Apr 1st, 8:00 AM

Remote Sensing Contributions to the Management of Renewable Resources

Charles Sheffield
Vice President, Earth Satellite Corporation

REMOTE SENSING CONTRIBUTIONS TO THE MANAGEMENT OF RENEWABLE RESOURCES

Dr. Charles Sheffield
Vice President
Earth Satellite Corporation
Washington, D. C.

ABSTRACT

This paper describes the present and future potential contributions of space-derived remotely sensed data to five major areas of renewable resources: agriculture, forestry, rangeland, coastal zone, and oceanic harvest management.

Following a summary of the relevant satellites and sensors flown in space in the 1972 to 1984 time frame, the data needs for each renewable resource area are described. Data sources and data needs are compared and areas of data deficiency and limitations are identified. From this, the profile of earth sensing satellites to fill these data gaps in the 1985 to 1995 time frame is presented. Necessary collateral data sources are also defined.

In the final section, a discussion is presented on ways in which space systems under development by different countries and international agencies could be dovetailed to create a supply of data of maximum utility in managing renewable resources.

INTRODUCTION

The renewable resources of the Earth logically include any source of energy or of material that is not depleted by use, and this encompasses such things as solar energy acquired by direct collection, either on the ground or in space. However, customary usage of the term "renewable resources" takes a more restrictive definition as follows: Renewable resources are those sources of energy or material that derive from biological processes and are replaced by continuous re-supply or re-growth. They exclude agents which are often referred to as "forces of nature." The latter class includes wind power, tidal power, ocean thermal power, hydroelectric power, and solar power. In practice, all these natural forces, including biological ones, have their origin in the influx of solar radiation, as does the non-renewable resource of fossil fuels.

The principal renewable resource products as defined above come from five major areas: agriculture (both foods and fibers), forestry, rangeland management, coastal land management, and ocean harvest. These are very much "earth-bound" activities, and it is perhaps surprising that spaceborne sensing systems are so important a tool in their management. That this is so arises from two main circumstances: the areal extent of the resources is very large (millions of square miles of forests, fields, ranges and oceans) so that some type of synoptic look at the resource is highly desirable; and at the same time many significant events take place on a small scale and in a tight time frame, so that exhaustive methods of examination, or even sample methods of examination, become prohibitively expensive using aircraft observation or ground sampling methods.

The United States is fortunate in this respect, since data collection systems based on ground and aerial methods already exist. However, the situation is much different through most of the rest of the world, where an infrastructure to implement an efficient ground and aerial data collection system is often lacking. Remote sensing systems using spaceborne instruments have great appeal in such circumstances, and the potential low-cost repetitive nature of spaceborne coverage is attractive even where other systems already exist.

In this paper, we will be concerned with four basic questions:

1. What are the principal tools that space can provide for the monitoring and measurement of renewable resources now and in the future?

2. What is the cost of these tools compared

with alternative methods, both in this country and abroad?

3. What are the main limitations of the present generation of spaceborne systems for renewable resource applications?

4. What do future systems, to be flown through the remainder of the 1980's and early 1990's, offer as promising new tools for these problems?

We will confine ourselves largely to the technical issues. When these lead to a larger question, e.g., a need for five-meter ground resolution with its implied problem of international surveillance agreements, the issue will be addressed only as a purely technical one of costs and benefits, and not one of political or diplomatic realities. The importance of these other factors is not dismissed, but a full discussion calls for a paper with a completely different emphasis.

DATA SOURCES FROM SPACEBORNE SENSORS

In Table 1 a summary is given of sensor systems already flown, or planned to fly in this decade. Of these, the Landsat spacecraft 1, 2 and 3 have sensors that were designed with renewable resources, particularly agriculture, in mind. SEASAT's synthetic aperture radar was designed primarily to measure properties of the ocean surface, although one of its virtues, its cloud-piercing power, is clearly of interest in monitoring ephemeral phenomena of any type of earth resources. Its short lifetime before a power failure (four months) limited the possible use of the SEASAT radar.

The Coastal Zone Color Scanner (CZCS) and the Advanced Very High Resolution Radiometer (AVHRR) are relatively low resolution instruments despite the promising name of the latter. They are therefore most useful only for broad overviews of large ground areas. The higher resolution sensors of SPOT and Landsat-D are still under development, with launches planned for 1984 and 1982, respectively. Stereosat and Mapsat are not part of any firm program, and in any case, Stereosat will be of most value to the non-renewable resource interests.

