Forest Ecology and Management, 50 (1992) 133–144
Elsevier Science Publishers B.V., Amsterdam

Differences in Monterey pine pest populations in urban and natural forests

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(Accepted 9 April 1991)

ABSTRACT

Nowak, D.J. and McBride, J.R., 1992. Differences in Monterey pine pest populations in urban and natural forests. *For. Ecol. Manage.*, 50: 133–144.

Monterey pines (*Pinus radiata* D. Don) planted along streets (i.e. street trees) within Carmel, California and its immediate vicinity, and naturally grown Monterey pine within adjacent native stands, were sampled with regard to intensity of visual stress characteristics, western dwarf mistletoe (*Arceuthobium campylopodum* f. typicum [Engelm.] Gill), and western gall rust (*Peridermium harknessii* J.P. Moore) infection, and frequency of sequoia pitch moth (*Synanthedon sequoiae* Hy. Edw.) and red turpentine beetle (*Dendroctonus valens* LeConte) attacks. The street trees were stratified into four geographic zones: one highly urban zone, two urban zones, and one suburban zone.

Dwarf mistletoe infections generally were more common in the forest stand than on street trees in the highly urban and urban zones for trees less than 50 cm dbh and were positively correlated with stand density. Pitch moth attacks were more common in all street tree zones than the natural forest, and were positively correlated with amount of pruning and wounding, and negatively correlated with amount of crown closure and stress.

Red turpentine beetle attacks were positively correlated with stress and diameter, and may follow pitch moth attacks. More beetle attacks occurred in the two urban zones than in the natural forest, probably due to significantly more large trees in these zones, and more pruning and wounding in the street tree setting than in the forest.

INTRODUCTION

Increasing urbanization is having a greater impact on natural forest stands, and may alter forest insect–pathogen–tree relations. A study of insects and diseases of Monterey pine (*Pinus radiata* D. Don) in Carmel-by-the-Sea, California and adjacent native stands was conducted in 1987 to understand how urbanization influences insect and disease dynamics. Carmel-by-the-Sea was

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Urban stratification

To understand differences within the street tree population, the urban/suburban area was divided into four zones: (1) CBD – the Central Business District; (2) City – urban areas (exclusive of CBD) within Monterey pine's native range; (3) Exterior – urban areas outside Monterey pine's native range; (4) Suburb – suburban/exurban areas within Monterey pine's native range.

Statistics

Spearman correlation was used to test for significant correlations among individual tree pest levels and environmental and biological variables. Kruskall–Wallis with individual Wilcoxon ranks sum tests to separate the means were used to test for significant differences among the urban zones and natural forest, and for significant differences among various categories within the urban and natural forest. Chi-square tests were used to test for differences among proportion of trees attacked by pests. Individual alpha levels were held quite small so that the combined overall alpha level for all tests was approximately 0.05 (Bonferroni test).

RESULTS

Urban vs. forest pests

The forest environment was significantly different from the urban environment in the proportion of highly stressed, dying and dead trees, with the forest exhibiting a higher proportion (10% vs. 1%). The forest also averaged significantly higher tree stress levels (forest trees, 0.27; street trees, 0.19).

The natural forest had a significantly lower proportion of pitch moth attacked trees than all four street tree zones (Table 1). The forest also had significantly fewer pitch moth attacks per tree than all street tree zones except the Suburb zone (Table 1).

The City and Exterior zones averaged a higher proportion of red turpentine beetle attacked trees and more beetle attacks per tree than the natural forest (Table 1).

The forest also had a significantly higher proportion of mistletoe infected trees and more infection per tree than all street tree zones except the Suburb zone (Table 1).

Trees with pitch moth attacks and lacking red turpentine beetle attacks averaged a stress index of 0.19; trees attacked by both insects averaged 0.25; trees with red turpentine beetle attacks and no pitch moth attacks averaged 0.35.

