Estimating Urban Vegetation Cover in Los Angeles

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ABSTRACT: Urban vegetation in the Los Angeles basin was analyzed as part of an investigation to estimate hydrocarbon emissions from leaf mass, and to assess the potential contribution of such emissions to photochemical air pollution. A positive print mosaic of NASA U-2 color infrared photographs (taken in 1972) was used for regional delineation of broad vegetation/land-use categories. Urban areas were additionally subdivided into sampling polygons. Randomly selected cells within 20 defined polygons were photographed in 1982 by a low altitude flight (1:3,000) with color infrared film. Vegetation was mapped and digitized for cover by a physiognomic classification which included trees, palm trees, shrubs, ground cover, and grasses. Urban vegetation cover ranged from about 4 percent to 58 percent for the sites sampled, with an average value of 27 percent. Field teams obtained vegetation cover and biomass data for the sample sites. Integration of the photography and field data provided leaf mass estimates for each vegetation class.

INTRODUCTION

The California South Coast Air Basin (CSCAB), which contains Los Angeles and adjacent cities, is the airshed most heavily impacted by photochemical air pollution in the world. The contribution of hydrocarbon emissions from vegetation to photochemical air pollution in such an urban airshed has been the subject of considerable interest for the past decade (Rasmussen, 1972; Coffey and Westberg, 1977; Sandberg *et al.*, 1978; Miller *et al.*, 1979; Bufalini and Arnts, 1981; Dimitriades, 1981; Altshuller, 1983). Resolution of this question has implications for present and future emission control strategies for reactive hydrocarbons from anthropogenic sources.

An essential requirement for addressing this issue is an inventory of hydrocarbon emissions from vegetation. This in turn requires estimates of leaf mass or areal cover by vegetation class or species, and determination of the rates of emission of hydrocarbons from such vegetation.

Aerial photography has been employed to develop biogenic emission inventories in several previous investigations of the potential contribution of vegetation hydrocarbon emissions to photochemical air pollution. Vegetation inventories have been compiled from large scale aerial photographs (Zimmerman, 1980), or by analysis of Landsat spectral data (Hunsaker, 1981; Hunsaker and Moreland; 1981 Salop *et al.*, 1983). In most studies, urban vegetation was ignored or given minor consideration. However, in the CSCAB urban vegetation is the major component on an areal basis and must be considered. Because little quantitative information was available concerning the structure, composition, and distribution of urban ornamental vegetation in the CSCAB, it was necessary to assemble a vegetation inventory specifically for this investigation.

Because of the large number of species grown in the subtropical Mediterranean climate of this region and the extremely large study area, a vegetation survey based on field work alone was impossible. Also, the large study area precluded detailed mapping of all vegetation. A stratified random-sample approach to assess urban vegetation was therefore designed which consisted of (1) the use of high altitude (1:130,000) NASA U-2 photographs to identify vegetation/ land-use cover and to stratify urban areas; (2) the use of low altitude aerial photographs (1:3,000 scale) to map and calculate areal cover of vegetation in randomly selected sample cells within each stratum; and (3) integration of mapped data with data collected from field studies in which species composition and leaf mass were determined.

We have reported elsewhere measurements of hydrocarbon emission rates from vegetation (Winer *et al.*, 1982, 1983) and our determination of the species composition of urban vegetation in the CSCAB (Miller and Winer, 1984). Here we specifically describe our use of aerial photography to map the distribution and calculate the area of ornamental vegetation in the Los Angeles basin. We further dis-

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cuss the use of these data to obtain leaf mass estimates for the development of an emission inventory for hydrocarbons from vegetation in the CSCAB.

METHODS

DELINEATION OF THE STUDY AREA

The area investigated was that portion of the CSCAB containing the majority (70 percent) of anthropogenic sources of hydrocarbons [with the remaining 30 percent of such sources being in the air pollution "receptor" areas of the Basin (SCAQMD/SCAG, 1982)]. Based on geographical and meteorological factors (DeMarrais *et al.*, 1965; Winer *et al.*, 1983), the study area was also defined as the Los Angeles coastal plain bounded by the Santa Monica and San Gabriel Mountains on the north, the Santa Ana Mountains and San Joaquin Hills on the east and southeast, respectively, and the Pacific Ocean on the west (Figure 1). Boundaries included the ridgeline of the Santa Monica Mountains, and the 1100-m contour of the San Gabriel and Santa Ana Mountains which was chosen to be above the average height of the summer temperature inversion layer.

