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VALIDATION OF THE MOUNTAIN PINE BEETLE RATE-OF-LOSS MODEL IN UNMANAGED LODGEPOLE PINE STANDS OF NORTHEASTERN UTAH

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Validation of the Mountain Pine Beetle Rate-of-Loss Model in Unmanaged Lodgepole Pine Stands of Northeastern Utah

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ABSTRACT

Pest subroutines have been developed for the Prognosis Model, a stand growth-and-yield model developed by the USDA Forest Service, to assist land managers in predicting timber losses due to pest outbreaks. Cole and McGregor (1983) developed a mountain pine beetle rate-of-loss model for lodgepole pine, which was later linked to the Prognosis Model. As the original mountain pine beetle model was developed in Montana, it was necessary to validate its use in lodgepole pine stands of northeastern Utah. Rate-of-loss model simulations were completed using data collected from 35 stands in the Intermountain Region. Projected and observed losses compared individual diameter classes as well as totals, both overall and by stand. The model accurately predicted losses in larger-diameter classes, but failed to accurately [illegible]edict losses in smaller-diameter classes.

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INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the insect most destructive to lodgepole pine (*Pinus contorta* Dougl.) forests in western North America. Mountain pine beetle often kills between 70 and 90 percent of lodgepole pine within a stand; as a result, forest managers in the Intermountain West have less than a 50-percent chance of growing lodgepole pine to 16 inches in diameter (Amman and Schmitz 1988; Roe and Amman 1970). With such a high probability of loss, resource managers are interested in models that accurately predict future impacts of mountain pine beetle on lodgepole pine stands. When linked to growth-and-yield models, the mountain pine beetle rate-of-loss model (Cole and McGregor 1983) increased the accuracy of growth-and-yield predictions within western lodgepole pine stands (Cameron et al. 1990). These models assist land managers in identifying situations in which silvicultural activities directed against mountain pine beetle may have the highest rate of return.

Lodgepole pine stands in northeastern Utah recently experienced devastating losses due to an extensive mountain pine beetle epidemic (1979-1987). Populations of mountain pine beetle have since collapsed, providing an opportunity to collect stand loss data in order to compare actual losses with model projections

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and validate predictive models, such as the rate-of-loss model. For this evaluation, validation is defin as the process of building or reducing confidence in the ability of the model to approximate the behavi of beetle-induced mortality in lodgepole pine stands of northeastern Utah (Gillespie et al. 1990).

THE PROGNOSIS MODEL

The Prognosis Model (Stage 1973; Wykoff et al. 1982) is the growth-and-yield model most widely used by Forest Service land managers in the western United States. The model was designed to predict stand growth and structure under various management scenarios.

The Prognosis Model is an individual-tree, distance-independent growth-and-yield simulation model that simulates stand development by predicting growth, mortality, and the impacts of various management activities for a sample of trees within the stand (Wykoff 1985). The model uses available forest inventory data to predict diameter and height increment, changes in crown sizes, and tree mortality over time. The Prognosis Model periodically summarizes stand conditions in terms of stand density and yield, and is capable of simulating management activities to explore planning alternatives. The various causes of mortality are not represented, and catastrophic mortality factors are not accounted for outside of regional mortality averages (Crookston 1978; Crookston and Stark 1985). Pest mortality models linked to the Prognosis Model modify losses in the simulated population of trees to reflect the effects of a single pest. This accounts for more realistic mortality factors and should greatly improve Prognosis Model stand projections.

THE RATE-OF-LOSS MODEL

Cole and McGregor calibrated their rate-of-loss model using data collected in Montana. Originally developed and integrated with the Insect and Disease Damage Survey Model (INDIDS) (Bousfield 1985), the rate-of-loss model has since been linked with the Prognosis Model. Validation is now under way to test the effectiveness of the model in predicting beetle-caused mortality in other states.

The rate-of-loss model is a deterministic computer model that estimates annual tree and volume losses and longevity of infestation based on existing stand conditions. The rate-of-loss model is easy to use in conjunction with the Prognosis Model, requiring only basic stand inventory data and limited knowledge of beetle biology.

The rate-of-loss model simulates mortality of lodgepole pine by reducing the number of trees per acre represented by the Prognosis Model's sample trees. Mortality is simulated for each incremental 2-inch diameter class based on: (1) the number of currently infested trees in that diameter class and (2) the probability, q, of an individual tree not becoming infested. The mortality equation developed by Cole and McGregor calculates tree mortality as follows:

$$D_{t+1} = G_t(1-q^{D_t})$$

where

D_{t+1} = number of infected trees per acre at time t+1 in each diameter class

G_t = number of growing trees per acre at time t per diameter class

q = probability of an individual tree surviving one year

= $(G_{t+1}/G_t)^{(1/D_t)}$

D_t = number of trees infested at time t

The value q is an assumed constant within each diameter class and is based on probabilities derived from the original Montana data set (Cole and McGregor 1983).

Since the probability of mortality (1-q) is highest for largest-diameter trees, the model removes the largest trees at the fastest rate, progressing downward through a 5-inch-diameter class limit. Mountain pine beetle rarely attacks small diameter trees; consequently, stems 5 inches and smaller are given zero probability of infestation. The rate-of-loss model projects losses due to mountain pine beetle for a preset 10-year cycle. Due to model dynamics, lodgepole pine mortality peaks in the first 2 to 4 years of an epidemic, followed by decreasing annual mortality for the remainder of the cycle. This results in model projections that simulate actual mountain pine beetle epidemic cycles, even though these cycles often last fewer than 10 years.

STUDY SITE

The Ashley National Forest is located in northeastern Utah on the north range of the Uinta mountains. Many of the forest stands consist exclusively of even-aged lodgepole pine. These stands have recorded cyclic mountain pine beetle epidemics since the 1940s, and offer excellent opportunities for study. The most recent outbreak began in the late 1970s around Greendale Junction, and intensified in the Flaming Gorge National Recreation Area. Epidemic infestation peaked in the early 1980s, when mortality increased from 60,000 trees to 3.5 million trees. Populations of mountain pine beetle returned to endemic levels by 1988.