The City and Exterior zones had a significantly higher proportion of trees

TABLE 1

Proportion of trees infected (PCT) with sequoia pitch moth, red turpentine beetle, and western dwarf mistletoe (Chi-square tests), and average number of beetle attacks per tree (BTL), pitch moth attacks per tree (PM), and average dwarf mistletoe rating per tree (MST) (Wilcoxon rank sum tests) for urban, suburban and forest areas in and near Carmel, CA in 1987

Area	*N*	Sequoia pitch moth				Red turpentine beetle				Western dwarf mistletoe			
		PCT	S	PM	S	PCT	S	BTL	S	PCT	S	MST	S
CBD	48	83	A	5.7	A	4	BC	0.0	BC	2	BC	0.0	BC
City	571	74	A	3.3	A	14	B	0.7	B	17	B	0.2	B
Exterior	87	51	B	2.2	B	31	A	1.4	A	5	C	0.0	C
Suburb	77	44	B	1.1	BC	7	BC	0.3	BC	31	A	0.4	A
Forest	518	28	C	0.8	C	6	C	0.3	C	33	A	0.5	A

N, Sample size.
S, Means followed by the same letter are not significantly different at overall significance level of 0.05.

greater than 50 cm than the CBD and Suburb zones and the natural forest (Exterior, 60%; City, 51%; CBD, 35%; Forest, 26%; Suburb, 14%).

Pest comparisons within diameter classes

The natural forest had a significantly lower proportion of trees attacked by pitch moths and significantly fewer attacks per tree than both the CBD and City zones for diameter classes between 10 and 70 cm (Table 2). The natural forest also had a significantly lower proportion of trees attacked by pitch moths and significantly fewer attacks per tree than both the City and Suburb zones for diameter class 70–90 cm (Table 2). The forest had significantly fewer attacks per tree than the City zone for diameter class 90+ cm (Table 2).

The Exterior zone was significantly different from the natural forest in both the proportion of trees attacked by red turpentine beetles and the average number of attacks per tree for diameter classes 50–70 and 70–90 cm. The Exterior zone had both a higher proportion (50–70 cm: Exterior, 41%; Forest, 11%; 70–90 cm: Exterior, 54%; Forest, 9%), and averaged more attacks per tree (50–70 cm: Exterior, 1.0; Forest, 0.8; 70–90 cm: Exterior, 2.4; Forest, 0.2). The overall proportion of trees attacked by red turpentine beetles increased with diameter (10–30 cm, 3%; 30–50 cm, 9%; 50–70 cm, 17%; 70–90 cm, 22%; 90+ cm, 27%).

Average infection rating per tree and proportion of trees infected with mistletoe was significantly different between both the City and Exterior zones and the natural forest for diameter classes 10–30 and 30–50 cm, and between the CBD and natural forest for diameter class 30–50 cm. The natural forest exhibited a higher proportion of mistletoe infected trees (10–30 cm: Forest, 43%; City, 20%; Exterior, 0%; 30–50 cm: Forest, 33%; City, 14%; CBD, 0%;

TABLE 2

Proportion of trees infested with sequoia pitch moth (PCT) (Chi-square tests) and average number of pitch moth attacks per tree (PM) (Wilcoxon rank sum tests) for urban, suburban and forest areas by diameter (dbh) class in and near Carmel, CA in 1987

dbh Class (cm)	Area	*N*	PCT	S	PM	S
10–30	CBD	13	69	A	1.8	A
	City	109	60	A	2.3	A
	Exterior	13	31	AB	0.4	AB
	Suburb	34	24	B	0.4	B
	Forest	233	19	B	0.6	B
30–50	CBD	18	83	A	6.0	A
	City	169	74	A	3.4	A
	Exterior	22	55	AB	2.2	AB
	Suburb	32	53	AB	1.2	B
	Forest	151	36	B	1.1	B
50–70	CBD	13	100	A	9.8	A
	City	159	75	A	3.4	B
	Exterior	27	59	AB	2.3	BC
	Suburb	8	75	AB	3.4	ABC
	Forest	90	38	B	1.1	C
70–90	CBD	2	50	ABC	4.0	AB
	City	93	85	B	3.6	A
	Exterior	13	46	AC	2.2	AB
	Suburb	3	100	AB	2.0	A
	Forest	32	22	C	0.3	B
90+	CBD	2	100	AB	3.0	AB
	City	41	90	A	4.0	A
	Exterior	12	50	B	4.0	AB
	Suburb	0		AB		AB
	Forest	12	58	AB	1.3	B

