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Using Indicator Plants to Assess Susceptibility of California Red Fir and White Fir to the Fir Engraver Beetle

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Using a Vegetation Drought Index (VDI) for estimating the susceptibility of California red and white firs to the fir engraver beetle (*Scolytus ventralis*) was evaluated in northern California forests where these true firs (*Abies* species) occur in mixed conifer and true fir stands. Midway through the summer drought, true fir moisture stress—a known predisposing factor—was highest on sites with highest VDI values (most xeric). In mixed conifer stands, the susceptibility of white firs—as indicated by the mean percentage of their basal area killed annually—was highest on sites with highest VDI values. But in true fir stands, the susceptibility of mixed red and white firs was highest on sites with the lowest VDI values. Regression models with VDI, stand basal area, and percentage of true fir as regressors lacked the required predictive range and precision, suggesting that VDI will likely have to be used in combination with predictors other than, or in addition to, those analyzed.

Retrieval Terms: California red fir, *Abies magnifica*, white fir, *Abies concolor*, fir engraver, *Scolytus ventralis*, susceptibility, indicator plants, site factors

In the environmentally diverse forests of northern California, the indicator plant approach has shown promise for productivity assessment.[1-3] Because of the typically long, dry summers in northern California, trees may often undergo high moisture stress, and plant indicators of site xericity or "droughtiness" could be a particularly useful management tool.

Griffin[1] identified indicator plants to develop a Vegetation Drought Index (VDI) for forests in the Pit River drainage of the Cascade Range in northern California. Soil moisture and vegetation patterns were assessed on 29 plots representing the major upland forest soils in the region. Species found only within a limited range of soil moisture regimes were assigned tentative drought values based on their apparent optimal soil moisture requirements as indicated by soil moisture tensions in atmospheres in late summer. VDI, expressed as the average of the drought values of the indicator species found on a plot, ranged from 3.0 (least xeric) to 6.7 (most xeric).

Although in need of further evaluation, VDI appears to be a useful indicator of site xericity in the montane forests of California, as both VDI and plant moisture stress displayed similar inverse correlations with elevation.[1,2,4] Moreover, because most useful indicator plants could be found on most sites even after drastic disturbances,[1] the VDI for a site should remain relatively constant over time. Trees under high moisture stress are generally more susceptible to insects and diseases, suggesting that a VDI may predict susceptibility to these pests.

Site xericity may partly determine the susceptibility of forest stands to the fir engraver beetle (*Scolytus ventralis* LeConte). This bark beetle attacks and kills true firs (*Abies* species) throughout much of western North America, and droughts often result in outbreaks that cause widespread tree mortality.[5] In California, the beetle's primary hosts are California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.) and red fir (*A magnifica* A. Murr. including var. *shastensis* Lemm). White fir is the principal component of the widespread mixed conifer forest, becoming more prevalent with increasing elevation and forming nearly pure stands of true firs with red fir at the lower elevations of the red fir forest.[6] In the region where Griffin's VDI was developed, moisture-stressed white firs were highly susceptible to the fir engraver,[7] and their mortality in stands generally increased in response to 2 or more dry years in succession.[8] However, some stands had little or no mortality even in drought years, suggesting that stand factors in addition to moisture stress caused by site xericity may influence fir engraver attack.

This note describes the relationships between Griffin's Vegetation Drought Index (VDI) and the susceptibility of California's true firs to the fir engraver beetle in mixed conifer and true fir stands in the region where VDI was developed. As the first step in the analysis, the relationship between VDI and true fir moisture stress was examined to determine if VDI is an indicator of the xericity of true fir growing sites. Next analyzed was the ability of VDI, in combination with mensurational variables expressing both stand density and true fir composition, to statistically explain observed variations in beetle-caused mortality of firs in these stands over periods including both drought and nondrought years. Indicator plant species found primarily in the most susceptible stands, as well as those occurring mostly in the least susceptible stands, were noted. Finally, the potential of using indicator plants for predicting stand susceptibility was evaluated. Both the indicator plant and stand mensuration approaches have been used for predicting the susceptibility of grand fir stands in Idaho to the fir engraver.[9]

Two direct relationships were found: (1) between VDI and true fir moisture stress during a dry summer, and (2) between VDI and white fir mortality in mixed conifer stands. VDI was inversely related to true fir mortality in red fir stands. But regression models to predict true fir mortality lacked the required predictive range and precision, suggesting that VDI will likely have to be used in combination with additional predictors.