METHODS

Two groups of data were used for model simulations in this study: data taken before the outbreak of mountain pine beetles and data taken after the outbreak. In 1972, prior to the latest mountain pine beetle epidemic, Forest Service timber staff established several permanent variable-radius plots within the study area. Ten variable-radius plots were systematically surveyed and mapped within each sampled stand. Forest Pest Management (FPM) staff relocated these plots and updated data from these stands in 1987, at the end of the mountain pine beetle outbreak. These surveys provided data sets before and after the outbreak in fourteen stands (numbered 1-14).

Data sets from the 1972 survey were used to project beetle losses. Using the Prognosis Model, stands 1-14 were allowed to "grow" for seven years, at which time the rate-of-loss model was initiated to project mountain pine beetle losses over a 10-year cycle (1980 through 1989). These 1989 mortality projections were compared to observed mortality data sets collected in 1987. Because the 1989 modeled projections and the 1987 observed data both represented endpoints in the mountain pine beetle epidemic, they were considered suitable for comparison.

In 1989, Forest Pest Management personnel surveyed twenty-one additional lodgepole pine stands (numbered 51-71) in the study area. Variable-radius plot data were collected on all live trees and recent mortality. Tree mortality was identified as due either to mountain pine beetles or other causes: recent mountain pine beetle-induced mortality was identified by larval galleries and blue stain. These data were used as the basis for the second simulation.

The 1989 data had to be manipulated in order to obtain the necessary starting data sets to run rate-of-loss model simulations. To simulate stand conditions prior to the beetle epidemic, (1) recent mortality needed to be changed to "live," and (2) live trees needed to have eight years of potential growth subtracted (backdated) from their size at the time of measurement. The latter was considered necessary because trees in larger diameter classes have much lower q values (probability of survival) than trees in smaller diameter classes: tree growth from 1980 to 1989 could have resulted in certain trees shifting into larger diameter classes, significantly altering mortality figures; not reducing diameter sized before running the simulation could result in model output that overestimates beetle-induced mortality.

The need for backdating tree size was examined in greater detail. In a previous validation effort, Cameron et al. (1990) found that backdating stands significantly changed modeled mortality rates. To verify this, backdating was experimentally conducted on three stands of the current study to observe differences in basal area mortality between backdated and non-backdated counterparts. Obtaining 8-year growth increment cores from live trees would have provided the most accurate estimate of past growth, but since these data were not available, the Prognosis Model was used to simulate an 8-year growth period. Live trees sampled in 1989 were “grown” for 8 years in low-density conditions, yielding maximum growth. This growth was then subtracted from the original live tree data, rate-of-loss simulations were run with both sets of data, and the results were then compared. Unlike the Cameron study, no significant difference was found between mortality projections of backdated and non-backdated stands.

Because lodgepole pine grows relatively slowly in the Ashley National Forest, and because almost all trees in the more sensitive, larger diameter classes had already been killed by mountain pine beetles, very few trees were assumed to have shifted into the larger diameter classes. As a result, stands 51-71 were not backdated, with the assumption that changing recent stand mortality to "live" would sufficiently resemble stand conditions prior to the beetle epidemic (Cameron et al. 1990, Gillespie et al. 1990). The rate-of-loss model was then run.

Projections run from the two data groups, stands 1-14 and stands 51-71, were statistically compared to determine differences in mortality projections. No difference in mortality projections was observed between the two simulations, as the simulations seemed to over- and under-predict mortality with equal frequency (see Figure 1). As a result, the two simulations were given equal weight in our analysis.

Some unavoidable problems existed with both data sets, which may have increased some of the variability in the rate-of-loss model output. Stands 1-14 were plots established in 1972, but were subsequently abandoned. Reestablishing these plots, finding exact plot centers, and accounting ffor every previously recorded tree proved challenging. In addition, these plots were originally surveyed using a basal area factor (BAF) of 40. This very often provided a very small number of trees sampled per plot. Stands 51-71 were surveyed using a BAF of 20, providing a larger sample of trees. However, as previously discussed, one data set collected approximately 10 years after the actual beetle epidemic began had to be manipulated to approximate stand conditions in 1979. More confidence will be gained in future validation efforts with data collected from well-established permanent plots.

Data from all 35 stands were used to generate 10-year mountain pine beetle mortality projections. Table 1 lists stand attributes prior to the beetle infestation. The total number of dead trees and basal area mortality figures were projected for each stand. Statistical comparisons between model projections and observed values were conducted to determine the model's ability to predict mountain pine beetle mortality for each stand. Projected stand values were also compared with observed results for each of the eight diameter classes (5-6.9, 7-8.9, 9-10.9, 11-12.9, 13-14.9, 15-16.9, 17-18.9, and 19+ inches) to identify where model bias occurred.

Results were analyzed using tree mortality and basal area mortality. Results varied little between these two measures. In addition, Gillespie et al. (1990) found little difference between basal area (ft^2/acre) and volume projections (ft^3/acre) in their validation analysis. As a result, basal area estimates are used for this discussion, even though they relate to both tree number and volume estimates.

RESULTS AND DISCUSSION

Figure 1 shows observed tree mortality and basal area mortality vs. rate-of-loss model projections for each stand. The dashed line represents the condition in which Y = X (observed basal area mortality = projected basal area mortality: the restricted model). If the rate of loss due to mountain pine beetle was projected with high accuracy (low bias) and high precision (low variance), all points would fall on or near this line. (Note that a model may be highly accurate, but have low precision (high variation), or a model may be precise, but not accurate.) The solid line represents the simple regression model ($Y = b_0 + b_1X$) for the data points. The vertical bars represent the upper and lower 95% confidence limits about the estimated mean observed basal area, for which the standard error was calculated according to plot data variation.

If there is no significant difference between the goodness of fit of the restricted and regression models, then the comparison shows no evidence of bias, and the the rate-of-loss model is assumed to predict losses with reasonable accuracy. To test this hypothesis, a regression analysis was run using a standard F test to measure the differences between the two models. A significant difference was found between the models ($P << 0.05$: see Table 2), which implies that the mountain pine beetle model did not adequately project stand losses.