N, Sample size.
S, Means followed by the same letter are not significantly different at overall significance level of 0.05.

Exterior, 0%), and higher average mistletoe infection ratings per tree (10–30 cm: Forest, 0.7; City, 0.0; Exterior, 0.0; 30–50 cm: Forest, 0.5; City, 0.2; CBD, 0.0; Exterior, 0.0).

Street trees

Sequoia pitch moth

Number of pitch moth attacks per street tree were positively correlated with amount of wounding ($r=0.15$), diameter ($r=0.26$), tree height ($r=0.15$), amount of crown pruned away ($r=0.14$), and was negatively correlated with

TABLE 3

Proportion of trees infested (PCT) with sequoia pitch moth and western dwarf mistletoe (Chi-square tests), average number of pitch moth attacks per tree (PM) and average mistletoe infection rating per tree (MST) (Wilcoxon rank sum tests) by adjacent land use and forest canopy position in and near Carmel, CA, in 1987

	N	Sequoia pitch moth				Western dwarf mistletoe			
		PCT	S	PM	S	PCT	S	MST	S
Adjacent use									
Single family	652	66	B	2.8	B	17	AB	0.2	AB
Apartment	9	67	AB	2.0	AB	0	AB	0.0	AB
Institutional	23	87	AB	3.7	AB	0	AB	0.0	AB
Commercial	48	96	A	7.5	A	2	B	0.0	B
Parking	5	100	AB	4.2	AB	0	AB	0.0	AB
Vacant	46	94	A	2.2	B	30	A	0.4	A
Forest canopy position									
Codominant[1]	239	35	A	1.0	A	23	B	0.3	B
Intermediate	104	32	A	0.8	A	38	AB	0.6	AB
Suppressed	135	14	B	0.4	B	44	A	0.8	A
Young–open	40	28	AB	0.9	AB	48	A	0.7	A

N, Sample size.
S, Means followed by the same letter are not significantly different at overall significance level of 0.05.
[1]Codominant and dominant trees.

crown closure ($r=-0.13$). Wounding and diameter were also positively correlated ($r=0.13$).

The CBD and City zone trees exhibited significantly more pitch moth attacks and percent of trees attacked than both the Suburb and Exterior zones (Table 1). The CBD and City zones had a significantly higher proportion of pitch moth infested trees than the Suburb zone for diameter class 10–30 cm and significantly more attacks per tree for diameter classes 10–30 cm and 30–50 cm (Table 2).

The CBD exhibited significantly more pitch moth attacks per tree than both the City and Exterior zones for diameter class 50–70 cm (Table 2). The City zone also had a significantly higher percentage of pitch moth attacked trees than the Exterior zone for diameter classes 70–90 and 90+ cm (Table 2).

Percent of trees with pitch moth attacks adjacent to commercial and vacant areas was significantly greater than percent of trees attacked adjacent to single family homes. However, street trees adjacent to vacant lots and single family homes averaged significantly fewer attacks per tree than street trees adjacent to commercial areas (Table 3).

Red turpentine beetle

Red turpentine beetle attacks were positively correlated with stress ($r=0.22$), amount of decay ($r=0.13$), diameter ($r=0.23$) and height

($r=0.15$). The Exterior zone was significantly different from the other three street tree zones, averaging more attacks per tree and a higher proportion of attacked trees (Table 1). The Exterior zone averaged the highest proportion of beetle infested trees for diameters greater than 30 cm, but was only significantly different from the City zone for diameter class 50–70 cm (Exterior, 41%; City, 17%).

