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Dwelling Unit Estimation with Color-IR Photos

Results can be obtained from scales as small as 1:20,000 having a statistically significant confidence level of 99 percent.

ABSTRACT: *One application of aerial photo-interpretation procedures to urban analysis receiving considerable attention is the estimation of dwelling units in areas of high population density. In this study, color-infrared photographs of metropolitan Boston of a scale 1:20,000 is examined and found to be capable of providing the signatures necessary for making accurate dwelling unit estimates. It is considered that further investigation of color-infrared photographs may reveal that accurate estimates can be made from scales vastly smaller than the 1:20,000 used here.*

INTRODUCTION AND REVIEW

AIRBORNE IMAGERY SEEMS to possess great potential as a tool for urban analysis. At present, however, research in this direction has been limited. One area where research has begun is in the development of methods for estimating the number of dwelling units in areas of high population density. From such estimates a number of additional estimates can be generated including total population and density of population. In this study dwelling unit estimates are made for selected areas of metropolitan Boston using good color-infrared (CIR) photographs flown at an altitude of 10,000 feet.[1] The purpose of the study is twofold: first, to determine whether accurate dwelling unit estimates can be made from medium-scale imagery (in this instance 1:20,000) and second, to determine whether in making these estimates CIR imagery offers advantages not offered by panchromatic and natural-color photographs.

Several studies have been prepared on dwelling unit estimation, including those of Green[2], Hadfield[3], and Binsell[4]. Green's study of Birmingham, Alabama, was the first of its kind. Using panchromatic stereo pairs of a scale 1:7,500, Green examined 17 residential subareas, recording several categories of housing type. The categories included single-family, double-family, multi-family 3–5, multi-family 6–8, and multi-family 9–11. Identification of housing types was based on such criteria as form and structure of roof, yards and courts; driveways and entranceways; size, shape ahd height of structures; and spatial relationships to other buildings. Three major error trends were revealed by this study. Firstly, dwelling units per block were underestimated by 7 percent; secondly single-unit detached structures were overestimated by 8 percent; and thirdly, the amount of error increased in areas having a higher prevalence of multi-unit structures. The investi-

[1] Part of Mission 104, NASA-MSC Earth Resources Aircraft Program, 14 September 1969, over Test Site 176 (New England). Ektachrome Aero Infrared Film 8443. This study was financed by U. S. Geological Survey, Department of Interior Grant No. 14-08-0001-G-8, Robert B. Simpson, Principal Investigation.

[2] Norman E. Green, *Aerial Photography in the Analysis of Urban Structure, Ecological and Social* (unpublished Ph.D. dissertation, Department of Sociology, University of North Carolina, June 1955).

[3] S. M. Hadfield, *Evaluation of Land Use and Dwelling Unit Data Derived from Aerial Photography*, Urban Research Section, Chicago Area Transportation Study, Chicago, 1963.

[4] Ronald Binsell, *Dwelling Unit Estimation from Aerial Photography*, Department of Geography, Northwestern University, June 1967.

gation further revealed that 99.8 percent of residential structures were accounted for by aerial photo-interpretation procedures.

S. H. Hadfields' study of Chicago also included a system for estimating dwelling units. The photos in this instance were at a scale 1:4,800; dwellings were classified simply as single-family or multiple-family. The estimates made from the photos were checked for accuracy in two ways: census data and field surveys. The latter were based upon observation of doorbells, mail boxes and utility meters. Hadfield found from his investigation that the original aerial survey showed 10 percent fewer dwelling units than the census count. However, where the field survey was used to provide a correction factor, the difference between the aerial survey and the census count was reduced to only 0.4 percent. Unfortunately, the nature and development of Hadfield's correction factor were not described in detail.

