1995

Changes Over Time in Fuel-Loading Associated with Spruce Beetle-Impacted Stands of the Kenai Peninsula, Alaska

Bethany Schulz

Recommended Citation

Schulz, B. (1995). Changes over time in fuel-loading associated with spruce beetle-impacted stands of the Kenai Peninsula, Alaska. USDA Forest Service, Forest Health Management, Technical Report R10-TP-53, 17 pp.

TECHNICAL REPORT R10-TP-53
CHANGES OVER TIME IN FUEL-LOADING ASSOCIATED WITH SPRUCE BEETLE-IMPACTED STANDS OF THE KENAI PENINSULA, ALASKA

JANUARY 1995

Prepared by:
Bethany Schulz
Bethany Schulz, Ecologist
Forest Health Management
Region 10, Alaska

Approved by:
Edward H. Holsten, Forest Entomologist
Forest Health Management
Region 10, Alaska

Paul Forward, Director
State and Private Forestry
Region 10, Alaska

USDA Forest Service
Forest Health Management
State and Private Forestry
3301 C St., Suite 522
Anchorage, AK 99503

Changes Over Time in Fuel-loading Associated with Spruce Beetle-Impacted Stands of the Kenai Peninsula, Alaska

Introduction

Alaska white, Lutz, and Sitka spruce (*Picea glauca* [Moench] Voss, *P.* x *lutzii* Little, and *P. sitchensis* (Bong.) Carr.) forests are subject to mortality from a variety of causes such as wind, disease, fire, and insect outbreaks. Of all the insects, the spruce beetle (*Dendroctonus rufipennis* Kirby) is the most devastating (Holsten et al. 1991). Ongoing and new infestations currently impact more than 641,000 acres in Alaska, with 295,000 acres located on the Kenai Peninsula in south-central Alaska (USDA 1994).

A variety of impacts are associated with spruce beetle infestations. These impacts include, but are not limited to, the loss of merchantable value of killed trees, long-term stand conversion, changes in wildlife habitat, and increase in fire hazard due to increased fuel loading (USDA 1993). Site specific factors must be considered when predicting the degree of impact and planning for treatment of impacted areas. Following an outbreak of spruce budworm (*Choristoneura fumiferana* [Clem.]) in eastern Canada during the 1960's and 1970's, several studies were conducted to assess fire potential and fire hazard (Stocks 1985; Péch 1993). The mixed conifer forests of central Ontario experienced an abundance of combustible surface and aerial fuels and high fire weather severity, resulting in many fires that were difficult to control (Stocks 1985). In contrast, the pure and mature stands of balsam fir on the Cape Breton Highlands of Nova Scotia had no accumulation of fuels and low fire weather severity; the cool, moist climate of the Highlands hastened the decomposition of dead woody materials (Péch 1993).

As the beetle epidemic continues, land managers must assess impacts and design treatments for areas close to human communities. Their decisions affect those living in the area, and fire hazard is often a central concern to the people who live and/or own property adjacent to beetle-impacted stands. A fire behavior analysis was done for the Cooper Landing area of the Kenai Peninsula in 1990 (See 1990) in direct response to the spruce beetle epidemic. Fire behavior analyses require site specific information on fuels, weather conditions, and topography. A major source of fuel load data had been collected in 1987 by the U.S. Forest Service Forestry Sciences Laboratory (FSL) in Anchorage, Alaska (USDA 1987). While this data set included stands in various stages of beetle outbreak, it did not include stands where trees killed by beetles had begun to break or fall to the ground. The analysis was incomplete due to a lack of local information on the changes in fuel loading conditions 15 years after initial infestation. It was recommended that additional fuels data be collected to reflect the changing fuels conditions (See 1990).