Western dwarf mistletoe

Dwarf mistletoe infections were positively correlated with stress ($r=0.15$) and negatively correlated with distance from the nearest forest stand ($r=-0.19$). Infections in the Suburb zone were significantly different from the other three street tree zones (Table 1), as was the City zone from the Exterior zone (Table 1) and vacant lots from commercial lots (Table 3), with the Suburb zone, City zone and vacant lots averaging the highest mistletoe infection rating per tree and the highest proportion of infected trees.

The Suburb zone was significantly different from all other street tree zones in the proportion of mistletoe infected trees and average infection per tree for diameter class 30–50 cm. The Suburb zone averaged the highest proportion (Suburb, 34%; City, 14%; CBD, 0%; Exterior, 0%) and most infection per tree (Suburb, 0.6; City, 0.2; CBD, 0.0; Exterior, 0.0).

Natural forest stands

Sequoia pitch moth

Number of pitch moth attacks per tree were positively correlated with amount of wounds ($r=0.20$), diameter ($r=0.18$) and negatively correlated with stress ($r=-0.17$). Suppressed trees were significantly different from both codominant/dominant and intermediate trees with suppressed trees averaging less pitch moth attacks per tree and a lower proportion of attacked trees (Table 3).

Red turpentine beetle

Red turpentine beetle attacks were positively correlated with diameter ($r=0.15$) and stress ($r=0.17$).

Western dwarf mistletoe

Dwarf mistletoe infections were negatively correlated with diameter ($r=-0.25$), height ($r=-0.25$) and basal area ($r=-0.17$), and were positively correlated with distance from urban areas ($r=0.17$), and stand density ($r=0.28$).

Codominant/dominant trees were significantly different from both suppressed and young–open trees with codominant/dominant trees averaging less mistletoe infection per tree and a lower proportion of infected trees (Table 3).

DISCUSSION

Many factors of the individual tree and the surrounding environment influence insect–pathogen–tree relations. Individually, these factors exhibit only a low correlation with specific pest abundance. However, it is likely that interactions and combinations of these factors significantly influence the insect–pathogen–tree relations.

Sequoia pitch moth

Wounding, pruning, and a more open environment are the three factors most highly associated with pitch moth attacks. These factors were most abundant in the street tree environment, especially in the CBD and City zones, where the most attacks were observed. This association is not surprising considering the insect's habits. The pitch moth usually deposits its eggs in sunny areas and at the edge of wounds (Brunner, 1914; Knight and Heikkenen, 1980).

Pitch moth attacks increase with diameter in the urban environment because larger trees exhibit more wounds, and in the forest environment because larger trees are less suppressed. Suppressed trees have significantly fewer pitch moth attacks, likely due to decreased light and other factors associated with suppressed trees (e.g. low resin production).

Johnson and Lyon (1976) state "it is believed that trees in a state of decline are especially attractive to this insect", while Powers and Sundahl (1973) note that "bole wounds from fuel-break pruning had caused resin flow and attracted insect attack – mostly in the largest, most vigorous trees". We also found that vigorous, large trees are more frequently attacked. Resin flow is correlated with tree vigor (Busgen and Munch, 1931) and pitch moths pupate in the resin mass (Knight and Heikkenen, 1980).

Repeated pitch moth attacks may predispose trees to bark beetle attack (Weidman and Robbins, 1947). Our data suggest a similar interaction between these insects. Pitch moths generally attacked larger, open grown, wounded, vigorous trees. Both red turpentine beetle and pitch moth attacked trees with increased stress. Beetle attacks alone occur on the most stressed trees and it is likely that increased stress (whether induced by beetles, moths or some other factor) makes the host unsuitable for pitch moths.

Pitch moths may attract *D. valens* via semiochemicals, or increase tree stress and the beetles may preferentially attack stressed trees. There may also be no direct interaction between these insects. Pitch moths may preferentially attack the least stressed trees and as stress increases, pitch moth infestation subsides, while *D. valens* attacks increase. The degree of association between these two insects remains to be established.

