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STATISTICAL SAMPLING OF AGRICULTURAL AND NATURAL RESOURCES DATA: A COMPARISON OF AERIAL SAMPLING AND AREA-FRAME SAMPLING TECHNIQUES WITH SPECIAL REFERENCE TO LESSER DEVELOPED COUNTRIES

By

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ABSTRACT

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The development of agricultural and natural resource management programs and related policies for lesser developed countries (LDC's) requires the availability of reliable information on the status and extent of the resource base. This focuses attention on the quality of the spatial information which is largely determined by factors such as spatial and temporary accuracy. The generation of this information involves important cost-accuracy trade-offs, especially if primary data collection efforts are introduced using remote sensing technologies.

The major objective in this research is to evaluate the potential of low-level aerial photographic sampling to effectively capture reliable resource inventory data. This includes the integration of these data with multi-level inventory procedures, such as satellite and high-altitude remote sensing as well as ground (sampling) surveys, in an effort to supplement secondary data and to improve the comprehensive quality of the resource information data base needed to effectively support natural resource monitoring, management, planning and policy analysis.

This research compares aerial sampling and area-frame sampling procedures to assess cost/accuracy trade-offs and to evaluate the

appropriateness of the techniques, given various topographical conditions, information needs and technology levels encountered in a typical LDC setting. In this process the design of aerial sampling procedures is discussed and two selected sampling designs and their associated sampling intensities are evaluated. Two modified, systematic, aerial sampling designs are tested for the capacity to provide accurate land cover/use estimates for a selected test site of intensive, mixed agriculture in a tropical region. Cost and accuracy of the aerial and area-frame sampling procedures are discussed in combination with the cost estimates for a nation-wide sampling survey.

Light aircraft survey techniques and sampling survey designs aim at providing an application-oriented framework to create an in-country operational capability to conduct agricultural and natural resource inventories using aerial sampling techniques.

Results of the Dominican Republic case study indicate that four of the five major land cover/use categories representing more than five percent of the surface area of the test site in intensive agriculture could be accurately predicted (with a 95 percent confidence level) using a sampling intensity as small as 4.8 percent. Therefore, it can be concluded that aerial sampling techniques, using a modified-systematic sampling design, could provide a viable, cost-effective resource inventory alternative, especially if access condition, time limitations and the state of technology pose significant constraints. This situation is frequently encountered in many developing nations.

The research identifies the need to improve the data specifications to support short- and long-term resource planning and policy development. These specifications should include the type, spatial detail, accuracy, timeliness and anticipated cost of data capture efforts over a period of time, as well as the institutional framework needed to support these activities. This identification process should include the selection of the appropriate technology for data capture, storage, analysis, and information retrieval. Selection criteria should consider the geographical, budgetary and technological constraints as well as the priorities for development identified by the individual countries.

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Special thanks is due to Dr. Shelton who guided me through the major stages prior to his untimely death on August 20, 1980.

Professors Barlowe, Ramm and Farness served on my committee and they provided me with many valuable comments and editorial assistance.

The support of the Comprehensive Resource Inventory and Evaluation System (CRIES) project staff is gratefully acknowledged. The CRIES project involves funding from and participation by the U.S. Agency for International Development, the U.S. Department of Agriculture, the National Aeronautics and Space Administration and Michigan State University. In addition, the support and assistance of the following institutions is gratefully acknowledged:

1. The AID Mission in the Dominican Republic;
2. La Secretaria del Estado de Agricultura--SEA--(The Secretariat of Agriculture);
3. Sistema de Inventario de Evaluacion de Recursos Agricolas--SIEDRA--(Agricultural Resource Inventory and Evaluation System); and
4. La Fuerza Aerea Dominicana--(The Dominican Air Force).

Finally, I want to thank my wife, Joanne for her support and the sharing of my feelings of frustration and accomplishment during the crucial last stages of this work.

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CHAPTER I

INTRODUCTION

Research Context, Funding and Development

The Congress has stated that the objective of U.S. foreign assistance programs is "to assist the people of less developed countries to acquire the knowledge and resources essential for development and to build the economic, political, and social institutions which will meet their aspirations for a better life with freedom, and in peace."[1] This statement focuses the necessary attention of aid programs for lesser developed countries on the major concerns and the primary needs of the more than 50 percent of the world population living in rural areas: food, shelter, and production potential of the agricultural sector.

Any operational program aimed at promoting active participation of the rural poor and small farmers in increased food production and resource development requires substantial information about the extent and the quality of the resource base, the various components of the production base, available and capable management, and the knowledge of technological options for development. Such a realistic assessment requires detailed knowledge of the agricultural sector:

[1] National Academy of Sciences, 1977, Resource Sensing from Space; Prospects for Developing Countries, Washington, D.C.

its current status, its potential and the existing linkages with other sectors of the economy.

The research reported here was conducted with the foreign assistance context expressed above, specifically in connection with a cooperative effort involving U.S. agencies and Michigan State University to develop this knowledge. The inventory and analysis procedures described as part of the research were conducted in connection with an agricultural study of the Dominican Republic. These efforts aim to adapt existing resource inventory methodology and to develop new techniques by the United States Department of Agriculture (USDA) and National Aeronautics and Space Administration (NASA) to improve agricultural sector planning systems and to expand matters addressed by sector analysis techniques. Their work was initiated as a result of efforts by the Economic Research Service (ERS) Foreign Development Task Force of the USDA resulting in a draft proposal in 1975:

> to explore over a one-year period the possibilities of estimating technological and economic potentials for agricultural production in developing countries.[1]

The specific proposal objectives listed were:

a. To determine the availability and quality of specific information about soil resources . . . and other important physical information such as water, weather, and climate . . . and to develop a system for organizing and handling such data.

b. To assess the availability and quality of current land use information as it relates to soils of different productivity.

c. To evaluate the prospects for acquiring information on present and prospective type, cost, and extent of resource development measures such as irrigation and drainage.

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[1]TA/AGR/ESP, 1976. A proposal for a comprehensive land and water inventory and evaluation system for agricultural planning.

d. To evaluate the availability and quality of yield-nonland input production function relationships.

e. To specify those economic, social, and institutional constraints which should be considered in assessing possibilities and costs . . .

f. To examine alternative methodologies for evaluating production potential . . .

g. To develop a detailed plan of work for undertaking a study . . .

This initial proposal resulted in negotiation with the U.S. Agency for International Development (AID) and subsequently in limited funding for the development of a plan of work. After several revisions of a draft plan of work, a final document[1] was produced in 1976 listing the following project goals:

1. To assist developing countries to develop their capacity to identify and analyze the consequences of alternative policies, programs, and prospects for agricultural and rural development in terms of their own multiple economic and social goals.

2. To improve the information and the analytical basis for making decisions on agricultural and rural development strategies, policies, and investments.

3. To expand the number and enhance the capability of developing country planning personnel to construct and use such an information base and analytical system.

The document listed the project purposes:

1. To select and apply techniques for collecting, classifying, collating and documenting data on a country's land and water resources, land use, production inputs and expected outputs, production costs, technology options, and institutional constraints.

2. To establish a system, using existing data management techniques and analytical processes, for evaluating these data.

3. To demonstrate the analytical capabilities of this system and to test the reliability and usefulness of the results.

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[1] Ibid., 1976.

4. To develop procedures for linking the source data and analytical system into a sector analysis.
5. To internalize the use of the techniques developed as part of the project and to integrate the system with sector analysis activities in-country.

Current AID-funded sector analysis work as applied in several lesser developed countries (LDC's) aims at providing policy makers with the necessary analytical and monitoring capabilities to develop policy instruments in meeting specific country objectives. This analytical capability is to provide insight into the status of the agricultural sector and its functional relationship with other sectors of the economy. For this reason agricultural sector modeling techniques include the location of available natural resources, as distributed among alternative enterprises, in order to provide an optimal spatial relationship between producers and resources. The modeling effort aims at achieving certain objectives (food, income, etc.), given certain constraints and model assumptions. One of the critical elements in sector analysis with the modeling approach is the use of realistic constraints and data, representing the relationship between land resources and their environment context. It is specifically this relationship which identifies the production environment available to meet a final demand.

The Dominican Republic was chosen as one of the test countries for such a comprehensive resource inventory and analysis effort, since a sector analysis project was being implemented. The Comprehensive Resource Inventory and Evaluation System (CRIES) project which resulted, involves funding from and participation by the U.S. Agency for International Development, the U.S. Department of Agriculture, the

National Aeronautics and Space Administration and Michigan State University. Participation of USDA is covered under PASA #AG/TAB-236-15-76 and NASA under PIO/T 931-0236.01-3178632. Participation between the Economic Research Service (ERS), U.S. Department of Agriculture, and Michigan State University is covered by Cooperative Research Agreement No. 12-17-07-8-1955. Two other countries, Costa Rica and Nicaragua, were chosen for similar prototype development during a three-year period from 1976 to 1979. A subsequent fourth country project was initiated in Honduras in 1980. Some of the techniques were applied to agricultural studies in Syria during 1978-79. The work is currently being extended to additional countries. However, the Dominican Republic was the first completed project and provided the opportunity to conduct the research reported here.

Problem Statement

The Dominican Republic case study illustrates the basic problems this research addresses. Agriculture remains, in spite of the recent growth of other sectors in the economy, the most important sector in the Dominican Republic (see Table 1). The direct contribution to the GNP is currently about 20 percent, with additional values added through forward linkages in sugar cane processing, cotton spinning, vegetable canning, etc. Exports of products with an agricultural origin amounted to approximately $500 million (US) in 1976, or about 68 percent of the total merchandise exports. More than 50 percent of the population employed in the sector experiences widespread underemployment and poverty. Rural incomes are not only lower than those of the urban population but also spread more unevenly. On the average, urban in-

TABLE 1

Gross National Product of the Dominican Republic by Activity

	1964	1967	1970
Agriculture:			
Crops	16.9	15.8	n.a.
Livestock	6.6	6.6	n.a.
Forestry & fishing	0.6	0.6	n.a.
Total agriculture	24.1	23.0	22.4
Manufacturing	16.5	17.9	17.9
Commerce	17.6	16.4	16.9
Public administration	13.1	11.9	10.6
Transport & communications	6.0	6.8	8.2
Rental property	6.2	7.0	6.7
Construction	4.4	4.7	5.4
Banking & insurance	1.7	1.3	1.7
Mining	0.9	1.3	1.2
Utilities	1.1	1.2	1.2
Other services	8.4	8.5	7.8
Total	100.0	100.0	100.0

NOTE: Numbers are percentages.

SOURCE: Neil, Thomas E., et al., 1973. Area Handbook for the Dominican Republic.

come per capita is estimated to be four times that of rural income. According to the Secretariat of Agriculture (SEA), approximately 64 percent of rural families earn an income at or near the rural poverty line of $35/month (DR) or less than 20 cents per day. This figure probably does not include the full estimated value of subsistence food production (Table 2).

The underemployment condition of the rural labor force could be improved by means of a technical assistance program to encourage the production of labor intensive crops that produce a higher cash flow per hectare such as tobacco, fresh vegetables and industrial crops like cotton (Table 3). The major crop with the highest yield per hectare is sugar cane. This crop accounts for 60-65 percent of the GNP during the last decenium and for 32 percent of the country's exports in 1978, with an annual production of 1.4 million metric tons. A great variety of other crops are grown; their yields vary greatly (Table 4).

The yield variations makes it difficult to optimally use the current processing capacity for sugar can and difficult to develop short- and long-term agricultural policies aimed at satisfying final demand.[1,2]

An additional problem expressed by government agencies is the increasing surface erosion and runoff in the catchment basins of hydroelectric powerplants. The Dominican government has recognized the need

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[1]Garcia, C., 1979. Personal correspondence. Director of Planning of the State Sugar Council, SEA.

[2]General Secretariat of the Organization of American States, 1969. Survey of the Natural Resources of the Dominican Republic. OAS, Natural Resources Unit, Washington, D.C.

TABLE 2

Distribution of Family Income Among Urban and Rural Population

Monthly Income (DR&)	Percent of Families		Average Monthly Income	
	Urban	Rural	Urban	Rural
0 - 50	29	64	36.0	37.3
50.1 - 100	24	28	79.0	70.5
100.1 - 300	33	8	168.1	135.8
over - 300	14	-	762.3	-

SOURCE: Secretariat of Agriculture, Diagnostico y Estrategia del Desarrollo Agropecuario, 1976-1986.

TABLE 3

Annual Labor Requirements of Major Agricultural Products

A. Crops	Man-days per hectare
Tobacco	130
Plantain	110
Potatoes	85
Yucca	80
Coffee	80
Sugarcane	70
Cacao	55
Beans	50
Corn	48
Rice[a]	45
Peanuts	35

B. Livestock	Man-days per animal
Dairy Cattle	16.5
Beef Cattle[b]	4.5
Other Animals	4.0

SOURCE: "Generacion de Empleo Productivo y Crecimiento Economico," ILO, Geneva, 1976, Tables 54 and 55.

[a]Average of rain-fed and irrigated rice.

[b]The countrywide average stocking ratio is 1 animal unit per hectare.

TABLE 4

Yield Trends For Principal Agricultural Products
Based on Three-Year Moving Averages:
1962-64; 1968-70; 1974-76

	1962-64	1968-70	1974-76	SEA Target 1977[a]	Yield Expected with Good Management[b]
Sugar	70.9	58.6	60.5	-	80.0
Rice (Paddy)	1.6	2.5	2.1	2.4	1.8- 3.6
Red Beans	0.8	0.9	0.9	1.0	1.4- 2.2
Sweet Potato	8.7	9.3	8.1	8.5	14.4
Corn	1.4	1.8	1.3	1.5	1.8- 2.2
Plantain	4.7	4.4	5.9	7.3	n.a.
Cassava	8.4	10.5	7.9	8.0	10.8-14.5
Cacao	0.6	0.5	0.5	-	2.2
Coffee	0.6	0.6	0.5	-	2.2
Tobacco	0.9	1.2	1.0	-	1.4
Pidgeon Peas	n.a.	na.a	1.8	-	4.3
Peanuts	n.a.	0.8	0.8	-	2.2

NOTE: Agricultural products in metric tons per hectare.

SOURCE: National Statistical Office; Central Bank; SEA; USAID.

[a]As stated in the SEA Operative Plan, 1977.

[b]Based on findings of a study team from the International Fertilizer Development Center which visited the Dominican Republic in 1975. For sugar, based on recommendations of Bookers study.

to protect the remaining forest resources and to make this issue a vital element in new resource management programs.[1]

Several regional studies, such as the DELNO project,[2] have emphasized the interrelation of natural, human and economic resources to improve the utilization of the various production factors in an effort to minimize negative impacts on the resource base. A comprehensive and nationwide resource planning orientation was often jeopardized by lack of spatial information.

These facts illustrate the critical need for a continuous and timely capability to gather reliable data on the quality and quantity of the natural resource base. This need is particularly crucial in many developing countries since, in the majority of the cases, the extent and condition of the arable lands, forests, rangelands, and water resources have not yet been adequately assessed. In a time of world food and energy shortages and of spreading environmental degradation due to soil erosion and environmental pollution, it is vitally important to carry out these inventory and monitoring efforts.

The nature, scope, and detail of the required resource information vary greatly from one country to another. These depend on the current quality (comprehensiveness, detail, and timeliness) of the

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[1]General Secretariat of the Organization of American States, 1969. Survey of the Natural Resources of the Dominican Republic. OAS, Natural Resources Unit, Washington, D.C.

[2]Secretaria General de la Organizacion de los Estados Americanos, 1977. Republica Dominicana: Plan de Accion para el Desarrollo Regional de la Linea Noroeste. OAS, Unidad Technica del Proyecto DELNO, Washington, D.C.

data base, the country's development objectives and critical needs for short-term policy development and evaluation.

The need for spatial information, as defined above, poses a problem. It relates to the fact that the institutional framework needs to be created to transform spatial data into relevant information for resource management, policy analysis, planning and implementation.

This case study addresses one element of this process, the efficient data gathering to procure timely, reliable data to be used by the decision makers (the agencies and institutions involved in resource management and planning). Relatively new techniques are introduced (remote sensing) and aerial sampling procedures are designed, evaluated and compared with an alternate sampling survey approach; area-frame sampling.

The CRIES Project

The Comprehensive Resource Inventory and Evaluation System (CRIES) project encompasses a cooperative effort between the United States Department of Agriculture and Michigan State University. The major objectives of the CRIES project are: (1) to develop a consistent approach to land resource classification adaptable to many countries, and (2) to provide the training and technical assistance to classify and inventory resources, evaluate crop adaptability and productivity, and develop food strategies in participating countries.

The land classification system developed provides the elementary spatial information framework to store, retrieve, update, and cross reference natural resource data as a basis for land use analysis, resource planning and evaluation. This system involves two land resource components, the resource planning unit (RPU) and the production potential area (PPA).[1] The RPU is the basic land resource classification unit: a mapped delineation of physically and environmentally homogeneous land strata used to identify areas in the resource inventory system. A PPA is an unmapped delineation within a RPU used to conceptually relate agronomic and economic data to a specific land resource area.

RPU's and PPA's are primarily based upon two major underlying taxonomies--soil and crop climate. Soil resources are stratified according to the USDA's Soil Taxonomy,[2] allowing for predictions of responses to management practices. Crop climate zones are differentiated based on temperature, day length, number of wet seasons, annual precipitation, wet season rainfall, and presence or absence of frost.[3]

Spatial Information System Component

A computer-based spatial information system is used by the CRIES project to store, retrieve and map resource data. The system is grid based; the relevant information is stored in its original form, based on the predominant resource category found within a predefined grid cell (e.g 1km^2). This allows for cross tabulation of data, like land cover/use breakdown by administrative region or RPU. Additional data sets can be added based on the expressed information needs. Derived

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[1]USDA/MSU, 1980. CRIES Report. Special report #1 (draft).

[2]Soil Taxonomy, A Basic System for Soil Classification for Making and Interpreting Soil Surveys. Soil Conservation Service, USDA, Ag. Handbook No. 436, December, 1978.

[3]"Crop Climate Taxonomy, A Second Approximation," Science and Education Administration, USDA, Unpublished Staff Report, 1978.

spatial information might include elements such as water availability, erosion, development potential, crop production costs, etc. to evaluate different planning alternatives and long-and short-term land use policies.

Area-Frame Sampling

The area-frame sampling concept, used in agricultural inventories, is based on the assumption that reliable estimates (95% confidence level or better) can be obtained for certain population parameters (agricultural statistics) with a relatively small sample at generally less than 10 percent of the cost for a complete enumeration. This indicates the usefulness of applying area-frame sampling techniques in lesser developed countries to provide initial estimates at the national level on crop acreages, on number and type of livestock, and more.[1,2,3,4,5]

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[1] Huddleston, Harold F. et al., 1979. Use of Landsat Classified Pixels for Estimating Annual Livestock and Crop Inventories. Paper presented at the Third Conference on the Economics of Remote Sensing. Incline Village, Nevada.

[2] Hanuschak, George, et al., 1979. Obtaining Timely Crop Area Estimates Using Ground-Gathered and Landsat Data. USDA/ESCS Technical Bulletin #1609 Washington, D.C.

[3] Cardenas, Manuel, et al., 1978. On the Development of Small Area Estimators Using Landsat Data as Auxiliary Information. USDA/ESCS Washington, D.C.

[4] Huddleston, Harold F. 1976. A Training Course in Sampling Concepts for Agricultural Surveys. USDA/ESCS, SRS #21 Washington, D.C.

[5] Craig, M., et al. 1978. Area Estimates by Landsat: Kansas 1976 Winter Wheat. ESCS, USDA.

Area-frame sampling refers to the use of small land areas as the sampling units and probability sampling as the method of selecting these sampling units with a known probability. In order to accomplish this, a design is used which initially stratifies the country in "homogeneous" strata in which the various sample segments, and the sample units contained within them, are delineated on a map base or existing aerial photography.[1] These area-sample boundaries must also be identified by the enumerator in the field and the desired information obtained for the farms or household within the sampling units. In the next stage this sampling information is expanded to provide estimates at the national level.

The area-frame sampling methodology just defined can provide the basis for a program of dependable, current statistics on agricultural production, land use, livestock inventories, farm size and number, etc. Various participating countries in cooperation with the U.S. Agency for International Development (AID) are applying the area-frame sampling design to generate the appropriate agricultural statistics. New AID efforts try to extend this technology to other LDC's with an

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[1]US/AID/DR, 1971. Probability Area-Frame Sampling for Data Collection. Internal Document US/AID Mission to the Dominican Republic, Agricultural Development Division, Santo Domingo, Dominican Republic.

increasing reliance on modern remote sensing techniques (Landsat and aerial survey data) to aid in stratification and primary data collection. Similar efforts are carried out in other parts of the world.[1,2]

The Potential of Remote Sensing

From a series of developments of remote sensing techniques (mainly military oriented), the launch of Landsat-1 in 1972 by NASA represented a major technological advancement in the application of spaceborn data acquisition to civilian use (see Chapter 2 for technical details). It became possible to record electromagnetic radiation in four different wavelength bands and to display the "spectral signature" of the earth surface on imagery and digital computer-compatible tapes for further analysis. The synoptic view Landsat scenes cover an area of 185 x 185 mm with a resolution element of approximately 79 x 56 meters (.4 hectare of 1.1 acre is the size of the picture element of "pixel"). They provide a near orthographic perspective well-suited to general natural resource inventory and mapping efforts. An added Landsat-1 advantage is its capability to provide repetitive coverage every 18 days. That time interval was reduced to nine days with the launch of Landsat-2 in January 1975.

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[1] Richard Hooley, et al., 1977. Estimating Agricultural Production by the Use of Satellite Information: An Experiment With Laotian Data. American Journal of Agricultural Economics November 1977, pp. 722-727.

[2] Mukai, Yukio and Shoji Takeuchi, 1979. Estimation of Primary Production of Vegetation in Agricultural and Forested Areas Using Landsat Data. Remote Sensing Technology Center of Japan, Tokyo.

Several studies indicate that air- and space-borne remote sensing makes a critical, positive contribution in many disciplines to the development of our natural resources.[1]

Because of its usefulness Landsat and other remote sensing data have been applied in numerous cases but especially in LDC's where a limited resource data base necessitates the generation of reliable land cover/use data for the evaluation of development strategies.[2,3,4,5] The Michigan State University Center for Remote Sensing, for example, is involved in such efforts in Syria and the Dominican Republic, where nationwide land cover/use information was generated using Landsat data.

The Need for Strata Refinement

Other Landsat-based inventory studies have been carried out for many parts of the world. In many cases, it was concluded that inter-

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[1]National Academy of Sciences, 1977. Remote Sensing from Space; Prospects for Developing Countries. Washington, D.C.

[2]Nossin, J.J., 1971, Promotion and Training Aspect of Integrated Surveys. Proceedings of the Fifth International ITC/UNESCO Seminar. ITC, Enschede the Netherlands.

[3]Broek, J.M.M. Vander, 1969. Integrated Surveys for River Basin Development. Proceedings of the Fourth International ITC/UNESCO Seminar. ITC, Enschede the Netherlands.

[4]Lafortune, Robert, et al., 1978. Landsat Applications to Land Use Mapping of the Cul de Sac Plain of Haiti, Proceedings 12th ERIM Symposium on Remote Sensing of the Environment, Ann Arbor.

[5]In INPE, 1978. Use of Landsat Data to Identify and Evaluate Areas of Sugar Cane. Instituto de Pesquisas Espacias, Sao Jose Brazil.

pretation accuracies for Level I information (urban, forest, intensive agriculture, range, water) could be expected above 95 percent.[1,2] Level I land cover/use classification defines, to some extent, the practical limitations of the system, based upon the pixel size. Areas exceeding .4 hectare in size are not always sufficiently resolved to allow for accurate visual or computer-aided image interpretation. Another aspect is the lack of sufficient spectral discrimination resulting from the variation between and within land cover/use classes. This is especially the case in the small scale farming systems in the tropics.

For these reasons it is practical to define major land cover/use (Level I) categories but not to provide a further breakdown of these categories. It is for example feasible in some cases to differentiate between deciduous and coniferous forest cover (with a decrease in accuracy), but not to differentiate between major vegetation associations within these categories.[3] However, a further refinement of information (crop types, percent irrigated land, percent clearcutting, etc.) can be essential to natural resource inventories, efficient management practices and agricultural sector analysis. This requirement

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[1]Anderson, James R., et al., Land Use Classification System for Use with Remote Sensor Data, Geological Survey Circular 671.

[2]Aldrich, R.C., N.X. Norich, and W.J. Greentree, 1978. Forest Inventory: Land-use Classification and Forest Disturbance Monitoring. From: Evaluation of ERTS-1 Data for Forest and Rangeland Survey, USDA Forest Serv. Res. Paper PSW-112, 67p. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

[3]See also, Holmes, Quentin A. and Robert Horvath, 1980. Procedure M: An Advance Procedure for Stratified Area Estimation Using Landsat. Paper presented at the 14th International Symposium on Remote Sensing of the Environment, San Jose, Costa Rica.

can only be fulfilled with the aid of medium-scale (1:20,000 to 1:50,000) aerial photography, or detailed, costly ground surveys.

The Level I data derived from Landsat can be compared with data developed in the agricultural sector analysis approach of the CRIES project. Data including soils, climate, etc., are classified on the basis of micro-climatological conditions and ecosystem and soil association factors to form the more or less homogeneous units or (sub) strata (referred to in area-frame sampling). These strata, derived from ground survey methods, are referred to as resource planning units (RPUs). The Landsat-derived strata and the RPUs should coincide at some aggregate level of mapping.

In order to improve the detail of spatial information as it relates to current resource information, the capability to more accurately assess the environmental variables within these categories must be improved. Currently this is being done by means of a costly, time-consuming process, area-frame sampling, with, in a practical sense, unknown estimation accuracies. The research reported here aims to improve population-parameter estimates by using aircraft surveys or aerial sampling techniques and to assess the cost, time and accuracy of these techniques in a specific, small-area agricultural inventories, in order to refine satellite-derived stratification.

Study Objectives

The primary objective of this study is to examine the feasibility of conducting random, systematic sampling procedures using aircraft surveys to derive area statistics on agricultural or natural resources. Within the context of this research, special attention is given to multi-stage sampling: the refinement of area statistics derived from space-borne remote sensing systems (a two- or three-stage sampling procedure). Recommendations are made on the developed procedure, its methodology, the sampling size, estimator accuracy and costs. The procedure specifically addresses typical resource information problems encountered in developing countries, such as the lack of a sufficient data base for economic development, insufficient aerial photographic coverage (scale, timeliness and areal extent), and lack of topographic data or other secondary data sources.

Major Study Goals

Specific goals of the study are:

a. The development of appropriate sampling procedures to refine area statistics for strata derived from Landsat satellite imagery or from ancillary information sources, such as resource units (RPUs) used in the CRIES agricultural sector analysis approach.

b. The evaluation of the utility of light aircraft surveys and/or aerial sampling techniques to provide the required information, to develop a low-cost, low-technology, data-acquisition methodology for developing countries.

c. The evaluation of the theoretical and empirical sampling errors inherent alternative sampling designs.

d. The comparison of the aerial sampling data with area-frame sampling information and the associated potential to estimate crop acreage, given certain accuracy/cost parameters.

e. The evaluation of elements relating to non-sampling errors associated with the aircraft survey technique and the area-frame sampling design.

Research Approach

The focus of this research is to develop light aircraft sampling procedures to obtain detailed land cover/use information and thus improve general resource management practices and provide relevant information for agricultural sector analysis. Figure 1 outlines the sixteen major steps for evaluation of the proposed aerial sampling procedures and a comparison with the area-frame sampling techniques.

