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Land-Use/Land-Cover Mapping from Aerial Photographs

The key for a successful project is trained and trainable photo interpreters, organized procedures, written category descriptions, and an accuracy determination.

Introduction

Land-use or land-cover mapping using remotely sensed data is very popular these days. At the national level, through the very productive and carefully coordinated Land Use and Data Analysis (LUDA) Program (Loelkes, 1977), maps showing two levels of land use/land cover will have been published for over half the country by Fiscal Year 1979. State programs in land-use/land-cover mapping have been coordinated with the LUDA program, and for the most part are consistent (Palmer, 1973).

use/land-cover classification systems can vary greatly from project to project. There appears to be little likelihood that a single classification system ever will be developed which will meet the demands of all planners for all situations. However, the U.S. Geological Survey has provided a partial remedy to this problem through its Land Use and Land Cover System for Use with Remotely Sensed Data (Anderson *et al.*, 1976). This system provides a hierarchical framework for the classification of land information. It has been carefully devised to accommodate virtually

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ABSTRACT: Land-use or land-cover mapping is currently very popular. Land-use maps provide an information source for sound land resource management decisions. If aerial photographs are to provide data for land-use/land-cover mapping, they must be suited for the job, must be interpreted in a professional manner, and the map product must be usable. A routine set of techniques should be developed. The key for a successful project is trained and trainable photo interpreters, organized procedures, written category descriptions, and an accuracy determination. Several illustrations of category definitions and pictorial elements for category recognition are presented.
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The primary purpose of most land-use/land-cover maps is to provide information to guide decisions concerning land resource management. Thus, a system used to classify land use/land cover must respond to the needs of decision-makers. Because of the varied problems which face resource managers, such as environmental impact studies, zoning enactment, taxation assessment for use-value, works planning for flood routing, strip mine monitoring, and numerous other local needs, the nature and detail of land-

any classification of land use/land cover. Organizations needing to classify land use would do well to examine the U.S. Geological Survey system as an early step in their mapping efforts. Here, much of the groundwork has been provided. Also, the standardization of maps prepared in the LUDA Program allows for comparisons of land-use data which have been collected at different times.

Too often, resource managers may become overzealous in their attempt to collect land

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information; the data may be far in excess of that which is needed to make prudent decisions. Furthermore, those who are unfamiliar with photographic interpretation may be unaware of the constraints imposed by the data needs, the photography to use and its cost of acquisition, the time available for the study, how the data will be acquired, presented, and analyzed, and numerous related problems.

Before an organization begins a land-use/land-cover mapping program based on interpretation of aerial photographs, it should review basic information about aerial photographs, their interpretation, and mapping from them. This review is necessary if the work is to be accomplished "in-house" and is advisable if the job is to be contracted.

Photographic interpretation projects for land-use/land-cover data should include a combination of trained and trainable aerial photo interpreters, recent aerial photographs of the type, scale, and image sharpness to allow the interpretation, base maps on which to portray the categories interpreted, and an evaluation of the accuracy of the work.

On the basis of several photographic interpretation contracts for land-use/land-cover data performed during the period 1975-1978, a routine has been developed for their conduct in minimum time. Overlays to 1/24,000 scale U.S. Geological Survey maps were prepared in each instance, but from different scales and kinds of aerial photographs. It is hoped that these steps may be helpful to others planning such projects.

Literature Search and Individual Contacts

There are many publications outlining general types of photographic interpretation. There are few describing specific projects. Most land management/land surface-related disciplines are represented in literature related to photographic interpretation of agricultural crops, forest and woodland types, and land uses. Many sources include photographic illustrations.

The senior interpreter on a project should be acquainted with the major publication outlets related to photo interpretation. Often, there are individuals in a project area who have experience working with the type of photographs best suited to land-use/land-cover problems who can be consulted.

Obtaining Suitable Aerial Photography

Two choices for obtaining aerial photography for land-use/land-cover mapping are available: (1) obtain already existing photography or (2) contract for new photography. The latter choice is preferred: it costs more, but the quality of photography can better be guaranteed. The National Cartographic Information Center (NCIC) of the U.S. Geological Survey acts as a national clearinghouse of available and planned aerial photography (U.S. Department of the Interior, Geological Survey, 1977). Several states also provide clearinghouse information for photographic coverage within their boundaries (Texas Natural Resources Information System, 1977) or house archival collections of aerial photography in the state (University of New Mexico, Technology Application Center, 1976).

