 years) and generate the bear-damaged stand gross board foot volume yield per hectare. The number of bear damaged trees to harvest was determined by the number of 100% girdled trees found on each plot. These data were analyzed on a dbh specific basis and the total number of trees 100% girdled for each dbh was divided by the total number of hectares surveyed in the damage transects. The result was then divided by the per hectare expansion to determine the percentage of available trees killed by bear damage. This percentage was then harvested before the first period of growth was begun. The stand was then grown for five years. The annual increment of bear damage was estimated from the resurveys of the damage transects. Again, only those trees 100% girdled were counted for the harvest. Since CRYPTOS only operates on five-year cycles, the annual percentage of trees to be harvested was multiplied by five to attain a five year harvest rate for each dbh. This process was repeated every five years until age 55 was attained. The stand was only "bear-damage harvested" until age 55 due to the results of surveys done on rotation age sites. These results indicated that less than two percent of the total damage attributable to bears had occurred between age 55 and 60.

The last step was to determine the net difference between gross total yield with no bear damage and gross total yield of a bear-damaged stand. This difference would be the difference attributable to bear damage over the life of the stand.

The yield loss estimation only included loss of 100% girdled redwood and Douglas-fir trees. In addition, the estimation assumed that the annual increment of bear damage would remain the same for the site until the site reached the age of 55.

RESULTS

Fourteen study sites were investigated for density of bear-damaged trees during the four years of this study. Five sites (ARCO, LP Big Lagoon, Simpson 1, Simpson 2, and PALCO) were investigated for density of bear-damaged trees during the 1988 field season. Four of these five sites (LP Big Lagoon, Simpson 1, Simpson 2, and PALCO) were revisited in 1989 to determine annual bear-damage to regenerating conifers. Two additional sites (LP Crannell and Simpson Bald Hills) were investigated for density of bear-damaged trees during 1989. Vegetation plots were established on all sites during 1989. Seven sites (LP Maple Creek, Elk River, Scout Camp, Klamath River 1, Klamath River 2, LP Diamond Creek, and LP F-5) were investigated for bear-damaged tree density during the 1990 field season. Vegetation plots were established on these seven sites during 1990. The six sites established in 1988 and 1989 were revisited in 1990. The 1991 field season consisted of revisiting all 13 previously established sites. Additionally, nine sites were investigated on a one-time only basis to determine bear damage tree density on near-rotation age stands.

The ARCO site was logged during 1989, so it was omitted from any tests or tables involving vegetation plots as well as annual damage measurements. Only 14 bear-damaged trees were found on the LP Crannell site and only 13 bear-damaged trees were found on the Scout Camp site, so they were eliminated from tests involving chi-square, due to inadequate sample size (Zar 1984).

The tests conducted to check for normality of data and equality of variances resulted in no significant departure from normality and no significant difference in variances. Therefore, the underlying assumptions of population normality and homogeneity of variance, for ANOVA and multiple comparison tests, were met.

Following the initial data analysis, the research participants decided that several of the variables originally collected for all bear-damaged trees were not related to damage (Table 1). Therefore, study sites established after this decision were not measured for these variables.

Density of Damaged Trees

A total of 1620 bear-damaged trees were tagged and investigated during four years of study. Of this 1620, 1256 were trees tagged on the first survey of the areas. The remaining 364 were found on the resurveys of the areas. The number of damaged trees per hectare varied greatly by site (Table 2). The least damage was 4.2 $\pm$ 2.2 damaged trees/ha on the LP Crannell study site; whereas the greatest number

Table 1. Variables and their relative importance to bear damage as determined by project participants.

Variable	Very important	Important	Semi-important	Unimportant
Species	X			
Dbh	X			
Percent Girdle	X			
Distance to Road	X			
Height to First Limb				X
Distance to Nearest Neighbor				X
Alone/Clump		X		
Year of Damage			X	
Height to Damage		X		
Girdle Aspect				X
Slope				X
Elevation				X
Crown Closure				X
Basal Area	X			
Understory Vegetation[a]				X

[a]Only measured on 0.04 ha plots.

Table 2. Number of bear-damaged trees per ha, based on first-time surveys, on fourteen sites in Humboldt County, CA.

Study site	Stand age (years)	Damaged trees	Number of Damaged trees/ha ($\bar{x} \pm$ SE)
ARCO	50	153	7.9 $\pm$ 1.2
Big Lagoon	38	224	14.8 $\pm$ 3.2
Simpson 1	30	141	26.7 $\pm$ 3.7
Simpson 2	35	91	21.0 $\pm$ 4.4
PALCO	30	101	38.5 $\pm$ 12.8
Crannell[a]	35/50	14	4.2 $\pm$ 2.2
Bald Hills	40	65	17.1 $\pm$ 2.0
Diamond Creek	17	81	36.8 $\pm$ 17.7
Elk River	23	27	9.7 $\pm$ 4.9
Scout Camp	17	13	5.1 $\pm$ 1.2
Klamath River 1	17	86	40.8 $\pm$ 9.9
Klamath River 2	23	86	42.0 $\pm$ 6.5
Maple Creek	35	100	40.2 $\pm$ 12.8
LP F-5	23	151	72.5 $\pm$ 8.2
MEAN of SITES			26.5 $\pm$ 5.1

[a]LP Crannell was the only two-age-class site investigated.

of damaged trees per ha was 72.5 $\pm$ 8.2 on the LP F-5 site (Table 2).