AERIAL PHOTOGRAPHY

For the initial stratification of urban vegetation, we employed a positive print mosaic of fifteen 240-mm format color infrared (CIR) photographs from a National Aeronautics and Space Administration (NASA) U-2 aircraft overflight of the Los Angeles basin (Mission 72-112). The photographs were taken in July 1972 from an altitude of 65,000 ft with a Wild RC-10 sensor type camera and Ratten 12 filter using Kodak Aerochrome infrared film 2443 (spectral band 520 to 900 mm).

Low-altitude photography for detailed mapping was obtained by Western Aerial Surveys Inc. of Riverside, California using a Piper Apache aircraft and a Zeiss RMKA 15/23 camera with a 6 inch focal length lens and Zeiss D filter. The positive transparency photographs were taken on 6 October 1981 at a scale of approximately 1:3,000 with 30 percent planned overlap on Kodak Aerochrome infrared film 2443. To minimize shadows of buildings that could conceal vegetation, photographs were taken in late morning and mid-day.

REGIONAL ANALYSIS

The scale of the U-2 photography was appropriate for a regional stratification of vegetation/land-use categories. Boundaries of urban, natural, and agricultural vegetation areas were determined primarily by color variations. The pale pink/grey signature of urban areas resulting from combined vegetation and urban surfaces contrasted sharply with adjacent dark red naturally vegetated areas. Agricultural areas, though small, were easily delineated by their bright red reflectance and generally rectangular shapes. Generally, these broad vegetation/land-use categories were easily defined.

Because the U-2 mosaic was nearly ten years old, updating for boundary changes was necessary. This was accomplished by superimposing current imagery on the vegetation/land-use map. Projection of 70-mm blank-and-white positive Landsat data (June 1981) over the U-2 defined boundaries, using an International Imaging Systems color combiner, enabled identification of any significant changes in

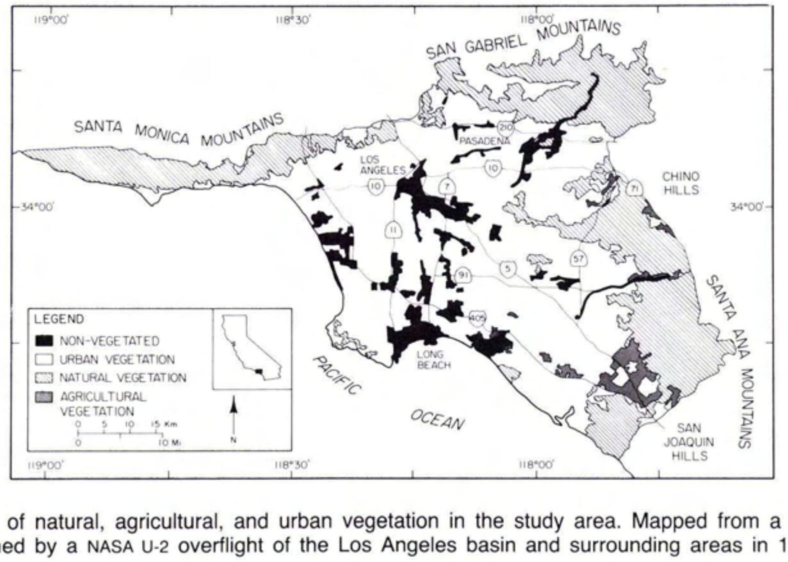

FIG. 1. Distribution of natural, agricultural, and urban vegetation in the study area. Mapped from a mosaic of 15 CIR photographs obtained by a NASA U-2 overflight of the Los Angeles basin and surrounding areas in 1972 at a scale of 1:130,000.

land-use cover. Boundary changes between 1972 and 1981 were found to be limited, and primarily involved urbanization of agricultural areas.

The resulting vegetation map is shown in Figure 1. Areal calculations of the urban, natural, and agricultural vegetation categories were carried out by digitizing, and it was determined that the vegetation categories and non-vegetated area comprised a total study area of 4515 km². The urbanized portion of this study area covers 2630 km² (58 percent). Natural vegetation on mountain slopes and rolling hills covers 1480 km² (33 percent) while agricultural vegetation is limited to 105 km² (2 percent) and was not included in the analysis.

A category termed non-vegetated (7 percent) encompassed the larger central business districts, airports, and industrial areas that have relatively little or no vegetative cover. These "non-vegetated" areas were eliminated from further investigation.