In areas of dynamic change it is imperative that recent photography be used. When interpretation of natural vegetation cover is required, color infrared photography may be necessary. Photo scale is important. For instance, level II land-use data may be interpreted from ultra-small-scale aerial photography, but this scale is unsatisfactory for mapping level IV land data, such as agricultural crops, timber size classes, or land under construction. Winter photography is unsatisfactory for identification of warm-season agricultural practices or hardwood species-groups; it would be satisfactory for mapping urban land or for classifying slopes under dense hardwood cover.

Trial Delineations

Trial delineations should be performed first. This uses literature search, personal contact, and experiences of the photographic interpreter. The senior photographic interpreter on a project should have three to five years experience interpreting and delineating with numerous types of aerial photography. He assists in training the other photo interpreters. Each interpreter then extrapolates from his experience in past interpretive work to the project area to produce a tentative delineation of approximately three to five frames from widely spaced portions of the area. At least two frames should be interpreted independently by each interpreter, the results compared, and a composite "trial" interpretation prepared.

Field Survey

After a trial interpretation has been made, each photo interpreter visits the project area and performs a ground check. Inconsistencies in his delineation are determined and corrections are made. From field observation

the interpreter can determine which land-use and -cover categories need additional study and interpretation training. Also, a judgment is made concerning which categories cannot be separated on the subject photography, such as orange and grapefruit trees in orchards. Ground photographs are useful in training photographic interpreters. Each ground photograph can be located on an overlay to an aerial photograph in the project area for later reference.

Category Definitions and Descriptive Keys

A definition and a descriptive key should be prepared for each category to be interpreted. This should convey to each interpreter the necessary and sufficient descriptors of the category, including how it looks on the photographs, how it looks in the field, and how it can be consistently separated from any other category. Classification systems can be compared only if the definitions are comparable. To illustrate, three examples of descriptions of selected land uses at levels III and IV for different scales of photography are shown (Appendix). They all depend on the same definitions of level I and II land uses per Anderson *et al.* (1976).

Separation of land uses into meaningful categories which can consistently be identified is the privotal step in land-use mapping from aerial photographs. To insure success, it is necessary to use all the evidence on the aerial photographs, the background information obtained from the literature and those working in the study area, and a willingness on the part of the interpreters to critically evaluate their work. When their attitude is positive—to do the best job possible—rather than negative—defending interpretations which are wrong—the chance for maximum success exists.

When it is not possible to separate land uses or land-cover conditions from the photography, combining categories or going to a lower category level may be necessary. A crop calendar is useful in determining which discrete categories of agricultural crops can be identified in a special aerial photo mission. For instance, when they emerge, it is not possible to readily distinguish between corn and sorghum even while standing beside them in the field. It would be unreasonable to try to perform this separation from aerial photographs.

Transitional areas are a problem in land-use/land-cover mapping projects. Usually it is not possible to obtain more than one photographic coverage in a project area. Time constraints may dictate that the photos be taken during a season of the year when certain information is difficult to obtain from interpretation of the photographs. For instance, mapping woodland habitats may be a difficult task if the photographs are taken in late fall and the interpreter training and field verification takes place in winter. What is seen on the photos is not what is seen on the ground. Using photos taken during one portion of the growing season may yield a large acreage in transition. If the same crop is in the same field year after year, there is little problem, but when crops are rotated it is not possible to identify the owner's intention to plant a particular crop.

Idle land being held for development is not a useful category in land-use mapping from aerial photographs. The photo interpreter can recognize idle land but cannot determine the intention of the owner. Field verification would not help much either. "For Sale" signs at the road often indicate the intention of the owner to sell for development, but the land without signs does not indicate the owner's intention.

The LUDA System has been tested and gives consistent accuracy by category for levels I and II of land use/land cover. Project needs may dictate finer subdivisions of categories at levels III and IV. This may be an easy task for some categories and a difficult task for others. To illustrate, under the level II category *Commercial and Services* (Code 12) it may be decided to further separate them into level III categories such as educational facilities, health care facilities, religious facilities, etc. When an attempt is made to further subdivide educational facilities into level IV categories, the accuracy of delineation may not be consistent for each category. As an example, it is easier to identify a college or university with a typical sprawling campus but difficult to find the community college housed in an old department store. Secondary schools can be more easily identified by their array of buildings and facilities such as the gymnasium, the stadium and track, and the grounds than elementary schools which are typically in residential areas and where the playground is often small and ill-defined. The larger churches are easy to identify, but small churches are very difficult to locate. Post offices, especially the branch type, are almost impossible to identify and delineate from photographic evidence only. Therefore, care should be taken in forming the categories at levels III and IV if the desired accuracy of mapping each is the same.