In a recent study of the Chicago area, Ronald Binsell has experimented with natural-color, continuous-strip transparencies at a scale of 1:5,240 for making dwelling unit estimates. Stereo pairs were not employed, and furthermore it was pointed out that no special advantage accrued from the use of color. A variety of residential areas was examined, none of which had been visited by the author prior to the dwelling unit estimation.

Binsell's methodology entailed compiling a list of keys for estimating the number of dwelling units per residential structure and testing it on two sample blocks. The blocks were then field checked, revealing a gross overestimation of dwelling units. The keys were adjusted for this factor, and an investigation was conducted on an additional 19 subareas. A field check of the 19 subareas revealed the following error trends in the estimates: firstly dwelling units were underestimated by 15.7 percent; secondly single detached dwellings were overestimated by 4.3 percent; thirdly the degree of error was found to increase with the prevalence of multi-unit residential structures; and forthly 99.9 percent of residential structures were identified by aerial imagery. The directions of error, then, were quite consistent with those found by Norman Green.

Methodology

The dwelling unit estimates described in the preceding review were derived from relatively large-scale imagery. Green used the smallest scale at 1:7,500 whereas Hadfield used the largest at 1:4,800. For this study a scale of 1:20,000 was selected in order to evaluate whether this medium-scale imagery could be used in making dwelling unit estimations. Furthermore, where previous estimates were derived from either panchromatic prints or natural-color transparencies, in this study CIR transparencies were employed. It was considered that in high-density areas CIR imagery would allow for easier identification of urban signatures.

The methodology consisted of selecting three test blocks of high-density housing in the metropolitan Boston area. Two of the blocks selected were located in Chelsea, the third in East Boston. The analysis of these blocks was done monoscopically although a stereoscopic analysis could have been conducted. Oblique photos were not available. However, as continuous strip transparencies were being used, a slight oblique view of some blocks was possible. Where such views were possible building heights (that is, the number of stories) could be readily determined. Magnification of the transparencies was done exclusively by hand lenses, the most powerful of which could magnify by a factor of 18.

As a starting point, the photo-interpretation keys developed by Binsell were systematically applied to the test blocks in order to estimate the number of residential structures and the number of dwelling units. Some of the keys, such as the arrangement of windows, were of little value in working at a scale of 1:20,000. Most, however, were quite applicable although in modified form.

A field check was conducted by the author to determine the accuracy of the estimates and the effectiveness of the keys. Dwelling-unit counts in the field were made on the basis of doorbells, mailboxes and utility meters. Where some question remained, the count was verified by questioning one of the building's occupants. On the basis of this field check, the keys were modified. Following is a list of the keys relevant to the dwelling-unit estimates made in this study.

Keys for determining number of dwelling units per structure.

1. Type of roof
2. Relative size of structure
3. Number of stories
4. Division of buildings
5. Availability of parking
6. Amount and quality of vegetation.

Keys for distinguishing between residential and non-residential structures.

1. Shape
2. Parking availability
3. Relative location
4. Amount and quality of vegetation.

With the completion of the field check, 15 additional city blocks within metropolitan Boston were selected for examination. Six of the city blocks were located in East Boston, five were located in Chelsea and four were located in Charlestown (Figure 1). Although none of the 15 blocks had even been visited by the author, some familiarity with the East Boston and Chelsea areas had obviously occurred as a result of the field check of the three test blocks. The four blocks in Charlestown, a section of Boston never visited by the author, were selected in order to test the significance of familiarity in the making of dwelling unit estimates.

The estimates of dwelling units for the 15 blocks were determined primarily on the basis of four photo keys—roof type, relative size, number of stories, and division of buildings. Roof type (that is, peaked or flat) was usually determined first. Structures with peaked roofs seldom contained more than two dwelling units. The decision was whether the structure was a single-family or two-family unit. Additional factors such as relative size or the presence of a single-car garage were necessarily considered.