Skylab has not been included here, since although its earth resources experiments were significant, they formed no part of a continuing series, and the observations were acquired with no uniformity of look angle or sun angle.

Each existing Landsat spacecraft has a ground repeat pattern that gives coverage of all the earth every 18 days, from latitudes 81° North to 81° South, cloud cover permitting. Landsat-D will have a 16 day repeat pattern, and SPOT a 26 day one. However, SPOT has a side-looking capability in its sensors that enable the same point on the ground to be seen on an average every two and a half days. This may be especially valuable in areas of frequent cloud cover, where Landsat may go for many months without recording a satisfactory cloud-free image.

To set the resolution properties of these spacecraft in context, note that the CZCS and AVHRR cannot see ground features that are as large as a 40 acre field, and a 160 acre field is at their borderline of distinguishable objects. The Landsat Multi-Spectral Scanner will allow observation of an area the size of a football field, and the Thematic Mapper of Landsat-D and Return Beam Vidicon of Landsat-3 will pick up objects as small as a baseball infield. SPOT, Stereosat and Mapsat can see single family houses. It is worth noting that no spaceborne civilian sensor announced for flight in the 1980's or 1990's has better than 10-meter resolution.

By comparison, aircraft photographic coverage can offer resolutions of one meter or better and stereo, natural color, or color infra-red pictures are readily obtained.

The advantages of aircraft coverage are resolution and flexibility. The advantages of spacecraft coverage are synoptic coverage, uniformity of look angle and sun angle, regularity of repeat coverage, and low cost. If the use of aircraft coverage is thought of as analogous to the use of a private automobile, allowing the owner to go when and where he chooses, then the spaceborne systems resemble public transportation systems. They operate along fixed routes and according to a fixed schedule, but they remove from the user the burden of operating the system. They can thus offer very low user costs to compensate for their lack of operational flexibility.

To pursue the analogy a little further, all public transportation systems are not equally useful for all purposes. When particular applications are looked at, the spaceborne remote sensing systems similarly show their advantages and their disadvantages. If high resolution coverage is essential, Landsat RBV, SEASAT, or in a few years time SPOT data must be preferred. If spectral range of coverage is important, the Landsat MSS, the CZCS, or later in the decade, the Thematic Mapper should be used; and if cloud-penetration capability is mandatory, only SEASAT or some as-yet unannounced successor's spaceborne synthetic aperture radar will serve.

It is not obvious a priori that these spaceborne sensors, existing and planned, can serve any useful purpose for renewable resource estimation. To decide that issue, it is necessary to review the data needs of different resources. This is addressed next.

Table 1: Resolution and spectral distribution for resource satellites, 1972-1984

Instrument	Ground Field of View	Spectral Distribution	Status
Multi-Spectral Scanner(1) (Landsat 1, 2, 3 and D)	79 meters (sampled to 57 x 79 meter pixel)	0.5 - 0.6 μm 0.6 - 0.7 μm 0.7 - 0.8 0.8 - 1.1	Flown
Return Beam Vidicon(1) (Landsat 1 and 2)	65 meters (medium contrast scene; little data available from these instruments)	0.475 - 0.57 μm 0.58 - 0.68 0.70 - 0.83	Flown
Return Beam Vidicon(2) (Landsat-3)	30 meters (medium contrast scene)	0.505 - 0.90 μm	Flown
Thermal Infra-Red(2) Channel (Landsat-3)	240 meters (Note: data from this sensor was never released)	10.4 - 12.6 μm	Flown
SEASAT Synthetic(3) Aperture Radar	25 meters (data only from July to October, 1978)	1.27 GHz	Flown
Coastal Zone Color Scanner(3)	825 meters	0.43 - 0.45 μm 0.51 - 0.53 0.54 - 0.56 0.66 - 0.68 0.70 - 0.80 1.05 - 1.25	Flown
AVHRR (Advanced Very High Resolution Radiometer on NOAA-6)	1000 meters	0.55 - 0.68 μm 0.725 - 1.10 3.55 - 3.93 10.5 - 11.5	Flown
Thematic Mapper(4) (Landsat-D)	30 meters 120 meters	0.45 - 0.52 0.52 - 0.60 0.63 - 0.69 0.76 - 0.90 1.55 - 1.75 2.08 - 2.35 10.4 - 12.5	For Fall 1982 Launch
SPOT(5)	20 meters 10 meters	0.50 - 0.59 μm 0.61 - 0.69 0.79 - 0.90 0.50 - 0.75	For 1984 Launch
Stereosat(6) (Proposed, but no approved program)	15 meters (tentative)	0.5 - 0.9 μm (tentative)	Flight Date Unknown
Mapsat(7) (Proposed, but no approved program)	10 meters	0.47 - 0.57 μm 0.57 - 0.70 0.76 - 1.05	Flight Date Unknown
ERS (Japanese system, details not yet available)	Not specified	Visible, infrared, thermal infrared, and radar	Proposed 1986 Launch