Quite often color infrared transparencies have two colors. There is a pink half and a red half, or a green half and a yellow half. When attempting to identify land-use/land-cover categories on this type of photography, descriptions for interpreting both halves of the photo are necessary. The best way to get the interpretation job done is to have this photography developed and printed in a custom lab to produce a consistent tone for a category throughout the print.

Over- or under-exposed photography poses a different problem. The same type of land use or land cover looks different on each type of photo. In a study using high-altitude photography, for instance, over-exposed spring photography produced good accuracy (93 percent) for forest types but under-exposed winter photography produced poor accuracy (46 percent). Accuracy of urban land uses was about the same on each type of photo (79 percent and 69 percent respectively).*

If land-use/land-cover mapping projects call for mapping historical as well as current categories, the earlier photography in most cases will limit the level and diversity of categories. On the same scale, type, and quality of photography a land use should look the same no matter how old the photographs are. But, it is not consistent to use color infrared photos, for example, to map current land-cover types and to use panchromatic photos to map cover types several years ago unless the type categories are those which can be recognized and separated on the panchromatic coverage.

Minimum Size Mapping Unit

The minimum area to be interpreted should be defined. It should be the smallest area which all interpreters on the project can *and will* interpret. It may be one size for urban land use categories and another for rural categories. The scale of the final map, not the photo scale, should govern the minimum size to be interpreted. If map data are to be digitized, this may affect not only the minimum size of each discrete category but also the general shape of the land-use boundaries, i.e., actual boundaries, smoothed-out boundaries, or stylized "straight-line" boundaries. Minimum area should be disregarded for features which are linear.

Category Delineation

A routine procedure should be developed for working each frame. The sequence will depend on the training, skill, and preferences of the interpreter. The routine varies, but includes the following steps:

a. *Using an overlay for delineating categories.* Although photo delineation for land use can be done on the photographic prints, using an overlay has definite advantages. A semi-transparent sheet of 2-mil drafting film is cut to the 9 by 9-inch format of the transparency or paper print and taped to it. Overlays such as this are versatile—they can be placed over the photo, removed from the film roll or paper print, placed on a reflecting projector, overlaid on a black-and-white paper print, placed adjacent to a base map, or photocopied, depending on the need.

b. *Putting the effective area and accessory information on the photo overlay.* For each photograph, determine the areas of overlap with adjacent photos. Determine on which photo this common area will be delineated. Usually, the area used is that closest to the geometric center of the photo, assuring minimum displacement of points from what their map overlay position will be. The collimation marks, photo number, and a north arrow are also marked on the overlay for maximum efficiency in identifying and handling it.

c. *Delineating the planimetric detail.* The road network is delineated in red and the watercourses in blue. All the roads throughout their entire length or only road intersections may be delineated on the photo overlay. Roads and watercourses are easily delineated, and most of them separate interpretation categories; they tend to block up the area for a more systematic task of interpreting and delineating land uses.

d. *Delineating categories with a predetermined routine.* A general rule in photographic interpretation is to proceed from the known to the unknown. As an illustration, within this general procedure the order of delineation on a crop mapping project generally was (Appendix, Example 2):

1. Orchards and cotton—easily identified by color tone and texture
2. Range land—easily identified since the photo interpreters were foresters
3. Transitional areas—generally monochrome and nondescript

* Study sponsored by National Aeronautics and Space Administration under Contract No. NAS-9-13089, Production and Evaluation of a 1971 and 1972 Land Use Inventory from Small Scale Aerial Photographs in the Houston Area Test Site.

4. Urban areas—distinctive in pattern and tone
5. Sorghum, pasture, hay, and other cereal-type crops—inconsistent in tone and texture; required close scrutiny under 6× magnification
6. Winter vegetables—usually shown as weeds on summer photos if the area had not been double-cropped; difficult to interpret.

Small areas of water (ponds and small lakes) and vegetated wetlands are delineated as the interpreter proceeds. These areas are usually contained within larger areas.

Quite often, questionable areas are omitted by the first interpreter who asks another interpreter to view them. The interpreters then discuss these doubtful areas and combine their interpretation skills to insure a "concensus" interpretation.

After the effective area on a frame is delineated, it is rechecked to locate omissions and discrepancies. Most of these, however, are detected during subsequent mapping. A sample photo and overlay for an area of intensive use and a photo overlay for an extensively managed portion of the study area should be posted for all interpreters to compare.

