REMOTE SENSING AND THE SOUTH:

A CRITICAL EVALUATION OF COMMON APPROACHES

by

Michele K. Johnson

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ABSTRACT

The results of this study suggest that, (1), although low cost airborne imagery is generally superior to orbital imagery for many Southern ("Developing World") applications, orbital sensors are commonly preferred in practice, and (2) the South's need for applied remote sensing studies is not being met in the published literature. Three major English language remote sensing journals (*International Journal of Remote Sensing, Photogrammetric Engineering & Remote Sensing* and *Remote Sensing of Environment*) were assessed for their Southern remote sensing content over the past eleven years.

Most published research from the South was technical in nature, used orbital imagery rather than aerial imagery and was done at a small scale. Very few mapping studies included local or community participation. Southern authors frequently stated that resource management and mapping should be a priority, however these types of articles only appeared with a frequency of 11%—much less than the percentages of technical articles (about 50%). The percentage of published articles written by local authors has increased over the years, showing that Southern researchers are acquiring the knowledge to study their own (and other Southern) countries, although their research concentration is just as technical as Northern authors.

It was difficult to determine what the appropriate methods for resource management and simple mapping in the South might be due to the low incidence of applied studies in the literature. A case study of a forest area in Kananaskis Alberta, Canada was used to assess the utility of several sensor systems at different scales and to compare the utility of digital and visual classifications. Results indicate that resource management applications may often require airborne imagery, but orbital imagery may

be useful in cases where aerial imagery is not available, and can be used for quickly mapping areas of interest at a small scale. Visual interpretation of aerial photography is the preferred technique for simple mapping and resource management in the South. When this is not available, orbital imagery can be used, but at a reduction in spatial resolution. Orbital imagery is best used for hazard detection and monitoring land use changes at a small scale. Visual interpretation (of both photographic and orbital imagery) is recommended over digital evaluation because of its simplicity and accuracy.

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Chapter 1. INTRODUCTION

1.1 Remote sensing and human needs

Remote sensing imagery has a broad potential to address human needs. Aerial photographs can supplement and update topographic maps and provide resource information more quickly than ground surveys. Orbital imagery (satellite imagery) can be used to provide quick and accurate small-scale maps of countries and continents, near real-time hazard assessment and early warning for floods, droughts and storms (Gregoire *et al.*, 1993; Ramana Murty *et al.*, 1993), and can provide a window into remote or politically sensitive areas where aerial imagery is not available. For example, orbital imagery can provide evidence of otherwise unmonitored logging activities.

My thesis is that low cost airborne imagery is superior to orbital imagery for many Southern ("Developing World") applications but that in practice orbital sensors are preferred. Remote sensing publications seldom address basic human needs: food, fuel, shelter, and environmental sustainability. Resource management is the most important application of remote sensing in the South (Ayyangar and Rajan, 1986; Hamza, 1986). Perhaps it isn't surprising that most published remote sensing papers deal with abstract technical subjects, but it is significant in light of the South's need for resource management. Local and indigenous people need to be empowered and given voice and presence. Map making can to create a database for thoughtful and creatfive land use decisions, and orbital imagery and aerial imagery can be used as powerful tools. Local and indigenous people should be able to make use of remote sensing technology to create maps that acknowledge their presence so that their voice will be heard in land use decisions.

This study examines general trends in remote sensing in the South since the 1970's and specific trends since 1986. It attempts to show whether Southern and Northern researchers approach their topic differently. Do they work at different scales and use different sensors? Do Southern researchers have a more applied focus than Northern researchers? Do Southern researchers include more local participation? Most importantly, do the publications and technologies of the international remote sensing community have any application to the needs of the South? A comprehensive literature assessment of three major international English language remote sensing journals from 1986 to July 1997, as well as a general review of other relevant sources, was used to examine these questions.

The lack of simple mapping and resource mangement studies published in the Southern literature makes it difficult to determine what methods might be appropriate for resource management and simple mapping in the South. This seems important in light of Southern authors' frequent statement that resource management and mapping should be a priority (Vayda, 1983; Ayyangar and Rajan, 1986; Hamza, 1986; Luscombe, 1990). In the remote sensing literature there are differences of opinion regarding the utility of various sensor systems. A case study was undertaken to determine the relative merits of common approaches to remote sensing of terrestrial resources, particularly regarding scale and sensors. Imagery from various sensor systems was examined for its ability to spatially and spectrally resolve forest classes and other features at various scales, and the assessment was used to recommend suitable applications for remote sensing in the South.

1.2 The research questions

The purpose of this study is: to assess the current remote sensing research in the South in a comprehensive way, and to create a remote sensing reference useful to Southern resource managers. In assessing the remote sensing research, the following questions were asked:

1. What types of research have been carried out in the South in the ten year period 1985-1996, and between 1996 and 1997?
2. What were the common scales and imagery sources used?
3. What percentage of Southern studies did Southern authors publish?
4. Did Southern and Northern researchers approach their topic differently; i.e. did they work at different scales and use different sensors?
5. Did Southern researchers publish more applied (less abstract) studies than Northern researchers?
6. Did either group use local participation in their research?

These questions were addressed through a literature assessment.

To create a remote sensing reference useful for Southern applications, I employed a case study of several sensors and also reviewed current literature. My goal was to be able to make recommendations for appropriate technologies and methods in specific Southern applications. While reviewing the literature and the case study imagery, the following questions were asked:

1. What are the common approaches to the following applications in the South: simple mapping, forest monitoring, mineral exploration, agricultural assessment, hydrological studies, flooding and hazard assessment?

2. Are there less expensive or simpler approaches that are equally effective for these applications? i.e. is low-cost aerial imagery superior to orbital imagery for many Southern applications?
3. Is the technology appropriate to the South's current level of technology and budget?
4. Are the common imagery choices appropriate and, if not, what approach would I recommend?
5. How well does remote sensing imagery perform in a boreal forest context? How well do the images discriminate forests, both digitally and visually?
6. Does a digital approach to classification have advantages over a visual approach?

After reviewing the literature, a set of images from orbital and airborne sensors were visually and digitally evaluated for their ability to resolve forest stands and features in an applied context. This was done to address the last three research questions. Following this the advantages of some common remote sensing approaches, including visual and digital classifications were demonstrated. Appropriate remote sensing recommendations were made for specific applications in the South such as the creation of and updating of maps and the application of remote sensing to tropical forests, minerals, arid landscapes, deserts, and agricultural applications at various scales.

1.3 Defining the South

The terms North and South replace the terms Developed and Developing countries, First and Third worlds, rich and poor countries (Cole 1987), or industrialized and non-industrialized countries (Dickenson *et al.*, 1983). Terms of this kind can oversimplify. The original focus was Southeast Asia, but the small amount of published research in this area prompted the inclusion of other areas with similar problems in terms of remote sensing and resource management, and broaden my focus to the South in general.

The Brandt report (Brandt, 1980), which distinguished the wealthy "North" from the poorer "South" (Figure 1), forms the basis for the geographical units used in this study. The South consists of the countries below the dividing line. Brandt's (1980) boundary between North and South generally agrees with World Bank groupings that use economic and political criteria to distinguish industrialized and centrally planned economies from low income, middle income, and capital-surplus oil exporters (Dickenson *et al.*, 1983).

Income is the most common measure used to distinguish North from South. Average Northern incomes are ten to one hundred times greater than in Southern countries (Cole, 1987). Some Southern countries have levels of poverty much more extreme than others. Money is not the only factor separating North from South.

> When compared to the 'rich' countries, the people of the poor world have diets which are deficient in quality and quantity. There tend to be more people working in agriculture than in manufacturing. The average duration of life tends to be lower. A higher percentage of the population is illiterate. The export economies depend on primary products, from agriculture to mining, and often only one or two of these generate the majority of the export earnings (Dickenson *et al.*, 1983).

The South tends to be dependent on exploitation of its natural resources, and has a lower level of education and fewer trained scientists to monitor the exploitation of resources. Development policies often overlook the fact that, within a country, the poor are often most directly linked to the environment. The wealthy are not vulnerable in this way and so are often in a position to make un-ecological decisions (Warford and Partow, 1990). The South is also characterized by ecosystem vulnerability due to rapid deforestation, erosion, soil loss, desert advancement, and flooding. In some cases, the South's need to monitor resources has reached a critical stage, as social pressures are forcing rapid colonization of rainforest and associated deforestation.

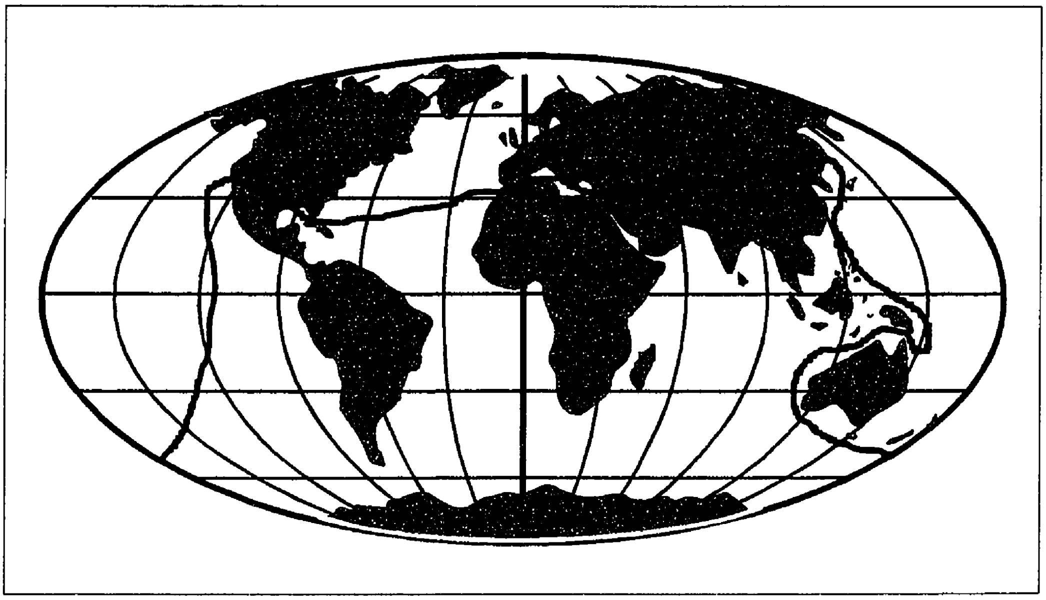


Figure 1. "North" and "South". This line (Brandt, 1980) distinguishes the countries of the rich North from the poorer South.

Chapter 2. REMOTE SENSING AND THE SOUTH

The South has very different social, economic, and natural resource conditions and constraints than the North and therefore may require a different approach to remote sensing.

Since 1970, researchers in the South have been studying growth in remote sensing with interest, resulting in an increase in published papers focusing on technology, and the contemporary application of it in Southern environments (see Chapter 5). Many studies are related to configuration of systems and testing new methods (Eva *et al.*, 1995; Franca and Cracknell, 1995; Rao *et al.*, 1995). Researchers generally limited their studies to small scales (less than 1:250,000) (Stone *et al.*, 1994; Lambin and Ehrlich, 1995), which do not address resources at a local level. For example, a remote sensing study may concern national-scale deforestation (Shimbakuro *et al.*, 1994), or natural resource assessments (Alwash and Zilger, 1994), utilizing orbital imagery, when a more immediate need may be a study of localized land-use change or indigenous peoples' traditional boundaries at a local scale. In this case, aerial photography or airborne multispectral imagery would be more appropriate than orbital imagery. A less expensive technology may have equal utility in a certain application. For example photographic products are cheaper than digital products, and would therefore be a better recommendation.

2.1 Technology transfer

Development for development's sake is a problem inherent in some Southern policies. Development should utilize technology to lead to "an improvement in the conditions of life" (Hamza, 1986), but often this goal is not kept in mind. It sometimes seems as though the South is adopting orbital imagery to compete with the North, where most remote sensing platforms have been developed and most remote sensing researchers are concentrated. To paraphrase the founding father of the Indian space program, thirty years ago, "the question is not whether India can afford a space program but whether it can afford not to be involved in such advanced technological activities." (Cracknell, 1986)

Some authors believe that remote sensing will not benefit the development of the South. It will only deepen the gap between rich and poor, both between and within countries (Dickenson, *et al.,* 1983; Chandrashekar, 1989). Many authors' concerns centre on the inordinately high costs of orbital digital products. Because of these costs "[I]t appears unlikely . . . except in a few special cases that the technology of remote sensing will contribute in any significant way to the real development of developing countries," (Chandrashekar, 1989) unless government policies are implemented in the North to permit sharing of remote sensing technology at a reasonable price (Alizai, 1990). The high costs of products may restrict remote sensing to the military in Southern countries, which will leave some countries with little money left over for the use of remote sensing for management of their natural resources (Chandrashekar, 1989). Poorer Southern countries are at a particular disadvantage.

In the 1980's researchers stressed the need for "appropriate technology" for the South (Harrison, 1992). Appropriate remote sensing technologies might vary between countries, but they would all have to be affordable. It is important that Southern countries be given accurate information to make their own technology decisions and that the technology fit the individual needs of the country.

2.1.1 Pressures influencing remote sensing decisions

There are strong external and internal forces encouraging Southern countries to adopt remote sensing technology and promote inventory monitoring and management of natural resources (Changchui, 1990; Luscombe, 1990). Current research is driven by funding and academic pressures, however, and not by social considerations. Funding, scientific bias, and commercial pressures may preclude researchers from addressing the basic needs of many countries for sustainable timber, food, and fuelwood sources.

Finances are most often implicated as a motivation for the North to promote remote sensing technology to the South. In the interest of fostering technology transfer, many studies have been done by outsiders funded by external granting agencies (Longdong, 1993). The North provides the South with grant money for adoption of orbital imagery technology, training, computing resources and satellite receiving stations. Since the late 1970's funding agencies such as the World Bank, USAID, CIDA and IDRC have provided a lot of direction for Southern researchers. Since most Southern countries' governments will rarely object to donations from large funding bodies, external forces tend to drive their technology choices.

The capabilities of remote sensing systems may be exaggerated by Northern technical enthusiasts, and the necessity for ground truth may be neglected when these systems are demonstrated to the South (Abiodun, 1977). "As with all newly developed remote sensing technology, there is a danger of exaggerating the capabilities of a system before its true potential can be demonstrated." (Justice *et al.*, 1986) Some researchers have self interests which are quite obvious, like the German space systems group which recommends its own satellite platforms as the "optimum solution . . . especially for developing countries." (Koelle and Meissner, 1986)

Map-making has historically been a source of power for the powerful (Harley, 1988). This statement was true for the early explorers to the "new world" of North America in the eighteenth century, and seems to be true for modern scientific methods of representing space as well (Brealy, 1995).

2.1.2 Barriers to remote sensing adoption

There are several barriers to remote sensing adoption in the South, many of which are economic (Specter and Sellman, 1986). Bottlenecks like lack of education and funding inhibit the South's ability to adopt remote sensing technologies to the same extent as the North. Large amounts of money are required to plan for remote sensing adoption, build ground stations to receive imagery, pay for imagery and data storage, buy the personal computers and workstations required to interpret the imagery, and train people to interpret it. Training is one of the biggest cost expenditures in adopting remote sensing technology (Niosi *et al.,* 1995). Because it requires less training, visual interpretation of hard-copy satellite imagery (photographic prints) and aerial photography is a recommended option until remote sensing imagery either becomes more affordable or there are more trained personnel in the South (Perera and Tateishi, 1995). Also, visual interpretation can more easily use the intelligence of the photo interpreter to greater advantage than computer classification of data by a non-specialist.

The costs of the imagery itself are a major barrier. A single digital image from either Landsat or SPOT costs over $4000 US. Digital products from Landsat are far more expensive than photographic products. The cost of Landsat imagery has risen sharply since Landsat was transferred to the private sector in 1986. Since then, the amount of digital products ordered by Southern countries has decreased. They are using mainly photographic products and this trend is likely to continue (Alizai, 1990).

Other barriers to remote sensing transfer to the South are high population growth, environmental degradation, poor intercommunication, low GNP and limited education (Perera, *et al.*, 1995). Solutions are vague in the literature. There is a general agreement that education is badly needed, as well as better communication between different levels of decision makers (Niosi *et al.*,1995). A published study of technology transfer to the South showed that the most successful transferees of technology were the ones that invested in preliminary research and development, before purchasing anything (Niosi *et al.*, 1995). Well educated transferees were the most likely to succeed in using a new technology effectively.

2.2 Mapping needs of the South

The South has a radically different economy and availability of trained personnel than the North (Brandt, 1980; Cole, 1987; Dickenson *et al.*, 1983). The South needs basic photogrammetric mapping, inexpensive imagery, and simple interpretation techniques. Each Southern country is different, making it difficult to lump their needs into a single category. Their ecosystems range from the most complex terrestrial ecosystem in the world (tropical rainforest) (Moffet, 1993) to one of the most simple (desert). They range in size from city states like Singapore, to countries with large relatively unmapped land masses, such as Brazil and Indonesia. Different countries will have different and varying mapping needs.

Different countries also have different levels of technology and educational sophistication. Use of satellite imagery as well as aerial photography has become relatively common in the larger Southern countries, such as China, India, Brazil, and

Indonesia (Longdong, 1993). These same techniques may not be appropriate for the smaller Southern countries. Each country may also have its own development agenda, including adoption of orbital imagery, though the level of sophistication in utilizing satellite imagery may lag behind the eagerness to acquire it.

Brandt (1980) considered agriculture, health, forests and food as priorities of the South. Resource management, environmental monitoring, hazard detection, and cultural mapping are important uses of remote sensing for the South. Many local and outside researchers have stated that management of natural resources is the most important use of remote sensing in the South (Vayda, 1983; Ayyangar and Rajan, 1986; Hamza, 1986; Luscombe, 1990).

Aside from the well-known problems of rapid resource exploitation in the South, there is also a problem of cultural rights (usually the right of ownership) being affected by logging and mining interests in traditional use areas. There are many land use conflicts between indigenous people and the more powerful government and industries, for example, logging and mining companies (Peluso, 1994). National mapping campaigns at large scales should address these conflicts in resource use. In absence of national attention, remote sensing can be a valuable resource, complementing standard mapping, to international assistance programs and local people to map and document their land tenure as well as historical use of the land.

Quite often in the South existing government base maps are either old, small-scale, inaccurate, or all three (Brown *et al.*, 1995; Flavelle, 1995). Some areas may not be mapped at all. Large-scale base maps are usually simply unavailable. There is a real need in the South to implement existing photogrammetric methods to create accurate, up-to-date base maps at a large scale to cover the entire country. Photogrammetric methods are the most widely accepted and used method to achieve this. Many

Southern countries are attempting to upgrade their topographic coverage, but often the resulting topographic maps and aerial photographs are not made available to the public for security reasons. Large-scale mapping efforts often have to utilize small-scale base maps and satellite imagery (Gilruth *et al.*, 1990; Welch *et al.*, 1990). To fill the gap in spatial information, there have been several large, national-scale mapping attempts in the South (Sader *et al.*, 1990; Rasch, 1994; Stone *et al.*, 1994) utilizing orbital imagery, either Landsat or NOAA AVHRR.

2.2.1 Including local information

Local information is commonly overlooked in scientific approaches to remote sensing and resource management. However, when assessing land use changes, it is essential to explore the social processes underlying the changes (Olive *et al.*, 1996). Local people should be used to provide local information to complement the resource assessment, rather than simply mapping missing chunks of forest. Technology-oriented researchers could learn from the techniques developed by human-oriented researchers (e.g. human geographers and anthropologists). Researchers can guard against using technology for technology's sake by ensuring their methods are grounded in ethnographic theory (Behrens *et al.*, 1994). In 1994, an entire issue of *Human Ecology* (Vol 22, No 3) was devoted to remote sensing, and every Southern article in this issue involved local participation. These (mainly Northern) Geographers and remote sensing researchers incorporated Participatory Rural Appraisal (PRA) and Rapid Rural Assessment (RRA) techniques developed by anthropologists. PRA is an approach to local studies in the South (and parts of the North) that encourages local participation, recognizing that the knowledge and expertise of villagers is often ignored in other scientific approaches (Chambers, 1994c).

Common PRA techniques include participatory diagramming and community mapping (Chambers, 1994a). An optimal scale for PRA is 1:5,000 (Poole, 1995a). Aerial photography can provide a useful starting point for local PRA mapping exercises (although the common scale of most available aerial photographs (1:20,000 to 1:60,000) can be too small-scale for community discussions) (Poole, 1995a). The resources of an entire village can be utilized to create sketch maps useful for community discussion and empowerment (Chambers, 1994b; Peluso, 1994). Common RRA techniques include informal interviews, key informants, direct observation, and group interviews. Interdisciplinary research can offer analysis at a scale that "bridges local adaptive strategies with ecological and economic variation at a regional level (Brondizio *et al.*, 1994)," especially when GIS is applied. The maps formed by PRA can be updated with aerial photography (Gonzalez *et al.*, 1995) and satellite images (Brown *et al.*, 1995). Updating the maps created during a PRA process is an attempt to use remote sensing in a manner appropriate to the South that reflects the needs of local people (Dove, 1986).

Chapter 3. SENSOR REVIEW: OVERVIEW OF ORBITAL AND AERIAL SENSORS

In the South, as in the North, the decision as to which remote sensing technology to use, or how to equip a remote sensing platform can be quite difficult, and depends on the applications to which the remote sensing systems will be put and the end products desired. This chapter presents an overview of the capabilities of several routinely available sensors: NOAA AVHRR, Landsat TM, Landsat MSS, SPOT, the Indian Remote Sensing Satellite, planned satellites, high resolution low orbit imaging satellites, aerial photography, aerial multispectral imagery (imaging spectrometers, multi-spectral scanners, video and electro-optical CCD), and radar.

3.1 Orbital Remote Sensing Systems

To simplify the presentation, Table 1 (adapted from Lillesand and Kiefer, 1994) lists the orbital sensors, their launch dates, orbiting altitude, return period, spatial resolution, swath width, and spectral channels. Aerial imagery is presented in section 3.3.2.

Table 1. Orbital Remote Sensing Systems

	Launch Dates	Orbiting Altitude	Return Period	Spatial Resolution	Swath Width	Wavelength Channels
NOAA AVHRR	several since 1979	833 km	daily	1.1 km	2400 km	red: 0.58-0.68 μm, near infrared: 0.72-1.10 μm, thermal: 3.55-3.93; 10.3-11.30; 11.5-12.50 μm
Landsat RBV	1972, 1975, 1978	900 km	18 days	80 m	185 km	green: 0.475-0.575 μm, red: 0.580-0.680 μm, near infrared: 0.690-0.830 μm
Landsat MSS	1972, 1975, 1978, 1982, 1984	900 km	18 days	79 m	185 km	green: 0.5-0.6 μm, red: 0.6-0.7 μm, near infrared: 0.7-0.8 and 0.8-1.1 μm
Landsat TM	1982, 1984, 1993 failed at launch (Landsat 7 planned launch 1998)	705 km	8 days	panchromatic: 30 m thermal: 120 m (Landsat 7 panchromatic: 15m, thermal: 60m)	185 km	blue: 0.45-.052 μm, green: 0.52-0.60 μm, red: 0.63-0.69 μm, near infrared: 0.76-0.90 μm, mid infrared: 1.55-1.75 μm, thermal infrared: 10.4-12.5 μm, mid infrared: 2.08-2.35 μm (Landsat 7 panchromatic 0.5-0.9 μμ)
SPOT	1986, 1990, 1993	832 km	26 days, but pointable	10 m (P), 20 m (XS)	60 km	Panchromatic: 0.51-0.73 μm; XS: 0.50-0.59, 0.61-0.68, and 0.79-0.89 μm
SIR-A and -B	1981, 1984 no longer in operation	260 km	-	A: 40 m, B: 25 m (azimuth), 15 m (range)	50 km	L-band: 23.5 cm
RADAR-SAT	1995	798 km	1-24 days	10-100m	various	C-band: 5.6 cm
IRS	1988	-	-	LISS-I: 73 m, LISS-II: 26 m	-	0.45-0.52, 0.52-0.59, 0.62-0.68, and 0.077-0.86 μm
QuickBird (planned)	1999	-	daily	multispectral: 3.28m panchromatic: 0.82 m	22 km	blue: 0.45-0.52 μm, green: 0.52-0.60 μm, red: 0.63-0.69 μm, and near-IR 0.76-0.90 μm

(adapted from Lillesand and Kiefer, 1994; Markham *et al.*, 1997; Earthwatch, 1998)

3.1.1 NOAA AVHRR

NOAA (National Oceanic and Atmospheric Administration) has launched several generations of satellites since 1979. Most of these satellites carry the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR was originally designed as a meteorological sensor--to estimate clouds and sea surface temperatures (Justice *et al.*, 1986). NOAA AVHRR has the lowest spatial resolution of the commercially available satellites (1.1 km). Its greatest advantages are rapid global coverage and a quick return period. It provides daily visible coverage and twice daily thermal infra-red coverage.

Its quick return period makes it easy to obtain cloud-free imagery in difficult areas such as the tropics. AVHRR's 1.1 km resolution is suitable for monitoring small-scale and global weather patterns and storms (Dang and Fang, 1988). It has also been successfully applied to global and continental scale mapping of land resources such as agricultural and forest areas (Malingreau *et al.*, 1989). The rapid return period makes it particularly suitable for hazard detection (e.g. fire and flood). AVHRR imagery has been used to monitor oceanic and weather conditions, volcanic activity, deforestation (Malingreau *et al.*, 1989), forest fire areas, agricultural areas, drought (Tucker *et al.*, 1987; Vukovich *et al.*, 1987), and to estimate soil moisture in Indonesia (Djojodihardjo, 1993).

The thermal channels are useful for monitoring very large forest fires and, to some extent, oil slicks. Saturated pixels in channel 3 can indicate fires, although field checks are necessary because other surface phenomena can also cause channel 3 saturation (Gregoire *et al.*, 1993). Oil spills can be monitored by visually interpreting thermal infra-red AVHRR channels due to differences in emissivity of the oil slick and the surrounding ocean (Cross, 1992). In the tropical forest, moisture, haze and smoke often prevent the use of visible and near infrared AVHRR data (Malingreau *et al.*, 1989). The thermal channel-3 can provide relevant deforestation features when the shorter wavelengths can not be used because of haze or smoke. The thermal range of wavelengths is least affected by water vapour.

There has been a great deal of interest in applying AVHRR data to vegetation classification. To this end, the Normalized Difference Vegetation Index (NDVI) was developed (Lillesand and Kiefer, 1994). This index, which measures the relative reflectance of the channel 1 (visible) band with the channel 2 (near-infrared) band (NDVI = Ch2-Ch1/Ch2+Ch1), can provide information on vegetation distribution and change. Vegetation has high NDVI values because of its relatively high near-infrared reflectance and low visible reflectance. NDVI can be used to discriminate vegetation from water and bare soil, and is often used for vegetation monitoring. NDVI has successfully estimated expected rainfall levels in the Sahel (Bonifacio *et al.*, 1993).

AVHRR data have been usefully applied to forestry, especially to global deforestation assessments (Malingreau *et al.*, 1989). They are best used at a very small scale, from regional to continental, or global. With AVHRR:

> First, the undisturbed primary forest can, in most cases, be discriminated from other secondary or non-forest formations using a combination of thermal and visible/near-infrared data. Secondly, the AVHRR analysis can provide unique elements of information related to particularly damaging events taking place in the forest; drought and fires can thus be detected, mapped and monitored (Malingreau, *et al.*, 1989).

Matson and Holben (1987) agreed that AVHRR's thermal channel showed the greatest contrast between clear-cut areas and the undisturbed tropical forest.

Small-scale agricultural assessments are possible with AVHRR data. Homogeneous areas such as savanna (Diallo *et al.*, 1991) and grasslands (Prince,

1991) are most easily discriminated by the 1.1 km pixels, however researchers must expect a preponderance of mixed pixels (Philipson and Teng, 1988) in global agricultural studies.

Given AVHRR's 1.1 km resolution, researchers should not try to apply AVHRR data to applications that require greater resolution. They will find that their studies are plagued with mixed pixels and result in inaccurate mapping. A forestry study in Ghana found that using AVHRR data may lead to inaccurate estimates of forest cover in regions of small subpixel forest or non-forest patches (Cross *et al.*, 1991). Forest classification of NOAA AVHRR imagery of Madagascar demonstrated that "1 km spatial resolution satellite data may be used to provide a reconnaissance level survey of the forest resources of a region or subcontinent when used in conjunction with fine resolution data," but warned that "AVHRR digital data cannot, in general, be used reliably to differentiate specific land cover types unless the classification is done in conjunction with fine resolution data." (Nelson and Horning, 1993) AVHRR data can not discriminate forests from woody crops in mesic areas (Achard and Blasco, 1990). NOAA AVHRR (and Landsat MSS) data were found to be too spatially coarse to be used for mapping land cover in low population density areas typical of central Africa, and other Southern areas (Wilkie, 1994). NOAA AVHRR data should be used for small-scale land assessments where a large area must be covered, or in cases where frequent updating is necessary.

