PEER-REVIEWED ARTICLE

Testing Microdensitometric Ability to Determine Monterey Pine Urban Tree Stress

Abstract

Microdensitometric analysis of aerial photographs has been used to quantify urban tree stress of deciduous species. A test of this procedure applied to Monterey pine indicates that variations in ground cover beneath urban trees among cities and variations in crown morphology among tree species can limit the ability of microdensitometry to quantify urban tree stress.

Introduction

Limited works have been performed in the aerial detection of urban tree stress. Fuhrer *et al.* (1981) evaluated a computer aided image analysis system using color infrared photos for discriminating urban tree's species and vitality. They found that the system could satisfactorily separate the tree species analyzed and could distinguish between healthy and damaged trees. Other studies have also reported on the successful application of color infrared photography in mapping damaged roadside trees in cities (Kenneweg, 1973; Stuber, 1975; Van de Garde, 1976).

Lillesand *et al.* (1979) used microdensitometric analysis to quantify tree stress of roadside maples in Syracuse and Rochester, New York. They reported that "aerial predictions were as reliable as ground estimations, particularly under drought conditions" and also concluded that "color infrared film is generally superior to color film in the stress quantification process". The authors suggested that further research was necessary over a range of alternative conditions, including changes in study location and species.

The objective of this study is to test if Lillesand *et al.*'s multivariate and microdensitometric techniques of aerial stress quantification of deciduous street trees can be applied successfully to a coniferous street tree population in a different urban environment. Monterey pine (*Pinus radiata* D. Don) street trees in Carmel-by-the-Sea, California were chosen for this analysis.

Study Area

Carmel-by-the-Sea was incorporated in 1916 at the edge of the largest of three mainland native stands of Monterey pine (Roy, 1966; Donley *et al.*, 1979). Carmel covers an area of 235 ha (D'Ambrosio, 1974) with a population of 4,990 (Fay *et al.*, 1987). This city is predominantly a residential community with a central business district which sustains a large tourist population. Other commercial and residential areas also exist immediately adjacent to Carmel. Pines (90 to 95 percent Monterey pines) comprise 40 percent of the city's 11,000 street trees (G. Kelly, City Forester, Carmel, California, pers. comm., 1988).

Methods

Ground Data Collection

In mid-August of 1987, 783 Monterey pine street trees were systematically sampled in and around Carmel. Only trees 10 cm in diameter or larger were sampled. Data were collected on ten crown parameters thought to be most indicative of tree stress. These variables were combined using principal components analysis of the variable correlations, which yielded three components (Table 1). These components were combined to yield an overall visual stress index that ranges between 0 (non-stressed) and 1 (highly stressed/dead) (Nowak and McBride, 1991).

TABLE 1. RESULTS OF PRINCIPAL COMPONENTS ANALYSIS FOR VISUAL STRESS INDEX OF MONTEREY PINE IN CARMEL, CALIFORNIA (NOWAK AND MCBRIDE, 1991).

	COMPONENT		
Tree Stress Symptoms	1	2	3
Needle loss[1]	0.650	0.185	0.108
Foliage color[2]	0.817	−0.280	−0.047
Percent large dead limbs	0.452	−0.382	−0.385
Percent small dead limbs	0.138	−0.232	0.877
Percent natural crown pruning	0.318	0.790	−0.170
Dead crown ratio[3]	0.277	0.477	0.353
Crown shape	0.388	0.597	−0.023
Foliage condition	0.890	−0.222	0.001
Trunk condition	0.801	0.017	0.002
General condition	0.932	−0.127	−0.018
Percent of total variance	39%	16%	11%
Eigenvalues	3.945	1.587	1.087

Underlined scores are above the cutoff point (0.400).
Component 1 - General condition component.
Component 2 - Limb loss component.
Component 3 - Small dead limb component.

[1] Maximum needle retention (3 years) minus actual needle retention.
[2] (primary color index × primary color percent) + (secondary color index × secondary color percent). Numerical color index: 1 = green; 2 = yellow green; 3 = yellow; 4 = red; 5 = brown.
[3] Percent of crown volume (if crown extended to ground) lacking branches.