In 1976, Forest Health Management and Forest Research personnel established 30 permanent plots in the Resurrection Creek drainage in south-central Alaska to study the impacts of an increasing spruce beetle population (Werner and Holsten 1982). The outbreak had subsided by 1985 after 48% of the spruce component had been killed, accounting for more than 90% of the commercial volume. In the same time period, only 7.5 trees per acre fell down. An additional 5% of the original live spruce were attacked and killed by the spruce beetle from 1986 until 1991. During the same time period, however, 62.2 spruce per acre fell down; the majority from stem breakage (Holsten et al. 1994). In 1994, a survey of fuel loads was conducted to quantify current conditions the Resurrection Creek drainage.

Objective

The objectives of this study were to survey fuel loads in forest stands where a spruce beetle outbreak initiated 20 years earlier resulted in heavy tree mortality and compare with fuel load data collected from similar stands at earlier stages of beetle infestation. From the comparison, changes in fuel load conditions in unmanaged forest stands with respect to spruce beetle outbreaks on the Kenai Peninsula, Alaska will be better understood.

Methods

1987 Data. In 1987, the Forestry Sciences Laboratory (FSL) in Anchorage, Alaska conducted a forest resource inventory on the Kenai Peninsula in response to the spruce beetle epidemic (van Hees1992). A total of 5,597 photo points was systematically located on 1:60,000-scale high-altitude photographs of the Kenai Peninsula; photo interpretation was used to classify the vegetation at each grid position. Of the total grid points, 12.3 percent were classified as timberland; 129 photo points within the timberland classification were randomly selected for field survey. One aspect of their data collection efforts was to inventory down and dead woody material (USDA 1987).

Data collection methods were based on Brown's "Handbook for Inventorying Downed Woody Material" (1974). Observations of downed woody material, duff depth, fuel height, and grass cover were recorded. Five sample planes of 37.5 ft length were established in each photo point plot. Sampling for downed woody material consisted of tallying woody twigs, branches and stems into size classes as per Brown (1974). Tally results were then computed into load equivalents of tons per acre.

For measurement purposes, duff was defined as the layer from the forest floor surface to, but not including, the decomposed material. Two duff depths were recorded to the nearest 0.25 inch per sampling plane: one in each of the first two adjacent 1.5 ft sections of the sample plane. The "plot point" is the designated beginning point of the sample plane, always located at the most southern end of the 37.5 ft plane. Fuel height is the vertical distance from the bottom of the litter layer to the highest intersected dead particle.

Two fuel height measurements per sampling plane were recorded to the nearest inch, again from the first two 1.5 ft sections. Ocular measurements of all understory vegetation were made, but *Calamagrostis canadensis* (Michx.) Beauv. was the only species of interest for comparison with the 1994 data.

Photo point plots were chosen by sorting the original data base of 129 plots by stand age, forest community type, and level of infestation. The sort first queried for plots where stand age was at least 80 years. Next, several community types, including closed needleleaf stands composed of white spruce, closed needleleaf stands of undescribed type (which equated to Lutz spruce), and open or closed mixed spruce-paper birch (*Picea-Betula papyrifera* Marsh.) community types were selected. Plots were required to be comprised of at least 70 % conifers to ensure a greater conifer than hardwood component for the mixed stand plots.

Forest community type was used as a criteria to ensure similarity to the stands described in the Resurrection Creek drainage in 1974: closed needleleaf forest stands comprised of white or Lutz spruce, with minor components of birch, mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.),and black cottonwood (*Populus trichocarpa* Torr. and Gray). Forest community type is also the most important variable determining the risk of a spruce beetle outbreak (Reynolds and Hard 1991). Mixed spruce-paper birch communities have the greatest overall risk of spruce beetle outbreak. Three of the 35 photo point plot data sets used were from mixed spruce-birch stands, the remainder were closed needleleaf forests of white or Lutz spruce .

Finally, four levels of infestation were sorted, including "uninfested", "potential", "ongoing", and "past" as defined by van Hees (1992). "Uninfested" plots were those plots where no live or dead trees showed any sign of beetle attack. "Potential" infestation were those plots where only live trees showed signs of beetle attack plus plots where live trees and trees dead more than five years showed signs of beetle attack. "Ongoing" infestation were plots where live trees and trees dead less than five years showed signs of beetle attack, and trees dead more than five years may or may not have showed signs of attack. "Past" infestation plots were those plots where only trees dead more than 5 years showed sign of beetle attack.

