An Overview of University of Alaska Anchorage, ENRI Research on the Spruce Bark Beetle Infestation, Kenai Peninsula, Alaska, 1997–2002

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Abstract—*In the mid 1990s, one of the largest bark beetle infestations seen anywhere in the world occurred on the Kenai Peninsula of Alaska. In one year, the infestation affected over one million acres of spruce in Alaska. This paper presents a coalescence of several aspects of study on the problem, including tree inventory and mortality, regeneration, understory response, a phytomass study, an assessment of mortality inventory methodology, and an assessment of forest health after the bark beetle infestation declined. The basis for the data collection in these studies was a two-phase sampling design (aerial photos and ground plots), established by the author in 1997 and subsequently re-measured in 1998.*

Introduction

The Deep, Dark, Forest by A.S. Harris

Crunch, crunch, crunch,
listen to 'em munch,
it's always time for lunch,
in the deep, dark, forest.

It's awful to behold
the creeping, crawling, mold,
entwining in its fold,
the deep, dark, forest.

The lepidopter-ees,
are eating up the trees,
until the winter freeze,
in the deep, dark, forest.

The parisite-ees hover,
and lunch upon each other,
including their own mother,
in the deep, dark, forest.

Oh Lord, deliver me,
from these awful mysteries,
as I crawl from tree to tree,
in the deep, dark, forest.

I will begin my presentation on this subject with figure 1. It is a graphic display showing estimates of the area impacted in Alaska (primarily in southcentral) by the spruce bark beetle (*Dendroctonus rufipennis* [Kirby]) between 1970 and 2003. These data are based on annual aerial insect surveys made jointly by the Alaska Department of Natural Resources (ADNR), Forestry (ADNR 1996), and the U.S. Forest Service, Office of State and Private Forestry (S&PF).

From this graphic, it is possible to see the progression of the bark beetle population from an endemic state, impacting only about 120,000 acres in 1970, and the increase to epidemic proportions in 1996, when it impacted an estimated 1.1 million acres. It is apparent that the bark beetle has eaten itself out of house and home until it only impacted about 54,000 acres in 2002.

The primary spruce species under attack were white spruce (*Picea glauca* [Moench] Voss) and Lutz spruce (*Picea Xlutzii* Little), although, in this study, some bark beetle presence was found in stands of black spruce (*Picea mariana* Mill. B.S.P.), and Sitka spruce (*Picea sitchensis* [Bong.] Carr.).

By 1995, there was a great reservoir of unique natural resource information to be gained from an inventory of the spruce bark beetle infestation on the Kenai Peninsula, and there certainly was a need to evaluate the changing forest health condition related to that epidemic. In 1997 and 1998, the University of Alaska Anchorage (UAA), Environment and Natural Resources Institute (ENRI) conducted two seasons of field measurements, resulting in six technical publications and two poster papers. It is the purpose of this paper to summarize those presentations.

In 1996, the University of Alaska awarded a $27,000 grant from its Natural Resources Fund to ENRI to conduct a field study to evaluate the inventory and mortality of the Kenai Peninsula forest stands during the summer of

YEAR	ACRES
1970	119,800
1975	102,366
1980	354,537
1985	290,394
1990	232,406
1991	375,000
1992	600,000
1993	700,000
1994	610,200
1995	893,900
1996	1,133,000
1997	563,700
1998	316,800
1999	253,300
2000	120,900
2001	104,200
2002	53,600
2003	92,800