The selected test site was based on the intensive agriculture category, as delineated using visual analysis of Landsat imagery, the description of RPU's, and the initial stratification used in the design of the area-frame sampling. Aerial photography was acquired over the test site during March 1979 and interpreted based on photo interpretation keys developed during the fall of 1979 from the available CIR photography and ground truth data. The land cover/use information was transferred to a 1:12,500 enlarged base map, produced from a 1:50,000 topographic map. Area statistics for the various crops within the test site and sample segment boundaries were calculated using a dot grid with a density of 1024 dots per square kilometer (1 dot = .0977 hectare). These were compared with the area statistics derived from the quarterly area-frame surveys (two segments) in an effort to compare the relative accuracy of the area-frame methods in generating crop inventory statistics. Next (Stage 14) the expansion factor (N/n) was used to predict the total crop area statistics for the counting unit (test site) based on the crop information accumulated during the ground survey methods used in the area-frame sampling. Stages 15 through 18 progress from the generation of sampling statistics and the estimation of land cover/use composition of the test site to a final comparison and evaluation.

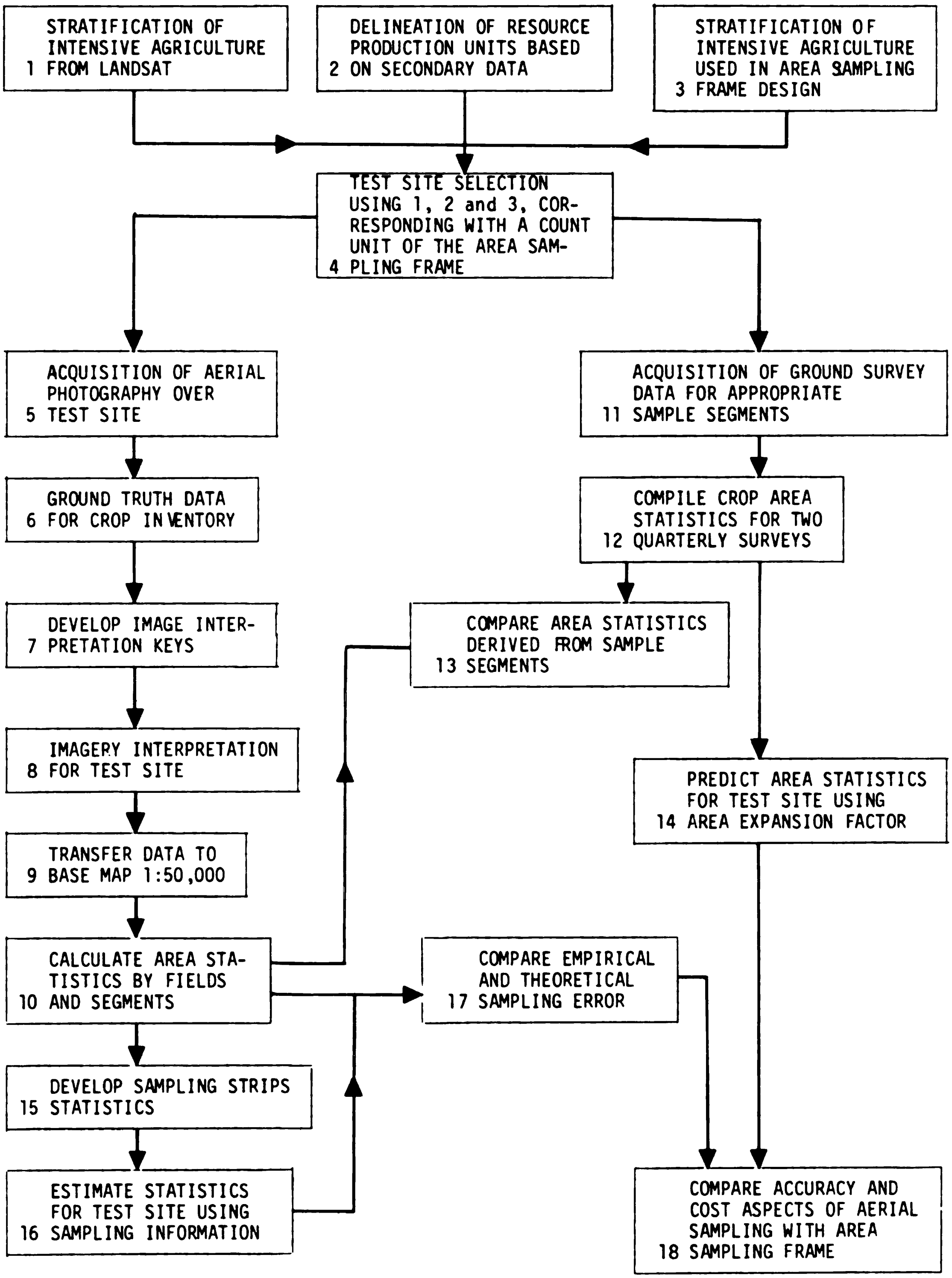

FIGURE 1. Flow Chart of Sampling Research

During the next phase a simulated strip-sampling approach was conducted using various sample sizes. These sampling strips are based on simulated aerial photographic coverage derived from aircraft sampling procedures at a selected image scale (approx. 1:30,000). The sample sizes selected were approximate samples with an increment of 5 percent, starting at 5 percent up to 20 percent. Also a sample size was selected which is approximately equivalent to the ration n/N that is used in area-frame sampling in order to compare the results with the ground-based survey.

Based on the various sampling sizes, estimates were made regarding the crop composition of the test site. Empirical and theoretical sampling error were determined using the total enumeration derived from the original inventory and the sampling design.

The last stage consists of an evaluation of the cost/accuracy aspects associated with the various sampling procedures in order to make a recommendation on the feasibility of conducting an aerial sampling approach in a typical agricultural inventory in the (sub) tropics.

County Description

The Dominican Republic occupies the eastern two-thirds of the island of Hispaniola, the second largest island in the Caribbean; the western one-third is occupied by the Republic of Haiti. Hispaniola is located between Cuba, on the west, and Puerto Rico, on the east.

The relief features of the Dominican Republic are dominated by four parallel mountain ranges which extend in a northwesterly direction, located mainly in the western part of the country, and a single range of low mountains extending from east to west in the eastern part. The southeast is dominated by a lowland plain suitable for intensive agriculture. Soil and climatological conditions vary greatly as a result of the complex topography.

The total area is 48,442 km^2[1] with a population of 4.8 million (1975) and a rate of growth of 3 percent over the period 1970-1975. This amounts to a population density of 99 persons/km^2 or 200 persons/km^2 of arable land, since almost 50 percent of the country's land mass is cultivated. Other population characteristics (1975) are a crude birth rate of 45.8 and a crude death rate of 13.0 _pro mille_. A relatively high infant mortality of 104.0 _pro mille_ exists. The adult literacy is increasing (51 percent in 1972), as is the GNP per capita ($720.00 in 1975). In an economy mainly based on agriculture, 54.6 percent of the total labor force were employed in that sector in 1970. The major crops are sugar cane, coffee, cacao and tobacco. Total agricultural production has expanded since 1960 at an average annual rate of about 2.5 percent. This expansion resulted mostly from an increase in the area under cultivation. Since almost all the cultivable land is currently in active agricultural production, future growth in agricultural output will have to originate from improved yields, through better management and appropriate land use policies. Although food production has outpaced population growth at an average annual rate of 4.2 percent over the last fifteen years, a large deficit still exists in the country's nutritional needs. This deficit is explicitly

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[1]The International Bank for Reconstruction and Development/The World Bank, _Dominican Republic_. 1978. Latin America and the Caribbean Regional Office, Washington, D.C., U.S.A.

referred to by the International Food Policy Research Institute;[1] calculations indicate that the total production needs expressed in nutritional equivalents of milled rice are about 620,000 metric tons compared to the total production of food crops of 260,000 metric tons. This difference is partially bridged by an import of 260,000 tons per year, leaving an unfilled nutritional gap of about 100,000 tons.

The World Bank study[2] indicates that the country's natural resources are adequate for the country to become self-sufficient in food production, taking into account diet requirements, and assuming that appropriate agricultural sector policies are followed.

Table 5 illustrates a land capability classification and associated production capacity ratings based on information of the National Statistics Office (DR) and a survey conducted by the Organization of American States. The figures show that less than 50 percent of the total land area can be classified as having some agricultural production capacity, assuming that careful management practices and conservation measures are used to sustain the long-term carrying capability of the resource base (see Table 6).

Description Study Area

The study area is located in the eastern Cibao Valley in the North-Central portion of the Dominican Republic. The Cibao Valley represents one of the best agricultural areas producing a variety of crops. The western part is currently being developed by means of

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[1]Ibid.

[2]IBRD/The World Bank, 1978. Dominican Republic. Its Main Economic Development Problems. Latin American and Caribbean Regional Office, The World Bank, Washington, D.C.

TABLE 5

Land Capability Classification

Class	Ha.	%	Cum %	Production Capacity
I	53,700	1.1	1.1	Excellent for cultivation
II	235,000	4.9	6.0	Very good for cultivation
III	312,200	6.6	12.6	Good for cultivation
IV	363,900	7.7	20.3	Limited or marginal for cultivation
V	607,100	12.7	33.0	Pasture - no erosion hazard
VI	561,100	11.8	44.0	Pasture - erosion hazard
VII	2,516,100	52.7	97.5	Forest
VIII	120,200	2.5	100.0	Wildlife
Total[a]	4,769,300	100.0		

SOURCE: Modified after National Statistics Office; and OAS Survey of the Natural Resources of the Dominican Republic.

[a]Does not include 58,800 ha. in islands, lakes and other unclassified areas.

TABLE 6

Land Capability and Conservation Requirements

Class	Land Capability and Potential Use	Conservation Requirements
I	Cultivable lands, suited to irrigation, with level relief and with important limiting factors. High productivity, given good management.	Require only good management practices.
II	Cultivable lands, suited to irrigation, with level undulating or smoothly hilly relief. Limiting factors not severe and can be compensated through moderately intensive management practices. High productivity, given good management.	Require moderate conservation measures.
III	Cultivable lands, suited to irrigation but only with very profitable crops. Level, undulating or smoothly hilly relief. Rather severe limiting factors. Moderate productivity, given intensive management practices. Possible crop range restricted.	Require intensive conservation measures.
IV	Lands of limited cultivability, not suited to irrigation except under special conditions and with very profitable crops. Chiefly suitable for pasture or perennial crops. Level to hilly relief. Severe limiting factors. Require very intensive management practices. Low to moderate productivity.	Optimum capability is for tree crops that require little tilling work.
V	Lands not suitable for cultivation, except for ricegrowing. Suitable chiefly for pasture. Very severe limiting factors, particularly in relation to drainage. High productivity for pasture or for rice, subject to very intensive management measures.	Optimum capability is for pasture, without restrictions.

TABLE 6 - Continued

Land Capability and Conservation Requirements

Class	Land Capability and Potential Use	Conservation Requirements
VI	Lands unsuitable for cultivation, except for mountain crops. Suitable chiefly for forestry and pasture. Very severe limiting factors, particularly steepness, shallowness, rockiness.	Optimum capability is for forest and pasture, with restrictions.
VII	Uncultivable lands, suitable only for forestry.	Optimum capability is for forest with severe restrictions.
VIII	Lands not suitable for cultivation. Suitable only for use as a national parks and wildlife areas.	Recreation and wildlife areas.

SOURCE: World Bank, 1978, Dominican Republic. Latin America and the Caribbean Regional Office, Washington, D.C.

infrastructural improvement and a new irrigation project. The crops produced here include rice, soy beans, tobacco, coffee, and some citrus. The eastern portion of the Cibao Valley includes significant tobacco production, north east of Santiago, and mixed, intensive, agriculture to the south. Here the fields become somewhat smaller and include a greater variety of crops.

Test Site Description

The selected test site is located in the east central portion of the Cibao Valley. It is an area around Moca consisting of level terraces and pediments over water-deposited sediments.[1] The climate is generally moist with mean annual rainfall in the 900-1,500 millimeter range.[2] The period January through March is considered a distinct dry season. The mean annual temperature is 25° - 27°C, nearly uniform throughout the year. The native vegetation[3] is estimated to have consisted of savannah and subtropical broadleaf forest types. The area is extremely productive and well suited for intensive agricultural land use. The major crops consist of plantains, yucca, sweet potatoes, kidney beans, coffee, cacao, tobacco and corn. The terrain is flat with gentle slopes. The climate supports rainfed crops; however, some irrigation can be practiced with increased yield. The topsoil is very

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[1]Arens, P.L. et al. 1976. "Republica Dominicana: Diversificacion y Aumento de la Produccion Agricola en el Valle del Cibao. CNIECA, San Cristobal, RD.

[2]CRIES, 1977. Land Resource Base Report 77-1, USDA, AID and Michigan State University (draft).

[3]Holdridge, L.R. 1967. Life Zone Ecology, Revised Edition. Tropical Service Center, San Jose, Costa Rica.

fertile and contains a high percentage of organic material. Table 7 summarizes the planting/harvesting period for the major crops in the area.

TABLE 7

Crop Calendar, Moca Test Site, Eastern Cibao Valley

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. *Musa* sp.												
Plantain			———	———	———			———	———	———		
Plantano	- - -	- - -			- - -		- - -	- - -		- - -		
2. *Manihot* sp.												
Cassave		———	———	———	———		———	———		———		
Yuca	- - -	- - -	- - -				- - -	- - -	- - -			- - -
3. *Ipomoea batatas*												
Sweet potatoes		———	———	———					———	———	———	
Batata		- - -	- - -	- - -		- - -	- - -	- - -				
4. *Phaseolus vul.*												
Kidney beans	———		———	———	———			———	———		———	———
Habicheulas		- - -	- - -	- - -	- - -	- - -	- - -	- - -		- - -	- - -	
Red/Rojo			———	———	———		———	———				
Black/Negro						- - -	- - -	- - -			- - -	
5. *N. tabacum*												
Tobacco	———									———	———	———
Tobaco	- - -	- - -	- - -	- - -	- - -	- - -						

TABLE 7 - Continued

Crop Calendar, Moca Test Site, Eastern Cibao Valley

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
6. *Zea mays*												
Corn			______	______	______				______	______	______	
Maiz	------	------	------				------	------	------	------		

SOURCE: Secretaria de Estado de Agricultura, 1976. Estudio del Efecto del Cambio en al Epoca de Siembra Sobre los Rendimientos e Ingresos Brutos en la Produccion de Algunos Cultivos en la Republica Dominicana. Publicaciones Administracion Rural No. 6. Santo Domingo, Republica Dominicana.

____________ Planting period

------------ Harvesting period

CHAPTER II

CONCEPTS OF REMOTE SENSING - BASED NATURAL RESOURCE INVENTORY SYSTEMS

Remote Sensing Systems: A New Perspective in Integrated Natural Resource Inventory Systems

Historically, man has evaluated and planned the development, use and management of natural resources, first from the highly restrictive view provided by ground observation, then from the substantially improved perspective of conventional aerial photography, and more recently, from the broader perspective of earth-orbiting spacecraft.

Within the same historical context, agriculture and natural resources have been managed quite restrictively by a multiplicity of interests of private landowners, small local units of government and cooperations. The increasing awareness of the complex environmental consequences of natural resource management has resulted in a more synoptic and comprehensive approach coordinated by regional, national and limited, international initiatives.

In this context remote sensing from different platform levels assumes its greatest potential. A multi-stage remote sensing approach is flexible for meeting a wide range of data requirements, from a synoptic view offered by earth-orbiting satellites, to detailed, and highly accurate data collection through low altitude aerial photography.

It is this flexibility in data-gathering techniques that allows for the generation of integrated data bases. Such data bases, by providing both the required level of detail as well as the synoptic overview, improve the quality of information to evaluate the ecological consequences of natural resource decisions. Remotely-sensed information can be utilized to monitor the status of the resource base and its relationship with on-going land use dynamics affecting the quality of life.

The Need for Natural Resources Information

Land resource managers and planners are faced with an increasing need for current and adequate resource data. Efficient management practices in agriculture, forestry, etc. require the capability to monitor the status of the system which is subject to management decisions.

Resource management calls for different management intensities depending on the management level. Extensive management requires extensive information. This generally means information relating to larger surface areas with limited information detail per hectare. Intensive practices, however, ususally focus on smaller land areas with higher capital and manpower investments per surface unit, making the timeliness and detail of data even more crucial elements.

Increasing demand pressures on the limited land resource base and its carrying capacity, as well as increasing environmental concerns, have shifted management practices from extensive to more intensive, thus increasing the importance of relevant, timely data acquisition.

The increasing dynamics of land and resource use processes reduce the value of non-current standard photographic coverage. The flexibility of small-format aerial photography to provide supplemental, localized information of a detailed and specialized nature, in a timely manner, has therefore become extremely valuable.

Contact Versus Non-Contact Data Gathering Techniques

Traditionally, data gathering techniques for resource management purposes have relied heavily on contact methods (ground surveys). Actual, on site visual observations or instrument measurements were carried out to obtain qualitative or quantitative information.

Increasing knowledge of statistical sampling procedures and the technological development of remote (non-contact information gathering have dramatically changed data collection methods. These non-contact surveying methods, including both air- and space-born remote sensing systems, prove especially useful where:

1. alternative data sources are not available, especially in many lesser developed countries, and where no other practical procedures are available to acquire the information in question, given time and technology constraints;

2. crucial policy development and evaluation require rapid, up-to-date and synoptical data collection;

3. cost/accuracy and efficiency aspects of information gathering play an important role.

Remote sensing data collection techniques provide this potential, reducing time and cost, without sacrificing a great deal of accuracy.[1]

Data Collection Using Remote Sensing

Remote sensing systems record electromagnetic energy variations, in pre-selected wavelengths and frequencies, in the form of reflected or transmitted energy from phenomena on the earth's surface.

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[1]Claire, M. Hay, 1974. Agricultural Inventory Techniques with Orbital and High-Altitude Imagery. ASP Journal, pp. 1283-1293.

The continuum of electromagnetic energies is called the electromagnetic spectrum (EM) and can be subdivided into different regions of wavelength magnitudes (bands) (Fig. 2).

Within the context of this research, we will limit our discussion to photographic sensor systems that record the magnitude of wavelength-specific radiation extending from the ultraviolet to the near infrared region (Fig. 3). Depending upon the film/filter combinations, photographic remote sensing systems are selectively operable in the .35 - 1.5 micron wavelength portion of the electromagnetic spectrum.

The significance of this selectivity is that the wavelength and the relative intensity of reflected or emitted radiation of any object are recorded by the selected remote sensing system and define the object in terms of a unique spectral signature. Utilizing this principle, it is possible to classify the earth's surface according to a pre-defined scheme (land use/cover information, vegetation stress levels, ecosystem classification, etc.). It is, however, important to realize that the recorded spectral signature varies with environmental conditions, such as haze, level of air pollution, time of the day (light intensity, sun angle), season, and conditions of the phenomena under surveillance.

The range of available remote sensing systems can be characterized in terms of resolving power: the capability of a given system to clearly discriminate between surface features. Resolving power plays a crucial role in determining the applicability of one system over another. Obviously, the information detail and reliability of spaceborne sensors is inferior to high-altitude systems, limiting their applicability for data gathering for intensive resource management, which requires a high level of information detail.

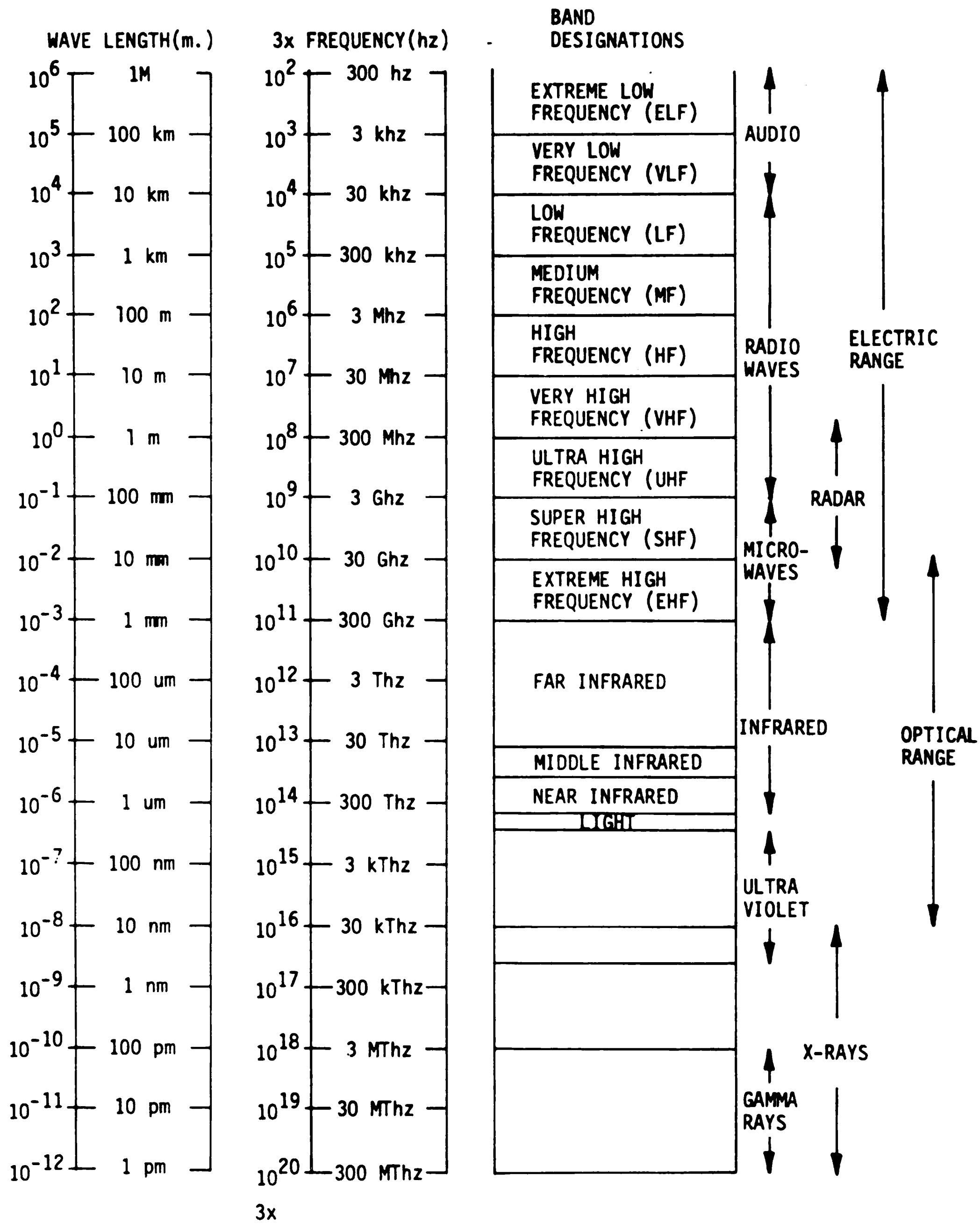

FIGURE 2. The electromagnetic spectrum: wavelength, frequencies, and band designations. (Adapted from Tomlinson, Geographical Data Handling).

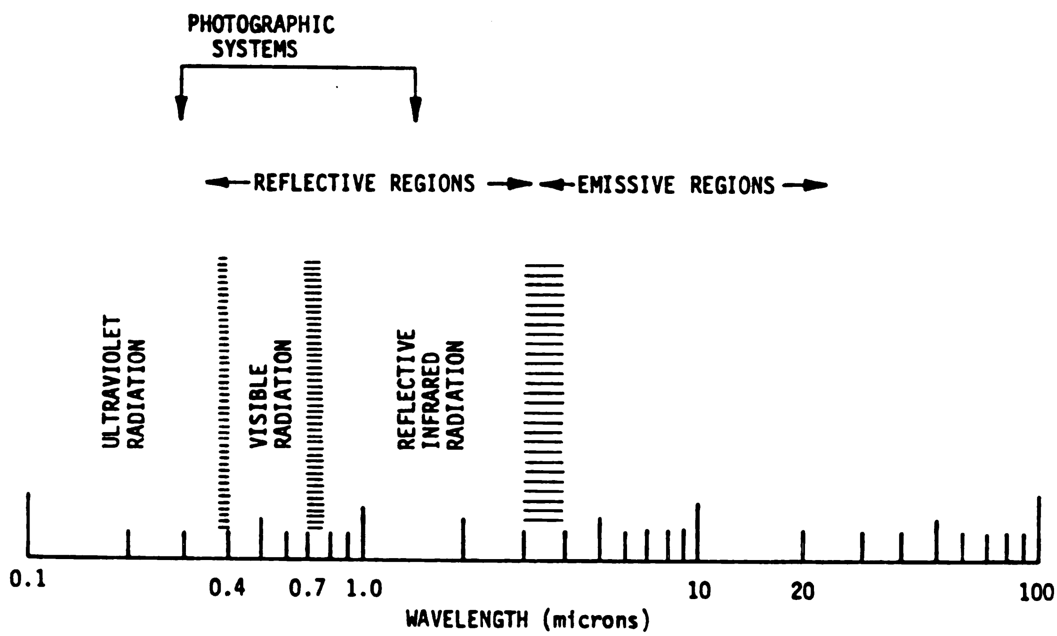

FIGURE 3. A portion of the electromagnetic spectrum. (adapted from Johanson, Remote Sensing for Planning Resource Conservation).

The sequence from high to low detail is associated with the following general characteristics:

a. an increasing area coverage per unit of time during data acquisition efforts, which reduces inventory cost per area unit and, more important, information accuracy;

b. a decreasing reliance on remote sensing as the primary and unique data source, and therefore, an increasing reliance on field data, lower level systems, sampling data or secondary data sources.

Selecting the optimum system or combination of systems to be utilized in resource inventory efforts depends on two basic parameters, data acquisition cost and required level of accuracy. In general, one should select any system or combination, which, given budget constraints and accuracy standards, increases the aggregate utility of resource information for efficient management practices.

Currently, operational spaceborne remote sensing systems for practical applications are limited to the Landsat series, in operation since the early 70's. The Landsat system, in combination with the large format camera, that will be carried as a part of the payload of future space shuttle missions, are discussed in the following section. Spaceborne systems can be considered the first stage of a comprehensive remote sensing-based inventory effort. Variations in image scale, associated with a multi-stage remote sensing approach, are summarized in Table 8.

TABLE 8

Typical Imagery Scales for Multi-Level Remote Sensing Systems

Stage	Platform description	Typical operation altitudes	Typical imagery scales
I	Spaceborne, Skylab	270 miles (435 km)	1:950,000-1:2,850,000
I	Spaceborne, Landsat	570 miles (920 km)	1:1,000,000-1:3,369,000
I	Spaceborne, Space shuttle	268-544 (km)	1:1,758,530-1:3,369,553
II	Airborne, U-2, RB-57, lear, jet propulsion	30,000'-60,000'	1:60,000-1:120,000
III	Airborne, twin-engine, piston, turbocharged	10,000'-30,000'	1:20,000-1:50,000
IV	Airborne, single-engine, Piston	1,000'-10,000'	1:2,000-1:20,000

Multi-Level Remote Sensing

Multi-level remote sensing usually incorporates the variety of sensors, imagery, image scales, interpretation and mapping techniques needed to satisfy information requirements.[1] The variables include the altitude of various data collection platforms, selected remote sensing systems and data output characteristics.

Information requirements (level of detail, scale and timeliness) will determine, given cost and accuracy constraints, which level is the most appropriate.

Low-level systems most effectively provide data for intensive inventories and management practices. The data output is adequate in scale and resolution to inventory small sites in a very accurate and detailed manner. Imagery scales may vary from 1:2,000 up to 1:20,000.

Typical features associated with a low-level system are effectiveness, simplicity, relatively low operation cost and quick information turn around. Typical aspects affecting the use of the acquired imagery are a high degree of information accuracy and a moderate skill level of imagery interpreters. The higher level of information detail makes it possible to reduce reliance on field information.