Urban Analysis

Distinct variations in reflective intensity and red tones indicative of vegetation existed within the urban areas on the U-2 photography. These variations were interpreted as differences in the proportion of vegetation cover to other surface materials. On this basis the urban vegetation class was visually subdivided into 20 polygons based on their relative color and brightness (Figure 2). Based upon the limited change in boundaries between 1972 and 1980 and the relatively mature and stable structure of residential and industrial areas, it was assumed that vegetation densities on the 1972 U-2 photography were applicable to the present study for the purpose of stratifying the study area.

A major problem in subdividing the urban area was vignetting on the U-2 prints. Distinctions between some areas were minor and vignetting may therefore have affected some stratification boundaries. Polygons were constructed to be of reasonably equal size, and as many subdivisions as possible were made to avoid wide variations within stratum. For statistical purposes, each of these polygons was assumed homogeneous in vegetation composition.

Samples were randomly selected for each of the 20 polygons by use of a grid covering the urban area. Grid cells covered about 1.2 km². Random numbers (Rand Corporation, 1955) were converted by computer to latitude and longitude coordinates of sample cell size and plotted over 1:250,000 scale U.S. Geological Survey maps. Cells were consecutively plotted until each of the 20 polygons contained at least one sample site.

Sample Site Analysis

For each of the 20 sample sites, five frames of photography were obtained. Time and resource constraints limited mapping to the frame lying over, or closest to, the center point of each sample site. Due to inherent distortions at the edges of the photographs which could affect the plant cover calculations, only about 60 percent of each frame was mapped. It was determined that this portion of the photographs was planimetric within national map standards. Vegetation areas were therefore mapped directly from the photography.

The scale of the photographs acquired at the sample sites ranged from 1:2,200 to 1:4,400. The mapped areas averaged ~0.3 km² per frame, but ranged from 0.16 to 0.64 km² due to scale variations. The total area mapped for the 20 sites was 6.2 km², or about 0.2 percent of the total urban study area.

Examination of the photography showed that five physiognomic (structural) vegetation categories could be consistently recognized and recorded. These five vegetation classes consisted of trees (broadleaf and conifer), palm trees, shrubs, ground cover, and grass. Defining vegetation in this broad way was acceptable because the field survey furnished accurate areal data and biomass estimates of individual plant species at the sample sites.

Vegetation classes were interpreted on the basis of tone, cover, shape, shadow, texture, and height. Mapping was performed by directly delineating individual plant areas. Due to varying size and the large number of tree species (more than 70 were identified in the field), difficulty was encountered in separating tree types. As a result, broadleaf and conifer trees were lumped into one class, to be differentiated by field examination. Shadows and image displacement permitted differentiations of trees and shrubs, which were based on relative sizes. Ground covers were distinguished from grasses primarily by "texture".

The vegetation maps produced were digitized and the areal cover of individual plants or plant areas summed for each of the five vegetation classes within their respective sample areas (Table 1). Areal calculations were corrected for variations in linear scale.

RESULTS AND DISCUSSION

The percent of vegetation cover varied greatly between sample sites, ranging from 4 percent to 58 percent (Table 1). Low values of about 10 percent occurred in business districts or industrial areas (Polygons 2 and 4). These contrasted with a heavily vegetated residential neighborhood (47 percent, Polygon 1) and with a site which included a golf course (58 percent, Polygon 14). In general, most values of total vegetation cover fell in the 20 to 30 percent range for urban residential areas throughout the study area.

Substantial variation was also observed between sites with respect to the relative areas occupied by the five vegetation classes. In some cases as much as an order of magnitude difference was found be-

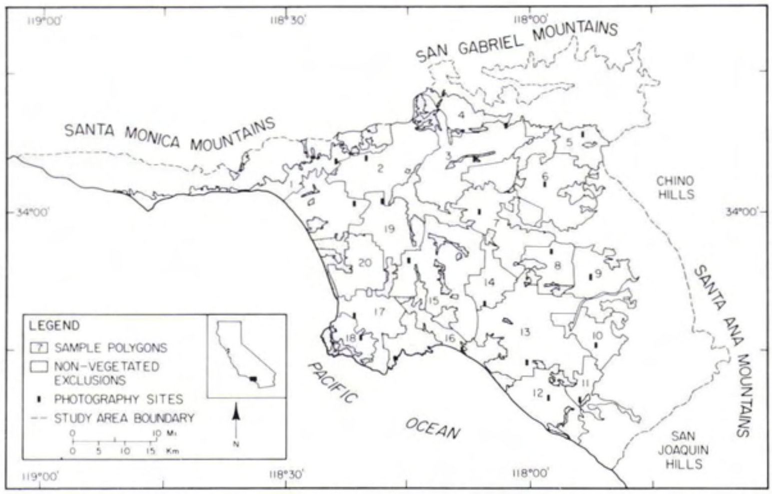

FIG. 2. Division of urban vegetation in study area into polygons based on relative tones and reflective intensity of NASA U-2 CIR photography. Approximate location of 20 randomly selected photography sites (not to scale).

tween sites for the ratio of the area of a given vegetation class to the total area of vegetation within a plot.

