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THE FACTOR OF RESOLUTION IN LAND USE STUDIES FROM ORBITAL-ACQUIRED IMAGERY

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BIOGRAPHICAL SKETCH

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ABSTRACT

Data acquired from orbital heights have potential application in a variety of land use studies. In contrast to conventional aerial photography, the resolution of orbital-acquired imagery may be a significantly limiting factor. A serious consideration of the wide variations found in physical and cultural landscapes suggests that a uniform level of information from all environments is not available. Illustration of this variation involves method and classification. Conventional aerial photographs were overlain with transparent grids, simulating ground resolution cells. The number of land use elements contained in each cell was recorded. The land use elements are defined in a land use classification scheme appropriate to thematic mapping.

THE FACTOR OF RESOLUTION IN LAND USE STUDIES FROM ORBITAL-ACQUIRED IMAGERY

An integral and important part of the geographic applications program of the U.S. Geological Survey has been concerned with the effective application of remote sensor data from orbital heights. Of particular significance is the utility of spacecraft data in land use studies: resource surveying, inventory, and management, land use and thematic mapping. The utility of Gemini and Apollo spacecraft photography for broad regional land use mapping has been analyzed by various investigators (Colwell et al., 1969; Simonett,

1969a; Thrower, 1970; Thrower and Senger, 1969). The assumption, implicitly at least, has been that the types and levels of information derived in these studies provide a fair measure of the type and levels of information we can expect from the telemetered imagery of the Earth Resources Technology Satellite (ERTS-A), scheduled to be launched by NASA in 1972.

To use satellite data effectively, according to Dr. Gerlach of the U.S. Geological Survey, "... we must reflect far in advance what we most want to know, instrument the satellites accordingly, and learn to process the results quickly." (Gerlach, 1969, p. 59). Analysis of Gemini and Apollo photography is not the only way to approach this problem. Analysis of the manner in which various environments or landscapes are "put together" or organized can reveal a great deal about the degree to which these environments or landscapes lend themselves to data retrieval from imagery. This is especially germane to the claim that space-acquired data will be of a uniform or systematic nature (Badgley and Vest, 1966, p. 787).

A serious consideration of the wide variations found in nature and in the works of man suggests that a uniform level of information from single-resolution space imagery is not available in all environments. Both nature and man mix land use elements such as cropland and trees in a variety of ways in different environments. The land use pattern developed in areas of the Great Plains has all but effaced the natural pattern, which was quite homogeneous. Although cropland has replaced grassland as the primary landscape element, the size, shape, and arrangement of fields presents a very different appearance from what must have been a quite uniform prairie broken only by riverine vegetation along streams. Conversely, man has made but very slight imprint in areas of tropical rainforest. The appearance of the landscape on the Mbozi plateau in Tanzania is another very distinctive example. Shifting cultivation in small, scattered plots has been superimposed on the heterogeneous pattern of native woodland, grassland and bush vegetation.

In an age when science and technology can provide synchronous and/or sequential data of large areas from orbital altitudes, the diversity of landscapes is very relevant to the types and levels of information these spacecraft systems can provide. For those interested in resource inventory, land use, and thematic mapping, the prospect of synoptic coverage and a uniform data base from space-acquired imagery is surely regarded with interest and anticipation. The quality of the imagery is a function of several factors, among which the most important are: 1. the quantity and quality of the illuminating source; 2. atmospheric degradation of the illumination and the energy return to the recording system; 3. the nature of the target; 4. the recording system. We can choose the times at which (1) will be optimal; (2) and (3) are fixed or given. The only direct control involves the camera and film characteristics (4). There are combinations involving the focal length, lens specifications and shutter speed to optimize resolution, scale or area covered in one frame. Film resolution and its operative counterpart, ground resolution, are fundamental properties. Ground resolution is the ground-size equivalent of the smallest resolved object. Anyone who has looked through an airplane window and studied the ground can gain a conception of the difference between convention aerial photography having a ground resolution of 3-5 feet and spacecraft photography with a ground resolution of 300-500 feet. Comparison of the sizes of things that can be recognized flying a few hundred feet above terrain and at 20,000 feet provides a practical analogy.

Depending on the size of features one is trying to identify, resolution is the critical factor. When this critical limit (the point at which the resolution is fine enough to identify areas of the minimum size appropriate for the particular study) is reached, there is little advantage in increasing resolution.