A measure of precision (or variance) is the distance between individual points and the Y=X line. Note that many of the vertical bars in Figure 1 do not bracket the Y=X line. This implies that in some individual cases there was a statistically significant difference (at the 95% confidence level) between the observed and projected estimates of basal area (Gillespie 1990). There also appears to be a trend in point distribution, resulting in underestimation of mortality in stands with less basal area, and overestimation for stands with greater basal area, indicating a possible density or stocking factor. The estimated correlation coefficient between observed and projected basal area mortality (Table 2) is 0.554.

Model projections and observed values for each 2-inch diameter class were analyzed in an attempt to determine where model bias occurred. The model projected basal area mortality with higher accuracy and less variance in larger diameter classes, and with less accuracy with each decreasing diameter class (see Table 2 and Figure 2). Table 3 lists observed minus projected values and the resulting means and standard deviations within each diameter class. Note the increasing variation as diameter decreases. Using the previously discussed standard F test analysis, diameter classes of 16-20 inches showed no significant difference between observed and expected mortality; diameter classes of 6-14 inches indicated that the observed and expected mortality was significantly different from the restricted (Y=X) model (Table 2).

Failure of the model seems largely due to error in mortality projections within these small diameter classes; particularly within the 6- and 8-inch diameter classes. 10- to 12-inch diameter classes, while showing significant difference from the Y=X model, still appear to project mortality losses with reasonable accuracy. Note the high correlation coefficient values (Table 2) and the observed vs. projected mortality graphs (Figure 2). 6- to 8-inch diameter classes exhibit low correlation coefficient values, large sample variation, and significant bias from the Y=X model. This is of particular concern since so many sample trees within the stands fall within these diameter classes, and therefore have a tremendous effect on overall model performance.

It is not surprising that the model has difficulty predicting basal area mortality for the smaller diameter classes. Beetle-induced mortality encompasses a very complex biological system with large natural variation. The probability of mountain pine beetle attacking smaller-diameter trees rather than larger-diameter trees is significantly smaller due to a variety of factors, including beetle preference and behavior, intensity and duration of attack, site index, stand density and structure, weather conditions, and phloem thickness, none of which are addressed by this model. In addition, number of trees per acre generally increase as stand diameters decrease, which would add more predictive variation to model projections.

Initially, it was felt the model would consistently over- or under-predict mortality within smaller, hard-to-project diameter classes. This would result in a fairly simple recalibration of q values to improve projection results. However, no such trend is readily apparent. Figure 3 compares observed minus projected distributions of basal area mortality by diameter class, with one observation for each diameter class per stand. The model appears to overestimate basal area mortality for the 6-inch diameter class, resulting in a skewed distribution. Otherwise, no clear bias emerges within other diameter classes. Also note the drastic increase in variation (decrease in precision) as diameter classes decrease from 20 to 6 inches.

As noted before, Figure 1 seems to suggest a pattern in point distribution, with underestimation of mortality occurring in stands with less basal area (possibly understocked stands) and overestimation in relation to greater basal area (possibly overstocked stands). In an attempt to more exactly define the cause for this bias, percent difference between observed and projected mortality was plotted for basal area mortality versus a variety of other variables, including relative density (Curtis 1982), stand density index (SDI) (Reineki 1933), site index, elevation, aspect, initial basal area, number of trees, quadratic mean diameter and total cubic feet. Relative density and stand density index revealed clear residual patterns (Figure 4), verifying a tendency of the model to underestimate basal area mortality in less dense stands and overestimate mortality in denser stands. Percent difference was used instead of observed minus projected values in an attempt to standardize results, which allowed for stands with different initial stockings.

Relative density and SDI vs. percent difference for each individual diameter class was also plotted to further pinpoint model bias. The strongest density relationship occurred in the 7- to 8.9-inch diameter class, with other diameter classes displaying minimal bias due to these density factors. This strong 8-inch diameter class density relationship may be due to a majority of sampled trees falling within this diameter class.

The rate-of-loss model does not account for differences in stand density, yet tree size and stand density are critical variables in determining mountain pine beetle hazard ratings (Anhold and Jenkins 1987;

Amman and Anhold 1989). The rate-of-loss model accounts for tree size, but fails to address stand density factors. Cole and Amman (1980) note that the most important factor in determining mountain pine beetle brood production is phloem thickness. Variables contributing to phloem thickness include lower stand densities and improved site conditions, which in turn increases mountain pine beetle brood size (Cole 1973) and thus includes potential stand mortality. Figure 4 appears to support this hypothesis, as stands in which losses were under-predicted were those with lower relative density and, most likely, thicker phloem with greater potential for brood production. Conversely, stands for which the model tended to over-predict mortality were those of higher relative stand density. The addition of a density variable within the model might result in a significant improvement in model projections.

CONCLUSION

Although the Cole and McGregor rate-of-loss model did not seem to adequately predict mountain pine beetle losses on the Ashley National Forest, model validation has supported the model's effectiveness in other areas (see Gillespie et al. 1990; Cameron et al. 1990; and Bousfield and Oakes (unpublished)). A majority of bias in our model projections came from small-diameter classes (8 inches and smaller). The model worked reasonably well in projecting mortality in 10- to 14-inch diameter classes. In 16- to 20-inch diameter classes, the rate-of-loss model projected mortality with a high degree of accuracy. The failure of the model in smaller diameter classes is due in part to the difficulty in measuring and modeling complex biological systems. Variables affecting selection of small trees by mountain pine beetle include beetle behavior, the duration and intensity of an epidemic, inclement weather conditions, site quality, presence of mountain pine beetle in surrounding trees and stands (spatial element), and stand density factors.

Most of these variables would be difficult to model and would be beyond the scope of a simple mortality projection model. Stand density measurements, however, are easily measured and readily available. Our analysis indicates the addition of a density variable would improve the performance of the rate-of-loss model in this area. Consideration should be given to the addition of a stand density variable within this model, as well as the continuation of validation efforts. Future validation projects that use previously established permanent plots in areas susceptible to insect attack will provide more appropriate data for assessing model validity. This would improve confidence in model prediction as well as reduce variability due to problems encountered with our data sets.