3.1.2 Landsat RBV and MSS

The Landsat satellites were the first series of satellites designed to systematically collect Earth resources data. NASA launched the first Landsat satellite (originally named ERTS-1) in 1972. To date, five Landsat satellites have been launched successfully; the sixth failed at the time of launch (October 5, 1993). The first three satellites, Landsat-1, -2, and -3 carried the Return Beam Vidicon system (RBV) and the Multispectral Scanner System (MSS). The last RBV was a panchromatic high resolution system. The earlier RBV consisted of three cameras with sensitivities similar to colour infrared film: green, red and near infrared. These cameras stored the image on a photosensitive surface, which was then scanned in raster form to produce a video signal, similar to a television camera. This method produced images with greater cartographic accuracy than the Landsat MSS. However, the system was plagued with technical problems, and MSS soon became the primary system (Lillesand and Kiefer, 1994).

The MSS system utilized a line scanning system and produced multispectral data in a digital format. Landsat-1, -2, and -3 operated at an altitude of 900 km and covered a 185 km swath width in four wavelength bands: two in the visible spectrum, (green and red), and two in the near infrared (Lillesand and Kiefer, 1994). Landsat TM (supplied on later satellites) can be resampled to MSS resolution, allowing quicker return coverage and data continuity with MSS. MSS images can be obtained either in digital format or as a photographic product: either black and white images of single bands or as colour composites, similar to the colour output of colour infrared film.

MSS imagery is best used for discovering large features (that may not be visible on larger scale aerial photographs, such as geological features), for long-term global monitoring and for small-scale changes over time. The most common application of MSS imagery has been geological mapping (Lillesand and Kiefer, 1994). Large fault lines and stratigraphic features are visible on MSS imagery (Baskaran *et al.*, 1987). Radar has been used to complement MSS images for reconnaissance of geological lineaments (Koopmans, 1986). Radar has also been found to complement MSS data to discriminate residential areas and constructed linear features in China (Jiyuan *et al.*, 1986). Small-scale (low resolution) agricultural studies are possible with MSS imagery. MSS was used for soil surveys in India, using prints for preliminary analysis (Singh, 1989), and CCT's for training classification (Biswas, 1987), and was found to be considerably cheaper than aerial surveys for large areas.

One of the most useful features of MSS data is its long timeline. It can be used in studies that compare land changes from 1972 to the present. In the 1980's TM data were chosen in favour of MSS imagery, but many researchers still use MSS because of this longer timeline. It is useful in areas with relatively homogeneous land-cover types such as forest, rangelands, and agricultural lands (Sandham and Rensburg, 1987), and agricultural soil characteristics (e.g. salinity and waterlogging: Sharma and Bhargava, 1988). MSS imagery is a valuable archived data source for long-term global monitoring. It has aided in detecting deforestation, agricultural expansion, rangeland degradation (Ringrose and Matheson, 1987), flooding and changes in river channel position (Frihy *et al.*, 1994). Time series of MSS along with other imagery has been used to determine old flood plain and river sedimentation patterns and to help predict future flooding (Nagarajan *et al.*, 1993). It has also been used to estimate and map suspended river and lake sediment in India (Reddy, 1993). MSS FCC (false colour composite) diapositives at 1:1,000,000 scale were visually interpreted in India to identify "wasteland" (Narayan *et al.*, 1989).

MSS's approximately 80 metre spatial resolution and specific visible and near infra-red wavelength bands (Table 1) may not be appropriate for certain tropical forest applications. Several studies have had problems discriminating between tropical forest types, such as primary and secondary forest, pioneer regrowth (fallow), and cultivated forest clearings and grassland. It is difficult to distinguish disturbed forest from primary tropical forest because the leaf reflectance characteristics of primary forests, and areas cleared and regrowing for only five years may be the same (Stone and Woodwell, 1988). Some tropical forest and non-forest types are not separable using MSS imagery. An Indian study (Singh, 1987) tested separability and found that two density classes of forest (dense closed subtropical evergreen forests, and tropical semi-evergreen forest) and two edaphic forest types (closed forest and dense mixed bamboo) were separable. However, they found that some pairs of cover classes could *not* be reliably separated using Landsat MSS data: bare soil and shifting cultivation; grassland and shifting cultivation; regrowth and shifting cultivation; regrowth and open forest (Singh, 1987). The spectral configuration of Landsat MSS makes it sensitive to the reflectance from green leaf biomass and not to total standing biomass, making it difficult to distinguish old growth from regrowth in tropical forest.

Some researchers have found it more successful to employ more than one data source for forestry studies. By comparing SIR-A brightness (Shuttle Imaging Radar) data with NDVI values from Landsat MSS imagery, researchers were better able to distinguish primary forests and cleared regrowing areas in Amazonia than with MSS imagery alone (Stone and Woodwell, 1988). Another reason for complementing MSS imagery with radar is that, due to "perennial cloud cover the distribution and extent of the different canopies cannot be determined from Landsat MSS or other images obtained at optical wavelengths." (Ford and Casey, 1988)

Landsat MSS data are suitable for small-scale applications. With a 900 km altitude and a 185 km swath width, Landsat MSS is not a substitute for aerial photographs. Small forest clearings are not clearly visible on MSS imagery, and certain forest and agriculture classes are impossible to distinguish (Gastellu-Etchegorry, 1989). Some features larger than 80 m (i.e. forest types and settlements) may not be distinguishable, if they do not have good contrast with their surroundings (Lillesand and Kiefer, 1994). On the other hand, some features, such as roads with widths smaller than 80 m may be visible if they have strong contrast with their surroundings. Small settlements and villages may not be visible on MSS imagery. An exploration of settlements in Nigeria found that built-up areas of at least 300 hectares were identifiable from Landsat, and the smallest identifiable settlements fell between fifty and seventy pixels (Ince, 1987). Because of the 18 day turnaround period, MSS imagery is not suitable for the detection of rapid-onset hazards, or for applications that require rapid and immediate coverage, especially in areas prone to cloud cover. Some of these limitations were addressed with Landsat's more recent platform, Landsat TM.

3.1.3 Landsat TM

Landsat-4 and -5 were launched in 1982 and 1984 with some improvements over the first three Landsat satellites. The Thematic Mapper (TM) system was introduced on -4 and -5. A sixth Landsat satellite was launched in 1993, but suffered a launch failure. The new series of Landsat satellites had their orbits lowered from 900 to 705 km, helping improve the ground resolution of the sensors from 80 m to 30 m. Landsat-4 and -5 have a sixteen day return cycle, but the two satellites were launched eight days out of phase, so an eight day return cycle is possible by using both satellites. TM data have a 256 digital number (8 bit) grey scale, an improvement on MSS's 64 digital number (6 bit) grey scale. Landsat TM is one of the most commonly used sensor systems, and is especially popular with Southern authors (Chapter 5). It offers a much improved resolution over NOAA AVHRR and MSS for applied studies.

TM acquires data from seven spectral bands instead of four. Landsat-4 and -5 synthesize the four original MSS bands for continuity of data, and for users who cannot afford to switch to the new more expensive data. The new bands are in the visible (blue), mid-infrared, and thermal portions of the spectrum. The new wavelength ranges improved the differentiability of earth surface features. Therefore, TM bands have improved vegetation discrimination by wavelengths. These spectral bands are narrower than the MSS bands in the green and red region and the near infrared band was more closely chosen to coincide with a narrow range that correlates with plant vigor (Lillesand and Kiefer, 1994). The blue band (band 1) is useful in bathymetry studies, coastal water mapping, and soil/vegetation discrimination. The green band (band 2) was designed to discriminate vegetation and cultural features. The red band (band 3) was designed to aid in plant species differentiation. The near infrared band (band 4) can be used to determine vegetation types and delineate water bodies. The mid-infrared bands (5 and 7) are useful for discriminating rock types, and vegetation moisture content, and band 5 for discriminating between snow and cloud covered areas (Lillesand and Kiefer, 1994).

The thermal infrared band (band 6) improved monitoring of vegetation stress, soil moisture, and other thermal mapping applications. Thermal mapping also includes monitoring fires and volcanoes. Bands 6 and 7 were used to show surface thermal anomalies associated with coal fires (Prakash *et al.*, 1995a), buried thermal features (Prakash *et al.*, 1995b), and active volcano temperatures in India (Reddy, 1993). Burning fires can be seen through the smoke plumes with thermal imagery. Visible wavebands can show the charred areas after the fire (Riggan *et al.*, 1993). Thermal data can also be applied to surface temperature mapping and monitoring microclimates of tropical rainforest (Nichol, 1995).

Landsat TM's 30 m resolution is approaching a resolution adequate for local resource management, especially in countries where aerial photography is restricted. It can be used to perform more detailed land cover mapping due to the decrease in "mixed pixels" made possible by the increased ground resolution. TM can be successfully used to monitor logging and to create maps of logging activities in areas where suitable maps and aerial photography do not exist. TM imagery can be a valuable mapping tool for local people who are threatened by logging or other industry. TM data provide more detailed coverage than NOAA AVHRR or MSS data for applied studies including forest fire monitoring, forest inventory, agriculture inventory, geology, flood monitoring, and suspended sediment. The 30 m resolution improves mappability; therefore settlements, agricultural fields, fallow lands, forest vegetation of different densities, wastelands, road and rail can be more easily discriminated by TM imagery (Deekshatulu, 1988).

Compared to MSS the narrower spectral bands of TM have improved our ability to distinguish tropical forest classes and consequently TM has been used in many tropical deforestation studies (e.g. Adams *et al.*, 1995; Jusoff and Manaf, 1995; Sader, 1995). TM has both a potential for global mapping of tropical forests (Lucas *et al.*, 1993) and tropical forest inventory at a small scale (Garcia and Alvarez, 1994). Photographic prints can be purchased and visually interpreted at a much lower cost than purchasing and interpreting the digital imagery. A band 3, 4, and 5 colour composite is effective for monitoring deforestation in the Amazon basin (Lillesand and Kiefer, 1994) and can be obtained in print form.

However, TM has similar difficulties to MSS in distinguishing old growth from secondary forest and some agriculture patterns (King, 1994). One study found that multi-temporal TM imagery was unable to adequately discriminate oil palm plantations from secondary forest (Lucas *et al.*, 1993). Time series are often necessary to discriminate age of tropical secondary forests (Lucas *et al.*, 1993).

TM imagery can be employed to estimate areas of agricultural fields at a small scale (Pestemalci *et al.* 1995) and it can provide a quick, relatively accurate means of mapping agricultural patterns. TM imagery is increasingly being used for identification of wastelands in India (Deekshatulu, 1989). Geological applications are also popular. Visual interpretation of false colour composite prints (often 1:250,000 scale) can indicate lithology (Patil and Patil, 1993). Combinations of bands 1, 4, and 5 or 7 can be used to discriminate rock types (Davis and Berlin, 1989).

TM has improved spectral bands for studying bathymetry: the three water penetrating bands are bands 1, 2, and 3. Band 4 is used for water boundary demarcation (Khan *et al.*, 1992). Single band processing techniques were found to work well to delineate water with dissolved sediment (Nichol, 1993). Time series of TM imagery can reveal changes in river channels (Jacobberger, 1988) and be used to prepare flood hazard maps (Ramana Murty *et al.*, 1993).

Because of the choice of wavelength bands, TM has been used to map features with comparable accuracy to SPOT (King, 1994). For large areas, mapping can be performed more quickly, and often more cheaply, with TM imagery than by using aerial photographs (Saxena, *et al.*, 1992). However, with TM imagery, there is a loss in resolution compared to aerial photography, and aerial photographs are often essential as "ground truth". TM imagery makes a good backdrop for larger scale studies employing aerial photographs or radar (Pope *et al.*, 1993), or SPOT (Welch *et* *al.*, 1990) for more detail. Recent studies employing TM imagery often used multiple data sources, such as NOAA AVHRR, SPOT, Radar, and aerial images. TM and SPOT can be combined and made into stereoscopic pairs, providing a useful view of rugged forest terrain, which can later be combined with aerial information (Welch *et al.*, 1990).

Although TM imagery can quickly and accurately be used to map land cover at small scales, some researchers are not optimistic about the future of satellite imagery in the South. The United Kingdom Ordnance Survey feels that satellite imagery can improve the presentation of land or topographic information, but cannot replace traditional mapping (Hartley, 1991). They found that using orbital imagery was not much cheaper than traditional map making techniques, since mapping studies using satellite imagery required just as many ground control points as studies using aerial photographs (Hartley, 1991).

SPOT has greater potential, because of its superior spatial resolution and stereoscopic possibilities. Landsat's major limitation compared to SPOT is that it does not have good stereoscopic capability. The ability to view in 3-D has been said (King, 1994) to be more important than both spectral and spatial resolution for discriminating land cover units.

3.1.4 SPOT

The first of the SPOT (Systeme Pour l'Observation de la Terre) satellites was launched by France in 1986. SPOT-2 and SPOT-3 were launched in 1990 and 1993. The SPOT satellites were designed as commercial earth observation platforms and were the first civilian satellites to employ pushbroom scanning and have pointable optics. SPOT satellites operate at an altitude of 832 km and repeat their orbit pattern over any given point every 26 days (Lillesand and Kiefer, 1994). However, because of the pointable sensor, off-nadir images of any given point can be obtained every four or five days. This is important in areas of frequent cloud cover, or in situations which require frequent coverage. Each SPOT satellite carries two identical high resolution visible (HRV) imaging systems that operate in two modes. The panchromatic (P: black and white) mode has 10 m resolution. The multispectral (XS) mode operates in three bands: green, red, and near infra red, and has 20 m resolution. Data are encoded over a 256 digital number range. The system can provide stereoscopic viewing, because of the off-nadir viewing capability of the HRV (Lillesand and Kiefer, 1994).

SPOT provides the best spatial resolution of the commercial satellites presently available. Because of this, some researchers believe it is the only orbital system that should be used in tropical research (Gastellu-Etchegorry, 1989). Panchromatic (P) images provide the best resolution as well as stereoscopic capabilities. The multispectral (XS) mode offers 20 m resolution, which is a small improvement over TM imagery. SPOT can be used to provide quick, accurate and inexpensive cartographic and thematic maps, even in tropical rainforest situations (Gastellu-Etchegorry, 1989). SPOT's higher resolution corresponds better with the heterogeneous nature of tropical forest classes. SPOT can provide excellent detail for updating maps in areas where accurate base maps do not exist, and is a valuable resource in Southern countries where aerial photographs are either restricted or unavailable.

SPOT (especially SPOT P) comes out ahead of Landsat MSS and Landsat TM in comparative studies in tropical research, except where haze is a problem. A study of similar shaped rice fields in Indonesia compared the relative resolutions of Landsat MSS, TM, and SPOT XS and P data. SPOT XS and P data allowed analysis of features larger than 0.16 ha and 0.04 ha, respectively, while Landsat MSS and TM data resolved features greater than 5 ha and 0.56 ha, respectively (Gastellu-Etchegorry, 1989). With SPOT, even 2-3 m wide roads can be mapped under favourable conditions (Gastellu-Etchegorry, 1989). Most soil units detected with aerial photographic stereo-pairs (in Indonesia) could also be distinguished with SPOT (Gastellu-Etchegorry *et al.*, 1990).

When available, SPOT P stereo pairs are often preferred over monoscopic SPOT XS. "Due to the unusual heterogeneity of the Javanese landscapes and to the present unavailability of locally-adapted textural classifiers, the visual analysis of SPOT P images provided better results than the digital processing of SPOT XS data." (Gastellu-Etchegorry, 1990) This is especially true whenever scales larger than 1:50,000 are used, with the goal of resolving local land units. For geological studies, the spatial approach (using SPOT P) is more effective than the spectral approach, because of overlying vegetation, except in well exposed areas (Gastellu-Etchegorry *et al.*, 1990). SPOT XS images are ordered more often than P because they offer a choice of colour interpretation, and are more suited to a wider variety of projects.

The onset of the higher-resolution satellites (SPOT and TM) coincided with the removal of satellite imagery from government control, and placing it in the private domain in the mid 1980's (Sheffner, 1994). The ensuing price increases have made satellite imagery prohibitively expensive for the South. SPOT is relatively more expensive than TM because more SPOT images are required to cover the area covered by a single TM scene. SPOT also charges more for a single digital image than Landsat and does not offer a reduced rate for a photographic (paper) product. If cost is not a problem, it is advantageous to combine SPOT imagery with other imagery. Researchers in Kenya found that merged SPOT and TM images had advantages over the separate images--it doubled their ability to map geologic faults and lithographic units (Jutz and Chorowics, 1993).

While SPOT has some obvious advantages, many researchers are still using TM imagery in Southern applications. TM products offer a broader spectral range. TM, with its greater number of bands, can be a better spectral resolver of ground units than SPOT (unless stereo capabilities are considered, in which case SPOT comes out ahead) (King, 1994). Landsat (except for the blue band) is often less affected by haze than SPOT imagery, because of Landsat's better selection of wavelength bands. In a comparison of Landsat and SPOT imagery, the following conclusions were summarized:

> The quality of SPOT imagery of the humid tropics is variable: frequently only the infrared band is useable...where the quality is good, stereoscopic imagery is preferred for demarcating land systems...Airphoto features can usually be easily recognized on the 10-30m resolution second generation of satellite imagery, but not on the coarser 80m resolution first generation Landsat MSS imagery. After stereoscopic resolution, spectral range appears more important than ground resolution for demarcating land systems. Landsat-TM imagery is preferred over SPOT because not only is it cheaper but the longer wavelengths (combined with vertical viewing) are more likely to penetrate the atmosphere of the humid tropics. Landsat-TM imagery discriminates vegetation subject to seasonal and permanent waterlogging better than any other sensor, including panchromatic aerial photography (King, 1994).

3.1.5 Radar--SAR, SIR-A, SIR-B, RADARSAT

Radar has been installed on aircraft and orbital platforms. The images produced are usually black and white, with speckling being typical of radar. A main advantage to using radar is that microwaves can penetrate clouds, haze, smoke, light rain and snow, and can be used day or night (Lillesand and Kiefer, 1994). Aircraft systems use side looking aerial radar (SLAR) and synthetic aperture radar (SAR). SLAR points an antennae to the side of the airplane, producing images adjacent to the flight line. Stereoscopic images can be produced either by flying parallel flight lines or by flying the same flight line at different altitudes (Lillesand and Kiefer, 1994). Orbital platforms use synthetic aperture radar systems (SAR) because real aperture systems (as in SLAR) would have insufficient resolution from higher altitudes.

Seasat, a satellite that failed 99 days after launch, provided the first orbital radar images of the earth. Seasat's was designed to monitor sea state and polar sea ice. Early orbital radar images of the earth were provided by two more short lived experimental satellites--shuttle imaging radar (SIR)--which covered a large portion of the earth in 1981 and 1984. SIR-A, operated in 1981, was operated from the space shuttle, at an altitude of 260 km. SIR-B experiments were conducted from the Space Shuttle in 1984. SIR-B could mechanically tilt its antenna to choose look angles ranging from 15 to 60 degrees. This made stereo viewing possible (Lillesand and Kiefer, 1994). The European Space Agency launched ERS-1 in 1991. It provides SAR data over a 100 km swath at a resolution of approximately 30 m, from an altitude of approximately 785 km. It has a relatively steeper look angle (23°) than other spaceborne SAR systems.

The Canadian Space Agency launched Radarsat in November 1995. It is primarily designed as a commercial satellite to provide Canadian sea ice conditions, coastal surveillance, land cover mapping, and agricultural and forestry monitoring. It operates in a sun-synchronous orbit at an altitude of 798 km. It provides repeat coverage from once every 24 days to daily repeat coverage over the high Arctic. Radarsat SAR can operate in a variety of beam selection modes, meaning that various swath widths and resolutions are possible. It can provide resolution from 100 m to its finest resolution, 10 m. It is expected to have utility in resource monitoring because of its fine resolution and its near real-time data acquisition and retrieval (Tack, 1996). This is especially true in equatorial and polar regions where cloud cover restricts the use of optical satellite imagery.

Radar has quite different imaging characteristics than optical sensors. The scale distortions of side looking radar imagery make it unsuitable for accurate planimetric mapping (Lillesand and Kiefer, 1994). Radar was primarily tested for military reconnaissance and more recently for acquiring natural resource data (Lillesand and Kiefer, 1994). Radar is still being tested for its application to land resource remote sensing (e.g. the reflectivity of specific resources is still not known) (Lillesand and Kiefer, 1994). In general, SLAR and SAR provide high returns from slopes facing the aircraft, rough objects, objects with a high moisture content, metal objects and corner reflections from urban or built up areas. Radar can provide excellent views of relief features in remote and cloud-covered areas. The side viewing nature of SAR imaging emphasizes hills and valleys, and areas of low topographic relief that may not be imaged by other orbital platforms, making it useful in geology, soil erosion, mineral exploration, hydrology and drainage pattern applications (Lillesand and Kiefer, 1994). Water can be detected in soil because of water's high specular reflectance. Rough sea water can be discriminated from smooth water and sea ice (Vyas and Andharia, 1987).

Radar data can effectively locate cultural features such as villages in the forest because of the high radar return of construction materials (Nezry *et al.*, 1993; Haack and Slonecker, 1994). Radar is of interest in arid regions for its ability to penetrate one to two metres of dry eolian sand, with potential for searching for near surface ground water and underlying minerals and structures. L-band radar waves (15-30 cm) can penetrate extremely dry desert material to reveal bedrock, buried river channels and other hidden features (McCauley *et al, 1982*). Radar can distinguish between agricultural crop types as well as stages within the same crop type, which is indispensable for agriculture monitoring (Lillesand and Kiefer, 1994).

Radar has potential for forestry due to its ability to observe canopy structure and tree trunks. A study in Europe demonstrated the ability of spaceborne SAR to discriminate deciduous from coniferous forest (Hallikainen *et al.*, 1988). In the tropics, clearcuts can often be discriminated from surrounding forest, because of the smoother surface of the clearcuts. In a deforestation application, SIR-A imagery used in conjunction with Landsat MSS imagery was better able to distinguish primary forests and cleared regrowing areas than Landsat imagery alone (Stone and Woodwell, 1988).

As with other imagery, determining tropical rain forest characteristics and discriminating between primary and secondary tropical forest is difficult with orbital radar imagery alone. SIR-B can distinguish forest types, marsh, clearcuts and clearings related to shifting settlements or swidden, but has difficulty with other major forest species associations (Ford and Casey, 1988). For best results in classifying forest types, radar imagery must be complemented with other imagery such as SPOT. "The SAR image is then helpful to discriminate moderately-vegetated areas (crops, rice fields, rubber tree plantations, young secondary growth), but of no help to discriminate between dense forests and degraded or secondary forest. On the contrary, these latter are identified on the SPOT image (Nezry *et al.*, 1993)." SPOT and SAR used together provide complementary information allowing discrimination of dense and secondary forests, homogeneous rubber tree plantations, and darker mosaics of fruit trees and gardens within the fishbones pattern of shifting settlement in Sumatra (Nezry *et al.*, 1993).

3.1.6 Indian Remote Sensing Satellite

India launched its first satellite, the Indian Remote Sensing Satellite, IRS-1A, in 1988. IRS-1A has two sensors, LISS-I and LISS-II operating in four identical spectral bands. Their spatial resolution and wavelengths are similar to Landsat's. There is little published literature about IRS in the three main international journals, although quite a few IRS studies were included in a 1993 Special Issue in *IJRS* (Cracknell 1993)

IRS was launched to alleviate the food problem in India (Sudarshana, *et al.*, 1993), though the published research explores many other directions. IRS estimated the wheat acreage of Punjab state with 90% accuracy (Mahey, *et al.*, 1993). IRS and MSS were found to work comparably for pre-harvest wheat yield predictions in India (Sharma, *et al.*, 1993). IRS-1A was used in district level planning, where photo interpretation skills of false colour composites were combined with slope, soil, land-use and ground water information in a GIS, and recommendations were made for soil conservation and change of land use (Ghosh *et al.* 1993). IRS was used to prepare a flood-hazard map of the Krishna Delta, India (Ramana Murty *et al.*, 1993). In India it was recommended that remote sensing (including IRS and Geographic Information Systems) be used to help manage natural resources and watersheds (Prasad *et al.*, 1993).

3.1.7 Planned satellites and high resolution low orbit imaging satellites

Landsat 7 is currently being built and tested for its planned launch in 1998 (Markham *et al.*, 1997). The major improvements over previous Landsat sensors include the addition of a panchromatic band and the improvement in spatial resolution of the thermal band to 60m (Table 1). The Panchromatic band will offer a ground resolution of 15 m, a considerable improvement over the 30 m resolution of the multispectral bands. The NASA New Millenium Program (NMP) is currently researching the Earth Orbiter Mission (EO-1) satellite, scheduled for launch in May, 1999 (Ungar, 1997). The EO-1 is a research vehicle for potential design of Landsat 8, and the design will include a high spectral resolution imaging spectrometer. It is planned to be less expensive to build and launch than previous Landsat satellites, while providing continuity with data from earlier Landsat missions. It will likely operate with a simple pushbroom scanner, and utilize a single hybridized Multi-spectral/Panchromatic (MS/Pan) Sensor Chip Assembly (SCA). Planned resolution in the panchromatic mode is 10 m, and 30 m in the multispectral mode. SPOT has also been making improvements to its satellite sensor systems. SPOT 4 is scheduled to be launched in 1998 with a new mid infra red band (1.58-1.75 μm) and a replacement of the panchromatic band with B2 (0.61-0.68 μm) (Guidolin, 1996). SPOT 5 is currently under development to provide higher ground resolution (3-5 m in panchromatic mode) to meet new consumer demands in cartography, agriculture, planning and environment (Guidolin, 1997). SPOT 5 will also have higher resolution in multispectral mode (10 m), and will return to its original panchromatic band to provide continuity for users (Guidolin, 1997).

It is expected that future developments in satellite design will include a reduction in size and cost of new satellites (Jilla and Miller, 1997). An example of this trend is the new "smallsat" satellites designed by NASA for exploration and research (Casani, 1995). Another recent satellite trend is in development of high resolution low orbit imaging satellites (Earthwatch, 1998). Within the next five years several satellite sensors will be launched that are capable of providing panchromatic imagery with spatial resolutions in the 1 to 3 metre range, and multispectral imagery in the range of 4 to 15 metres (Guindon, 1997). This imagery will rival the geometric accuracy of aerial photography and will have potential in topographic mapping at 1:50,000 scale or larger (Guindon, 1997).

Earthwatch (formed by a merger of Worldview Imaging and Ball Corporation in 1995 (McCarty, 1995) is a key player in developing high resolution satellite systems. Ball holds a one metre remote sensing commercial license and Worldview holds a three metre license, granted by the United States Department of Commerce (McCarty, 1995). In recent years Earthwatch has designed the Early Bird and QuickBird remote sensing satellites, both with high resolution stereographic capabilities, expected to provide potential data for accurate and inexpensive mapping of entire countires (Earthwatch, 1998). The Early bird was designed to acquire imagery with three metre resolution from a near-polar, sun-synchronous orbit. Earthwatch suffered a disappointing setback when it lost communication with the Early Bird satellite four days after its launch on December 24, 1997 (Earthwatch, 1998). Earthwatch is now focusing its efforts on completion of the QuickBird satellite, designed to provide 0.82 m panchromatic resolution and 3.28 m multispectral resolution (Table 1). QuickBird is scheduled for launch in 1999 in a medium-inclination, non-polar orbit (Earthwatch, 1998).

3.2 Aerial photography and photogrammetry

Airborne systems provide far greater spatial resolution than orbital sensors, and should be used for large and medium-scale studies. Virtually any type of sensor can be installed in an aircraft (aerial photography, electro-optical CCD: i.e. video and digital imagery, imaging spectrometer, airborne scanners, and radar). Airborne systems have the advantage that they can be flown at varying flying heights, producing varying resolutions, depending on the application. Imaging spectrometers and airborne multispectral scanners are used widely in the North but they are experimental, expensive, have constrained usefulness for most applied resource management and mapping, and are therefore of limited interest to the South. Aerial photography has a far greater utility in these applications.

Aerial photography is the most commonly used aerial imaging system. It has been in use since prior to World War I, when it was introduced for mapping and reconnaissance (Reeves, 1975), and has since been perfected for many mapping applications. Topographic mapping utilizes aerial photography and standardized photogrammetric techniques (Reeves, 1975). Aerial photography and photogrammetric techniques have been developed and standardized over their long history. The history of remote sensing, description of sensor systems, and elucidation of remote sensing techniques such as rectification of images, orthophotography, stereoscopic imaging and image interpretation are fully described in manuals such as Reeves (1975).