The queries and sorts of the FSL 1987 data base resulted in four data sets: thirteen uninfested plots, five potentially infested plots, eight plots with ongoing infestations, and nine plots with past infestations.

1994 Data. Thirty one-fifth acre permanent plots were established in 1976 in the Resurrection Creek drainage of the Chugach National Forest, located 10 miles south of Hope, AK (lat. 60° 47' N, long. 149° 29' W). At that time, the average stocking level of the live spruce component was 283 stems per acre. and the average stand age was 148 years. In 1984, a prescribed burn was conducted to improve moose habitat (Werner and Holsten 1982). Seventeen of the original 30 plots were located within the burn, and all overstory and understory vegetation were consumed. The thirteen unburned plots are located at the upper elevations of the drainage (1300 - 2000 ft), and were the focus of the 1994 data collection efforts. These plots represent fuel conditions in the fifth stage of infestation: 20 years after initial outbreak.

Inventory methods were also based on Brown (1974). In contrast to the 1987 FSL survey, three sample planes of 40 ft length were established in each plot, duff depths were recorded at one and four feet from the plot point, and three fuel height measurements were made per sample plane; one for each of three adjacent two-foot-wide vertical partitions, beginning at the plot point. Ocular estimates of grass cover were also recorded.

Data Comparison. Data from all five stages of infestation (uninfested, potential, ongoing, past, and 20 years from initial outbreak) were summarized by plot into estimates of tons/acre fuel loads, average duff depths, fuel heights and grass cover (Appendix 1, 2, 3, 4, and 5). Averages and relative standard deviations were calculated for each data set. Since relative standard deviations were large and assumptions on distribution normality could not be made, nonparametric methods based on medians and ranks were used to compare the data sets (Conover 1980). The Mann-Whitney Test in the nonparametric statistics module of CoStat version 4.2 (CoHort Software) was used to determine if fuel loads from the various data sets were the same. The Mann-Whitney test is the nonparametric version of the two-sample t-test (Conover 1980) Results are summarized in Table 1. The null hypotheses was that the fuel loads from the earlier stages of infestation were equal to or greater than the fuel loads of plots in the later stages of infestation. The alternative hypotheses was that the fuel loads from earlier stages were less than the fuel loads from the later stages.

Results and Discussion

Fuel loads. There is a general tendency for increasing fuel loads in later stages of infestation for all size classes of downed woody material except for the smallest size class (0 - 0.25 in) and for rotten pieces three inches in diameter or greater (Table 1). Duff depths decrease with later stages of infestation, while fuel height and percent grass cover increase. Data sets for each stage of infestation were compared to all other individual data sets using the Mann-Whitney test. Because the Mann-Whitney test is based on ranks and accounts for differences in sample sizes, comparing medians alone does not always reveal

Table 1. Summary of median tons per acre by size class, duff depth, fuel height, and percent grass cover for all stages of beetle infestation.

Stage of Outbreak	Diameter size class, by inches: 0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Duff Depth	Fuel Height	Grass Cover
	Tons per Acre						inches		-% -
uninfested (n=13)	0.17a	0.32a	0.46ab	0.0a	5.57a	7.89a	5.56a	1.80a	0a
potential (n=5)	0.20a	0.51ab	0.45ab	0.36ab	3.44a	7.32a	5.23a	4.70ab	2a
ongoing (n=8)	0.18a	0.61ab	0.34ab	1.68b	2.91a	7.67a	3.64ab	3.38ab	0a
past (n=9)	0.18a	0.64ab	0.91b	1.82ab	5.49a	9.90a	4.10a	2.80ab	0a
20 yrs p.i.o. (n=13)	0.32a	0.89b	1.68a	23.16c	3.90a	35.38b	2.50b	7.22b	50b

Note: Medians followed by same letter within a column denote no significant difference, with level of significance set at 0.01, as determined by the Mann-Whitney test.

where significant differences lie. Thus, some of the significant differences (p = 0.01) reported in Table 1 may not appear to make sense to the casual observer. For example, for the variable "1 - 3" inch diameter class, samples from the "past" and "20 years past" infestation stage are significantly different from each other, but "20 years past" is not significantly different from the earlier stages.