PROCEDURES

Water Potentials and VDI

The relationship between xylem water potentials in true firs and Griffin's Vegetation Drought Index (VDI) was investigated on 19 of his original plots. All the plots were in mixed conifer, or true fir stands at elevations ranging from 2300 to 6200 ft (700 to 1900 m). Basal areas varied from about 43 to 456 ft^2/acre (10–100 m^2/ha) consisting of up to 67 percent of white fir and minor amounts of red fir (two plots). VDI values for these plots ranged from 3.0 to 5.3. All the plots had true firs suitable for pressure bomb measurements that would reflect the underlying xericity of the growing site. The sampled firs (three per plot) were open-grown saplings or poles having healthy foliage near the ground. Their xylem water potential, P in bars (-15 bars $= -1.5$ mega-Pascals = 15 bars water stress) was measured in a 7 cm-long twig cut from a healthy branch at a height of about 2 m.[7] Firs were sampled near dawn, midway through the summer drought season, to reflect the seasonal lows in soil moisture. P was measured in both a dry year (1977) and a wet year (1978), and mean plot values ($\bar{P}$) were calculated for each.

Regression analysis was used to explore the relationship between calculated mean plot values ($\bar{P}$) and Griffin's VDI values.[1] Year was included as a dummy independent variable to assess year-to-year variations. Regressions were calculated for the full model (both independent variables included) and for restricted models (one independent variable excluded). Partial F-tests based on residual sums of squares were used to determine if VDI and years were statistically significant sources of variation in $\bar{P}$.

Stand Susceptibility and VDI

Mixed Conifer Stands

The relationship between susceptibility to the fir engraver and VDI was assessed in 21 mixed conifer stands that were once part of a study of bark beetle-caused mortality in pines.[10] These stands were selected randomly within hazard zones for pine bark beetle,[11] in numbers roughly proportional to the area of each zone. All were mature stands varying in elevation from 3300 to 6600 ft (1006–2012 m), logging history (virgin or lightly cutover), and the percentage of white fir in the sawtimber volume (1.2 to 68.9 pct). Fir mortality from 1944 to 1954 was determined by annual survey of a 20-acre (8 ha) plot within each stand. Stem d.b.h. (diameter at breast height, about 4.5 ft or 1.5 m) was recorded for each dead fir over 11 inches (28 cm) d.b.h., and about 3 ft^2 (0.3 m^2) of bark at this height was chopped away to identify any infesting subcortical insects by their gallery patterns. Of the years in which stands were surveyed, annual precipitation was considerably below normal in 1944-47, 1949, and 1953-54.[8]

The species and d.b.h. of each live tree over 11 inches (28 cm) were recorded for each plot in the year it was established. The d.b.h. of live trees and of the true firs killed by the fir engraver were used to calculate the basal area of the initial live stand (TOTBA), of true firs only (FIRBA), of FIRBA as a percentage of TOTBA (%FIR), and the mean percentage of FIRBA killed annually (%FIRBAK).

VDI values for the stands were estimated from vegetation surveys conducted in spring and early summer 1980 and 1981. Because the vegetative cover was roughly uniform, it was surveyed on a random 1-acre (0.4 ha) subplot within each mortality survey plot. To maximize the number of indicators per plot as Griffin recommended, all overstory and understory plants were identified,[12] except for some grasses and sedges that defied identification. Drought values of the indicator plants[13] were averaged to obtain the plot VDI.

Susceptibility of true firs to the fir engraver was expressed as the average percentage of FIRBA killed annually (%FIRBAK). The ability of VDI and the mensurational variables—TOTBA (expressing stand density), and %FIR (the percentage of true fir in the stand) to account statistically for variation in %FIRBAK was analyzed by linear regression.