Damaged Tree Characteristics

Fifteen variables (Table 1) were measured on 789 of the 1620 bear-damaged trees. The mean dbh of damaged trees ranged from 9.4 $\pm$ 0.2 cm to 74.6 $\pm$ 1.7 cm (Table 3). The distance to the nearest neighbor was very consistent, ranging from 0.8 $\pm$ 0.1 m to 2.0 $\pm$ 0.2 m (Table 3). Crown closure was consistently high on all study sites, having a mean crown closure range of 83.9 $\pm$ 1.1% to 88.2 $\pm$ 0.2% (Table 3). Basal area differed greatly from site to site (Table 3). The largest basal area/ha was observed on the Elk River site (21.6 $\pm$ 1.0 m^2) and the smallest occurred on the Klamath River 2 site (10.1 $\pm$ 0.3 m^2) (Table 3). Mean elevation and slope varied considerably between sites, and damaged trees were found on a wide spectrum of both elevation and slope.

Species of Trees Damaged

Redwood, Douglas-fir, western hemlock, and Sitka spruce were the tree species damaged by bears. The percentage of damaged trees that were redwood ranged from 67.4% to 100% (Table 4) and redwood was the species most often damaged on all sites. Douglas-fir was the next most

Table 3. Dbh, nearest neighbor, slope, elevation, crown closure, and basal area ($\bar{x} \pm SE$) measured for bear-damaged trees on fourteen sites in Humboldt County, CA.

Study site	Number of trees	Dbh (cm)	Nearest neighbor (m)	Slope (%)	Elevation (m)	Crown closure (%)	Basal area (m^2)
ARCO	153	74.6 ± 1.7	1.8 ± 0.2	33.4 ± 1.5	154.2 ± 4.7	88.2 ± 0.2	17.1 ± 0.5
Big Lagoon	224	51.0 ± 0.9	1.0 ± 0.1	32.5 ± 1.0	134.0 ± 3.4	86.8 ± 0.2	17.6 ± 0.4
Simpson 1	141	29.2 ± 0.9	1.9 ± 0.1	24.5 ± 1.1	132.4 ± 10.3	85.9 ± 0.3	12.6 ± 0.3
Simpson 2	91	32.9 ± 1.1	2.0 ± 0.2	32.0 ± 1.6	182.4 ± 13.5	85.5 ± 0.4	13.2 ± 0.6
PALCO	101	36.9 ± 1.5	0.8 ± 0.1	49.1 ± 1.8	210.5 ± 7.9	86.4 ± 0.4	17.4 ± 0.7
LP Crannell	14	61.0 ± 3.1	1.5 ± 0.5	49.0 ± 4.9	64.2 ± 14.2	83.9 ± 1.1	16.3 ± 1.6
Bald Hills	65	37.4 ± 1.6	2.0 ± 0.2	41.0 ± 2.0	222.3 ± 3.8	85.1 ± 0.3	10.8 ± 0.5
Maple Creek	100	16.9 ± 0.7					17.8 ± 0.5
Elk River	14	17.6 ± 1.3					21.6 ± 1.0
Scout Camp	13	14.8 ± 1.0					16.2 ± 1.0
Klamath 1	86	12.4 ± 0.4					11.5 ± 0.3
Klamath 2	86	12.2 ± 0.4					10.1 ± 0.3
LP Diamond	81	9.4 ± 0.2					14.4 ± 0.6
LP F-5	151	10.5 ± 0.2					14.9 ± 0.2

Table 4. Bear-damaged trees by tree species on fourteen study sites in Humboldt County, CA.