MANAGING RENEWABLE RESOURCES: THE INFORMATION NEEDS

Renewable resources are defined here as biologically renewable sources, i.e., as the supplies of animal and vegetable materials. Remote sensing of the earth from space is useful for managing these resources to the extent that relevant biological phenomena can be observed, measured or inferred. Even when indirect indicators of biological or related physical events are acceptable as data sources (example: change in hue of a Landsat image area as evidence that crop germination has taken place), it is necessary to have that information available within a certain time, and to know when the event occurred in real time. This stands in contrast to non-renewable resource studies, where data timeliness is usually less critical. This timing element, plus the need to study individual fields, shorelines, and timber stands, implies resolution requirements and timing requirements that are generally different for each resource. For example, the data needs for annual and perennial crops are quite different.

In Table 2 a representative (but certainly not exhaustive) list of data needs is suggested for different areas of renewable resources. This list assumes that the spaceborne systems available are making observations of land and water beneath directly, rather than through the intermediary instruments of a data collection system (DCS) as carried on Landsat 1-3. A DCS presupposes in situ measuring devices down on earth, and it uses the satellite above only as a convenient method of collecting signals sent from those devices. Data collection systems are a good way of receiving direct information on soil moisture, snow depths, glacial flows, wind speeds, stream flows, and many other parameters of physical interest. Since the best use of space-derived information on ground-based resources generally implies the combination of that information with collateral data (such as soil moisture and crop calendars) the value of a data collection system to resource estimation is potentially very great.

Table 2 also represents a massive grouping and simplification of the many factors that apply in practice to the measurement and management of resources. All geographical variation, caveats on use, and complications have been omitted. This reduction is necessary to allow any sort of summary to be presented in a single table. It should be noted that there are in the literature long discussions of the main factors that limit the use of remotely sensed data for each of the areas mentioned here.[7] The use of the table presented thus permits only gross comparisons of data needs and data sources. However, other uncertainties, such as those of data processing options, data timeliness, and equipment performance, suggest that any attempt to achieve a finer match of needs and sources is probably self-deluding. In addition, on the data supply side no allowance has been made for the possible entry of Japanese spaceborne earth sensing equipment in the 1980's, or of the possibility that the United States program will change significantly as a result of private enterprise involvement in the U.S. earth resources program.

In summary, the entries of Table 2 should be looked to more for the way in which they point out the relative needs of different renewable resource areas, rather than for the absolute accuracy of the numbers that the table contains.

There is another implied assumption built into Table 2, and it is one that needs careful examination. Present methods for managing renewable resources are based on certain operating practices that have evolved over the years, in which remotely sensed data have not played much part. Thus rather than asking the general question, "How can remotely sensed data be useful in estimating renewable resources?", there is a tendency for user groups to ask a rather different question, namely, "What properties should remotely sensed data possess to be directly substitutable for present data sources?"

The two questions are profoundly different. The emphasis on direct substitution of one data source for another, rather than the acceptance of some different use of spaceborne data to give the same answers (even though not perhaps using the same methods) reflects the need for more experience with remote sensing data. When the properties and limitations of spaceborne data are better understood, users will be better able to relax the requirement of Table 2, and to recognize that it is not necessary for space-derived data to serve as a direct substitute for conventional data sources.