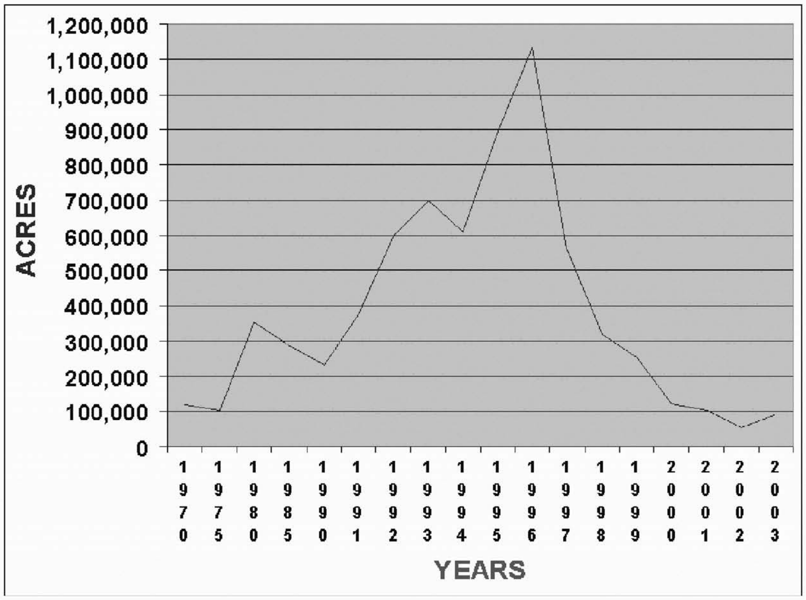

Figure 1. Alaska Acres Impacted by Spruce Bark Beetle 1970 to 2003.

1997. The objective of this study was to conduct a study of five-year spruce mortality and spruce regeneration and the effects of inhibiting vegetation (grasses, shrubs, etc.) on spruce regeneration on a pilot area within the region of the Kenai Peninsula that was road accessible.

Specifically, the objective was to answer the following questions:

1. What was the estimated area of High, Moderate, and Low intensity bark beetle impact areas?
2. To what extent was the bark beetle impacting growing stock, especially for white and Lutz spruce? What size trees were being attacked? What percent of the trees were being impacted? What was the ratio of live tree growth to mortality?
3. What was the level of regeneration in the above impact areas, especially for white and Lutz spruce? Was there any indication that grass was inhibiting regeneration of spruce where the spruce overstory was killed by beetle attack.

The results of the 1997 study were published in a UAA ENRI report (LaBau 1998). In the fall of 1997, another Natural Resource Fund award in the amount of $25,000 was made to ENRI to revisit the 1997 plots and evaluate a one-year impact of the bark beetles and to try to collect fuel- loading information associated with the bark beetle kill. It was also decided to evaluate the efficacy of sampling plot designs in capturing mortality information. The number of ground plots sampled was increased in the 1998 study.

The objectives of the 1998 study were twofold:

1. Expand the 1997 study, primarily to collect data to develop a forest fire fuels model (Rothermel1983) as well as collect additional data on total vegetation phytomass and down wood biomass.
2. Expand the study sample size and ground plot configuration to evaluate the efficacy of sampling plot designs in capturing mortality information.

The results of the 1998 study were published in a UAA ENRI report (LaBau 2002). Additional results were presented at the Carbon Sequestering Conference in Anchorage, AK, in May 2000 (LaBau and Mead 2001), giving an overview of what the phytomass distribution and fuel loads were relative to the 1998 re-inventory study.

The results of the study to evaluate efficacy of the sample plot designs can be found in a paper presented at an IUFRO and SAF Inventory Working Group Conference in Boise, ID in August 1998 (LaBau and Hazard 2000).

Finally, an evaluation was made of forest health of the residual live spruce and birch (*Betula paperifera* Marsh) on the Kenai Peninsula. The results of that evaluation were published in the 2002 National Society of American Foresters Convention in Winston Salem, NC, in October 2002 (LaBau and Boughton 2003).

As previously mentioned, the purpose of this presentation is to provide an overview of the results of those various studies.

Methodology

The first step of the study was to establish the sample unit. A sample unit boundary was laid out to encompass the major areas of bark beetle attack, which had been mapped up through 1995 on the S&PF maps for the Kenai Peninsula (see Map A). This boundary was established following section, township, and range lines so that land areas could be assigned to the sampled area at a later time. Subsequent evaluations of the sample area using U.S. Bureau of Land Management (BLM) land records resulted in an estimated 2,802,569 acres for the entire sample unit.

It had been predetermined that there was not sufficient funding to sample areas beyond 6 miles from the road system (designated as "inaccessible" areas). The final "accessible" sampling unit was 1,232,587 acres in size. Given the limitations of funding, it was decided that a statistical design should be utilized that would provide a maximum return for the money. It was felt that the study should take advantage of ancillary information from aerial photography, as well as from the ADNR/S&PF aerial insect survey maps, and attempt a stratification of the populations of interest to the greatest degree possible.