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Table 1: 1979 pre-epidemic stand attributes.

Stand #	Slope[1]	Aspect	Elev.	Site Index	QMD[2]	Basal Area[3]	SDI[4]	Relative Density[5]
1	1	W	8300	33.0	5.5	212.0	492	90.4
2	1	NW	8400	39.0	5.8	141.0	320	58.5
3	2	NE	9000	33.0	4.6	129.0	323	60.1
4	1	N	8600	33.0	4.0	167.0	440	83.5
5	0	E	9600	32.0	5.6	153.0	352	64.6
6	0		9700	29.0	4.7	176.0	437	81.2
7	0		8600	28.0	4.2	92.0	237	44.9
8	1	NE	9200	30.0	6.3	196.0	430	78.1
9	2	NW	9600	31.0	4.3	132.0	338	63.7
10	0	W	10700	28.0	6.5	225.0	488	88.2
11	2	SE	9400	27.0	4.7	113.0	279	52.1
12	0		9400	37.0	4.0	112.0	292	56.0
13	3	E	10000	31.0	5.9	216.0	488	88.9
14	1	SW	8800	28.0	4.3	72.0	184	34.7
51	5	W	9000	39.0	7.7	129.0	263	46.5
52	10	W	9100	34.0	10.5	131.0	234	40.4
53	10	E	9100	38.0	7.3	196.0	407	72.5
54	5	SW	8900	37.0	6.8	156.0	333	59.8
55	5	SW	9300	33.0	10.0	133.0	242	42.1
56	8	S	9700	33.0	10.0	177.0	324	56.0
57	5	SE	9500	35.0	10.8	163.0	289	49.6
58	5	E	9600	38.0	6.9	166.0	351	63.2
59	10	S	9500	38.0	8.1	165.0	328	58.0
60	5	SE	9500	37.0	7.9	176.0	353	62.6
61	10	S	9300	39.0	6.7	129.0	277	49.8
62	5	E	9800	39.0	9.9	200.0	368	63.6
63	5	SW	9400	33.0	10.2	163.0	297	51.0
64	6	W	9500	33.0	9.7	163.0	303	52.3
65	7	SW	9600	33.0	8.9	157.0	301	52.6
66	5	SW	9600	31.0	9.1	204.0	387	67.6
67	15	SW	9200	35.0	9.5	185.0	346	60.0
68	10	W	9800	38.0	9.9	170.0	312	54.0
69	5	E	9500	33.0	9.9	204.0	375	64.8
70	7	E	9700	38.0	7.8	190.0	384	68.0
71	5	S	9200	45.0	11.5	191.0	330	56.3

[1] Codes for slope are 0 = less than 5%, 1 = 6-15%, 2 = 16-25%, 3 = 26-35%, 4 = 36-45%, 5 = 46-55%, 6 = 56-65%.

[2] Quadratic mean diameter.

[3] ft^2/acre.

[4] Reineke's stand density index.

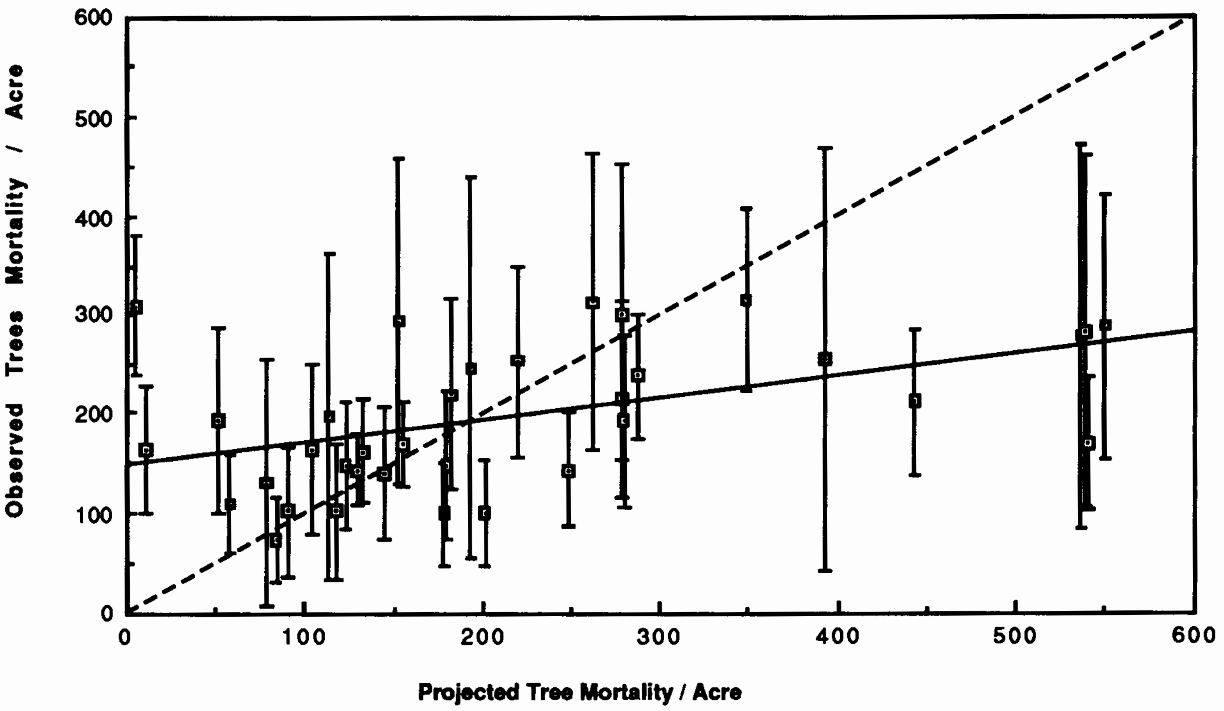
[5] Basal area/quadratic mean diameter$^{.5}$ (Curtis 1982)

Table 2: Estimated correlation coefficients (Pearson's R) between observed and projected estimates. Calculated F statistic for comparison between complete model (Y = a + bX) and restricted model (Y = X) with corresponding P-value (probability of Type I error).
Critical F value = 3.29