Aerial photography is the most flexible imaging technique, since the film and flying height can be tailored to the application. Optical airborne sensors (photographs and CCD imagery) have a wide range of applications and options--you can pick the film sensitivity, filters, flying height, and resolution. Unlike orbital imagery, the flying time can be chosen to image a specific event, or to avoid clouds. Much greater resolution can be achieved than with orbital imagery. This makes aerial imagery particularly well suited to resource monitoring at a detailed level. Aerial photographic images are acquired using a lens and shutter mechanism and captured onto a photographic plate at the back of the camera. Panchromatic (black and white) or colour film can be used. Colour film has advantages for the interpreter, since colours are more easily interpreted than grey scales. Normal colour film has three dye layers which respond to the red, green, and blue portions of the spectrum reflected from the ground (Lillesand and Kiefer, 1994). Colour infrared film has the same three dye layers, but the dye layers respond to the green, red, and near-infrared (0.7 to 0.9 μm) portions of the spectrum, creating a "false colour" film (Lillesand and Kiefer, 1994). Colour infrared film is particularly sensitive to vegetation, and is widely used for resource studies. Healthy vegetation shows up as bright red, from its high reflectance in the near infrared.

Almost every country has been photographed, at least to a small scale. However, in many Southern countries availability of these photographs is restricted and unavailable for general use. It may be impossible to obtain recent aerial photographs at small or large scales, or topographic maps without government permission. While photogrammetry and aerial photography are well developed techniques, aerial photography can also be the last foothold of the amateur mapper. In areas where imagery is needed immediately, it is possible to rent a plane and take 35 mm small format photographs (in countries where this is permitted) for less cost than buying orbital imagery.

Aerial photographs are often used in place of ground truth in studies that use orbital imagery as the primary data source. In the three journals reviewed, aerial methods were mentioned infrequently as the primary sensor, and aerial photography was generally used in conjunction with other remote sensing media or was used in place of ground truth. Sometimes comparisons were made. In a study of deforestation of tropical rainforest, large-scale 35 mm aerial photographs were considered best for accurately depicting land use change, as compared to Landsat MSS imagery and large-scale video imagery (Gilruth *et al.*, 1990). Satellite images can identify general areas of degradation and expanding agriculture, but large-scale photographs and captured video images were needed to assess the actual amount of degradation and to make models and predictions for land development (Gilruth *et al.*, 1990).

Aerial photographs can be an aid to hazard detection. For hazard detection, a requirement is the availability of aerial photographs from older dates, preferably at more or less regular intervals (Nossin, 1993). To study geomorphic hazards, Nossin (1993) procured aerial photographs from 1937 to the present, and digitized them and referenced them to a panchromatic SPOT image of 1990. Overlays showed the migratory behaviour of the river and identified the areas under flood hazard.

3.3 Aerial multispectral Sensors

The most widely used imagery source for topographic mapping (Roberts, 1995), forest cover mapping and forest resource inventory continues to be aerial photography (Hall and Fent, 1995). Aerial photography has well known advantages in spatial resolution and photogrammetric accuracy. However, other airborne sensor systems are receiving attention from the remote sensing community for their advantages in certain applications. They often have improvements in spectral resolution and in near real-time availability of imagery. Some sensor systems, notably electro-optical CCD, offer good mapping capability at an affordable price. The aerial sensor systems discussed here include spectrographic imagers, multispectral scanners, airborne video and electro-optical CCD. For reference, the swath width and resolution of several aerial multispectral sensors (MEIS, CASI and video) are compared with aerial photography in Table 2.

Table 2. The approximate achievable resolutions and swath widths of several aerial sensors

Sensor	Swath width (pixels)	Swath width (angle)	Highest Resolution (m)
Aerial photography	10,000	+/- 37	0.25[1]
MEIS	1,000	+/- 20	0.40
MIES-FM	6,000	+/- 35	0.25
CASI	500[2]	+/- 17	2.00[3]
Video	512x480	+/- 22	0.70[4]
Digital Camera	1024x1024[5]	+/- 22	0.30[6]

Table based on Leckie and Gillis, 1993
[1]Resolution is dependent on scanning frequency: 25cm is based on 25 micron scanning
[2]Can achieve 1000, and multi-module system could give 3000-5000 pixels
[3]Can probably achieve 1.0 m, but less than 1.0 m will not be available in near future
[4]Can be a higher resolution (e.g. 0.40 m) with different lenses
[5]2048x2048 is available but expensive
[6] Can be a higher resolution (e.g. 0.15 m) with different lenses

3.3.1 Aerial spectrographic imagers

Spectrographic imagers simultaneously acquire images in a large number of contiguous spectral bands, so that a complete reflectance spectrum can be derived for each pixel (Ben-Dor *et al.*, 1996). Pre-processing of the raw data (i.e. radiometric calibration and atmospheric removal processes) is essential due to the large amount of spectral information. The most commonly known spectrographic imager is the Compact Aerial Spectrographic Imager (CASI). CASI was developed in Canada by Itres Research (Babey and Anger, 1989), and was designed specifically to enable low cost acquisition of multi spectral imagery for aquatic and terrestrial studies (Babey and Anger, 1989). CASI is an electro-optical line imaging system (linear array pushbroom scanner) which has the advantage of being operable in two modes: spectral and spatial. In the spectral mode CASI has a maximum of 288 non-overlapping bands in a continuous reflectance spectrum from 430 to 950 nm in 1.8 nm increments. It does not have a well-represented infra-red portion (maximum 950 nm). In the spatial mode CASI can operate as a multi spectral scanner (MSS), improving its spatial resolution, and can acquire data from a maximum of 15 bands. CASI records onto low cost 8 mm video cassettes. The large number of spectral channels effectively provides near continuous spectral information from each pixel, which is expected to allow the spectral resolution of features (e.g. geological materials) with narrow wavelength reflection characteristics (Lillesand and Kiefer, 1994). The CASI along track scanner produces images that require registration to existing data with geographic accuracy before they can be visually interpreted. An image from this type of sensor is presented in Figure 5.

CASI has been tested extensively in aquatic studies (summarized in Franklin, 1994) and forestry studies (Franklin, 1994; Franklin *et al.*, 1997; Niemann, 1995). It can be used to discriminate subalpine forest species at a high degree of accuracy (Franklin, 1994) and to discriminate *kalmia angustifolia* shrub from other regenerating shrubs in a regenerating coniferous/shrub environment in Newfoundland (Franklin *et al.*, 1997). It tested poorly, however, at detecting stand ages (especially distinguishing between the older forest classes) in Coastal Douglas-fir forest near Victoria, B.C. (Niemann, 1995). CASI also has significant problems with geometric distortion, and cannot be used operationally at altitudes below 1,500 m (Roberts, 1995). Other spectrographic imagers include the Airborne Visible-InfraRed Imaging Spectrometer

(AVIRIS), and the Geophysical Environmental Research (GER) spectrographic imager

While most recently developed imaging spectrometers collect their data from linear arrays, the Airborne Visible-InfraRed Imaging Spectrometer (AVIRIS) operates on the whiskbroom principle with four individual spectrometers recording 224 contiguous wavebands between 400 nm and 2450 nm with a bandwidth of 10 nm. AVIRIS was designed by NASA, largely as a test medium for future spacecraft imaging spectrometers (such as the High-Resolution Imaging Spectrometer (HIRIS) planned for the year 2003) and for land applications requiring high spectral and spatial resolution. AVIRIS has fewer spatial distortion problems than other imaging spectrometers because of its high altitude (20 km) and low field of view (30°) (Ben-Dor *et al.*, 1996). AVIRIS has found application in geologic studies and in lithologic mapping above the timberline in Southeastern B.C. (Bowers and Rowan, 1996), and has been tested with favourable results over coastal oceanic environments (Carder *et al.*, 1993). Signal to noise ratio can give uneven results, but AVIRIS was successfully used to predict and map the foliar biochemical contents of a forest canopy in central Florida, although time series of images was required for acceptable results (Smith and Curran, 1995).

The Geophysical Environmental Research imaging spectrometer (GERis) is manufactured by GER of New York. GER records data with 63 bands in the 400 to 2500 nm spectral region with three linear detector arrays. GER has significant geometric distortions along the cross-track direction due to its low altitude (1-5 km) and high field of view (90°) that affects its usefulness in surface mapping (Ben-Dor *et al.*, 1996). Researchers found that the large geometric distortions of the GER data made it impossible to obtain a perfect match between the image and the geological map used for registration (Ben-Dor *et al.*, 1996).

Often when assembling a complement of sensor systems to outfit a dedicated remote sensing small airplane, cost is a factor. VIFIS is a low cost ($3,000 to assemble onto existing video cameras, $30,000 for the entire system) alternative to CASI (approximately $300,000) (Roberts, 1995) VIFIS is a CCD-based imaging spectrometer developed by researchers at the University of Dundee (Sun and Anderson, 1993). The VIFIS system utilizes a two-dimensional CCD video camera with a variable interference filter (Sun and Anderson, 1993) and records the images onto video tape. The filters can provide 10 nm bands, from either 400 nm to 700 nm (visible), or 700 nm to 1000 nm (near infra-red) on separate cameras. The two-dimensional imaging system offers the advantage of less geometric distortion than expected from the line imaging system of CASI.

All of the spectrographic imagers require extensive pre-processing to be used in a mapping context. They offer the advantage of selectivity of wavelength bands. Linear array technology is problematic at low altitudes, because image reconstruction problems occur when the aircraft is rolled, pitched and yawed by turbulent flying conditions (Light, 1996). However, if the proper consideration is given to image registration beforehand, low spatial accuracy airborne imaging spectrometers can be used to create maps (Ben-Dor *et al.*, 1996).

3.3.2 Aerial Multi Spectral Scanner (MSS) and MEIS

The term Multi Spectral Scanner (MSS) encompasses a variety of sensor systems (Multi-detector Electro-optical Imaging Scanner (MEIS), digital cameras and aerial video (if captured digitally via electro optical CCD)). A multi spectral scanner is designed to have a better spatial resolution than an imaging spectrometer, at the expense of radiometric resolution, and therefore has potential as a mapping tool.

The aerial Multi-detector Electro-optical Imaging Sensor for Forestry and Mapping (MEIS-FM) was developed by MacDonald Dettwiler Associates of Vancouver and the Canada Centre for Remote Sensing (CCRS) in Ottawa with the intention to supplement aerial photography in forestry and mapping studies (Leckie and Gillis, 1993). MEIS II uses eight spectral bands which can be selected by mounting particular filters in front of the scanner lenses. A mirror system can create forward and aft-looking channels in addition to the downward-looking channel, and stereoscopic images can therefore be produced (Lillesand and Kiefer, 1994). MEIS-FM uses a linear array of six focal plane detectors, with two separate optical channels for stereo capture. MEIS makes more complete use of the colour spectrum than aerial photographs and can be automatically georegistered.

MEIS has received considerable attention in application to forestry (Gougeon, 1993; Leckie, 1993; Murtha, 1993). Airborne spectral remote sensing data (i.e. MEIS) offers advantages over both aerial photography and Landsat TM imagery: higher resolution, and the ability to adjust the spectral windows. However, considerable thought must be put into choosing the imaging filters to achieve good results (Singh *et al.*, 1989). Choosing band filters that were too wide resulted in low correlation between the classified image and geochemical data (Singh *et al.*, 1989). Because of the high degree of processing involved, the full potential of digital aerial images will only be realized when most of the processing can be done by computers (Gougeon, 1995). Another limitation of MEIS data is its low geometric accuracy. It is optimally integrated into a GIS to produce mapping accuracy (Linders and McColl, 1993). MEIS was combined with GIS to complete large-scale municipal mapping of Guelph, Ontario, with acceptable spatial accuracy and timeliness (Linders and McColl, 1993).

Digital cameras are beginning to go down in price, but are significantly more expensive than surveillance video cameras (Roberts, 1995). Digital cameras generally have higher resolution than airborne video, and acquire images with a similar system of charge coupled devices (CCD). Digital cameras will generally have more photosites in their area array than video (King, 1995). This increase in photosites results in a higher data rate and inherent problems with development of high-speed data storage (King, 1995). Although presently, spatial resolution is inferior to aerial photography and thematic mapping is found to have low accuracy, advances in digital camera technology predict that most topographic mapping will begin to use these cameras as their primary image source (King, 1995). Digital cameras have a potential to create digital orthophotographs at a lower cost than the conventional method of scanning aerial photographs (Duhaime *et al.* 1997).

3.3.3 Aerial Video

Aerial video presents a cost-effective imaging system that should be considered when operating a dedicated remote sensing system. There are a wide variety of techniques and camera types associated with aerial video (even a hand held video camera in a helicopter yields a certain "interesting" result (Maas and Kersten, 1997)). Aerial video operates with an area array of CCD sensors. CCD spectral sensitivity is typically 400 to 1000 nm. Data can be either acquired directly in a digital format ("electro-optical CCD") or transferred onto tape ("video") and images can be later "frame-grabbed" on a frame to digital frame basis.

Aerial electro-optical CCD is a very flexible imaging system, ideally suited to research. Filters can be selected according to the study location, and the analytical procedures and classifications can be varied depending on the application. Video offers the advantages of near real-time, interactive data acquisition and the simplicity of acquiring data in an already digital format. Digital interpretation can be cheaper than visual interpretation of imagery when large amounts of imagery are considered (Holopainen and Wang, 1998). Multispectral video offers the least expensive airborne multispectral remote sensing system (Roberts, 1995), and has potential for low cost mapping. Of the electro-optical systems, a video system is the most cost efficient and flexible for a skilled research team to operate. Video products are relatively inexpensive because they benefit from the large supply on the consumer market. There are three categories of video cameras: surveillance cameras (the most common, usually utilizing CCD), colour, and thermal. Black and white surveillance cameras offer the best flexibility and performance for remote sensing (Roberts, 1995).

Video products generally have a much better radiometric resolution than aerial photographic products. Direct acquisition of data in digital format (512 by 512 CCD) offers slight advantages in spatial resolution over video recording (Roberts, 1995). However, the photogrammetric accuracy is not as well developed as aerial photographic cameras, and for mapping purposes, the imagery should be integrated into a Geographic Information System (Roberts, 1995). Despite the problems inherent with digital systems, developments point in the direction of digital advancements, and researchers predict a greater role for digital imagery in the future (King, 1995; Light, 1996). Aerial multispectral video has found application in land-cover and land-use classification and mapping in remote regions and logistically difficult environments in the South (Brazil and Senegal) due to its ease, speed, and flexibility and interactiveness of acquisition (Meisner, 1986; Marsh *et al.*, 1990; Marsh *et al.*, 1994).

Limitations to multispectral video are that it is not suitable for spectral analysis of targets with unknown spectral properties (the proper filters need to be chosen beforehand) (Roberts, 1995). It also may require more specific training to interpret than aerial photography, although research has shown that even minimal training (three hours) was sufficient to markedly improve the ability of interpreters to visually identify plant classes from video (Drake, 1996). For thematic mapping, video generally has less utility than aerial photographs, due to lower spatial resolution and less operational standardization (King, 1995). It can be expected that for both forest and agricultural targets, video will provide better spectral definition, while aerial photographs will provide better image texture related to vegetation species differences (King, 1995).

Extensive radiometric corrections/calibrations are required of video prior to thematic mapping. Classification accuracy of forest is significantly improved by using a number of processing techniques: noise reduction, addition of texture, edge enhancement and post-classification thematic map smoothing (King and Vlcek, 1990). A certain amount of processing of video and electro-optical CCD imagery may be necessary before it can be digitally interpreted. For example, it was found that illumination compensation (using a model derived from a digital elevation model) was necessary to reduce interpretation errors in a shadowy, mountainous area in the German Alps (Pellikka, 1996) (although with visual interpretation, the interpreter may have been able to compensate for these illumination differences).

More improvements to classification of video can be effected if bands are selected prior to imaging with good pre-planning (King and Vlcek, 1990). Multispectral video is best used for large scale applications of areas up to the size of watersheds (King, 1995). Multispectral video has advantages over line-array imaging spectrometers (i.e. CASI) that require time consuming and elaborate processing and geometric corrections for mapping. One consideration in choosing CCD is that computer hard drives cannot be operated above 3,000 m and therefore a disk or tape archival system must be employed. Digital tape and video tape can both be operated up to 6,000 m altitude (Roberts, 1995).

3.3.4 Electro-optical CCD

Airborne electro-optical CCD (charge coupled device) systems offer many of the benefits of aerial photography at an extremely reduced price. The initial cost of cameras is much less, and the cost of processing film is eliminated. However, computer processing is necessary to view the images. Aerial electro-optical CCD imagery provides the option of viewing different spectral bands in video and digital format and has the added advantage over photography that it can be viewed immediately. In the literature CCD imagery and digital frame systems are sometimes referred to as "video," although this term normally implies the use of video signals and recording. Video records standard analog television signals onto magnetic tapes or disks. Video can be viewed as a continuous image, or individual digital images can be viewed in a computer using a "frame grabber." There are many possible video camera and computer configurations. Video images can be obtained with a system of four solid state (CCD) array cameras, each equipped with narrow bandpass filters from the visible or near infrared range (King and Vlcek, 1990; Roberts and Liedtke, 1993).

Video imagery has better spectral and radiometric resolution than aerial photographs. Aerial photographs have better spatial resolution than video (Roberts and Longdong, 1993). A useful option is to carry both electro-optical sensors and photographic systems while flying an area. Using both types of images in resource management studies has yielded good results (Gilruth *et al.*, 1990). Aerial video has been successfully employed along with aerial photographs and MSS imagery to assess tropical deforestation (Gilruth *et al.*, 1990).

In an agricultural land-use study in Senegal, Meisner (1986) cited four advantages of video data in logistically difficult environments:

> (1) the immediate availability of the data; (2) the ability to view live images during data acquisition to assess system performance and aid aircraft navigation; (3) the efficient manner in which data are recorded and stored on extremely inexpensive medium (avoiding the temperature constraints of color-infrared film); and (4) the fact that analog images can be either interpreted manually from a video monitor, or converted to digital values and enhanced using digital image processing systems (Meisner, 1986, quoted in Marsh, *et al.*, 1990).

The only problems they encountered with video were initial difficulties in mosaicing the data, which they felt could be overcome with use of a global positioning system (GPS) for ground truth (Marsh, *et al.*, 1990).

Airborne digital electro-optical CCD systems have been studied extensively at Simon Fraser University, Canada. In a study of suspended sediment, multispectral video was found superior to colour photography (Roberts and Longdong, 1993). Its near real-time acquisition is an aid to rapid monitoring of environmental hazards and pollution. It has shown itself to be beneficial in monitoring accidental oil spills (Roberts, 1993).

Multispectral sensors have vast utility in the area of research, and are being tested further in the area of mapping. Combining the utility of several sensor systems is recommended. When outfitting a dedicated remote sensing aircraft with sensor systems, it is recommended to have three or four cameras. An inexpensive system could include electro-optical CCD or video, an imaging spectrometer (such as VIFIS for inexpensive alternative to CASI), and one or more small format (35 or 70 mm) aerial photographic cameras. This configuration could be assembled for less than $50,000 (Roberts, 1995). Multi spectral video systems are the least expensive of the electro-optical multispectral systems, and offer advantages in ease of system development and image interpretation, however, the analysis of imagery for resource management does require specific training in video image processing and interpretation (Roberts, 1995). The aerial photographic cameras would be of utility in mapping situations requiring high degrees of accuracy, the imaging spectrometer for situations requiring fine spectral detail, and the electro-optical CCD or video for situations requiring specific types of digital image classifications (Roberts, 1995). A flexible and affordable system, such as electro-optical CCD or video, coupled with aerial photographic cameras and VIFIS can utilize the benefits of more than one sensor system for research. Developments in multispectral video and digital cameras are such that they are becoming affordable to buy or lease, in comparison to buying data (King, 1995; Roberts, 1995).

3.4 Ultralight aircraft

Ultralight aircraft equipped with video cameras can be used in the South as a smaller, less expensive alternative to aircraft, although there can be problems using these smaller, less sturdy platforms. The ultralight aircraft combined with a video system was found to be "a powerful tool for remote sensing purposes in remote areas and a complementary instrument to more conventional surveys." (Gregoire and Zeyen, 1986) Researchers from Utah State University are enthusiastic about the capabilities of their ultralight aircraft for low-altitude large-scale imagery. Their aerial photographic camera equipped ultralight has been effectively used for imaging archaeological field sites and agricultural fields (Hinckley and Walker, 1993). They found that the low speed of their ultralight aircraft results in sharp images without any image motion blur. They also found that remarkable advantages in clarity of observation can be obtained from low altitude, large-scale imaging from a very cost-effective ultralight plane (approximately $1,000, including camera)—this is not just “the poor man’s approach to remote sensing” (Hinckley and Walker, 1993).

Chapter 4. METHODS

To address the research questions presented in Chapter One, I undertook a content assessment of three primary English language remote sensing journals published in the period 1985-1997, and carried out a case study of imagery of the Kananaskis forest in Alberta. A method was developed to analyze the publications of Southern authors quantitatively, expecting that the quantity and type of research that was published in a selection of journals by and about the South would indicate trends in the larger body of research that is being carried out. The three journals evaluated were: *The International Journal of Remote Sensing* (*IJRS*), *Photogrammetric Engineering and Remote Sensing* (*PE&RS*), and *Remote Sensing of Environment* (*RSE*). These journals were selected because they are the most widely read and available international remote sensing journals, and represent a major body of publications. All Southern articles published between 1986 and 1997, inclusive, were evaluated. Southern articles include all articles applied to a country or region in the South whether written by Southern or Northern authors.

4.1 Literature content analysis

In order to quantify the data, selected information was entered into an Excel spreadsheet with thirteen fields. The thirteen fields were selected in order to provide summary information on the articles and provide information that could be used to answer the research questions. Some fields were used for analysis and some were descriptive. The fields filled out for each article were: 1. Author, 2. Year, 3. Volume and number of the publication, 4. Local/Outsider/Joint authorship, 5. Research type, 6. Page numbers, 7. Title, 8. Country, 9. Land, 10. Scale, 11. Imagery used, 12. Participatory, and 13. Comments. See Table 3. for an example of the thirteen fields and an example article.

Table 3. Example of literature assessment database with 13 fields[1]

Author	Year	Volume	Country	L/O/J	Type	Page	Title	Land	Scale	Imagery	Par	Comments
Pope, Kevin C., Jose M. Rey-Benayas and Jack F. Paris	1994	Vol. 48, No 2, 1994	Belize	O	5	205-219	Radar Remote Sensing of Forest and Wetland Ecosystems in the Central American Tropics	forest	?	SAR	N	US. stats to determine which "biophysical index" best for manip'ing SAR data. they found ITI was best. "there is a great need for radar systems in ecological studies of the tropics bec ground access is often difficult and frequent cloud cover and dense foliage limit the use of optical sensors." same story for every satellite company. sell sell sell. true about the clouds though. **read**

[1]Example of one Southern publication, taken from Remote Sensing of Environment. The thirteen fields refer to: author(s) of publication, year of publication, volume and number, country of interest, local/outside/joint authorship (L,O,J), type of publication (1-8), page numbers, title of article, predominant land cover or land use, scale (? indicates unknown scale), local participation (Par, yes or no), and comments on the article (these are subjective, and condensed due to space limitations in the database).

The first three fields (author, year, and volume) are self explanatory, and contained either text or numbers. The next ten paragraphs describe fields 4-13.

4. Local, outside, or joint authorship was determined by the location of the author's (or authors') affiliated organization(s), as mentioned in the article. This field contained either L, O, or J (local, outsider, or joint). No attempt was made to determine the authors' country of birth. Local authorship indicated that a researcher whose documented affiliation was with a Southern organization wrote the article. Outside authors were affiliated with Northern organizations. Joint authorship was a joint effort between Southern and Northern researchers.

5. Research type: All articles were assigned to one of eight research types, indicated by a numeral (1-8). The categories were constructed after a preliminary review of international remote sensing literature from the last two decades showed that most research was carried out along a small number of similar themes ranging from simple mapping to technical studies. Two overview articles also helped to create the categories; Ehrlich *et al.*, (1994), divided thirty two environmental remote sensing articles into three groups to simplify their discussion, and Sader *et al.*, (1990) reviewed a range of tropical forest remote sensing applications (Sader *et al.*, 1990). The eight research types are:

1. Basic mapping: including topographic mapping and vegetation classification.
2. Resource inventory and land use planning: forest, agriculture, mineral, and water resources, inventory and land use planning.
3. Monitoring/estimating human and natural impact: such as deforestation, erosion, dune movement, ecosystem or land use changes. Often time series (using imagery from different time periods).
4. Biophysical and geophysical parameters: these articles examined photosynthesis, dry matter accumulation, greenness vs. leaf area index,

transpiration, thermal patterns, lithography, faulting, sediment concentrations in water, above ocean weather patterns, and other phenomena.

5. Abstract, technical studies: Articles in this category often involve experimentation with or comparison of techniques and imagery, modeling, or evaluating remote sensing techniques. Articles that had no specific application to the South and could have been carried out anywhere (such as laboratory studies) were placed in this category.

6. Overviews and summaries: of remote sensing activities in a given country, or of a given type.

7. Discussing technology transfer and training: these articles discussed problems with remote sensing implementation, training and appropriate technology.

8. Other: this category was created for the few articles that fell outside the classification.

Types one through three are applied studies. The fourth and fifth types are considered abstract studies, although type four articles could be partly applied. The fifth category contains the articles with the highest level of abstraction--the purely technical studies. Types six and seven discuss different aspects of remote sensing in the South, either by overviewing its applications, or discussing its possible merits and limitations.

6. Page numbers: The page numbers of the journal article, for reference.

7. Title: The complete title of the journal article.

8. Country (if mentioned): This field contained the country which was studied in the article (i.e. the location of the remote sensing imagery), or, in the case of the smaller scale studies, the continent or region. In non-applied studies this field contains the country where the research took place.

9. Land: This field contained a one or two word description of the predominant land cover in the area being studied. It was difficult to decide upon consistent land covers, since there are so many different landscapes in the South, and some studies covered several. Some examples are: tropical forest, savanna, desert, urban, water, geology. If land cover was impossible to determine, the intent of the study was

substituted (i.e. "geol"--short for geological mapping). In the case of overview studies where no or many land uses and land covers were mentioned, the field was left blank.

10. Scale: This field contained the scale of the imagery used or the scale of the maps created in the article. The field shows the scale in either text form (S, M, L for small, medium, large), or the numerical denominator of the scale fraction (i.e. "250,000" for 1:250,000). The scale categories used in the table were chosen to cover the most common operating scales in the studies. Large-scale studies were greater than 1:20,000, medium-scale were between 1:20,000 and 1:100,000, and small-scale are smaller than 1:100,000. These scales roughly correspond to the USGS levels (I-IV) as indicated by Avery and Berlin (1992). Many articles did not mention scale, and it had to be inferred by the type of imagery or left blank. If NOAA AVHRR, Landsat MSS or TM imagery was used, the scale was assumed to be small (S), unless the article indicated otherwise.

11. Imagery used: An abbreviation for the type(s) of imagery was entered in this field. NOAA AVHRR, Landsat, SPOT, Radar, airborne electro-optical video, and aerial photography were N, L (sometimes TM, or MSS), S, R, V, and A, respectively. The field was left blank if the authors neglected to name the imagery, or if the article did not deal with a specific type of imagery.

12. Participatory approaches were those that involved local participation (as distinct from local authorship). This field was simply Y or N, (Yes or No) to indicate if local participation was used. Any type of interaction or information exchange with local people was considered. Participatory Rural Appraisal (PRA) techniques, community mapping, informal surveys, and use of local guides or informants were considered.

13. Comments. This field contains a short text description of the main ideas in the article. These comments were often subjective (see the example in Table 3). Some articles were summarized in more detail.

Fields 2, 4, 5, 10 and 12 were quantitatively analyzed. To show the trends in the data, I organized the data into two five year periods, 1986-1990 and 1991-1995, which I refer to as "pre-1991" and "post-1991." The data were tallied and tabulated over the ten year period, and over two five year periods in various combinations designed to answer the first six research questions (section 2.1) about the literature. The years 1996 and 1997 were assessed separately, after the ten year period.

4.2 Case study

After assessing the articles and finding a high reliance on orbital imagery but few common approaches to utilizing remote sensing imagery in the South, I undertook a case study to assess different remote sensing imaging systems. An evaluation of a forest dataset was used to evaluate the merits and limitations of various systems, address the last six research questions (section 1.2), and assist in making recommendations.

A comprehensive imaging dataset was utilized for the Kananaskis region (115°04'30''W, 51°01'N) to make comparisons of as complete a set of remote sensing imagery as possible. In the South, complete imagery sets are not readily available, and in order to make general comments about remote sensing methods, this region in Canada was considered appropriate. The Kananaskis forest is a mesic forest type in southeastern Alberta supporting *Pinus contorta* (Lodgepole Pine, Pl), *Populus tremuloides* (Trembling Aspen, Aw), *Populus balsamifera* (Balsam Poplar, Pb) and *Picea engelmannii* (Engelmann Spruce, Sw). The study area is shown in Figure 2.