The sampling design chosen was a two-phase (double) sampling (Bickford 1952) approach, stratifying the populations of interest on high altitude color infrared (IR) aerial photos at the first phase. For both the "Accessible and Inaccessible" Zones the photos were interpreted (15 points systematically gridded around each photo center) and each point was assigned strata codes based on photo interpretation techniques. A minimum area of about .4 hectares (one acre) was evaluated at each photo point. To provide a strata of bark beetle attack intensity, four years (1992-1995) of ADNR insect aerial survey maps (ADNR 1996) were overlain on 1:250,000 USGS maps of the Kenai Peninsula, and bark beetle impact intensity strata were assigned as follows:

- *High Impact*: Photo point falling inside an S&PF mapped insect attack polygon.
- *Moderate Impact*: Photo point falling within one mile of an attack polygon.
- *Low Impact*: Photo point beyond one mile of a polygon, but within one mile of a "dot" on the S&PF maps, indicating an area of isolated attacks.
- *No Impact*: Photo point beyond one mile of a polygon or "dot."

The data collected at the phase 1 level at each photo point included:

- USGS Map Quad (1:250,000)
- Photo Flight Year
- Photo Flight Roll
- Photo Flight Number
- Photo Grid Point Number
- Forest Type
- Accessibility Type
- Distance to Road
- S&PF Insect Impact Intensity

A recording form and a manual of photo interpretation procedures and coding instructions were prepared. Over 2600 photo plots were evaluated within the area selected, of which about 1100 were in the "accessible" zone. These data were entered directly into EXCEL spreadsheets in order to facilitate summarization later.

In phase 2, a random sub-sample was selected in proportion to photo interpreted bark beetle impact classes from the strata of phase 1. This sub-sample was then visited on the ground to collect more detailed data on the populations of interest. In this study, ground data were desired to obtain more detailed information about how many trees are attacked or killed, the size of the trees killed, regeneration following the bark beetle killing the overstory, and the response of vegetation that might inhibit tree regeneration. Forest health data were also collected following National Forest Health Monitoring (FHM) procedures (Conklin 1996).

In establishing the phase 2 sampling frame, because funds were not available to use aircraft to travel into inaccessible areas, only the "accessible" zone photo points were sampled. All nonforest, water, and hardwood photo calls were assumed to have been made without error, and having no spruce forest present, these photo plots did not need to be ground visited. Therefore, the sampling frame for the ground plots consisted of the photo points from just the four impact strata within the "accessible" zone, giving a sampling frame of 456 photo points. Ten phase 2 plots were selected at random from each of the four impact strata in the "accessible" zone giving a total of 40 ground plots to visit.

After receiving permission from the landowners to access the plots on the ground, the ground plots were visited and data measurements taken and observations made during the summer of 1997 by a two-person crew trained in measuring forest inventory and forest health monitoring plots.

Recording forms, a manual of ground plot measurement procedures, and coding instructions were prepared as part of the study plan. In 1997, the ground plots were visited in order of their draw until all funds were expended. This resulted in the visitation and data collection for seven ground plots in each of the four strata (28 ground plots). Each ground plot consisted of four subplots on which the live tree and vegetation information was measured or observed and a full acre plot taken to record all trees that had died within the previous five years. Accepted U.S. Forest Service guides were used to estimate 5-year mortality. For the 1998 re-measurement, twelve more ground plots were added (three in each strata). A 6-year mortality criteria was applied and a larger mortality plot (1.5 acres) was laid out. All measurements were recorded in metric units. A diagram of the ground plot layout is shown in figure 2.