To offer one practical example, none of the data sources available from space in the 1980's will permit the viewing and measurement of single tree crowns. To many foresters, that says that those data have no useful part to play in the process of forest inventory. However, that is not the case. Landsat data, particularly when Landsat-D is in orbit, permit the general mapping of forest types on a broad scale. This in turn permits the definition of a more efficient sampling frame, from which aircraft and ground survey can be designed, and this more efficient frame means that fewer survey samples are needed to achieve prescribed accuracies of inventory. The spaceborne data will not serve as a substitute for the other data sources, but

Table 2: Data needs

Agriculture	
Acreages:	Spatial resolution: 15 meters Spectral resolution: 0.1 μm Spectral range: 0.45 μm to 1.1 μm Frequency/timing: 3 times per growing season, selected dates Collateral: crop calendars, crop practices
Yield:	(1) for growth models Spatial resolution: 1 km Spectral resolution: panchromatic in visible and in thermal infrared Spectral range: 0.4 to 0.7 μm and 10 to 12 μm Frequency/timing: 4 times/day in growing season Collateral: crop calendars, soils, weather stations
	(2) for model calibration and adjustment Spatial resolution: 15 meters Spectral resolution: 0.1 μm Spectral range: 0.45 μm to 1.1 μm Frequency/timing: bi-weekly through growing season Collateral: soils, crop type
Forestry	
Inventory:	Spatial resolution: 3-5 meters Spectral resolution: 0.1 μm Spectral range: 0.5 μm to 0.8 μm Frequency/timing: annual coverage Collateral: species, stand sizes, stand types
Stratification:	Spatial resolution: 80 meters Spectral resolution: 0.1 μm Spectral range: 0.5 μm to 1.0 μm Frequency/timing: twice per year at selected dates Collateral: soils, slopes, species, stand sizes
Rangeland Management	
Stratification:	Spatial resolution: 100 meters Spectral resolution: 0.1 μm Spectral range: 0.5 μm to 1.1 μm Frequency/timing: twice per year at selected dates Collateral: species, soils, rainfall
Inventory:	Spatial resolution: 2.5 meters Spectral resolution: 0.1 μm Spectral range: 0.4 μm to 0.7 μm Frequency/timing: 4 times/year (seasonal) Collateral: species, soils, rainfall
Coastal Zones	
High/low tide delineation and coastal changes:	Spatial resolution: 1 meter Spectral resolution: 0.05 μm Spectral range: 0.4 μm - 0.8 μm Frequency/timing: selected dates (that depend on local seasons) Collateral: species
Currents, erosion, sediments, pollution:	Spatial resolution: 30 meters Spectral resolution: 0.1 μm (visible near infra-red), 2 μm (thermal) Spectral range: 0.4 μm to 1.1 μm, 10-12 μm Frequency/timing: seasonal coverage Collateral: weather, flow rates
Ocean Harvest	Spatial resolution: 10 meters Spectral resolution: 0.1 μm (visible and near infra-red), 2 μm (thermal) Spectral range: 0.4 μm to 1.1 μm, 10-12 μm Frequency/timing: every two weeks, through year Collateral: currents, weather, temperatures

will render their use far more efficient.

For renewable resources, there is an alternative to observing the status of plant and animal communities, and that is to model the status dynamically. When this approach is adopted, the types of variables needed change drastically, and in particular the resolution and frequency requirements for spaceborne data may become totally different.

As a well-studied example[8] of this approach, consider the estimates of production for a crop, such as wheat, cotton or soybeans. The production from an area (county, state or country) depends on two factors: the acreage planted, and the yield of each such acre. One approach to determining the total production is therefore via ground-based estimates of acreage and associated yield for a series of sample plots, and then the expansion of the sample data to the total production through some type of statistical sampling model. This approach has been used for a long time, and it depends on frequent observation of crop condition to provide the estimates of probable plant yield. However, this conventional approach would require very high resolution data if the same sort of analysis were attempted using remote observations. It would be necessary to see leaf and flower condition on the plants in sample areas, and to observe the effects of insects and disease at first hand.

As an alternative to this, it can be argued that the growth of a plant is a deterministic process, and one that should be able to be modeled in terms of simple and fundamental physical variables such as rainfall, solar radiation budget, planting date, and soil type and depth. Indeed, such growth models, termed phenological models, have been developed for a variety of crops. For any particular crop, the knowledge of the appropriate set of physical variables should allow one to compute the crop condition, and hence its yield, without ever seeing the plants themselves.