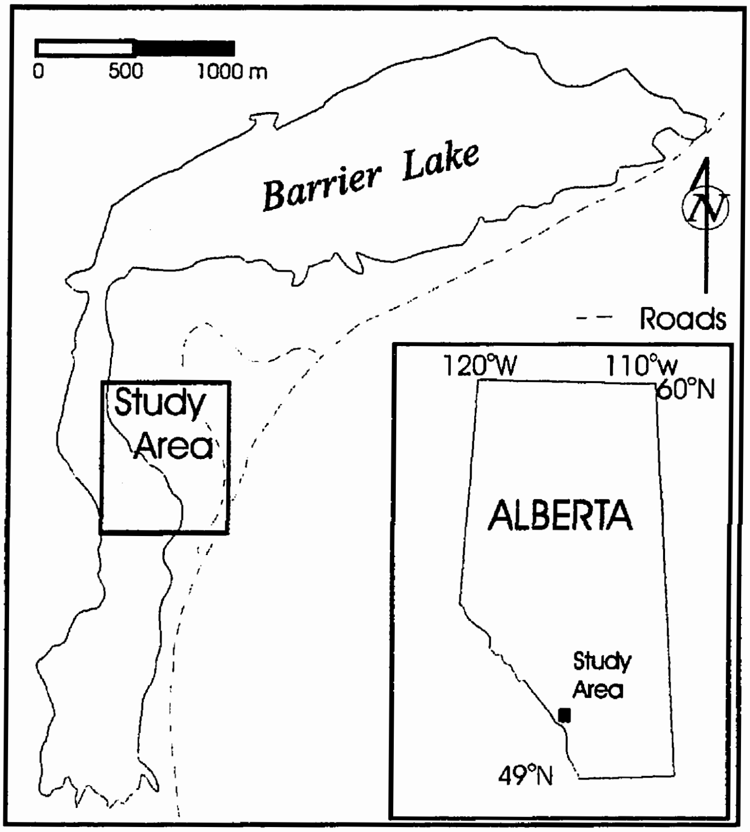


Figure 2. Kananaskis study area, Kananaskis, Alberta

The dataset consisted of Landsat TM, SPOT images and aerial images at six different altitudes 152, 305, 610, 1219, 2438 and 4633 m (500, 1000, 2000, 4000, 8000, and 15,200 feet). The aerial images were compact aerial spectrographic imagery (CASI), digitally recorded CCD NTSC camera images and aerial photography (colour and colour infrared 35 mm diapositive film). The aerial imagery was flown on July 9 and 11, 1996. Ground truth data was collected concurrently, in the same week of July, 1996. The CASI image was flown July 6, 1994 at 3050 m above sea level. The Landsat TM image was acquired August 1984 and the SPOT was acquired August 1991. Each image was visually interpreted for its ability to discriminate forest stands, non-forest areas, ground cover and road features at its respective resolutions. While visual interpretation was meant to be the primary means of evaluating the imagery, two digital evaluation methods are also presented as a means of comparison with subjective interpretative procedures. Ground truth information was used to select training areas in the coniferous and deciduous stands, and summary statistics presented. Supervised classifications were run to compare the spectral ability to separate the different forest stands (coniferous and deciduous), and the classified pixel values were compared to ground truth.

Ground truth information was collected by researchers from the University of Alberta in the study area. Their methods are described in Wulder *et al.*, (1996). The ground truth information was collected in ten by ten metre plots along ten transects, approximately 45 metres apart. The transects ran northeast to southwest across the study area from the road to the beach of Barrier Lake, each transect being between 340 and 415 metres in length. The ground truth information gave details of overstory and understory percentages of tree species, crown closure, soil moisture regime, and ground vegetation. The overstory percentages of tree species were used for an accuracy assessment of the supervised classification. There were four plots per transect, or forty plots in all. Most of these plots were located with GPS (Global Positioning System) coordinates.

Data from transects 6-10 (see Figure 3) were used to help select the training areas on the imagery. The data provided information to interpret the visual cues on the imagery and select training areas for coniferous and deciduous forest regions. Unvegetated and water training areas were selected as well, mainly to improve the supervised classification of the forest regions. One training area for each class (coniferous, deciduous, water and unvegetated) was selected per image. The training areas for the orbital and higher altitude aerial imagery were necessarily less detailed than the training areas for the lower altitude aerial imagery, as visual cues were used as well as the ground truth information.

The aerial photographs were scanned, and all images were rectified to a common base map using ER Mapper software. When the imagery was flown, visual targets were placed at the beginning and ends of each transect, and GPS coordinates were recorded. Unfortunately, the targets on the beach were not visible on any of the scanned imagery, (although some were visible on the lower altitude aerial photography) and could not be used to accurately register the images. A supervised classification was run, using ER Mapper on each image: the Landsat TM, SPOT, CASI, and aerial photography and aerial electro-optical CCD at each flying height. The minimum distance to mean classification procedure was used because it provided the best classification.

Data from transects 1-5 were used to check the accuracy of the supervised classifications. Of these 20 plots, two did not have GPS coordinates and eight were in mixed stands, which were not useable in the accuracy assessment. This left ten available plots for an accuracy assessment on two forest classes. Jensen, (1996) recommends 51 sample points per class in order to assess the accuracy of a classification using error matrices. However, the ground truth available was compared on a region by region basis with the imagery, and an overall accuracy percentage was calculated for each image. Because the ground truth information was collected on an area, and not a point basis, the ground truth had to be compared with numbers of pixels on the imagery, approximately 25 pixels on the lower altitude imagery, up to one pixel on the higher imagery, and less than one pixel on the orbital imagery. For the ground truth data, if the stand was greater than 85% coniferous or deciduous, it was considered to be a pure stand, otherwise if it was a mixed stand it was excluded from the accuracy assessment. This left 14 locations for the comparison. I compared the ground truth data to the predominant pixel value in each area of the ground truth plots.

4.2.1 Statistical methods

To validate the visual assessment of the imagery, pixel values were analyzed for the training areas of the coniferous and deciduous forest. Summary statistics (maximum, minimum and mean pixel values and standard deviation) are provided for the training areas. Principal components analysis (PCA) was used to extract eigenvectors in order to provide further information on the independence of the wavelength bands of the imagery. Principal components analysis is a method of converting an auto-correlated array (matrix) of data into its principal orthagonal components (Davis, 1994). In a remote sensing context, PCA can simplify a confusing array of correlated bands and provide information on which bands are redundant.

With multispectral data, the first principal component will ordinarily account for the largest percentage of the total scene variance, and the succeeding components will each contain a decreasing percentage of the scene variance (Lillesand and Kiefer, 1994). Each band duplicates some of the information in the other bands. The eigenvalue provides a quantifiable means of comparison of the degree of auto-correlation in the bands (Davis, 1994). In the case of the imagery used in this study, the three variables (the three wavelength bands of the aerial and orbital imagery) were converted into three eigenvectors and three eigenvalues. The lengths of the eigenvectors (the eigenvalues) were a measure of the independence of the variables. They explain whether the three bands are independent or whether only one or two bands are needed to display most of the information in the imagery--they can identify redundant variables. The correlation eigenvalue was used because it enabled comparison of eigenvectors between imagery sources.

Chapter 5. RESULTS OF THE LITERATURE CONTENT ANALYSIS

Results of the comprehensive (1986-1997) literature assessment of *IJRS*, *PE&RS*, and *RSE* are presented in this chapter as proportions of articles published by local, outside and joint authors, at small, medium and large-scales, according to the type of remote sensing imagery used, and as frequency of different types of applied and non-applied studies. The results from the ten year period 1986-1995 are presented first; broken into two five year periods so that trends can be evaluated. The results from the more recent years (1996 and 1997) are presented for comparison in section 5.4.

5.1 Tabular results of the literature analysis

Articles published between January 1986 and July 1997 inclusive in *IJRS*, *PE&RS* and *RSE* were assessed. Between 1986 and 1995 the three journals published 650 articles related to the South (Table 4). I evaluated the 650 articles as a group and broken into two five year blocks of time (1986-1990 and 1991-1995). Between January 1996 and July 1997 a further one hundred and fifty three Southern articles were published. These articles are treated separately in section 5.4. The data were tabulated in Excel's spreadsheet, using the "sort" function and simple summation queries and results from 1986-1995 are summarized in Tables 4 through 12, below. The tables show the numbers of Southern articles published by each journal (Table 4), the percentages of local, joint and outside studies (Table 5), the percentages of small, medium and large-scale studies (Tables 6-7), and the types of imagery used (Table 8). The percentages of each of the eight types of studies are shown in section 5.2 in Tables 9-12.

Most of the 650 articles were published in *IJRS* (Table 4). *IJRS* published 494 Southern articles and letters between 1986 and 1995, inclusive. *PE&RS* and *RSE* each published seventy eight Southern articles in the same ten year period. The numbers of Southern articles published have increased gradually since 1986 in each journal.

Table 4. Numbers of articles published from the South between 1986 and 1995 in *International Journal of Remote Sensing, Photogrammetric Engineering and Remote Sensing* and *Remote Sensing of Environment* (650 total)

Journal	1986-1991	1991-1995	Total
IJRS	226	268	494
PE&RS	37	41	78
RSE	32	46	78
Total	295	355	650

Local and outside authors were published about equally, overall. Of the total 650 articles, local and outside authors each accounted for approximately forty five percent (Table 5). Joint authorship accounted for the remaining ten percent. There was a trend for local authors to be published with greater frequency after 1991, although this trend was not displayed equally by the three journals. Local authorship increased from 37 to 61 percent in *IJRS*, pre- to post-1991 (Table 5). In *RSE*, the percentage of local authorship decreased post-1991 (from 38% pre-1991 to 28% post-1991), but the percentage of joint authorship increased, and outside authorship remained about the same (Table 5). *PE&RS* showed an increase in local and outside authorship (from 35-41% for local authors, 41-49% for outsiders), and a decrease in joint authorship, moving from pre- to post-1991. Joint authorship increased in *IJRS* (from 5 to 9%), while outside authorship decreased from 58-30% after 1990 (Table 5). These trends show that, in general, published articles about the South are tending to be written more by local authors, and that Southern researchers are gaining the knowledge to study their own (and other Southern) countries.

Table 5. Percentages of local, outside and joint authorship in Southern articles published in *IJRS, PE&RS* and *RSE* between 1986 and 1995

Authorship	IJRS	PE&RS	RSE	Total
1986-1995				
Local[1]	50	38	32	46
Joint	7	17	19	10
Outside	43	45	47	44
Total %	100	100	100	100
1986-1990				
Local	37	35	38	-
Joint	5	24	13	-
Outside	58	41	50	-
Total %	100	100	100	-
1991-1995				
Local	61	41	28	-
Joint	9	10	24	-
Outside	30	49	48	-
Total %	100	100	100	-

[1]Local authorship indicates the author(s) is/are affiliated with a Southern organization, Outside indicates an affiliation with a Northern organization, Joint indicates joint authorship.

Many articles did not mention the scale they were working at and I often had to extrapolate scale from the type of imagery used. Most studies (69%) were done at a small scale (< 1:100,000), with low resolution orbital imagery (Table 6). Overall, small-scale studies increased pre- to post-1991 for all groups (57-73% for local authors, 60-83% for outsiders, and 64-75% for joint authors) (Table 6). Of the three groups, outside authors focused on small-scale studies at 70% overall (and 83% after 1991), whereas small-scale studies for local and joint authors reached 67% and 71% respectively (Table 6).

Table 6. Percentages of small, medium and large-scale studies in Southern articles published in all three journals between 1986 and 1995

	1986-1990			1991-1995			Overall		
Authorship	% S Scale	% M Scale	%L Scale	% S Scale	% M Scale	% L Scale	% S Scale	% M Scale	% L Scale
Local[1]	57	12	4	73	5	4	67	7	4
Joint	64	0	5	75	15	0	71	10	2
Outside	60	3	1	83	2	3	70	2	2
Total	59	6	2	77	5	3	69	5	3

Percentage of published journal articles at small (< 1:100,000), medium (1:20,000 to 1:100,000) and large-scales (> 1:20,000). The scale is either stated in the article, or assumed from the imagery source: orbital imagery is small-scale. [1]Local authorship indicates the author(s) is/are affiliated with a Southern organization. Outside indicates an affiliation with a Northern organization. Joint indicates joint authorship.

IJRS published a greater frequency of small-scale studies (involving scales or imagery sources less than 1:100,000) than *PE&RS* or *RSE* (Table 7). Local authors were slightly more involved in medium (1:20,000 to 1:100,000) and large-scale (greater than 1:20,000) studies than outside authors. *RSE* published a higher percentage of large-scale studies done by local authors than the other journals (Table 7). *PE&RS* published a higher percentage of medium-scale studies by local authors than the other journals. However, out of all articles, only 3% were done at a large scale (Table 6).

Table 7. Percentages of small, medium and large-scale studies in Southern articles published in *IJRS*, *PE&RS* and *RSE* between 1986 and 1995

	IJRS			PE&RS			RSE		
Authorship	% S Scale	% M Scale	% L Scale	% S Scale	% M Scale	% L Scale	% S Scale	% M Scale	% L Scale
Local[1]	74	7	3	33	18	3	63	0	17
Joint	69	7	0	46	15	0	50	6	6
Outside	64	3	1	69	3	6	76	0	2
Total	70	5	2	51	11	4	66	1	7

Percentage of published journal articles at small (< 1:100,000), medium (1:20,000 to 1:100,000) and large-scales (> 1:20,000). The scale is either stated in the article, or assumed from the imagery source: orbital imagery is small-scale. [1]Local authorship indicates the author(s) is/are affiliated with a Southern organization. Outside indicates an affiliation with a Northern organization. Joint indicates joint authorship. Note: *IJRS* showed a marked increase in local small-scale articles from pre-1991 to post-1991.

The lack of large-scale studies was reflected by the imagery choices of the authors. Overall, the studies showed a great dependence on low resolution orbital imagery (Table 8). Table 8 shows the percentages of the different imagery sources used by local, joint, and outside authors. Only one sensor is shown in the table, the primary sensor used, although often more than one sensor system was used in one study. The most common imagery sources were NOAA AVHRR (19%) and Landsat TM (16%), and Landsat MSS (11%). Airborne video is a relatively recent phenomenon, receiving more study in the North. It received much less mention than aerial photography in Southern research, though it received more mention in *PE&RS* than *IJRS*. Aerial methods (A + air + V) accounted for only 5.4% of all studies, as the primary sensor (Table 8). The trends show an increase in percentage of local authors' publications for orbital sensors, but a decrease for aerial sensors (and a decrease for MSS which has been largely replaced by TM).

There was a distinction between types of imagery used by local, outsider and joint authors. The most common sensor for local authors, overall, was Landsat TM; MSS imagery pre-1991 (22.7%), and TM imagery post-1991 (29%). Local authors made little use of either the low resolution NOAA AVHRR or the higher resolution SPOT (around 5% each after 1991). Joint authors had the highest use of aerial photography and SPOT imagery of the three author groups. After 1991 their use of each of these was about 10%, while local and joint authors used aerial photography and SPOT much less. Joint authors had their highest percentage use in NOAA AVHRR, like outside authors. Some researchers have chosen to employ more than one data source for their studies.

Table 8 shows that outside authors more frequently used very small-scale imagery (NOAA AVHRR) than local authors. NOAA AVHRR was the most popular imagery source pre-1991 for outsiders (23%) and became even more popular (45%)

post-1991. Most NOAA research is in North America. Of the Southern research, a good fraction was in Sahelian Africa, and in South American and African tropical forest (Ehrlich *et al.*, 1994 IJRS). Entire issues of *IJRS* have been dedicated to NOAA AVHRR research in Africa (i.e. 1986 *IJRS* Special Issue: Monitoring the Grasslands of Semi-arid Africa Using NOAA AVHRR, and 1991 *IJRS* Special Issue: Coarse Resolution Remote Sensing of the Sahelian Environment). Outsider authors published only 17% of their articles utilizing TM imagery post-1991, while local authors published with TM imagery at 29% post-1991. Local authors were much less interested in NOAA AVHRR than outsiders—only 5.2% of their studies post-1991 used this low resolution imagery. The difference between author groups shows that local and joint authors were more interested in information that can be obtained from higher resolution orbital imagery, but that of the orbital imagery, local authors are more interested in the higher resolution sensor, TM, and that outside authors are more interested in the lower resolution sensor, AVHRR. Outside authors tend to be more interested in regional and global studies than local authors, and these studies are possible with very low resolution imagery.

Table 8. Types of imagery used in *IJRS*, *PE&RS* and *RSE* 1986-1995
as a percentage of articles published by joint, local and outside authors and as a percentage of total. "A" refers to aerial photography, "air" to other aerial methods (i.e. radar, airborne imaging spectrometer), "IRS" to Indian Remote Sensing Satellite, "MSS" to Landsat MSS, "N" to NOAA AVHRR, "R" to orbital radar, "S" to SPOT, "TM" to Landsat TM, and "V" to aerial video and digital frame systems, "other/none" to all other imagery and articles with no particular imagery.

Imagery	% 1986-1990	% 1991-1995	% of Total
A:Joint	4.5	10.0	
A:Local	5.5	2.1	
A:Outside	2.5	2.5	
A:total			3.4
air:Joint	0%	2.5	
air:Local	5.5	0.5	
air:Outside	0%	0.8	
air:total			1.4
IRS:Joint	0%	0%	
IRS:Local	0.9	10.8	
IRS:Outside	1.9	0%	
IRS:total			3.9
MSS:Joint	18.2	7.5	
MSS:Local	22.7	10.3	
MSS:Outside	8.7	2.5	
MSS:total			10.7
N:Joint	22.7	30.0	
N:Local	4.5	5.2	
N:Outside	23.6	45.0	
N:total			19.2
R:Joint	9.1	5.0	
R:Local	2.7	2.6	
R:Outside	4.3	1.7	
R:total			3.2
S:Joint	9.1	10.0	
S:Local	2.7	4.6	
S:Outside	1.2	4.2	
S:total			3.9
TM:Joint	0%	17.5	
TM:Local	7.3	29.4	
TM:Outside	8.1	16.7	
TM:total			16.2
V:Joint	0%	5.0	
V:Local	0%	0%	
V:Outside	0.6	0.8	
V:total			0.6
other/none:J	45.5	7.5	
other/none:L	45.5	35.1	
other/none:O	49.1	26.7	
other/none:total			37.6

5.2 Results of the literature assessment by research type

I had expected local authors to have a greater focus on applied studies and outsiders to have a greater focus on technical studies. The results show that local authors performed just as many abstract, technical (type 5) studies as (and in some years, more than) outside authors.

Technical studies were by far the most common. Type 5 (technical, abstract) articles were the most common type of study overall (Table 9). Type 5 articles accounted for twenty eight percent of all articles. Local authors had a slightly higher percentage of type 5 studies than outsiders, which was more pronounced in later years (Table 10). This shows that local researchers have similar pressures (funding and academic) to outsiders to perform technical rather than applied research. Type 4, the second most technical category, was the second most common, at twenty three percent.

Table 9. Percentages of research types (1-8)[1] in all three journals, 1986-1995

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Articles Total %	11	11	10	23	28	13	4	1

Total: 650 Southern articles and letters.
[1]Type 1: Basic mapping; Type 2: Resource inventory and land use planning; Type 3: Monitoring/estimating human and natural impacts; Type 4: Biophysical and geophysical parameters; Type 5: Abstract, technical studies; Type 6: Overviews and summaries; Type 7: Discussing technology transfer and training; Type 8: Other.

Before 1991 there was less of a technical focus and a greater frequency of simple mapping (type 1) studies. Table 10 shows that in *IJRS* pre-1991, simple mapping (type 1) studies and abstract (type 5) studies were undertaken with about equal frequency by local researchers, and were the most common categories for local researchers. Pre-1991, Southern researchers' main goal was to get their map inventories to a basic standard. They were still getting used to the idea of using remote sensing technology. Post-1991, the focus on publishing technical studies increased this category to fifty percent of all studies done by local researchers. Simple mapping decreased in importance to fifth place post-1991, after biophysical and geophysical studies (type 4), resource inventory (type 2), and finally monitoring human and natural changes (type 3 studies) (Table 10).

Table 10. Percentages of research types (1-8)[1] in *IJRS*

IJRS 1986-1995	(494)								
Authorship	% of Total	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Local	50	15	15	9	22	28	7	3	2
Joint	7	3	14	9	31	37	6	0	0
Outside	43	10	8	10	17	20	26	8	0.5
Total	100	12	12	9	21	26	15	5	1
IJRS 1986-1990	(226)								
Local	37	23	11	2	18	24	12	8	2
Joint	5	9	0	9	64	9	9	0	0
Outside	58	10	5	10	15	15	37	8	1
Total	100	15	7	7	19	18	27	8	1
IJRS 1991-1995	(268)								
Local	61	10	16	12	24	30	5	1	1
Joint	9	0	21	8	17	50	4	0	0
Outside	30	10	15	10	20	30	6	9	0
Total	100	9	16	11	22	32	5	3	1

[1]Type 1: Basic mapping; Type 2: Resource inventory and land use planning; Type 3: Monitoring/estimating human and natural impacts; Type 4: Biophysical and geophysical parameters; Type 5: Abstract, technical studies; Type 6: Overviews and summaries; Type 7: Discussing technology transfer and training; Type 8: Other.

RSE and *PE&RS* showed similar distribution of research types—type 5 studies increased in importance over the years to become the most common category for local and outside authors (Table 11 and 12). Overall, (Table 9) categories 1, 2, 3 and 6 had about equal incidence for all articles (between ten and thirteen percent). Discussing technology transfer (type 7) was relatively uncommon, at four percent. Articles that could not be classified except by "other" (type 8) were very uncommon (only one percent). Nearly all articles fit the classification scheme.

Table 11. Percentages of research types (1-8) in *PE&RS*

PE&RS 1986-1995 (78) Authorship	% of Total	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Local	38	0	0	10	23	63	0	0	3
Joint	17	15	0	31	15	38	0	0	0
Outside	45	9	14	23	14	23	17	0	0
Total	100	6	6	19	18	41	8	0	1
PE&RS 1986-1990 (37)									
Local	35	0	0	8	0	92	0	0	0
Joint	24	11	0	44	11	33	0	0	0
Outside	41	7	33	7	20	20	13	0	0
Total	100	5	14	16	11	49	5	0	0
PE&RS 1991-1995 (41)									
Local	41	0	0	12	41	41	0	0	6
Joint	10	25	0	0	25	50	0	0	0
Outside	49	10	0	35	10	25	20	0	0
Total	100	7	0	22	24	34	10	0	2

[1]Type 1: Basic mapping; Type 2: Resource inventory and land use planning; Type 3: Monitoring/estimating human and natural impacts; Type 4: Biophysical and geophysical parameters; Type 5: Abstract, technical studies; Type 6: Overviews and summaries; Type 7: Discussing technology transfer and training; Type 8: Other.

Local researchers and outsiders had different approaches. Outside researchers in all three journals had more evenly distributed interests across the eight categories (Table 10, 11, and 12). Local researchers tended to concentrate their energies on a smaller number of categories, especially focused on technical studies post-1991. Local researchers actually had greater percentages of technical studies than outside researchers in most journals and most years (see Tables 10, 11, and 12). Researchers often have a pressing need to carry out publishable research, which may not include the simple large-scale mapping that the South needs. The focus on technical studies may reflect a stringent publication requirement by the journals for Southern authors, or it may reflect pressures from funding and academic agencies to publish more theoretical than applied studies. The publishing policy of the major journals may exclude applied studies.

Table 12. Percentages of research types (1-8) in *RSE*

RSE 1986-1995 (78)									
Authorship	% of Total	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Local	32	12	12	0	36	40	0	0	0
Joint	19	13	7	27	33	20	0	0	0
Outside	47	8	0	0	51	38	3	0	3
Total	100	10	5	5	42	35	1	0	1
RSE 1986-1990 (32)									
Local	38	8	17	0	42	33	0	0	0
Joint	13	0	25	0	75	0	0	0	0
Outside	50	13	0	0	63	19	0	0	6
Total	100	9	9	0	56	22	0	0	3
RSE 1991-1995 (46)									
Local	28	15	8	0	31	46	0	0	0
Joint	24	18	0	36	18	27	0	0	0
Outside	48	5	0	0	41	50	5	0	0
Total	100	11	2	9	33	43	2	0	0

[1]Type 1: Basic mapping; Type 2: Resource inventory and land use planning; Type 3: Monitoring/estimating human and natural impacts; Type 4: Biophysical and geophysical parameters; Type 5: Abstract, technical studies; Type 6: Overviews and summaries; Type 7: Discussing technology transfer and training; Type 8: Other.

It was surprising to find that so many authors were interested in publishing technical type 4 and 5 articles.

5.2.1 Research type 1: Basic topographic mapping, vegetation classification

Simple mapping (type 1) is an "applied" research category (along with types 2 and 3). Type 1 articles simply classified and mapped the land cover. Simple mapping had greater importance pre-1991 than post-1991. Researchers in this category usually endeavored to create medium to small-scale maps of their region, country, or continent.

Simple mapping studies commonly used Landsat TM imagery. Most studies were small-scale. Some studies clearly called for orbital imagery—because of their small scale, or by their rushed nature. For example, Stone *et al.* (1994) used NOAA images with 1.1 km resolution to classify the vegetation and map the entire continent of South America within a short time period. In some cases greater resolution imagery was needed, but the use of satellite images was necessitated by the absence of good base maps for the area (Olive *et al.*, 1996). In these cases, satellite imagery may not have disclosed enough detail of the area, but was used as an overview, while fieldwork and aerial photography filled in the details. Simple mapping studies in the South were usually limited by one or more constraints, such as cost, availability of imagery, cloud cover, or lack of existing accurate maps (Flavelle, 1995).

Researchers used both visual and digital interpretation techniques. Visual interpretation is recommended for Southern research because it is a simpler technique and because it is often warranted by the extreme complexity of some tropical situations (Lo and Fung, 1986; Gastellu-Etchegorry, 1990). Different mapping applications included geological, hydrological, forestry, agriculture, bathymetric, and soil mapping.

Aerial imagery may be being overlooked because of the current trend towards satellite imagery, and the real and perceived unavailability of aerial imagery. In some studies, aerial imagery could have been used as a secondary sensor to complement the low resolution orbital imagery (Sader *et al.*, 1990). Aerial photographs are "still the most reliable and operational source of remote sensing data available in most tropical countries." (Sader *et al.* 1990) In one case, aerial photographs were not taken even though it would have added little extra cost to do so. In a 1:50,000 mapping exercise in the Philippines (Rasch, 1994), a reconnaissance was flown by airplane to visually check the results of a SPOT visual interpretation, but the researcher did not take aerial photographs at the same time even though they could have been an aid to the interpretation.

5.2.2 Research type 2: Resource inventory

Resource inventory (type 2) is an applied category, like simple mapping (type 1), but rather than simply mapping land cover, these articles focused on resources. The primary focus was agriculture. Forestry was secondary, and there was also some mention of mineral surveys, grass and rangelands. Although resource management was commonly mentioned as a primary need of the South, this type of article did not show up with great frequency. Overall, only 11% of all articles fell into this category—much less than the percentages of the technical categories 4 and 5.

Type 2 articles were slightly more common for local than outside authors. They were rare in *PE&RS* and *RSE*, more common in *IJRS*—15% frequency for local authors and 10% for outsiders. Resource studies showed an increasing trend for the entire period. The *IJRS* percentages of resource studies increased from pre-1991 values of 11% for local authors and 5% for outsiders, to 16% and 15%, respectively, post-1991.

In the three primary journals, many studies were small-scale (less than 1:100,000, or used orbital imagery) and, as with all other categories, showed negligible local participation. There was evidence of some confusion about local resource management practices by outsiders (see section 6.2 for details), probably caused by their lack of inclusion of local knowledge.

Noticing that resource management was frequently mentioned by Southern authors as a need for the South, I decided to look in other sources to find more examples of type 2 articles. Resource management studies may show a greater incidence in other publications, such as conference proceedings that are easier for

Southern researchers to publish in. The *Proceedings from the 20th International Symposium of Remote Sensing of Environment*, in Kenya (1986), did in fact show a greater focus on resources and simple mapping than I found in my three primary journals. Many of the symposium's Southern articles were devoted to remote sensing of natural resources (existing and potential) such as food crops and farmland (Barisano, 1986), groundwater and minerals (Mathai, 1986), desertification (Al-Hinai and Moore, 1986; Mainguet and Chemin, 1986; Maxwell and Jaccoberger, 1986;), forest and forest depletion (Epp and Kimanga, 1986). The South's interest in resource management is higher in the Symposium proceedings than that indicated by the three primary journals.

