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Modelling the Distribution of Leaves, Oakworms and Damaged Foliage for the Coast Live Oak[1]

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Abstract: A single Coast Live Oak tree (Quercus agrifolia) from Marin County California was selected for modelling the distribution of leaves, damaged foliage and the number of California Oakworms (Phryganidia californica). Branches for the study tree were classified according to crown level and compass direction. Twenty-four branches were randomly selected, each terminal shoot tagged. Resulting data collected per tagged shoot included number of leaves (damaged and undamaged) and oakworm larvae. Numbers of damaged and undamaged leaves, varied with crown level and branch diameter. Modelling of leaf totals and oakworm counts showed little difference when compared with totals from field observations. The ecological and pest management aspects of results are discussed.

The evergreen oak flora is an extensive and important resource in California. America north of Mexico has 68 species of oaks, of which 16 are native to California (Munz, 1970). In California, the dominant evergreen oak is the Coast Live Oak, Quercus agrifolia. Quercus species grow on 15-20 million acres making them one of the largest, although under-utilized, natural resources in the state (Callaham, 1980). Leaf distribution, foliage damage and defoliator number models are exiguous or nonexistent.

In California, the principal insect herbivore of the Coast Live Oak is the California Oakworm, Phryganidia californica Packard (Furniss and Carolin, 1977). This insect is a native California species whose populations erupt sporadically, every 5 to 7 years, in the state (Harville, 1955). Oakworms feed almost exclusively on oaks: all native and many introduced species are susceptible (Koehler et al., 1978). The population dynamics (Sibray, 1947; Harville, 1955; and Young, 1977), nutritional ecology (Volney et al., 1983a; Puttick, 1986), sex pheromone (Hochberg and Volney, 1984) and frass-drop measurement (Volney et al., 1983b) have been studied in some detailed. Still many gaps remain in our knowledge of this pest's biology, behavior and ecology.

Modelling urban pest populations is a recent innovation that is still undergoing development. The greatest advances in modelling are in agriculture (Getz and Gutierriez, 1982) and forestry (Waters and Stark, 1980). Early attempts of modelling shade-tree defoliator systems were by Olkowski et al., 1978. However, no data was presented revealing the number of leaves, foliage damage nor number of insect defoliators. Here, Q. agrifolia leaves from a study tree were counted to produce a model which allows for projections of foliage damage and numbers of P. californica.

METHODS

Field Methods

A Coast Live Oak tree, Q. agrifolia Nee, was selected for sampling from Marin Municipal Water District land near Mount Tamalpais in Marin County California. All major branches 15 mm in diameter or larger were grouped into three size categories. Every major branch was tagged and assigned to the crown location from which its foliage was borne. These crown locations were obtained by stratifying the crown into three vertical levels and into four compass directions. Vertical levels were obtained by dividing the tree canopy into three equal upright positions. Level 1 being the nearest the ground, Level 2 mid-crown height and Level 3 the uppermost third of the crown. Compass direction was defined using standard designations (e.g., north, east, south and west).

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The branch selection method employed for this study was a randomized design adapted from Jessen (1955). Each selected branch was followed by climbing and use of ladders until a fork along the limb was reached. At the fork, the choice as to which lateral limb was to be followed was based on a probability distribution of the cross-sectional branch diameter. At each selection stage, the branch selection probability was recorded. The process was continued until a terminal leaf cluster was reached, later being tagged with weather resistant identifying labels for future observations. This process was repeated two times per crown sampling quadrant,resulting in a total of 24 tagged shoots per tree.

Tagged leaf clusters were visited monthly for one year (February 1985-1986) to make observations on:

1. Total number of leaves.
2. Total number of leaves damaged by oakworms (other defoliator species were excluded).
3. Total number of oakworm larvae.

These observations were made from ladders at the periphery of the crown.

Laboratory Methods

In February 1986, 22 randomly selected branches (32 - 72 mm in diameter) were excised from the sample tree and brought back to the laboratory. All leaves from field collected branches were sorted into damaged and undamaged categories, their totals recorded and entered into a computer. All data manipulations and statistical testing (Chi-Squared, t-test, F-test, Regression and ANOVA) were accomplished using the Statistical program StatView (Feldman and Gagnon, 1985) on an Apple MacIntosh computer.