Diameter Class	6"	8"	10"	12"	14"	16"	18"	20"	Total
TREES									
Correl. coef.	.773	.528	.824	.737	.970	.956	.973	.99	.484
F-Statistic	249.7	12.6	16.3	12.7	6.0	3.0	2.5	1.4	61.3
(P-Value)	(.00)	(.00)	(.00)	(.00)	(.01)	(.06)	(.09)	(.25)	(.00)
BASAL AREA									
Correl. coef.	.774	.543	.821	.770	.968	.956	.976	.988	.554
F-Statistic	228.8	13.1	15.9	14.2	5.2	3.8	2.6	2.4	17.6
(P-Value)	(.00)	(.00)	(.00)	(.00)	(.01)	(.03)	(.09)	(.10)	(.00)

Table 3: Projected basal area mortality minus observed mortality for total and individual diameter classes. Mean and standard deviation values are included.

Stand	6 "	8 "	10"	12"	14"	16"	18"	20"	Total
1	45.5	16.6	-6.6	-11.6	-2.7	0.0	0.0	0.0	41.1
2	-11.8	0.0	-5.9	7.4	4.4	0.0	0.4	0.0	-5.4
3	0.2	-8.7	-15.6	-1.1	-2.3	3.4	-5.0	0.0	-29.0
4	0.7	8.6	-16.0	-4.7	-2.7	0.0	0.0	0.0	-14.2
5	1.5	21.1	11.3	-12.7	4.3	0.0	0.0	0.0	25.6
6	-17.0	-8.4	-4.2	-17.0	-4.7	-5.7	0.0	0.0	-57.0
7	0.4	-38.6	-25.2	-13.3	2.0	0.0	0.0	0.0	-74.7
8	-3.3	21.9	23.2	-0.9	0.5	2.9	0.0	0.0	44.3
9	35.2	-20.6	-6.5	-6.4	0.0	0.0	0.0	0.0	1.7
10	0.3	2.9	21.9	30.3	5.0	12.9	-5.0	1.9	70.1
11	0.1	-24.8	-10.6	-26.7	-12.0	0.0	0.0	0.0	-74.0
12	0.0	-4.6	-19.7	1.0	-5.2	-3.7	0.0	-1.9	-34.1
13	0.1	3.0	4.4	4.5	4.9	0.4	0.1	-0.1	17.2
14	0.1	-78.9	0.2	-39.5	0.0	0.0	0.0	0.0	-118.1
51	-3.8	7.3	-12.8	-5.1	-3.0	-0.7	-0.8	-1.0	-19.7
52	-1.3	-8.8	-0.6	0.8	1.3	0.0	-0.2	0.0	-8.9
53	40.5	23.3	-11.2	0.2	-0.0	0.0	0.0	0.0	52.9
54	45.9	11.6	-7.9	-5.4	0.0	0.0	0.0	0.0	44.1
55	0.0	-6.2	-2.5	4.5	-0.0	-0.1	-0.5	0.0	-4.7
56	0.0	13.2	11.8	2.8	-0.0	-0.0	-0.3	0.0	27.4
57	0.0	0.1	-2.4	9.4	1.8	0.0	-0.0	-0.3	8.6
58	56.0	30.3	-13.5	-8.0	-2.3	0.0	0.0	0.0	62.5
59	-8.6	29.5	3.3	-1.2	-1.9	-0.5	0.0	0.0	20.4
60	-9.4	27.7	0.0	-5.3	0.0	0.0	0.0	0.0	13.0
61	52.2	-4.9	-6.4	-5.8	-1.9	0.0	0.0	0.0	33.2
62	-8.3	-0.6	0.1	-0.7	2.2	0.0	0.0	2.1	-5.0
63	-1.6	-4.4	0.9	9.5	6.7	1.7	-0.1	-0.9	11.8
64	-9.9	-0.7	-6.8	6.6	-0.7	3.3	0.0	-0.5	-8.7
65	-11.1	-8.3	-2.8	-1.2	-0.1	0.0	-0.0	0.0	-23.5
66	-7.9	0.2	-8.7	-0.2	-0.2	0.0	0.0	0.0	-16.8
67	-3.5	-10.3	6.3	1.6	-0.1	-0.1	-0.3	0.0	-6.4
68	0.0	-4.3	10.7	6.8	-3.2	-1.1	-1.0	-1.0	6.9
69	-7.9	1.1	2.4	-0.1	0.0	0.0	-0.6	0.0	-5.0
70	26.6	-0.9	3.7	-1.8	-0.3	-0.2	-0.4	0.0	26.8
71	-1.5	-9.3	6.3	4.0	1.6	0.0	0.0	0.0	1.0
Mean	5.7	-0.7	-2.3	-2.3	-0.3	-0.4	-0.4	-0.1	0.1
Std.Dev.?¿	20.0	20.4	10.6	11.4	3.4	2.7	1.2	0.7	39.7