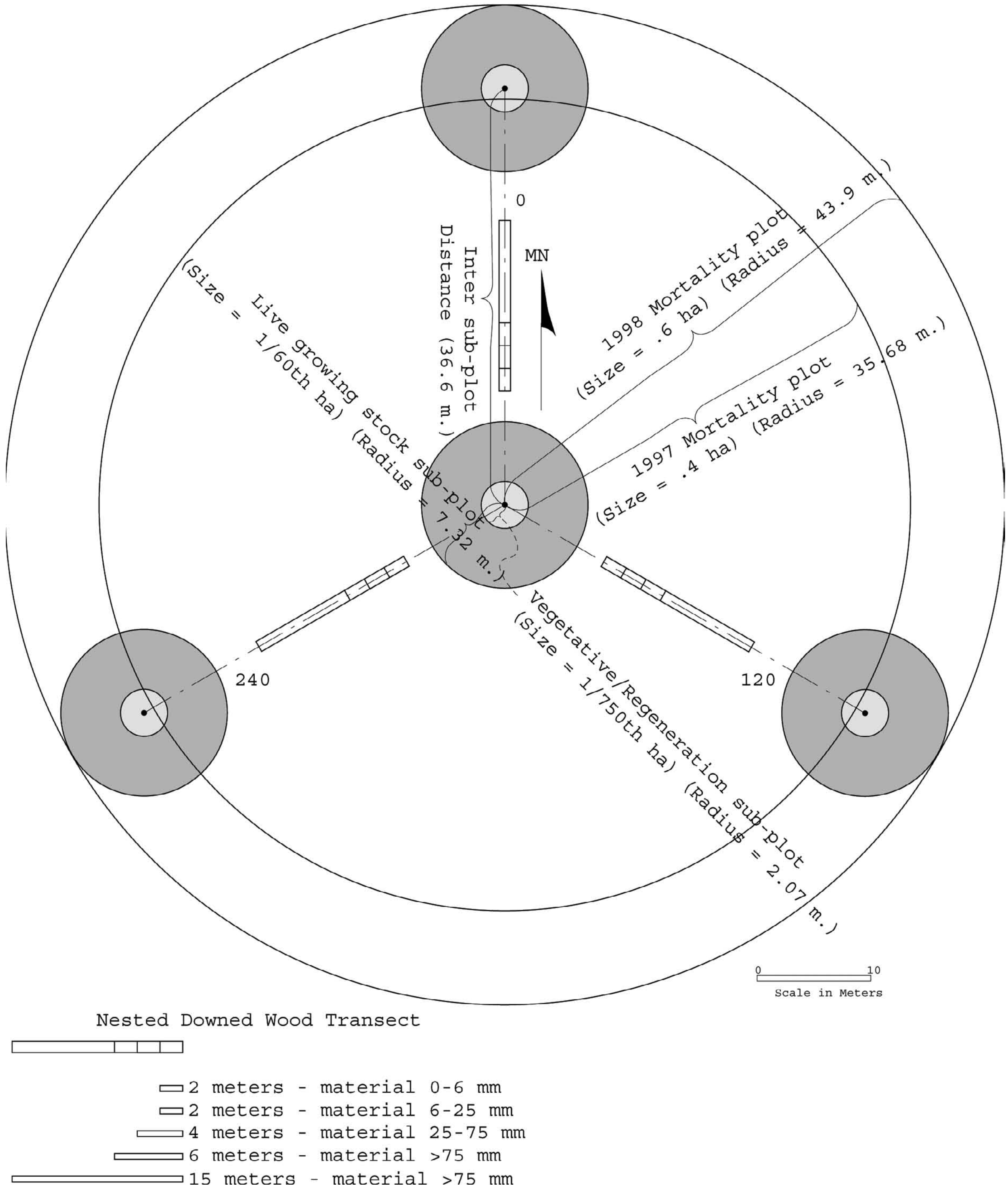

Figure 2. Spruce Bark Beetle Study Plot Schematic, 1998.

The following data were collected in the various categories of interest:

- Live tree tally for all trees over one inch in diameter at breast height recording:
- Species, diameter at breast height, dominance, total height, and beetle attack if any. Forest health observations were also made relative to crown ratio, density, dieback, and transparency. Assessments of damage to the tree were also made according to type of damage, severity, and location on the tree. Finally, all trees were monumented by recording the distance and azimuth from the plot center to the tree.
- Regeneration of seedlings over 0.3 meters tall recording:
- Count by species, height and age.
- Mortality trees (trees dying within the last five in 1997 or six years in 1998) were tallied on one acre in 1997 and on the 1.5 acres in 1998, recording:

- Species, diameter at breast height, dominance, total height, cause of death, estimated year of death, and beetle attack if any. All mortality trees were monumented by recording the distance and azimuth from the plot center to the tree. The mortality plot size was enlarged to 1.5 acres in size in 1998 to accommodate a planned mortality sampling accuracy test using a Chi Square analysis (Freese 1960).
- Plot ground vegetation composition—percent cover of:

Mosses, shrubs, grasses, herbs, seedlings under 1 foot tall.