Structures with flat roofs usually contained two or more dwelling units. Few structures in the areas investigated contained more than three dwelling units. The number of stories of structures became the best indicator. The determination was made primarily on the basis of shadows, except in those few instances where oblique views were available. To utilize shadows effectively a point of reference such as a garage had to be found. The shadow cast by this structure was then compared to the shadows cast by the residential structures to determine the number of stories. At this point roof divisions such as firewalls were sought to determine whether the building was a single structure or attached.

Although the areas investigated were heavily residential, some nonresidential structures were found. For structures such as neighborhood meeting halls or churches, shape (such as indicated by shadow) was the best key. Parking areas and landscaping were frequently absent from such structures. Other nonresidential structures (grocery stores or laundromats) could be identified by their corner location or flat roof and one-story height.

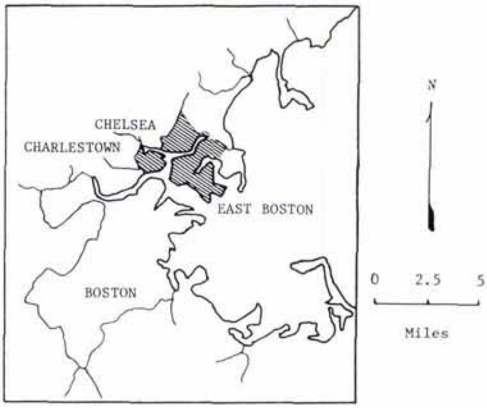

FIG. 1. Location of sample areas and blocks studied. The overall population densities of Chelsea and Boston (of which East Boston and Charlestown are a part) in 1967 were 14,569 and 14,273 per square mile, respectively.

RESULTS

The results of the investigation of the 15 blocks are shown in Table I. Estimating the number of residential structures per block by aerial imagery of a scale 1:20,000 proved highly successful. Here the CIR film was extremely helpful by providing sharp contrast between buildings and vegetation. The figures, therefore, show an overestimation of only one residential structure for the five-block total in Chelsea, an underestimation of only two residential structures for the six-block total in East Boston, and the four-block total in Charlestown. Upon examining the figures for the individual blocks, the number of errors seems to be somewhat greater. However, in the area totals, the degree of error is less because underestimations are in some instances offset by overestimations. The total for the three areas shows an underestimation of only three residential structures out of 655. This correct identification of 99.5 percent of the residential structures compares favorably with Green's 99.8 percent and Binsell's 99.9 percent.

The areas selected for investigation, as it turned out, were comprised primarily of multi-family structures. There were, in fact, few single-family detached units. As previous studies had all shown the degree of error in dwelling-unit estimates to increase in areas having a prevalence of multi-unit structures, it is not surprising that the estimates of dwelling units in this study were less accurate than the estimates of residential structures.

The data in Table I show the number of

TABLE I. ESTIMATED AND ACTUAL NUMBER OF RESIDENCES AND DWELLING UNITS PER BLOCK FOR THREE SAMPLE AREAS

Block Nos.	*No. Residences Per Block*		*No. DUs Per Block*		*No. Residences DUs Correctly Estimated*
	Photo	*Ground*	*Photo*	*Ground*	
			East Boston		
1	52	52	137	138	35
2	47	50	160	151	31
3	41	41	137	147	28
4	46	45	96	87	25
5	52	52	139	137	33
6	48	48	124	127	26
Total	286	288	793	787	178 (61%)
			Chelsea		
1	45	43	108	116	22
2	48	48	125	124	29
3	21	21	66	76	17
4	50	51	162	175	26
5	39	39	116	110	32
Total	203	202	577	601	126 (62%)
			Charlestown		
1	30	31	43	55	15
2	51	50	76	90	29
3	43	45	106	107	25
4	39	39	95	104	18
Total	163	165	320	356	87 (52%)
Grand Total	652	655	1690	1744	391 (59%)

dwelling units in the six-block total for East Boston to have been overestimated by 6, in the five-block total for Chelsea the number was underestimated by 24, and in the four-block total for Charlestown an underestimation of 36 dwelling units occurred. However, if the figures for individual blocks are examined, the number of errors is greatly increased. Again, the degree of error in the totals is reduced by the offsetting of underestimates by overestimates. Significantly, this latter situation did not occur in Charlestown where the number of dwelling units per block was consistently underestimated. This was due in large part to a particular type of roof which was continually misread. Had a test been done in Charlestown, this roof type would undoubtedly have been discovered, and the resulting analysis would have displayed fewer errors.