The light (single engine) aircraft surveys are typical for low level remote sensing involving conventional small format (35 mm and 70 mm) cameras. (see also Appendix 1)

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[1] Jensen, Mark S. and Meyer, Merle P., 1976. A Remote Sensing Applications Program and Operational Handbook for the Minnesota Dept. of Natural Resources and Other State Agencies. Remote Sensing Laboratory, University of Minnesota, St. Paul.

Medium-level systems, providing imagery scales in the 1:20,000-1:50,000 range, are most appropriate for medium intensity management activities extending over larger areas. While low-level systems might be used primarily for areas up to 100km^2, medium-level systems involve more extensive aerial coverage encompassing larger management districts or regions. Most of the operational resource management practices use medium-level photography, sometimes in a specific small area supported by low level systems.

The primary utility of this medium scale photography, with its high resolution, exact scale and high photogrammetric precision, is in traditional mapping and inventory efforts requiring skilled personnel and precision equipment. Trained resource specialists with skills in air-photo interpretation are required to optimize the utility of this information source.

High-level systems provide small scale imagery (1:60,000-1:120,000) of moderate resolution. The imagery is usually acquired for a large region on a project basis. It provides synoptic land use and inventory information with limited detail and is therefore most suitable for extensive management practices. Inventory efforts are associated with relatively high mission cost, and require specialized interpretation personnel, more sophisticated equipment, and a reduction in accuracy of information, even with the increased reliance on field data. In recent years, especially since research related flights by the National Aeronautics and Space Administration (NASA) with U-2 and RB-57 aircraft were carried out, high-level systems have proven to be a viable alternative to middle stage systems, with lower cost for information acquisition per unit area and with limited sacrifice of accuracy standards.

Current and Future Spaceborne Systems for Natural Resource Inventories; Landsat and Space Shuttle

The evaluation of the potential of remote sensing systems to provide data on the status of natural resources requires an assessment of the quality and the detail of information needed. Each management problem and level has its own general scale and resolution requirements. Resolution in this case refers to the spectral, spatial and temporal resolution, involving a strong relationship of compromises.

The utility of current remote sensing systems for environmental management and planning is largely determined by these basic image characteristics:

a. Scale is the relationship between a given distance on an image and the corresponding distance on the earth surface. It is determined by remote sensing system specifications, typically the focal length of sensing equipment and the platform altitude of a given system. As stated earlier, scale considerations are important to optimize the effectiveness of techniques for data extraction and information gathering.

b. Ground or spatial resolution is a measure of the ability of an imaging system to separate adjacent objects. This ability can be measured in lines per millimeters (mm), or the least separation in mm being the width of a just resolved line pair at the ground scale. The spatial resolution varies with image system characteristics and can also be affected by image motion at the time of exposure. The ability to interpret images accurably and efficiently (data extraction) is affected by the resolving power of the system. Optimizing spatial resolution, by using an appropriate remote sensing system configuration, given cost constraints, is therefore a critical element in data collection efforts.

Characteristics of Imagery and Imaging Systems

Two major factors have to be considered in comparing the characteristics of aerial imagery:

a. the imaging platform and its average altitude above ground level (the operational altitude) of the air or spaceborne remote sensing system affects the scale of the final image product; and

b. the imaging system affects the scale of the image and determines the ground resolution (data characteristics) of the final product.

Various platform levels, their corresponding image scales, data characteristics and image types are given in Table 9.

The Landsat System

Currently three remote sensing satellites, Landsat 1, 2 and 3 (after Land Satellite) are orbiting the earth as a part of the Earth Resource Observation System (EROS) of the U.S. Department of the Interior. Landsat 1 is, however, no longer functional. The operational altitude of these spacecraft is 920 km (570 mi). They orbit the earth in a north-south direction in a sun-synchronous tract with a combined capability to cover any location on earth once in every nine days (NASA, 1976). Two types of sensor systems are used:

1. three Return Beam Vidicon (RBV) cameras detect energy in 3 spectral bands (1, 2 and 3);

2. a Multispectral Scanner (MSS), the major sensor system consist of a mechanical line scanning device (not a photographic system), and records reflected spectral information from the earth surface in four discrete spectral bands (bands 4, 5, 6 and 7).

TABLE 9

Characteristics of Remote Sensing Imagery

Category	Operational altitude	Image scale	Image type	Frame coverage (sq. mi.)**	Data Characteristics
Landsat imagery	920 km (570 mi)	1:3,369,000	MSS*	13,225	Very small scale, synoptic view, low resolution, statewide repetitive coverage, digital data, themetic mapping.
Skylab imagery	435 km (270 mi)	1:2,850,000 1:950,000	MB COL	10,201 4,624	Very small scale, synoptic view, low-moderate resolution, thematic mapping.
Space shuttle, large format camera (LFC)	268 km 544 km	1:1,758,530 1:3,509,553	COL/CIR PAN	126,036 519,229	Very small scale, synoptic view, moderate resolution, repetitive coverage on a low frequency basis, topographic mapping.
NASA high altitude aircraft imagery	18 km (60,000 ft)	1:450,000 1:120,000 1:60,000	MB COL/CIR CIR	244.1 290.0 72.6	Small to moderate scale, moderate resolution, regional coverage on a project basis, topographic mapping.

TABLE 9 - Continued

Characteristics of Remote Sensing Imagery

Category	Operational altitude	Image scale	Image type	Frame coverage (sq. mi.)**	Data Characteristics
Regional/county imagery	varies	1:60,000	PAN/COL	72.6	Moderate scale, moderate to high resolution, periodic county coverage, potential periodic state coverage, topographic mapping.
		1:40,000	PAN	32.3	
		1:36,000	CIR	26.1	
		1:31,680	CIR	20.3	
		1:24,000	CIR/PAN	11.6	
Local/imagery	varies	1:20,000	CIR/COL/PAN	8.1	Large to very large scale, high to very high resolution, selected project sites, topographic mapping.
		1:12,000	varies:PAN/COL	2.91	
		1:9,600		1.86	
		1:6,000		.73	
		1:4,800	CIR	.46	

*Abbreviations: MSS (Multi-Spectral Scanner), MB (Multiband), COL (Color), CIR (Color Infrared, PAN (black and white), BWIR (black and white infrared).

**Based on Standard Camera configurations and image format.

The total Landsat spectral capability is summarized in Table 10.

TABLE 10

Landsat Spectral Bands

Band (NASA Code)	Sensor System	Wavelength (nanometers)	Spectral Range
1	RBV	475-575	Visible, yellow-green
2	RBV	480-680	Visible, green-red
3	RBV	690-830	Visible, red-invisible infrared
4	MSS	500-600	Visible, green
5	MSS	600-700	Visible, red
6	MSS	700-800	Invisible, reflected infrared
7	MSS	800-1100	Invisible, reflected infrared
8	MSS	10200-12600	Invisible, emitted thermal infrared

Adapted from: NASA, 1976. Data Users Handbook, Goddard Space Flight Center, Greenbelt, Maryland; and Taranik, J.V. 1978. Characteristics of the Landsat Multispectral Data System, U.S. Department of the Interior, USGS, Sioux Falls, South Dakota.

The recorded radiation is transmitted to ground receiving stations and stored on magnetic tape. MSS taped data can be transformed into an image by means of an electron beam recorder converting variations of electromagnetic radiation into different gray tones. In this manner a black and white image for each band is composed. To facilitate visual interpretation a color composite image can be produced by assigning the three primary colors to each band using color additive techniques.

Another data product is Computer Compatible Tapes (CCT's), requiring digital image processing (automated computer-aided classification).

One Landsat scene covers an area of 185 x 185 km (115 x 115 mi), or an area of approximately 35,225 km^2 (13,225 sq mi). The effective resolution (in terms of the smallest adjacent ground features that can be distinguished as separate entities) is about 80 m (262 ft), resulting in a spatial resolution of approximately .5 ha or 1.2 acres.

Landsat 3 launched on March 5, 1978 has an improved Return Beam Vidicon (RBV) System providing high resolution (40 m or 131 ft) panchromatic (B/W) imagery. Landsat 2 has an RBV system also, but very few images were produced due to system failures. In addition to the MSS System on board Landsat 3, a thermal sensor has been added with a resolution of 240 m (787 ft). This sensor became, however, inoperative shortly after the launch.

Landsat D, planned to be launched in 1981, will provide a major new step in the application of remote sensed data from space. It will introduce the Thematic Mapper (TM), a seven spectral band, mechanically scanned, radiometer with a 30-meter spatial resolution. It will operate from a 709 km circular sun-synchronous orbit, imaging an identical 185 km swath with a 20-day frequency. Image data will be transmitted on a real time basis via the TDRS satellite to the White Sands terminal, and from there, via the DOMSAT satellite to Goddard Space Flight Center for processing.

The Large Format Camera

The large format camera (LFC), similar to the thematic mapper (TM), will provide an additional remote sensing capability from space.

The camera (image size of 23x46 cm)[1,2] will be carried as a part of the payload on future space shuttle missions, beginning in 1982. Expected operational altitudes after a launch from NASA/KSC (Kennedy Space Center) will vary from a low-altitude orbit of 268.2 km to a high-altitude orbit of 544.1 km with a 6 inch focal length and an image size of 23x46 cm. This will mean an area coverage of 404x808 km for a low-altitude launch and a 820x1640 km coverage for a high-altitude launch. The ground resolution of the expected coverage would be better than 20 meters for color and color infrared film and better than 25 meters for black and white film. This would allow topographic mapping from space, rather than the thematic mapping capabilities provided by current spaceborne sensing systems. A high-altitude launch from Vandenberg Air Force Base and an orbit inclination of 97.6° would require 3,468 photographs (80% overlap) to acquire almost world-wide coverage after two 8-day missions. This potential will introduce a new capability to generate worldwide, topographic coverage at a 1:50,000 scale as a result of successive shuttle flights during the 1980's. For the first time in history this would allow the systematic compilation of detailed map coverage for large parts of the world. As Brandenburger[3] points out, only 20 percent of the world's land area is adequately covered by up-to-date maps needed to meet economic planning and development demands. New maps are currently added with a

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[1] Itek, 1978. Large Format Camera, Description and Applications, Itek Optical Systems, Lexington, Mass.

[2] Ondrejka, R. 1979. Personal correspondence. System Development Manager, Itek Corporation, Lexington, Mass.

[3] Brandenberger, A.J. 1976. "World Cartography," United Nations.

rate of less than 1 percent per year, while critical information compiled for many developing areas becomes obsolete at a faster rate. The mapping photography required for topographic maps is in line-pairs per millimeter at the scale of the map product. The Metritek lens developed by the ITEK Corporation would provide an 80 lines/mm resolution on high definition aerial film. This means that 1:250,000 scale maps can be produced from the smallest scale expected (1:3,569,553) image, reducing the final mapping resolution to approximately 6 lines/mm.

This new technology along with the future potential introduced by the push broom systems associated with linear arrays of solid state detectors with a 10-15 meter swath width will soon provide a greater advancement in spaceborne resource assessment and monitoring capabilities. Operational systems are in the design stage in Europe and the U.S. The ITEK Corporation has been contracted by the U.S. Geological Survey to perform a conceptual design for a mapping satellite (MAPSAT) capable of acquiring stereo multispectral images of the earth.[1] These systems will employ this new solid-state technology improving the satellite's stability and pointing precision, thereby, maximizing mapping accuracy and reducing cost.

Sample Survey Considerations Using Light Aircraft Sampling Techniques

A number of advantages are associated with sampling procedures compared to a complete census. With data representing only a small fraction of the total population, especially if the population is large,

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[1] U.S. Geological Survey. 1980. Landsat Data Users Notes. USGS, EROS Data Center, Sioux Falls, S.D. 57198.

results can be obtained at a fraction of the cost and with acceptable accuracies to make valuable inferences regarding the total population possible.

Data collection and summarization for a small portion of the aggregate will, for the same reasons, save time, an important factor in analysis procedures when data are urgently needed to provide information for the evaluation of alternative policies and programs.

The reductions in cost and time allow for a more comprehensive data collection effort and a greater flexibility and scope in information gathering. At the same time, a limited sample survey will almost always improve the quality of the data collection, since better training and supervision can be provided, insuring a greater data accuracy for a sample survey than for a complete census. Using a sampling approach it is, therefore, possible to gather inventory data at considerable time/cost savings without sacrificing great accuracy (the measurement or observation compared to the time value).

A small number of applied aerial sampling designs are used in forest resource inventories. These few studies document the great potential of large-scale aerial photographic sampling as an alternative to the slow and expensive conventional field sampling techniques.[1,2] Large-scale photography is being used to measure detailed population variables such as tree species, height, diameter, basal area, stocking

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[1]Nielsen, U. et al., 1979. A Forest Inventory in the Yukon Using Large-Scale Photo Sampling Techniques. Forest Management Institute, Canadian Forestry Service, Ottawa, Ontario.

[2]Aldred, A.H. and J.J. Lowe, 1978. Application of Large-Scale Photos to a Forest Inventory in Alberta. Forest Management Institute, Canadian Forestry Service. Ottawa, Ontario.

level and volume data. A stratified random sampling scheme proved very satisfactory,[1] resulting in very small errors (less than 2 percent at the 95% confidence level). Tree species were identified with an accuracy of better than 95 percent. Various sampling designs were tested, from randomly located flight strips to a two-stage cluster sampling design with stratification.[2,3,4] It appears, however, that when population strata are somewhat scattered (small tree stands), a stratified random sampling design would be preferred rather than the less flexible and less effective cluster sampling design. In addition, cluster sampling would result in higher cost for photography and a greater difficulty in locating the individual clusters reducing sampling precision. A general problem in the use of systematic sampling is the fact that unbiased, efficient estimators are not available. Bonnor[4] indicates that the use of the simple random sampling appears to be valid since the resulting estimates appear to be sufficiently accurate.

Studies in tropical regions have indicated that when field conditions provide limited orientation (landmarks, roads, etc.) and access (wet season), aerial-based inventories provide a viable alternative to field surveys.[5,6] Sayn-Wittgenstein[7] emphasizes the great difficulty

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[1]Ibid.

[2]Sayn-Wittgenstein, L. and A.H. Aldred, 1969. A Forest Inventory by Large-Scale Aerial Photography. Pulp Paper Magazine. Canada. Sept. 5.

[3]Bonnor, G.M. 1975. Cluster Sampling with Large-Scale Aerial Photography in Forest Inventories. Canadian Forest Service, Forest Management Institute. Ottawa, Ontario. Inf. Rep. FMR-X-80.

[4]Bonnor, G.M. 1977. An Evaluation of Systematic Sampling in Malaysia Forest Inventories. The Malaysian Forester. Vol. 40, No. 4.

[5]Clement, J. 1973. Utilisation des photographies aeriennes au 1/5000 en couleur pour la detection de l' okoume dans la foret dense du Gabon. Proceedings IUFRO, Frerburg, W. Germany.

[6]Heinsdijk, D. 1953. Begroeiing en luchfotografie in Suriname. ITC. Enschede, The Netherlands. Publ. 12.

in species differentiation in a tropical forest, since hundreds of species might occur in a new square kilometers, as compared to a temperate zone where rarely more than 20 species will occur in a similar size area.

The sampling approach of this research relates to the current activities of the CRIES project which are directed towards establishing land use by RPU. The information unit (RPU) and the smallest "homogeneous" land cover/use unit delineated on Landsat imagery should, ideally at least, at some aggregate level coincide. Sampling methods are desired that will provide information on the land cover/use percentages which make up the total composition of these inventory units.

Resource Planning Unit (RPU) Inventory

Resource planning units (see Table 11) are defined as land areas which are to some extent homogeneous in respect to soil association, microclimate, water regime, plant adaptability, and agricultural productivity rating. RPUs have sufficient similarity in land capability and potential to be considered as planning units at the regional and national levels.

Typical parameters compiled for a specific RPU can be considered in discriminating among RPUs (See Table 11 with a typical RPU description in the Dominican Republic).

RPUs vary considerably in size from a few hundred km^2 to several thousand km^2. Many of the 37 RPUs in the Dominican Republic are in the range from 200 to 400 km^2. Several RPUs are not contiguous; in such cases the typical crop mix of land cover/use pattern for a discontiguous RPU could be estimated by appropriate sampling of the discontiguous portions.

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[7]Sayn-Wittgenstein, L. et al., 1978. Identification of Tropical Trees on Aerial Photographs. Canadian Forest Service, Forest Management Institute. Ottawa, Ontario. Inf. Report FMR-X-113.

TABLE 11

Example of Resource Planning Unit Description
in the Dominican Republic

RPU #6

Location: Three widely separated areas near the Caribbean Coast.

Major Settlements: San Farael Tel Yuma

Native Vegetation: Dry forest (Phylostylon.Tabebuia,Prosopis,cacti)

Soils: This RPU is comprised entirely of soil sub-group VUPa L/LS. Detail description of this soil type follows this page.

Remarks: This area is especially suited to growing cotton.

Map Unit Symbol: VUPa L/LS

Map Unit Name: Typic Pellusterts

Composition of Map Unit (principal components and estimated proportion of the map unit represented by each):

#1 60% Typic Pellusterts on level plains
#2 20% Paralithic Ustropepts on knolls

Underlying Geologic and/or Soil Parent Material: Coral limestone

Agricultural Potential: Moderately High

Features limiting use (by components of map unit):

#1 Clayey texture, drainage
#2 Slope, depth to rock

Mean Annual Precipitation (including seasonality): 1,000-1,400 mm, with distinct first-quarter dry season.

Mean Annual Temperature (including seasonality): 26-27°C, nearly uniform throughout the year.

Terrain and Landform: Plains apparently slightly modified from the original constructional coral reef surfaces.

Local relief: 5-10 m

Elevation (above sea level): 5-100 m

TABLE 11 - Continued

VUPa L/LS

Estimated Soil Properties and Special Features

	Map Unit Component #1	#2	#3
Property/feature	Estimates		
1. Slope (percent)	0-3%	3-15%	
2. Depth to bedrock (m)	1-3 m	0.1-0.5 m	
3. Soil texture	fine	fine	
4. Coarse fragments	nonstony	nonstony	
5. Permeability	very slow	slow	
6. Reaction	neutral	mildly alkaline	
7. Salinity	nonsaline	nonsaline	
8. Available water capacity	moderate	very low	
9. Flooding	rare	none	
10. Soil drainage class	somewhat poorly	well drained	
11. Base saturation	50%	50%	
12. Other features			

Sampling Resource Planning Units

Some of the limitations and capabilities of the light aircraft sampling procedure constitute constraints for the development of the sampling design. For example, linear sampling elements are introduced by sampling along flightlines and, in contrast, wind/crab angle conditions introduce random elements.

Initial random reference points can be selected and located at the periphery of an RPU (See Figure 4), by locating a random point at the approximate center of the RPU and plotting imaginary radials (increments of 1°). A random number table could be used to select a specific radial and determine the intersection of this radial with the RPU boundary (e.g. 44° and 224° in Fig. 1). This would then be the primary determinant in the random selection of the sampling direction of the flight lines. An alternative to the random selection of the sampling direction would be a judgment sampling approach, e.g., to locate the sample direction perpendicular to certain gradients distinguishable in the terrain (agricultural zones, cultivation patterns, relief variation, etc.) in order to maximize the variation included in the sample and to reduce the sampling error. This would require the prior knowledge of certain terrain features, cropping patterns, etc., derived from old aerial photography, other secondary information sources, etc., a condition not likely to be encountered in some countries.

Next to random or judgmental selection of the sampling direction accuracy and sample size parameters dictate the total number of photo plots or homes along with the area contained within a frame in relation to the RPU area. Given a certain size requirement (n), the ratio $\frac{n}{N}$

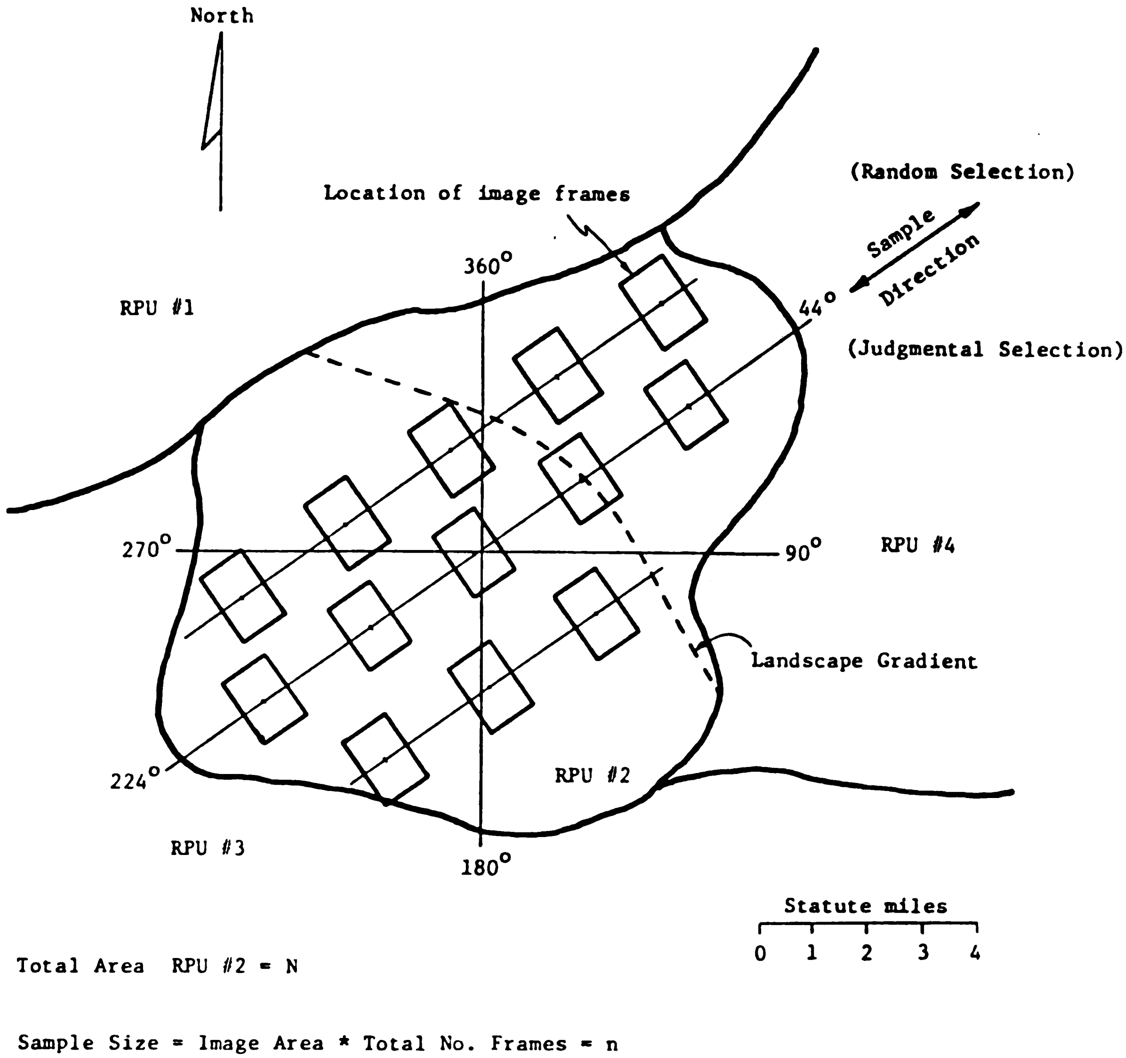

FIGURE 4. Selection of a systematic random linear-sampling procedure for resource planning units.

(total area RPU-N) will determine the total number of frames (given the camera format, flight altitude and camera focal length). For example, if the RPU area of interest is 600 square miles and a 10 percent sample would be considered adequate to compile land cover/use information at a particular confidence level, then at least 60 square miles would have to be sampled. Based on prior experience in the Dominican Republic, an 8000' AGL (above ground level) flying altitude is a reasonable flight level for small format photography. With a 70mm camera and an 80mm focal length, the area coverage per frame is 1.085 square miles. A linear sample of 60 frames would cover, in a random, systematic way (along and parallel to the initial sampling direction selected), a surface area of 60 x 1.085 - 65.1 square miles. This would then suffice to provide the essential information with the desired degree of confidence previously specified.

The location of the frames along the flight lines can be arranged systematically by locating the flight lines at consistent intervals to prevent sidelap and at consistent intervals along the flight lines to prevent overlap. In order to calculate the distance between exposures, the total flight line length should be divided by the total number of frames and their dimension, e.g., 130 miles of flight line and 60 frames ($\frac{130}{60 \times 1.047} = 2.08$) would require a spacing between exposure center points of 2.08 miles. At a certain groundspeed a corresponding camera exposure interval can be calculated to ensure proper frame spacing.

Sampling Considerations

The light aircraft sampling survey procedure outlined above includes elements of <u>random</u> as well as <u>systematic sampling</u>. The selection of starting points for exposure, as well as aircraft drift and crab, introduces random elements. The selection of parallel flight lines (preferably perpendicular to gradients) and flight line and exposure spacing introduce systematic elements.

The resource inventory sampling design is therefore of a random-systematic or, rather, modified, systematic nature. Systematic sampling provides additional usefulness to the sampling procedure since it is easier to perform, less prone to sample selection errors and provides greater information per unit cost than random sampling. This latter characteristic is due to the fact that a systematic sampling frame is frequently spread more uniformly over the entire population than the equivalent amount of data contained within a simple random sample.

Periodicity of the population is another aspect to be considered. A population is periodic if the elements in the population are subject to cyclical variation. Crop-related inventory work, especially in countries with distinct seasonal variation and growing cycles for which systematic sampling is applied to fairly homogeneous populations has, therefore, to be weighted in terms of information per unit cost depending upon the sampling procedure used. In most Central American countries, the growing/harvesting cycles are less distinct, however. This combined with the typical cropping patterns (great crop variation, small acreage, ownership patterns, subsistence farming, etc.) results in land cover/use characteristics which favor the choice of a systematic sampling approach.

The suggested light aircraft sampling procedure combines, to some extent, the advantages of a random and systematic sampling scheme.

Fowler[1] introduces another consideration in the sampling of natural resources population: the shape of the sampling plots. He emphasizes the bias associated with the use of mutually exclusive, equal area, circular sampling plots as opposed to the higher precision of square plots. He found that standard deviations in general, were larger for circular plots inscribed inside square plots, but decreased, as expected, with the increase of plot size. Taaffe[2] emphasizes the use of the relationship between coefficient of variation and sampling plot size to determine optimum size for a given inventory. Obviously, this can only be determined after an initial sampling survey. The distribution of sampling plots using flight lines or line transects, as described in the previous section, can introduce a certain amount of bias. Lund[3] describes a method that uses a systematic sample layout using equilateral triangles and a random start. This method would be costly and inefficient, however, if aerial sampling techniques are used.

Selection of the Sample Size/Sampling Error

The characteristics of an RPU clearly imply, as a result of the finite number of area units, the finiteness of the population subject to sampling. The sample size equation for a finite population can be expressed as:

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[1]Fowler, Gary W. and Carl F. Davis. 1979. Sampling Natural Resources Populations: Mutually Exclusive Fixed-Area Sampling Units. Resource Inventory Notes. BLM-23. USDI. Bureau of Land Management. Denver, Colorado.

[2]Taaffe, Kenneth E. 1979. Computing Optimum Plot Size for Wildland Inventories. Resource Inventory Notes, BLM-23 USDI, Bureau of Land Management, Denver, Colorado.