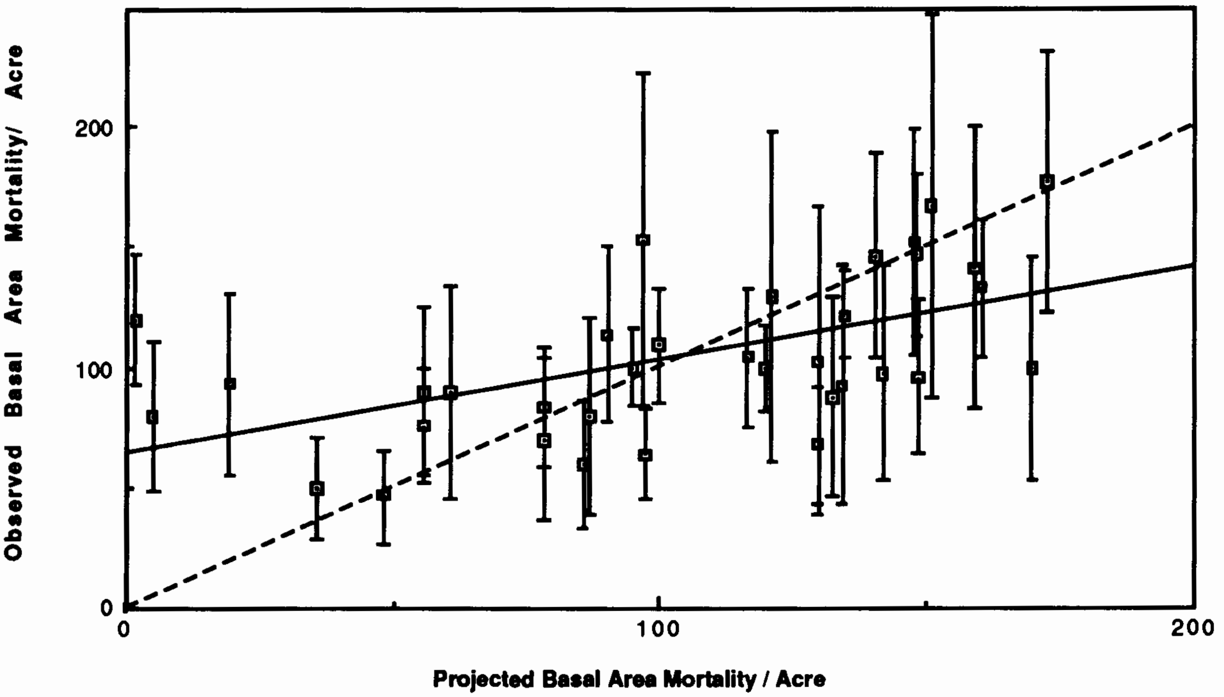


Figure 1: Total observed lodgepole pine mortality vs. 10-year projected mortality. Verticle bars indicate the upper and lower 95% confidence