If one can trade scale for resolution, Katz (1960, 6) advises to trade in the direction of lower resolution and smaller scale number (larger scale). This reciprocity can be carried only so far before the advantage of large areal coverage is lost. Photography at different times of the year can provide supplementary information but this is only a partial substitute for resolution (Simonett, 1969b, 476). A study conducted by the Aero Service Corporation, using photography of varying scales, contrasts and resolutions, suggests that there is an optimal resolution related to the identification of particular subjects (Aero Service Corporation, 1960, Chapter V).

For the purposes of mapping area-extensive land uses, conventional aerial photography provides a very uniform data base since the ground resolution is usually several orders of magnitude smaller than the sizes of land uses being mapped. For most purposes, then, the imagery is not resolution-limited. But if the resolution is much coarser, what effect do various environments have on the types and levels of information which are capable of being retrieved? Stated in other terms, what if the imagery is resolution-limited in

certain types of landscapes? It is quite obvious that, for land use mapping, the resolution required for homogeneous landscapes, such as a tropical rainforest, is much coarser than that required for heterogeneous landscapes, e.g., a mixed agricultural area.

The relationships between resolution requirements and landscape diversity involves analysis, not only of different landscapes imaged with a given resolution, but also of each landscape imaged with varying resolution. The procedure selected to achieve this consists of counting the number of landscape elements (shown on conventional arial photographs) which occur within simulated resolution sizes. Transparent grids, drawn in accordance with the scale of each photo, simulate ground resolution sizes of 1,000', 400', 200', and 100'. Each scaled grid was overlain on each of the photos and the frequency of the occurrence of land use elements (but not land use types) was recorded (each grid cell contained one, two, three or more than three land use elements.

The rationale for using this procedure is based on the unambiguous detection of landscape elements. If a majority of the grid squares (hereafter referred to as cells) of a particular size contain only one element, the information obtained by photography with that respective resolution capability is optimal for land use studies. But if most of the cells of one particular size contain more than one element, the film will combine the return from all of those elements, averaging them together in a hue or tone which will not be representative of any single element. Suppose one wished to photographically resolve a wheatfield in the shape of a square, 100 ft. per side. The resolution required would need to be less than 100 ft. since any resolution cell would not fall directly on the wheatfield but would probably fall partly on the field and partly on adjoining areas. Finer resolution would be required for other wheat fields of the same size, area-wise, but with varying shapes.

The method involved a classificatory problem: what should constitute an element? Counting the mere number of gray tones was very unsatisfactory. A classification scheme appropriate to resource inventory and thematic mapping was devised as follows:

1. Settlement and Associated non-agricultural land
   a. urban areas of all sizes
   b. farmsteads with associated trees, stockpens
   c. all roads within a cell
   d. other transportation lines
2. Cropland; individual fields counted separately
3. Grassland
   a. pastures
   b. naturally occurring patches or grassy areas

4. Woodland; species differentiation, if detectable

5. Brush
   a. heterogeneous mixtures of trees, brush, and grass
   b. bush and scrub vegetation

6. Water bodies

7. Naturally bare ground (exposed rock, sand, etc.)

8. Snow and Ice

This list is far from being comprehensive but includes the essential landscape features encountered in the various photographs. The majority of the areas analyzed were predominantly rural and the numbers of elements found in various cell sizes reflect, in the main, agricultural land use patterns.