[3]Lund, H. Gyde. Uniformly Distributing Sample Within a Type Island. USDI Bureau of Land Management. Denver, Colorado.

$$n = \frac{N\,(CV_2)\;^2t^2}{N\,(DSE_{\%})^2 + (CV)^2t^2} \quad \text{or} \quad \frac{\dfrac{(CV)^2t^2}{(DSE_{\%})^2}}{1+\dfrac{1}{N}\,\dfrac{(CV)^2t^2}{(DSE_{\%})^2}} \qquad 1)$$

N = total population size (area)

CV = coefficient of variation or standard deviation expressed as a percent of the mean = $\frac{\sigma}{\mu}$ (100)

t = the number of standard deviations

$DSE_{\%}$ = desired sampling error in percent

Suppose we are dealing with an entire population composed of 500 area units. (For the sake of simplicity, an area unit is considered to be equivalent to a population element). In the literature a CV of 20 to 100 is frequently considered in forestry sampling approaches. Let's assume a CV : 60% and t = 2 (we wish to be 95% confident that the true mean of the population theoretically for all samples in size n to be determined) is somewhere between the sample mean and $\pm$ 10 percent of the sample mean, $DSE_{\%}$ = 10).

$$n = \frac{500\;(60)^2 2^2}{500\;(10)^2 + (60)^2 2^2} = 111.8 \text{ or } 112$$

The sample size would be 112 or $\frac{112}{500}$ = 22.4% of the population. With a coefficient of variation of 40, the required sample size would be reduced to 58 or 11.6%. A sample size like this, approaching 10%, seems to be more realistic, for a number of reasons:

a) The sample size equation for a finite population is based on random sampling. Since the sampling frame is predominantly systematic in nature, however, we can assume that a reduction of the sample size would be acceptable without resulting in an increase in sampling error.

b) A coefficient of variation (the standard deviation expressed as a percentage of the mean) of 40% might be more realistic than the 60% used initially in calculating the sample size. To determine the validity of this assumption a small land cover/use inventory could be carried out to determine the coefficient of variation and associated sampling error as they relate to sample size (frame area x number of frames).

c) A sampling direction, perpendicular to natural gradients, can be selected to minimize the sample size required to arrive at population proportion estimates within the specified sampling error.

d) The sampling frame and associated error calculation ignore the fact that the individual photo frames contain aggregate subsamples of land cover/use proportions rather than the presence/absence of a specific population unit. This should improve the accuracy of population proportion estimates given a certain sample size.

Sampling Error Associated with Area Measurement Using a Dot Grid Method

In discussing sampling error due to sample size, it is necessary to consider the method of data extraction and its associated possibilities to create possible sampling and non-sampling errors. The total sample size is determined by the total number of photo frames and the ground area contained within such a frame. Within each frame the land cover/use categories are classified by means of photo interpretation. The area for land cover/use categories within such a frame is then calculated. The most simple and the most common method is to determine the percent of each categories contained within a frame by means of a dot grid overlay to assign a specific code (land cover/use category) to the class coinciding with a specific dot. Since the dots represent a fraction of the area contained within a photo frame, the aggregate proportion of the land cover/use classes can be easily calculated. This is in fact, a dot sampling procedure and the dot interspacing or the grid size determines the accuracy of the procedure of estimating the proportions of the land cover/use classes.

The area estimation procedure using a dot grid with fixed spacing is similar to a systematic sampling procedure. Again here, as in the linear sampling procedure, the error of the estimate can only be approximated by formulas for random sampling. Therefore, the error calculation will overestimate the actual error resulting from the systematic procedure. However, in estimating the aggregate error due to measurement error, recording error, and sampling error, it is only the last error factor which can be approximated based on the selection of a certain grid density.

An unbiased estimate of the standard error of a proportion of a stratum (j) for a finite population, where N (the total area is relatively large in proportion to the sample size (n), can be written as:[1]

$$S^2_{P_j} = \frac{P_j(1-P_j)}{n-1} \quad \text{or} \quad \frac{P_j(1-P_j)}{n} \quad \therefore \qquad 2)$$

The standard error $S_{Pj} = \frac{\sqrt{P_j(1-P_j)}}{n}$

$P_j = \frac{aj}{n} = \frac{\text{total number of dots in that class or stratum;}}{\text{total number of dots counted.}}$

[1]See Cochran, W., 1977. Sampling Techniques. Wiley and Sons, New York.

For the total area the standard error would consequently be:

$$S_{AJ} = N \frac{\sqrt{P_j(1-P_j)}}{n} \qquad 3)$$

which can be translated into a precision of the estimate using the appropriate t value for the probability level (usually t = 2,95% accuracy, students t value 1.96).

The precision is then the t value x s or 1.96 x the standard error.

One can, using Formula 3, now estimate the error of an area estimate for a specific land cover/use category. Expressed as a percentage of the stratum: .˙.

$$S_{Pj}\ \% = \frac{S_{Pj}}{P_j} \times 100 = \frac{\sqrt{P_j(1-P_j)}}{n} \cdot \frac{100}{P_j} \qquad \text{or}$$

$$S_{Pj} = \frac{\sqrt{10^4(1-P_j)}}{n.P_j} \qquad 4)$$

Another approach would be to specify an allowable standard error for determining the area of a stratum and then calculate the required dot density.

Formula 2 can be used to this purpose, and be written as:

$$n = \frac{t^2 P_j(1-P_j)}{E_j^{\,2}} \qquad 5)$$

n = the total number of dots required for the area of the photo frame

t - students t value

P_j = estimate of the proportion of the land cover/use category

E_j = specified allowable error for the determination of the area for a specific land cover/use category (stratum j)

E_j = expressed as a percentage of the stratum can be written as:

$$E_{j\%} = \frac{E_j}{P_j} \text{ X } 100; \quad n = \frac{t^2(1-P_j) \text{ X } 100^2}{E_j\%^2 \cdot P_j} \qquad 6)$$

After specifying the allowable error E_j and estimating the approximate proportion of a land cover/use category (P_j) contained within the photo frame, the total number of dots can be calculated using Formula 6. The total number of dots required for the photo frame can be translated into a dot density required. With this required dot density the area of a proportion of the photo frame (stratum) can be determined and the actual error of estimate can be calculated using Formula 4.

Area-Frame Sampling Methodology

The first area sampling effort in the United States began with selection of areas called census enumeration districts as permanent samples to permit a relatively accurate measurement of year-to-year changes of certain population parameters. The result of these investigations indicated that a sample size of considerable magnitude would be required in order to obtain an acceptable level of sampling variance.[1] At that time, however, little was known about the relationship between sampling efficiency (the comparison of alternative sampling variances of various sampling plans under assumption of equal sampling fractions)

[1]Houseman, Earl E. 1975. Area Frame Sampling in Agriculture. Statistical Reporting Service, SRS #20, USDA, Washington, D.C.

and the size of sampling units.[1] Later research indicated, however, that these initial sampling units were too large to create reasonable sampling efficiency.

In general agricultural and natural resource inventories, using sampling techniques, it is important to realize that the sampling efficiency is influenced to a great degree by the size of the sample units using equal sampling fractions (n/N). For instance, a five percent sample of small areas would result in a much lower sampling variance than a five percent sample of a relatively small number of larger areas (sampling units).

The first such test was conducted in the late thirties in Iowa.[2] The sampling units consisted of quarter sections (approximately 160 acres). A stratified random sample was used, covering the entire state and containing 900 sampling units, which represented a sampling fraction of less than 0.5 percent. The results were very encouraging since a relative standard error (coefficient of variation) of estimates of less than four percent was obtained for important farm characteristics. These results indicated the utility of using the area-frame sampling approach in estimating relevant variables in agricultural inventories with an acceptable degree of accuracy without the need to conduct a yearly farm census. As a result area-frame sampling has been adopted for use in all states in the U.S.[3]

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[1] Perring, W. Edwards. 1960. Sample Design in Business Research. Wiley and Sons.

[2] Jessen, Raymond J. 1942. Statistical Investigation of a Sample Survey for Obtaining Farm Facts. Iowa State University, Research Bulletin 304, Ames, Iowa.

[3] King, A.J. and Jessen, R.J. 1945. Master Sample of Agriculture. Journal of the American Statistical Association, Vol. 40:38-46.

Important Considerations in Area-Frame Sampling

The central concept of area-frame sampling means that all information within the sampling units (area) is current and complete. The information contained within this sample of segments is then expanded using the estimates of a sample total ($\frac{N}{n} \Sigma x$). In order to produce an unbiased estimate of a specific parameter of the total population with the use of the expansion factor ($\frac{N}{n}$) the information must be a complete and correct representation (total enumeration) of the population parameters within the segment. In practice, this can be a significant problem since selected field boundaries, as they appear on aerial photography to define a selected sample segment, are sometimes difficult to match with ground survey data.

This is especially true in developing countries where small-scale (sometimes subsistence) agriculture, frequent crop rotation and intercropping practices create more difficult conditions for ground survey efforts, increasing the likelihood of introducing sampling bias.

As indicated above, sampling variance depends on the size of the sampling segment. Other factors influencing sampling variance are the variation between segments and the variation of the segment size. To reduce the sampling variance, the segments need to be nearly equal in "size" (to reduce the variance between segments) and to decrease the size of the segment to an "optimum" size, minimizing the variance within a segment. The "optimum" size of a segment relates directly to sampling variance and not be mean square error, (the result of the combination of bias and sampling variance). This means that, based upon mean square error considerations, the "optimum" size of a segment could be larger than based on the consideration of sampling variance. It is difficult to determine the optimum size on these considerations alone, since other factors, like topography and survey costs, affect the accuracy of the estimates. For all practical purposes it is, therefore, essential to use field boundaries which can be identified accurately in the terrain given a certain amount of topographic detail and to minimize the segment size while taking into consideration cost constraints.

A number of problems associated with the use of a sampling frame survey have to be anticipated, especially if applied in developing countries where up to date topographic base maps and agricultural production records are often not available. Some of these problems can be defined as:

a) Inconsistencies or inaccuracies in the delineation of the sample segments may result in a coverage error. This may result from difficult identifiable field boundaries using natural landscape features that are subject to change over time, preventing a consistent area definition and sampling over time.

b) Lack of correspondence between segment boundaries delineated and available data accumulated on the basis of ownership and farm management records.

c) Incompleteness in frame design resulting in the omission of a part of the population.[1] This frequently leads to the exclusion of certain population elements possessing some special characteristics.

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[1] Huddleston, Harold F. 1976. A Training Course in Sampling Concepts for Agricultural Surveys. Statistical Reporting Service, USDA, Washington, D.C.

d) Duplication, (the opposite factor of incompleteness) resulting in an increased possibility for certain units to be over represented in the survey.

e) Inadequacy of the frame to represent certain characteristics of features of interest like marginality or subsistence factors in agricultural land use.

f) Timeliness of the information captured for a certain sampling segment. Here the question of short-term change (cropping patterns, rotation and shifting agriculture) and long-term change (infrastructural change, rural development, urbanization, irrigation development, etc.) has to be addressed and the appropriateness of the current frame design to estimate the variables of interest.

g) Omission and commission errors due to the relatively long time period needed to conduct a ground survey. This could be an especially significant problem, if for example an attempt is made to estimate roaming livestock dispersed throughout the survey area.

h) High cost per unit of information. Huddleston (1976) points out that many growers in rural communities do not know the actual area planted in crops, requiring subsampling or area determinations in the field. This can be a very costly process and can influence the accuracy of the estimates considerably if the non-sampling errors are high (measurement errors, bias, etc.).

i) Unknown operational costs. It is difficult to assess the cost of an area-frame sampling effort, especially if large-scale non-repetitive surveys are involved. This sometimes makes it highly desirable to initiate a pilot survey which, in turn, would reduce the already scarce potential funds for data collection.

j. Unknown population parameters, like coefficient of variation makes it hard to select an appropriate sample size based on the sampling error requirement (expected accuracy of the estimate).

Sampling Frame Methodology as Applied in the Dominican Republic

The initial step in developing an area sampling frame is the stratifying of the population to reduce the sampling error. The object of stratification is twofold: to minimize the variation within strata and to maximize the variation between strata. If the inventory objective is to develop information on land cover/use, like agricultural patterns, a stratification can be used to meet this specific objective. Since the stratification influences the accuracy of the final population estimates, this effort is a critical element in the design of the sampling frame. It is here, where the great potential of a remote-sensing based stratification for regional and national land cover/use estimates comes into play.[1] Ideally, before any sampling frame effort is carried out, a Landsat-based national land cover/use map would greatly enhance the stratification results, therefore, improving the overall estimates by reducing sampling error.

The stratification used in the Dominican Republic consisted of five classes mainly related to agricultural use. These strata definitions are given in Table 12.

The areas as they appear in Figure 5 were outlined on photographic index sheets and topographic maps.

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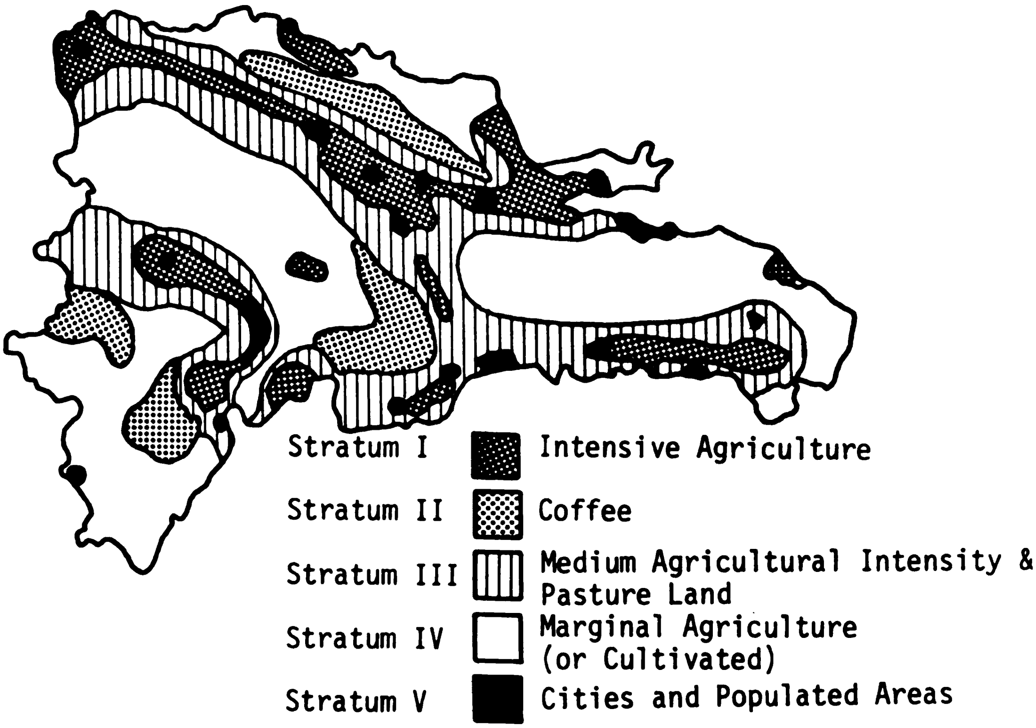
[1]See also, Hanuschak, Georg A. 1977. Pilot Study of the Potential Contributions of Landsat Data in the Construction of Area Sampling Frames USDA/SCS, Washington, D.C.

TABLE 12

Strata Definitions Used in Sampling Frame Design of the Dominican Republic

Strata	Definition
I	Intensive agriculture. This stratum consists of cultivated land. Many of the crops will be irrigated. Include tree crops, exclusive of coffee, such as bananas, cacao, and plantains. Other crops will include rice, sugar cane, maize, tobacco, beans, and peanuts.
II	Coffee and cacao. Land in tree cover, devoted primarily to the production of coffee and cacao above 100 meters. This is limited as much as possible to land where coffee is specifically indicated. This stratum may include some cacao where it is interplanted.
III	Extensive agriculture. A mixture of cropland and cleared land used for grazing livestock. This is the most loosely defined stratum and, in practice, it is land which fits none of the other definitions.
IV	Nonagricultural land. Land in natural cover which supports very little or no agricultural activity. This will include mountains, forests and swamps.
V	Urban. Concentrations of population ranging from small rural towns to major cities.

SOURCE: Secretaria de Estado de Agricultura, 1975, "Economica Agropecuria," Vol. I, No. 1, Departamento de Economia Agropecuria, SEA Santo Domingo, Republica Dominicana.



SOURCE: Secretaria de Estado de Agricultura, 1975
"Economica Agricultura" Vol. I, No. 1,
CEA, Santo Domingo, R.D.

FIGURE 5. Area-frame sampling stratification of the Dominican Republic.

Within these strata, continuous land areas of different sizes were selected. Within these areas the primary frame units or counting units are defined which contain an assigned number of sampling units. The count unit boundaries were delineated on topographic base maps and should, ideally, be of "permanent" nature and easy identifiable in the field.

The complete area frame is constructed as outlined in Table 13.

TABLE 13

Sample Unit Allocation by Stratum and Total Area

Strata	Typical Count Unit Size (km^2)	Area (km^2)	Typical Sampling Unit Size (km^2)	Sample Units (Number)
Strata Total		49,036.8	.	15,084
Stratum I	12-24	7,173.7	- 2	3,191
Stratum II	12-24	1,808.1	- 2	978
Stratum III	24-48	29,266.2	- 4	7,873
Stratum IV	24-48	10,680.2	- 4	2,784
Stratum V	--	108.6	--	258

From this frame a number of sampling units are being selected with a known probability. Since this total sampling frame represents the whole country, estimates for certain population parameters can be made.

Based on the objectives of the survey, a sample can be drawn to meet these needs. The sample could be enlarged or reduced according to the different characteristics which need to be analyzed. An example of a typical breakdown of strata into samples is given in Table 14.

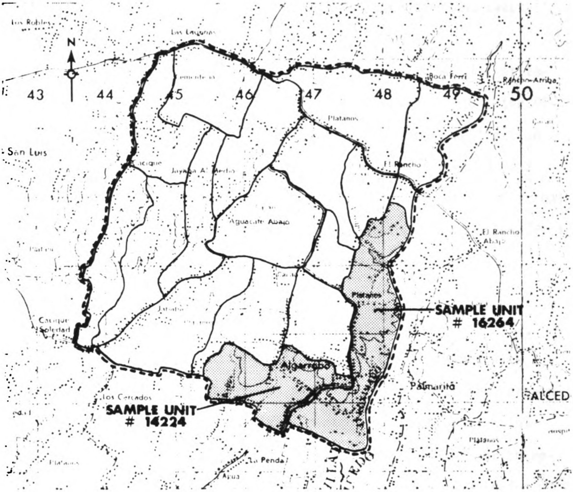
TABLE 14

The Selection of Samples Used in Past Surveys in the Dominican Republic Employing the Area-Frame Sampling

Stratum I:	9 sub-samples	(20 segments)	=	180 segments
Stratum II:	3 sub-samples	(20 segments)	=	60 segments
Stratum III:	12 sub-samples	(10 segments)	=	120 segments
Stratum IV:	2 sub-samples	(10 segments)	=	20 segments
Stratum V:	2 sub-samples	(10 segments)	=	20 segments
		Total	=	400 segments

The selection of the sampling units was done according to the principles of systematic random sampling after the delineation of the strata. The information source used for strata differentiation consisted of 1:50,000 scale topographic maps and photo index sheets prepared from panchromatic aerial photography acquired in 1966 (original scale 1:40,000).

Ground survey data are acquired on a quarterly basis for the selected sample segments within the count units. Fig. 6 defines a count unit, and the associated sixteen sample segments, located in the eastern portion of the Cibao Valley, one of the best agricultural regions in the



LEGEND

----- Count Unit Outline

_____ Sample Segment Outline

Sample Units for which ground survey data are obtained

0 1
KILOMETERS

FIGURE 6. Outline of the Moca test site. This area conforms with the count unit of the area sampling frame and contains 16 sample segments.

Dominican Republic. The area consists of fertile soils with an excellent suitability for intensive agriculture. The major crops in the area are plantain, coffee, cocoa, corn, kidney beans, cassave and sweet potatoes.

The surveys conducted so far have been used by several institutions in the Dominican Republic such as the agricultural bank, the Office of Community Development, the Institute for Price Stabilization and the National Statistics Office. Every survey is preceeded by a training period for the individuals involved in carrying out the actual work, questionnaire design, sample segment selection and location, field work, etc. in an effort to reduce non-sampling errors.

Multi-Stage Sampling: An Integration of Landsat and Aerial Sampling Data

Multi-stage sampling is the refinement of data obtained with a specific remote sensing platform and system to obtain data for certain sampling locations using a lower-level platform and system with increased remote sensing capabilities. This is usually a two- or three-stage sampling approach, frequently applied to forestry inventories.[1,2] Developments in the interpretation of Landsat imagery, high- and low-altitude aerial photography, have improved their usefulness in an applied multi-stage sampling design. Studies indicate high correlations

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[1]Aldrich, Robert C., et al., 1977. Inventory of Forest Resources (including water) by Multi-level Sampling. Rocky Mountain Forest and Range Experiment Station, Forest Service/USDA, Fort Collins, Colorado.

[2]Langley, Philip G., 1976. Sampling Methods Useful to Forest Inventory when Using Data from Remote Sensors. Paper presented at the SVI IUFRO World Congress, Oslo, Norway.

of wood volume estimates from aerial photographs and ground samples, greatly reducing the amount of sampling required in succeeding stages.[1]

An example of a multi-stage method of estimating timber species/volume can be described as follows:

Stage I. Classification of Landsat data and primary sample unit selection

Broad categories of vegetation are identified by species or volume classes using visual or computer-aided image analysis techniques in combination with appropriate training site information (ground truth).

Stage II. Imagery interpretation and volume estimation on low-altitude photographs

Low-altitude photography captures species and/or volume data over the selected sample units.

Stage III. Selection of trees for precise ground measurement of timber volume

The volume is calculated for all trees of merchantable size. In the final analysis the information of the three stages is combined to develop cumulative estimates.

Langley[2] documents a procedure using the random selection of space and aircraft imagery with a selection probability proportional to a prior prediction as to the relative resource quantity contained in the population units. This method has proven to result in unbiased

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[1] Kirby, C. L. and P. I. VanEck, 1977. A Basis for Multi-stage Forest Inventory in the Boreal Forest Region. Paper presented at the Fourth Canadian Symposium on Remote Sensing, Quebec.

[2] Langley, Philip G., 1969. New Multi-Stage Sampling Techniques Using Space and Aircraft Imagery for Forest Inventory. Proceedings Sixth Symposium on Remote Sensing of the Environment, ERIM, Ann Arbor, MI.

estimates and the sampling error appears a function of the accuracy of the prediction made at each stage.

Other multi-stage information gathering efforts have proven successful in the tropics as well. Multi-stage crop area estimates were produced in Brazil using a digital processing of Landsat data combined with color infrared imagery of various scales.[1]

An Operational Two-stage Approach to Refine Landsat Information

The Landsat-based national land cover/use inventory carried out by the CRIES project will produce a final (1:250,000 scale) land cover/use map which will include the following agricultural categories:

a. Sugar: Predominant form of agriculture; sugar cane, irrigated and non-irrigated.

b. Mixed Agriculture: All other major agricultural crops, excluding sugar cane, usually associated with lowland areas. This production includes rotational, intercropping practices and tree crops.

c. Marginal Agriculture: Small scale, predominantly subsistence agriculture (and some improve pasture), primarily in foothills and hilly terrain. Tree crops may be present.

d. Pasture: Predominantly improved pasture used for grazing.

Based on this stratification and on (smaller) areas coinciding with the breakdown of these categories into resource planning units, a priority for additional information needs can be established. A

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[1]Instituto de Pesquisas Espacias, 1978. INPE's Crop Survey Program Using Combined Landsat and Aircraft Data. INPE, Sao Jose, Brazil.

sampling scheme can be designed (e.g. based upon proportional allocation of sampling units) and the resource planning units, similar or larger than the test site in this study, can be sampled by aircraft survey techniques. This allows for a prediction of the crop composition for a predefined area. Such a sampling procedure will be associated with a (theoretical) prediction accuracy and confidence level, if population estimates with "know coefficients of variation" are used (based on previous total enumerations), since it is not expected that the coefficient of variation will change significantly over a short period of time (5-10 years). Otherwise, within certain time intervals, a total enumeration of the larger area units, subject to prediction, would have to be carried out to determine the coefficient of variation and, therefore, verify the expected future prediction accuracy associated with the sampling design.

CHAPTER III

DOMINICAN REPUBLIC CASE STUDY: METHODOLOGY

The case study outlined here addresses the utility of aerial sampling techniques to refine Landsat derived cover/use strata or resource production units and to evaluate these techniques as an alternative method of enumerating area-frame sampling units. The interpreted Landsat data show the total area in mixed agriculture. The aircraft survey data allow for a total inventory (crop area breakdown) for the selected testsite (the count unit) while the quarterly survey data provide the basis for a realistic comparison between the two data sets and provide thus, an indication of ground survey problems introduced as a result of measurement error or bias.

Landsat Data and Derived Information

The primary Landsat data used for the development of a national land cover/use inventory for the Dominican Republic consisted of color composite images produced from 9' x 9' (1:1,000,000 scale) positive transparencies of MSS bands 4, 5 and 7, using the color additive diazo process. Acetate sheets were used to produce contact prints in the three photographic secondary colors; yellow (Band 4), magenta (Band 5), and cyan (Band 7), to generate a simulated color infrared image.

This color composite image was visually interpreted using existing ground data to calibrate tonal variation and to provide other clues for the mapping of land cover/use information. Ten Landsat scenes had to be used in this process to ensure sufficient countrywide coverage to provide multi-temporal information and to minimize cloud cover problems. Table 15 indicates the specific dates of imagery used to obtain sufficient coverage. A period of approximately four years was required to meet all these objectives. Figure 7 shows an image mosaic of the Dominican Republic and a portion of Haiti compiled with the use of these Landsat scenes.

Information Extraction

The Landsat imagery was interpreted based on the classification system of Table 16, to determine the predominant categories for a 1 km^2 area. This inventory effort established the initial stratification of agricultural land use. The information was geocoded for use with the existing computer-based spatial information system developed by CRIES. The system and associated information base allows for the generation of cross-tabulation of data sets (based on 1 km^2 grid); such as land cover/use by resource planning unit or political boundaries. The total land area for the various categories can also be computed as is indicated in Table 17.

Refinement of Landsat-Based Strata

The land cover/use breakdown in Table 17 indicates the limited utility of these data for resource management aimed at satisfying specific planning objectives, at the national or regional level. The purpose of the aerial sampling procedures is primarily to refine the area tabulations based on the initial Landsat-based stratification, without going through the higher expense of additional complete and more detailed inventories. The philosophy behind this is the

TABLE 15

Imagery Scene Number and Dates Used in the National Land Cover/Use Inventory of the Dominican Republic

Scene I.D.	Imagery Date
E-2015-14332	6 Feb 75
E-2015-14334	6 Feb 75
E-21436-14140	28 Dec 78
E-21454-14150	15 Jan 79
E-21454-14153	15 Jan 79
E-21471-14092	1 Feb 79
E-21417-14075	9 Dec 78
E-30306-14230	5 Jan 79
E-21471-14095	1 Feb 79
E-21470-14040	31 Jan 79

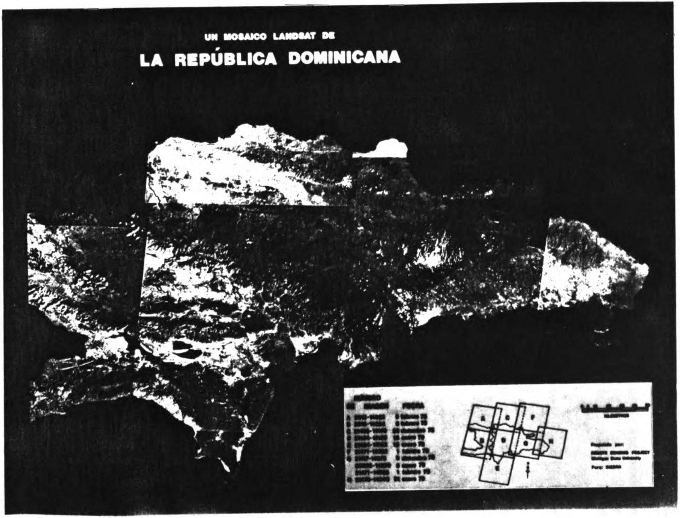

FIGURE 7. Landsat mosiac of the Dominican Republic.