- Plot summaries of forest condition on each of four subplots, recording:

Forest type, stand size class, stand age, slope, aspect, and past disturbance.

In the 1998 study, two more data sets were collected, recording:

- Downed wood on three 45 foot transects to help assess fuel loads (Brown 1974).
- Understory phytomass in tree seedlings, shrubs, grasses, forbs, mosses, and lichens (Yarie and Mead 1988). Understory profiles would be constructed to assess phytomass of the lower vegetation.

Aboveground phytomass, as oven dry weight per unit area, would be derived from:

- Sapling trees (>1.0 inch but < 5.0 inches diameter at breast high (dbh)),
- Live trees (> 5.0 inches dbh),
- Mortality trees (> 1.0 inches in dbh)

At the end of the day, all data were coded into EXCEL spreadsheets in a laptop computer to facilitate easy analysis at a later date. At the end of the field season, a complete check was made comparing the original field data sheets with the EXCEL summaries. All discrepancies of this type were resolved prior to any data analysis being made.

During the analysis phase, cubic foot volumes were computed using formulae provided by the USFS's Anchorage Forestry Sciences Laboratory. These were the same formulae used in their most recent inventory of the Kenai Peninsula forest resource (van Hees and Larson 1991).

Also, during the analysis phase, a decision was made to evaluate tree health. It was therefore necessary to establish a method for determining poor health trees ("at risk" trees). With the consultation of various colleagues familiar with tree health criteria, a matrix of tree condition factors was developed that could be used to establish the "at risk" tree class (LaBau and Boughton 2003). The criteria in that matrix included crown condition, such as ratio, density, dieback, etc. and presence of significant tree damage, such as conks, wounds, broken or dead branches, and dead tops.

Results (1997 and 1998 Assessments)

Area Estimates

Area estimates were derived for strata classes along with respective standard errors for the 1,232,587 acres in the "accessible" zone. Of the 1.2 million acres evaluated with photo and ground plots, the study inferred that about 515,000 acres was in forest, and of that forested area, about 33.3 percent was in High impact areas, 25.0 percent in Moderate impact areas, 19.8 percent in Low impact areas, and 18.9 percent in the No impact areas. The remaining 3.1 percent was in unaffected pure hardwood stands.

About 78 percent of all forest land (conifer, mixed, and hardwood) was impacted by the bark beetle. Over 58 percent was within the combined High and Moderate impact areas. One encouraging finding was that when variances and percent sampling errors were evaluated for the four combined strata of interest (High, Moderate, Low, and No), the percent sampling error for the combined strata was a very respectable 5.38 percent.

Growing Stock Tree Inventory Findings

Standard report tables of cubic foot volumes were prepared, but they will not be the focus of this report. For detailed information in that regard, see LaBau (1998).

Six-year Spruce Mortality Findings

For the plots measured in 1997, it is estimated that 32.2 percent of the basal area of white and Lutz spruce that was alive in 1992 had been killed by the bark beetle. However, the 1998 study showed a dramatic one-year increase in mortality, resulting in 41 percent of the 1992 white and Lutz spruce being killed, primarily by bark beetles. The occurrence of spruce mortality followed the expected trends set forth when stratifying areas into the insect impact strata.

About 57 percent of all spruce mortality occurred in the High insect impact class, with more than 80 percent of all spruce mortality occurring in the High and Moderate impact classes. The 1998 study showed a one-year increase in mortality of about 83 percent for all forested areas, with about 106 percent increase in the High insect impact class. This increase in one-year mortality occurred, despite a decrease in rate of bark beetle spread, as observed in the 1997 and 1998 S&PF aerial surveys (fig. 1). This implies that although the rate of spread was decreasing, the bark beetles were making heavy impact on the stands that had already been infected by them in prior years.

The bulk of the insect mortality occurred in trees 10 inches in diameter or larger. However, as the insect population began to kill most of the larger trees, they moved into smaller trees, some as small as three inches. Further, as the live white spruce and Lutz spruce disappeared, the beetles also killed even black spruce as small as 3 inches dbh.