To clarify data interpretation, all data sets collected in 1987 were combined and then compared, via the Mann-Whitney test, to the data set collected in 1994. The results are summarized in Table 2. The trends mentioned previously were followed, except for the "0.25 - 1" inch diameter class, where no significant difference was found. In terms of fire behavior hazard, the most notable results are increased percent grass cover and sound wood pieces three inches or greater in diameter (Figure 1).

Calamagrostis grass cover provides a fine, flashy fuel. In Alaska, *Calamagrostis* can grow to five feet in height in one growing season (Mitchell 1974) and is favored by forest canopy removal (Haeussler et al 1990). Fire spreads rapidly through *Calamagrostis* because of the large volumes of fine dry litter present. Live plant material is resistant to burning, but may not slow the rate of fire spread (Sylvester and Wein 1981).

Table 2. Summary of median tons per acre by size class, duff depth, fuel height, and percent grass cover for each survey year data set.

Year of	Diameter size class, by inches:						Duff	Fuel	Grass
Survey	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	Tons per Acre						*inches*		-% -
1987 (n=35)	0.18a	0.45a	0.45a	0.32a	5.17a	8.88a	4.1a	2.48a	0a
1994 (n=13)	0.32a	0.89a	1.68b	23.16b	3.90a	35.38b	2.5b	7.22b	50b

Note: Medians followed by same letter within a column denote no significant difference, with level of significance set at 0.01, as determined by the Mann-Whitney test.

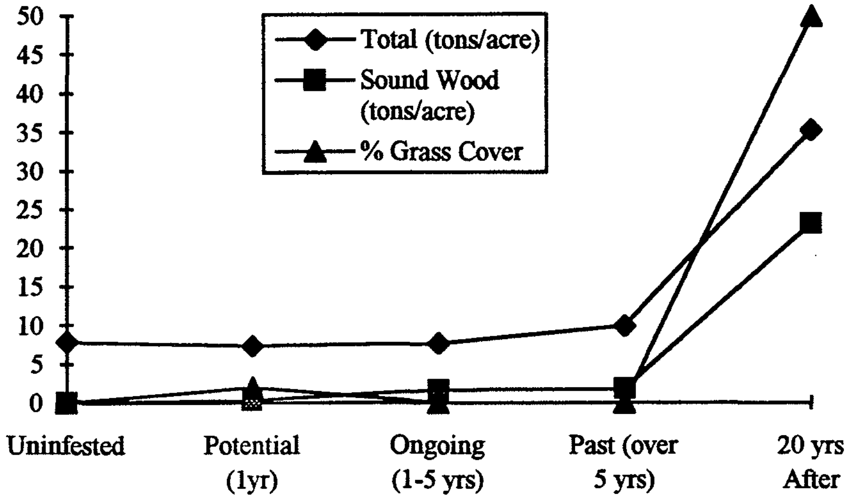

Figure 1. Total and sound wood fuel loads in tons/acre, and percent grass cover at different stages of a spruce beetle outbreak on the Kenai Peninsula,

The increase in total tons per acre was due to the increase in sound wood pieces. In 1987, large sound wood pieces accounted for 3.6% of the total downed wood fuel. In 1994, sound wood was 65% of the total fuel tonnage. Sound wood pieces are the heaviest component of the fuels complex. They do not ignite readily, but once ignited they burn at higher temperatures for a longer period. While climatic conditions and topography must also be used to conduct a complete fire behavior analyses, the combination of flashy fine fuels (grass) with large diameter sound woody materials can result in intense fires that are difficult to control.