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Aerial Data Collection

Color infrared aerial photographs of the study area were flown on 8 September 1987 between 12:00 and 1:00 PM. The photographic coverage took the form of 1:6000 scale, 9- by 9-inch format, vertical color infrared (Kodak 2443, Wratten 15 filter) positive transparencies. A Zeiss 6-inch focal length camera equipped with forward motion compensation and automatic exposure control was used to obtain the transparencies. A 21-step calibration wedge was exposed on the film prior to processing. The IR-balance of the film was 39 which is "normal" (Fleming, 1978). Emulsions in the "normal" category are used for low altitude photography without color compensating filter modification.

Aerial Data Measurements

To minimize vignetting effects, only ground-sampled Monterey pine lying within 5 cm of the principal point of the positive transparency were analyzed (337 trees). Ground checks were conducted to match photographed trees with ground sampled trees.

Spot density readings of trees were made through the use a microdensitometric system (Lillesand *et al.*, 1979). This system consists of a Bausch and Lomb Zoom 240 Stereoscope/Richards Light Table combination to which a densitometer assembly has been added. This system is calibrated during each use with a standard step wedge.

The 1:6000 photo scale and a 200-μm spot size (1.2-m ground diameter) were used in this study to duplicate the scale and measurements used in the Lillesand *et al.* (1979) study. Three spot density readings were taken on each crown along a line perpendicular to the azimuthal direction of the sunlight at the time of imaging. The three readings were averaged to form the "raw" density reading on each tree crown.

Each density measurement consisted of three spectral readings through Wratten filters number 94, 93, and 92 for yellow, magenta, and cyan film dye layers. Raw density readings (D) were converted to their corresponding exposure values (E) by using a characteristic curve, calculated from the 21-step calibration wedge, for each film layer. This characteristic curve took the form: $\text{Log } E = b_0 + b_1D + b_2D^2 + \dots + b_kD^k$ and permits accurate computation of log E values from measured D values. Sequential F-tests indicated that seventh, seventh, and fifth degree polynomials adequately fit the step wedge data for the yellow, magenta, and cyan film dye layers, respectively. All densities were converted to relative exposure values using these equations. Film exposure is directly related to reflectance of the object imaged at that point (Lillesand and Kiefer, 1979).

The exposure values from all three film dye layers, ratios and sums of these values, and second and third order terms were used as independent variables to predict (1) general condition component, (2) limb loss component, (3) small dead limb component, and (4) overall visual stress index, with one model to predict each dependent variable. The three component values were calculated by weighting the standardized variables by component values above 0.4 and adding these weighted scores together (Comrey, 1973) (Table 1). The four predictive models were developed through stepwise regression. Plots of residuals were examined to be certain the residuals were unpatterned.

Results

The overall visual stress index, general condition component, limb loss component and the small dead limb component models were all significant at alpha = 0.1 (Table 2). However, the low r^2 values indicate an inability of these models to adequately predict tree stress or individual stress components.

Discussion

Microdensitometric analysis of color infrared photography proved to be an unreliable predictor of Monterey pine street tree stress under the conditions of this study. Although microdensitometric analysis of maple tree stress along streets in Rochester and Syracuse proved as reliable as ground estimation (Lillesand *et al.*, 1979), we suggest that differences in the urban environment between Carmel and Rochester/Syracuse, and dissimilarity in tree morphology and physiology between Monterey pines and maples led to our inability to repeat Lillesand *et al.*'s findings.

As tree stress increases, foliage color and crown shape change, and foliage density decreases as leaves are shed in response to the stress. As foliage density decreases, more bark and understory ground cover are exposed in an aerial view of the tree canopy.

Monterey pine crown morphology is a likely reason for the inability to measure tree stress with microdensitometry. While healthy maples tend to have a full crown, healthy Monterey pine crowns tend to have tufted foliage, thus increasing within-crown shadows, understory spectral influence, and the spectral variation within the crown.