Study Site	Redwood	Douglas-fir	Western Hemlock	Sitka Spruce
ARCO	98.7 (151)	1.3 (2)		
Big Lagoon	92.0 (206)	6.2 (14)		1.8 (4)
Simpson 1	75.9 (107)	16.3 (23)	5.7 (8)	2.1 (3)
Simpson 2	78.0 (71)	15.4 (14)	6.6 (6)	
PALCO	97.0 (98)	3.0 (3)		
LP Crannell	92.9 (13)	7.1 (1)		
Bald Hills	69.2 (45)	30.8 (20)		
Maple Creek	96.0 (96)	4.0 (4)		
Elk River	100.0 (27)			
Scout Camp	100.0 (13)			
Klamath River 1	79.1 (68)	20.9 (18)		
Klamath River 2	67.4 (58)	32.6 (28)		
Diamond Creek	100.0 (81)			
LP F-5	96.7 (146)	2.6 (4)	0.7 (1)	

frequently damaged species. Redwood was damaged in significantly greater ($P < 0.05$) proportions than it was available on eight of 13 study sites (Table 5). On five other study sites the proportion of damaged trees that were redwood did not differ significantly from the proportion of available redwood trees (Table 5). On six of seven sites where data on the nearest undamaged redwood neighbor was obtained, damaged redwood trees were significantly larger in diameter than the nearest undamaged redwood neighbor (Table 6). On sites with data on both damaged redwood tree and vegetation plot redwood trees, nine of the 13 sites had damaged redwood trees that were significantly ($P < 0.05$) larger than redwood plot trees (Table 6).

Damaged Stump Sprout Trees

When six sites were tested for differences in the number of damaged redwoods that were stump sprouts compared to the number of available redwood stump sprouts, a significant difference ($P < 0.05$) was detected at only one site (Table 7). The PALCO site had a significantly ($P < 0.05$) greater percentage of stump sprouts available than were damaged.

Percent Girdle of Damage

All 12 sites had significant ($P < 0.05$) results for the chi-square goodness-of-fit test on the number of redwood

Table 5. Number of damaged and available redwood trees on thirteen sites in Humboldt County, CA.

Study Site	Damaged Redwood number (%)	Available Redwood number (%)	P
Big Lagoon	206 (92)[a]	281 (74)[b]	< 0.05
Simpson 1	107 (76)	138 (28)	< 0.05
Simpson 2	71 (78)	137 (43)	< 0.05
PALCO	98 (97)	484 (95)	> 0.05
LP Crannell	13 (93)	448 (71)	> 0.05
Bald Hills	45 (69)	174 (58)	> 0.05
Maple Creek	96 (96)	368 (78)	< 0.05
Elk River	27 (100)	634 (93)	> 0.05
Scout Camp	13 (100)	439 (96)	> 0.05
Klamath River 1	68 (79)	86 (49)	< 0.05
Klamath River 2	58 (67)	61 (34)	< 0.05
Diamond Creek	81 (100)	240 (87)	< 0.05
LP F-5	146 (97)	223 (58)	< 0.05

[a]Percentage of all damaged trees that were redwood.

[b]Percentage of all conifers on 0.04 ha plots that were redwood.

Table 6. Comparison of dbh (cm) of damaged redwood trees, nearest undamaged redwood neighbor, and redwood plot trees on fourteen sites in Humboldt County, CA.

Site	Damaged Trees ($\bar{x} \pm$ SE) (n[a])	Nearest Undamaged Neighbor ($\bar{x} \pm$ SE) (n)	Plot Trees ($\bar{x} \pm$ SE) (n)
ARCO	75.2 ± 1.6^{b} (151)	52.3 ± 2.2^{c} (120)	
Big Lagoon	51.7 ± 0.9^{b} (206)	36.2 ± 1.0^{c} (171)	37.5 ± 1.0^{c} (281)
Simpson 1	30.1 ± 1.1^{b} (107)	24.2 ± 1.3^{c} (70)	28.1 ± 1.2^{bc} (135)
Simpson 2	34.6 ± 1.3^{b} (71)	26.6 ± 1.8^{bc} (53)	26.3 ± 0.9^{c} (143)
PALCO	36.9 ± 1.5^{b} (98)	25.7 ± 1.3^{c} (88)	31.4 ± 0.7^{d} (482)
LP Crannell	61.7 ± 3.2^{b} (13)	36.0 ± 3.3^{c} (11)	27.7 ± 0.6^{c} (444)
Bald Hills	43.4 ± 1.5^{b} (45)	33.6 ± 1.6^{c} (42)	34.6 ± 0.8^{c} (172)
Maple Creek	17.0 ± 0.7^{b} (96)		9.8 ± 0.2^{c} (368)
Elk River	16.2 ± 1.0^{b} (27)		12.9 ± 0.3^{c} (636)
Scout Camp	14.8 ± 1.1^{b} (13)		13.7 ± 0.4^{b} (436)
Klamath River 1	13.5 ± 0.4^{b} (68)		10.0 ± 0.4^{c} (87)
Klamath River 2	13.5 ± 0.4^{b} (58)		11.1 ± 0.5^{b} (61)
Diamond Creek	9.4 ± 0.3^{b} (81)		7.9 ± 0.2^{b} (240)
LP F-5	10.6 ± 0.3^{b} (146)		8.4 ± 0.2^{c} (223)

[a]n = number of trees.

[b,c,d]Different superscripts within a row denote significant differences of a Duncan's multiple range test at $P < 0.05$ (all entries with the same letter, within a row, are not statistically significantly different).