TABLE 16

Land Cover/Use Classification Categories of the Original National Landsat Inventory

1	Urban and built-up	Man-made structures accomodating residential, industrial, commercial and transportation related land uses.
2	Agriculture	Land used for the production of food and fiber.
	2.1 Sugar	Predominant form of agriculture; sugar cane, irrigated and non-irrigated.
	2.2 Mixed agriculture	All other major agricultural crops, excluding sugar cane, usually associated with lowland areas. This production includes rotational, intercropping practices, and tree crops.
	2.3 Marginal agriculture	Small scale agriculture predominantly of a subsistence nature (and some unimproved pasture), concentrated in foothills and hilly terrain. Tree crops may be present.
	2.4 Pasture	Predominantly improved pasture used for grazing.
3	Rangeland	Areas with a predominant brush and grass vegetation cover. Limited potential for grazing. Presence of Xerophylotic plants common in the foothills.
4	Forest	Land primarily associated with timber production. Forest lands generally include a crown closure of ninety percent or more.
5	Wetlands	Areas with a hydrologic regime accommodating aquatic or hydrophytic vegetation. Excluded are areas in rice production.

TABLE 16 - Continued

Land Cover/Use Classification Categories of the Original National Landsat Inventory

6	Barren/open	Areas with exposed soil and little or no vegetation cover. Surface mining areas are included in this category.
7	Water	Inland water surfaces.
8	Cloud cover	Areas for which during the period from August 1972 to February 1979 cloud-free satellite imagery could be obtained.

TABLE 17

Total Land Area (km^2) by Land Cover/Use Category as Identified in the National Landsat Inventory

Category	Area (km^2 10^3)	Percentage
1.0 Urban and Built-Up	292	0.6
2.1 Sugar	4,205	8.8
2.2 Mixed Agriculture	6,496	13.6
2.3 Marginal Agriculture	8,281	17.4
2.4 Pasture	2,325	4.9
3.0 Rangeland	5,278	11.1
3.1 Limited Rangeland	12,788	26.8
4.1 Deciduous Forest	6,518	13.7
4.2 Coniferous Forest	311	0.7
5.0 Wetlands	269	0.6
6.0 Barren/Open	402	0.8
7.0 Water, inland	315	0.7
8.0 Cloud Cover, unclassified	177	0.4
Total	*47,677	100.0

*This area figure found on initial computer calculation. This total differs 1,2% from official source in the Dominican Republic (48,279,000 km^2).

assumption that, with limited additional expenditure, information of a more detailed and accurate nature can be produced, providing the data base for more specific policy development and planning efforts for selected areas. This assumption also includes the frequently encountered reality that the type of detail required in policy development and planning usually does not justify complete inventory efforts given accuracy/cost trade-offs and the quality of information extracted from secondary data sources.[1]

The aerial strip sampling procedures, stress therefore, the low cost of using single flight lines (randomly or judgmentally selected) in refining Landsat derived stratification, providing more specific information within a spatially defined context. The area-frame sampling procedure could apply as well to these objectives regarding the estimation of population parameters and the predicted proportion of crop types, forest species, potential erosion areas, crop damage, etc., for specific regions.

Aircraft Survey Data

The primary data acquisition was carried out during two periods. The aerial photography and related ground calibration were obtained during March 1979, and follow-up ground verification (after imagery interpretation) was done in September of the same year. The main objective of the second ground survey was to check the interpretation of certain fields for which a positive identification could not be made as a result of growing stage.

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[1]See also, Chappelle, Daniel E. 1976. How Much Is Information Worth? Proceedings: Resource Data Management Symposium. Purdue University, West Lafayette, Indiana.

Imagery Acquisition

The imagery acquired over the test site consisted of 70mm color infrared (CIR) transparencies (Kodak Aerochrome Infrared film 2443). The photography was obtained on March 6, 1979 between 10 and 11:30 a.m., using a Hasselblad 500 EL/M camera with an 80mm focal length lens producing a photo scale of approximately 1:30,000.

The 70mm photographs were acquired from a T-41 aircraft provided by the Dominican Air Force. A camera platform was used, mounted on the outside of the aircraft (see Fig. 8) which accommodates 70mm or 35mm camera systems with a 70 to 400 exposure capability. The camera mount allows for in-flight platform leveling using three spring-mounted screws. The actual camera orientation can be adjusted by rotating the cameras in the platform to offset or reduce crab and provide, therefore, better photo coverage along flight lines. The cameras are equipped with a motor-driven film advance mechanism and can be remotely controlled from inside the aircraft. An intervalometer can be used. A Hasselblad 70mm camera equipped with an 80mm lens provides a ground coverage of 105 x 105m at a scale of approximately 1:3,810 to 305m AGL; and coverage of 2096 x 2096m at a scale of 1:38,099 at 3050m AGL*.

Ground Truth Acquisition

During the first week of March 1979, just prior to the photo acquisition on March 6, the Moca test site was visited. A topographic base map (1:50,000 and black-and-white aerial photography (1:20,000) was used to identify numerous fields and associated crops. The ground validation consisted of written descriptions of the crop (intercropping)

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[1]AGL stands for Above Ground Level.

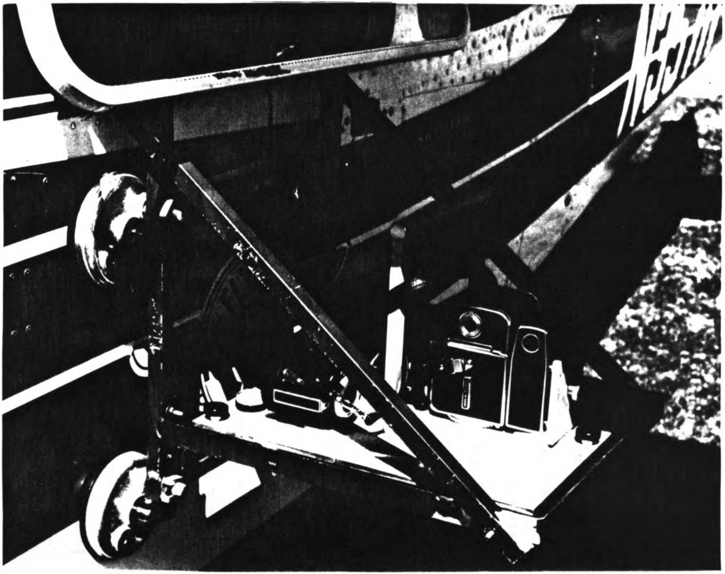

FIGURE 8. Aircraft camera slide-mount with 70mm and 35mm camera systems installed.

types, stage of growth and an identifier code used to link the field information with the field boundaries delineated on a black-and white photo mosaic covering the area. This information was later used to establish an image interpretation key for the various crops (see Appendix 1).

After the photo interpretation during the summer of 1979, a second field trip, with Dominican counterparts, was made on August 29 to verify some of the interpretation. This verification was needed primarily to obtain, from farmers in the area, a definite identification for some crops which were in a very early growing stage on March 3, 1979.

Development of the Classification Key

Before the actual interpretation of the different fields, various identification elements and their role in the interpretation process were defined, as well as their significance in discriminating among the various land cover/use categories contained within the Moca test site (see also Appendix 2). This understanding was needed particularly to provide interpreters with a basic insight into the various cropping practices and the appearance of the various categories on color infrared imagery at a scale of 1:30,000.

The availability of such a photo interpretation key is an essential and crucial element in any crop classification procedure using aerial photography. During the development of the key, care is taken to identify imagery features like density, size, shape, assemblage, appearance, texture, tone, etc., to support large to medium scale (1:10,000 - 1:30,000) photo interpretation. The classification elements should be well defined, ensuring the use of relatively easily identifiable features as the basis of the classification process using various film types and imagery scales.

Ancillary information such as crop calendar data, ground observations and knowledge regarding cultivation practices maximize the utility of the elements identified in the interpretation key to discriminate between crop types. A comprehensive key can compensate to a large degree for an interpreter's lack of experience in a particular geographic area.

The developed key was intended for use in combination with three film types and image scales. The key includes the primary subdivisions of agricultural land use and natural vegetation. The agricultural land uses were broken down by the major crops in the area; platanos (plantains), yucca (cassava), tobaco (tobacco) and batatas (sweet potatoes) and two "rest" categories: other crops and land in cultivation. "Other crops" includes those of minor importance while "land in cultivation" refers to arable land without identifiable crop cover. The natural vegetation category comprises herbaceous and brush cover. A third class, forest, includes areas primarily with mature shade trees used in the production of cocoa and coffee. Residential areas were a fourth and minor class.

Imagery Interpretation and Area Calculations

The 70mm imagery was interpreted after projection on frosted mylar, using a Transyscop Optical drafting system. The projected images were enlarged to scale 1:12,500 and registered to an enlarged topographic base map of the same scale (original scale 1:50,000). After delineation of the various categories on the mylar base, paper copies were produced as a basis for area measurements. An extremely fine dot grid was used for area measurements: 1024 dots for a 250 x 250 meter area on the 1:12,500 base map. This fine sampling resolution (1 dot represented 61.04 m^2) was selected to minimize measurement error. The land cover/use category coinciding with each dot was determined and the total area for 940 fields was calculated using the area converison factor.

In the next stage all individual fields belonging to a specific classification category were added to produce the totals in hectares and percentage of the total test site (see Table 18).

TABLE 18

Total Enumeration for the Moca Test Site by Classification Categories

Classification Categories	Total Hectares	% of Total
1A - Plantains	588.20	27.99
1B - Yucca	306.06	14.56
1C - Tobacco	20.40	.97
1D - Sweet potatoes	82.14	3.91
1F - Other crops	32.75	1.56
1G - Cultivated land	561.28	26.71
2 - Natural vegetation	172.17	8.19
3 - Forest	272.25	12.96
4 - Residential	66.32	3.16
Total test site	2,101.57	

The same area calculation method was applied to determine the crop areas or percentages contained within the two sample segments (Table 19).

TABLE 19

Total Enumeration of Classification Categories for Two Sample Segments Based on Aerial Survey Information

Classification Category	Sample Segment #14224		Sample Segment #16264	
	Hectares	% of Total	Hectares	% of Total
1A - Plantains	37.9	26.83	59.06	25.84
1B - Yucca	22.74	16.10	12.78	5.59
1C - Tobacco	--	--	--	--
1D - Sweet potatoes	2.83	2.00	8.89	3.89
1F - Other crops	.49	.35	2.44	1.07
1G - Cultivated land	47.45	33.59	54.51	23.89
2 - Natural Vegetation	9.67	6.84	41.91	18.34
3 - Forest	16.59	11.74	38.69	16.93
4 - Residential	3.61	2.56	10.19	4.46
Total Segment	141.28		228.57	

Quarterly Survey Data of Area-Frame Sampling

The ground survey data, reflecting the tareas (1 tarea = .0629 hectare) for the various annual and perennial crops harvested and planted, were collected as a part of the area-frame sampling procedure. Tables 20 and 21 summarize these data for sample segments #14224 and

TABLE 20

Crop Inventory for Survey Segment #14224 Included in the Moca Test Site, December 1978 and March 1979

Variable	Annual Crop				Perennial Crop		
	Corn (Maiz)	Kidney Bean (Habichuelas)	Cassave (Yuca)	Sweet Potatoes (Batata)	Plantains (Platano)	Coffee (Cafe)	Cocoa (Cacao)
December 1978							
- Harvested tareas of the single crop (hectares)	222 (14.0)	--	300 (18.9)	95 (6.0)	405 (25.5)	--	--
- Harvested tareas intercropped (hectares)	50 (3.1)	--	100 (6.3)	0 (--)	--	--	--
- Tareas planted, single crop (hectares)	102 (6.4)	--	565 (35.5)	265 (16.7)	425 (26.7)	--	--
- Tareas planted intercropped (hectares)	75 (4.7)	100 (6.3)	107 (6.7)	70 (4.4)	--	--	--
March 1979							
- Harvested tareas of the single crop (hectares)	29 (1.8)	258 (16.2)	--	--	355 (22.3)	157 (9.9)	--

TABLE 20 - Continued

Crop Inventory for Survey Segment #14224 Included in the Moca Test Site, December 1978 and March 1979

Variable	Annual Crop				Perennial Crop		
	Corn (Maiz)	Kidney Bean (Habichuelas)	Cassave (Yuca)	Sweet Potatoes (Batata)	Plantains (Platano)	Coffee (Cafe)	Cocoa (Cacao)
- Harvested tareas intercropped (hectares)	3 (0.2)	--	--	--	--		
- Tareas planted, single crop (hectares)	106 (6.7)	--	--	--	355 (22.3)	157 (9.9)	--
- Tareas planted intercropped (hectares)	--	--	--	--			

SOURCE: CEA (Secretariat of Agriculture).

* 0629 ha = 1 tarea

TABLE 21

Crop Inventory for Survey Segment #16264 Included in the Moca Test Site, December 1978 and March 1979

Variable	Annual Crop				Perennial Crop		
	Corn (Maiz)	Kidney Bean (Habichuelas)	Cassave (Yuca)	Sweet Potatoes (Batata)	Plantains (Platano)	Coffee (Cafe)	Cacao (Cacao)
December 1978							
- Harvested tareas* of the single crop (hectares)	16 (1.0)	--	374 (23.5)	30 (1.9)	348 (21.9)	--	--
- Harvested tareas intercropped (hectares)	16 (1.0)	--	128 (8.1)	35 (1.9)	--	--	--
- Tareas planted, single crop (hectares)	--	--	--		445 (28.0)	--	--
- Tareas planted, intercropped (hectares)	--	--	--		208 (13.1)	--	--
March 1979							
- Harvested tareas of the single crop (hectares)	--	59 (3.7)	--	--	388 (24.4)	631 (39.7)	520 (32.7)

TABLE 21 - Continued

Crop Inventory for Survey Segment #16264 Included in the Moca Test Site, December 1978 and March 1979

	Annual Crop				Perennial Crop		
	Corn (Maiz)	Kidney Bean (Habichuelas)	Cassave (Yuca)	Sweet Potatoes (Batata)	Plantains (Plantano)	Coffee (Cafe)	Cacao (Cacao)
- Harvested tareas intercropped (hectares)	10 (1.0)	425 (26.7)	--	--	--	--	--
- Tareas planted, single crop (hectares)	3 (0.2)	--	--	--	388 (24.4)	631 (39.7)	631 (32.7)
- Tareas planted, intercropped (hectares)	36 (2.3)	--	--	--	--	--	--

SOURCE: CEA (Secretariat of Agriculture)

* .0629 ha = 1 tarea

#16264 located in the southeastern portion of the area count unit (the Moca test site, see Fig. 6).

The difference between the December 1978 and March 1979 data reflects the practice of frequent crop rotation, intercropping and a relatively short growing season for the annual crops. The December data set is, therefore, not very useful for a comparison with the aerial photography (March 1979). The continuous harvesting in progress during March limits the usefulness for comparison even further to the perennial crops like plantains, coffee and cocoa. Since coffee and cocoa are grown as shadow cultivation, the real comparison between the area-frame statistics and the aerial inventory shall focus on the plantain crop.

CHAPTER IV

RESULTS AND ANALYSIS

Comparison of Area Statistics Derived from the Aerial Survey and the Area-Frame Sampling Survey Relating to the Sample Segments

Initially the utility of the aerial survey techniques, as compared to the ground survey methodology for acquiring crop statistics, can best be evaluated in comparing the information for the two sample segments (#14224 and #16264). The errors associated with the two methods of complete enumeration have to be considered in this process. For the aerial survey this is the interpretation accuracy error associated with the accurate classification of various crops as they appear on the color infrared imagery and the measurement error based on the dot grid area measurement (or dot sampling). For the ground survey the errors are associated with non-sampling errors, such as measurement errors, recording errors and bias included in the questionnaire. It is not possible to assess these last errors separately in the context of this study. It is, however, feasible to compare the ground survey with the aerial survey data and derive at an assumption regarding the composite error factor of the ground survey if error bounds for the aerial data are available.

In order for a realistic comparison to be made between the aerial sampling methodology and the ground survey data, the December inventory must be excluded since, as the table indicates, many of the annual crops were being harvested/planted during the period December

1978 - March 1979. The March data, overlapping with the period that the aerial survey was conducted, however, do not reflect, the number of major crops present at that time. The two annual crops identified were corn and kidney beans. Corn is a relatively minor crop in the area and is, as the tables indicate, often intercropped with other minor crops. A comparison of the area in kidney beans would not be realistic since major harvesting was carried out during March, and the exact area was not determined on the date that the aerial survey was conducted.

For these reasons a comparison regarding the utility of the two techniques in estimating crop acreage and composition has to concentrate on the perennial crops identified during the aerial survey, most particularly, plantains. A comparison based on the shade tree crops, coffee and cocoa, might not be justified since not all identified shade cover necessarily reflects the active cultivation of these crops. Concentrating on one perennial crop, plantains, will allow for all the reasons indicated above, a realistic comparison between the usefulness of the two techniques in collecting complete crop inventory data.

Error Estimation of the Aerial Survey Inventory

As previously indicated two error factors have to be evaluated; interpretation error and measurement error associated area determination.

Interpretation Error[1,2,3,4,5,6]

A test was carried out to assess the interpretation error associated with the interpretation of color infrared photography at a scale of 1:30,000 for various crops in the area.[7] Interpretation error (%) for a specific class was defined as:

$$\frac{\text{\# of fields of class Y correctly interpreted}}{\text{total \# of field in class Y}} \times 100$$ (this error can also be found by substracting the omission error from 100. Omission error (%) for class Y is then defined as:

$$\frac{\text{\# of fields in class Y incorrectly assigned to other classes}}{\text{total \# of fields in class Y.}} \times 100$$

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[1]See also the following literature dealing with interpretation accuracy: Hord, Michael R. and William Brooner, 1976. Land-Use Map Accuracy Criteria. Photogrammetric Engineering and Remote Sensing, Vol. 42, No. 5, May 1976, pp. 671-677.

[2]Kalensky, Z. and L. R. Scherk, 1975. Accuracy of Forest Mapping from Landsat Computer Compatible Tapes. Proceedings 10th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan.

[3]Hoffer, Roger M. and Michael D. Fleming, 1974. Use of Computer-aided Analysis Techniques for Cover Type Mapping in Areas of Mountainous Terrain. Paper presented at the 14th Int. Congress of Surveyors. Washington, D.C.

[4]Hay, Alan M., 1979. Sampling Designs to Test Land-Use Map Accuracy. Photogrammetric Engineering and Remote Sensing, Vol. 45, No. 4, April 1979, pp. 529-533.

[5]Draeger, William C., 1974. Test Procedures for Remote Sensing Data. Journal of the American Association of Photogrammetry. 1974, pp. 175-181.

[6]Stellingwerf, D. A., 1966. Interpretation of Tree Species and Mixtures on Aerial Photographs. International Institute for Aerial Survey and Earth Sciences (I.T.C.) Enschede, the Netherlands.

[7]Schultink, G. and Karteris, Michael A., 1980. An Evaluation of Photographic Imagery Parameters Relating to Agricultural Inventories in the Dominican Republic. Draft report MSU/USDA.

The test included four interpreters with a degree of experience which ranged from virtually none to more experienced. One of the more experienced interpreters had some additional in-country exposure to the phenology of the various crops. As Table 22 indicates, the interpretation accuracy for plantains for all four interpreters combined was 94.5 percent. This test indicates the difficulty in crop interpretation rather than the absolute accuracies that could be expected if trained interpreters would conduct an inventory. Even though four interpreters were used in this case, the accuracy is acceptable. An accuracy of greater than 99 percent can, however, realistically be expected (95 percent confidence level) if trained interpreters are used.

Measurement Error Associated with the Use of the Dot Sampling Method

The error estimate of the area estimate for a specific land cover/use category[1,2,3,4] can be approximated by:

$$S^2p_j = \frac{P_j(1-P_j)}{n} \quad \text{or} \quad Sp_j = \sqrt{\frac{P_j(1-P_j)}{n}}$$

where $P_j = \frac{a_j}{n} = \frac{\text{total number of dots in stratum plantains}}{\text{total number of dots in the two sampling segments}}$

$= \frac{15891}{60591}$ (based on 61.04 m^2 per dot)

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[1]See also Bonnor, G. M., 1975. The Error of Area Estimates from Dot Grids. Canadian Journal of Forestry Research, 5, 10, 1975.

[2]Cochran, William G., 1977. Sampling Techniques. Wiley, New York.

[3]White, Mike E., 1977. Surface Area Measurements and Seasonal Variation of Selected New Mexico Lakes. Technology Applications Center, Univ. of New Mexico.

[4]Barrett, J. P. and Philbook, J. S., 1970. Dot grid area estimates: precision by repeated trials. Journal of Forestry 68(3), pp. 149-151.

TABLE 22

Matrix* with Percentages of Commission Errors, Interpretation Accuracies, Overall Performance, and Omission Errors Associated with the Interpretation of Color Infrared Film, Scale 1:30,000

Photo Interpretation Classes	1A	1B	1C	1D	1E	1F	Omissions	Interpretation Accuracy
1A Plantains	94.5		.9		.9	3.7	5.5	94.5
1B Yucca	1.5	83.8	5.9		7.4	1.4	16.2	83.8
1C Tobacco		40.0	35.0	10.0	10.0	5.0	65.0	35.0
1D Sweet Potatoes				93.8	6.2		6.2	93.8
1E Other Crops		25.0	6.0		56.3	12.5	43.7	56.3
1F Other cult. land		2.3				97.7	2.3	97.7
Commissions	.9	12.3	42.8	11.8	50.0	15.7		

*Underlined values along the diagonal are interpretation accuracies for various crops.

SOURCE: Schultink and Karteris, 1980. An Evaluation of Photographic Imagery Parameters Relating to Agricultural Inventories in the Dominican Republic. USDA/MSU.

The standard error $Sp_j = \frac{.262(1-.262)}{60591} = .001787$

The <u>standard error expressed as a percentage of the stratum</u>; $Sp_j \% =$

$$\frac{Sp_j}{P_j} \text{ X } 100 \text{ or } \frac{.001787}{.262} \text{ X } 100 = 0.68 \text{ percent.}$$

We can therefore, state that we are 95 percent confident that the total area in plantains for the two segments combined is between 46.7 ± 1.96 x .68% or 46.7 hectares ± 1.33 percent.

In estimating the error associated with this inventory based on aerial survey techniques we can be 95 percent confident that the total error factor is within 3 percent. If, however, the test results of the four interpreters are taken into consideration, the error bounds for the 95 percent confidence level can be calculated (see Table 22) as 94.5 ± 3.4%. This would assume a case in which interpreters with limited experience are used. Consequently this would result in a combined error factor of 94.5 ± 4.73%, or maximum possible error of 5.5 + 4.73 = 10.23 percent.

Crop Inventory and Error Comparison for Plantains for the Sample Segments #14224 and #16224

Based on the aerial and the ground survey data the crop information for plantains can be compiled (Table 23) for the two segments. Taking into consideration the maximum possible aggregated error percentage (10.23%, 95% confidence interval level) we can conclude that the total area in plantains is 96.96 ± 10.23%. This means that in the most favorable situation the difference between the two inventory procedures is (96.96 - .1023 X 96.96) - 46.7 = 40.34 hectares. We can therefore, state (with 95% confidence) that the total absolute

TABLE 23

Area-Frame Sampling Data for the
Two Sampling Segments (Plantains)

	Sample Segment #14224 (Plantains)		Sample Segment #16264 (Plantains)		Total for Two Segments (Plantains)		Aggregated Error % Interpreters with	
	Hectares	%	Hectares	%	Hectares	%	Limited Experience	Sufficient Experience
Aerial Survey	37.9	26.83	59.06	25.84	29.96	26.22	max. 10.23	max 3.0
Area Sampling Frame	22.3	15.78	24.4	10.68	46.7	12.63	*not known	*not known

*See calculation of this paragraph.

inventory error (plantains) for the two sample segments combined, as found during the area sampling frame ground survey, is at least $\frac{40.34}{46.7} \cdot 100 = 86.38$ percent.

Development and Analysis of Linear Sampling Procedures Based on Aerial Surveys

Based on the considerations, as described under 2.4, linear sampling procedures (modified systematic) could be carried out to estimate the areal extent of various land cover/use categories, within the test site, using various sampling designs and intensities.

Two aerial sampling designs are tested in this context. The two designs are based on linear or strip sampling techniques and represent random as well as systematic sampling elements.

The first aerial sampling design consisted of a set of overlapping samples of various intensities (approximately 5 to 20 percent) centered around a single flight line (Figure 9). The sampling direction can be randomly or judgmentally selected. A random flight line (sampling) direction assumes no prior knowledge of population variance or landscape gradient. If, however, information regarding these elements is available, a judgmentally-selected flight line would theoretically, given a certain sampling size, allow for a better prediction of desired population parameters. Improved estimator accuracy would, for example, result from the selection of a sampling direction which would increase the variance included in the sample (a sampling direction maximizing the orthogonal orientation in respect to identified landscape gradient).

In this case (see also Figure 9) each sample consisted of one or more parallel, overlapping sampling strips with the number of strips

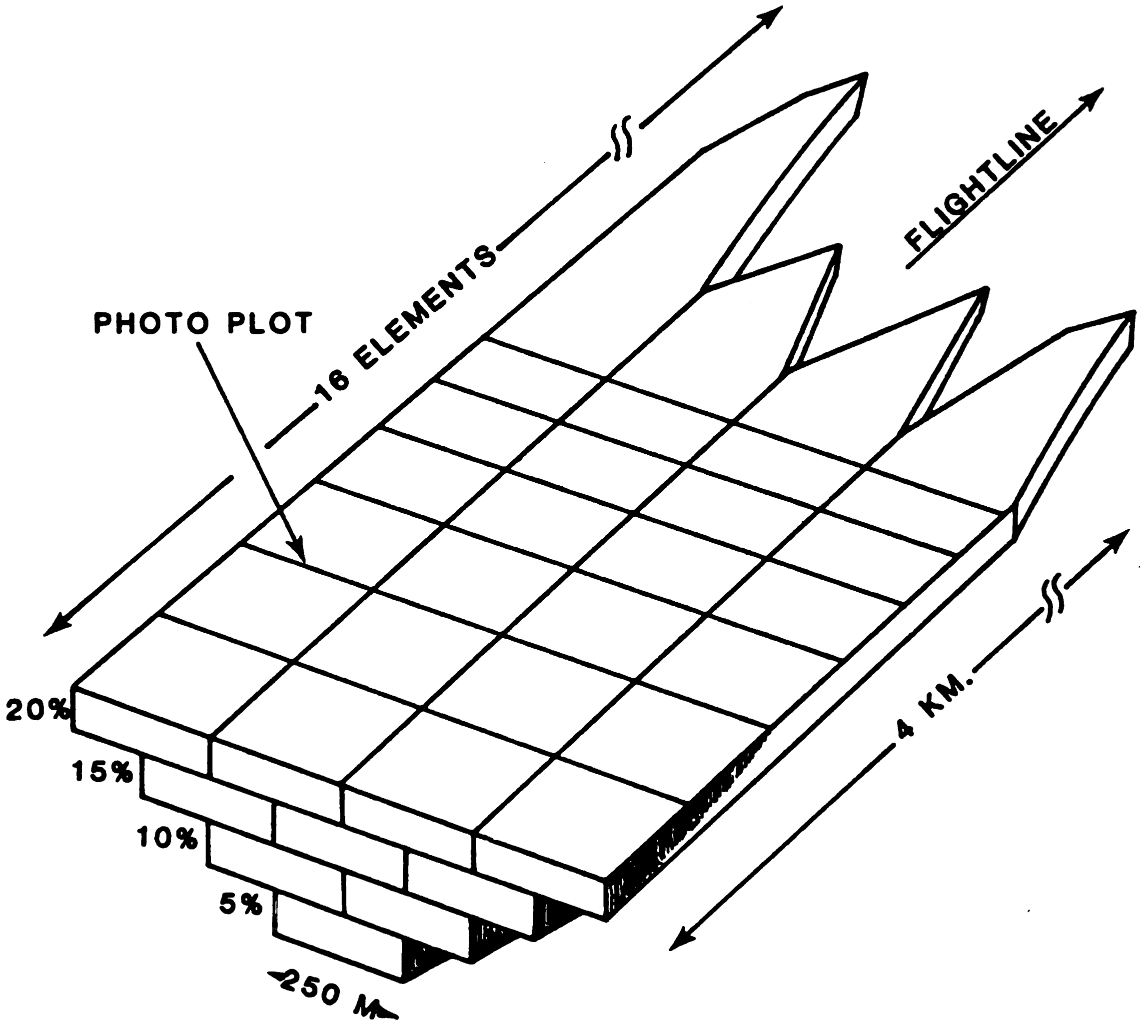


FIGURE 9. Schematic outline of various samples centered along a single, 4 km. long, flight line. The layers represent captured surface information for sample intensities of approximately 5% through 20%. The four sample sizes are assumed to consist of a 4 km. long strip, composed of 16 elements, (photo plots) each.

depending on the sampling intensity. Each sampling strip was composed of 16 sample units or photo plots. The area covered by one of these strips is 250 x 4000 meters with photoplot areas of 250 x 250 meters.