Regeneration Findings and Effect of Grass Invasion

Regeneration rates for white and Lutz spruce appear to be about at par with what forest management minimums are for stocking. The High impact stands had the most regeneration of seedlings (under 1 inch diameter). Regeneration plots in these areas showed about 450 white spruce seedlings per acre and an additional 1500 seedlings per acre from birch, aspen, and black spruce. The other three strata (Moderate, Low, and No impact) had a regeneration rate of from 150 to 407 spruce seedlings per acre and 557 to 1500 other species. The Chugach National Forest tries to manage for about 300 seedlings per acre in their white spruce forests. Birch regeneration is quite high, but survival to tree size for any given birch seedling is greatly limited by moose browsing. About 67 percent of the birch seedlings showed signs of moderate to severe browsing.

Because these studies were limited to two years, it was not possible to establish definitive measurements of grass invasion. However, it was apparent that the stands where most of the overstory had been killed by bark beetle attack showed higher levels of grass in the understory, and this would inhibit establishment of spruce seedlings, and where seedlings did get established, there was evidence of the spruce seedlings being damaged by "lodging" due to the dead tall grass going down and pushing the seedlings down with it in the fall and winter months.

Phytomass Findings–Fuel Loading Implications

- Phytomass was summarized by five vegetation components (live trees, six-year mortality trees, saplings, understory plants, and downed wood). The most important findings for the tree components were:
- The live tree component of the aboveground vegetation contained more phytomass than the remaining components combined. Live trees accounted for 77 percent of the aboveground phytomass in the No impact class.
- The highest proportions of phytomass in the six-year mortality component occurred in the Moderate (32 percent) and High (29 percent) insect impact classes. Only 2 percent of the phytomass was in mortality trees in the No insect impact class.
- Phytomass in sapling trees varied between 2.5 percent and 6.0 percent across the four insect impact classes. Most saplings were present before the bark beetle seriously impacted the Kenai forests.
- Understory vegetation made up about 2 percent of the total phytomass in each insect impact class. Increases in understory phytomass resulted from overstory mortality and increased sunlight reaching the understory.
- Shrub phytomass accounted for over 40 percent of the understory phytomass in three of the four insect impact classes. Shifts in shrub phytomass in response to reduced conifer overstory were not apparent.
- There was an inverse relationship between conifer-seedling phytomass (29 percent) and the mass of grass and forbs (16 percent). Grass phytomass was three to four times greater in the High and Moderate insect impact classes than in the Low and No impact classes. This tends to support the suspected trend of increasing densities of grass and forbs where overstory is decreases, and supports the theory that in beetle-killed forests increasing grass cover may impede conifer regeneration.
- Hardwood seedling phytomass was four to ten times larger in the High and Moderate insect impact classes than in the Low and No impact classes suggesting a hardwood invasion in response to increased light under the beetle-killed conifer stands.
- Moss phytomass was inversely related to severity of the beetle infestation. Moss was 6.3 percent, 9.2 percent, 8.3 percent, and 10.5 percent of the understory phytomass in the High, Moderate, Low, and No insect impact classes, respectively. Opening of the conifer overstory increased light intensity and drying of the understory vegetation, thus reducing moss presence.
- Lichens were less than 1 percent of the understory phytomass in all impact classes.

Down-Wood Findings–Fuel Loading Implications

- The downed wood component is important in modeling fuel loading and wildfire potential. The following are some of the implications of this study:
- As beetle-killed spruce fall, the potential for serious ground fires increases. As of 1998, few of the standing beetle-killed spruce had fallen. The downed wood in

the highly impacted areas, where bark beetle attacks were generally less than 10 years old, averaged 21.4 metric tons per hectare. This compares reasonably with accumulations found in stands impacted for 5 and 9 years which showed, respectively, about 16 and 22 metric tons per hectare of downed wood (Schulz 1995).

- Plots in the No insect impact class had most of the large Sitka spruce and hemlock trees. When these trees mature and fall, the ratio of down to standing wood inflates due to the large size of the dead material.
- The combined dead material in standing mortality and downed wood comprises 54.5 percent, 50.0 percent, and 33.0 percent of all phytomass in the High, Moderate, and Low beetle impact classes, respectively. As more of the surviving white and Lutz spruce are killed, these percentages will increase in all impacted areas.