Table 7. Number of damaged and available redwood trees that were part of a clump on six sites in Humboldt County, CA.

Study Site	Damaged Redwood number (%)	Available Redwood number (%)	P
Big Lagoon	178 (86)[a]	253 (90)[b]	> 0.05
Simpson 1	53 (50)	77 (56)	> 0.05
Simpson 2	24 (34)	40 (27)	> 0.05
PALCO	80 (82)	455 (94)	< 0.05
LP Crannell	7 (54)	319 (71)	> 0.05
Bald Hills	34 (76)	144 (83)	> 0.05

[a]Percentage of all damaged trees that were redwood.

[b]Percentage of all trees on 0.04 ha plots that were redwood.

trees in each of four categories of girdle percentage. The 76-100% girdled category was responsible for a relatively large portion of the chi-square value on four sites (Table 8) (e.g. on one site, the 76-100% category accounted for 26.7 of the total chi-square value of 39.4). Five sites had significant ($P < 0.05$) chi-square values, but the subdividing analysis did not result in any single category contributing a relatively large portion to the chi-square value (Zar 1984). Sites could not be combined for a chi-square test analysis because variances were heterogeneous.

Distance from Damaged Tree to Nearest Road or Trail

All data could not be combined for a chi-square test analysis because variances were heterogeneous. Significant ($P < 0.05$) differences existed between the number of damaged redwood trees observed and expected for the distance from a bear-damaged tree to the nearest road or trail. Ten of twelve sites had significant ($P < 0.05$) results, but no single category added a large portion to the chi-square value for any site (Table 9).

Yearly Bear Damage to Trees

Yearly bear damage to regenerating conifers was variable for the thirteen sites investigated (Table 10). The overall mean was 4.2 ± 0.9 damaged trees per ha per year.

Table 8. Number of trees observed (obs.) and expected (exp.) by chance in each of four categories of percent girdled on twelve sites in Humboldt County, CA.

Study Site	1-25		26-50		51-75		76-100	
	obs.	exp.	obs.	exp.	obs.	exp.	obs.	exp.
ARCO[a]	39	38.3	48	38.3	15[b]	38.3	51	38.3
Big Lagoon[a]	51	56.0	59	56.0	29	56.0	85	56.0
Simpson 1[a]	33	35.3	25	35.3	17	35.3	66[b]	35.3
Simpson 2[a]	18	22.8	25	22.8	13	22.8	35[b]	22.8
PALCO[a]	11	25.3	24	25.3	6	25.3	59	25.3
Bald Hills[a]	5	16.3	19	16.3	5	16.3	36	16.3
Maple Creek[a]	30	25.0	32	25.0	5[b]	25.0	33	25.0
Elk River[a]	6	6.8	8	6.8	0[b]	6.8	13	6.8
Klamath River 1[a]	10	21.5	23	21.5	7	21.5	46	21.5
Klamath River 2	11	21.8	22	21.8	15	21.8	39[b]	21.8
LP Diamond Creek[a]	7	20.3	22	20.3	16	20.3	36	20.3
LP F-5	22	37.8	39	37.8	35	37.8	55[b]	37.8

[a]Superscripts denote significant differences between expected and observed number of trees of a chi-square goodness-of-fit test at $P < 0.05$.

[b]Superscripts indicate categories that contribute a relatively large amount to the calculated chi-square value.

Table 9. Number of damaged trees observed (obs.) and expected (exp.) in each of four categories of distance from damaged tree to nearest road or trail on thirteen sites in Humboldt County, CA.

Study Site	0-30.5		30.6-76.2		76.3-152.4		152.5-304.8	
	obs.	exp.	obs.	exp.	obs.	exp.	obs.	exp.
ARCO[a]	17	8.2	9	9.3	20	15.5	16	31.0
Big Lagoon[a]	16	14.8	11	22.2	48	37.0	75	74.0
Simpson 1[a]	12	13.0	26	19.4	50	32.3	41	64.5
Simpson 2[a]	35	8.8	14	12.9	25	21.5	12	43.0
PALCO[a]	21	8.6	18	12.8	20	21.3	25	42.5
Bald Hills	0	3.0	3	4.5	9	7.5	18	15.0
LP Maple[a] Creek	25	8.8	26	13.2	14	22.0	23	44.0
Elk River[a]	22	2.7	4	4.1	1	6.8	0	13.5
Scout Camp[a]	13	1.3	0	2.0	0	3.3	0	6.5
Klamath[a] River 1	20	8.6	21	12.9	35	21.5	10	43.0
Klamath[a] River 2	17	8.6	27	12.9	32	21.5	10	43.0
LP Diamond[a] Creek	9	8.1	26	12.2	43	20.3	3	40.5
LP F-5[a]	45	15.1	45	22.7	41	37.8	20	75.5

[a]Superscripts denote significant results of a chi-square goodness-of-fit test at $P < 0.05$.