SATELLITE DEVELOPMENT NEEDS

An examination of Table 2 raises questions about the validity of the data needs listed there. In the past, attempts to obtain estimates of the resolution needs, spatial and spectral, of different disciplines have proved to be misleading. Most users cannot quote resolution needs. They do not know them. They quote the resolution of existing systems that provide them with the data used for their operations. An interesting analogy with the early days of the Landsat program can be drawn, when before the launch some users were calling for one-meter resolution on the ERTS-1 system, and asserting that the system would be useless for agriculture, for example, unless such resolution was achieved.

However, even allowing for the tendency to state resolution of present data rather than resolution needs, it is clear from Table 1 and Table 2 that in all five areas of applications for renewable resources the desired data performance exceeds the available data, both spatially and spectrally, for projected satellites of the 1980's.

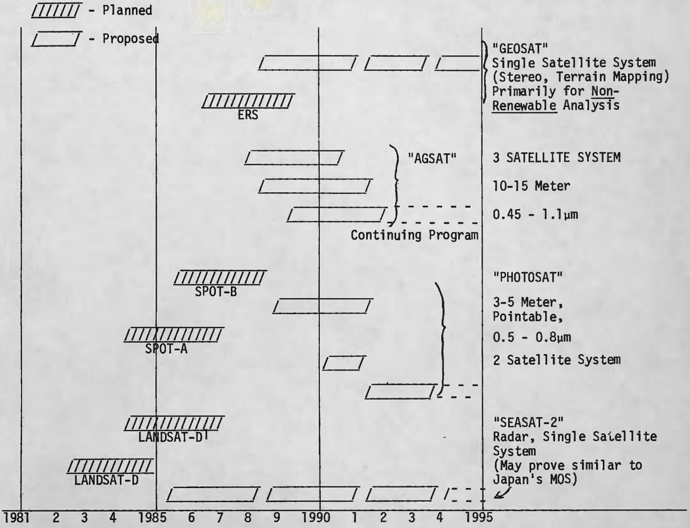
There are two main needs that remain unfilled. One is for a very high resolution (five meters or better) system, through the visible out to perhaps 0.9 micrometers, to sense selected areas of the earth's surface on a sampled basis. The other is for a shorter wavelength coverage, in the blue band from 0.4 to 0.5 micrometers. This is especially useful for water penetration and submarine topography analysis. Space coverage for this shorter wavelength, however, is difficult because of the large atmospheric scattering. Skylab imagery in the blue band showed high sensitivity to atmospheric haze, and the Skylab S-192 scanner data at its shortest wavelength provided little more than back-scattered light from the earth's atmosphere. Special ground processing methods are needed to produce a useful signal against this background of visual noise.

The provision of the collateral data called for in Table 2 is not the concern of the satellite programs, though such data is essential for the overall program plan. Restricting attention therefore to the needed satellite coverage, a profile of proposed and desirable satellites for the period 1985-1995 is shown in Table 3. Note that this table is concerned with the needs for renewable resources only, but that the capability provided by non-renewable resources systems, where the latter are already proposed, is presumed to be available.

It is clear that the planned systems fall short of what would be needed to satisfy the needs for renewable resources data from spaceborne systems in the next fifteen years. There is no plan to launch any satellite with five meter resolution or better in that time frame. Perhaps this reflects political sensitivities more than technology limitations, but there is also another factor at work. Five meter coverage from aircraft is provided on an as-required basis, and in each application there is likely to be an economic analysis which decides whether or not that coverage is necessary, or if alternate data sources might be used to provide the information as cheaply.

The use of a satellite to provide this high resolution coverage, on the other hand, calls for a different sort of decision. Although one can predict with some confidence that data derived from space should be an order of

Table 3: Launch Program
(Renewable Resources Needs)



magnitude less costly than aircraft data, this is true only when the development and launch cost of the spaceborne system is spread over many different applications and over a long period of time. How then can the initial capital investment be justified?

Since no single project can justify this investment, a decision to launch a satellite system is logically preceded by an analytic effort that aggregates many future needs for the data, and establishes the cost per unit of data in terms of that large aggregation. Unfortunately, most projects that might use the spacecraft data will have not been defined when the spacecraft justification study is performed. As a result, one can seldom hope to justify the satellite system on such a basis. Instead, one must rely on a general argument asserting that the market for, say, five meter resolution satellite data is there, even though it is hard to quantify in advance. Such logic is never popular with accountants.