Red turpentine beetle

Increased number of beetle attacks on larger trees may be the result of increased host surface area. Larger trees may also be less resistant to beetle attacks due to increased stress or other physical or chemical changes. The beetle's association with stress may be the result of stress symptoms being induced after beetle attack.

Though our data indicated no relationship between amount of wounding and number of beetle attacks per tree, *D. valens* are attracted to wounded trees (Owen, 1985) and resin (D. Wood, personal communication, 1990).

There are three possible reasons why the Exterior zone exhibited the highest proportion of beetle attacked trees and number of attacks per tree. Though this zone was not significantly more stressed than any other street tree zone (Nowak and McBride, 1991), factors that prevent Monterey pine from occupying this area may predispose these trees to more bark beetle attacks. McDonald (1957) concluded that the limitations of soil depth, summer precipitation, and amount of nitrogen and water soluble phosphate content of the soil seem to limit Monterey pine to its present borders.

The Exterior zone also contained the highest percent of large trees. Considering increased beetle attacks are associated with larger trees, an area with the most large trees would likely be able to support the largest beetle population.

Another possible reason is the difference in maintenance practices that occurs in the Exterior zone which generally falls outside the City of Carmel's jurisdiction. Within Carmel (CBD and most of City zone), beetle attacks are cut out of the tree, and attacked and adjacent trees are sprayed with carbaryl (Sevin). If the beetle attacks are too numerous, only spraying is done (G. Kelly, personal communication, 1988). No such maintenance occurs in areas adjacent to Carmel. An interaction among site, maintenance practices and diameter structure is the most probable explanation for the distribution of *D. valens*.

Western dwarf mistletoe

Within the forest, the smaller trees are more highly infested with dwarf mistletoe because of the mechanism of seed dispersal which generally spreads the seed downward. Smaller forest trees also have more mistletoe than comparable City, Exterior and CBD zone trees because of the more closed stand structure and near monospecific composition of the forest which facilitates the spread of this species-specific mistletoe. Maintenance procedures for mistletoe in the more open, diverse urban forest, do not account for this difference because pruning of mistletoe infections is not a common practice in Carmel (G. Kelly, personal communication, 1988).

As the urban forest structure approaches more closed-canopy forest stand conditions (i.e. vacant lots, Suburb zone), the amount of mistletoe infection also increases.

No significant correlations exist among western gall rust, dwarf mistletoe, and red turpentine beetles in the Carmel area. However, in a study of another native stand of Monterey pine at Cambria, California, Chorover and McBride (1987) reported positive correlations among all three organisms. These organisms are more abundant in the Cambria stand than the stands near Carmel (i.e. gall rust: 33% vs. 4%; dwarf mistletoe: 70% vs. 33%; red turpentine beetle: 40% vs. 6%). They also reported positive correlations among these three pests and forest density.

CONCLUSIONS

Urbanization of forested areas influences the insect–pathogen–tree relations by altering stand structure and the physical environment. Urbanization opens the relatively dense Monterey pine stand structure, increasing sunlight penetration and reducing plant competition. Plantings of exotic tree species between these pines further reduces the density of Monterey pines in urban areas. Wounding of trees also increases with urbanization as a result of tree pruning and other anthropogenic factors.

There appears to be a conflict in managing both the natural forest and street tree population. Management toward a more closed tree environment is conducive to increased tree stress (Nowak and McBride, 1991), and mistletoe infections, yet a more open tree environment is conducive to increasing pitch moth attacks, and tree pruning and wounding are conducive to increasing both pitch moth and red turpentine beetle attacks.

Urbanization in and around relatively dense natural forest stands will likely increase the proportion of wound-associated pests, and organisms associated with decreased tree density, and decrease the proportion of organisms dependent upon a more closed forest structure. Forest managers must recognize the potential of urban forests as a reservoir for certain pest populations (e.g. pitch moth and red turpentine beetle), and urban forest managers must recognize the potential of natural forest stands as a reservoir for other pests (e.g. dwarf mistletoe).