The single flight line in combination with the overlapping samples is selected to analyze the relative increase of estimator accuracy based on an increase of sample size, while minimizing the effects of variance differences among sample rates. This method simulates the minimum cost approach for obtaining samples based on one single flight line. The random-systematic or modified systematic approach, using four flight lines and 16 photo plots, approximates the benefits of a random sampling distribution and associated higher estimator accuracy, but with only a limited increase in inventory costs.

The second sampling design is similar to the systematic one applied in ground surveys. It consists of a set of four systematically selected, simulated flight lines with four photo plots per flight line, representing an approximate 5 percent sampling intensity (Fig. 10). This differs from the conventional systematic sampling in that within each flight line the first photo plot is randomly selected. This alternative approach increases the random elements (more degrees of freedom) of the sample, providing a design which approximates simple random sampling and gives therefore, a more valid estimate of the sampling error.

Development of the Single Flight Line Sampling Design

A linear-random sampling approach is defined by a random flight line covering a ground swath of a predefined sample size. A number of advantages would be associated with this aerial survey sampling approach:

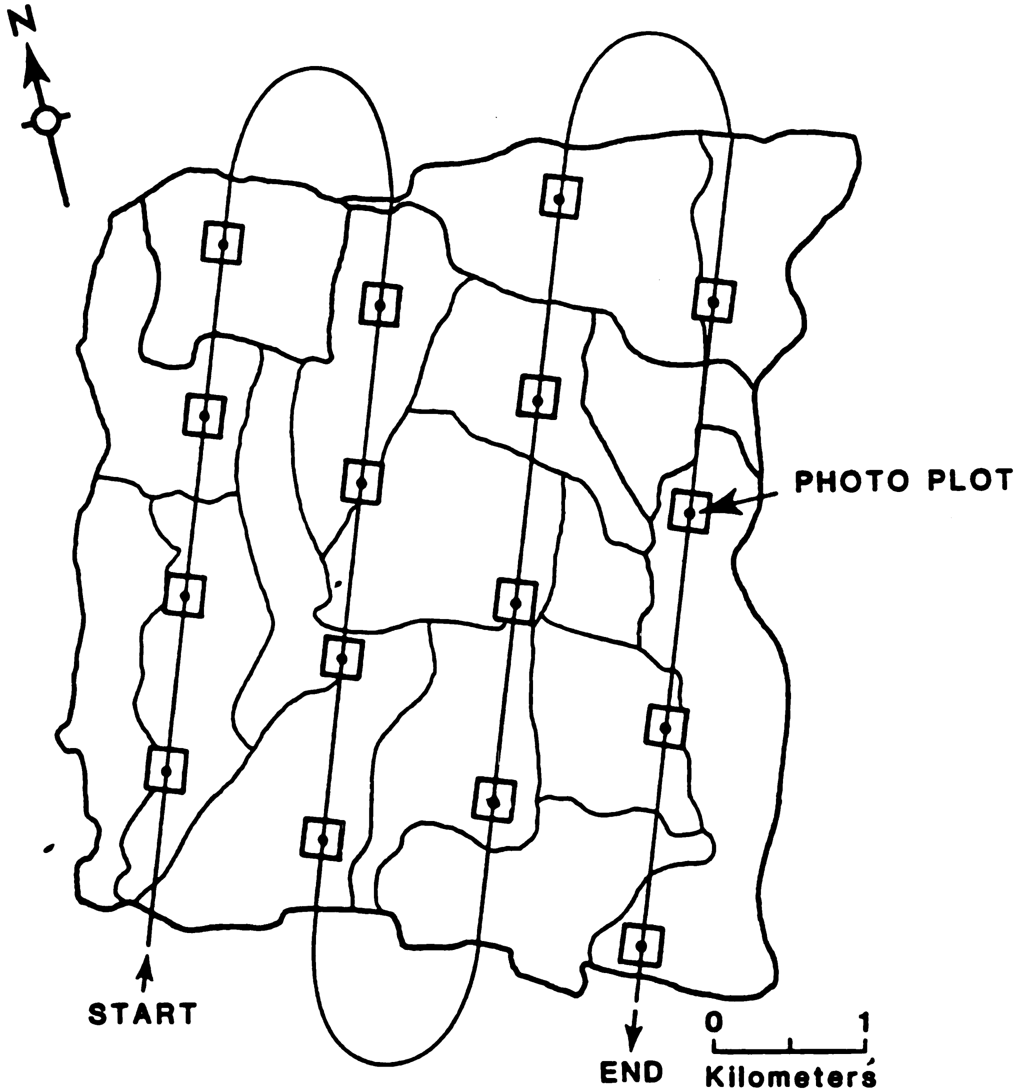


FIGURE 10. Schematic outline of sample test site and four flight lines associated with the Modified, Systematic sampling design. Intervals between flight lines and frames are constant; starting points are randomly selected for each flight line.

a. A cost saving in flight time, imagery plotting, interpretation and data transfer, compilation and analysis.

b. The comparison of various overlapping samples of different size (see Figure 10) allows for a more realistic evaluation of expected sampling accuracies since the difference between sampling variances included within the various sample sizes can be expected to be smaller than would be the case if non-overlapping samples associated with a random sampling procedure based on various flight lines were to be used.

Since the objective of the study was to test the practical application of the suggested techniques, these advantages played an important role. For this reason it was decided to compare sampling sizes based on, and centered around, a single, simulated flight line.

Three aspects were associated with the determination of a flight line for sampling purposes.

(a) The sampling location (point),

(b) The sampling direction (azimuth),

(c) The sampling size (length of flight line, area coverage, imagery scale).

Since the methodology centered around the random selection of a flight line, a method was selected to determine (a) and (b) in a random manner. A random number table was used to determine the sampling point and the sampling direction. The 1 kilometer square grid was divided in units of 10 meters; 6 digits were selected to determine the x, y-coordinates (3 digits each) of the sampling point within the test site in relation to the selected origin (1-9-4-0, 2-9-3-0). The second step was the random selection of the sampling direction using a random number table; 042°. Based on these two parameters the flight line direction was defined, simulating a random aircraft survey over the test site using a single flight line (see Figure 11).

In order to compare various sampling sizes, an area calculation was carried out for the test site and the two area frame sampling units contained within the count unit/test site outline. The result of this area calculation using a planimeter were:

a. Total count unit area--2101.57

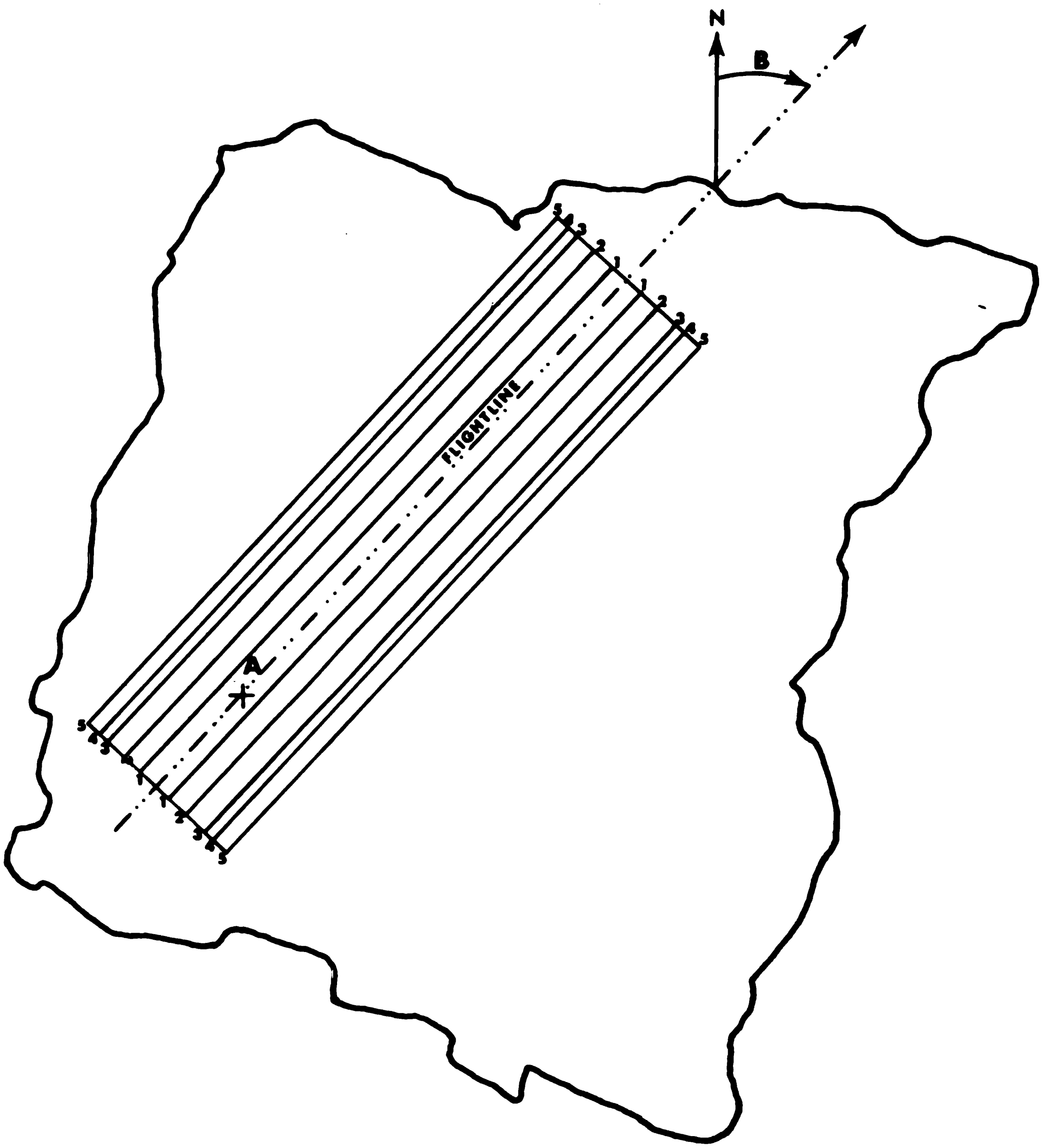
b. Total sampling unit #14224--141.28 hectares

c. Total sampling unit #16264--228.57 hectares

To compare the aerial sampling procedure with the area-frame sampling method, a sampling size had to be used, equivalent to the ratio of the total area of the two ground sampling units (#14224 and #16264) of the area frame and the total count unit area, or

$$\frac{141.28 + 228.57}{2101.57} = 17.6 \text{ percent.}$$

It was decided to evaluate the single flight line sampling procedure using samples of approximately 5, 10, 15 and 20 percent. Given assumed cost/accuracy trade-offs, smaller or larger sampling size seemed impractical. This resulted in the use of the following sample areas in designing a simulated aerial survey sampling procedure based on a selected linear flight line distance of 4 km and a heuristic area selection (see Table 24).



A. Sampling point location (randomly selected)

B. Sampling direction (randomly selected, 42°)

Location of corner points defining sample area outline:

1. ~5%
2. ~10%
3. ~15%
4. ~17%
5. ~20%

FIGURE 11. Outline of samples representing a simulated aerial survey to estimate crop composition of the test site.

TABLE 24

Selection of Initial Sampling Size to Determine the Actual Sampling Size and Intensity

Initial Sampling Size Selection	5%	10%	15%	20%
Sampling area (hectares)	106.2	212.3	318.5	424.6
Random area selection based on a 4 km flight line (km)	4x.25	4x.5	4x.75	4x1
Resulting actual sampling intensity (km^2)	1.00	2.00	3.00	4.00
Actual sampling intensity (%)	4.76	9.52	14.26	19.03
Total number of frames (1:12,500) or sample size	16	32	48	64

Figure 11 defines the various sample sizes and their overlapping location within the test site boundaries. In a practical aerial photo mission a 4 x 1 km swath can easily be obtained using a 70mm camera system with an 80mm lens and a flying altitude of 6000' AGL (Above Ground Level). For comparison a scale and coverage matrix for two small format cameras and typical lens-camera combinations were calculated (see Table 25). In an application of this nature a randomly selected imagery swath can be flown over a test site and a portion of the imagery can be interpreted based upon sampling size/accuracy requirements.

In order to evaluate the alternative sampling design based on multiple flight lines, a size equivalent sample of one of the four single flight designs (4.76%) was drawn, consisting of 16 photo plots.

Sampling Statistics and Evaluation of Two Sampling Designs

The dot-grid method, described earlier, was used to calculate the sample means and associated standard deviations of the various land cover/use percentages contained within the photo plots of the various sampling designs. The results are summarized in Table 26. With the use of these sampling statistics the confidence limits of the population percentages for the various categories were calculated. The best available estimator, as used here is based on random sampling procedures.[1] Since the techniques employed contain principles of random, as well as systematic sampling, it can be assumed that the random estimator will provide reasonably accurate confidence limits for the final land cover/use estimates, even more so as the sampling design approaches a more systematic character. Tables 27 and 28 summarize the results, the mean; and the standard deviation of the absolute error (the difference between population mean and sample mean) for all categories combined.

Initial analysis of the estimator results for the major land cover/use categories in the area (representing more than 5 percent of the surface area) and the known population mean indicates the usefulness of the modified systematic sampling procedure. The cases in which the population mean was predicted correctly, given the 95 percent confidence level, are indicated in Table 29.

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[1] $CI = \bar{x} \pm t \sqrt{\frac{(1-f)S_x^2}{n}}$. Based on a selected 95 percent confidence level and the appropriate degrees of freedom (n-1);

t = the Student t value,
f = sampling intensity,
n = sample size or number of photo plots, and
S_x = standard deviation

TABLE 25

Scale and Coverage Matrix for Selected Small-format Camera Systems Used in Low-altitude Photography*

ALTITUDE (AGL) / CAMERA SYSTEM	500' 152.4m	1000' 304.8m	1500' 457.2m	2000' 609.6m	2500' 761.9m	3000' 914.4m	4000' 1243m	5000' 1523.9m	6000' 1828.7m	7000' 2133.4m	8000' 2438.3m	9000' 2743.0m	10,000' 2047.9m	
HASSELBLAD	1905	3810	5715	7620	9524	11430	15538	19048	22859	26669	30478	34288	25399	SCALE
70mm CAMERA FRAME FORMAT	344^2	687^2	1031^2	1375^2	1719^2	2062^2	2802^2	3437^2	4079^2	4812^2	5500^2	6187^2	4583^2	COVERAGE (feet)
55 x 55 mm 80mm LENS	105^2	209^2	314^2	419^2	524^2	628^2	854^2	1048^2	1243^2	1467^2	1676^2	1886^2	1397^2	(meters)
HASSELBLAD	1269	2540	3807	5080	6350	7620	10358	12670	15240	17779	20319	22859	25399	SCALE
70mm CAMERA FRAME FORMAT	225^2	449^2	674^2	898^2	1146^2	1375^2	1863^2	2246^2	2696^2	3162^2	3666^2	4079^2	4583^2	COVERAGE (feet)
55 x 55 mm 150mm LENS	69^2	137^2	205^2	274^2	349^2	419^2	568^2	684^2	822^2	964^2	1117^2	1243^2	1397^2	(meters)
NIKON	3046	6093	9140	12187	15234	18281	24327	30469	36574	42670	48766	54860	60988	SCALE
35mm CAMERA FRAME FORMAT	225 X 350	450 X 700	675 X 1050	900 X 1400	1125 X 1750	1350 X 2100	1800 X 2000	2250 X 3500	2799 X 4199	3266 X 4900	3733 X 5600	4199 X 6200	4500 X 7000	COVERAGE (feet)

TABLE 25 - Continued

Scale and Coverage Matrix for Selected Small-format Camera Systems Used in Low-altitude Photography*

ALTITUDE (AGL) CAMERA SYSTEM	500' 152.4m	1000' 304.8m	1500' 457.2m	2000' 609.6m	2500' 761.9m	3000' 914.4m	4000' 1243m	5000' 1523.9m	6000' 1828.7m	7000' 2133.4m	8000' 2438,3m	9000' 2743.0m	10,000' 2047.9m	
35 x 24 mm 50mm LENS	69 X 107	137 X 213	206 X 320	274 X 427	343 X 533	412 X 640	549 X 610	686 X 1067	853 X 1280	996 X 1494	1138 X 1707	1280 X 1890	1372 X 2134	(meters)

*From Schultink, G. Light aircraft remote sensing using small-format cameras. MSU Remote Sensing Project. Draft report, 1978.

TABLE 26

Data Summary of Sample Parameters for Two Sampling Designs, Various Sample Sizes Intensities and Associated Land Cover/Use Categories

Land Cover/ Use Category	Single Flightline								Four Flightlines	
	16 Photo Plots Sampling Intensity 4.76%		32 Photo Plots Sampling Intensity 9.52%		48 Photo Plots Sampling Intensity 14.26%		64 Photo Plots Sampling Intensity 19.03%		16 Photo Plots Sampling Intensity 4.76%	
	$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x
Plantains	28.4	20.4	29.0	23.5	31.3	24.8	20.4	28.4	22.7	23.3
Yucca	8.4	13.0	14.3	19.5	12.4	15.8	14.4	17.8	18.6	23.5
Tobacco	--	--	0.1	0.6	0.1	0.5	0.3	1.8	1.8	7.0
Sweet potatoes	2.6	5.8	2.1	5.7	2.4	6.4	2.1	6.2	4.4	9.4
Other crops	--	--	--	--	0.4	2.3	0.2	1.6	1.8	6.6
Other cultivated land	15.5	17.5	12.4	18.1	12.8	18.0	16.3	19.6	26.4	22.8
Natural vegetation	7.9	12.2	11.9	15.9	14.8	23.0	15.6	24.2	16.5	26.0
Forest	28.3	17.9	25.1	21.3	21.0	22.4	18.1	22.0	4.9	6.2
Residential	8.8	7.1	5.1	5.7	4.8	6.5	3.6	5.4	2.9	4.7

NOTE: Entries are sample percentages.

TABLE 27

Estimates of Population Percentages[a] for Sampling Intensities of 9.52%,[b] 14.26%,[c] and 19.3%[d]

	Population mean	9.52 Percent Sampling intensity		14.26 Percent Sampling intensity		19.03 Percent Sampling intensity	
		Conference interval	Absolute error	Conference interval	Absolute error	Conference interval	Absolute error
	μ	$\bar{X} \pm t\,s_{\bar{x}}$	$\mu-\bar{x}$	$\bar{X} \pm t\,s_{\bar{x}}$	$\mu-\bar{x}$	$\bar{X} \pm t\,s_{\bar{x}}$	$\mu-\bar{x}$
Plantains	28.0	29.0 ± 8.1	1.0	31.3 ± 6.6	3.3	29.4 ± 6.3	1.4
Yucca	14.6	14.3 ± 6.7	0.3	12.4 ± 4.2	2.2	14.4 ± 3.9	0.2
Tobacco	1.0	0.1 ± 0.2	0.9	0.1 ± 0.1	0.9	0.3 ± 0.4	0.7
Sweet potatoes	3.9	2.1 ± 1.9	1.8	2.4 ± 1.7	1.5	2.1 ± 1.4	1.8
Other crops	1.6	--	1.6	0.4 ± 0.6	1.2	0.2 ± 0.4	1.4
Other cultivated land	26.7	12.4 ± 6.2	14.3	12.8 ± 4.8	13.9	16.3 ± 4.3	10.4
Natural vegetation	8.2	11.9 ± 5.5	3.7	14.8 ± 6.1	6.6	15.4 ± 5.3	7.2
Forest	13.0	25.1 ± 7.3	12.1	21.0 ± 6.0	8.0	17.7 ± 4.8	4.7
Residential	3.2	5.1 ± 1.9	1.9	4.8 ± 1.7	1.6	4.2 ± 1.2	1.0
			Mean absolute error = 4.2 Standard deviation = 5.2		Mean absolute error = 4.3 Standard deviation = 4.4		Mean absolute error = 3.2 Standard deviation = 3.5

TABLE 27 - Continued

NOTE: Based on a randomly selected flight line and associated absolute errors of known population means ($\mu-\bar{x}$).

[a] 95% confidence level

[b] fpc = .9048, t = 2.04

[c] fpc = .8575, t = 2.0

[d] fpc = .897, t = 1.96

TABLE 28

Estimates of Population Percentages[a] (95% Confidence Level) for a 4.76% Sampling Intensity[b]

Test Site Categories	Population Mean	4.76 Percent Sampling Intensity. Single Randomly Selected Flightline			4.76 Percent Sampling Intensity. Four Random-Systematic Flightlines		
		Confidence	Interval	Absolute Error	Confidence	Interval	Absolute Error
		$\bar{X}$	$t\,S_{\bar{x}}$	$-\bar{x}$	$\bar{X}$	$t\,S_{\bar{x}}$	$-\bar{x}$
Plantains	28.0	28.4 ±	10.8	0.4	22.7 ±	12.4	5.3
Yucca	14.6	8.4 ±	6.9	6.2	18.6 ±	12.5	4.0
Tobacco	1.0	--		1.0	1.8 ±	3.7	0.8
Sweet Potatoes	3.9	2.6 ±	3.1	1.3	4.4 ±	5.0	0.5
Other Crops	1.6	--		1.6	1.8 ±	3.5	0.2
Other Cultivated Land	26.7	15.5 ±	9.3	11.2	26.4 ±	12.1	0.3
Natural Vegetation	8.2	7.9 ±	6.5	0.3	16.5 ±	13.8	8.3
Forest	13.0	28.3 ±	9.5	15.3	4.9 ±	3.3	8.1

TABLE 28 - Continued

Estimates of Population Percentages[a] (95% Confidence Level) for a 4.76% Sampling Intensity[b]

Test Site Categories	Population Mean	4.76 Percent Sampling Intensity. Single Randomly Selected Flightline			4.76 Percent Sampling Intensity. Four Random-Systematic Flightlines		
		Confidence	Interval	Absolute Error	Confidence	Interval	Absolute Error
		$\bar{X}$	$t\ S_{\bar{x}}$	$-\bar{x}$	$\bar{X}$	$t\ S_{\bar{x}}$	$-\bar{x}$
Residential	3.2	8.8 ±	3.8	5.6	2.9 ±	2.5	0.3
				Mean Absolute Error = 4.0 Standard Deviation = 5.4			Mean Absolute Error = 3.1 Standard Deviation = 3.4

NOTE: Based on randomly selected single flight line, a random systematic sample including four flight lines, and associated absolute errors of the known population means ($\mu-\bar{x}$).

[a]95% confidence level.

[b]fpc = o, t = 2.131.

TABLE 29

Correct (C) and Incorrect (I) Prediction[a] of Population Means for Five Major Categories

Test Site Categories	Single Flightline Four Sampling Intensities 4.76%	9.52%	14.26%	19.03%	Four Flightlines Single Sampling Intensity 4.76%
Plantains	C	C	C	C	C
Yucca	C	C	C	C	C
Other cultivated land	I	I	I	I	C
Natural vegetation	C	C	I	I	C
Forest	I	I	I	C	I

[a]95% confidence level

These results clearly indicate -- as does the smallest absolute error for all crops combined, associated with the second 4.76 percent sampling intensity -- the improved accuracy of a multiple flight line sampling approach.

When sampling unknown populations the second sampling design is preferred, since it results in error reduction. Another element which plays a role in the sampling procedure is based on the capture of information of various sampling plots within a single flight line: the aspect of independence between the individual plots. The standard error formula $\sqrt{(1-f)S_x 2/n}$ used in constructing the confidence intervals is based on an assumption of n independently selected elements (photo plots). If a positive correlation between the photo plots within the clusters (the 16 elements of the strip sample) exists, then this formula would underestimate the actual standard deviation. This in turn would produce estimates with confidence intervals too narrow to have the prescribed confidence level of 95 percent.

The independence of the photo plots contained within a single sampling strip or cluster can be tested by computing the intracluster correlation coefficient ρ.[1,2] In this case ρ was calculated for plantains based on four clusters each containing 16 sample units. The following formula can be used (Jessen, 1978):

$$\rho = \frac{\left(\frac{N-1}{N}\right) B - W}{MT} \qquad \text{where}$$

$$T = S^2 = \frac{\sum_{i=1}^{N} \sum_{j-1}^{M} (Y_{ij} - \bar{\bar{Y}})^2}{NM-1}, \qquad B = \frac{\sum_{i=1}^{N} \sum_{j=1}^{M} (\bar{Y}_i - \bar{\bar{Y}})^2}{N-1}$$

$$W = \frac{\sum_{i=1}^{N} \sum_{j=1}^{M} (Y_{ij} - \bar{Y}_i)^2}{N(M-1)}$$

N = number of photo strips
M = number of photo plots per photo strip
T = mean square of the total
B = mean square between photo strips
W = mean square within photo strips
Y_{ij} = the observed value for the jth photo plot within the ith photo strip
$\bar{Y}_i$ = mean per photo strip
$\bar{\bar{Y}}$ = mean of all photo plots

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[1] Cochran, W., 1977. Sampling Techniques. Wiley and Sons, New York.

[2] Jessen, R. J. 1978. Statistical Survey Techniques. Wiley and Sons, New York.

The intracluster correlation coefficient was 0.1457, which indicates the problem associated with this sampling approach; the assumption of independently drawn photo plots is questionable. In computing the variance for cluster sampling using the formula;

$$\sigma_{\bar{\bar{Y}}}2 = \frac{S^2}{M} \left(\frac{NM-1}{NM}\right) \quad (1+(M-1)\rho) \quad ,$$

the last factor $(1+(16-1)\rho) = 3.2$, is the inflation factor for the variance. This means an inflation of $\sqrt{3.2} = 1.78$ for the standard deviation for plantains, or an under estimation of the confidence limits by that factor, that is the predicted means and associated confidence limits do not cover the actual population means in some cases.

In comparing the absolute error for the five major cover/use categories (Table 30) however, it is clear that the two techniques result in relatively small errors, especially in the multiple flight line sampling design.

Aggregate costs were computed based on previous light aircraft inventory efforts carried out in the Dominican Republic. These costs include image acquisition and processing, image indexing, plotting, interpretation and data transfer[1] and total $\$19.71/km^2$, based on a 1:30,000 image scale. Image acquisition cost, using a 70mm camera system and an 80mm, lens did amount to $\$0.83\ km^2$ for the same image scale or 4.21 percent of the total inventory cost. This last cost, percentage is the only anticipated variable cost associated with the

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[1]Schultink, G., M.A. Karteris and R. Hill-Rowley. 1979. Cane Rust Damage Assessment in the Dominican Republic. The Use of Light Aircraft-Small Format Photography in Small Area Agricultural Inventories. Paper presented at the Third Symposium on the Economics of Remote Sensing, Incline Village, Nevada.