The predictive potential of VDI was evaluated by comparing the slopes and standard errors of its regressions on %FIRBAK with those required to meet minimum standards for predictive usefulness. For example, a minimal requirement was that %FIRBAK (per year) be estimable within 0.5 percent with 95 percent statistical confidence, so that 5 percent mortality over a 10-year period would be distinguishable from no mortality. This translates roughly into a requirement that standard errors from regression be 0.25 percent or less. In considering the minimum slope necessary, VDI might be considered a useful predictor of mortality if an increment in %FIRBAK of 0.5 percent per year could be accounted for by any expected increase in VDI. If—on the basis of all past data available—the usual maximum range in VDI is assumed to be 2.0, then the required slope will be 0.5 divided by 2, or 0.25 percent.

True Fir Stands

The relationship between susceptibility to the fir engraver and VDI was studied in 18 true fir stands. These stands are part of a study begun in 1975 to develop risk-rating systems for mature true firs.[14] The stands are either virgin or lightly cutover, with mature red or white firs comprising 60 percent or more of the overstory. Ranging in elevation from 5600 to 7000 ft (1700–2100 m), they are transitional between mixed conifer forest and pure red fir stands at higher elevations.

Methods of survey and analysis were the same as those used in the mixed conifer stands except that the live stand characteristics were measured on the 1-acre (0.4 ha) subplots, and the lower d.b.h. limit was 10 inches (25.4 cm). The stands were surveyed annually from 1975 to 1979 including 2 years (1976 and 1977) when precipitation was considerably below normal.

RESULTS

Water Potentials and VDI

Water potentials ($\bar{P}$) of true firs were more negative in 1977 (range -5.2 to -17.6 bars) than in 1978 (-3.2 to -10.2 bars). In both years, $\bar{P}$ was lower in plots with VDI higher than 4.4 (*table 1, fig. 1*). Analysis of variance indicated that both the year of measurement and VDI were significant ($P<.01$) sources of variation in $\bar{P}$. In both years, two plots with low VDI and some red fir were among those with higher $\bar{P}$.

Differences in $\bar{P}$ between years were attributable to differences in precipitation during the preceding winter and spring. Precipitation was 50.4 percent below normal in 1977 and 23.8 percent above normal in 1978 at nearby Hat Creek Powerhouse No. 1, according to annual summaries of California weather.[15]

Stand Susceptibility and VDI

Mixed Conifer Stands

Mixed conifer stands varied widely in total basal area and in percentage of true firs (*table 2*). Susceptibility to the fir engraver, expressed as the average percentage of fir basal area killed annually (%FIRBAK), ranged from 0.0 to 2.4 percent per year. The number of indicator plant species averaged 13 per stand (range = 6–21), and VDI varied from 3.6 to 5.1—a range similar to that on the Griffin plots.

The regression with %FIRBAK as the dependent variable and TOTBA, %FIR, and VDI as regressors accounted for only 22.3 percent (r^2 adjusted for df) of the variation. As the slope estimate for VDI

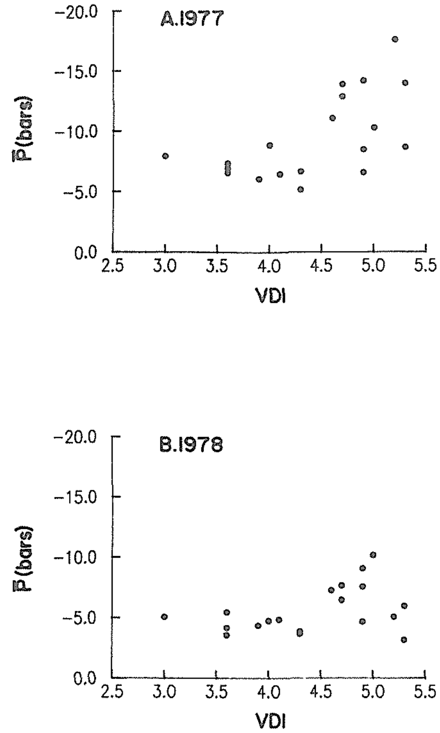

Figure 1—Relationship between dawn xylem water potential ($\bar{P}$) of young true firs in midsummer (n = 3 trees) and the Vegetation Drought Index (VDI) in a dry (A) and a wet (B) year on mixed conifer sites in northern California (see End Note 1).