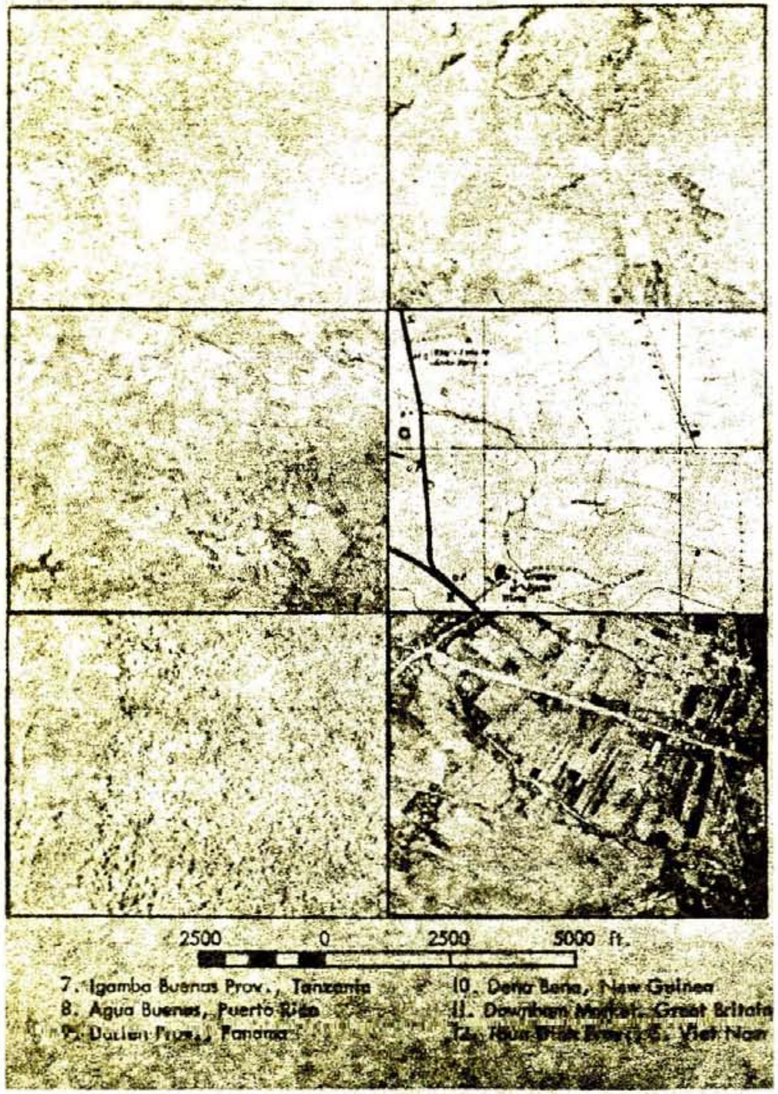
The sizes of the elements in category (1) are of a smaller order of magnitude than the other elements. Cultural features, particularly those of a linear nature, show up much better than natural features and fields. Studies of the detection of transportation networks in the Dallas-Fort Worth area from Apollo VI space photography have shown that essentially all of the divided highways with average width (road plus shoulders) of 70 ft. are detectable (Simonett, Henderson, and Egbert, 1969, 113). Though the effective ground resolution of the space photos is 300-400 ft., the high contrast ratio between roads and adjoining areas, the bright return from road surfaces, and their lineation result in the detection of features much finer than the resolution cell size. Similar considerations apply to farmsteads and urban areas. Further analysis of the importance of element size led to the criterion requiring that any feature must occupy more than 10% of a cell before it constitutes an element.. The selection of 10% is based on the premise that any feature less than a certain size would not materially affect the overall return from a resolution cell.

Twelve areas were sampled according to the procedure given above. Figures 1 and 2 show the areas at a common scale. Each quadrangle is approximately 1 mi. x 1.25 mi. The types of landscapes are: 1. Stanton Co., Kansas: extensive dryland farming; 2. Finney Co., Kansas: mixed irrigated agriculture; 3. Douglas Co., Kansas: mixed agriculture; 4. Orange Co., Virginia: cropland and woodland; 5. Ventura Co., California: orchard and truck gardening; 6. Alajuela Prov., Costa Rica: cropland and woodland; 7. Igamba Prov., Tanzania: shifting cultivation, woodland and brush; 8. Agua Buenas, Puerto Rico: pineapple and sugarcane; 9. Darien Prov., Panama: tropical rainforest; 10. Bena Bena Area, New Guinea: primitive cultivation, grassland, 11. Downham Market,

Figure 1

1. Stanton Co., Kansas
2. Finney Co., Kansas
3. Douglas Co., Kansas
4. Orange Co., Virginia
5. Ventura Co., California
6. Alajuela Prov., Costa Rica

Figure 2



Great Britain: mixed farming, market gardening; 12. Thuan Dinh Prov., S. Viet Nam: intensive rice cultivation.

Figure 3 is an example of the percentages, by grid size, of the cells which contain, one, two, three, or more than three land use elements. It illustrates the inverse relationship between cell homogeneity and resolution size. If the ground truth signatures or keys which have been developed are to have any validity in the interpretation of remote sensor data, the resolution of the imagery should permit more than the mere detection of objects.