Results indicate that ground fuel loads in spruce beetle-impacted stands in the Resurrection Creek drainage are greater than in similar stands surveyed at an earlier stage of the beetle epidemic. Cahill (1977) reported similar findings in Colorado 30 years after a spruce beetle outbreak. The results also support the observations and predictions of fuels specialists who have analyzed conditions on the Kenai Peninsula (See 1990; Vanderlinden 1991; and Rounsaville 1992).

Management implications. A survey was conducted following the Greater Yellowstone fires of 1988, where fuel loads, fire severity, and fire damage in extensively managed, mature forests was compared to that in intensively managed, clear-cut reproduction areas. Some of the mature stands had experienced up to 70% mortality caused by the mountain pine beetle (*D. ponderosae*) since 1960. Survey results revealed that the mature stands had significantly higher fuel loads, and fire severity and damage was greater than in the intensively managed stands (Omi and Kalabokidis 1991).

Among the impacts resulting from large scale spruce beetle epidemics in Alaskan forests is long-term stand conversion from closed-canopy spruce stands to open, grassy woodlands Holsten et al 1994). One way to re-establish spruce stands is to allow a disturbance to occur that will expose mineral soil seed beds where spruce seed will germinate. One such form of disturbance is an intense, or stand replacement fire (Zasada 1972). The fire history of the Kenai Peninsula includes infrequent, but large fires (Vanderlinden 1991).

The Alaska Interagency Fire Management Plan includes a variety of response levels, depending on the resources at stake. Fires in remote, uninhabited areas are allowed to run their course, but are closely monitored. The fuels resulting from beetle-impacted stands are of a nature that would encourage a stand replacement fire. This may be appropriate for remote, wilderness areas, but possibly not for stands in close proximity to human communities.

Care must be taken when extrapolating the fuel conditions found in the Resurrection Creek drainage to other areas of the Kenai Peninsula. The Kenai Peninsula is composed of two distinct geographic regions (Martin et al 1915). The eastern portion, bordered by Prince William Sound, is dominated by the Kenai Mountains and associated glaciers. The climate is considered to be maritime, with cool summers and abundant precipitation. The western portion is dominated by the Kenai lowlands, with rolling to flat terrain resulting from past glacial events. The climate is more continental; with less precipitation, warmer summers, and colder winters than the eastern portion. The Resurrection Creek drainage is within the Western Kenai Mountains Subsection, as defined by the USDA Forest Service ECOMAP classification. The climate is transitional, between marine and arctic continental, with mild summers, cool winters, and relatively low precipitation and snow packs (DeVelice and Davidson 1995).

Summary and Recommendations

Fuel loads calculated for spruce stands in the early stages of spruce beetle outbreak (1987 data) are less than fuel loads calculated for stands that have gone through an epidemic (1994 data). The 1994 data were collected from only one drainage, while the 1987 data were collected from numerous sites on the Kenai Peninsula, although there was an attempt to match stand age and forest community type for comparison purposes.

While the results from this study indicate a significant increase of fuel loads 20 years following the initial outbreak of spruce beetles in the Resurrection Creek drainage, there is a need to collect fuels and weather data from other beetle-impacted areas of the Kenai Peninsula. Emphasis should be placed on those areas in suppression category "Critical" within the Alaska Interagency Fire Management Plan. A series of surveys in particular areas would be most desirable, resulting in a guide to how fuels evolve over time in that area. Data could also be collected in impacted areas that are scheduled for treatment, demonstrating "before" and "after" conditions.

References Cited

Brown, J.K. 1974. Handbook for inventorying downed woody material. U.S.D.A. For. Serv. Gen. Tech. Rep. INT-16. 24 p.

Cahill, D.B. 1977. Net impact of spruce beetle outbreak on the White River National Forest, 1939-1951. U.S.D.A. For. Serv. Rocky Mt. Reg. Rep. 1977. Fort Collins, CO. 18 p.