5.2.3 Research type 3: Monitoring human impact: deforestation, land use changes

Type 3 articles showed up with a frequency of about ten percent. This percentage is conspicuously low, (like type 2) considering the frequently stated need by and for the South to monitor its resources. Over the years, this type of study has increased only slightly. Since 1990 Southern authors have showed increasing interest, but generally Northern researchers have had more interest in this type. Global deforestation is an issue that strikes a chord with researchers in the North. Type 3 studies usually had a small or global scale, with NOAA AVHRR and Landsat imagery commonly used to monitor national or global deforestation.

National or global studies of this kind may not be of interest to the people in the South. Their governments often desire to raise the production and export of tropical forest products to increase the standard of living. This desire may run counter to the desires of indigenous people affected by encroaching logging. It may be in the interests of the people in power and the logging companies to ignore this conflict. To address both party's interests, the Southern country needs to invest in studies of a larger, localized scale, in order to approach sustainability and land use conflicts in discrete areas (Poole, 1995b). A global approach is not as relevant to them.

Satellite images can identify general areas of degradation and expanding agriculture, but aerial photography was found to be the best for accurate land use change (Gilruth *et al.*, 1990). In a large-scale study done by Gilruth *et al.* (1990) in West Africa, effects of degradation of the landscape were studied, including erosion, on a large, regionally useful scale. Manual interpretation of stereo photo pairs showed increases in permanent and shifting agriculture. They were able to make predictions of the worsening of the situation in this area.

5.2.4 Research type 4: Biophysical and geophysical studies

This category has a primarily abstract, technical focus, although some articles may have been applied in some way. This was the second most common category overall (23%). Type 4 articles were similar to simple mapping articles but rather than concentrating purely on mapping land units, these studies had an additional focus on biophysical and geophysical parameters such as: factors relating rainfall to net primary productivity (Chong *et al.*, 1993), soil reflectivity (Valeriano *et al.*, 1995), surface thermal patterns (Saraf *et al.*, 1995), sediment concentrations (Novo, 1989), ocean circulation (Vyas and Andharia, 1987), determining canopy temperatures (Luvall *et al.*, 1990) or the seasonal evolution of vegetation (Achard and Blasco, 1990).

Local and outside authors were highly involved in this type of study (Table 9). Overall, in *IJRS*, twenty one percent of local authors published type 4 studies, outside authors published seventeen percent, and joint authors published thirty one percent.

5.2.5 Research type 5: Abstract level in technical studies

Technical studies (type 5) represent the height of abstraction in remote sensing studies. While type 4 studies may have had some application, (e.g. to agriculture or forestry), technical studies were almost purely technical. This was the most popular category for Southern research. Local authors have adopted the technical approach to scientific research even more strongly than outsiders have. Perhaps the trend towards more applied science, begun by the social sciences, has not hit the South yet (Chambers, 1994b). This category included lab research and semi-applied research where the authors were testing methods.

Many of these articles were concerned with the utility of certain techniques in the tropics. Comparison of different imagery was common: aerial photographs, Landsat imagery, airborne video, or profiling laser for measuring tree heights (Arp *et al.*, 1982). Often these studies were concerned with developing a method or a technique, for example a cloud-masking technique (Franca and Cracknell, 1995). Some discussed statistical methods of manipulating digital images (Mahar and Afifi, 1995). A lot of these studies were purely technical, with no practical application. Many were lab studies. For example one group of Southern researchers photographed a toy plastic moose against a three-dimensional background (Wong and Ho, 1986) to test their camera system's three dimensional imaging capabilities.

5.2.6 Research type 6: Overviews and summaries

This category included articles that summarized remote sensing projects with similar applications or the history of remote sensing in a particular country. Before adopting remote sensing technology, it is important to thoroughly examine the usefulness of several types of imagery. These articles discussed remote sensing media and its applicability in various situations. Advances in remote sensing were stressed through the years.

This category had a variety of articles, from the history of remote sensing in a country (Saeed, 1993), or relating to an application (Sader *et al.*, 1990), to announcements of upcoming conferences. Many of the overviews were concerned with applications to deforestation (Sader *et al.*, 1990). There were quite a lot of "Remote Sensing Letters" published in *IJRS*, and most of these fell into type 6, inflating the number in this category. Remote sensing letters in *IJRS* are short or preliminary versions of important research, or clarifications, criticisms, or rebuttals to previously published research. This category of research was more common for outside authors than local and joint authors, and was published mainly in *IJRS* (see Table 13. for *IJRS* percentages). The amount of writing on this topic has declined in *IJRS* (27% to 5%) from pre- to post-1991, due possibly to changes in editorial policy.

5.2.7 Research type 7: Technology transfer, training and appropriate technology

This category was not a common one, occurring in only five percent of *IJRS* articles, and not at all in the other two journals. Most of these articles were written by outside authors. Southern and Northern researchers are concerned about the push toward adopting remote sensing technologies and whether they fit the South's needs. There are strong external and internal forces encouraging Southern countries to adopt remote sensing technology and promote inventory monitoring and managing of natural resources (Changchui, 1990; Luscombe, 1990). Self interests in funding or resources may drive these forces. Remote sensing projects are usually government funded, or funded by international agencies.

Of the fifteen articles that made up this category, there was good agreement that education needs to be addressed before remote sensing technology transfer can take place properly (Niosi *et al.*, 1995). Some articles discussed training that is already taking place. Some authors are concerned that remote sensing has been pressed on the

South as a quick and easy mapping tool, without regard for ground truthing. Many Southern countries are not ready to adopt digital remote sensing techniques as they are still mastering conventional aerial photography techniques. Several authors wrote that more appropriate techniques are visual interpretation of photographic products and they encourage adoption of manual photographic interpretation techniques (Reddy and Hilwig, 1993; King, 1994; Mishtra *et al.*, 1994).

Technologies should be selected that are affordable, and give weight to real needs, and less weight to market forces. Technological needs of each country will depend on their present level of technology and individual mapping goals. Concerns over the transfer of remote sensing technology began early: "Although remote sensing technology offers a very great potential, attempts at marketing its unproven capability and/or at downplaying the role and importance of ground-truthing may encourage over dependence on this technology." (Abiodun, 1977) Some authors believe remote sensing is a necessity for developing countries: "It makes it possible to overcome the difficulties of obtaining information on natural resources, and the environment, quickly, at little cost, and in inaccessible places." (Kabbaj and Mehrez, 1994) Other authors are certain that transfer of remote sensing technology to the South will only serve to increase the gap between wealthy and poor countries, and will negatively influence the South's development (Chandrashekar, 1989). As with other categories, resource management was mentioned often as an important focus for Southern countries.

5.2.8 Research type 8: Other

Only six articles, or one percent of the total, did not fit the research types and had to be classified as "other." The articles that did not fit the classification scheme were: two articles relating to traffic accidents and road networks (Koo and Aw, 1991; Lakshman Rao and Reddy, 1993); two articles predicting cloud cover and related problems in ordering satellite data in Indonesia (Gastellu-Etchegorry, 1988a and 1988b); one article about an award given to a scientist (Vaughan, 1986); and a call for papers in *RSE* (Vaughan, 1989).

5.3 Local participation

Local participation was very rare in all three journals for both local and outside researchers. As with the lack of large-scale articles and articles dealing with resource and social issues, there was a distinct lack of studies involving local knowledge and participation. This is discussed further in section 7.2. Participatory articles accounted for only 0.6% of all articles from 1986 to 1995. This represented only four articles out of the total 650. *PE&RS* and *IJRS* had only two participatory articles each, three of them published after 1991. *RSE* did not have any participatory studies. Two participatory studies were published by outsiders, one each by local and joint authors.

5.4 Results of January 1996-July 1997 literature analysis

The trends in the data are similar to previous years: between January 1996 and July 1997 *IJRS* published the majority of the one hundred and fifty three articles (Table 13); local authorship appears to still be on the rise (Table 14); local authors continue to increase their percentage of technical articles (Table 15) from pre-1996 figures (Tables 10-12), while outside and joint authors continue to increase their percentage of type 4 (biophysical and geophysical) articles (Table 15). There was a similar devotion to small-scale, orbital imagery dependent studies as in previous years.

Table 13. Numbers of Southern articles published between January 1996 and July 1997 in *IJRS*, *PE&RS* and *RSE* (total 153 articles)

Journal	Total
IJRS	110
PE&RS	13
RSE	30
Total	153

Table 14. Percentages of local, outside and joint authorship in Southern articles published between January 1996 and July 1997 in all three journals

Authorship	IJRS	PE&RS	RSE	Total
Local	61	46	23	52
Joint	12	38	23	16
Outside	27	15	53	31
Total %	100	100	100	100

Local authorship indicates the author(s) is/are affiliated with a Southern organization. Outside indicates an affiliation with a Northern organization.

Table 15. Percentages of research types (1-8) [1] in all three journals, January 1996-July 1997

Authorship	% of Total	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Local	52	4	13	13	24	46	0	0	0
Joint	16	4	12	12	48	24	0	0	0
Outside	31	6	8	13	44	29	0	0	0
Total	100	5	12	12	33	38	0	0	0

[1]Type 1: Basic mapping; Type 2: Resource inventory and land use planning; Type 3: Monitoring/estimating human and natural impacts; Type 4: Biophysical and geophysical parameters; Type 5: Abstract, technical studies; Type 6: Overviews and summaries; Type 7: Discussing technology transfer and training; Type 8: Other.

Chapter 6. CASE STUDY: COMPARISON OF ORBITAL AND AERIAL SENSORS

This chapter presents the results of a case study, where orbital sensors and aerial sensors at several flying heights were tested over the Kananaskis study area. Aerial photography was scanned for digital comparison with the electro-optical CCD imagery. All images were viewed as false colour images (with infra red, red and green bands viewed as red, green and blue). The imagery was first visually assessed for forest stand discrimination. It was then digitally analyzed for discrimination of deciduous and coniferous forest stands. Training areas were selected for coniferous and deciduous forest types, and summary statistics presented. The imagery was classified and the results were compared to the ground truth.

6.1 The Ground Truth

The ground truth data (Table 16) confirms that there are basically two types of forest stands, coniferous and deciduous, and areas with mixed species between and within the stands. The coniferous stands are much more mixed than the deciduous stands. Training areas for coniferous, deciduous, water, and unvegetated land are marked on each image (Figures 3-14). The coniferous stand is quite mixed. The figures vary throughout the coniferous stand (30-100% Lodgepole pine; 10-50% Engelmann spruce; and 0-30% trembling aspen), some areas being much more mixed with deciduous species. The training areas for the coniferous stand roughly represents the areas that are greater than 85% coniferous species. The deciduous stand is much more homogeneous than the coniferous stand, and the training areas are approximately 100% trembling aspen. A visual inspection of the imagery confirmed that there are roughly two types of forest stands within the study area, a darker coniferous area and a brighter deciduous area (Figures 5b and 11a). Transects 6-10 were used to help select the training areas, shown on each figure as coniferous and deciduous. Training areas for water and unvegetated land were also selected.

Table 16. Ground truth data for Kananaskis study site

	Plot 4	Plot 3	Plot 2	Plot 1
Transect 1	Aw4Pl4Sw2 (M)	Pl7Aw2Sw1(M)	Aw9Sw1(D)	Pl6Aw4 (M)
Transect 2	Aw7Pe3 (M)	Aw10 (D)	Aw10 (D)	Pl6Sw4 (C)
Transect 3	Pl10 (C)	Aw8Sw2 (M)	Aw10 (D)	Pl9Aw1(C)
Transect 4	Aw7Sw3 (M)	Aw9Sw1(D)	Aw10 (D)	Pl9Aw1 (C)
Transect 5	P8Aw2 (M)	Aw8Pb1P1(M)	Aw10 (D)	P8Sw2 (C)
Transect 6	Aw8Pb2 (M)	Aw10 (D)	Sw5Pl5 (C)	Pl5Aw5 (M)
Transect 7	Aw10 (D)	Aw10 (D)	P9Sw1 (C)	Aw5P3Sw1 (M)
Transect 8	Aw5Sw3Pb2 (M)	Aw10 (D)	Pl6Sw2Aw2 (M)	Pl6Aw3 (M)
Transect 9	Aw10 (D)	Aw10 (D)	Aw10 (D)	Pl10 (C)
Transect 10	Pl10 (C)	Aw6Pl3Sw1(M)	Aw5Pl5 (M)	Aw9Pl1(D)

Plots are 10 by 10 metres. Aw is Trembling Aspen, Pb is Balsam Poplar, Pl is Lodgepole Pine, Sw is Engelmann Spruce. The numbers indicate the percentages of tree species in the overstory of the plot, for example Aw4Pl4Sw2 is 40% Trembling Aspen, 40% Lodgepole Pine and 20% Engelmann Spruce. C indicates the plot is greater than 85% coniferous species, D indicates greater than 85% deciduous species, and M indicates a mixed plot.

There were many mixed plots with both deciduous and coniferous species. For the purposes of comparison with the supervised classifications, the mixed plots were not used. If a plot had greater than 85% either deciduous or coniferous species, it was considered to be deciduous (D) or coniferous (C), respectively. Plot 2 in transect 1 and plot 1 in transect 2 did not have GPS coordinates. This left ten plots from transects 1-5 (C and D, excluding M stands) to be used for an accuracy assessment with the supervised classifications. The results of this comparison are presented as "overall accuracy" of the supervised classification for each image, equal to the total number of correctly classified pixels divided by the total number of plots visible on the image (Table 17).

Table 17. Overall accuracies of the supervised classifications

Imagery Source	Number of correctly classified plots	Number of plots on image	Overall Accuracy of Image
Landsat TM	10	10	100%
SPOT	9	10	90%
CASI	9	10	90%
Aerial Photography: 15,200'	7	10	70%
Aerial Photography: 8,000'	7	10	70%
Aerial Photography: 4,000'	9	10	90%
Aerial Photography: 2,000'	5	10	50%
Aerial Photography: 1,000'	4	9	44%
Aerial Photography: 500'	5	6	83%**
Aerial Electro-optical CCD image: 4,000'	10	10	100%
Aerial Electro-optical CCD image: 2,000'	8	10	80%
Aerial Electro-optical CCD image: 1,000'	2	4	50%
Aerial Electro-optical CCD image: 500'	-	0	-

Overall Accuracy of Image is equal to the total number of correctly classified plots on image divided by the total number of plots on the image.
**The 500' aerial photograph classified all of the plots as deciduous, including the mixed plots. The Overall Accuracy of 83% is misleading because it just happened that the ground truth for the five plots available on this image were deciduous.

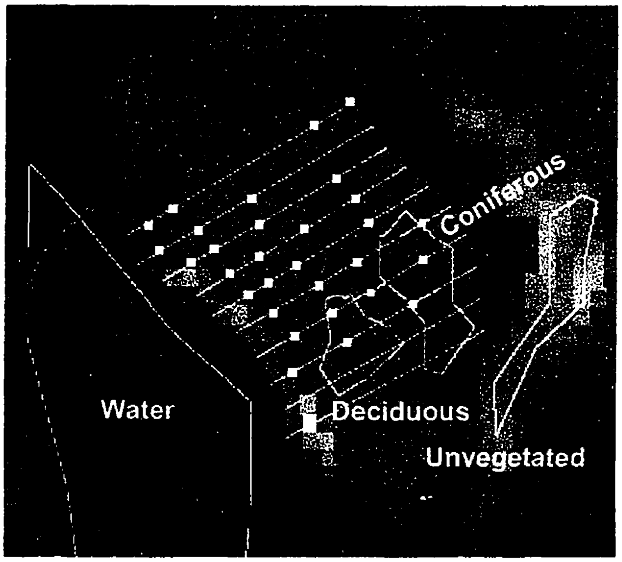
6.2 Orbital imagery

6.2.1 Landsat TM

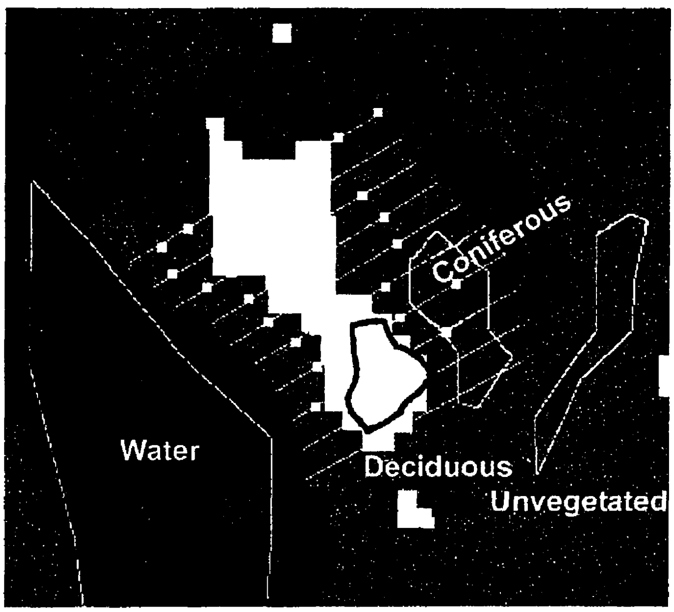
Landsat TM bands 4, 3, and 2 were displayed as red, green, and blue, producing a false colour image (Figure 3). With visual inspection, the TM image shows an interesting pattern of geological features in the area surrounding the study site, but very little detail in terms of forest species identification (Figure 3a). When the image is enlarged to show the study site (Figure 3a), the pixels in the resulting image become very generalized--more like a plaid tartan than a forest. The ground truth data were used to corroborate the visual information, and the stands were easily identified: the deciduous area appeared slightly brighter than the coniferous area. The non-forested areas were quite distinct in the TM imagery (appearing as white areas in Figure 3b), though it was not possible to distinguish whether the non-forest was bare rock or soil with sparse vegetation. Figure 3a and b. shows the Landsat TM image that was visually interpreted. Major roads are easily discriminated; minor roads are less visible. The entire TM image (not shown) clearly shows the major geological structures such as snow-capped mountains, river valleys, narrow coastlines, and bare rock outcrops.

On the TM image, the shadow elements are integrated with the trees, resulting in mixed pixels and a darker coniferous stand, so that the TM image showed spectral separation between the stands, whereas the aerial imagery at lower flying heights did not separate as well. The supervised classification of this image gives the impression that the forest is not composed of heterogeneous mixed stands. It very clearly groups the forest into areas of coniferous and deciduous. The low resolution results in a high degree of mixed pixels, and the coniferous forest is classified as an undifferentiated homogeneous area. This level of classification is of value in homogeneous stands that cover large areas. This image had an overall accuracy of 100% (Table 17), which showed that it represented stands rather than individual trees in its pixels. A similar study in Southern Alberta (Franklin, 1994) found high agreement between the classified TM image and the forest inventory ground truth, for the reason that the TM image had a very coarse spatial resolution which could distinguish the stands but not the trees. In the tropics TM would be useful for discriminating unvegetated from vegetated areas but would not be capable of discriminating forest types from one another because tropical forests are much more heterogeneous than temperate ones.

Figure 3. Landsat TM false colour image of Kananaskis study site
3 a. Study Area
3 b. Supervised classification of study area



3 a.



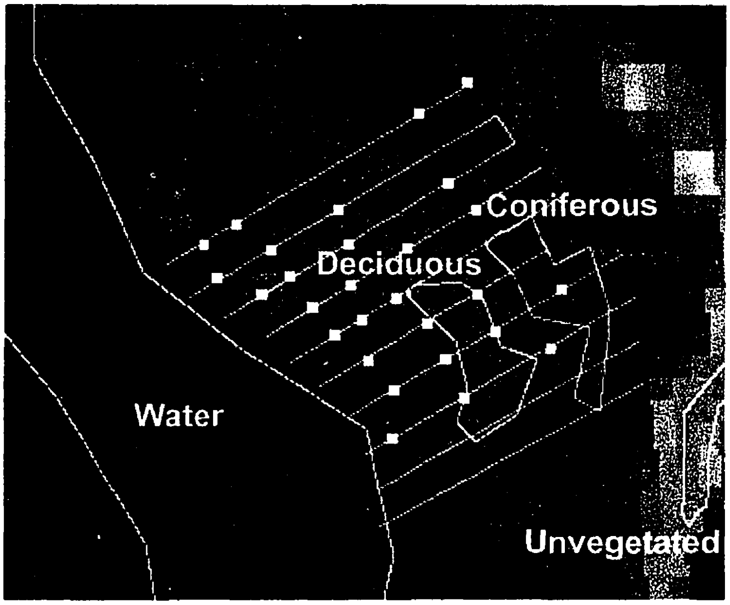
3 b.

3 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.
3 b. Results of a supervised classification of the TM image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

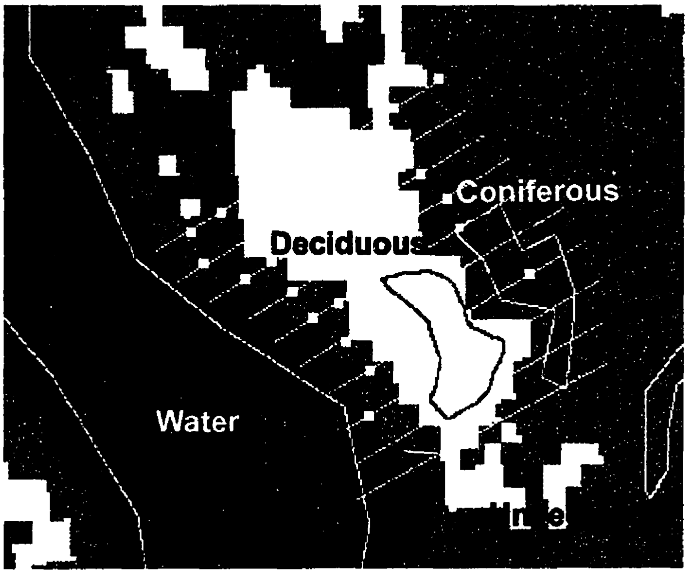
6.2.2 SPOT

SPOT bands 4, 3, and 2 were displayed as red, green and blue, producing a false colour image (Figure 4). SPOT multispectral (XS) imagery (acquired in August, 1991) provided limited improvements over the resolution of TM imagery. With SPOT imagery the same features (highways, roads, geological features, forest/non forest, and a vague impression of deciduous versus coniferous boundaries) could be visually discriminated as with a visual analysis of TM imagery, with only slight advantages in clarity (Figure 4a). The study area (Figure 4a) shows the same plaid tartan effect as the TM image (Figure 3a). The SPOT image also generalizes the mixed stand very effectively into coniferous and deciduous groupings (Figure 4 b). The overall accuracy of the supervised classification is 90%.

Figure 4. SPOT false colour image of Kananaskis forest
4 a. Study Area
4 b. Supervised classification of study area



4 a.



4 b.

4 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

4 b. Results of a supervised classification of the SPOT image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

The summary statistics for Landsat TM and SPOT (Table 18) show that the mean pixel (cell) values for the deciduous training area are higher than the mean cell values for the coniferous training area, as is expected from the appearance of the imagery (Lillesand and Kiefer, 1994). The standard deviations of the cell values for the SPOT and TM imagery are in the same order of magnitude for each training area (between 3.7 and 12.4); both imagery sources have a similar amount of spread of pixel values. Eigenvectors from the principal components analysis show that most of the information lies in the first principal component, but that the second principal component also holds up to 33% of the information. In most cases, the first and second principal components add up to approximately 90% (except in the SPOT coniferous area), showing that the intrinsic dimensionality of TM and SPOT bands is effectively two--meaning two bands are needed to view most of the information available in the data.

The mixing of species was not picked up by the orbital imagery (the standard deviations are roughly the same for the mixed coniferous and deciduous stands) because the resolution is too low, and the mixed stands have become merged into mixed pixels. Mixed pixels would probably be an even greater problem in tropical rainforest. The overall accuracies show that the orbital imagery discriminated stand boundaries well, indicating that they do not have an adequate level of detail to discriminate individual trees, or heterogeneous stands.

Table 18. Summary statistics for Landsat TM, and SPOT images and training areas

	Number of Cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev. (n-1)	Corr. Eigenval.	% Variance
Landsat TM							
coniferous training area							
band 4	5	198	222	210.8	9.1	2.38	79%
band 3	5	40	69	56.2	10.9	0.35	12%
band 2	5	66	74	69.2	4.4	0.27	9%
deciduous training area							
band 4	11	214	255	246.9	13.6	1.68	56%
band 3	11	52	73	58.7	8	1	33%
band 2	11	74	82	79.8	3.7	0.32	11%
entire image							
band 4	47824	0	255	107	74	1.79	60%
band 3	47824	0	240	39	36	1.06	35%
band 2	47824	0	228	55	41	0.16	5%
SPOT							
coniferous training area							
band 4	6	156	173	168.8	7.1	1.68	56%
band 3	6	44	65	51.5	8.8	0.78	26%
band 2	6	49	57	51.7	4.1	0.54	18%
deciduous training area							
band 4	7	198	231	217.7	12.4	2.1	70%
band 3	7	44	65	55.6	6.1	0.63	21%
band 2	7	66	82	69.4	6.3	0.26	9%
entire image							
band4	52800	0	255	89	59	1.78	59%
band 3	52800	0	203	29	28	1.08	36%
band 2	52800	0	201	41	32	0.14	5%

In TM and SPOT imagery: band 4 is infra red, band 3 is green, band 2 is red. Cell value refers to pixel values (0-255) in training areas shown in Figures 3-5. Corr. Eigenval. is the correlation eigenvalue from a PCA of the training areas, and % Variance is equal to Corr. Eigenval./(sum of Corr. Eigenval.s) * 100%

6.3 Aerial Imagery

6.3.1 Compact Aerial Imaging Spectrometer

The spectral bands selected for the CASI imagery were infrared: 8.01-8.06 mm, red: 6.75-6.82 mm and green: 5.48-5.55 mm. These were displayed as red, green, and blue to produce a false colour image that could be compared with the orbital and other aerial imagery. In the CASI image (Figure 5a and b) the deciduous area is clearly brighter than the coniferous area, and roads and coastline are apparent. The summary statistics for CASI data are provided in Table 19. The CASI data also have an intrinsic dimensionality of around two. There is a much higher standard deviation in the infra red band in the coniferous area than the deciduous area, reflecting the greater mixing of tree species in this stand that is shown in the ground truth.

The spectral bands chosen for the CASI imagery classified the coniferous and deciduous stands quite well (Figure 5c). It grouped the stands well, and there is a little more speckling in the coniferous area, reflecting the fact that the coniferous stand is a mixed stand with deciduous trees present. The overall accuracy of the supervised classification was 90% (Table 16). The CASI image had quite similar acccuracy to the orbital imagery, but for different reasons. The CASI imagery's higher spatial resolution is at a level commensurate with distinguishing heterogeneous stands, and so the image shows a greater detail. In a similar study in Southern Alberta, TM and CASI were found to have remarkable similar agreement with the forest inventory, for different reasons—CASI because its high resolution (which could distinguish the trees), and TM because of its coarse spatial resolution (which could generalize the stands) (Franklin, 1994).

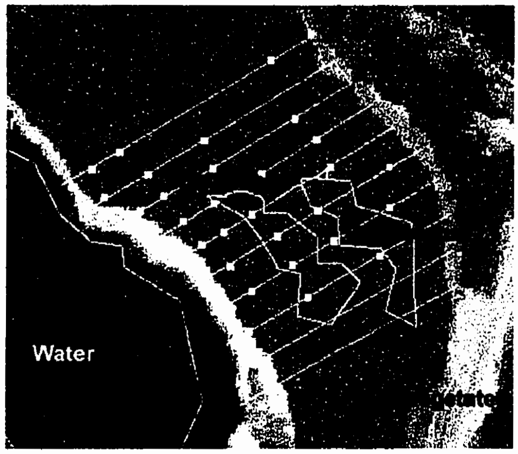
Table 19. Summary statistics for CASI image and training areas

	Number of Cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev. (n-1)	Corr. Eigenval.	% Variance
CASI							
coniferous training area							
band 1	253	75	190	131.8	24.1	1.96	66%
band 2	253	15	46	29.4	5.8	0.82	27%
band 3	253	25	84	54.2	8.2	0.21	7%
deciduous training area							
band 1	150	149	215	191.9	9.6	1.8	60%
band 2	150	25	40	31.9	2.9	0.72	24%
band 3	150	52	75	66.6	4.4	0.47	16%
entire image							
band 1	143616	0	255	138	79	2.01	67%
band 2	143616	0	255	88	55	0.86	29%
band 3	143616	0	255	125	51	0.13	4%

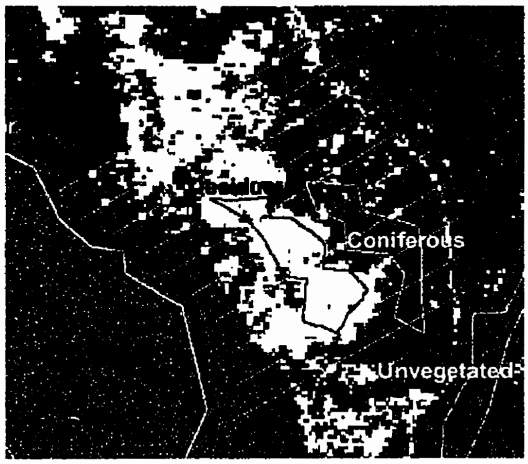
In CASI imagery: band 1 is infra red (8.01-8.06 μm), band 2 is red (6.75-6.82 μm), band 3 is green (5.48-5.55 μm). Cell value refers to pixel values (0-255) in training areas shown in Figures 3-5. Corr. Eigenval. is the correlation eigenvalue from a PCA of the training areas, and % Variance is equal to Corr. Eigenval./(sum of Corr. Eigenval.s) * 100%

Figure 5. CASI image of Kananaskis forest
5 a. Entire image
5 b. Study Area
5 c. Supervised classification of study area

5 a.