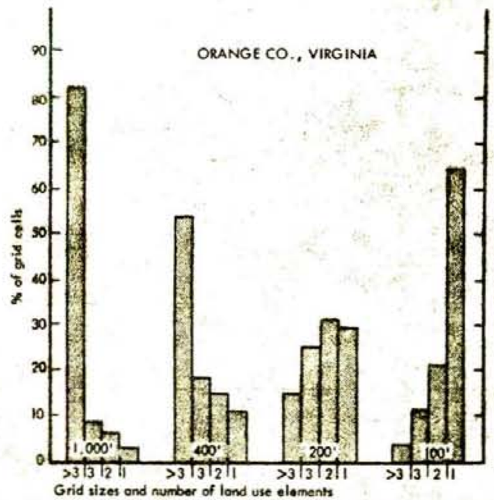


Figure 3. Distribution of Land Use Element Frequency as a Function of Resolution Size

Figure 4 shows the percentages of single land use element cells at each of the 4 resolution sizes and for each of the 12 sites. For land use mapping purposes, the minimum resolution requirements would seem to be the size at which at least 50% (and preferably considerably higher percentages) of the cells contain but a single element. Moreover, it is not known whether these minimum resolutions would involve the mere detection of an element or permit its identification or description. A hierarchy of photographic interpretation levels are associated with respective ground resolutions (Waddell and Waddell, 1969). For example, general identification of terrain requires a subject resolution of 300 ft., precise identification requires 15 ft. and description, 5 ft.

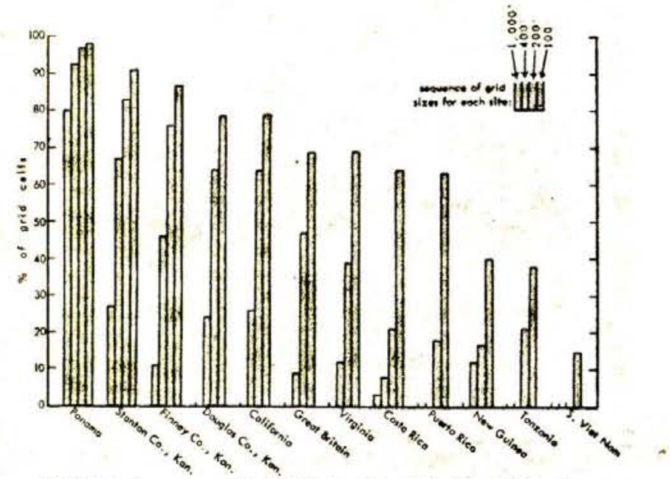


FIGURE 4. Percentages of Grid Cells Containing Only One Land Use Element

In a study of thematic land use mapping using Apollo IX photography of the Dallas-Ft. Worth area, Simonett et al. (1970, p.39), concludes that effective land use mapping would require resolutions on the order of 100 ft. Probably the most realistic indication of the land use mapping capabilities of ERTS-A[1] is Norman J.W. Thrower's (1970) map of land use in the Southwestern U.S., generated from Gemini and Apollo imagery with ground resolution of 300-400 ft.

[1] Expected ground resolution of RBV cameras #1 and #2 is 408 ft. (124 meters) for effective TV lines at maximum contrast and 497 ft. (151 meters) for effective TV lines at 10:1 contrast (Colvocoresses, 1970, p. 558).

A very important, and appropriate, question regarding this study is the degree to which the twelve sites represent major types of landscapes in the U.S. and other countries. I will not attempt to quantify their relevance but I can assert that they were not selected for their unique or exotic nature. Landscape diversity and land use element sizes were major considerations in the selection of the sites. The diversity of landscapes is a complex function of topography, land use capabilities, political, social, and historical factors. Recognition of the degree to which the quality of information on orbital-acquired imagery is a function of resolution and environment should provide useful guides in designing future earth resources satellite programs and realistic estimates of the utility of space imagery in land use studies. This is not to suggest that the resolution specifications be at the maximum for the most heterogeneous landscapes or that the resolutions be adjusted to different areas. Data acquisition costs and information quality should be determinants in the selection of systems resolution. A prior knowledge of the way in which an environment is put together in a spatial sense will, however, prevent users from having unwarranted expectations. It will also show the need for supplementary sampling and other data.

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