Conover, W.J. 1980. *Practical Nonparametric Statisics, 2nd Ed.* John Wiley and Sons, Inc. New York, New York. 493 p.

DeVelice, R. and D. Davidson. 1995. Descriptions of the ecological subsections of the Chugach National Forest. (in cooperation with the ECOMAP Team of the Forest Service U.S. Geological Survey).(in review)

Haeussler, S., D. Coates, and J.Mather. 1990. Autecology of common plants in British Columbia: a literature review. Forestry Canada and British Columbia Ministry of Forests. FRDA Report 158. 272 p.

Holsten, E.H., R.W. Thier, and J.M. Schmid. 1991. The spruce beetle. U.S.D.A. For. Serv., Forest Insect and Disease Leaflet 127. 12 p.

Holsten, E.H., R.A. Werner, and R. Develice. 1994. Effects of spruce bark beetle (Coleoptera: Scolytidae) outbreak and prescribed fire on volume, structure, and ground vegetation of a Lutz spruce stand in Alaska. Ann. of Ent. Soc. of America. (in press).

Martin, G.C., B.L. Johnson, and U.S. Grant. 1915. Geological and mineral resources of Kenai Peninsula, Alaska. Washington D.C.: U.S. D. I., U.S. Geologial Survey. 243 p.

Mitchell, W.W. 1974. Native bluejoint: a valuable forage and germplasm resource. Agroborealis. 6(1):21-22.

Omi, P.N., and K.D. Kalabokidis. 1991. Fire damage on extensively vs. intensively managed forest stands within the North Fork fire, 1988. NW Science. 65:149-157.

Péch, G. 1993. Fire hazard in budworm-killed balsam fir stands on Cape Breton Highlands. For. Chron. 69:178-186.

Reynolds, K.M., and J.S. Hard. 1991. Risk and hazard of spruce beetle attack in unmanaged stands on the Kenai Peninsula, Alaska, under epidemic conditions. For. Ecol. Manage., 43:137-151.

Rounsaville, M. 1992. Fuels analysis. Seward Ranger District, Chugach National Forest. U.S.D.A. Forest Service. unpub. 12 p.

See, John. 1990. Cooper Landing spruce beetle fire behavior analysis. Division of Forestry. Alaska Dept. Nat. Res. unpub. 91 p.

Stocks, B.J. 1985. Forest fire behavior in spruce budworm-killed balsam fir. Pages 198-209. *In* Recent advances in spruce budworm research. Proc. CANUSA Sruce Budworm Res. Symp. 16-20 September 1984. Bangor ME. Can. For. Serv., Ottawa, Ont.

Sylvester, T.W. and R.W. Wein. 1981. Fuel characteristics of arctic plant species and simulated community flammability by Rothermel's model. Can J. Bot. 59:898-907.

U.S. Department of Agriculture. 1987. Field procedures for the 1987 Kenai bark beetle inventory, Kenai Peninsula, Alaska. U.S.D.A. For. Serv., PNW Station, Forestry Sciences Lab. Anchorage, AK. 110 p.

U.S. Department of Agriculture. 1993. Forest insect and disease conditions in Alaska. U.S.D.A. For. Serv., Alaska Region Report R10-TP-32. 36 p.

U.S. Department of Agriculture. 1994. Forest insect and disease conditions in Alaska. U.S.D.A. For. Serv., Alaska Region Report. (in press).

van Hees, W.W. 1992. An analytical method to assess spruce bark beetle impacts on white spruce resources, Kenai Peninsula, Alaska. Res. Pap. PNW-RP-446. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

van Hees, W.W., and F.R. Larson. 1991. Timberland resources of the Kenai Peninsula, Alaska, 1987. Resour. Bull. PNW-RB-180. Portland, OR: U.S.D.A., Forest Service, Pacific Northwest Research Station. 56 p.

Vanderlinden, L. 1991. Fire behavior considerations for Cooper Landing Contingency Plan. *In* Pot Hole Lake Fire Contingency Plan, June 3 1991. Alaska Interagency Type 1 Incident Management Team. unpub.