RESULTS

Leaf Distribution

Mean totals for field collected leaves are presented in Table 1. Total oak leaf numbers increased proceeding up the crown of the tree. These results were shown to be statistically significant. Controlling for crown level differences, damaged and undamaged leaf totals were greatest for branches 49 - 64 mm in diameter, Table 2. All row means were statistically significant.

TABLE 1. Mean damaged, undamaged, and leaf totals per crown level [1*]

Crown Level	Damaged[2*]	Undamaged[3*]	Total[4*]
1	67,186	19,642	86,828
2	79,732	29,005	108,737
3	114,939	44,541	159,480

1* Total height of tree divided into three equal vertical quadrants; 1 being the quadrant nearest the ground and 3 the uppermost quadrant of the tree crown

2* Statistically significant at $\alpha = .05$; $F_{2,19} = 5.473$

3* Statistically significant at $\alpha = .05$; $F_{2,19} = 6.764$

4* Statistically significant at $\alpha = .05$; $F_{2,19} = 6.136$

TABLE 2. Mean damaged, undamaged, and leaf totals per branch diameter

Diameter Interval (mm)	Damaged[1*]	Undamaged[2*]	Total[3*]
32 - 48	27,137	6,897	34,034
49 - 64	153,045	53,505	206,550
65 - 78	79,402	48,672	128,074

1* Statistically significant at $\alpha = .05$; $F_{2,19} = 5.779$

2* Statistically significant at $\alpha = .05$; $F_{2,19} = 5.408$

3* Statistically significant at $\alpha = .05$; $F_{2,19} = 5.921$

TABLE 3. Actual vs. predicted leaf counts by crown level

Crown Level	Actual Counts	Predicted Counts[1*]	Z statistic
1	86,842	105,164	
2	108,737	70,796	
3	159,480	99,722	
total	355,059	275,682	.85[2*]

1* calculated using model equation

2* not significant at $\alpha = .05$; $r = .929$; $r^2 = .863$

TABLE 4. Actual vs. predicted larval counts

	Larval Counts
Actual 1*	68,250
Model 2*	55,135

1* Data summed over 48 branches from one sample tree during summer 1981. The observed field rate was one larvae for every five leaves.

2* Equation Used: $l_m = \left(\frac{obs}{p_1 \cdot p_2}\right)(l_v)(b_r)$

See results section for model specifics.

Modelling

Actual leaf counts were compared to predicted leaf counts obtained by modelling, Table 3. The model equation used was:

lm = (obs/p1 * p2) (lv) (br)

Explanation of aforementioned variables contained in the equation are listed as follows:

- lm = Predicted leaf totals.
- obs= Observed leaf counts from tagged shoots in the field.
- p1 = Overall between branch selection probability.
- p2 = Overall within branch selection probability.
- lv = Correction constant for differences in crown-level leaf counts.
- br = Branch totals per crown level corrected for diameter differences.

Correlation statistics show this leaf prediction model to describe 86 percent of the total variance, Table 3. Using the above model, estimates for oakworm larval counts were obtained, Table 4. Larval estimates were obtained by substituting Predicted Larval Counts (lar) for Predicted Leaf Totals (lm) in the equation. An additional equation modification was changing Observed Leaf Counts (obs) to Observed Oakworm Counts. Field larval counts were collected from another sample tree (Berkeley, California) in the summer 1981. These data were compared with modelled larval values, Table 4. Both estimates of larval number approximate the same value (86 percent of variance explained). No test of significance was attempted.

DISCUSSION

Ecological Considerations

Although studies exist for other hardwood species (Red Maple, *Acer rubrum* L.) which disclose foliage and defoliator distribution patterns (Volney, 1979), no attempts were made to estimate actual leaf counts. From the current study, the majority of leaves (damaged and undamaged) were found in the upper two-thirds of the crown. The percentage of damaged leaves (75 percent) was high compared to defoliator damage for other oak species (Puttick, 1986). Compass direction and leave growth patterns were not statistically correlated. However, data from a larger tree sample (nine trees) shows differences in leaf counts (Lewis, 1986). As previously reported, oak leaves survive at least 2 years on shoots. The peak leaf flushing period being, March-April.