5 b.



5 c.

5 b. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.
5 c. Results of a supervised classification of the CASI image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

6.3.2 Aerial photography

Aerial photography (infrared false colour film) and digital electro-optical CCD were flown at six different flying heights, and assessed for their ability to resolve forest stands and other features. The 35 mm aerial photography was digitally scanned at 1200 dots per inch (dpi) and georeferenced using ER Mapper software. The photographs were visually assessed in digital form using a computer monitor, for easy comparison with the digital electro-optical CCD imagery. Table 20 summarizes the flying heights and the resultant approximate resolution of the scanned photographs. The scale of the contact print is a direct result of the flying height of the airplane. Scale of prints can vary with the amount of enlargement, but this has no effect on image resolution, which is contingent on the film used. For remote sensing imagery it is often more effective to consider the resolution of the imagery, rather than the scale, although for purposes of comparison I have shown the scale of the film in Table 19. With a 35 mm negative, the scale of the negative will be much smaller than any resulting prints other than contact prints. Figures 6-10 are aerial photographs of the Kananaskis forest, and are approximately six inches in size. Their approximate scales are indicated in Table 20.

Table 20. Flying heights and relative resolution and scale of aerial photographs

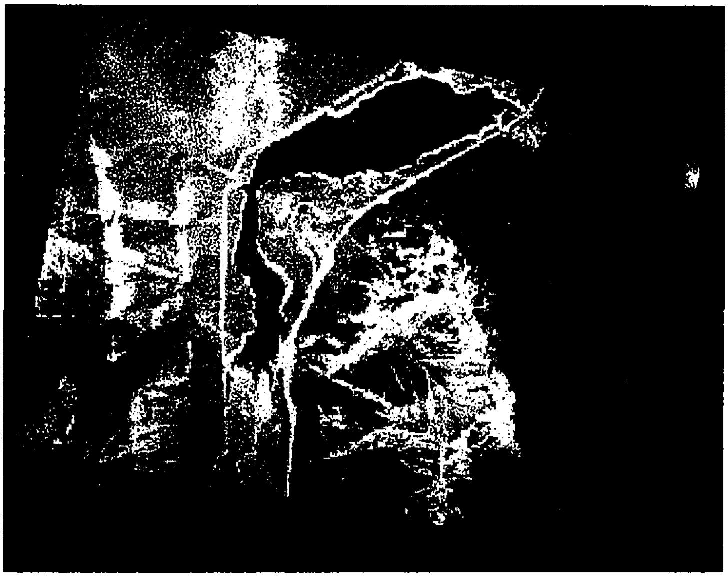
Aircraft flying height (m)	Scale of Negative (35 mm), 24 mm focal length	Approximate resolution of pixels (in m), scanned at 1200 dpi	Approximate scale of 6" print of negative
152 (500')	1:6,000	0.1	1:1,500
305 (1000')	1:13,000	0.3	1:3,000
610 (2000')	1:25,000	0.5	1:6,000
1219 (4000')	1:50,000	1	1:12,000
2438 (8000')	1:100,000	2	1:24,000
4633 (15200')	1:200,000	5	1:45,000

The highest flying height chosen was 4633m (15,200 feet) above ground (altitude was 6400 m (21,000 feet) above mean sea level). Many small planes have a maximum flying height near this level, commensurate with medium to small scale mapping efforts (Table 20). At this height, more forest detail can be seen than on the Landsat TM imagery, although there is a slight haze problem due to the interceding atmosphere. On the scanned aerial photographs the non-forested areas can be distinguished from forested areas (as on the Landsat TM), and roads and coastline are clearly visible. Comparing Figure 6 with Figure 3a shows that deciduous and coniferous stands can be resolved in a general way on both the 4633 m (15,200 foot) aerial photograph and the TM image. The roads are much more distinct on the aerial photograph than the TM image. At this resolution a forest texture can be seen that was not visible on the Landsat TM image and this aids in stand identification. Individual trees were not distinguishable. Viewing the film in its original unscanned state improves detail of the scanned 35 mm imagery.

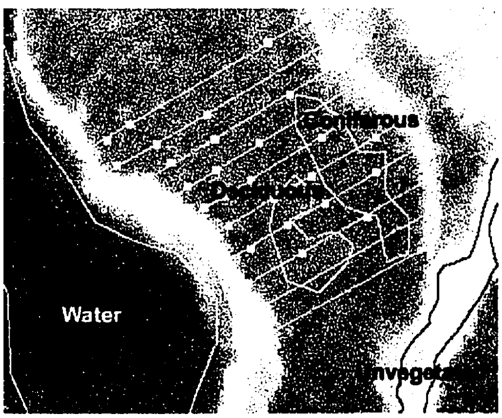
The summary statistics for aerial photography in the training areas confirmed what was first found by a visual assessment. Table 21 and 22 show that in the aerial photographs, most of the variance in the dataset can be accounted for by the first eigenvector (representing the infra red band). In most cases (and always in the coniferous area) the first eigenvector accounts for at least 90% of the variance. In many cases the other two eigenvectors are quite short, and account for a small percentage of the variance. Visually, all of the images appeared quite red (Figures 6-11), which showed that the infrared band was displaying most of the information for the image. Comparing the mean cell values (especially obvious in band 1) shows that the deciduous training area is always a brighter shade of red than the coniferous area. At 4633 m (15,200 feet) the mean cell values for band 1 are 209.7 (SD 10.2) in the coniferous training area and 224 (SD 4.2) in the deciduous area, indicating that the deciduous area has a higher reflectance in the infrared range. The standard deviations in the coniferous training areas increase as the flying height decreases. This shows that at the lower flying heights the cell values are picking up what is obvious to the naked eye: that the coniferous area is a mixed stand, with a variety of reflectances.

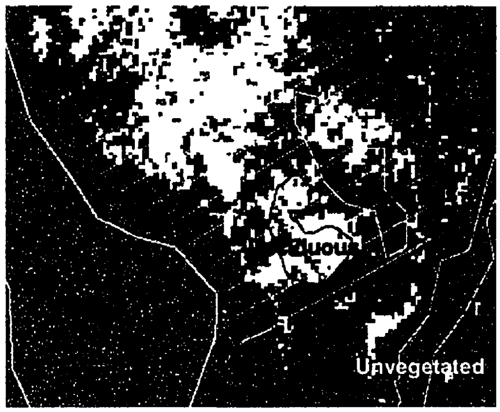
At 4633 m (15,200 feet) the overall accuracy of the supervised classification is 70% (Table 17). At this height there is less generalization than the orbital imagery, but still a high degree of mixed pixels. Generally, smaller scale scanned photographic imagery will be better able to discriminate forest stands than larger scale (Holopainen and Wang, 1998 in a forest in Finland), and larger scale imagery will detect individual trees. The supervised classification is very generalized in the study area, owing to the large pixel size compared to the detail of the stands (Figure 6 c). This is a result of the heterogeneity of the stand being incompatible with the pixel size of the imagery. In any situation, classified imagery will generally perform better on homogeneous stands than on mixed coniferous stands (Franklin, 1994). The resolution of imagery commensurate with 4633 m flying height was incompatible with detecting stand boundaries with any degree of accuracy because of the heterogeneity of the stand.

Figure 6. 4633 m (15,200 foot) 35 mm aerial photograph of Kananaskis forest
6 a. Entire image
6 b. Study Area
6 c. Supervised classification of study area



6 a.





6 b. 6 c.

6 b. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

6 c. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

Table 21. Summary statistics for higher altitude aerial photographs

	Number of cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev. (n-1)	Corr. Eigenval.	% Variance
Photography: 15,200'							
coniferous training area							
band 1	252	180	233	209.7	10.2	2.78	92%
band 2	252	102	175	134.9	11.9	0.12	4%
band 3	252	17	63	34.9	8.2	0.11	4%
deciduous training area							
band 1	206	213	234	224.6	4.2	2.27	76%
band 2	206	126	163	142.9	6.9	0.49	16%
band 3	206	33	62	46.2	5.6	0.23	8%
entire image							
band 1	1277824	1	255	139	68	2.5	83%
band 2	1277824	1	247	103	65	0.45	15%
band 3	1277824	1	227	43	43	0.05	2%
Photography: 8.000'							
coniferous training area							
band 1	2080	146	211	178	14.5	2.78	93%
band 2	2080	83	141	110	11.5	0.14	05%
band 3	2080	15	57	33	7	0.09	03%
deciduous training area							
band 1	1392	188	218	206	6.8	2.49	83%
band 2	1392	107	146	128	8.0	0.37	12%
band 3	1392	36	61	48	5.2	0.15	5%
entire image							
band 1	1700496	1	255	161	83	2.68	89%
band 2	1700496	2	252	133	72	0.31	10%
band 3	1700496	4	238	68	53	0.01	1%
Photography: 4000'							
coniferous training area							
band 1	531	135	222	180.3	14.8	2.78	93%
band 2	531	75	167	111.3	12.9	0.12	4%
band 3	531	15	64	34.2	7.4	0.1	3%
deciduous training area							
band 1	283	186	222	207.5	6	2.38	79%
band 2	283	106	151	128.8	7.1	0.46	15%
band 3	283	36	70	48.4	5.1	0.16	5%
entire image							
band 1	496240	7	255	154	78	2.62	87%
band 2	496240	9	253	124	63	0.35	12%
band 3	496240	7	245	63	48	0.02	1%

Band 1 is infra red, band 2 is red, band 3 is green. Cell value refers to pixel values (0-255) in training areas shown in Figures 6-10. Corr. Eigenval. is correlation eigenvalue, and % Variance is equal to Corr. Eigenval./(sum of Corr. Eigenval.s) * 100%

Table 22. Summary statistics for lower altitude aerial photographs

	Number of cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev. (n-1)	Corr. Eigenval.	% Variance
Photography: 2000'							
coniferous training area							
band 1	1194	117	233	184.8	17.8	2.8	93%
band 2	1194	64	183	118.9	18.4	0.13	4%
band 3	1194	14	84	38.2	12.4	0.08	3%
deciduous training area							
band 1	775	182	227	209.2	6.4	2.7	89%
band 2	775	105	160	135.8	8.5	0.21	7%
band 3	775	29	77	55.9	7.1	0.11	4%
Photography: 1000'							
coniferous training area							
band 1	6890	99	249	200.6	25.4	2.9	96%
band 2	6890	47	221	134.7	31.1	0.08	3%
band 3	6890	14	137	53.6	23.1	0.04	1%
deciduous training area							
band 1	2184	181	248	228.3	9.1	2.8	93%
band 2	2184	37	200	159.2	13.7	0.13	4%
band 3	2184	32	136	82.7	15.8	0.07	2%
Photography: 500'							
coniferous training area							
band 1	77547	22	244	146.7	41.5	2.8	94%
band 2	77547	14	224	82.8	36.1	0.15	5%
band 3	77547	11	150	34.7	20.1	0.03	1%
deciduous training area							
band 1	33611	92	237	174.3	23.1	2.9	96%
band 2	33611	30	178	94.9	24.1	0.11	4%
band 3	33611	12	117	36.1	16.1	0.02	1%

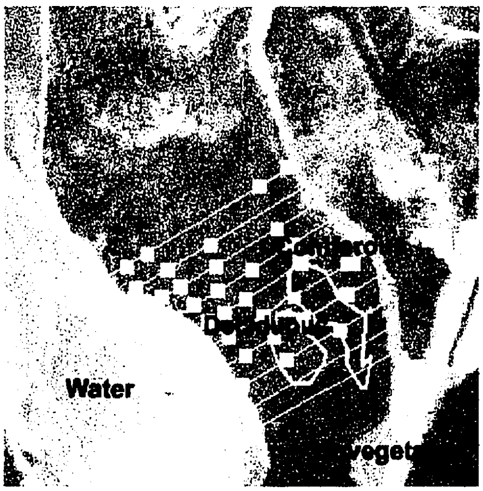
Band 1 is infra red. band 2 is red, band 3 is green. Cell value refers to pixel values (0-255) in training areas shown in Figures 6-10. Corr. Eigenval. is correlation eigenvalue, and % Variance is equal to Corr. Eigenval./(sum of Corr. Eigenval.s) * 100%

At 2438 m (8,000 feet) the haze problem was greatly reduced, and the stands were slightly more distinct (Figure 7). Forest texture is noticeably improved, and it is possible to note crown closure differences of the stands. The images from this flying height could be used to accurately map the stand boundaries from a visual inspection. The roads and trails are visible, and the parking lot can be distinguished as a widening of the road. Coloured tarps of approximately four square metres were placed near the parking lot, on the road, and on the beach as visual targets, and some of the ones near the parking lot can be seen as small coloured dots.

The overall accuracy of the supervised classification of the 2438 m (8,000 feet) image is the same as for the 4633 m (15,200 foot) image: 70% (Table 17). Both of these images had seven correctly classified plots out of ten, and both seemed to overestimate the deciduous areas somewhat. At this height there is less generalization than the orbital imagery and the 4633 m (15,200 foot) image, but still a high degree of mixed pixels.

Figure 7. 2438 m (8,000 foot) 35 mm aerial photograph of Kananaskis forest
7 a. Entire image
7 b. Study Area
7 c. Supervised classification of study area

7 a.



7 b.

7 c.

7 b. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

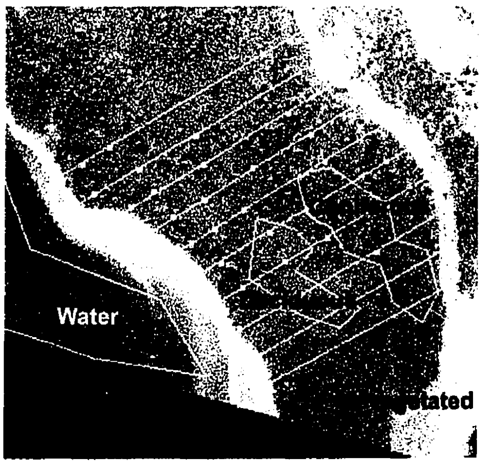
7 c. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

At 1219 m (4,000 feet) the stands were much more distinct and I can begin to be able to distinguish individual trees (Figure 8). This flying height is commensurate with medium to large scale mapping efforts (Table 20). The different stands and their densities stand out like different pile types in a shag carpet (Figure 7). Mixed stands are visible. The very dense deciduous stand is uniformly red due to high infrared reflectivity (marked D on Figure 8). The targets on the road are visible, but not the ones placed on the beach (too little contrast). The parking lot (not shown on this image) showed two tiny cars and the hint of lines in the parking lot. At this height it is possible to distinguish bare soil from grassy areas.

At this height (as with all other heights) the standard deviation of cell values is higher in the coniferous area than the deciduous area, indicating the greater heterogeneity of this stand (Table 22). This height produced the best looking supervised classification--the stands looked like stands with distinct boundaries, and very little of the generalization of the higher flying heights or the salt and pepper effect of the lower flying heights. This flying height produced the highest overall accuracy of the aerial photographs: 90% (Table 17). This flying height produces imagery that most closely represents the heterogeneity of this forest stand. Lower flying heights will represent the individual trees more, rather than the stands, and this is reflected by their lower overall accuracies (Table 17).

Figure 8. 1219 m (4,000 foot) 35 mm aerial photograph of Kananaskis forest
8 a. Entire image
8 b. Study Area
8 c. Supervised classification of study area

8 a.



8 b.

8 c.

8 b. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

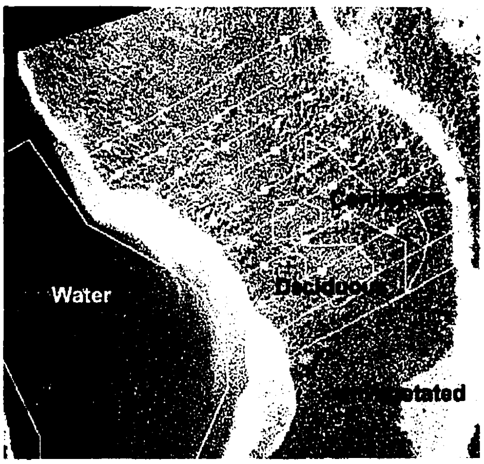
8 c. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

At 610 m (2000 feet) the denser area resembling shag carpet (the deciduous area, marked D on Figure 9) is distinguishing itself into individual strands. Flying heights of 610 m (2000 feet) and above are commensurate with large scale mapping efforts (Table 20). The resolution produced by a 610 m (2000 foot) flying height marks the point where it becomes difficult to see the stand boundaries, because the viewer is too close and boundaries are fuzzy. Individual trees are becoming more distinct, and separating into more distinct shades of yellows and reds, though they are still quite small. Texture could play more of a part in the interpretation at this height. It is becoming apparent by the texture (or shadows) that the coniferous area (marked C in Figure 9) is actually a mixed stand. At 610 m (2000 feet) the lines in the parking lot are visible, as are two red and blue rectangular shapes indicating parked cars. I can begin to distinguish whether the trees have rounded or conical tops. This sort of discrimination would be essential in the tropics, where forest communities are more diverse than in Kananaskis.

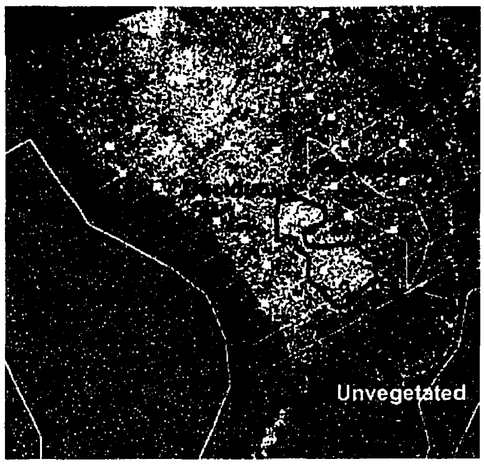
The visual evidence of coniferous stand heterogeneity is backed up by the summary statistics in Table2, which show that the standard deviations for the cell values in the coniferous training area has increased at 610 m (2000 feet) over the standard deviations at 1219, 2438 and 4633 m (4000, 8000 and 15,200 feet). The overall accuracy of the 610 m (2000 foot) image was 50%, a large drop from 90% at 1219 m (4000 feet).

Figure 9. 610 m (2000 foot) 35 mm aerial photograph of Kananaskis forest
9 a. Entire image
9 b. Study Area
9 c. Supervised classification of study area

9 a.



9 b.



9 c.

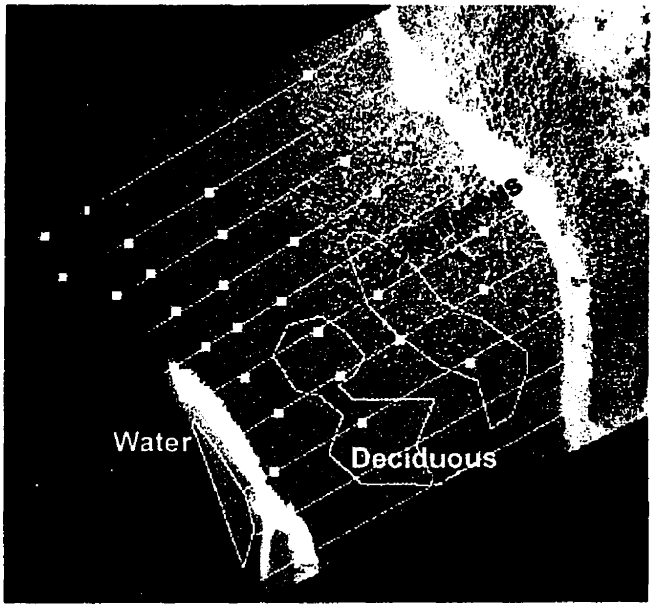
9 b. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

9 c. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

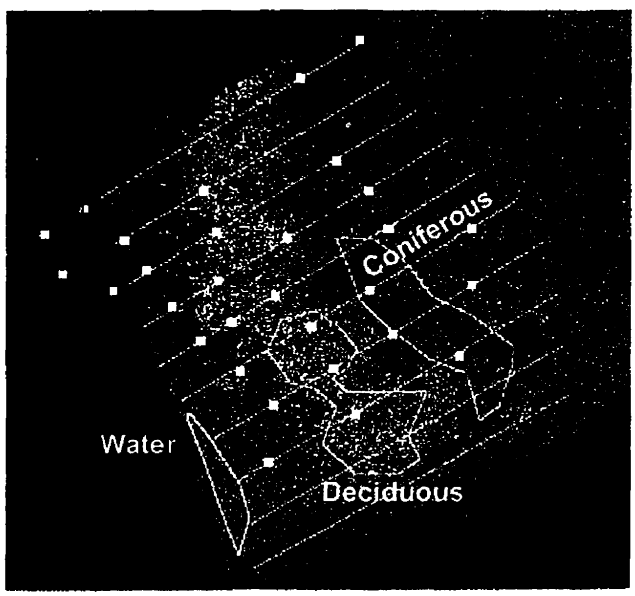
At 305 m (1000 feet) the treetops are clearly conical or rounded, and have more individual colours of reds and yellows. Individual trees and their shadows can be seen. This is an appropriate resolution for analyzing individual trees, but it is even more difficult to distinguish the boundaries of the stands (Figure 10).

The standard deviations of the coniferous stands have increased over the higher flying heights, indicating the increased discrimination of the heterogeneity of the stand. At this height, the supervised classification has a very salt and pepper appearance. The speckled appearance indicates that stands are no longer being discriminated, but rather individual trees and their shadows, as can be seen visually.

Figure 10. 305 m (1,000 foot) 35 mm aerial photograph of Kananaskis forest
10 a. Study Area
10 b. Supervised classification of study area



10 a.



10 b.

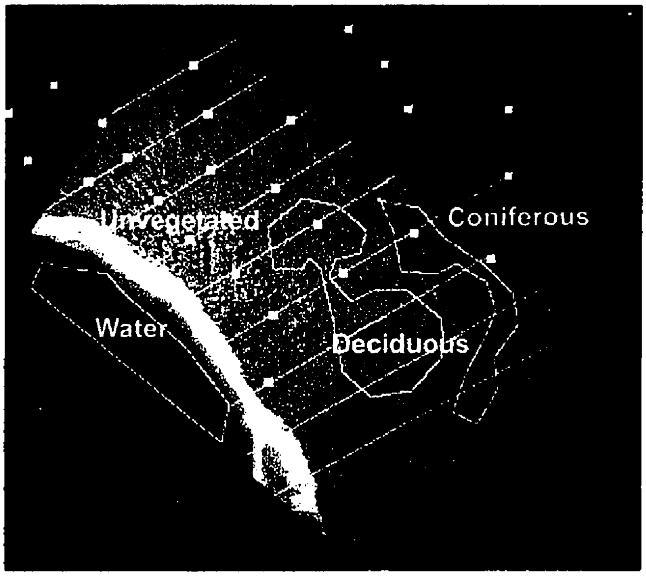
10 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest and water are shown.

10 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

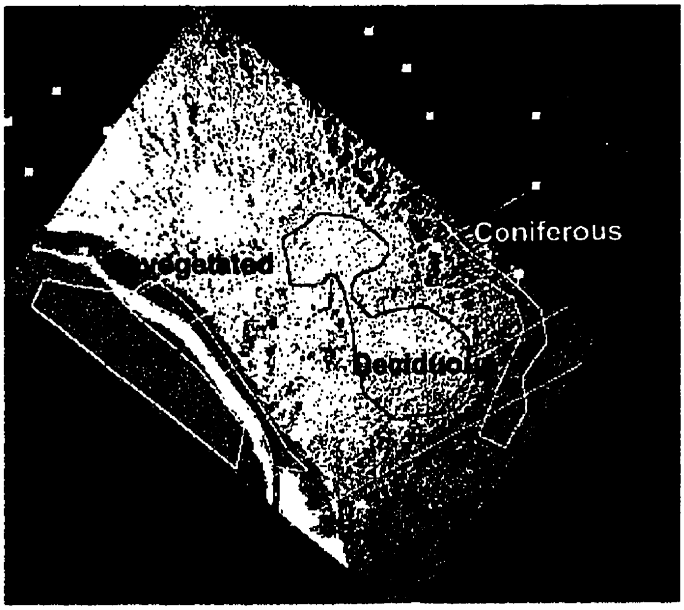
The 152 m (500 foot) image shows remarkable detail. On other images at this height I can count the stairs in a staircase, see individual trees, tufts of leaves, branches, and tufts of grass in the non forested areas. The cars in the parking lot were very clear. The targets were clearly visible as coloured tarps with folds and wrinkles. Even the bare rock is beginning to have texture. This height allows detail to assess individual tree stress. In the image shown (Figure 11) the deciduous and coniferous stands (marked D and C) are clearly distinguishable by their differences in shadow and texture. It is clear that the coniferous area is a mixed stand with different tree heights. The detail of the scanned 35 mm imagery would be improved if the film were viewed in its original unscanned state. The detail possible with aerial imagery flown at 152 m (500 feet) would allow very detailed resource assessments of small areas.

This flying height had the greatest standard deviations in the coniferous area of all aerial photographs. The supervised classification had a very speckled appearance. This image had only 6 plots available for an accuracy assessment, and 5 of 6 were correct (83%). However, this overall accuracy is overestimated, because 5 of the 6 plots were deciduous, and the image overclassified deciduous--all of the mixed plots were classified as deciduous as well.

Figure 11. 152 m (500 foot) 35 mm aerial photograph of Kananaskis forest
11 a. Entire image
11 b. Supervised classification



11 a.



11 b.

11 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.
11 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

The detail of the stands becomes more clear as the flying heights decrease from 4633 m (15,200') to 1219 m (4,000 feet) on the aerial imagery. Visually, at 1219 m (4,000 feet) the stands are at their clearest. The overall accuracy of the supervised classification is also the highest at 1219 m (4,000 feet), showing that 1219 m (4,000 feet) is the optimum height for discriminating stands in the Kananaskis forest study area. The optimum flying height would change depending on the heterogeneity of the stands being studied. The detail of the individual trees and tree shadows becomes more clear as the flying heights decrease from 1219 m (4,000 feet) to 152 m (500 feet) and are at their clearest at the lowest flying height. The heterogeneity of the coniferous stand becomes more apparent as the flying height decreases, and it becomes clear that it is a mixed stand at the lower flying heights. The summary statistics for the training areas reflect the heterogeneity of the coniferous stand. The standard deviations in the coniferous training areas increase as the flying height decreases. At the lower flying heights the cell values are reflecting what is obvious to the naked eye: that the coniferous area is a mixed stand.

6.3.3 Electro-optical CCD

The detail apparent on the scanned aerial photography was mirrored in the digital electro-optical CCD imagery, but at a lesser resolution. It was necessary to approximately halve the flying height to produce the same resolution in a digital electro-optical CCD image as in a scanned photographic image. The electro-optical CCD imagery was flown at 1219, 610, 305 and 152 m (4,000, 2,000, 1,000 and 500 feet). A 1219 m (4000 foot) aerial digital electro-optical CCD image of the study area is shown in Figure 12, in which the stand boundaries are distinguishable by different hues.

The summary statistics for electro-optical CCD imagery training areas (Table 23) reflect the observations made visually. With the CCD imagery, in most cases it takes (at least) two bands to account for 90% of the variance in the data. The correlation eigenvalues are more evenly distributed between the bands than they were in the photographic imagery (Table 21 and 22), showing that there is not as much redundant band information. This is an improvement over the photographic images. The values for the aerial photographic imagery and the electro-optical CCD imagery (Table 21-23) are similar in that the mean cell values for coniferous areas are consistently lower than for deciduous areas. There is a greater reflectance in all bands from deciduous leaves than coniferous (Lillesand and Kiefer, 1994), and in the imagery the deciduous areas appear brighter than the coniferous. The standard deviations of the electro-optical CCD imagery were quite a bit higher than the standard deviations of the photographic images. The standard deviations do not follow a similar pattern to the standard deviations of the photographic imagery (Tables 21 and 22). The standard deviations of the coniferous areas increase from 1219 m (4,000 feet) to 305 m (1,000 feet), indicating the increasing resolution of the heterogeneity of the coniferous stand, but decrease again at 152 m (500 feet) (Table 23).