Werner, R.A., and E.H. Holsten. 1982. Mortality of white spruce during an outbreak on the Kenai Peninsula in Alaska. Can. J. For. Res. 13: 96-101.

Zasada, J.C. 1972. Guidelines for obtaining natural regeneration of white spruce in Alaska. U.S.D.A. Forest Service. Portland, OR. Pacific NW Forest and Range Exp. Sta. 16 p.

Appendices

Appendix 1. 1987 survey fuel loads of uninfested plots, in tons per acre by diameter size class, duff depths, fuel, heights, and percent grass cover.

Plot	Diameter size class, by inches:						Duff	Fuel	Grass
ID	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	- - - - - - - - - - - - - - *Tons per Acre* - - - - - - - - - - - - - - -						- - - *inches* - - -		%
1	0.13	0.32	0.23	0.0	12.99	13.66	9.76	0.92	0
76	0.18	0.97	2.91	0.0	30.96	35.03	3.32	4.28	0
77	0.26	1.37	0.46	0.0	3.44	5.54	7.84	13.8	0
85	0.10	0.38	0.23	0.32	3.03	4.06	2.36	1.64	7
88	0.21	0.77	4.08	0.0	4.10	9.15	3.60	3.52	1
96	0.18	0.06	1.13	0.0	0.24	1.61	5.92	2.42	4
97	0.46	0.13	0.45	0.0	9.35	10.39	3.48	1.40	0
98	0.16	0.25	0.91	0.0	2.06	3.39	9.28	1.00	0
100	0.07	0.06	0.0	0.0	1.71	1.85	5.56	1.90	1
106	0.17	0.32	0.23	0.64	5.57	6.93	6.80	1.80	10
108	0.06	0.06	0.0	0.89	8.76	9.78	2.00	0.12	15
112	0.10	0.33	0.47	0.0	7.07	7.89	10.72	1.36	0
116	0.27	1.06	2.03	1.23	8.60	13.21	3.48	5.40	0
average	0.18	0.39	1.01	0.24	7.52	9.42	5.70	3.05	2.93
RSD	59%	104%	124%	176%	105%	92%	52%	116%	165%
Median	0.17	0.32	0.46	0.0	5.57	7.89	5.56	1.8	0

Appendix 2. 1987 survey fuel loads of "potential" infested plots, in tons per acre by diameter size class, duff depths, fuel height, and percent grass cover.

Plot	Diameter size class, by inches:						Duff	Fuel	Grass
ID	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	- - - - - - - - - - - - - - *Tons per Acre* - - - - - - - - - - - - - - -						- - - *inches* - - -		%
95	0.10	0.46	0.69	0.00	2.76	4.01	5.23	1.90	2
104	0.22	0.51	0.45	2.64	9.07	12.89	3.04	4.70	5
114	0.20	1.54	0.23	0.00	5.35	7.32	3.00	7.10	0
127	0.03	0.13	0.00	0.89	0.00	1.05	8.90	2.10	12
128	0.53	3.58	2.79	0.36	3.44	10.70	10.50	16.80	0
avgerage	0.22	1.24	0.83	0.78	4.12	7.19	6.14	6.52	3.8
RSD	87%	114%	135%	141%	82%	67%	56%	94%	132%
Median	0.20	0.51	0.45	0.36	3.44	7.32	5.23	4.70	2

Appendix 3. 1987 Survey fuel loads on plots with ongoing infestations, in tons per acre by diameter size class, duff depth, fuel height, and percent grass cover.