ACKNOWLEDGMENTS

We thank the City of Carmel, especially their City Forester, Gary Kelly, for his assistance, Drs. David Wood, Gerald Walton, Wayne Zipperer and Carl Koehler for manuscript review. The use of trade, firm, or corporation names

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REFERENCES

Brunner, J., 1914. The sequoia pitch moth, a menace to pine in western Montana. USDA Bulletin No. 111, 11 pp.

Busgen, M. and Munch, E., 1931. The Structure and Life of Forest Trees. John Wiley, New York, 436 pp.

Chorover, J. and McBride, J.R., 1987. Structure and function of Monterey pine forest at Cambria, California. Research conducted for the Nature Conservancy. Dept. of Forestry and Resource Management, University of California, Berkeley, CA, 41 pp. (unpublished).

D'Ambrosio, G., 1974. Carmel's computerized trees. Arborist's News, 39(9): 150–152.

Donley, M.W., Allan, S., Caro, P. and Patton, C.P. (Compilers), 1979. Atlas of California. Pacific Book Center, Culver City, CA, 191 pp.

Fay, J.S., Lipow, A.G. and Fay, S.W. (Editors), 1987. California Almanac. Pacific Data Resources. Santa Barbara, CA, 635 pp.

Fowells, H.A., 1965. Silvics of forest trees in the United States. USDA For. Serv. Agric. Handbook No. 271, pp. 390–397.

Furniss, R.L. and Carolin, V.M., 1977. Western forest insects. USDA For. Serv. Misc. Publ. 1339, 654 pp.

Hawksworth, F.G., 1977. The 6-class dwarf mistletoe rating system. USDA For. Serv. Gen. Tech. Rep. RM-48, 7 pp.

Johnson, W.T. and Lyon, H.H., 1976. Insects that Feed on Trees and Shrubs. Comstock Publishing Associates. Ithaca, NY, 464 pp.

Knight, F.B. and Heikkenen, H.J., 1980. Principles of Forest Entomology. McGraw-Hill, New York, 461 pp.

Koehler, C.S., Frankie, G.W., Moore, W.S. and Landwehr, V.R., 1983. Relationship of infestation by the sequoia pitch moth (Lepidoptera: Sesiidae) to Monterey pine trunk injury. Environ. Entomol., 12(3): 979–981.

McDonald, J.B., 1957. An ecological study of Monterey pine in Monterey County, California. MS Thesis, University of California, Berkeley, CA, 56 pp. (unpublished).

Nowak, D.J. and McBride, J.R., 1991. Comparison of Monterey pine stress in urban and natural forests. J. Environ. Manage., 32: 383–395.

Offord, H.R., 1964. Diseases of Monterey pine. USDA For. Serv. Res. Pap. PSW-14, 33 pp.

Owen, D.R., 1985. The role of *Dendroctonus valens* and its vectored fungi in the mortality of Ponderosa pine. Ph.D. Dissertation. Dept. of Entomological Sciences, Univ. of California, 69 pp. (unpublished).

Peterson, R.S., 1960. Western gall rust on hard pines. USDA For. Serv. Leafl. 50, 8 pp.

Powers, R.F. and Sundahl, W.E., 1973. Sequoia pitch moth: a new problem in fuel-break construction. J. For., 71(6): 338–339.

Roy, D.F., 1966. Silvical characteristics of Monterey pine (*Pinus radiata* D. Don). U.S. For. Serv. Res. Pap. PSW-31, 21 pp.

Smith, R.H., 1961. Red turpentine beetle. USDA For. Pest Leafl. 55, 8 pp.

Weidman, R.H. and Robbins, G.T., 1947. Attacks of pitch moth and turpentine beetle on pines in the Eddy Arboretum. J. For., 45(6): 428–433.