TABLE 30

Absolute Error Percentages* for Major Land Cover Use Estimates Based on Various Sampling Designs and Intensities

Test Site Categories	Single Flight Line Four Sampling Intensities				Four Flight Lines Single Sampling Intensity
	4.76%	9.52%	14.26%	19.03%	4.76%
Plantains	0.4	1.0	3.3	1.4	5.3
Yucca	6.2	0.3	2.2	0.2	4.0
Other cultivated land	11.2	14.3	13.9	10.4	0.3
Natural vegetation	0.3	3.7	6.6	7.2	8.3
Forest	15.3	12.1	8.0	4.7	8.1
Mean absolute error (major categories combined)	6.7	6.3	6.8	4.8	5.2

*Absolute error = $\mu - \bar{x}$

selection of the two sampling methods discussed for the 4.76 percent sampling intensity, due to additional flight time. From the aspect of sampling efficiency it is obvious that this small increase in cost could be justified in an effort to reduce the overall absolute error, especially for all categories combined from 4.8 to 3.1 percent (Table 28).

CHAPTER V

CRITICAL ANALYSIS OF ALTERNATIVE SAMPLING PROCEDURES FOR AGRICULTURAL AND NATURAL RESOURCE INVENTORIES

The high cost associated with resource inventory procedures is related to the extensive data needs that ensure reliable information for vast areas on a repetitive basis, especially for those resource factors which are subject to change. The classic project study starts with the survey and evaluation of natural resources, progressing through analysis to the development of alternatives and results in a detailed, evaluated project design and implementation. A more common and modern variant in project studies encompasses a phase where natural resource or physical inventories are paralleled by economic and social studies, identifying needs and development priorities to be matched with the constraints of the identified resource base.

The two approaches indicate the essential place of the resource inventory and identification element to ensure acceptable study results, program alternatives, development strategies and implementation. This fact plays an especially important role in the typical data void encountered in many lesser developed countries. Too often, situations are encountered where inappropriate technology is used before overriding resource constraints, insufficient identified prior to project implementation, have doomed many development projects or associated components at their beginning. It is for this reason that economizing on critically needed data gathering efforts, without an awareness of its effect on project design and implementation, can have serious implications in terms of opportunity cost or overall project cost/ benefit ratio.

Within the data gathering process it is crucial to accurately assess current land use patterns versus perceived land use capabilities. As Vink[1] points out, "present land use is only rarely in accordance with the interplay of today's resources and human society." This is due to the complex nature of the resource base as well as those determinants with a cultural, social, or historical and economical context. This forces us to assess, on a repetitive basis, the discrepancies between current and potential land uses expressed in land use suitability or capabilities. An example would be the potential capability of a "homogeneous" land class to support a given land use or, a crop specific, production level under current or anticipated cultural and socio-economic conditions.

The consideration expressed above emphasizes the critical need for the creation of an adequate spatial information base relating to the current status of a nation's natural resources. The potential of modern remote sensing techniques provides an excellent opportunity to contribute to those primary data capture efforts and to provide reliable information at a fraction of the cost of traditional ground surveys.

In an effort to reduce overall inventory cost without sacrificing significant information accuracy, the sampling techniques as discussed

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[1]Vink, A.P.A., 1975. Land Use in Advancing Agriculture. Springer-Veilag, New York, Berlin.

in the previous chapters (the area-frame sampling and the modified-systematic aerial strip sampling) have a great potential depending on time/cost consideration, terrain conditions, and associated cultivation practices.

A critical analysis of the area-frame sampling methodology and its application potential in lesser developed countries leads to the conclusion that this sampling approach has definite operational limitations, not encountered by aerial sampling methods. One significant limitation, for example, is the problem with field boundary definitions of area segments, which is frequently the case in many regions where marginal or subsistence agricultural production methods are present. Field boundaries change over time since many natural features used to define sample segments are ephemeral in nature (field trails, dry river beds, gullies, hedgerows, etc.)

Other limitations are also important, the major one is the measurement error associated with field identification problems during the actual ground survey, caused by field boundary changes due to changing production practices, the modification of field boundaries, or communication problems between interviewer and farmer. Another major factor, resulting in bias or measurement error, is the consistent under-reporting of crop yields or livestock numbers by producers to hide the real picture for taxation purposes. This fact might have contributed to the under-reported crop yields for plantains found in the Dominican case study.

Several factors contributed to a limited number of personnel. These include limited transportation means, road conditions, fuel availability, etc., as well as budget constraints, changes in priorities, and associated budget allocations within governmental agencies or departments, have resulted in a limited staff trained in the area-frame sampling methodology and in a high turnover rule of personnel. This might lead to "remote-yield assessment": adjusting the best available crop figures from previous periods with an arbitrary or heuristic factor to account for the current climate conditions or phyto-pathological field conditions to arrive at a "realistic" yield assessment.

All these factors make it even more critical to evaluate the accuracy and cost aspects associated with the area-frame methodology, especially in comparison with alternative aerial sampling techniques. Such evaluations should consider to what extent the two sampling approaches are identical, unique or complimentary in relation to specific resource inventory objectives.

A Comparison of Area-Frame and Aerial Strip Sampling Procedures

Various design conditions result from the applications of area-frame sampling and aerial strip sampling approaches. These conditions arise from the theoretical background of the techniques as well as the empirically determined requirements to be met prior to implementation.

Requirements and Limitations for the Application of the Two Sampling Procedures

The following requirements and resulting limitations can be identified for the use of the area-sampling frame:

a. The existence of a well-defined need for specific agricultural statistics, including data on crop areas, livestock (non-nomadic grazing), farm characteristics, production practices and other related socio-economic data. This includes the information requirement for specific population parameters, desired accuracy levels, measurements, etc.

b. A relatively up-to-date (less than 10-15 years old) photo base (photo mosiacs) is needed, at scales of 1:40,000 or larger, to delineate strata boundaries, count units and sampling segments. This is a critical element in frame design since a well-defined area framework is essential to efficient sampling design. The design involves the initial stratification, and the strata delineation on the actual photobase, to maximize variance between strata and to minimize the variance within a stratum. The quality, scale and timeliness of a photobase determine the potential to delineate count units as well as sampling segments in an effort to minimize field identification problems and associated measurement errors.

c. The need to spatially reference the sampling units requires the availability of a reasonably up-to-date mapping base (preferably 1:50,000). Smaller scale topographic maps are only acceptable if sufficient surface detail (terrain features, contour lines) is included.

d. An existing transportation network, vehicles and fuel supplies, with appropriate government backing are essential to sustain a long-term survey effort with minimum measurement error.

e. A trained staff of statisticians is needed to develop initial strata, frame design, re-stratification and modified designs to meet specific future sampling survey objectives.

f. The availability of trained enumerators (socially acceptable to target population in order to minimize bias, intensional under-reporting, etc.) with the capability to speak the various dialects or languages of the population groups or tribes to minimize measurement and/or recording error.

g. There should not be a short-term need for data and derived information. A time frame of approximately three to five years is needed for the production of the first nation-wide estimates.

h. There should not be a need to produce provincial or regional estimates. The frame design is geared toward national statistics. Sub-level estimates require a modified frame design.

i. Agricultural and natural resource data should be excluded that are difficult (or impossible) to measure objectively, using field surveys (i.e., spatial distribution and assessment of vegetation cover types, specific crop types, erosion potential, crop stress, forest species, etc.).

Similarly, the following conditions have to be met prior to conducting an aerial strip sampling effort:

a. Prior land cover/use stratification on a mapping base 1:250,000 or larger is needed to maximize sampling efficiency. Landsat-derived stratification transferred to the appropriate base maps, meets this need. If more specific, sub-regional estimates are required, an existing photobase is strongly recommended.

b. The need for agricultural/natural resource data which can be derived from identifiable parameters on specific imagery types (film, filter and scale combinations) with an acceptable degree of accuracy.

c. The creation of an in-country capability to process and interpret imagery for data extraction. Experience has indicated that regular panchromatic photo products allow for the differentiation of the major crop types with a reasonable degree of accuracy (on the average better than 90 percent for interpreters with minimal training* using image scales of 1:20,000). Color or Color Infrared Photography increases the interpretation accuracy to better than 95 percent.[1]

d. The availability of a statician or resource analyst to derive strata composition estimates for various land cover/use categories.

Design Task Elements and Information Quality Aspects

A number of design elements can be identified as part of an applied frame or aerial sampling effort. These various considerations further differentiate between the characteristics associated with the two techniques. They allow also for a better understanding of the prerequisites, flexibility, difficulties and data type and information quality resulting from these differences. The following table identify these systematic differences.

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*Training of appropriate staff requires 5-10 weeks. Equipment needs: camera, $5,000; Image processing facility, $2,000; Basic interpretation equipment, $4,000.

[1]Schultink, G., et al., 1980. An Evaluation of Imagery Parameters Relating to Agricultural Inventories in the Dominican Republic. USDA/MSU (draft) Report.

TABLE 31

Some Design and Information Quality Aspects of
Area-Frame and Aerial Sampling Procedures

Design Aspect Comments	Area-Frame Sampling Procedures	Aerial Sampling Procedures
Initial stratification	Stratification is done from existing Landsat data, photographic or ancillary data sources. A relatively simple and low-cost task from Landsat data for an experienced interpreter.	Identical
Frame design: Segment and count unit allocation on existing photo base	This requires "up-to-date" photo base to minimize ground survey problems. Time consuming method and potentially inaccurate if less than optimal photo base is available.	Not needed
Field and sampling segment identification during ground survey	This constitutes potentially a significant error source; error is a function of imagery date, terrain conditions, cultivation practices, type of agriculture etc. Boundary definition problems occur specifically in traditional or subsistence type agriculture. Timing of survey can be critical.	Not needed

TABLE 31 - Continued

Some Design and Information Quality Aspects of Area-Frame and Aerial Sampling Procedures

Design Aspect / Comments	Area-Frame Sampling Procedures	Aerial Sampling Procedures
Type of survey data possible	The potential exists for detailed agricultural statistics (live stock, crop acreage, farm characteristics, cultivation practices) if sufficient funding is available to conduct an extensive survey. Co-operation of farmer as data supplier essential.	Only those parameters which can be measured on aerial photography (including crop acreage, other land cover/use types, erosion aspects, vegetation species composition, etc.) may be sampled.
Data quality	There are many potential error sources (see also D.R. case study) including bias, purposely under reporting for tax purposes, measurement error as a result of field boundary definition and recording error.	Limited sources for survey error (limited to image interpretation error, and area measurement error). Automated procedures for area calculations can be used using image densitometric analysis or digitizers.
Staffing and training requirements	There are substantial staffing needs, e.g. Core staff of highly qualified personnel. Training often results in high personnel turnover (job promotion).	Substantially less than area frame staff. Moderate training level no significant problem with personnel turnover.

TABLE 31 - Continued

Some Design and Information Quality Aspects of Area-Frame and Aerial Sampling Procedures

Design Aspect / Comments	Area-Frame Sampling Procedures	Aerial Sampling Procedures
Data quality control	Difficult to apply. Quality control has not (yet) been introduced in applications in various LDC's as known by author. Significant data reliability problem (see also D.R. Case Study).	Relatively easy to apply. Appropriate techniques available.
Survey timing and duration	There exists a critical timing problem in tropical areas with short growing seasons for multiple crops. Intercropping and shifting cultivation (Intercropping) additional source for confusion. Limited staff has to cover large areas with distant, out lying segments, randomly selected. Especially problematic if transportation problems are severe.	Large areas can be covered with relative east. Difficult terrain conditions (relief, road condition, wet season, etc.) do not pose problems. Limited staff required, quick data turn around, timing of survey relative easy. Limited time requirements reduce survey cost.
Timeliness of survey data and resulting estimates	The initial result should not be expected within 3-5 years.	The initial result can be expected within 1-2 years. (Within 1 year for sub-regional estimates).

TABLE 31 - Continued

Some Design and Information Quality Aspects of Area-Frame and Aerial Sampling Procedures

Design Aspect / Comments	Area-Frame Sampling Procedures	Aerial Sampling Procedures
Modification of data needs	This would require a substantial change in area stratification and/or frame design. Potentially a long and expensive process.	This can more easily be accommodated, especially if re-stratification would not be required.
Expected data reliability and accuracy of estimates	Publicized claims of 95% accuracy are questionable given the nature of consistent error sources.	The test site results in the D.R. cast study indicate that an appropriate sampling design can produce estimates with a relative error of 5 percent or better for some of the major crops (95% accuracy).

Cost/Accuracy Assessment of the Two Inventory Techniques Aerial Sampling and Area-Frame Sampling

Based on the Dominican Republic case study, it is difficult to assess all the cost factors associated with a nationwide sampling survey. Other studies, however, provide a reasonable indication of the anticipated cost associated of an aircraft survey effort similar to the procedures outlined in the aerial sampling approach. Computed aggregate cost of previous light aircraft inventories efforts, specifically aimed at identifying sugar cane fields and various stages of canopy stress associated with cane rust infestation, indicate costs of $19.71/km^2 (using an Imagery scale of 1:30,000).[1] This includes image acquisition and processing, image indexing, plotting, interpretation and data transfer to a selected (1:50,000 scale) topographic base. Actual image acquisition costs (using a 70mm camera system with an 80mm lens) amounted to $0.83/km^2 for the same image scale, only 4.2 percent of the total inventory cost. Some of the cost factors, as mentioned above, would not play a role in an aerial sampling procedure: image indexing and plotting. However another cost factor would be added. Namely, the cost for area calculations to arrive at crop composition percentages for individual crop types contained within the individual photo plots. Empirical data from work carried out at the Remote Sensing Project at Michigan State University indicate that aggregate inventory cost, using an aerial sampling approach, would be in the range of

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[1]Schultink, G., et al., 1979. Cane Rust Damage Assessment in the Dominican Republic: The Use of Light Aircraft-Small Format Photography in Small Area Agricultural Inventories. Paper presented at the Third Symposium on the Economics of Remote Sensing. Incline Village, Nevada.

$12-20/km^2, depending on flight time between selected sites and a number of other variables.

Based on the case study, it was concluded that a multiple (four) flight line, in comparison to a single flight line sampling design, reduced the overall absolute error for all land cover/use categories combined from 4.0 to 3.1 percent (Table 28). These findings were based on a sampling intensity as low as 4.76 percent. In all cases the four crops were correctly predicted given the 95 percent confidence interval. (Table 32).

TABLE 32

Correctly Predicted[a] Population Percentages for the Four Crops Included in the Test Site Study

Test Site Category	Population mean (%)	Predicted population percentages[b]
Plantains	28.0	22.7 ± 12.4
Yucca	14.6	18.6 ± 12.5
Tobacco	1.0	1.8 ± 3.7
Sweet Potatoes	3.9	4.4 ± 5.0

[a]95 percent Confidence Interval.

[b]Based on a 4.76 percent sampling intensity of four random systematic flight Lines.

To conduct an aerial sampling, as demonstrated in this case study, on a nation-wide basis all land cover/use strata (as defined from Landsat data would have to be included which, at the same sampling intensity, would require a sampling survey of approximately 2,400 km^2.

Given the anticipated cost levels of a range from $12-20/km^2, this would require $28,000-48,000 for a nation-wide survey.[1] If, however, information on crop acreage is required excluding the other strata (see also Tables 16 and 17), than the sampling effort should concentrate on the agriculture stratum and substrata 2.1 through 2.4 (Table 17): sugar, mixed agriculture, marginal agriculture and pasture. This would greatly reduce the total area sampling requirements, from approximately 2,400 km^2 to 1,065 km^2 (5 percent of 21300 km^2), resulting in an anticipated cost savings of around $15,000-27,000 and a total budget of $13,000-21,000 for the total 48,000 km^2 of the Dominican Republic. This final figure assumes the availability of a well-defined strata,[2] such as derived from Landsat or current aerial photography.

The area-frame sampling costs can be divided into the initial cost for frame design and the (repetative) survey cost. Frame design, if done well, may accomodate a multitude of survey needs. The critical element in this design process appears to be sufficient stratification. Lack of stratification, usually due to insufficient spatial data, results in a need for re-stratification in an effort to improve estimator accuracy. Furthermore, reorientation of survey needs might require a

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[1]See also: Sader, Steven A. and Robert W. Campbell, 1979. Cost and Accuracies of Tropical Land Cover Mapping Using Landsat and Medium Scale CIR Aerial Photography: A Costa Rican Example. Proceeding of the Third Conference on the Economics of Remote Sensing. Incline Village, Nevada.

[2]Strata delineations to be transferred to a 1:250,000 scale base (country wide) and to a 1:50,000 scale topographic base, or a photo mosaic at comparable scale, illustrating stratum agriculture including the delineation of the four substrata.

modified stratification to accomodate specific sampling of other population parameters.

Table 33 presents a breakdown of the cost factors, based on the initial coffee survey and the first crop and livestock survey in the Dominican Republic. The total survey cost amounted to $69,500. Actual frame design costs were $31,500 (including a modification of the stratum extensive agriculture and pasture). The combined survey costs were $38,500 including a special survey to provide national estimates of coffee acreage and production levels.

A realistic comparison of the two techniques discussed, area-frame sampling and the aerial sampling, is difficult to make. The objective of the area-frame is to supply nationwide estimates, that of the aerial sampling to provide more detailed estimates on a (sub)regional basis. It is, however, possible to compare the standard error associated with a specific crop type, as included in the case study, and to estimate the cost of a nationwide survey for the two methods.

The standard error for plantains, to provide an estimate for the "intensive agriculture" stratum as defined in the area-frame sampling procedure, is 28.2 percent. The standard error in the multiple flight line sampling approach for the same stratum and the same crop was 5.8 percent. Based on these data as well as the cost figures discussed above, it is possible to predict that a nationwide plantains survey could be conducted within the stratum intensive agriculture for approximately $40,000 using the area-frame approach, while the same nationwide estimate (with an anticipated reduction of sampling error) using aerial sampling could be accomplished for less than $20,000.

TABLE 33

Cost for the Initial Coffee Survey and
First Crop and Livestock Survey

Frame	Work Period	Costs
Frame Design		
Initial frame	March-December, 1971	
Overhead		$ 5,000
Supervision		5,000
Construction personnel		13,000
Selection of 160 segments		2,000
Total		25,000
Proposed modification of Stratum III (extensive agriculture and pasture)	July-November, 1974	
Overhead		1,000
Supervision		500
Frame construction personnel		3,000
Selection of 180 segments		2,000
Total		6,500
Survey		
Initial coffee survey	March-April, 1972	
Enumeration		6,500
Supervision (including training)		3,500*
Summarization		3,000*
Total		13,000
First crop and livestock survey	May-July, 1973	
Enumeration		16,000

TABLE 33 - Continued

Cost for the Initial Coffee Survey and
First Crop and Livestock Survey

Frame	Work Period	Costs
Supervision (including training)		4,000*
Summarization		5,500*
Total		25,500

*Some of these costs are salaries of people assigned to the Secretariat of Agriculture (SEA).

SOURCE: Modified after Huddleston, Harold F. and Dunkerley, C., 1974. A Methodological Report on: Agricultural Statistics in the Dominican Republic. (mimeographed)

The advantage of an area-frame sampling effort should be emphasized additional data (e.g. live stock statistics), while sacrificing accuracy and time. The aerial sampling, however, would provide more accurate crop data within one-third of the anticipated time period of the area-frame survey.

Applicability of the Two Sampling Procedures

Area-frame sampling has proven to be a valuable, effective and reliable tool in providing agricultural statistics in many areas of the U.S.A.[1] The procedure, however, has limitations in some mountainous and desert areas in the United States. These limitations are even more severe in many lesser developed countries with marginal forms of agriculture. The area-frame allows for the gathering of various types of data which are difficult or impossible to obtain using aerial sampling techniques. As pointed out previously, both sampling procedures have their limitations in applications. Certain conditions clearly indicate the need to select one procedure over the other. In other situations they can be considered as complementary if properly used in agricultural and natural resources inventories. This fact may be illustrated using some imaginary conditions that might be encountered in lesser developed countries:

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[1]Hanuschak, George et al., 1979. Obtaining Timely Crop Area Estimates Using Ground-gathered and Landsat Data. USDA-ESCS Tech. Bulletin No. 1609.

Country I

Conditions:

a. Major portions of the country are characterized by field boundaries that are well-defined for areas of intensive agriculture, eg. Cibao Valley, Dominican Republic or irrigated agricultural production similar to the Azua Valley, Dominican Republic or Gezira Scheme, Republic of Sudan (Blue Nile).

b. The well-defined field boundaries can be accurately delineated on existing aerial photography.

c. There exist a clearly defined need by the national government to acquire agricultural statistics for the modern agricultural sector; such statistics include areas in production by crop, livestock data, farm characteristics, cultivation practices, yields, etc.

d. This identified data need is clearly backed by an in-country commitment to set data gathering priorities, provide funding and logistical support for a long-term program.

e. A core staff of statisticians/enumerators is available or a commitment has been made to provide a training program (eventually with outside support) to meet these objectives.

f. There exist no immediate (within 3 to 5 years) time constraint on data needs.

Conclusion:

Area-frame sampling procedures would be considered an appropriate technology. Country conditions are such that an application is feasible.

Country II

Conditions similar to Country I except for:

a. The existence of time constraints: inventory data are needed within one year.

b. The inventory data needs are limited to crop acreages.

c. The existence of area constraints: the program is aimed at providing crop acreage for a number of regions in order to set investment priorities for new irrigation projects.

Conclusion:

A combination of area-frame sampling and aerial surveys (not sampling) can provide the data. An area-frame design based on appropriate stratification and aerial surveys is used to conduct enumeration of the sampling segments allocated during the area-frame design to the various strata and count units. The aerial survey and acreage determination for various crop types can provide the needed data quickly and accurately. The area-frame design is used to provide the required regional estimates (modified area frame).

Country III

Conditions similar to Country I except:

a. The situation is characterized by large areas in traditional (subsistence) agriculture; consequently great difficulties exist with field boundary identification and delineation on existing photography.

b. Existing photography is only available for part of the area and is 20-30 years old.

c. Great transportation problems exist for enumerators in traditional areas (e.g. migrating tribes, nomadic grazing, lack of road system).

Conclusion:

The area-frame approach can only be applied in non-traditional areas where the existing photobase and other conditions will support basic frame design and make data collection efforts using field enumerations feasible. Traditional areas can be sampled using appropriate stratification and aerial sampling design. This poses limitations on the type of data which can be acquired (livestock, farm characteristics, etc., not available) but provides the only acceptable alternative. The two sampling techniques clearly complement each other.

Country IV

Conditions:

a. Major portions of the country consist of desert or semi-desert ecosystems with small pockets of traditional agriculture (including nomadic grazing). The field boundaries are difficult to define and clearly ephemeral as a result of desertification and resettlement, caused by stagnation of the water supply.

b. Tribal disputes and migration patterns make even a list frame approach unacceptable. Existing topographical maps (scale 1:250,000) date back to the period 1910-1915 and show only a few permanent landmarks. Scattered photography at various scales is available covering 40-50 percent of the area. Significant transportation problems exist due to lack of a road network, transportation means, fuel rationing, etc. (This hypothetical situation is very typical for a major portion of the western Sudan).

Conclusion:

The area-frame sampling is clearly not an acceptable method. Aerial sampling approach provides a realistic alternative after careful analysis of data needs, types, priorities, and a careful (landsat-derived) stratification to optimize the sampling efficiency.

These four hypothetical bountries exemplify the range of conditions one faces in comprehensive agricultural/resource inventory efforts in lesser developed countries. Budget considerations as well as data specifications, including data types and accuracies, come into play in evaluating the various data-gathering options. Standard solutions do not exist and every sampling method will, given a specific geographical setting, have its limitations as well as advantages. A careful analysis of each country, its data needs, its available technology, the available budget and numerous other factors, had to be made prior to recommending an "appropriate procedure." For many areas this recommendation probably will consist of sampling designs which are hybrid in character and which can be modified in the future if information requirements change. Only in a few cases could the (standard) area-frame approach appropriately be applied, and even then the various non-sampling related error factors inherently present (especially if conditions for application are less than optimal), should be acknowledged.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

This study addresses sampling procedures used to capture agricultural and natural resource information to aid in the evaluation and development of alternative agricultural and natural resource policies and programs for lesser developed countries. The future implementation of selected development programs is critically determined by the availability, spatial detail, timeliness and reliability of resource data. Remote sensing techniques, specifically aerial sampling procedures, are evaluated for their capacity to produce accurate, timely, and spatially referenced data in a cost-effective manner. The area-frame sampling approach is discussed in combination with two modified systematic aerial sampling designs. The two techniques are evaluated in terms of error sources (sampling and non-sampling) and applicability to provide land cover/use estimates, after initial area stratification, at a national, regional, (multi-)stratum or sub-stratum level. A case study, conducted in a selected area in the Dominican Republic, was used to evaluate the theoretical and empirical sampling error associated with the two aerial sampling designs of different intensities. A comparison between area-frame sampling and aerial sampling procedures was made to arrive at tentative conclusions about the applicability of the procedures under various conditions as well as some resulting accuracy/cost considerations.

Needs for Further Research

A frequently encountered reality in developing a profile on the data needs of national governments is the lack of data specification. This relates to the type, spatial detail, accuracy, timeliness and cost of data gathering efforts to sustain short- and long-term resource planning and policy development. For this reason a critical need exists, especially in lesser developed countries, for detailing the spatial information base needed to support current as well as anticipated development programs. In this process it is clearly necessary to identify development objectives and goals over time, and to use this framework as a basis for applied training and development of the appropriate information base. Obviously this cannot be considered a one-time effort since information needs will change over time along with modified development programs and changing priorities. Such an effort will prevent, to some extent, duplications and overlap in data gathering efforts associated with (sub) regional projects and introduce economies of scale as well.

Research is critically needed to specify data requirements associated with special development programs (agricultural sector analysis and planning, forest management, classification studies, etc.) to help schedule data gathering efforts based on priorities and, especially, to address information cost/benefit relationships.

For this research, the typical in-country situation has to be evaluated in terms of topography, agricultural production, the current stage of development and the potential for future development, existing socio-economic development priorities, and comprehensive information needs over time given the identified and country specific constraints.

After the initial analysis of data needs, the findings have to be translated into specifics: data type, quality, data gathering methods, cost, etc. in order to develop a national spatial information development strategy over time.

Similar research has been accomplished for certain projects or project components in a number of LDC's but in these studies the comprehensive nature and the dynamics of the information gathering process (the systems approach) is frequently partially or completely lacking.

The realization that the number of alternative inventory techniques is subject to change as a result of ever improving technologies is a critical element in this research. Increasing capacities in the field of automated data storage, retrieval, analysis and spatial information display have a significant impact on data characteristics, input formats (spatial resolution and referencing) and considerations in primary as well as secondary data capture efforts. A case study introducing these elements in a country-specific spatial information system design would be an extremely valuable contribution.

Conclusion and Recommendations

Two alternative, modified systematic sampling designs were evaluated as potential methods to produce land cover/use estimates for small regions--Landsat-derived strata or (homogeneous) resource planning units. It was found that for a specific test site in the intensively cropped Cibao Valley of the Dominican Republic, a linear aerial sampling procedure using parallel flight lines and photo plots, both with systematic intervals and random starting points, could produce accurate estimates of the major land cover/use categories. For instance, four of the major crops were accurately predicted at the 95 percent confidence level based on a sampling intensity as small as 4.67 percent. It can therefore be concluded that these aerial sampling techniques provide an excellent potential for assessing the resource base and agriculture production levels in developing countries. This is true especially where topography, budget constraints, and other considerations would limit the application of alternative sampling procedures such as area-frame sampling.