Table 10. Yearly bear damage to regenerating conifers on thirteen sites revisited in Humboldt County, CA, 1988-1991.

Study Site	Age (years)	Damaged Trees/ha/Year ($\bar{x} \pm$ SE)
Big Lagoon[a]	38	2.2 ± 0.6
Simpson 1[a]	30	2.0 ± 0.4
Simpson 2[a]	35	3.0 ± 2.2
PALCO[a]	30	3.1 ± 2.1
Bald Hills[b]	40	8.0 ± 4.0
LP Crannell[b]	35/50	0.3 ± 0.1
Diamond Creek[c]	17	4.9 ± 4.0
LP F-5[c]	23	3.8 ± 1.9
Maple Creek[c]	35	3.6 ± 1.5
Elk River[c]	23	0.3 ± 0.3
Scout Camp[c]	17	0.7 ± 0.7
Klamath River 1[c]	17	23.5 ± 6.4
Klamath River 2[c]	23	22.5 ± 10.7
GRAND MEAN		6.0 ± 2.2

[a]Resurveyed three years.
[b]Resurveyed two years.
[c]Resurveyed one year.

Yield Loss Attributable to Bear Damage

Estimated yield loss was highly variable between sites (Table 11). The Simpson properties accounted for the largest (54.3%) and one of the smallest (1.7%) percentages of yield lost. Therefore, it appears as though yield loss can be highly variable within ownership as well as between ownerships. The percentage of yield lost figures reflect the variability in bear damage that was reported in the density of bear damaged trees/ha data as well as the variability that existed in the yearly bear damage data. As implied in the methods section, these estimates of percentage of yield lost required several assumptions necessary to make the final yield loss predictions. If any of these assumptions do not hold true (e.g. if yearly bear damage greatly fluctuates), then these estimated percentage-yield-loss values may be either low or high.

Bear-Damaged Tree Density Estimation of Rotation-Aged Stands

Bear-damaged tree density of stands at or near rotation age was highly variable (0.8 - 31.1) (Table 12). The overall mean of 15.9 damaged trees per ha was 40% lower than the number of damaged trees per ha on the other, younger sites surveyed as part of this study. The percentage of damaged trees that were redwood was relatively constant and reflects findings similar to those reported for the younger sites

Table 11. Analysis of yield loss due to bear-damage on thirteen study sites in Humboldt County, CA[a].

Study Site	No Bear Damage		Bear Damage		Percent of Yield Lost
	Bd Ft Vol/Ac	Total Yield[b]	Bd Ft Vol/Ac	Total Yield[b]	
Big Lagoon	76,726	16.425	56,068	12.003	26.9
Simpson 1	103,907	10.386	67,336	6.731	35.2
Bald Hills	106,354	10.287	101,832	9.849	4.3
Simpson 2	108,454	5.793	106,626	5.696	1.7
PALCO	206,999	12.817	181,745	11.253	12.2
LP Crannell	149,375	8.644	147,027	8.508	1.6
LP F-5	41,390	1.675	30,073	1.217	27.3
Maple Creek	163,114	9.241	127,086	7.200	22.1
Klamath River 1	94,048	3.806	42,971	1.739	54.3
Klamath River 2	82,706	3.347	59,799	2.420	27.7
Elk River	263,389	12.897	229,239	11.225	13.0
Scout Camp	274,508	11.090	272,754	11.038	0.5
Diamond Creek	53,078	2.148	26,094	1.056	50.8
MEAN ± SE					21.4 ± 5.0

[a]Figures reflect only the yield produced by redwood and Douglas-fir.
[b]Figures given as millions of board feet.

Table 12. Density, percentage redwood, and dbh of bear-damaged trees on nine sites between 59-61 years of age in Humboldt County, CA.

Study site	Number of trees	Trees/ha	Redwood (%)	Dbh[a] ($\bar{x} \pm$ SE)
LP F-8	26	11.3	96.2	59.1 $\pm$ 3.7
Beech Creek	33	22.0	93.9	71.5 $\pm$ 3.7
Mule Creek	1	0.8	100.0	76.2
Carlotta	31	23.8	100.0	66.4 $\pm$ 2.6
NF 1000	14	8.8	100.0	61.1 $\pm$ 3.8
Panther Creek	25	27.8	96.0	46.7 $\pm$ 2.7
PALCO Sec. 11	5	3.8	100.0	67.6 $\pm$ 7.5
PALCO Sec. 16	28	31.1	100.0	59.6 $\pm$ 3.2
PALCO Sec. 15	12	13.3	100.0	64.1 $\pm$ 4.7
MEAN $\pm$ SE		15.9 $\pm$ 3.6		63.6 $\pm$ 2.8

[a]Figures are reported in cm.

investigated during this study. Mean dbh was obviously larger and less variable than for the younger sites investigated (63.6 $\pm$ 2.8 cm versus 29.8 $\pm$ 5.5 cm). The variability in the younger sites results from the variation in ages, while the low variability in the rotation-aged stands is due to the nearly identical ages of all nine stands.