Of particular research interest, is estimating the number of oakworm causing visual damage. Published findings forward conflicting values. A CIAS pamphlet (CIAS, 1981) states larval densities of 0.5 per shoot as not causing appreciable damage. Yet other workers report complete defoliation at larval densities of 1 per shoot (Volney et al., 1983a). Field observations for this study indicate larval densities of 3 per shoot resulted in total defoliation (Lewis, 1986). The discrepancies in insect counts may be due to varying sampling designs and the difficulty of randomly sampling trees, especially in the higher crown levels.

Nutritional ecology studies conclude older oak leaves are less digestible, particularly late in the summer (Feeny, 1970). This decrease in digestibility is due to increases in Tannin content and leaf toughness. Concurrently, protein availability is diminishing as leaves approach maturity. Similar results were obtained for *Q. agrifolia* (Puttick, 1985). Because of this process, larval feeding and leaf damage are accelerated as oakworms obtain their nutritional requirements for growth and development. Given this to be true, fewer larvae than expected may cause significant defoliation in the summer compared to the spring generation. However, longitudinal studies on field defoliation rates show elevated levels of Tannin to correlated poorly with protein decline (Faeth, 1985). This finding may explain the patchiness of defoliated trees observed in the field. It has been theorized that temperature or chemical and physical changes within damaged leaves are more important parameters in describing defoliation patterns (Faeth, 1985).

Reviewing previously mentioned data tables, most leaves show signs of damage (Tables 1, 2). Damage is greatest at the top of the crown. This is consistent with published reports of oakworm infestations starting at the top and proceeding down the crown (CIAS, 1981). The greatest leaf numbers are for branches 49-64 mm in diameter. It is not known why branches of this size have the more leaves. A possible explanation is that asymmetry of leaves on some branches is due to the asymmetry of sunlight on different compass directions. In Table 3, the model overestimated leaves in the lowest crown level (1). This is due to a bias in the model from more branches being located in level 1 compared to other levels. A weighted correction factor is needed when computing values. Predicted larval and field result are similar (Table 4). However, until the data from all nine sample trees are analyzed, generalizations would be premature.

Pest Management Considerations

Oakworm populations have been reported to sporadically outbreak. The causes for these outbreaks are unknown. Natural enemies are often cited as the cause for the cyclic demise of field larval populations. The exact mechanism is unknown. One possible explanation forward is that at high population densities defoliation allows more light penetration. By reducing foliate surface area, host location by predators and parasites is easier. Another possible mechanism, is chemical and physical changes that occur in damaged leaves act as attractive lures for predators and parasites.

Random insecticidal treatments are of little benefit if parameters for success (e.g., undamaged leaves, reduced larval and egg counts) are dismissed. Since branch sampling high in the crown is laborious an easier and economical sampling protocol is needed. Frass-drop measurements provides the necessary variable inputs for quick and accurate estimates of insects and resulting damage (Morris, 1949). Oakworm Frass-drop experiments from the laboratory and field have been conducted (Volney et al., 1983b). Reviewing these workers regression equations, the slope value of (1) imply an one-to-one relationship between leaf weight consumed (leaf damage) and weight of frass produced (monitoring tool reflecting damage). In depth refinement of this relationship by correlating leaf biomass consumed by oakworm with biomass lost by damaged leaves is needed. The intended result being, safe and efficacious control campaigns with minimal expense to the consumer and environment.

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Interest and concern about hardwoods in California has been increasing dramatically. This symposium addressed the State's hardwood resources and included sessions on silviculture, protection and damage factors, urban forestry-recreation, wildlife, wood products-utilization, inventory-measurements, range, and policy and regulation. Use and value of the hardwood resource will continue to grow as the population increases, the resource diminishes, and new uses for hardwoods develop.

Retrieval Terms: damage factors, inventory, measurements, policy, protection, range, recreation, regulation, silviculture, urban forestry, utilization, wildlife, wood products