Table 1—*Mean xylem water potentials ($\bar{P}$) in young true firs at dawn, measured in midsummer of a dry (1977) and a wet (1978) year in mixed conifer and true fir stands in northern California*

Plot[1]	VDI[2]	$\bar{P}$ (SD) 1977	$\bar{P}$ (SD) 1978
		bars	
1	4.9	6.6 (2.8)	9.1 (1.7)
2	4.7	12.9 (4.7)	7.7 (0.9)
3	4.9	9.5 (1.7)	7.6 (0.7)
4	4.9	14.2 (4.3)	4.7 (1.1)
5	4.1	6.5 (0.4)	4.9 (0.9)
6	5.0	10.3 (1.3)	10.2 (0.7)
7	3.9	6.1 (0.3)	4.4 (0.9)
8	4.3	6.7 (0.9)	3.7 (0.4)
9	4.6	11.1 (0.9)	7.3 (0.3)
10	3.6	7.4 (0.5)	5.5 (0.5)
11	3.0	8.0 (0.9)	5.1 (1.1)
12	3.6	6.6 (1.1)	3.6 (1.0)
13	4.3	5.2 (1.6)	3.9 (0.6)
14	4.7	13.9 (1.0)	6.5 (1.5)
15	4.0	8.9 (5.4)	4.8 (0.5)
16	3.6	7.0 (0.4)	4.2 (0.3)
17	5.2	17.6 (7.1)	5.1 (1.2)
18	5.3	8.7 (1.2)	3.2 (0.7)
19	5.3	14.0 (1.8)	6.0 (1.1)

[1]Three trees were sampled per plot.
[2]Vegetation Drought Index (see End Note 1).

Table 2—*Mensurational characteristics of mixed conifer stands sampled in northern California, 1944-54*

Stand number	Total basal area[1]	True fir component: Basal area	True fir component: Mortality[2]	Stand VDI[3]
	ft²/acre	*ft²/acre*	*pct*	
1	111.72	26.60	0.8	4.1
2	109.84	16.20	1.2	4.6
3	157.49	54.20	1.2	4.7
4	122.22	7.36	2.0	4.4
5	62.19	1.69	1.2	4.9
6	60.14	2.91	2.4	5.1
7	112.28	30.54	0.4	4.0
8	91.86	15.98	0.4	4.0
9	91.11	28.86	0.8	4.1
10	84.14	5.14	0.6	4.2
11	147.56	36.15	0.6	3.9
12	142.67	21.05	0.4	4.5
13	156.00	37.40	0.4	4.4
14	121.18	4.50	0.0	4.7
15	117.66	19.79	1.0	4.9
16	94.15	4.27	0.0	3.8
17	124.81	35.45	0.3	3.6
18	106.40	53.53	0.5	4.3
19	152.82	91.68	0.7	3.7
20	106.47	8.05	0.0	4.5
21	240.80	201.92	0.3	3.7

[1]1 $ft^2/acre = 0.23\ m^2/ha$.
[2]Mean annual mortality, 1944-54.
[3]Vegetation Drought Index (see End Note 1).

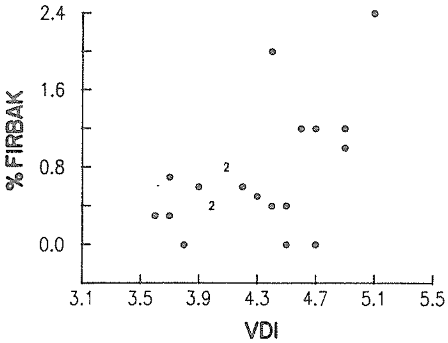

Figure 2—Relationship between the annual percentage of true fir basal area killed by the fir engraver (%FIRBAK) and the Vegetation Drought Index (VDI) in mixed conifer stands in northern California.