interval estimates about the mean observed values. The dashed line indicates the condition where Y=X.

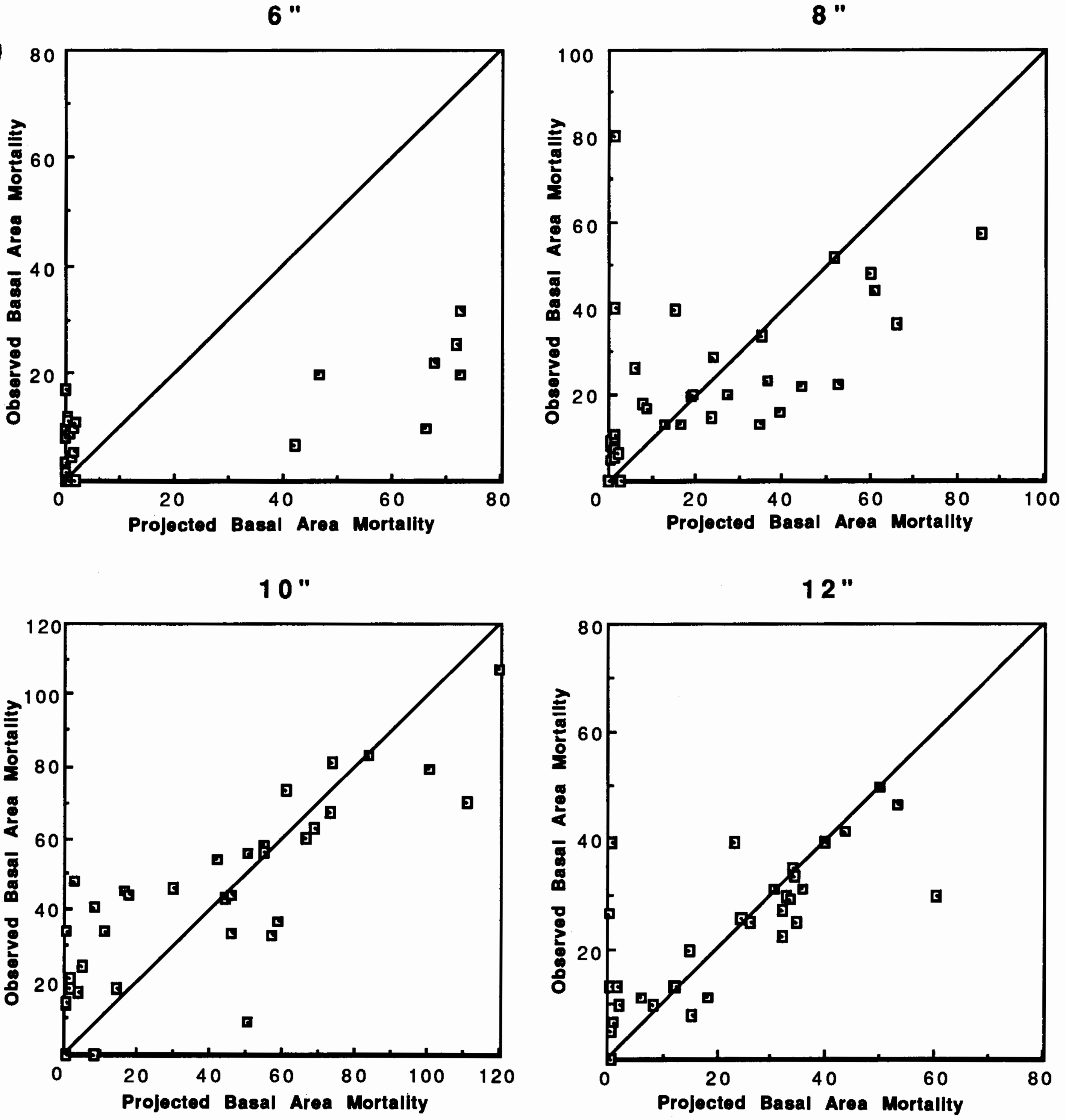
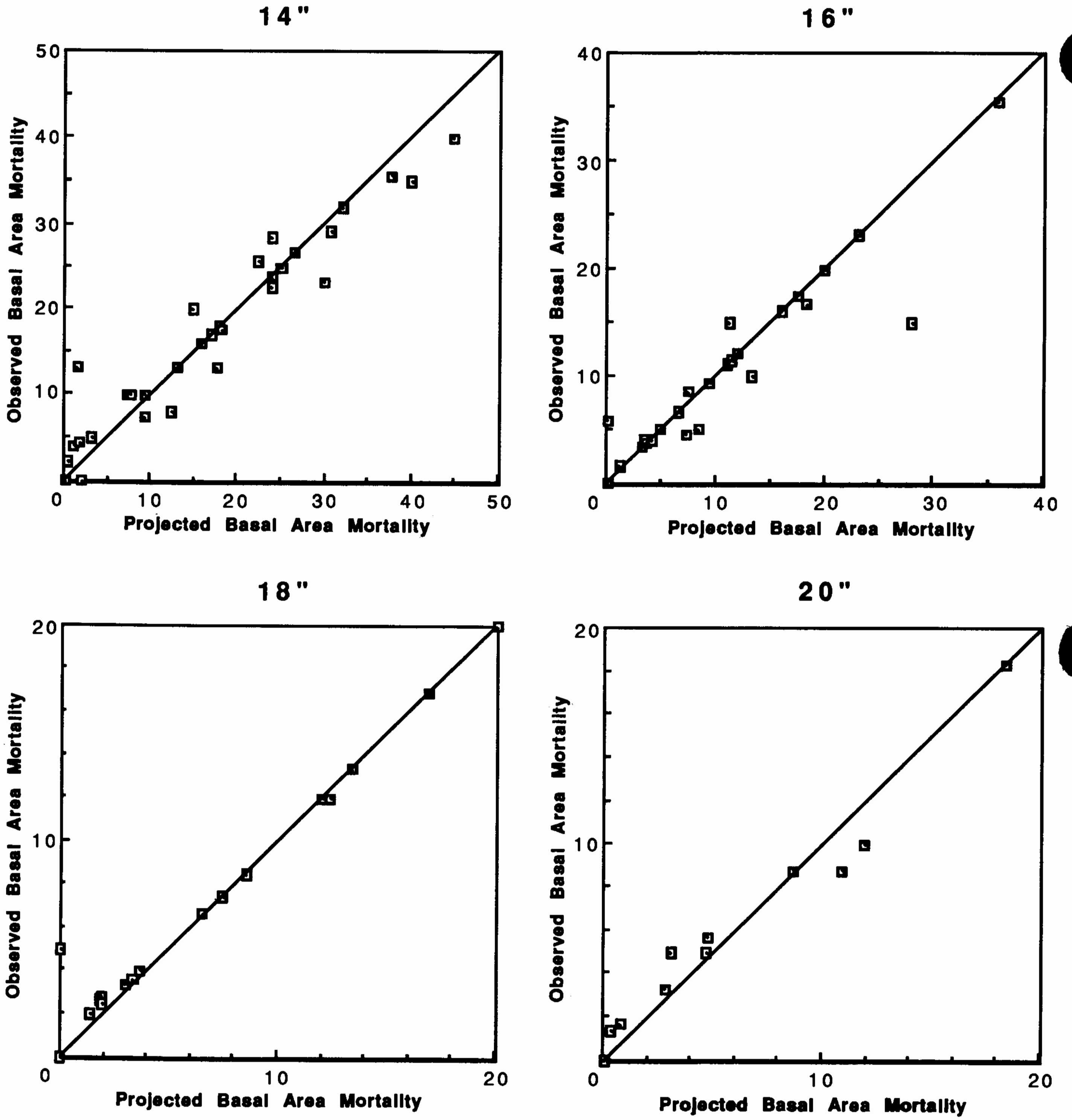