Mapping on Overlays to Base Maps

Vertical aerial photographs are not planimetric maps. They contain distortions of the points on the surface of the Earth that planimetric maps do not contain. Even in flat terrain, there is considerable displacement of images from their true position. This distortion can be absolutely corrected by employing sophisticated and expensive procedures and photogrammetric plotters. Distortion is relatively corrected in the mapping procedure whereby land use is portrayed on overlays to base maps which have been prepared photogrammetrically.

Scale changes resulting from displacement must constantly be made as overlay mapping occurs. In addition, the scale of the aerial photographs used in land-use projects may be different than the scale of the base map, and this necessitates a scale change also.

Therefore, the need to make constant minor scale adjustments and the need to have an average enlargement or reduction factor to make the photo and map scales coincide necessitates using a map projection instrument. Reflecting projectors allow a delineated photograph or photograph overlay to be projected optically onto a sheet of drafting film. By locating selected control points on the base map, transferring these to the map sheet overlay, and then adjusting these points as seen from the projected photograph overlay, the operator of the projector can map the land-use boundaries with reasonable accuracy.

The outer boundaries of the map should be traced on the overlay in colored pencil with the map sheet title (top and bottom) also marked. The exterior boundaries of the project area also should be placed on the appropriate map overlays.

The photo interpreters must be careful to match land-use boundary lines at the edges of the effective area. Each category delineated must contain a symbol and the symbol must be correct. The overlays must be checked; those who delineated the photographs are the best qualified to resolve any discrepencies noted.

Evaluation of Accuracy

To achieve acceptability of his product, the land-use mapper who uses photographs to prepare his map must be able to specify its accuracy, just as planimetric and topographic mappers have done for many years. In order for the exact map accuracy to be verified, the land-use mapper must check his errors of delineating land-use boundaries and of land-use classification. Error checking can best be done by ground survey. However, due to time and cost constraints, the mapper cannot check all land-use parcels on the ground. Therefore, field verification in land-use surveys must utilize a sound statistical sampling design which efficiently tests the correctness of each land-use attribution at each level mapped.

Ordinarily, land-use/land-cover interpretation and mapping to level II should be between 90 and 95 percent correct. This level of accuracy should be obtained if the principles outlined in this paper are followed.

Conclusion

The basic procedures for aerial photographic interpretation have been presented by many authors. Application of these procedures requires experience. On a photographic interpretation project the experienced interpreters should train those who are less experienced by working with them. The theme should be "togetherness" and "efficiency." Procedures should be developed and written at all stages in the project so that the photo interpreter can transfer his "art" to others.

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Appendix

Illustrations of Level III and IV Land Use/Land Cover Definitions from Color Infrared Photos

The authors have followed the entreaties of Anderson *et al.* (1976) to develop land-use classifications which are consistent at levels I and II. Therefore, all the case examples shown include the same level I and II classification schemes as Anderson and the other authors have suggested. Only at levels III and IV have other, more refined categories been employed.

Example 1
Definitions of Agricultural Crops
Interpreted from 1/30,000 Scale
Color Infrared Transparencies

The following selected categories at level II would be classified code 21 (Cropland and Pasture) according to Anderson *et al.* (1976). They are level III land uses and were derived from interpreted summer photography (by type and use of field) in a gross project area of 400,000 hectares (Lower Rio Grande Basin, Texas).

Code	*Crop Name and Description*
21Pa	*Pasture.* Field size varies from minimum area to hundreds of hectares. Color varies widely, commonly being pink, greenish brown, or brown. Irrigated or non-irrigated. Pattern is uniform to mottled with indefinite to definite field boundaries and occasionally contains boquillas. Texture is smooth to fine with a low profile. Exhibits a row pattern as contrasted with sorghum, cotton, and sugarcane which have no row pattern. Most always has plant cover. Grazing animals may be present or cowtrails may be visible.
21C	*Cotton.* Field size varies from minimum area to 40 hectares. Color is brilliant red with mottled green and white patches (root rot areas). Is irrigated and non-irrigated. Exhibits no perceptible pattern unless largely magnified showing evenly spaced minute rows. Texture is homogenously smooth to coarse. Distinguished from other crops by the pocked pattern caused by root rot. The row cropping pattern distinguishes it from pasture and range. It is brilliant red as opposed to the duller reds of sorghum or sugarcane. Has a rougher texture than hay.
21S	*Sorghum.* Field size varies from minimum area to hundreds of hectares. Dark brown color with a pink cast due to weeds. Both irrigated and non-irrigated. No pattern to evenly spaced minute rows. Fine, smooth homogeneous texture. The brown color distinguishes it from cotton, sugarcane, and hay. Difficult to separate from corn; however, the row spacing stands out more in old fields, which also have a rougher texture and mottled appearance. Can be confused with cotton which is not growing well because of pinkish caste.