Douglas-fir was most often damaged on sites of age 25-45 years. Fritz (1951) reported that, in the Redwood Region, only very young redwood trees up to approximately 25 years old were damaged, while Glover (1955) reported that damage tended to be greatest in the 10 to 20 year old age group.

Size of Trees Damaged

This study showed a dbh range of damaged trees of 8.9-138.2 cm with both extremes being redwood trees. Glover (1955) reported that the trees most often damaged were in the 15.2-25.4 cm dbh group. The trees most often damaged during this study were larger than reported by Glover (1955). Reports in the literature from Alaska (Lutz 1951) and Washington (Levin 1954) suggested that bear damage to white spruce (*Picea glauca*) and Douglas-fir, respectively, most frequently occurred in the 25.4-45.7 cm dbh size category. Fritz (1951) also reported that only young redwood trees from 10.2-76.2 cm in dbh were bear-damaged.

Distance to Nearest Neighbor

On all sites where this variable was measured, the average distance from a damaged tree to the nearest neighbor tree was 2.0 m or less. Glover (1955) reported that 60 percent of the damaged trees investigated were less than 1.8 m from another tree. The distance to the nearest tree is a measure of the density of trees on a site, as is the basal area of a site (Husch et al. 1982). Mason and Adams (1987), however, reported that thinned sites (i.e lower tree density) had significantly greater bear damage than adjacent unthinned sites. Schmidt (1987) reported results that supported the theory of higher densities of bear-damaged trees on lower tree density sites. In this study, the second and third highest averages for the number of damaged trees per ha occurred on sites that had been thinned (Klamath River 1 and 2).

Species of Damaged Trees

Several authors have reported that bears exhibit some form of species preference when damaging trees (Resner 1953; Glover 1955; Childs and Worthington 1955; Maser 1967). Glover (1955) indicated that a preference existed for redwood. On all sites investigated, redwood was the most frequently damaged tree species (88.8% of damage) as well as the most available conifer species (66.5% available). Glover (1955) reported that an increase in damage to Douglas-fir in the future should have been expected as Douglas-fir become a more prevalent component of the stand. He reported a level of damage to Douglas-fir of 9%. On five of fourteen study sites investigated as a part of this study, more than 9% of all damage was to Douglas-fir (ranged from 15.4% to 32.6%). Western hemlock received small amounts of damage on two sites (5.7% and 6.6%) where

Douglas-fir received, compared to other sites, relatively high amounts of damage (16.3% and 15.4% respectively). Western hemlock comprised a larger percentage (20.5% and 16.9%, respectively) of the total stand on those two sites compared to the other sites. Maser (1967) reported that western hemlock and Sitka spruce were found damaged in Oregon, but in much smaller percentages than that for Douglas-fir.

Jacobs (1974) reported that selective feeding occurs when a feeder consumes available food resources that occur together at different rates. In this study, damage was assumed to be equivalent to usage. On all sites investigated, the percentage of damaged trees that were redwood was greater than the percentage of available redwood trees, although this difference was not statistically significant on five of the 13 sites.

Farentinos et al. (1981) reported that tassel-eared squirrels (Sciurus aberti) exhibited a preference for certain ponderosa pine (Pinus ponderosa) trees. He showed, in one case of two trees less than one meter apart, that one was heavily defoliated while the other was hardly utilized. He further reported that of 18 monoterpenes found in twig samples, alpha-pinene was the single best predictor of tassel-eared squirrel feeding trees. Alpha-pinene is the main volatile part of droplets of resin found in the bark of some redwood trees (E. Zavarin, Forest Products Laboratory, pers. comm.). Radwan (1969) analyzed four species of trees damaged by black bears and reported significant differences between species in terms of the contents and kinds of some chemical constituents. He also reported that only total sugars in relatively high concentrations and ash in relatively low concentrations appeared to be related to differential use by black bear. Unfortunately, no chemical analysis was able to be performed in this research.

Dbh of Damaged Trees

Six identical parameters were measured on damaged redwood trees and their nearest undamaged redwood neighbor on the initial eight sites. At the onset of this study it was not known which, if any, of these variables would differ between these two groups of trees. Only dbh was significantly different between the two groups of trees such that the damaged trees were significantly larger than their nearest undamaged neighbor. Given that the average distance from a damaged tree to its nearest neighbor never exceeded 2.0 m, significant differences in slope, aspect, elevation, crown closure, and basal area would not be likely. These variables described the habitat where a tree was found growing and extreme changes in these variables, within short distances, would not be encountered.