Table 23. Summary statistics for aerial electro-optical CCD imagery

	Number of Cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev.(n-1)	Corr. Eigenval.	% Variance
CCD: 4000'							
Coniferous training area							
band 1	9382	39	183	93.5	21.8	1.97	66%
band 2	9382	31	94	47.1	6.7	0.79	26%
band 3	9382	31	89	50.3	7.7	0.24	8%
Deciduous training area							
band 1	3465	81	153	127.4	10	1.65	55%
band 2	6435	36	61	50.3	3	0.92	31%
band 3	6435	41	71	57	4	0.43	14%
entire image							
band 1	326512	7	203	80	38	1.87	62%
band 2	325808	11	235	53	35	0.93	31%
band 3	325856	10	191	61	29	0.20	7%
CCD: 2000'							
Coniferous training area							
band 1	20977	28	129	60.7	15.9	1.7	56%
band 2	20977	26	90	42.1	7.6	0.91	30%
band 3	20977	25	106	55	11.1	0.41	14%
Deciduous training area							
band 1	18885	45	159	99.3	17.2	1.72	57%
band 2	18885	27	75	46.9	6.1	0.89	30%
band 3	18885	25	122	65.5	10.3	0.39	13%
entire image							
band 1	394688	8	175	67	30	1.75	58%
band 2	394672	10	227	56	29	1.03	34%
band 3	394688	7	255	80	37	0.21	7%
CCD: 1000'							
Coniferous training area							
band 1	20115	2	255	73.9	47.7	2.07	69%
band 2	20115	2	209	43.5	27.6	0.71	24%
band 3	20115	3	255	75.7	46	0.21	7%
Deciduous training area							
band 1	21109	9	255	165.4	49.1	2.01	67%
band 2	21109	2	144	57.6	19.8	0.71	24%
band 3	21109	3	255	116.6	39.3	0.28	9%
entire image							
band 1	244480	2	255	114	61	1.89	63%
band 2	244992	2	255	66	43	0.79	26%
band 3	245488	3	255	114	58	0.32	11%

(continued)

Table 23. Continued

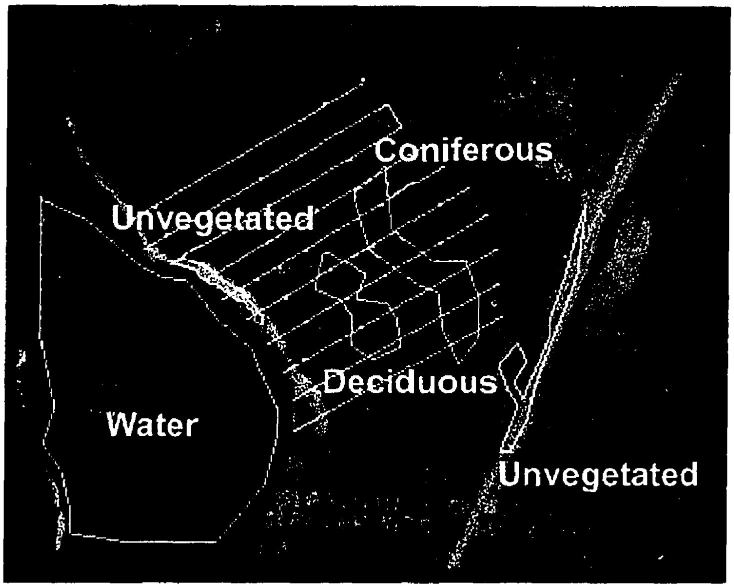
	Number of Cells	Minimum cell value	Maximum cell value	Mean cell value	Std. Dev.(n-1)	Corr. Eigenval.	% Variance
CCD: 500'							
Coniferous training area							
band 1	8622	31	146	71.7	22.8	2.56	85%
band 2	8622	25	228	52.6	16.6	0.3	10%
band 3	8622	28	135	64.1	20.7	0.14	5%
Deciduous training area							
band 1	6878	50	179	124	26.3	2.62	87%
band 2	6878	29	96	57.1	11.2	0.32	11%
band 3	6878	32	137	80.6	17.9	0.06	2%
entire image							
band 1	334352	9	189	83	33	2.35	78%
band 2	334400	11	232	64	38	0.52	17%
band 3	334352	8	255	78	44	0.13	4%

Band 1 is infra red, band 2 is red, band 3 is green. Cell value refers to pixel values (0-255) in training areas shown in Figures 11-14. Corr. Eigenval. is correlation eigenvalue, and % Variance is equal to Corr. Eigenval./(sum of Corr. Eigenval.s) * 100%

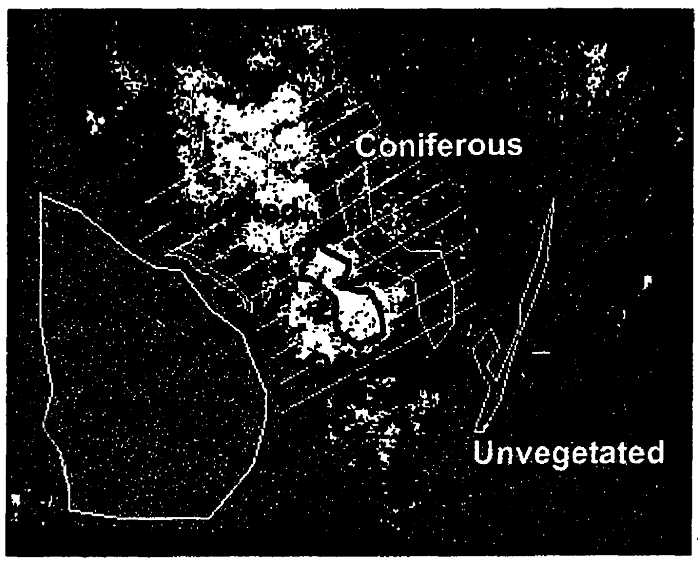
The supervised classification of the 1219 m (4000 foot) CCD image (Figure 12 c) shows the stands more clearly than the 1219 m (4000 foot) photograph's classification (Figure 8). The stands are much more distinct, and there is less speckle. This image had the highest overall accuracy of the aerial imagery, 100% (Table 17).

A 610 m (2000 foot) aerial digital electro-optical CCD image of Kananaskis forest is shown in Figure 13, which shows approximately the same resolution as the scanned aerial photograph from 1219 m (4000 feet) shown in Figure 8. This image had an overall accuracy of 80% (Table 17), slightly less than the 1219 m (4000 foot) CCD image (100%) and the 1219 m (4000 foot) aerial photograph (90%).

Figure 12. 1219 m (4000 foot) aerial electro-optical CCD images of Kananaskis forest
12 a. Entire image
12 b. Supervised classification



12 a.

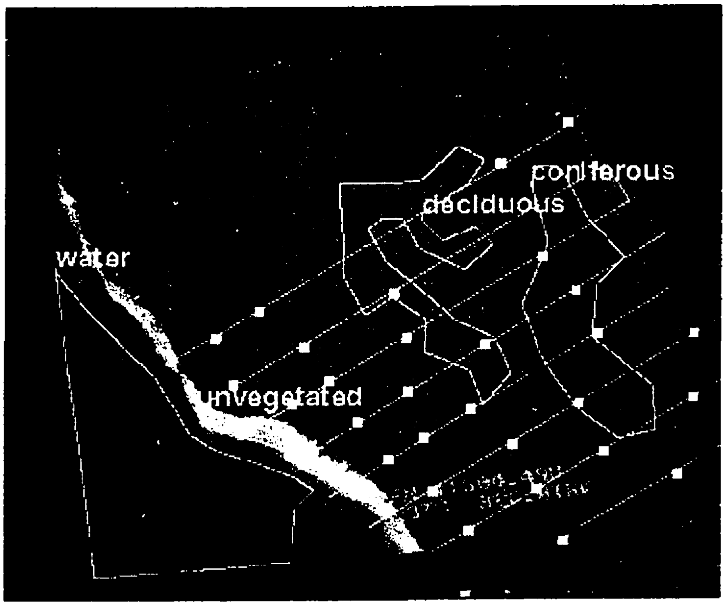


12b.

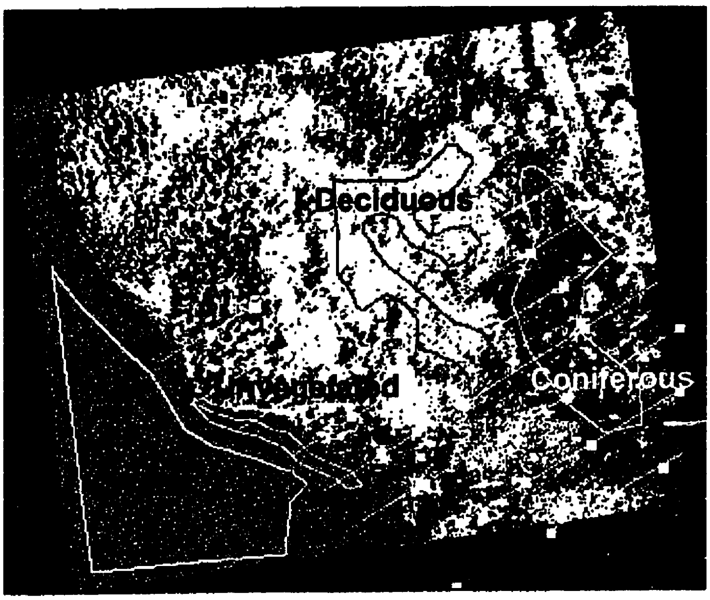
12 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

12 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

Figure 13. 610 m (2000 foot) aerial electro-optical CCD images of Kananaskis forest
13 a. Entire image
13 b. Supervised classification



13 a.



13 b.

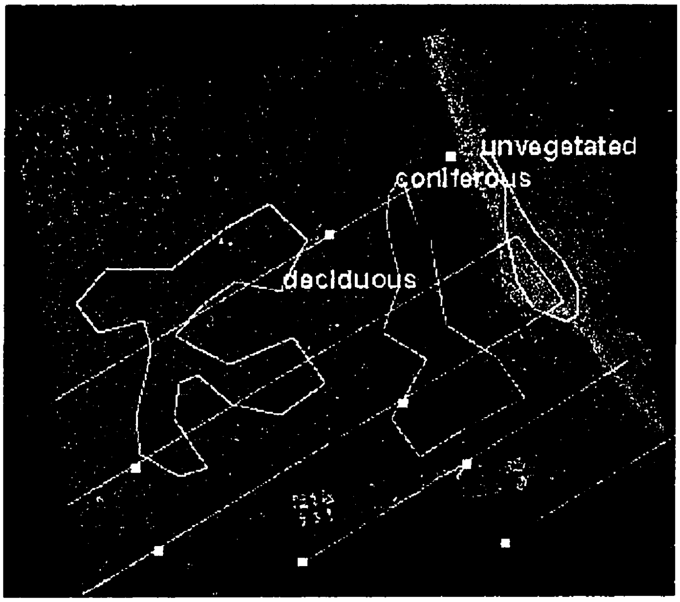
13 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest, water and unvegetated areas are shown.

13 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

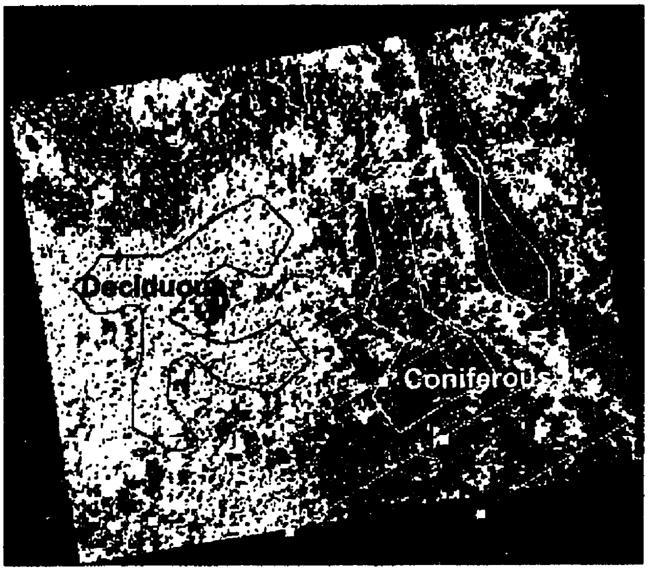
Figure 14 is the 305 m (1000 foot) aerial electro-optical CCD image, and it is clear that the coniferous and deciduous stands (marked C and D) have very different hues from each other, as well as different textural information. The textural information is quite distinct, showing the heterogeneity of the coniferous stand. This image had an overall accuracy of 50%.

At 152 m (500 feet) (Figure 15) the coloured targets (centre of image) are visible. The parking lot and one of the two parked cars can be seen. Individual trees and their shadows are visible, however the resolution is less than that of the 152 m (500 foot) aerial photograph. The supervised classification of this image was quite speckled (Figure 15), as were the photographic images at the lower flying heights (Figures 10 and 11). There were no plots available in this particular image for an overall accuracy assessment, but chances are it would have been quite low.

Figure 14. 305 m (1000 foot) aerial electro-optical CCD images of Kananaskis forest
14 a. Entire image
14 b. Supervised classification



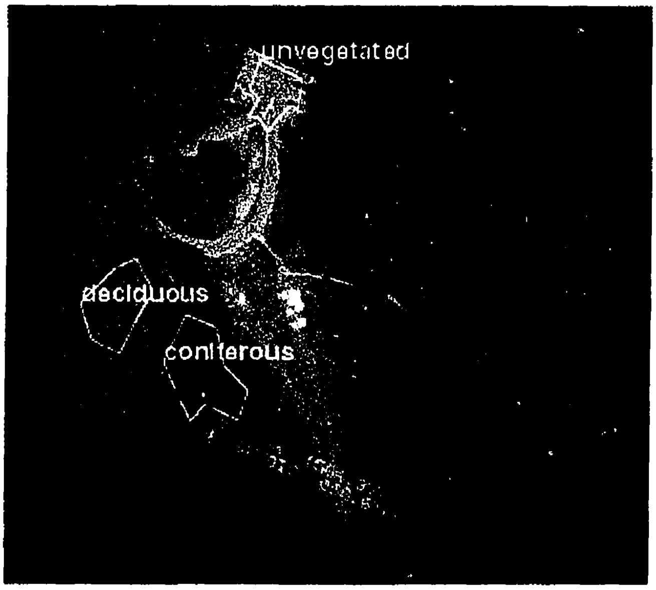
14 a.



14b.

14 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest and unvegetated areas are shown.
14 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

Figure 15. 152 m (500 foot) aerial electro-optical CCD images of Kananaskis forest
15 a. Entire image
15 b. Supervised classification



15 a.

15 b.

15 a. The transects are numbered 1-10, and plots are numbered 1-4 on each transect. The first point on the North end of transect 1 is the starting point, not a plot. The training areas of coniferous forest, deciduous forest and unvegetated areas are shown.

15 b. Results of a supervised classification of the image: the yellow represents pixels classified as deciduous forest, dark green represents the mixed coniferous stand, Barrier lake is blue and unvegetated areas (beach and roads) are red.

The visual interpretation of digital electro-optical CCD imagery flown at various heights above the Kananaskis study area showed that digital electro-optical CCD could be easily employed to monitor forest stands at a medium to small scale. The CCD imagery has better radiometric resolution than the scanned aerial imagery—the stand boundaries appeared clearer than on the aerial photography at a comparable resolution. The images also appeared slightly less "red," (Figures 12-15) indicating that information from other bands was not simply redundant, as in much of the aerial photography (Figures 6-11). The summary statistics for electro-optical CCD imagery training areas (Table 23) reflect the visual observations. In most cases it takes at least two bands to account for 90% of the variance in the data.

The coniferous and deciduous areas appeared with a greater difference in hues than on the aerial photographic images. The 1219 m (4000 foot) electro-optical CCD image had a higher overall accuracy than all photographic images, reflecting its greater radiometric resolution and ability to discriminate reflectance differences between tree species. In this way, the CCD images offer an improvement over aerial photographs--in radiometric resolution. However, digital electro-optical CCD has a decreased spatial resolution compared to aerial photography flown at the same height.

Electro-optical CCD imagery showed a decrease in overall accuracy of classified plots below 1219 m (4,000 feet). Overall accuracies decreased from 1219 m (4,000 feet) to 305 m (1,000 feet), with the greatest accuracy at 1219 m (4,000 feet) (100%, Table 17). The resolution of individual trees and tree shadows increased from 1219 m (4,000 feet) to 152 m (500 feet) flying height. For this set of imagery, the 1219 m (4000 foot) imagery resolved the heterogeneity of the forest stands, while the lower altitude imagery discriminated more individual tree detail. High resolution aerial imagery would be necessary to resolve the even greater stand heterogeneity and mixed forest uses of tropical forests in the South.

Chapter 7. DISCUSSION AND RECOMMENDATIONS

7.1 Literature assessment and content analysis

Countries in the South require different approaches to remote sensing than Northern countries. They are poorer in money and technical skills and are more dependent on natural resources and the environment. Humid tropical areas are heavily clouded and many countries are lacking in base map coverage and/or available aerial photographs. Some Southern countries routinely limit access to aerial photographs and topographic maps to anyone other than those engaged in government mapping projects. For example, when working in Malaysia, I have found all topographic maps to be *terhad* (restricted) and unavailable to the public. In Indonesia I found that aerial photographs were available only with government approval. Several non-government organizations in these countries expressed their concern to me over their inability to obtain recent maps or aerial photographs from the government.

Many researchers have recognized the South's need to map its areas quickly, and at the same time address resource management and local empowerment of indigenous people (Peluso, 1994; Olive *et al.*, 1996). While in the South there is a need for basic operational mapping, resource management, and training, these priorities are not reflected in the published literature. Several sources have reviewed applied remote sensing in Southern countries (Thailand: Vibulsresth, 1990; Pakistan: Saeed, 1993; tropical forests in Africa: Ehrlich *et al.*, 1994), and there is a stated concern in each of these that applied remote sensing in the South be made a priority. There were no indications that more technical studies were needed and I did not find any overviews of Southern technical studies in the literature. However, the majority of published Southern research leans toward technical studies, not applications of remote sensing.

The remote sensing resources of the South are limited, and the narrow focus on technical studies is at the expense of applied studies. In many cases, countries in the South are still coming to terms with their mapping problems and have not yet laid the groundwork for more technical studies. For example, countries which still need to create accurate maps of their land mass should have less immediate impetus to determine canopy temperatures (Luvall *et al.*, 1990) or the seasonal evolution of vegetation (Achard and Blasco, 1990).

Remote sensing and orbital imagery can be used successfully for small-scale resource assessment, hazard detection and industrial monitoring. Currently the literature concentrates on small-scale endeavors utilizing orbital imagery. The orbital focus is limiting studies to a small scale. Resource inventories usually focus on resources of immediate financial potential (mining and logging) rather than on local forest and agricultural resources (Luscombe, 1990). Topics such as water and fuel wood are important to local people and should be included along with the current focus on forest and mineral exploration (Millington, 1987). Involving local people in the mapping process at local scales is essential. In some cases local people and involved organizations are starting to make their own maps, in order to demonstrate their existence and the rationality of their sustainable practices (Flavelle, 1995).

There was a lack of community oriented mapping, very little participatory mapping, and a lot of mineral-geological and global scale mapping. There was very little inclusion of local people and large-scale mapping in the literature. This may not reflect the actual amount of large-scale mapping projects being carried out in the South. Some studies may not make it into the literature because of local politics, or may be published in journals other than remote sensing journals, for example *Human Ecology*, *Cultural Survival Quarterly*, and Symposia Proceedings. Many interest groups in the South have a pressing need to have large-scale maps made of their traditional boundaries, and local resource use activities. This is currently being carried out with the help of various non-government Northern organizations (Flavelle, 1995; Peluso, 1994) which may not be interested in publishing the results of their mapping projects for political reasons.

Remote sensing of and for Southern countries is most important for applied studies rather than abstract or theoretical research (Hamza, 1986). It should be simple and based on modest techniques related to the country's human and material capabilities. Research shows that studies are most successful when they incorporate many different levels of research such as using different remote sensing media, ground truth, people truth, and time series.

7.1.1 The importance of local participation

Because there was such a lack of local participation published in the three journals, I feel it is important to explain its importance here. Results from studies including local people suggest that ". . . "people truthing," or understanding land use from the perspective of those who manage land featured in an image, is as important to image interpretation as "ground truthing" . . ." (Behrens *et al.*, 1994). Local people can offer invaluable insight into natural processes that affect land use and land cover. Maps have characteristically been "sources of power for the powerful" (Peluso, 1994). They are notable for and can exert a social pressure by the features they represent as well as the ones they omit. Maps often reflect economic priorities. For example, mineral exploration, agriculture, and forestry may receive more mapping priority than traditional boundaries or environmental conservation. The expense of the technology can be a barrier to all but the government and most wealthy organizations. Provincial forestry maps were developed in Indonesia in 1985 that used six categories of forest lands based entirely on physical topographic characteristics, and completely overlooked local people's previous claims to the land, and existing vegetative cover

(Peluso, 1994). On many official maps in Southeast Asia, whole villages are often incorrectly located, named or missing (Flavelle, 1995).

When assessing land use changes, it is essential to get at the root of the problem--the social processes underlying the changes in land use--rather than simply mapping the locations of missing patches of forest (Olive, *et al.*, 1996). If the local land use practices are not taken into account, outsider bias can result. For example, Harnapp and Knight (1971), in a study of tropical agriculture in Puerto Rico, would have found quite different results if they had consulted the local agricultural experts in they area they were studying; instead they wrote that fallow is not necessary in the tropics, and that agricultural production could be increased by eliminating it. Other authors have stated that fallow periods are absolutely necessary in the tropics, since tropical soil is nutrient poor, owing to the almost constant rainfall and leaching (Chang, 1968; Hecht *et al.*, 1988). Including local people and local wisdom might reduce these kinds of errors and research bias.

7.2 Kananaskis case study

Orbital imagery proved to be effective in visually discriminating vegetated from unvegetated areas and in discriminating large homogeneous stands from one another. However, the orbital imagery generalized the heterogeneous stands, resulting in mixed pixels. The mixing of species in the Kananaskis study area was not picked up by Landsat TM or SPOT imagery because the resolution is too low, and the mixed stands have become merged into mixed pixels. Mixed pixels would probably be an even greater problem in tropical rainforest.

The fact that SPOT offers little advantages in clarity over TM may explain why TM is mentioned in the literature with greater frequency than SPOT, even though SPOT provides better spatial resolution, and the option of stereo viewing. TM imagery is also less expensive than SPOT imagery, and can be purchased in photographic print form alone, at a much lower cost.

Both the aerial photography and the aerial electro-optical CCD imagery were most effective in discriminating stand boundaries at a flying height of 1219 m (4000 feet). The optimum flying height would change depending on the heterogeneity of the stands being studied. The detail of the individual trees and tree shadows became more clear as the flying heights decreased from 1219 m (4,000 feet) to 152 m (500 feet) and are at their clearest at the lowest flying height.

On the aerial photography the stands were easily separated with the naked eye by their difference in texture. At the lower altitudes the difference between the stands is apparent mainly in the shape and shadow of the trees. On the 1000' and 500' imagery individual trees and their shadows are visible, which caused classification errors in the supervised classification. With the supervised classification, the higher altitude (8,000-15,200') and lower altitude (500-2,000') images had a lower ability to discriminate the stand boundaries than the 4000' imagery (Table 17). The spectral information was not sufficient to separate the stands at the higher altitudes, and the tree shadows complicated the results at the lower altitudes. Visual interpretation had less problems with discriminating tree shadows from trees, and enables a more accurate interpretation of stand boundaries because it is possible to take both colour and texture into account, whereas supervised classifications usually only use spectral information. The visual interpretation is also much quicker and simpler than the digital evaluations which usually require extra training and experience to interpret.

This case study was an experiment in the North. Many different problems would be encountered in the South. The South has higher population densities and the population of the South has a higher ecosystem dependence. The Kananaskis forest study area did not have any local occupants dependent on its resources. Local occupants would necessitate a more complex classification including classes for farms, woodlots, cleared and regrowing areas. Questions about farming practices and resource extraction patterns would arise that could best be answered by local people. In the South, local occupants of the land base would need to be incorporated into the ground truth. From my experience working in the South, community based mapping is the best option. Rather than classifying imagery digitally and then using objective ground truth to assess the accuracy of the classification, the remote sensing researcher should work with local residents of the area to classify the images. The local resident could guide the researcher through the area, and together they could create classification categories relevant to the people that co-exist with the land.

7.3 Remote sensing imagery recommendations

On the basis of the review of the literature and on the experience with the case study I have made recommendations for remote sensing applications in the South. This is meant to be a reference useful to Southern researchers.

7.3.1 Aerial versus orbital imagery

For most applications in the South, aerial photography is recommended over orbital imagery. Aerial photographs are easy to use and standardized mapping techniques exist. Aerial photographs can have a much greater resolution than orbital imagery, and are more appropriate for resource mapping and management. It is problematic to use orbital imagery for large-scale mapping because of its low spatial resolution. Except for a single 1:100,000 project in Yemen, the Ordnance Survey of the UK has not found any mapping projects "where the use of satellite remote sensing over more traditional aerial photographic techniques has overwhelming technical or financial advantages." (Hartley, 1991) Quite often, orbital imagery is chosen in the South and this limits projects to small scales. Working at a small scale means that local features such as forest gardens, small villages, woodlots and local resource use patterns are not resolved. In many cases, a larger scale product should be considered.

Orbital imagery can be used to accurately and quickly map resources of a country or continent at small scales. Orbital imagery can aid in counter-mapping: the use of maps to dispute land ownership and land use by the government and powerful logging and mining companies (Peluso, 1994). Local people can use orbital imagery to create maps that show their territorial boundaries, and possible logging encroachment on these boundaries (Peluso, 1994). Orbital imagery is also useful in hazard detection and monitoring, and can aid quality of life in areas where drought and flood are potential hazards.

Orbital imagery's strengths are its convenience and ready availability. When accurate base maps and resource information at a small scale are needed quickly and at low cost, orbital imagery is the best option (Kabbaj and Mehrez, 1994). For large-scale efforts however, cheaper, simpler technologies may be more accurate, and more broadly useful. It may be more beneficial to spend money on aircraft and cameras for flying imagery than on a satellite receiving station. Airborne imagery (photography and digital multispectral imagery) can be tailored more exactly to individual applications than satellite imagery.

It is often difficult to establish enough ground control points that will be visible on low resolution orbital imagery. One group of researchers set up a study with large ground control points made of crossed logs painted yellow, assuming that they would be visible on their SPOT imagery (Soofi *et al.*, 1991). When they were not visible, they had to backtrack and use their aerial photography. Similar problems were encountered with the Kananaskis imagery where some ground control points were not visible on the scanned imagery. Similarly, ground truth data must be combined with studies using orbital imagery, and the ground truth should be well planned in advance.

Orbital imagery should only be chosen when working with very large areas, or when fine resolution is not a necessity. For a project size of over 10,000 square km, satellite imagery becomes less expensive than aerial photographs, because of the expense of covering large areas with air photos. However, in some areas of the South, aerial photographs are restricted by the government, are old or small-scale, or are nonexistent. There is also a lack of accurate large-scale base maps in some Southern countries. It may be a benefit to some Southern countries to update their aerial photographic base before focusing on orbital imagery. In countries where aerial photography is available to everyone (such as countries in Europe), orbital imagery is hardly used at all (Hothmer, 1986). The lack of available aerial photographic coverage in the South causes orbital imagery to be considered a viable mapping product (Hartley, 1991).

Aerial techniques are often preferable in areas where they are available. Simple techniques of aerial photographic interpretation can be coordinated with large-scale community mapping projects. Aerial electro-optical CCD should also be considered, because it is a low cost alternative to aerial photographic and other electro-optical scanning systems (Roberts, 1993).

7.3.2 Visual versus digital techniques

Orbital images can be viewed either digitally or as a photographic product. A review of the literature indicates that photographic products and manual (visual) interpretation techniques are preferable over digital images (Reddy and Hilwig, 1993). Simple visual interpretation can take both spectral and textural information into account (for both aerial and orbital imagery). Visual interpretation techniques are cheaper and more effective than digital classification procedures in many environments (Mishtra, *et al.*, 1994; King, 1994; Reddy and Hilwig, 1993). A trained interpreter can distinguish more types of land units and objects than a computer classification. Not only trained interpreters but local community participants can visually interpret images and photographs. Colour is the best visual interpretation cue, because the human eye can distinguish more colours than grey scales.

Manual interpretation techniques of orbital photographs are similar to aerial photographic interpretation techniques. Professional photogrammetrists, and facilities for training them already exist in most countries. Digital techniques require extra training and computer facilities. Scanning aerial photographs and then visually or digitally interpreting them on the screen is a simple method, although it requires computer proficiency, software and a loss in resolution. Other simple techniques for aerial or orbital photographic interpretation involve simply tracing features of interest from the photograph onto different layers of mylar, and then scanning them or digitizing them into a GIS.