Example 2
Definitions of Natural Woodlands
Interpreted from 1/12,000 Scale
Color Infrared Transparencies

The following selected definitions of Level III and IV woodland and forest were derived from interpreted fall photography in a project area covering 25,000 hectares (Walnut and Williamson Creek watersheds, Travis County, Texas). To preserve the integrity of land use classification according to Anderson *et al.* (1976), the first two digits of the numerical code correspond to those level I and level II

codes for forest land and the last two digits comprise woodland species-group composition and height/density respectively.

Code	*Species-Group Name and Description*
4111-4114	*Elm-Hackberry.* Crowns are pink, highlighted at the tip. Crowns have a "hairbrush" appearance, and some interior branches are visible. Trees generally in thickets. Appears along fence lines and roads. Grows from mid-slope down to stream banks.
4131-4133	*Mesquite.* Sparse star-shaped crowns. Leaves not visible. Crowns appear indistinct or hazy as if viewed through a half-surfaced mirror. (Photo scale too small to clearly see crowns of individual specimens.) Light gray tone. Usually grows on dry sites, but sometimes at streambanks.
4211-4213	*Juniper-Red Cedar.* Larger specimens (over 9 feet tall) have dark brown foliage with globular crowns. Crowns compact—cannot see past the upper limbs. All trees the same height in pure stands. Smaller specimens (less than 9 feet tall) have dark chocolate brown crowns, appearing as dots. Often appear on shallow limestone (white toned) soils. Grows on hilltop to creek banks.
4311-4314	*Live Oak-Juniper-Red Cedar.* Tone and crown shapes as described for each species above. In these mixed stands live oak specimens dominate. Grows from hilltop to creek banks.
4321-4323	*Mesquite-Juniper-Red Cedar.* Tone and crown shapes as described for each species above. In these mixed stands juniper is usually twice as tall as the mesquite, and juniper crowns do not overlap.

Level IV descriptions and codes:

1 *Brush.* Under 9 feet tall. More than 10% crown cover.
2 *Park.* Over 9 feet tall. 10-30% crown cover.
3 *Woods.* 10-30 feet tall. Over 30% crown cover.
4 *Forest.* Over 30 feet tall. Over 30% crown cover.

Example 3
Definitions of Residential Land Uses
Interpreted from 1/6,000 Scale
Color Infrared Transparencies

The following selected definitions of Level III and/or IV residential land uses were derived from interpreted summer photography in a project area comprising 4,700 hectares (College Station, Texas). The large scale photographs enable an experienced photographic interpreter to detect subtle differences in housing type and density and condition of land under development, including construction status of buildings.

Code	*Name and Description*
111	*Single Family Residential.* The street layout is well-defined. A single driveway and front walk leads to each house. Yards are separated by either fences or differences in lawn vigor. Lots are landscaped with trees and shrubs. Houses are rectangular or L-shaped. There is usually a reasonable distance between adjacent houses. Density classes can be added if desired after sampling for density and determining the appearance of each level of density desired.
112	*Multi-Family Residential.* This covers apartments, townhouses, and multiplex housing units.
1121	*Duplexes, Triplexes, Quadplexes.* Duplexes have a double-width driveway and two front walks—one for each unit. Each unit has its own patio and backyard. They are built alongside single-family residences in many shapes and sizes. Triplexes and quadplexes are simply combined forms of duplexes. Shape and size is often characteristic of the constructor whose name can often be determined by consulting tract plats.
1122	*Apartments, Townhouses, and Condominiums.* Apartments, townhouses, or condominiums are identified by large structures with several similar units laid out in an orderly and geometric manner, often replicated. Usually a large parking area is present; it may be open, covered, or a combination of both. Alleyways often appear within the development, being curbed but typically narrow. Numerous paved walks lace the area. There is usually a swimming pool, tennis courts, and other recreational facilities near the buildings. Small clumps of trees may be present near these recreational areas. Sometimes these features are present in townhouse developments, but not ordinarily. Apartments and townhouses face the major arteries in many subdivisions, with multiplexes behind them and single family residences further back. (An additional breakdown can be performed to delineate multi-story, single story,

and mixed developments. Condominiums are often two storied; apartments may be multi-storied or a combination of single and multi-storied.)

113 *Mobile Home Parks.* This category includes any area where the primary use is to provide space for groups of mobile type homes. The area is usually less than 20 acres. Individual structures are small and rectangular on individual lots 1/4 acre or less. The area has a "herringbone" appearance. A driveway is usually paved, but is narrow and is immediately adjacent to the street end of the mobile home.

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