COOPERATIVE EFFORTS TO DEVELOP THE NEXT GENERATION OF EARTH RESOURCES SATELLITES

It seems unlikely that any data system proposed for construction in the next fifteen years will satisfy all the needs of renewable resources projects. However, it may be that no single data acquisition system should be looked to to provide all such data inputs. A better approach is to look at complementary multiple systems.

This would call for a change in the present methods of satellite system design, where the different proposed national systems seem to be competitive rather than complementary. However, one can argue that by emphasizing the differences among systems already under construction, we can see the way to provide a system of satellites that may serve our needs. For example, the French satellites of the SPOT series are limited in their spectral range, but they have good ground resolution. By holding their response to a micrometer or less in wavelength, and by the increased use of linear arrays in a sampling observation mode, the SPOT series could be focused primarily on substitution for conventional aerial photographic coverage.

Landsat-D lacks this spatial resolution, but it has much greater spectral range. It would be logical for the U.S. programs to concentrate in the longer wavelength coverage, perhaps from one micrometer out to twelve micrometers, accepting the resolution limitation of between 30 and 240 meters that this implies in the next few years (though perhaps the shorter wavelengths could go to 20 meters). The combination of high resolution, sampled SPOT data with lower resolution synoptic data from Landsat-D and its successors is a problem only of ground processing, not of satellite construction and design. Already there are multi-level data systems in development that will allow the use of such combinations of different types of data.(9)

The Japanese have already announced their plans for a Marine Observation System (MOS), although more recently they have proposed the merger of this with their Land Observation System (LOS) into a general Earth Resources System (ERS). One can argue that this may be a mistake. The best method might be for the Japanese to concentrate on a satellite system that offers good coverage of the oceans, with the wavelengths and the resolution appropriate to that, leaving the coverage of the land areas to other systems. So long as an "open skies" policy applies to all the earth resources data collected, each country has the chance to obtain desired data without the need to launch all necessary data acquisition systems themselves.

Cooperative approaches of this kind are never easy. They present problems of organization, of national pride, of national confidence in the performance of foreign partners, of multiple-source financing, of national security (in the case of high-resolution sensing instruments), of operational guarantees, of multi-lateral legal agreements, of currency exchange, of developed versus developing country rights and privileges, of technology transfer, of integrated system design, and of the reconciliation of varied national interests.

Despite these complications, an international approach (modeled, as many have already suggested, on the Intelsat concept) may be the only way that the desired results can be achieved. It is unlikely that any nation can, on a fully cost-justified basis, launch and maintain their own satellite system for the purpose of monitoring and measuring their own renewable resources. All the systems existing or proposed expect to derive a good part of their revenue from the monitoring of resources that are located in other countries than the purchasers of the data. This can only work if access to such resources is assured to the purchaser, or if the purchaser already operates in a way competitive with the monitored resource (for example, a wheat grower will want to know the world-wide wheat crop, even if he cannot influence the production in any area other than where he grows the crop).

In the long term, despite all the complications, an international approach to the spaceborne sensing of renewable resources is the most promising way to proceed. Given energy and initiative by three or four nations, it could happen by 1990.

REFERENCES

1. ERTS Data Users Handbook; Goddard Space Flight Center (1972, with updates)
2. Landsat Data Users Handbook; Goddard Space Flight Center (1972, with updates)
3. Sherman, J.W., Report on the Conferences on the National Oceanic Satellite System; Appendix E and F. U.S. Department of Commerce (September 1980)
4. Landsat-D Operational Quality Assurance/ Performance Evaluation Review; Goddard Space Flight Center User Needs Review (February 11, 1981)
5. SPOT satellite-based remote sensing system; Centre National d'Etudes Spatiales brochure (February 1981)
6. Preliminary Stereosat Mission Description; Jet Propulsion Laboratory report 720-33 (May 30, 1979)
7. Conceptual Design of an Automated Mapping Satellite System (MAPSAT); Itek Optical Systems, report prepared for U.S. Geological Survey (February 1981)
8. Merritt, E.S., Landsat interactive applications with the CROPCAST system for crop yield assessments. ACSM/ASP Fall Convention and Exhibition, October 1978. American Society of Photogrammetry (1978)
9. Multiresource Inventory Methods Pilot Test (Phase I), Volume II; USDA Forest Service (1980)