Figure 2: Lodgepole pine 1989 observed basal area mortality vs. 10-year predicted mortality for each seperate diameter class. The solid line indicates the condition where Y=X.



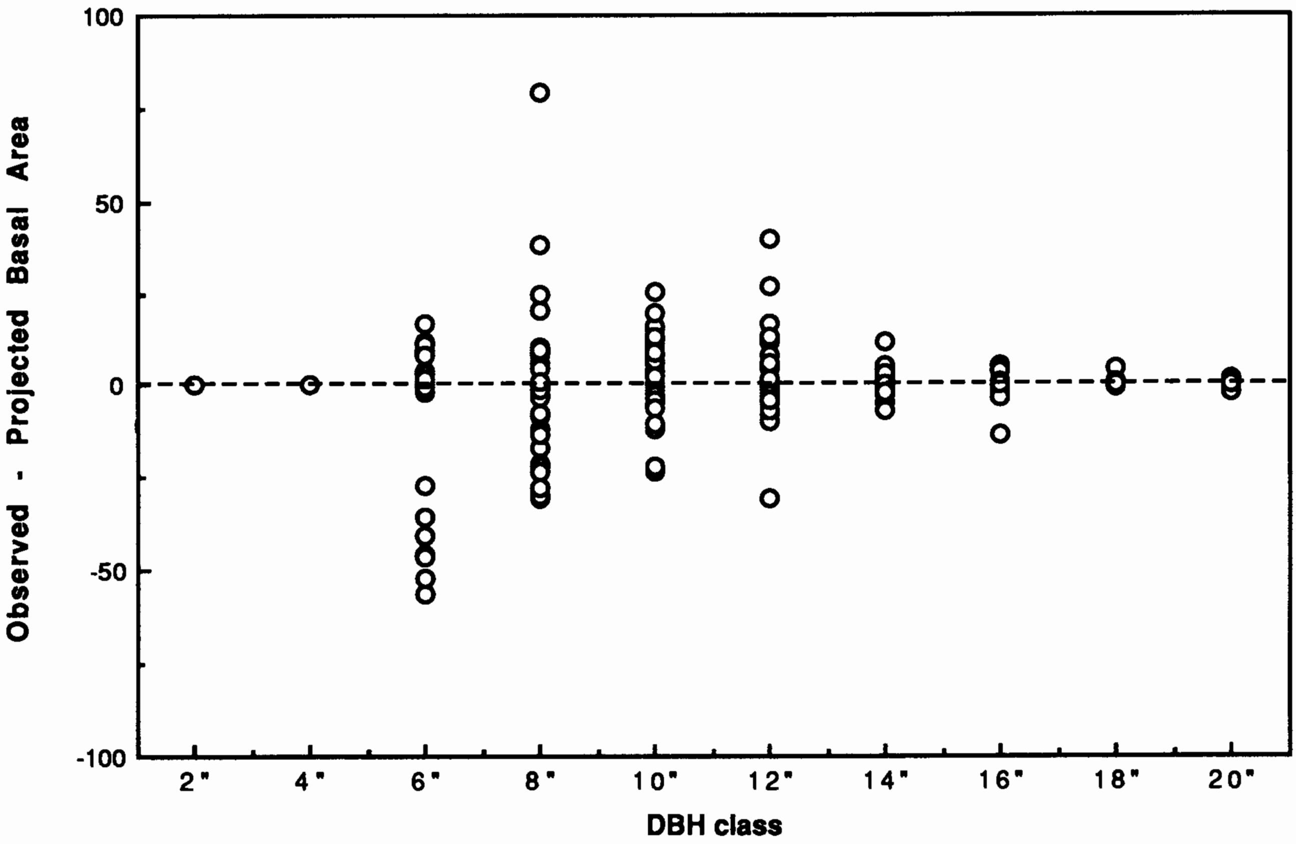
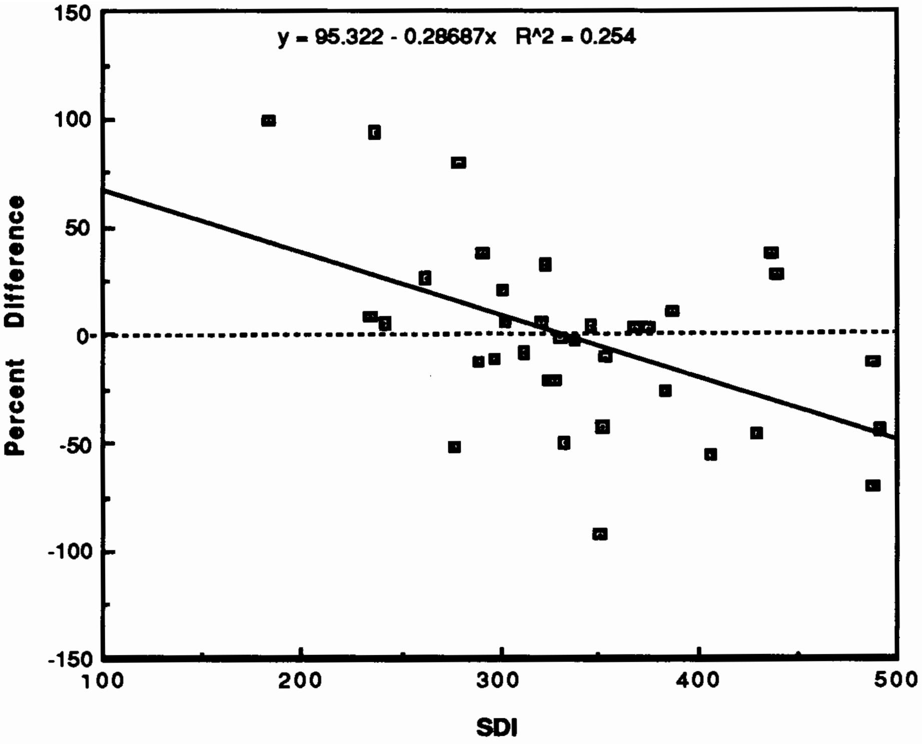


Figure 3: Difference in basal area mortality [observed - projected] vs. diameter class for all stands.



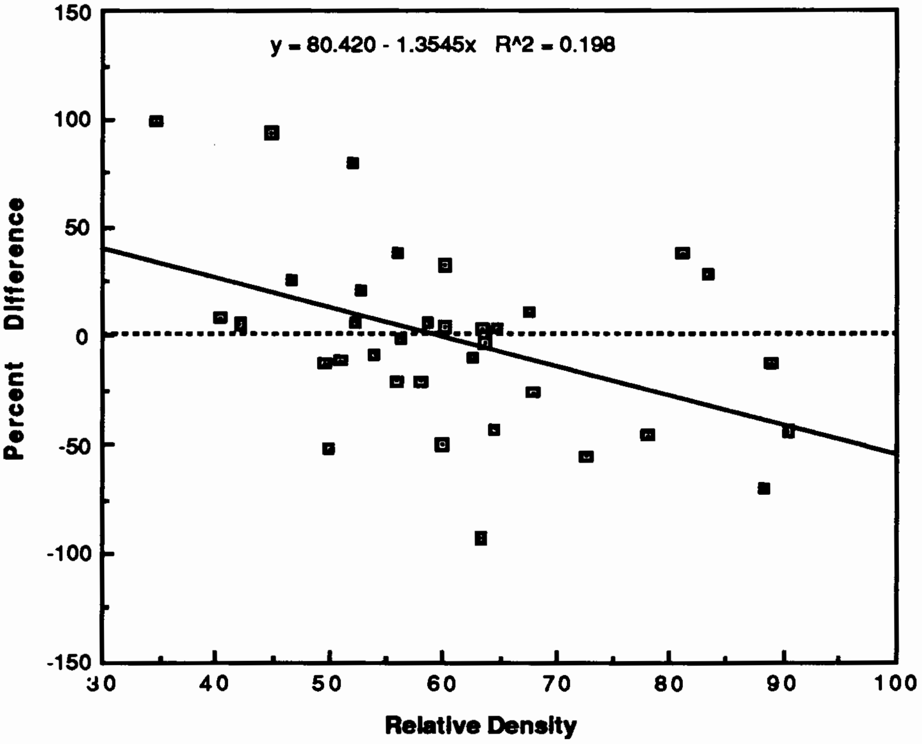


Figure 4: Percent difference in basal area mortality [(observed - projected)/ observed * 100] vs. SDI and relative stand density for each stand.
SDI = Reineke's stand density index
Relative Density = Basal area/quadratic mean diameter **.5 (Curtis 1982)

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