7.3.3 Scale recommendations

It is difficult to unequivocally state an optimum scale for a certain sensor, though some scales make more sense than others. It is not possible to state a minimum size resolvable unit for any remote sensing medium. The resolution of any feature depends on the contrast between the feature and its surroundings. Thus 8-10 m wide logging roads can often be clearly viewed with Landsat TM's 30 m pixels, but secondary forest can usually not be distinguished from primary forest, regardless of the size of the forest units. SPOT's theoretical resolution of ten metres has "little practical value" in real application, since objects often need to be 20-100 m or more in size to be detected by interpreters (Gastellu-Etchegorry *et al.*, 1990). For this reason, it is not possible to state unequivocally a minimum working scale for each remote sensing medium.

I have found in practice while working with local villagers in Indonesia and Malaysia that 1:20,000 is a minimum scale for community mapping--and this only for groups with large traditional boundaries. At this scale, good basemaps (often 1:50,000 can be enlarged to 1:20,000) are pieced together and overlaid with land use and historical information. At this scale, aerial photographs are an asset, and satellite images are not. Satellite imagery can be later used to provide the big picture of how the traditional land use areas are linked in space and show the logging or mining activities within and around them.

The U. S. Geological Survey (Avery and Berlin, 1992 p. 217) uses four levels of classification (I-IV) for manual interpretation of land use and land cover and suggests appropriate remote sensing platforms to use at each level. They recommend that orbital imagery only be used for studies with a scale smaller than 1:250,000 (Level I). Aerial sensors are not recommended for this range. For working at the scale range of 1:60,000 to 1:125,000 (Level II) the recommended sensor altitude is 9,000 to 22,000 m. This flying height indicates aerial sensors, not orbital, although TM and SPOT imagery can be applied in some cases (Lillesand and Kiefer, 1994). Aerial imagery is recommended for all but the smallest scales (Level I, and some Level II). For working with the scale range of 1:20,000 to 1:60,000 (Level III classification) the recommended sensor altitude is 3,000 to 9,000 m. For working with the scale range of 1:8,000 to 1:20,000 (Level IV), the sensor altitude is 1,200 to 3,000 m. Level IV analysis is designed to map local detail, and large-scale aerial images must be used, along with supplemental information (Lillesand and Kiefer, 1994).

High resolution datasets are 1:10,000 to 1:100,000. The published literature mainly relies on low resolution datasets: 1:1 million to 1:5 million and smaller. There is usually a tradeoff made between using a large enough scale to show detail, and saving money by using a smaller scale, and therefore having to buy fewer images. This can explain some of the popularity of using orbital imagery in the South. Another explanation for the focus on low spatial resolution satellite data (and non-applied studies) is that NASA, which remains the primary source of funding for land remote sensing research, has switched its emphasis from applications research towards quantifying global resources. NASA is evaluating coarse-resolution satellite data for providing global-scale monitoring (Justice *et al.*, 1986).

The spatial accuracy of a sensor is distinct from its spatial resolution. SPOT images can be used to locate features with 20-40 m spatial accuracy (Gastellu-Etchegorry, 1989), assuming enough ground control points can be found to accurately register them. Orbital images can be used at a larger scale to locate features and update existing maps than to classify land units. Features on orbital imagery can be located with a high degree of map accuracy--if features are clearly visible on the imagery, and if there are enough ground control points to register the image. NOAA AVHRR is suitable for global and continental scales. TM and SPOT bridge global and local, especially in areas where there are no aerial photographs available. Aerial photographs are the most suitable imagery for local studies.

In general, Landsat TM can be used for mapping at scales of 1:250,000 and smaller (Avery and Berlin, 1992). In the literature, Landsat TM is commonly used at 1:250,000 scale to classify land cover, indicating that many researchers agree that this is an appropriate scale for TM. However at least one researcher feels that TM's extraction of features is insufficient to support mapping at scales larger than 1:500,000 or 1:100,000 without extensive additional data (Hartley, 1991). Geometric accuracy commensurate with mapping up to 1:25,000 is possible, but systematic mapping or revision, even at 1:100,000 is not possible--it could lead to misclassification of features (Hartley, 1991). I have found that TM is adequate to delineate major roads and forest/non-forest, commensurate with a 1:250,000 mapping effort, but not larger (see Figure 3).

SPOT images are commonly used for mapping at 1:50,000 scale. SPOT platforms orbit at 832 km--far from the three to nine kilometre altitude called for by level III classification. However, SPOT was often used in the literature to classify land cover at scales of 1:50,000 (Gastellu-Etchegorry, 1989; Theodossiou and Dowman, 1990). For classifying land cover at scales larger than this, aerial photographs must be used. There is no significant gain in classification accuracy from SPOT P than SPOT

XS, however SPOT P is recommended for visual interpretation of features because of its greater resolution.

The Ordnance Survey of the United Kingdom states that SPOT can be used to locate features with extreme accuracy (even down to 1:25,000 scale), but that it is not possible to use it for any systematic type of mapping or revision, even at 1:100,000 (Hartley, 1991). A test of SPOT's capability at 1:25,000 found that it missed 50 percent of tracks, and misclassified several field boundaries as tracks (Hartley, 1991). Another author states that SPOT has a potential to provide data for topographic mapping at 1:50,000 scale with 20 m contours, and "if the image quality is very good and the ground control is sufficient, 1:25,000 scale plotting is also possible." (Theodossiou and Dowman, 1990)

Aerial imagery can be used at any scale. It is best used for large and medium-scale mapping studies, but can also be used as additional information for medium and small-scale studies that use orbital imagery as the primary sensor. The published studies from the three journals showed a high reliance on orbital imagery. The reliance on small-scale datasets went hand-in-hand with the low incidence of aerial imagery and the exclusion of local participation. As discussed in Chapter six, aerial imagery can discriminate forest stands and local information, relevant to resource management that might otherwise be missed by orbital imagery. A flying height of 2438 m (8000 feet) or less is necessary to view textural differences between stands.

Aerial photographs are suited to large-scale mapping projects. They are easily understood and employed, making it possible to incorporate them into community mapping projects, and to include local knowledge in the mapping process. Aerial photographs can provide a link between small-scale orbital imagery and the large-scale real world. This is especially important for the South, where there is often a lack of accurate base maps and orbital imagery is chosen as a substitute.

7.4 Remote sensing recommendations for specific applications

7.4.1 Simple mapping and topographic map revision

Existing Southern maps are often old, inaccurate, or at too small a scale to be used for land use decisions. However, land use decisions continue to be made. High resolution large-scale maps are needed (Estes and Mooneyhan, 1994). In countries where accurate base maps do not exist, the first priority is to create accurate base maps (Hartley, 1991). Type 1 articles (Appendices 1, 2, 3) can be used as references for this type of activity. With these maps the basic environmental management questions can begin to be answered.

Maps of a scale larger than 1:100,000 are lacking in many parts of the South. Mapping and classifying the land cover is an important step in visualizing the landscape, which can aid in land management and planning. Orbital and aerial imagery can be used to classify land cover, including forested and agricultural land. This can be done by visually interpreting the image, or by computer-aided classification. An inexpensive approach is to manually interpret a photographic product, using mylar overlays. Optical mechanical devices can be utilized to reduce the distortion of the image. The spatial information can then be incorporated into a geographic information system (GIS). Care must be taken to use a remote sensing product of an appropriate scale and accuracy for the application. Compromises often have to be made in the South because preferred imagery is not available, either due to political constraints, funding, or too-prevalent cloud cover. Ground truth is absolutely essential.

1:40,000 is a recommended scale for classifying tropical agricultural systems (Harnapp and Knight, 1971) and tropical forests (Ibrahim and Hashim, 1990). I found with the Kananaskis case study that aerial photographs flown at approximately 2438 m (8000 feet) (1:100,000 contact scale with a 24 mm lens) were able to discriminate forest stands and information that would aid in resource management at large to medium-scales.

At scales above 1:100,000, successful approaches include local participation, and involve more than one phase of research (Gonzalez *et al.*, 1995). The first phase of mapping includes plenty of community discussion, the design of the questionnaires, and field work. Community input can be used to help draw sketch maps of rivers, hunting, fishing, firewood, and forest construction materials. In the second phase, sketch maps are combined with government base maps and aerial photographs or satellite imagery, whichever is available. The sketch maps are transferred onto one basemap to remove inconsistencies, prior to incorporating the information into a GIS (Olive *et al.*, 1996). An up-to-date base map can be created from older maps and SPOT imagery (Olive *et al.*, 1996). The information from questionnaires is included with the mapping. This can be a lengthy process, and maps may have to be returned to the field for consultation with locals. In the third phase, final maps are created which combine and integrate the sketch maps with government maps and aerial photograph information. If land use change is to be assessed, time series imagery is needed.

I have found in practice through working with local communities in Indonesia and Malaysia that a Landsat photograph (preferably false colour), enlarged to 1:250,000 can provide a record of logging activities where no other record is available. Only the roads can be seen, and the resulting slope failures, not the logging activity itself. This exercise was very important to the community members as a record of the logging companies' encroachment onto their traditional territory, and was useful as a backdrop and verification of their sketch maps of local areas at a much larger scale.

In countries where base maps already exist, care must be taken to keep them up to date. Landsat and SPOT are being successfully employed in some Southern countries to revise old and inaccurate government base maps. When working with orbital imagery, scales greater than 1:250,000 are not generally feasible, and problems can exist even at these scales. Tests on reliability show that SPOT provides acceptable geometry, but "unacceptable levels of reliability in feature recognition and classification." (Hartley, 1991)

Southern countries are turning to orbital imagery because of their savings in cost and time: "It has been showed that digital processing of TM data is capable of satisfying the classification and mapping needs in the country with a reasonable degree of precision (85%) in much less cost and time when compared with the aerial photographs" (Saxena *et al.*, 1992). But orbital imagery can not be used in absence of extensive ground truth or aerial images. In some cases, more ground control points are needed with orbital images than if aerial imagery were used (Soofi *et al.*, 1991).

7.4.2 Tropical forest monitoring

Resource inventory of tropical rainforest is a pressing need in light of rapid deforestation. Local people and traditional agro-forestry systems are being displaced. Resource management studies most commonly focused on tropical rainforest in the literature. Landsat is useful for establishing the actual amount of remaining forest cover at a broad scale (Myers, 1988). With Landsat TM imagery, logging roads and skid trails are visible (Brown *et al.*, 1995), and roads and non-forest areas (Figure 3).

Orbital imagery is well suited for monitoring ecosystems undergoing rapid change (Sader *et al.*, 1990). NOAA AVHRR can be used for deforestation information at a broad or global scale. Discriminating forest from non-forest is possible with NOAA AVHRR data (Jaakola, 1990). NOAA AVHRR data can be used to provide a reconnaissance level survey of the forest resources of a region, if used in conjunction with fine resolution data (Nelson and Horning, 1993). It can also be used to monitor large forest fires. To monitor tropical deforestation due to forest fires, the researcher can use saturation of the thermal channel 3 on NOAA's AVHRR (Gregoire *et al.*, 1993) and Landsat TM's thermal infra red bands. NOAA's channel 3 is least affected by moisture, haze and smoke that affect the NDVI data, so can discriminate deforestation features.

Tropical rain forests are very different from their temperate rainforest relations. Where a temperate forest might have ten or twenty tree species in any given hectare, and can have huge areas with only one or two main species, the same hectare in a tropical forest can have two hundred species. Tropical rainforests are the most complex ecosystem in the world (Tucker, *et al.*, 1984) with a diversity of plant life, canopy layers, lianas and epiphytes. The human use patterns that have evolved in coexistence with tropical rainforests are similarly heterogeneous. Swidden agriculture consists of numerous small fields in various stages of crop and fallow. The fallow fields are allowed to regrow for ten to twelve years, at which point they become difficult to distinguish from primary forest. Sometimes rattan (a woody vine) is planted among the standing trees as a cash crop. This type of agriculture is done at a very small scale. Due to their heterogeneous nature and the ability of certain forest classes to blend in with each other, tropical forests require different remote sensing methods than those suitable for simpler ecosystems (Schreuder *et al.*, 1995). A system with a higher spatial resolution is needed. SPOT is recommended over other orbital platforms, especially SPOT P with its 10 m spatial resolution and stereo capabilities. However, even SPOT's resolution may not be appropriate for detailed mapping of tropical forests.

TM bands 3 and 5 and near IR provide the best contrast between surrounding forest (dark) and rubber tree family clearings (1-10 ha, light) (Brown *et al.*, 1995; Gonzalez *et al.*, 1995). However, visual interpretation of Landsat for reforestation and computer aided analysis will only show the larger plantations--it won't show the smaller (Filho *et al.*, 1982). Rubber gardens in Borneo are less than one hectare in size (Dove, 1993)--a size too small to be discriminated with TM (Gastellu-Etchegorry, 1989). Discrimination of these small gardens is technically possible with SPOT's resolution (Gastellu-Etchegorry, 1989), but is not consistently possible in reality because of the poor spectral contrast between rubber tree plantations and forest. As with other applications, to observe forest areas at a detail necessary for resource management and to include locals in the decision making process, aerial photographs are necessary (Gilruth *et al.*, 1990). Satellite images can identify general areas of degradation and expanding agriculture, but large-scale photos or video must be used to assess the actual amount (Gilruth *et al.*, 1990). Combining more than one remote sensing source is recommended (Rasch, 1994; Welch *et al.*, 1990).

1:40,000 is considered a good scale for classifying tropical forest and mangrove (Harnapp and Knight, 1971; Ibrahim and Hashim, 1990). This excludes any type of orbital imagery, which is not suitable for larger scale analysis. SPOT and TM can only reasonably classify down to scales of 1:50,000 and 1:250,000, respectively (see section 7.3.3 on scale). Home gardens and swidden can only be seen on 1:20,000 photos, and with difficulty on 1:50,000, and not at all on MSS imagery (Gilruth *et al.*, 1990). At heights above 4633 m (15,000 feet), the aerial imagery was only able to generalize the heterogeneity of the stand to produce classification results. This level of detail represented the forest as mixed pixels. I found that with 35 mm film and a coniferous Canadian forest, flying heights of less than 4633 m (15,000 feet) were required to distinguish the heterogeneity of a mixed forest stand. Tropical forest can be expected to be much more heterogeneous, indicating that higher altitude aerial and orbital imagery is not appropriate for anything but discriminating forested from non-forested areas.

Aside from spatial requirements, tropical forests have particularly stringent spectral requirements. Orbital imagery has difficulty distinguishing primary forest from secondary growth (Singh, 1987 with MSS; Gastellu-Etchegorry *et al.*, 1993 with NOAA; Stone *et al.*, 1994 with NOAA) and plantations from secondary forests (Lucas *et al.*, 1993 with TM). To overcome this, a multi-level approach must be used. Radar imagery can be combined with orbital imagery's visible wavebands to discriminate the difficult forest types. Radar (SAR) imagery alone is helpful in discriminating moderately-vegetated areas (crops, rice fields, rubber tree plantations, young secondary growth) from each other, but is of no help in discriminating between dense forests and degraded or secondary forest (Nezry *et al.*, 1993). Radar can distinguish primary from secondary forest when used in conjunction with visible wavelength orbital imagery (Thompson and Dams, 1990). Aerial photographs or video can be used to provide detail. Finally ground truth and local knowledge confirm the information. Local knowledge is essential in the agro-forestry context. Any forestry program should include local inputs (Food and Agriculture Organization of the U.N., 1986).

Visual wavelength orbital imagery is not well suited to forestry volume inventories, since reflectivity of forests is related to canopy characteristics, not volume of standing timber, not to mention that it is generally too small a scale. To determine the age of plantations (e.g. oil palm) in the forest, time series data must be used (Lucas *et al.*, 1993).

Another problem particular to the tropics is cloud cover, associated with the heavy rainfall. Gastellu-Etchegorry (1988b) estimates that a researcher can sometimes wait months to obtain an 80% cloud-free SPOT image in Indonesia. If the researcher is in a hurry, Landsat TM will only have a slightly shorter wait. Therefore, for certain applications which need a high repeatability, like agriculture studies, an orbital study is not possible. Some applications require less frequency of imaging, and are possible with SPOT data--i.e. forestry and geology. TM has better wavelength bands for penetrating haze (King, 1994) and has more of a selection than SPOT. The cloud problem can be overcome by using radar imagery in conjunction with other orbital imagery (Ford and Casey, 1988). "Owing to perennial cloud cover the distribution and extent of the different canopies cannot be determined from Landsat MSS or other images obtained at optical wavelengths," however SIR-B could distinguish forest types, marsh, clearcuts and clearings relating to shifting settlement and swidden (Ford and Casey, 1988), and villages from surrounding forest.

7.4.3 Resource studies: minerals, soils and agriculture

Quite often the small scale of geological and mineral explorations makes orbital imagery feasible. For detecting lineaments, Landsat TM can provide a synoptic level of coverage. Once areas of interest have been identified from the satellite imagery, aerial photographs provide a finer level of detail. A three phase approach was used to study transcurrent faults in an inaccessible area of Central Arabia: 1) an integrated view of the whole system with AVHRR Thermal IR; 2) high resolution TM multispectral and SPOT stereoscopic images to refine location for the third phase; 3) field work to test hypotheses from the first two (Andre, 1989). Drainage networks have been accurately delineated on Landsat but not on radar imagery, although SIR-A allowed better delineation of various rock units, moisture content variations, and drainage in flat areas (Alizai and Ali 1988).

Most soil units distinguishable with stereoscopic aerial photographs are distinguishable with SPOT data (Gastellu-Etchegorry *et al.*, 1990). SPOT P data are recommended because for geology the spatial approach to image analysis is better than the spectral approach, because of overlying vegetation, except in well exposed areas (Gastellu-Etchegorry *et al.*, 1990). In well exposed areas, TM band ratioing and analysis provide better results than aerial photographic interpretation for detecting copper deposits (at 1:60,000 scale, Amos and Greenbaum, 1989). If you're using TM data of the Sahara, the imagery may be clouded by dust-laden winds (*Harmattan*), and you can compensate by incorporating longer wavelength infra-red bands 5 and 7 into your image (Vaughan, 1988).

Orbital imagery is not suited to ongoing agriculture monitoring at any but regional and international levels. Crop monitoring using orbital imagery has mainly been limited to the international level. A lot of effort has been put into defining new crop monitoring techniques, but these techniques have not been adopted by national monitoring and early warning systems in the South, largely because the experiments were not relevant to users' needs, and proposed techniques are way outside of available budgets (Bartholome, 1991). "The current state of the art shows that while remote sensing techniques can be used in an operational way to improve agricultural statistical surveys, direct crop estimates seem hardly feasible in Sahelian countries (Bartholome, 1991)." Reasons given range from the scale and cost of orbital surveys to the inability to keep up with the massive amounts of field data needed. A proposed solution is to monitor (by remote sensing method) a small series of sites scattered throughout the territory. This would provide sub-continental level information, but nothing on a local level.

In order to update existing topographic maps of agricultural land use, a combination of orbital (i.e. Landsat TM) imagery with air photos is recommended (Salem, *et al.,* 1995). SPOT provides more reliable estimates of smallholder agriculture than Landsat TM (King, 1994), but overall aerial photographs are best (Gilruth *et al.*, 1990). I found that aerial photographs from flying heights of approximately 2438 m (8000 feet) (contact scale 1:100,000 with 24 mm focal length), or 1219 m (4,000 feet) aerial electro-optical CCD images could discriminate between different types of barren areas. This could be extrapolated to soils information.

7.4.4 Grassland and desert monitoring

Compared to the more diverse tropical forests, grassland and desert monitoring seems to call for small-scale approaches. Many African studies have used NOAA AVHRR to monitor desert and grasslands. A simple ratio of infrared to red reflectivity is quite sensitive to the fraction of the soil surface that is obscured by green vegetation (Justice *et al.*, 1986). IRS has been used to map and monitor grassland in India, by combining satellite data, topographic maps and ground truth (Jadhav *et al.*, 1993). TM imagery is suitable for distinguishing between forested and grassland areas, and between grassland and desert, as are high altitude aerial images.

7.4.5 Hydrology studies and water quality

Landsat TM images usually do not provide enough detail to distinguish any but larger rivers and creeks in rain forest (from personal experience with Landsat TM images of Sarawak, Malaysia). To resolve greater detail, data commensurate with a greater detail should be used, such as existing base maps and aerial sensors--photography and video. Radar has been found to be useful for discriminating topographic relief--riverbeds and watersheds. NOAA AVHRR imagery can be used to monitor rainfall, mainly by estimating cloud cover. For detailed river information--such as sedimentation of small to medium sized streams, aerial imagery must be used.

7.4.6 Hazard assessment: fire and flood

Researchers in India have been using IRS for flood monitoring and prediction of disasters (Ramana Murty *et al.*, 1993). NOAA AVHRR's rapid return period makes it particularly suitable for monitoring hazards such as fire, oil slicks and flood at a small and global scale. NOAA AVHRR (Gregoire *et al.*, 1993) and Landsat TM's thermal bands are useful for monitoring small-scale forest fires and oil slicks. MSS is an excellent resource for hazard prediction, because of its long timeline availability. Aerial imagery's strength for hazard detection and monitoring is that the right type of film and filters can be chosen for the situation and in an emergency it can be flown immediately.

Chapter 8. CONCLUSIONS

Southern countries are characterized by ecosystem vulnerability and have some of the most complex ecosystems in the world. Pressing problems in the South include lack of resource information and inventory, eco-vulnerability, exploitation of resources, lack of local empowerment and a lack of available base maps and aerial photographs. Although there is a recognizable need for the South to monitor its resources, Southern researchers have several barriers--financial, political and technical--that may preclude them from applied resource studies. Remote sensing and technology transfer to the South are complex and difficult subjects, grounded in politics and commercial interests. In general, in the three major English language international remote sensing journals, the percentage of articles published by local authors has increased over the years, showing that Southern researchers are acquiring the knowledge to study their own (and other Southern) countries. However, local and outside authors alike are focused on technical, abstract studies, rather than applied studies.

The thesis looks at whether the publications and technologies of the international remote sensing community have any application to the resource needs of the South. Results show that the needs of the South for resource management and applied mapping are not being met in the published literature. Most published research from the South is technical in nature, uses orbital imagery rather than aerial imagery and is done at a small scale. Very few mapping studies include local participation. Some Southern authors have stated that resource management and mapping should be a priority, however these types of articles appeared with a frequency of 11%—much less than the percentages of technical articles (about 50%). The current remote sensing research focuses on orbital imagery which limits studies to a small scale. Resource management requires more detailed levels of information that can only be provided by aerial imagery and ground truth.

The lack of applied studies in the published literature makes it difficult to assess appropriate methods for resource management and simple mapping in the South. In order to assess sensor systems and methods in an applied context, a case study of a forest area in Kananaskis Alberta was used. Results indicate that resource management applications can often require airborne imagery. Orbital imagery can be useful in cases where aerial imagery is not available and can be used for quickly mapping areas of interest at a small scale. Interpretation of aerial photography is the preferred technique for simple mapping and resource management in the South.

Orbital imagery is suitable for global scales, forest/non-forest discrimination, hazard assessment, and monitoring human impacts such as deforestation. It can be used for mapping indigenous territories at a small scale in the absence of aerial photographs. Satellite imagery is excellent for showing the big picture—global deforestation, weather patterns, continental mapping, and is also very useful for addressing areas of land use conflict at small scales. The minimum scale for orbital imagery is 1:250,000, although if aerial photographs are unavailable, orbital imagery may have to be used at larger mapping scales by default, with losses in resolution.

For simple mapping, appropriate to Southern needs, I recommend an aerial approach, and one that includes ground truth and local people. In the absence of aerial imagery, good basemaps and locally-informed ground truth should be used. In the absence of good base maps and aerial photographs, orbital imagery (preferably SPOT P if there is no cloud problem) should be used to create a base-image on which to overlay the ground truth and survey information. Mapping at a large scale is necessary in order to include local knowledge on resources and resource use that might otherwise be missed.

Orbital imagery is only suitable for creating maps at a small scale. Local people can use orbital imagery to create maps that convincingly show their territorial boundaries and potential boundary conflicts with industry (Peluso, 1994), but for more detailed resource assessment and management, aerial imagery and ground truth should be used. Orbital imagery (either TM or SPOT, or MSS if a long timeline is needed) are best used for global or small-scale resource assessments and mapping. In actual practice, the availability of remote sensing imagery in the South is usually limited. If aerial imagery is not available, orbital imagery can be used to make a useable base map, and the results of local sketch mapping, surveying, or other large-scale data collection method can be overlaid.

In the best case scenario, where all types and scales of remote sensing imagery are available for an area, researchers have more options available. Aerial imagery can be flown, and if high radiometric resolution is desired, electro-optical CCD can be used. Aerial photographs are the oldest and best known remote sensing imagery, and visual interpretation of aerial photographs is still the most reliable method for local scale resource assessment and mapping.

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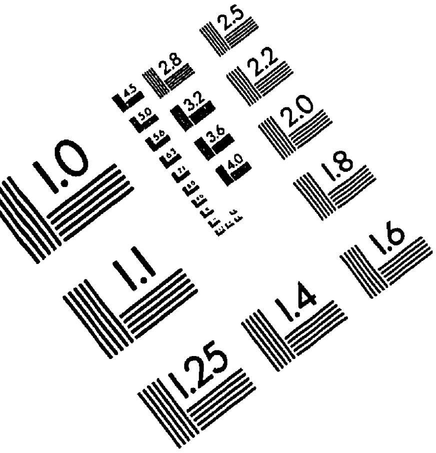
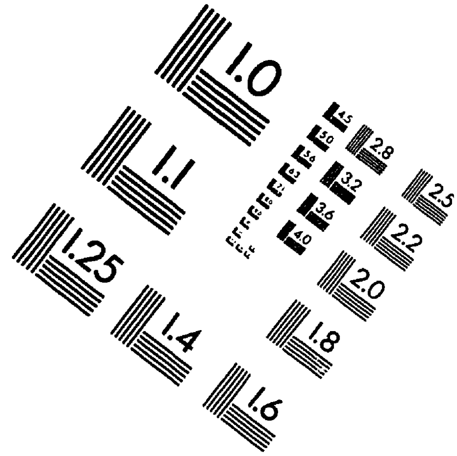
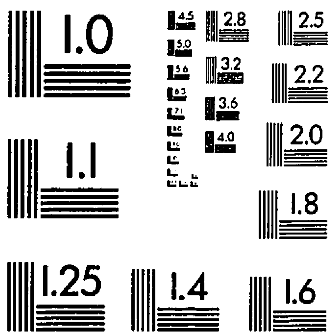
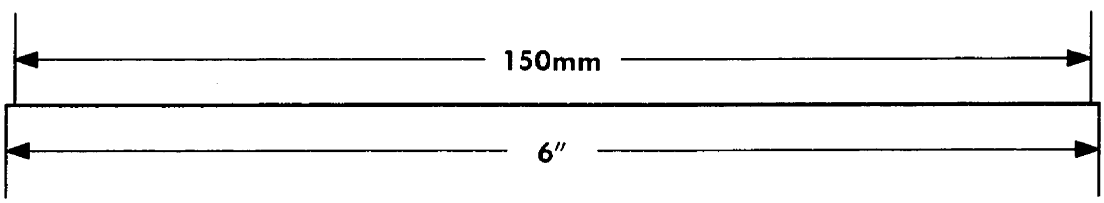
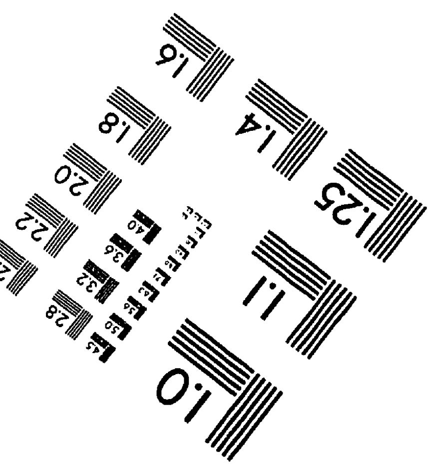
IMAGE EVALUATION TEST TARGET (QA-3)

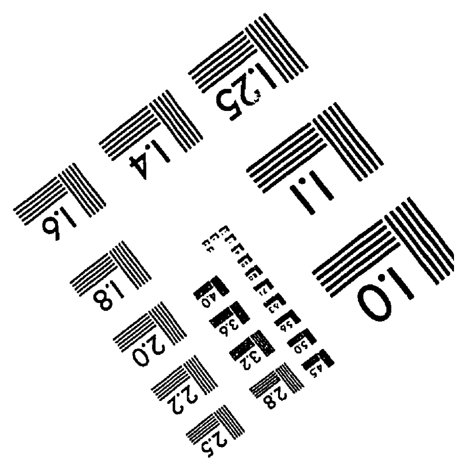












APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989