Table 3—*Mensurational characteristics of true fir stands sampled in northern California, 1975-79*

Stand number	Total basal area[1]	True fir component		Stand VDI[3]
		Basal area	Mortality[2]	
	ft²/acre	*ft²/acre*	*pct*	
1	75.74	75.74	0.7	3.3
2	160.60	159.94	0.4	3.6
3	194.28	180.91	0.2	3.4
4	308.06	308.06	0.4	3.3
5	277.36	269.00	0.4	3.5
6	132.31	132.31	0.2	3.1
7	210.07	210.07	0.7	3.0
8	131.67	106.47	1.0	2.4
9	92.60	85.75	0.6	2.6
10	227.42	163.17	0.4	3.3
11	217.76	123.60	0.6	3.3
12	246.22	226.20	0.3	3.3
13	364.92	270.52	0.4	3.7
14	303.10	303.10	0.3	2.8
15	205.92	205.92	0.6	3.0
16	272.85	241.23	0.2	3.4
17	236.08	236.08	0.1	3.0
18	271.29	265.34	0.6	2.3

[1] 1 ft²/acre = 0.23 m²/ha.
[2] Mean annual mortality, 1975-79.
[3] Vegetation Drought Index (see End Note 1).

(0.84) had a standard deviation of 0.33, it could not be assumed to exceed 0.25—the minimum required for predictive usefulness. Also, the standard error of prediction associated with the equation was 0.54 percent, which exceeded the 0.25 percent maximum value allowable for this purpose, indicating the equation would not be capable of the required predictive precision. Susceptibility was greatest, and most variable, in stands with VDI higher than 4.4 (*fig. 2*). This variation could be partly attributable to the low basal areas of true fir (denominators of %FIRBAK) in some of the sample stands.

Although VDI is based on all indicator plant species present, some species—such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), California black oak (*Quercus kelloggii* [Newb.]), bitterbrush (*Purshia tridentata* [Pursh] DC), birchleaf mountain-mahogany (*Cercocarpus betuloides* Nutt. ex T. & G.), slender-tubed iris (*Iris tenuissima* Dykes), and checker bloom (*Sidalcea malvaeflora* [DC] Gray ex Benth)—tended to occur primarily in stands that had a higher VDI and tended to be more susceptible to the fir engraver. Other species—such as bush chinquapin (*Castanopsis sempervirens* [Kell.] Dudl.), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), prince's pine (*Chimaphila umbellata* var. *occidentalis* [Rydb.] Blake), and white-vein shinleaf (*Pyrola picta* Sm.)—tended to occur primarily in stands with lower VDI, which tended to be less susceptible to the fir engraver.

True Fir Stands

Compared with the mixed conifer stands, true fir stands tended to have greater basal areas, and higher percentages of true fir (*table 3*). Over the years studied, mean percentages of the fir killed annually (%FIRBAK) by the fir engraver in true fir stands tended to be similar but somewhat less variable than those in the mixed conifer stands. VDI of the true fir stands ranged from 2.3 to 3.7, indicating that virtually all of the true fir sites were less xeric than those of the mixed conifer stands. Also, fewer indicator plant species were found in the true fir stands (mean 6, range 3 to 10) than in the mixed conifer stands.

The regression with %FIRBAK as the dependent variable and TOTBA, %FIR, and VDI as regressors accounted for only 28.4 percent (adjusted r^2) of the variation. The standard error was 0.19, indicating that the equation would have the required predictive precision. The slope estimate for VDI (0.26) had a standard deviation of 0.13, however, indicating that the predictive range would be inadequate. Susceptibility to the fir engraver was highest in true-fir stands with lowest VDI (*fig. 3*), but susceptibility was highest in mixed conifer stands with highest VDI.