Plot	Diameter size class, by inches:						Duff	Fuel	Grass
ID	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	Tons per Acre						*inches*		*-% -*
33	0.46	1.22	0.9	6.46	5.22	14.27	10.40	11.60	0
34	0.36	1.22	7.60	2.00	0.75	11.93	3.24	4.32	3
69	0.14	0.77	0.00	1.21	1.3	3.43	4.70	7.20	0
72	0.21	0.45	0.23	3.46	4.53	8.88	5.40	6.92	0
73	0.43	1.38	3.67	1.62	23.87	30.97	2.12	2.44	0
99	0.11	0.06	0.23	0.00	0.00	0.40	2.80	0.64	14
109	0.06	0.26	0.00	1.75	0.24	2.31	2.24	0.60	0
140	0.16	0.45	0.45	0.00	5.40	6.46	4.04	1.30	0
avgerage	0.24	0.73	1.64	2.06	5.16	9.83	4.37	4.37	2.12
RSD	64%	68%	164%	101%	152%	99%	62%	89%	231%
Median	0.18	0.61	0.34	1.68	2.91	7.67	3.64	3.38	0

Appendix 4. 1987 Survey fuel loads from plots with past infestations in tons per acre by diameter size class, duff depth, fuel height, and percent grass cover.

Plot	Diameter size class, by inches:						Duff	Fuel	Grass
ID	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	Tons per Acre						*inches*		*- % -*
19	0.18	0.19	0.23	0.00	5.17	5.77	6.07	2.48	3
46	0.18	0.96	0.91	9.46	60.07	71.58	2.72	4.52	0
47	0.08	0.13	1.41	1.82	13.84	17.29	2.84	1.56	0
74	0.26	1.02	1.13	8.02	7.65	18.08	4.10	2.16	0
78	0.78	1.19	1.17	0.00	6.29	9.42	3.56	7.29	0
89	0.07	0.00	0.00	0.00	0.00	0.07	4.40	3.16	4
91	0.26	0.64	0.23	3.28	5.49	9.90	8.04	2.80	0
105	0.11	0.00	0.23	0.04	4.01	4.35	3.84	2.60	5
124	0.25	1.34	1.81	14.53	4.20	22.14	11.10	9.20	3
avgerage	0.24	0.61	0.79	4.12	11.86	10.50	5.18	3.97	1.67
RSD	89%	88%	81%	129%	155%	69%	54%	65%	123%
Median	0.18	0.64	0.91	1.82	5.49	9.90	4.10	2.80	0

Appendix 5. 1994 survey fuel loads of 20 years post-initial-outbreak (p.o.i.)conditions in tons per acre by diameter size class, duff depth, fuel height, and percent grass cover.

Plot	Diameter size class, by inches:						Duff	Fuel	Grass
ID	0 - 0.25	0.25 - 1	1 - 3	Sound 3+	Rotten 3+	Total	Depth	Height	Cover
	Tons per Acre						*inches*		-%-
101	0.15	0.22	1.3	41.28	0.0	42.95	2.83	4.56	60
102	0.58	1.81	5.03	33.1	8.06	48.58	2.83	19.56	20
103	0.32	0.64	0.42	18.27	0.0	19.65	2.5	4.5	20
104	0.02	0.11	2.52	23.05	9.89	35.59	2.33	3.33	40
105	0.89	2.24	1.26	20.99	3.55	28.93	2.75	22.89	70
106	0.39	0.96	2.52	18.12	0.0	21.99	2.17	2.67	50
107	0.54	1.89	2.18	23.16	3.9	31.67	3.00	1.78	5
108	0.4	0.89	1.31	30.22	10.29	43.11	1.75	25.33	30
109	0.28	0.64	2.94	48.77	5.65	58.28	1.42	9.94	60
110	0.21	1.07	2.52	36.24	14.99	55.03	3.25	19.11	70
112	0.06	0.0	1.68	1.32	0.0	3.06	1.38	0.81	30
113	0.43	1.49	1.26	30.42	1.78	35.38	1.17	18.33	65
114	0.11	0.21	0.0	14.32	7.74	22.38	2.58	7.22	60
avgerage	0.34	0.94	1.92	26.10	5.07	34.35	2.30	10.78	44.62
RSD	71%	78%	66%	48%	96%	45%	29%	83%	49%
Median	0.32	0.89	1.68	23.16	3.90	35.38	2.50	7.22	50