INTEGRATION OF PHOTOGRAPHIC AND FIELD DATA

Associated field surveys were conducted at each photographic sample site within each polygon. Each specimen from the field survey was assigned to one of five vegetation classes. Areal cover and volume estimates were calculated from shapes and dimensions. Estimates of leaf mass for each species in each class were calculated as the product of the volumes and the leaf mass densities. Ground cover and grasses were reported by area only.

Areal measurements from the field survey were combined with the photographic data to yield a larger sample size. Specifically, the total leaf mass for a given class of vegetation in a polygon was estimated by combining leaf mass data and the photographically determined plant areas according to the following algorithm:

$$\begin{array}{l}\text{Total Leaf}\\\text{Mass for}\\\text{Given}\\\text{Vegetation}\\\text{Class in}\\\text{Polygon}\end{array} = \left(\frac{\sum_{i=1}^{N} (\text{Leaf Mass})_i}{\sum_{i=1}^{N} (\text{Cover Area})_i} \right) \left(\frac{\begin{array}{c}\text{Photographically}\\\text{Determined Plant}\\\text{Cover for Class}\end{array}}{\begin{array}{c}\text{Photographic}\\\text{Area Mapped}\end{array}} \right) \left(\begin{array}{c}\text{Polygon}\\\text{Area}\end{array} \right)$$

where N is the total number of species in a given vegetation class. The green leaf mass totals for each of three classes (trees, palms, and shrubs) for each polygon are shown in Table 2. Also shown are the total areas of the 20 polygons. These can be used with the leaf mass data to obtain overall leaf mass densities for each polygon for these three classes of vegetation. These data reveal that trees, palms and shrubs represent an estimated 350×10^6 kg of leaf mass in the study area, or an average of 14×10^4 kg km^{-2}. Leaf mass estimates were not made for ground cover and grasses because, for these classes of vegetation, emission rates were determined as a function of area.

The leaf mass estimates in Table 2 were combined with experimentally determined emission rates of isoprene and selected monoterpenes to obtain hydrocarbon emissions for trees, shrubs, and palms for each polygon (Winer *et al.*, 1983). These data were added to calculated hydrocarbon emissions from ground cover and grasses in each polygon. Summation over the polygons provided a total inventory of isoprene and selected monoterpene emissions for the urban study area. This inventory was then used to assess the potential for such hydrocarbon emissions to contribute to photochemical air pollution in the Los Angeles basin (Winer *et al.*, 1983). The results obtained suggest that isoprene and monoterpene emissions contribute no more than, and probably much less than, 10 percent of the ozone formed from anthropogenic sources of reactive hydrocarbons in the study area.

COMPARISON BETWEEN PHOTOGRAPHIC ANALYSES AND FIELD SURVEYS

It was of interest to compare the data for vegetation cover (by class) obtained by the field and the photographic methods. Comparisons between

TABLE 1. AREAL COVER (M^2) BY VEGETATION CLASS DETERMINED FROM PHOTOGRAPHIC MAPPING OF TWENTY RANDOMLY-SELECTED SAMPLE SITES IN CSCAB STUDY AREA