A comparison of the aerial sampling and area-frame sampling procedures indicates that the two procedures can be applied when certain conditions (data requirements, data gathering options and applied analysis) are met. The two techniques thus have unique applications, but can also be considered complementary if terrain and access conditions, cultivation practices and information requirements vary at the regional or national level.

A number of potential error sources were identified in the various procedures. The case study, as carried out in the Cibao Valley, Dominican Republic, indicated a large discrepancy in area totals for a selected crop when comparing the total enumeration of sample segments used in the area-frame with aerial survey data. This indicates a significant problem in field enumeration during the area-frame sampling work, resulting from intentional under reporting or a number of other potential (non-sampling) error sources. It seems that a careful analysis of the error sources as well as some quality control on the field enumeration data is warranted.

The practice of intercropping in many tropical areas creates additional problems for ground enumeration. A well-defined procedure is needed to measure vegetation density (biomass) per field to arrive at areas of interplanted crops. This is necessary in order to provide consistent and reliable information per field, rather than the gross area interplanted, which is often not consistently defined by the enumerators of the area-frame and their respondents.

Quality control efforts might require the use of aerial photography to be taken simultaneously with ground enumeration to identify specific error sources and to improve overall data reliability.

A critical need exists to optimize the efficiency of sampling procedures by ensuring the best available stratification as a basis for the design of various sampling schemes. Prior to any inventory programs and the detailed analysis of application oriented information requirements, a Level I/II/III inventory[1] derived from Landsat data should be carried out to translate the anticipated data gathering efforts into associated costs. This inventory would also provide the initial stratification needed to analyze the appropriateness of selected sampling procedures and their associated sampling designs. This approach would minimize the need to re-stratify a country based on the variances found in the initial surveys.

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[1]A mixture of first, second and third order land cover/use classifications categories, such as agriculture (Level I), cultivated cropland (Level II), and Plantains (Level III). See also, Michigan Land cover/use classification system, Tanner, H., 1975. Dir. of Land Resource Programs, Michigan Department of Natural Resources.

APPENDICES

APPENDIX 1

LIGHT AIRCRAFT SURVEY TECHNIQUES

Within the context of the current remote sensing inventories carried out in the Dominican Republic, special attention is being given to the development of an initial image acquisition capability as a part of an operational center for remote sensing. Low cost imaging platform and photographic capabilities are being evaluated to allow for the creation of a small-area inventory capability using remote sensing techniques. The evaluation involves scale and other imagery parameters for agricultural inventories using light (single engine) aircraft and small format (35 mm and 70 mm) camera systems. The emphasis on relatively low cost/low technology systems has, based on research by the author and other members of the NASA/MSU Remote Sensing Project, resulted in the development of a light aircraft camera mount which can be attached to most, single engine, highwing aircraft without the need for any modification to the basic airframe or fuselage. This camera mount allows for the simultaneous generation of 35/70 mm photography, using motordriven camera systems.

Small Format Cameras Used in Light Aircraft Photography

Photographic sensing uses camera-film-filter combinations as a sensor, recording spectral information in the visible (400-700nm), the near infrared (700-900 nm) and the ultraviolet (300-400 nm) portions of the electromagnetic spectrum.

The primary sensor is the camera, in combination with the lens/ filter configuration controlling the amount of radiation reading the recording medium, the photochemical sensor or film.

Cameras are normally electrically driven and connected to an intervalometer permitting sequential exposures at a preselected interval. The interval time selected usually allows for an endlap between successive frames (standard 60%) allowing for stereo viewing, interpretation and mapping.

Small format cameras (35 mm and 70 mm) have been used by the NASA-MSU Remote Sensing Project for near vertical and oblique photography. These cameras are typical for the low stage (intensive management) application system and provide an efficient data acquisition method at relatively low cost. Two typical cameras for 35 and 70 mm systems used by the Remote Sensing Project are the Nikon F (35 mm) and the Hasselblad 500 EL/M (70 mm). A general comparison of systems features is described in Table 34.

These two camera systems (see Fig 12 and Fig. 13) provide good versatile usage. They are compact enough for field work and oblique photography and are sufficiently light for aircraft exterior side-mount use.

Imaging Considerations

The ground coverage of an image is determined by the angle of view of the lens and the camera platform altitude. The angle of view in turn depends on the focal length of the lens and the image dimension. The smaller the focal length, the larger the angle of view and therefore the ground coverage (see also Fig. 14). An increase of image size (the

TABLE 34

Comparison of 35 mm and 70 mm Camera Systems (1978)

Feature	35 mm	70 mm
Approximate cost complete system	Under $2,000.	Over $3,000.
Repairs	Comparatively low cost, service and parts readily available. Relatively easy and fast.	Comparatively costly, service and parts difficult to obtain. Com-pilicated and slow.
Operational training and ease	Relatively simple, limited training required.	More complicated, requires specific training.
Operational reliability	High.	Variable, temperamental.
Film availability	Excellent for 20-36 exposure rolls in B/W and color CIR film good, in bulk available via minimum order of $1,900.	Good for 12 exposure rolls (color). CIR or color in large rolls, like Ektochrome MS 5256 or CIR special order.
Film processing	Quick turnaround using standard facilities and processes. 250 exposure rolls slower.	Limited facilities. Special equipment required. Slow turn-around. Special mounting required.
Imagery format	35 * 24 mm.	55 * 55 mm.
Area coverage at 10,000 feet with standard lens	f=50 mm; 4500 & 7000 (feet) or 1372 * 2134 meters.	f=80 mm; 6875 * 6875 feet or 2096 * 2096 meters (50% more coverage).

TABLE 34 - Continued

Comparison of 35 mm and 70 mm Camera Systems (1978)

Feature	35 mm	70 mm
Image reproduction	Easily available.	Special reproduction procedures involving minimum charges.
Image analysis	Stereo viewing possible with adequate endlap (60% or more) annotation problematic, viewing and mapping possible from enlarging projector (microfiche reader, tracing projector and reflecting projector; good quality enlargement possible if fine grain film is used.	Stereo viewing possible in strips with proper endlap (60%), annotation possible of most terrain features, special projector for direct projection, excellent resolution of MS 5256 film makes good reproduction possible. Same or better possibilities for viewing and mapping.
Photographic recycling time	Usually 3-8 frames per second. General applications 1 frame/second adequate.	Hasselblad 1 frame/second, other up to 20 frames per second.
Shutter speed	1/500 sec. up to 1/2000 sec. generally 1/500 sec. adequate.	Hasselblad 1/500 sec., others up to 1/7200 sec. (calibration needed).
Aperture calibration	Nikon full stop; Canon 1/2 stop. Advantage for very low altitude CIR photography.	Mostly 1/2 stop calibration possible. Identical advantage.

FIGURE 12. Nikon 35mm camera, large motorized back for 250 exposures, battery pack and intervalometer.

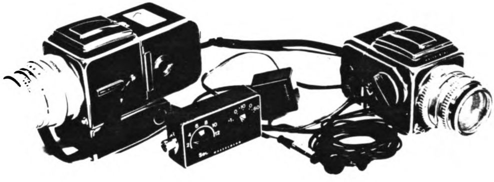

FIGURE 13. Hasselblad cameras (70mm), 500 EL/M, 150mm lens, medium-size back of up to 60 exposures (15 feet of film), motorized film transport with battery pack included, adapter, intervalometer, cable release for manual operation (10 feet) and standard Hasselblad camera with 80mm lens and small back (12 exposures).

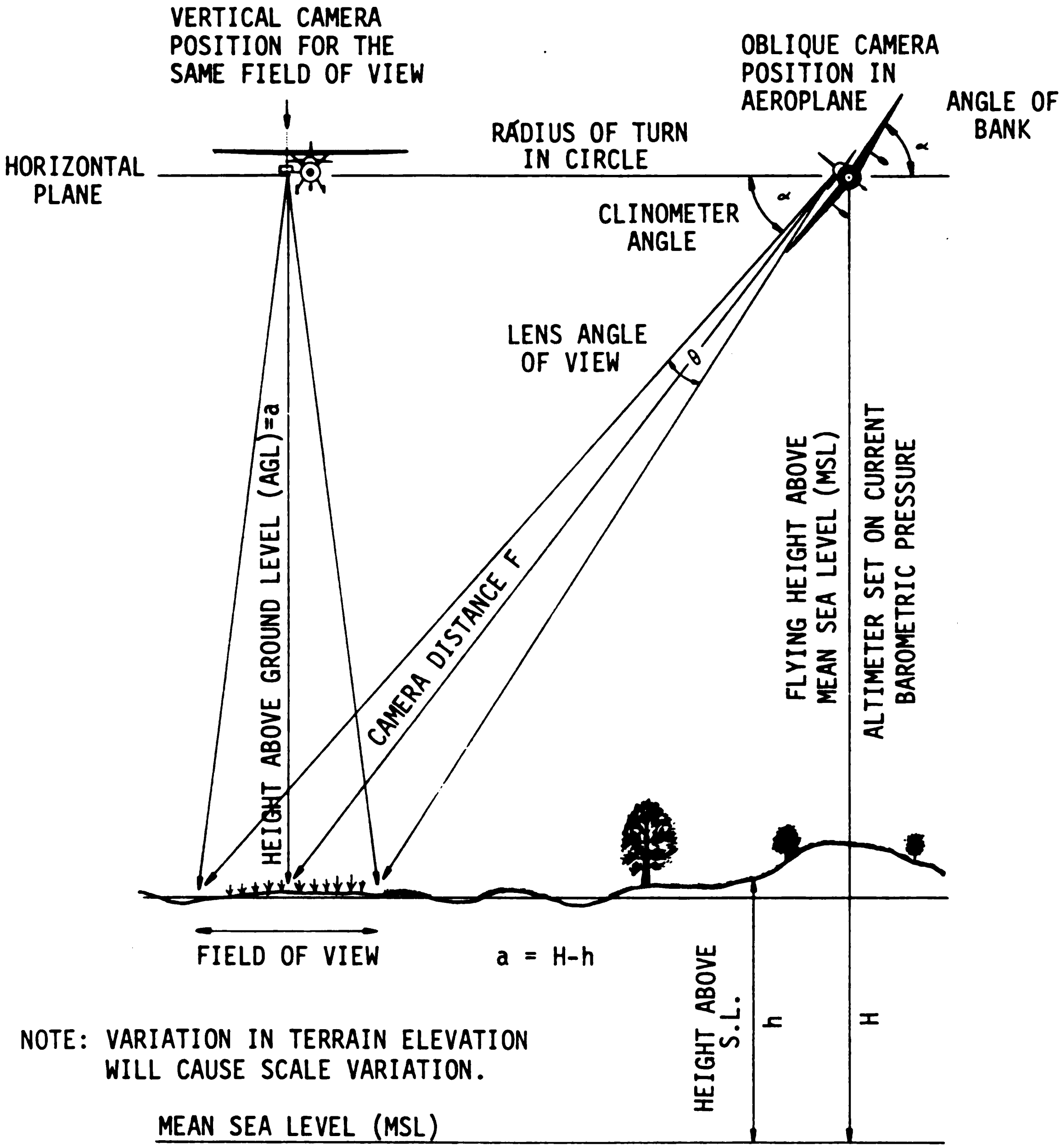

FIGURE 14. The relationships between camera distances and flying height for vertical and oblique aerial photographs.

image opening in the focal plane of the camera) would theoretically increase the ground coverage as well. Since this is standard for a specific camera, it is only a factor in comparing the utility of camera systems and in determining the actual cost of data collection per unit area.

The scale of a photographic image is determined by the ratio flying height (Above Ground Level)/focal length. The determination of the AGL height can be problematic since terrain elevation varies. The plane altimeter, adjusted for the current barometric pressure, indicates the altitude above Mean Sea Level or MSL (see Fig. 14). By subtracting the average terrain elevation, the absolute altitude (AGL) can be calculated and used in combination with the focal length to determine the scale.

Ground resolution is a measure of the ability of an imaging system to separate adjacent objects. This ability can be measured in lines per mm, or the least separation in mm. being the width of a just-resolved line pair at the ground scale. The resolution varies with film and lens characteristics and can be affected by image motion at the time of exposure. Effort has to be made to optimize the ground resolution using fine grain films, high quality lenses and adequate short exposure time to prevent any image blur caused by image motion (usually 1/500 sec. is adequate). The actual linear resolution of an image can be determined by means of bar targets with varying line widths.

The geometry of a photo image is perspective; a two-dimensional reproduction of a three-dimensional image. This also is the case for a vertical photography where varying terrain heights lead to radial displacements. This characteristic is of great advantage since two overlapping images can be fused to a stereo model allowing three-dimensional viewing, height measurements, contour-mapping, etc. The typical vertical image perspective can be distorted by movements of the camera platform along the three axis of the aircraft resulting in pitch, roll and yaw movements of the camera focal plane. More precise photographic applications, like topographic mapping, therefore require gyro stabilization of the camera mount.

Films and Filters

The selection of the appropriate film-filter combination is an essential element in remote sensing information gathering, since it determines which portion of the electromagnetic spectrum is used to highlight selected features of interest.

Panchromatic (PAN) or black and white film is sensitive to the visible portion of the EMS (400-700 nm.) and records reflected energy in various gray tones. The use of a light yellow filter (Wratten No. 15) is recommended to reduce the effects of haze at lower flying levels (5000 feet). Higher altitudes require an increased capability to reduce the blue (haze) wavelength and in those cases a red filter (Wratten No. 25) is recommended. In all cases careful consideration should be given to the filter factor in determining the required lens aperture and exposure time. A filter factor of 8,(2^3) requires that the normal f-stop setting be opened up three stops.

The general advantage of the use of PAN-film is the relatively low cost of film processing, printing and reproduction, and the possibility of correcting improper film exposures during the printing process.

Black-and-white infrared film (IR) records reflected energy in the 700-900 nm. band of the EMS. Its principal advantages over panchromatic film are the increased capability to provide contrast and excellent haze penetration, revealing detail not visible to the eye under limited visibility conditions. A typical use of infrared (IR) film is derived from its capability to register a wide range of infrared reflectance of chlorophyll concentrations in vegetation cover, allowing for species differentiation and mapping.

Typical filters used to eliminate the blue and ultraviolet radiation are Wratten 25, 29 or 70. B/W Infrared film is available in 20 exposure rolls for 35 mm. cameras. An important aspect limiting this film's use is the fact that it must be loaded in cameras in total darkness.

In contrast to panchromatic film, correct exposure of infrared film is critical. Also, exposure meters, capable of measuring infrared radiation, have only been developed on an experimental basis and are definitely not available in the local photo shop. Therefore, an exposure test flight is recommended to determine different haze conditions at different altitudes in order to develop an exposure calibration chart for regular applications using certain film/filter combinations.

Color film offers a greater advantage in aerial applications than B/W film, since it has a tonal range of natural color, a distinct benefit in photo interpretation. Color film consisting of three emulsion layers sensitive to blue, green and red light, is sensitive to the complete visible light range (400-700 nm.) of the EMS. But variation in atmospheric conditions (haze and pollution) does affect the quality of the photo image, to a large degree, limiting the period of data collection to good or excellent flying weather. Only for low altitude applications (2000 feet or 600 meters) can reasonable results be expected if the visibility is in the 7-15 miles range. The sensitivity to haze conditions of color film requires the use of an ultraviolet (UV) filter. For visibilities better than seven miles, a Wratten 1A is recommended. Flying altitudes over 5000 feet with visibilities less than seven miles require a Wratten 2B or an HF-3 aerial filter.

It is important to distinguish between negative and positive (or reversal) color film. The color balance and the density variation of negative color film can be controlled during the printing process, which is a great advantage. Color negative film has a greater exposure latitude and versatility than reversal film. Negative color film can be used to produce color and black-and-white prints, slide or large transparencies. Positive color film produces transparencies or slides and allows for contrast enhancement by means of making an internegative. This requires special processing facilities but can "save" a mission flown under bad (haze) conditions. Film availability generally does not pose any problems, especially for 35 mm cameras. Color film for 70 mm cameras (120) has to be special ordered for use in 15-foot camera cassettes (Ektochrome MS 5256).

Color infrared film (CIR) combines some of the advantages of infrared and color film. CIR consists, like color film, of three layers sensitive to green-red light and to reflected infrared radiation (700-900 nm.). The resulting images display therefore false natural colors, recording healthy vegetation (large chlorophyll concentrations) as red, red as green and green as blue. The combined advantages of infrared and color film have made CIR film an invaluable data recording tool in vegetation studies, crop stress monitoring, pollution detection and land cover/use mapping efforts at a regional scale. CIR-films have to be exposed with a yellow (minus-blue) filter to eliminate the blue light scattered by the atmosphere, especially during hazy conditions. A Wratten 12 filter is recommended. Exposure charts should be developed for different flying conditions. It is important to consider the variation in reflected radiation of various surface features and ground cover, especially for flying altitudes below 2000 feet. The exposure latitude of CIR film is $\pm$ 1/2 f-stop.

Light Aircraft and Camera Mounts

Light (single engine) aircraft have become increasingly valuable in aerial surveys and environmental monitoring practices. The choice of aircraft for large format photography is affected by operation cost/hour, the total flying time required, the complexity of the navigation equipment needed, the type of photography to be carried out and the maneuvering required.

Most single engine aircraft have an operation cost (plane and pilot) within the \$30-\$60/hour range. The time saved by higher operating speeds of high performance single engine aircraft generally offsets the higher operation cost/hour. Since most of the photography is carried out with good-excellent VFR (Visual Flight Rules) conditions at target areas within two hours flying time of the departure point, at IFR (Instrument Flight Rules) equipped aircraft is not required by certainly useful in order to optimize the overall utility.

High wing aircraft are preferable for oblique photography and, using exterior side mounts, for vertical photography.

The use of helicopters as a camera carrying platform could be considered if special requirements have to be met. Its great advantage is the capability to fly at very low airspeeds and very low altitude, allowing for extra-large scale photography of spot locations. In mountainous terrain this can be very important where facilities are limited for fixed-wing aircraft and where up and down drafts make flying at low altitudes hazardous. There are, however, a number of significant disadvantages associated with helicopter use: operation cost/hour is 4-6 times that of fixed-wing aircraft, aircraft vibrations require high shutter speeds for mounted cameras and the payload is generally rather limited.

Light Aircraft Mounts

Several applications of 35 mm. and 70 mm. photography, using light aircraft camera mounts for exterior use, have been carried out. The "Montana System," one of the more recent and successful systems, was developed by the Remote Sensing Laboratories of the University of Minnesota. A standard motor driven camera in an exterior side mount is clamped on the door of a high wing aircraft. This has the advantage of low fabrication cost, the ease of reloading and the fact that it does not require modification of the fuselage, door or window of compatible highwing aircraft (e.g. Cessna).

Experience during various applications by personnel of the MSU Center for Remote Sensing have made it possible to formulate general specifications for a camera side mount:

a. Optimize adaptability of the mount without aircraft modification.

b. Provide for in-flight leveling.

c. Keep procedure simple for long flight-time operations.

d. Make camera platform retractable for camera reloading and calibration.

e. Make monitoring configuration standard to allow for consistent near-vertical coverage with lenses of various focal lengths.

f. Provide for a crab-correction capability (camera rotation).

g. Provide for multicamera applications.

h. Keep construction cost low.

The School of Forestry of Austin State University, Texas developed a mount with capabilities to meet some of these specifications (Mason, 1978). A light weight versatile camera mount was designed for external attachment without aircraft modification. The basic mounting frame consists of aluminum tubing supported at the corners and stress points by sheet aluminum, with overall dimensions of 18" x 14" x 6". The mount may be attached to the door of a high-wing light aircraft (Cessna 172), by securing it through the open window by means of two swivel turn clamps and additional support of a number of heavy duty suction cups (Fig. 15). This basic design has been modified by the author (See Fig. 8). This new design makes single or multiple camera operations possible with remote control from the airplane (intervalometer or manual). The camera platform pallet is attached to the mounting frame by means of three spring/bolts assemblies which allow for in-flight level adjustment. Rotation of the camera fixture in relation to the lower pallet makes crab correction during various wind conditions possible in order to improve coverage during flight-line photography.

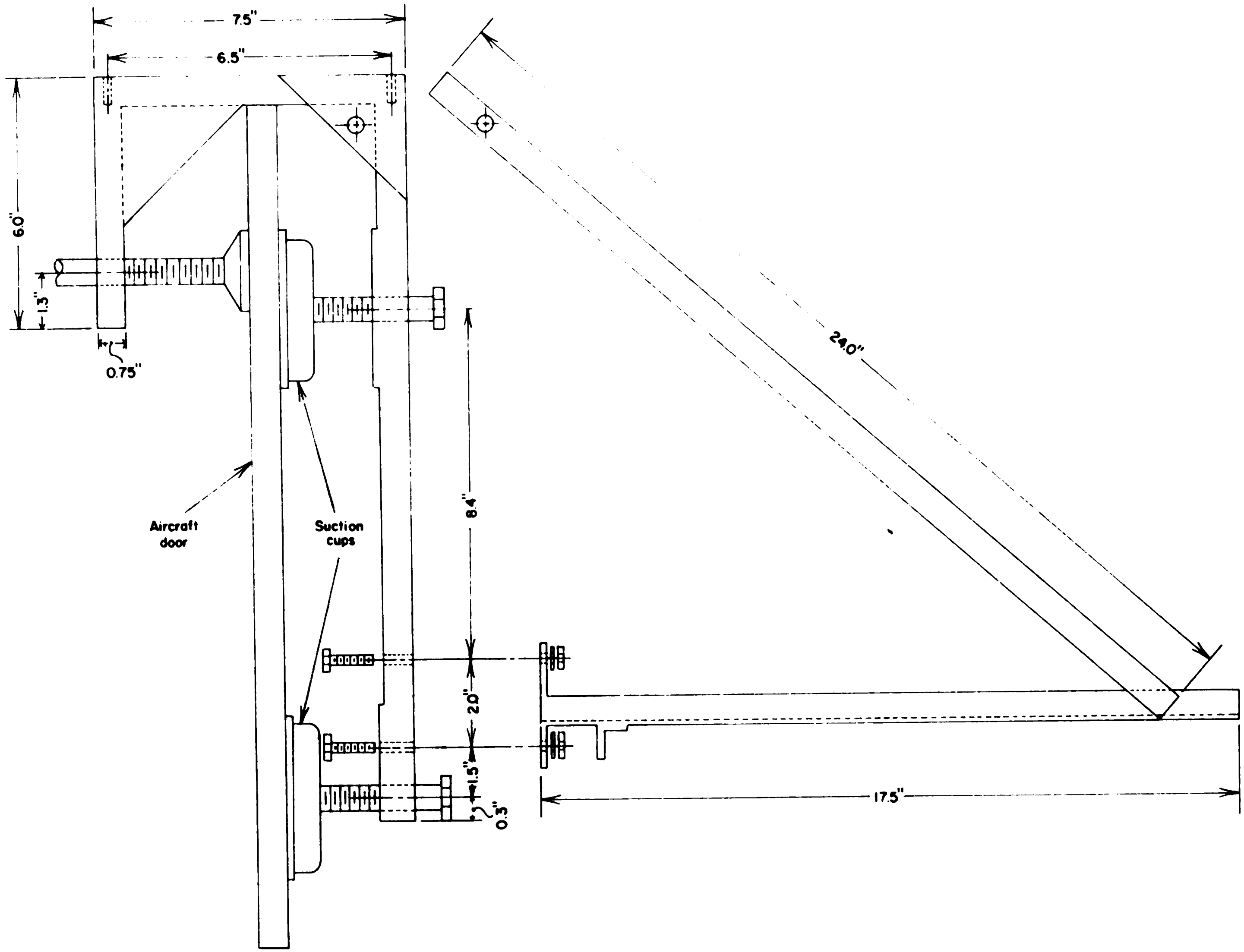

FIGURE 15. Camera mount for light aircraft. MSU remote sensing project configuration for 35/70mm camera system, lower platform.

APPENDIX 2

PHOTO INTERPRETATION KEY FOR SELECTED CROPS IN MOCA REGION

In the Moca region, none of the cultivated crops to be identified are grown in fields having sufficiently unique shapes, sizes, sites, or associations to allow discrimination between them. These particular attributes will be generalized to apply to all of the crops. The distinguishable characteristics of pattern, shadow, texture, and tone will then be detailed for each crop. The interpretation key is for the Moca region only. The same crops in other regions may have different characteristics.

Shape of Field: Variable. Usually regular to irregularly shaped polygons. Some fields, however, may have curvilinear boundaries that conform to the topography.

Size of Field: Variable. Plantains sometimes are grown in larger fields than the other crops but there are many smaller fields of this plant, too.

Site: All of these crops are preferentially planted on level to gently undulating topography.

Association: None of the identified crops are associated with any particular location a production method. Cacao, however, is often grown under large trees which provide it with shade.

Classifications

A. Plantains - Platano* (_Musa_ sp.)

B. Yucca (Cassava) - Yuca* (_Manihot_ sp.)

C. Tobacco - Tobaco* (_N_. tubacum)

D. Sweet Potatoes - Batatas* (_Iopmoea batatas_)

E. Other Crops

F. Cultivated Land*

V. Natural Vegetation **

In the Moca region most of the natural tree cover is Guama (local name).

Plantains (Platano)

Pattern: Plantains are usually planted with a regular geometric arrangement and in the early stages of growth this is the crop's most distinguishing characteristic. A square pattern is most common but diamond, rectangular, or triangular designs exist. When the crop is mature, the foliage from adjacent trees tends to merge and obscure the pattern somewhat. Fields which have been cut and allowed to resprout exhibit an even more indistinct arrangement.

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*Covers fields being prepared for crops at the time of the photography. No identifiable crop is visible.

**Includes: forested land
herbaceous and shrub rangeland
abandoned fields
pasture

Shadow: On large scale photographs the distinctive shadow cast by the plant is observable within most fields of intermediate growth and along the edges of fields containing mature crops.

Texture: In the intermediate and mature stages of growth a coarse texture predominates.

Tone: In the early stages of growth the tone is dominated by the characteristics of the topsoil.

Black and White: Throughout its growth the crop is a mixture of light and dark tones, the dark predominating, until the crop is cut down and allowed to regenerate. Then the light-toned portions (litter on the surface) predominate.

Color: The crop has a green to dark green color. Second growth fields have distinct white portions representing the litter.

Color Infrared: Varies from pink to red. White portions exist in second growth fields.

Sweet Potatoes (Batatas)

Pattern: No particular pattern is evident in this crop because the plant covers the whole field uniformly. However, on very large scale photography very recently planted crops will have a row pattern.

Shadow: No shadow effect.

Texture: Sweet potatoes have a fine or velvety texture very soon after planting and throughout the other growth stages.

Tone: In the very early stages of growth, tone is dominated by characteristics of the topsoil.

Black and White: This crop is light-toned at all stages of growth.

Color: Green.

Color Infrared: Bright pinkish-red.

Tobacco (Tobaco)

Pattern: Like Yucca, a row pattern is evident in the young and intermediate stages of growth. Unlike Yucca, a faint row pattern often persists even in mature fields.

Shadow: Shadow is not a viable component in the identification of tobacco.

Texture: A coarse texture is apparent in both intermediate and mature stages of growth. However, the texture at mature stage can be described as stippled.

Tone: Tone is dominated by characteristics of the topsoil in the early stages of growth.

Black and White: The crop is imaged in medium to light tones.

Color: Medium green.

Color Infrared: Red.

Yucca (Yuca)

Pattern: For young and intermediate stages of growth a row pattern is evident. When the crop matures, however, the intermingling branches and leaves of adjacent plants eradicate any pattern.

Shadow: Mature plants may cast a small shadow at the edge of a field but it is apparent only on quite large scale photography.

Texture: Intermediate stages of growth evidence a texture similar to worn corduroy. Mature fields have a medium or wool-like texture.

Tone: In the early stages of growth tone is dominated by characteristics of the topsoil.

Black and White: This crop is imaged in light tones.

Color: Light green.

Color Infrared: Bright pink to medium red.

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