Two previous reports (Lutz 1951; Childs and Worthington 1955) have suggested that the larger trees of a site were more frequently damaged than the smaller trees. In this study the average dbh of damaged redwood trees was compared with the average dbh of the nearest undamaged redwood neighbor on seven sites, and with the average dbh of all redwood trees sampled in the 0.04 ha sampling plots on 13 sites. The average dbh of the nearest undamaged neighbor was very similar to the average dbh of the sampled plot trees. Sampled plot trees were assumed to be representative of the average dbh of redwood trees on the site. Conversely, it appeared as though the average bear-damaged redwood tree was larger than the average undamaged redwood neighbor and the average redwood tree growing on the site. If bears utilized redwood trees as a food resource, then larger trees would provide more surface area of potential food per unit of volume than smaller trees. This may account for the use of larger redwood trees over nearby smaller redwood trees.

Damaged Trees Growing as Part of a Clump

It has been suggested (J. Adams, Arcata Redwood Company, pers. comm.) that redwood trees that occurred as part of a clump may have been damaged in a proportion unequal to their occurrence on the site. The percentage of available redwood trees that grew as part of a clump was, on all but one of six sites, greater than the percentage of bear-damaged trees which was growing as part of a clump. On only one site (PALCO) was this difference significant ($P < 0.05$). Therefore, it did not appear that clumped redwood trees were predisposed to bear damage.

Girdle Percentage of Damaged Trees

If the girdle percentage by the bear was assumed to be random, one would expect the same number of trees to be girdled in each category of girdle percentage. Glover (1955) reported that, in analyzing the extent of damage to trees, similar numbers of trees were 0-25% damaged as were 76-100% damaged. This study found that at 12 of 14 sites where this was tested, more damaged trees were observed in the 76-100% girdled group than were expected. Therefore, results of this study do not concur with Glover (1955). At least twice as many damaged trees were found in the 76-100% category as those found in the 1-25% category on eight of the 12 sites. Trees that are girdled between 76-100% are exposed to two risks. First, if they are girdled 100%, they are going to die and be of little or no commercial value at harvest. Second, the greater the girdle percentage, the more area is exposed to secondary infection which may also reduce tree productivity or result in death of the tree.

One possible explanation for the results associated with the girdle percentage measurements may be optimal foraging theory (Emlen 1966). Since all 12 sites had more trees observed than expected in the 76-100% category, perhaps the maximum possible mass intake resulted when a larger percentage of the tree was girdled. Pyke et al. (1977) suggested that, among other things, handling time and food value must be taken into account to determine the net rate of food gain. Once a bear had begun to damage (handle) a tree, the net food gain may be realized as a result of a larger percentage of girdle. Similarly, if the initial investment of damaging a tree is equivalent for all trees, the best return on investment may come from almost complete girdling of larger trees.

Distance From Damaged Tree to Nearest Road or Trail

Lutz (1951) reported that, in Alaska, damaged trees were not restricted to locations adjacent to trails and occurred at random. In this study, damaged trees were not restricted to locations near roads or trails and in fact some damaged trees were found several hundred meters from the nearest road or trail. However, on eight of 13 sites, the number of bear-damaged trees that were found in the first distance interval (0-30.5 m) was at least twice the number expected. The assumption of a random distribution of damaged redwood trees throughout these four distance intervals does not appear to be valid.

Fraser (1979) reported that bears were often encountered on roads in early spring in Ontario, Canada and suggested that bears often ate herbage along roadsides during this period. He reported on 28 bear sightings on or near roads which were made between 5 May, 1978 and 31 August, 1978, of which 24 were sightings between 5 May, 1978 and 10 June, 1978. This same pattern may have occurred in coastal Humboldt County. Reported damage has occurred during the early spring months of April, May, and June (Fritz 1951; Lutz 1951; Resner 1953; Glover 1955; Pierson 1966; Maser 1967; Poelker and Hartwell 1973) which coincides with the time reported by Fraser (1979). The black bear may be foraging along roadsides for herbage and, therefore, be more likely to damage trees that occur within a short distance of the road or trail. This may be the reason for the unexpectedly greater number of observed bear-damaged trees in close proximity to roads or trails.

Yearly Bear Damage to Trees

The amount of annual damage to trees by bears varied between sites. The grand mean of 6.0 trees per ha per year suggests that a substantial number of trees could be damaged annually on any one particular site. The variation observed in the annual increment is similar to the variation observed in the mean number of trees damaged per hectare figures. The annual increment does not appear to be related to age of the stand, as the two greatest and the two lowest mean annual increment figures came from 17 and 23 year old sites.

The differences in mean annual increment may be a result of different bear densities, different vegetational compositions, or different management strategies.