Polygon	Trees	Palm Trees	Shrubs	Ground Cover	Grass	Total Area of Vegetation	Area Mapped	Percent Vegetation Cover
1	87,300	2,900	21,400	1,200	71,900	185,000	393,000	47
2	17,000	600	4,920	1,900	7,280	31,700	374,000	8
3	38,000	810	7,100	1,300	40,600	87,800	288,000	30
4	16,700	680	6,500	2,670	6,300	32,800	362,000	9
5	20,500	1,100	7,020	1,660	47,100	77,400	343,000	23
6	29,000	810	6,520	1,150	27,900	65,400	286,000	23
7	20,200	140	4,080	130	55,900	80,400	280,000	29
8	1,900	25	3,500	1,000	18,800	25,200	194,000	13
9	26,600	630	5,880	2,950	75,600	112,000	296,000	38
10	10,700	0	4,360	0	21,900	37,000	272,000	14
11	18,700	0	3,530	940	28,000	51,200	326,000	16
12	22,600	430	5,770	30	77,600	106,000	340,000	31
13	12,900	310	4,370	2,520	32,500	52,600	167,000	31
14	17,500	140	9,980	6,860	147,000	181,000	311,000	58
15	17,100	800	3,260	60	46,800	68,000	232,000	29
16	600	70	5,960	5,860	1,900	14,400	347,000	4
17	33,400	30	11,200	16,400	13,700	74,800	215,000	35
18	156,000	270	47,400	30,600	21,200	255,000	642,000	40
19	15,400	1,900	3,750	0	20,300	41,400	228,000	18
20	34,000	230	10,800	16,800	37,600	99,400	337,000	29
Totals	596,100	11,875	177,300	94,030	799,880	1,678,500	6,233,000	

TABLE 2. TOTAL LEAF MASS ESTIMATES FOR 20 POLYGONS (10^6 KG)

Polygon. No.	Polygon Area (km^2)	Trees	Palms	Shrubs
1	115.2	9.0	0.9	8.2
2	172.6	62.7	0.0	3.0
3	201.3	38.5	0.8	6.9
4	59.3	2.8	0.2	1.0
5	69.1	2.4	0.4	2.9
6	203.7	26.9	1.2	8.6
7	161.9	18.7	0.1	3.1
8	69.4	0.0	0.0	0.9
9	113.7	7.9	0.2	5.2
10	86.8	5.8	0.0	1.3
11	50.9	0.7	0.0	0.7
12	115.7	7.9	0.2	2.9
13	278.1	22.9	0.8	5.9
14	69.9	1.3	0.0	0.0
15	233.1	6.0	1.2	2.0
16	40.8	0.0	0.0	0.8
17	105.3	6.1	0.0	6.3
18	54.9	4.7	0.0	1.8
19	117.5	11.7	2.9	1.7
20	224.4	29.5	0.2	8.0
Totals	2544	266	9	71

TABLE 3. COMPARISON BETWEEN VEGETATION COVER DETERMINED FROM FIELD SURVEY AND PHOTOGRAPHIC INTERPRETATION[a]

	Field Survey[b]		Photographic Interpretation[c]	
	Percent of Areal Cover	Percent of Vegetation Cover	Percent of Areal Cover	Percent of Vegetation Cover
Trees	5	21	10	35
Palm Trees	2	8	2	7
Shrubs	15	62	13	46
Ground Cover	0.3	1	0.2	1
Grass	2	8	3	11
Totals	24.3	100	28.2	100

[a]Totals from all measurements.
[b]Based upon analysis of 833,000 m^2 of which 211,000 m^2 were covered by vegetation.
[c]Based upon analysis of 6,200,000 m^2 of which 1,700,000 m^2 were covered by vegetation.

percentages of areal vegetation cover (Table 3) revealed comparable values and a consistent order for the two sampling methods. In both cases shrubs comprised the largest percentage cover, followed by trees, grass, palm trees, and ground cover, respectively.

The data from the two sampling methods can also be compared for each vegetation class and for total percent areal cover. The data in Table 3 reveal that percents of areal cover (columns 1 and 3) determined by both sampling methods were in good agreement for all vegetation classes except trees. As a percent of total vegetation cover (columns 2 and 4), the greatest variation occurred for shrubs which were estimated from the field survey to comprise 62 percent of total vegetation cover while photographic interpretation yielded an estimate of 46 percent. The sums of percent areal cover for the five vegetation classes varied by ~15 percent for the two methods (24.3 versus 28.2). Considering the limited areas sampled, the good agreement observed between results from the field measurements and the photographic analyses suggests that these independent methods provided reliable estimates of vegetation cover.

CONCLUSION

Ornamental vegetation in a region as large as the Los Angeles basin is extremely varied in composition and density, making total direct measurement unfeasible. Moreover, measurement of the extent and composition of vegetation in such a basin by any statistically-based methodology is a complex task and is necessarily subject to great uncertainty. However, in the interest of resolving one aspect of an important environmental issue, we used a method of estimation based on stratified random sampling in which interpretation of aerial photography played an essential role.

The approach developed here could be applied to other airsheds for which similar data are required. In such applications, it would be desirable to analyze a larger portion of each polygon which would provide more robust statistics than was possible within the scope of this study.

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