Associations between VDI and the occurrence of any specific indicator plant were weak. Some indicator plants—such as California stickseed (*Hackelia californica* [Gray] Jtn.), and spotted coral-root (*Corallorhiza maculata* Raf.)—were found more frequently in stands with lower VDI, which tended to be more susceptible to the fir engraver. Others—such as sugar pine (*Pinus lambertiana* Dougl.), mountain monardella (*Monardella odoratissima* spp. *pallida* [Heller] Epl.), and spreading snowberry (*Symphoricarpos acutus* [Gray] Dieck) occurred similarly in stands with higher VDI which tended to be less susceptible.

DISCUSSION

Mean moisture stress in true firs at dawn, midway through the summer drought, were higher in a dry year (1977) than in a wet one (1978). In both years,

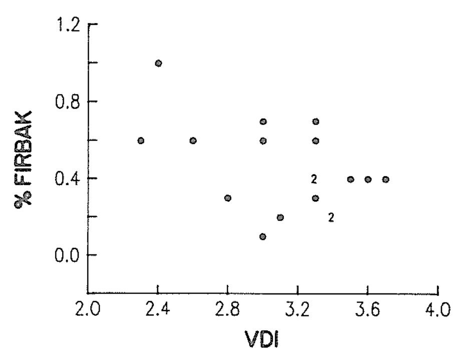

Figure 3—Relationship between the annual percentage of true fir basal area killed by the fir engraver (%FIRBAK) and the Vegetation Drought Index (VDI) in true fir stands in northern California.

however, stresses were highest on the more xeric growing sites, where Vegetation Drought Index (VDI) values exceeded 4.4. Among the lowest stresses in both years were those in the higher elevation true fir stands. In 1977, stresses in white firs growing in some mixed conifer stands at lower elevations approached the threshold of susceptibility to the fir engraver (dawn xylem water potential of -20 bars) previously established for these firs.[7] Results indicated that VDI might be used as an index to the xericity of true fir growing sites in the region studied.

Susceptibility of true firs to the fir engraver, as indicated by mean percentages of basal area killed annually during both drought and nondrought years, was also related to VDI values. In the mixed conifer stands, susceptibility of white fir was highest in some stands on sites with VDI exceeding 4.4. This relationship agrees with the measured moisture stress. White fir was a minor component in some of these stands, which were either lower elevation stands containing Douglas-fir and California black oak, or stands containing mainly pines with bitterbrush in the understory. In the true fir stands, however, susceptibility of true firs (red and white combined) was highest on sites with VDI of 2.6 or less (least xeric sites).

The contrasting results from the mixed conifer and true fir stands may have been attributable to differences in site xericity. Based on their VDI, the mixed conifer sites were more xeric (range 3.6–5.1) than were true fir sites (2.3–3.7). Differences in the degree to which site xericity determine stand susceptibility to the fir engraver are probably attributable to the site elevations. The true-fir stands are at higher elevations with greater precipitation and snowpack, lower temperatures, and shorter growing season. Griffin[1] and Myatt[4] also found a tendency toward lower VDI values on higher elevation sites. On higher sites, true firs may seldom be under enough moisture stress to render them susceptible to the fir engraver. Plant moisture stress never reached critical levels at higher elevations in the nearby Siskiyou Mountains.[2]

The results suggest how plant indicators of site xericity might be used to predict susceptibility of true firs to the fir engraver in mixed conifer and true fir stands in California. Because the VDI is based on all indicator species present, using it to predict susceptibility would seem to be a sound approach. Indicator plants will have to be developed for other regions in California before the use of VDI can be evaluated for them. Regression models developed in the study reported here lacked the range and precision required for predictive usefulness and did not statistically explain considerable variation in susceptibility. Also, the standard errors of prediction obtained for VDI likely are not true measures of predictive potential because they were not based on random sampling. Development and validation of predictively useful models will require random sampling, and VDI likely will have to be used in combination with additional predictor variables expressing stand condition. Important stand condition variables not analyzed in the present study appear to be the incidence and extent of defoliation,[16] mistletoes,[17] logging disturbance,[18] and especially root disease.[19]

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