Bear Damage-Caused Yield Loss

The percentage of yield loss due to bear damage was highly variable. One site estimate resulted in a projected loss at rotation age of over 54%. Mason and Adams (1987) reported that bear damage may result in as much as a 17% reduction in merchantable board feet/acre. The mean of 21% projected yield loss, which again only included the loss of 100% girdled trees, indicates that Mason and Adams may have underestimated the potential reduction in board feet attributable to black bear damage.

Both Mason and Adams (1987) and Schmidt (1987) reported that damage was heaviest where tree densities were lowest. This study found that basal area (a measure of tree density) and damaged tree density appeared to be related. Two of the three areas with the smallest average basal area were also in the top three of the highest averages of bear-damaged tree density per ha. Alternatively, three of the five areas with the highest average basal area were in the bottom five of lowest average number of bear-damaged trees per ha. Therefore, the results of this study appear to confirm the conclusions drawn by Mason and Adams (1987) and

Schmidt (1987); high tree-density stands appear to suffer less bear damage than low tree-density stands.

Bear-Damaged Tree Density of Rotation-Aged Stands

The investigation of sites at or near rotation age resulted in several conclusions. First, the grand mean of damaged trees per ha was lower in rotation aged stands than in various aged younger stands. This may be a result of those trees previously girdled 100% being already removed, due to death, from the stand prior to the survey and therefore not tallied on the near-rotation aged surveys. Second, the average dbh seems very large compared to average dbh's of younger sites. This average dbh reflects the dbh of the trees as they are now. It was noted by the surveyors that only three of the 175 trees (1.7%) found on the nine sites surveyed had been damaged within the last five years. Therefore, this average is misleading in that it does not reflect the average dbh of trees when they were damaged. Third, the percentage of bear-damaged trees that were redwood was extremely high on all nine sites. The percentage of available trees was not surveyed, so the bears may be damaging redwoods in proportions equal to their availability. Or, it may be that other species of conifers that were damaged prior to the survey were more prone to forces that would remove them from the stand and make them less observable in this type of survey.

Geographic Extent of Bear Damage in California

A limited effort was extended to determine the north-south delineation of where bear damage occurs. No ground truthing was performed for this assessment. The logistics and expenses associated with performing such an effort prevented any scientific collection of data that would enable a clear determination to be made. However, several local professionals were contacted to discuss where they had and had not seen prevalent bear damage. The first report was that bear damage occurred into north Mendocino County and had been observed as far east as Willits, CA (D. Drennan, California Department of Forestry, pers. comm.). This appears to be agreed upon, as another authority reported that bear damage was insignificant in central Mendocino County below Piercy, CA (B. Kleiner, Western Timber Services, pers. comm.). The reasons for the reported decrease south of this area are not known although several possibilities may exist. First, bear densities may be lower, but bear densities are largely unknown throughout California. Second, the available non-vegetational food base (e.g. invertebrates, mammals, carrion) may be such that damaging trees is not necessary for survival and/or nutrition. Third, the vegetational food base may be such that bear damage to coniferous trees is not needed. These are speculative hypotheses that should be examined in further studies.

Effects of Pre-Commercial Thinning on Bear Damage

There has been frequent speculation on the effects that pre-commercial thinning operations have on the levels of bear damage. It is believed by many that bear damage increases after a thinning operation in response to the effects that the operation has on both the structure of the stand and the remaining trees. In order to study such a correlation, at least two stands that were identical except for thinning would have to be compared. On managed timberlands it would be very difficult to find such a situation. Often at least one other variable, be it soil type, bear density, vegetative species composition, and/or any one of a number of other variables, would differ between the two stands. Although this study did survey sites that had been precommercially thinned (e.g. Simpson 1 and Simpson 2, there were no known "replicate" unthinned sites to compare them to). The correlation between thinning and bear damage is a serious question that should be investigated in a situation where the difference can be attributed to the thinning operation only.

CONCLUSIONS

This study produced eight conclusions about black bear damage to regenerating conifers in northwestern California. First, the density of damaged trees is highly variable. However, a mean of 26.5 bear-damaged trees per ha suggests a serious impact on the forest. Second, redwood was the species most often damaged. On 8 of 13 sites, redwood was damaged in significantly greater proportions than it was available. Third, in general, damaged redwood trees had a larger mean dbh than the average redwood tree available on the site. Fourth, all sites investigated had more trees in the 76-100% girdled category than any other category. Fifth, more black bear-damaged trees were observed along roads or trails than were expected. Sixth, the mean annual bear damage to regenerating conifers of 6.0 trees per ha per year may represent a serious problem in northwestern California. Seventh, yield loss due to black bear damage projected to the rotation age (or time of harvest) is highly variable and averaged over 21% yield loss with a high yield loss of over 54%. Eighth, bear damage assessed on near-rotation aged stands indicated that density of bear damaged trees was, again, highly variable, but redwood trees comprised almost all of those trees found damaged.

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