The total of the three areas shows an underestimation of 54 dwelling units, or 3.1 percent. The percentage of error compares extremely well with previous studies. Green underestimated his dwelling units by 7 percent, Hadfield by 10 percent and Binsell by 15.7 percent.

One final statistic computed which did not occur in previous studies was the number of dwellings for which dwelling units were correctly estimated (Table I). The largest number of correct estimates was made in the East Boston and Chelsea areas, where percentages were recorded of 61 and 62 respectively. In Charlestown, the one area not visited by the author, only 52 percent of the houses were correctly identified as to exact number of dwelling units.

A chi-square test was applied to the data in Table I as a means of determining the statistical significance of the estimates. In Table II the statistical significance of the

TABLE II. STATISTICAL SIGNIFICANCE OF ESTIMATES FOR NUMBER OF RESIDENTIAL STRUCTURES PER BLOCK

Area	*Chi-Square Value*	*Critical Value at Rejection Rate of*		
		0.10	*0.05*	*0.01*
East Boston	.213	9.24	11.07	15.09
Chelsea	.109	7.78	9.49	13.28
Charlestown	.146	6.25	7.81	11.34
Total	.468	21.06	23.68	29.14

TABLE III. STATISTICAL SIGNIFICANCE OF ESTIMATES FOR NUMBER OF DWELLING UNITS PER BLOCK

Area	*Chi-Square Value*	*Critical Value at Rejection Rate of*		
		0.10	*0.05*	*0.01*
East Boston	2.189	9.24	11.07	15.09
Chelsea	3.471	7.78	9.49	13.28
Charlestown	6.850	6.25	7.81	11.34
Total	12.510	21.06	23.68	29.14

estimates of residential structures per block is tested. The chi-square values are presented for the East Boston, Chelsea and Charlestown areas, as well as for the total of the three areas. The estimates are statistically significant if the chi-square value is less than the critical value at selected rejection rates. The critical rejection rates used are 10 percent, 5 percent and 1 percent. In Table II the chi-square values of each of the three areas and the chi-square value of the total are all significant statistically at the confidence level of 99 percent.

In Table III the statistical significance of the estimates of dwelling units per block is tested. Again, the chi-square values are presented for the East Boston, Chelsea and Charlestown areas as well as the total of the three areas. The chi-square values of East Boston, Chelsea and the three-area total are fully significant statistically at the 99 percent confidence level. The chi-square value of Charlestown is significant at the 93 percent confidence level.

CONCLUSION

The major conclusion of this investigation is that accurate dwelling-unit estimates can be made from aerial photographs of a much smaller scale than has been employed in the past. In this instance a scale of 1:20,000 made possible estimates which were shown to be statistically significant at the 99 percent confidence level. It should be emphasized that a familiarity with the area under investigation, no matter how slight (a single visit even), will greatly improve the accuracy of the results. If it can be assumed that in most applications an interpreter will have some knowledge of the area in which he is working, then the accuracy of dwelling unit estimates from scales even smaller than 1:20,000 may remain relatively high. Further testing should be conducted using such smaller scales.

Comment should also be made on the value of using color infrared film. It is considered by this investigator that CIR is the most effective film for studying high-density residential areas. Much greater detail can be obtained from its use; the contrast between built-up and nonbuilt-up areas is most obvious. However, even in built-up areas, detail is sharper than with panchromatic or natural-color films.