Findings Relative to Forest Health of Residual Stands

- Only about 5 percent of the residual white and Lutz spruce trees were rated as having "at risk" tree health in 1998, comprising 9.5 percent of the spruce basal area.
- About 26 percent of the residual paper birch trees were rated as having "at risk" tree health in 1998, comprising over 35 percent of the birch basal area.
- The paper birch, when evaluated on a basal area basis, was found to have almost four times as much basal area in the "at risk" tree health class as the spruce.
- When assigning tree health, it is important to not just evaluate crown conditions, but to also include tree health risks, such as conks, wounds, and insect attacks.
- About 24 percent of the white and Lutz spruce trees still alive in 1998 were under attack by bark beetles.

Findings Relative to Mortality Sample Plot Evaluation Using Chi Square

For over a decade, a debate has been going on as to how well the four-point cluster of 1/24th acre plots (1/6th acre sample in total) (Conklin 1996) would capture the Poisson distributed population of mortality trees. The efficacy of that four-point cluster design is very important when considered in the context of measuring mortality to assess forest health. For the past decade, the four-point cluster has been comparatively evaluated against a larger 1-acre plot throughout the forests of California, Oregon, and Washington.

To test the efficacy of the cluster design in the epidemic beetle attack situation of the Kenai, a plot 1.5 acres was laid out (completely encompassing the 4-point cluster), and all trees 5 inches and larger dying between 1992 and 1997 were measured and stem-mapped, noting if they also occurred on the four point cluster.

Four Chi Square tests of accuracy (Freese 1960) were run, one for each of the strata in the study, with 10 pairs of data being tested in each strata, providing 10 degrees of freedom for each strata tested. For the ten degrees of freedom in these tests, the Chi Square threshold for rejecting the null hypotheses at the .05 level is 18.31. The larger 1.5 acre plot was assumed to capture the "true population" for the purposes of this test. However, it is recognized that the larger plot population is still from a sample, and is not, in fact, a "true population" statistic.

For all four of the strata evaluated, the null hypotheses were rejected at the .05 level, implying that the tally of mortality trees on the four-point cluster is significantly different from the tally on the 1.5 acre plot, and that the four-point cluster plot did not give estimates of mortality as accurately as the larger 1.5 acre plot. More details of this analysis can be found in LaBau and Hazard (2000).

Summary

In summarizing the findings of the two UAA/ENRI bark beetle studies there are several points that should be highlighted. The author encourages those interested in more detail to read the original papers. The most important findings of the various papers are listed below:

- Of the white and Lutz spruce alive in 1992, by 1998, 41 percent had been killed by the bark beetle. By the turn of the century, the bark beetles killed most of the oldest and most vulnerable spruce in the study area.
- As expected, the largest numbers of mortality trees were found in the High and Moderate impact classes.
- The stratification system used in this study worked well, yielding a sampling error of only 5.4 percent for the 1.2 million acres of Kenai area forest under study.
- Regeneration of spruce seedlings in the study area was marginal to poor and there was strong evidence that spruce seedling establishment was being inhibited by grass competition and lodging. Birch seedlings were regenerating at a very acceptable rate, but because of heavy moose browse, few would reach growing stock size (5 inches dbh) without severe browsing by moose. As expected, the highest bank of phytomass

was found in the live and dead trees over 5 inches in dbh, with the distribution of phytomass being about equal between the live and dead growing stock trees. This is consistent with the fact that 41 percent of the spruce had been killed in the previous 6 years.

- Understory phytomass was only about 2 percent of that found in the overstory with almost half of the understory phytomass occurring in shrub vegetation.
- There was evidence of an increase in grass phytomass and a decrease in moss phytomass as the crown cover disappeared due to the bark beetles killing the spruce overstory, with grass phytomass in High and Moderate impact strata was found to be up to four times greater than in the Low and No impact strata.
- In evaluating the down wood, the bark beetle killed trees were just beginning to fall down at the time of the study. This was more in evidence in the High impact strata. The down wood component should see significant increase in phytomass in the near future as more spruce trees fall down.
- From a forest health perspective, only about 5 percent of the residual white and Lutz spruce trees were rated as having "at risk" tree health in 1998. However, about 26 percent of the residual paper birch trees were rated as having "at risk" tree health. The paper birch was found to have almost four times as much basal area in the "at risk" tree health class as the spruce.
- In a Chi-square test of accuracy, the standard four-point cluster used by FIA and FHM underperformed the larger 1.5 acre plot. The test was significant at the 95 percent probability level.

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