Ground cover under street trees in Rochester and Syracuse is fairly homogeneous, consisting of predominantly asphalt, cement, and grass. In the much smaller city of Carmel, street tree understories are highly variable. Sidewalks and curbs are fairly uncommon in Carmel and much of the street tree understory consists of shrubs, soil, ivy, grass, and duff. Along with the mix of understory vegetation, soil, and hard surface types, understory vegetation itself will have differing spectral reflectance based on vegetation type and condition. Thus, the spectral reflectance of stressed trees in Carmel is likely more variable than stressed trees in larger urban environments due to the relatively high variability in understory reflectance.

A similar problem was exhibited in trying to detect air pollution stress using the Landsat Thematic Mapper (Westman and Price, 1988). Natural variation in canopy closure, and the subsequent exposure of understory elements, were sufficient to change spectral variation and obscure the spectral changes due to air pollution.

Our experience suggests that analyzing street tree stress for management purposes under such conditions is best conducted through ground surveys. The cost and relative difficulty of microdensitometric analysis suggest that the practical application of this technique is limited to situations of relatively uniform crown morphology and understory.

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TABLE 2. RESULTS OF STEPWISE REGRESSION RELATING EXPOSURE VALUES TO TREE STRESS INDEX AND INDIVIDUAL COMPONENTS OF TREE STRESS ON MONTEREY PINE. SAMPLE SIZE = 337.

	Dependent Variables			
	STRESS	GCC	LLC	SDL
R-Square	0.045	0.143	0.027	0.008
Alpha	0.000	0.000	0.002	0.076

STRESS - overall visual stress index
GCC - general condition component
LLC - limb loss component
SDL - small dead limb component
Alpha - model significance level

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References

Comrey, A. L., 1973. *A First Course in Factor Analysis.* Academic Press, New York, 316 p.

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

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

Fay, J. S., A. G. Lipow, and S. W. Fay (eds), 1987. *California Almanac.* Pacific Data Resources. Santa Barbara, California, 635 p.

Fleming, J., 1978. Exploiting the variability of Aerochrome infrared film. *Photogrammetric Engineering & Remote Sensing.* 44(5):601–605.

Fuhrer, J., K. H. Erismann, H. J. Keller, and A. Favre, 1981. A system for quantitative determination of species and vitalities of urban trees on color-infrared photographs. *Rem. Sens. Environ.* 11:1–8.

Kenneweg, H., 1973. Interpretationen von Luftaufnahmem für die Erforschung und Gestaltung von Vegetationsbestanden in westdeutschen Ballungsraumen. *Proceedings of the Symposium on IUFRO S 6.05 Remote Sensing including Aerial Photography,* Freiburg im Breisgau. Fed. Rep. Germany, 17–21 Sept., pp. 87–116.

Lillesand, T. M., B. B. Eav, and P. D. Manion, 1979. Quantifying urban tree stress through microdensitometric analysis of aerial photography. *Photogrammetric Engineering & Remote Sensing.* 45(10):1401–1410.

Lillesand, T. M., and R. W. Kiefer, 1979. *Remote Sensing and Image Interpretation.* John Wiley and Sons, New York, N.Y., 612 p.

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

Roy, D. F., 1966. *Silvical Characteristics of Monterey Pine* (*Pinus radiata* D. Don). U.S. Forest Service Research Paper PSW-31, 21 p.

Stuber, E., 1975. Untersuchungen über den Gesundheitszustand des Baumbestandes der Stadt Salzburg. *Studie über die umwelthygienisch-okologische Situation der Stadt Salzburg.* Bundesministerium für Gesundheit und Umweltschutz, Vienna, Austria.

Van de Garde, H. J., 1976. Present application of false colour photography in Holland. *Practical Application of Remote Sensing,* Summer School Alpbach/Tyrol, 28.7.-6.8. Austrian Solar and Space Agency, Vienna, Austria.

Westman, W. E., and C. V. Price, 1988. Detecting air pollution stress in Southern California using Landsat Thematic Mapper band data. *Photogrammetric Engineering & Remote Sensing.* 54(9):1305–1311.