Mapping of Vegetation, Land Cover, and Land Use by Satellite – Experience and Conclusions for Future Project Applications

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Since the launch of the first civilian remote sensing satellite LANDSAT in 1972, satellite remote sensing has become a useful tool for mapping, monitoring and environmental studies at local, regional, and global levels. In 1986, the first SPOT satellite heralded a new era of high-resolution optical remote sensing from space; and from the more recent radar-equipped ERS-1 satellite, supplementary data can be collected regardless of cloud conditions and day-light.

Since 1987, the Swedish Space Corporation and its subsidiary SSC Satellitbild, referred to jointly as SSC below, have conducted several large operational projects on the interpretation and mapping of vegetation, land cover and land use (commonly called land cover in the following) in Southeast Asia and southern Africa. Projects have been carried out in the Philippines, Malaysia, Indonesia, Thailand, Malawi, and Namibia, and they have required close cooperation with the clients in these countries, including training both on-the-job and in SSC's facilities in Kiruna.

This article describes the execution and results of two representative projects and provides experience on and conclusions drawn from the performance of these and other projects. The projects are "Mapping of the Natural Conditions of the Philippines" executed in 1987-88, and "Forest Resources Mapping and Biomass Assessment for Malawi" performed in 1992-93.

In both these cases, the World Bank played a significant role. In the Philippine project, the Bank was the client; the Swedish government the financing agency (through BITS); and the Philippine National Mapping and Resource Information Authority, NAMRIA, the cooperating agency. The Malawian project was financed by the World Bank with the Malawian Department of Forestry in the Ministry of Forestry and Natural Resources as the client and cooperating agency.

The Philippine project marked a major breakthrough in the field of remote sensing, being the first project of its kind in the world with practical application on a large country-wide scale. In the Malawian project, the assessment of biomass volume on district level was added to the "conventional" land cover mapping.

The objective of the Philippine project was to satisfy the World Bank's need for up-to-date information on the land cover of the entire Philippines (300,000 sq.km) for their Forestry, Fisheries and Agricultural Resources Management (FFARM) study of the country. The aim was to acquire land cover statistics by region (12 nos.) and province (74 nos.) for eleven land use classes and two sea classes (siltation patterns and coral reefs). The contract was signed in July 1987 – completion time was March 1988. In order to fulfill this requirement, SSC commenced the project in April 1987.

Only multispectral SPOT imagery was used, the main reason for this being SSC's direct access via Spotimage to the programming and operation of the SPOT system. The tight time schedule made no other satellite system competitive in providing sufficiently cloud-free imagery at the required pace.

At the beginning of the project, very few acceptable SPOT scenes were at hand in the SPOT archives. Within the stipulated time frame,

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about 190 such scenes covering the entire Philippines were acquired, processed, and prepared in digital and analogue format for application in the project. Using existing topographic maps, the scenes were precision corrected (geocoded) to the coordinate system of the country and then produced as color transparencies on a scale of 1:100,000 for visual interpretation.

Execution of the Philippine project based on SPOT data is demonstrated, in principle, by the Activity

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Flow Chart for the Malawian project (based on Landsat imagery), which follows later in this article.

Air and ground field work was undertaken to "calibrate" image features with ground features. For about two months, from mid-April to mid-June 1987, nineteen slow-speed air reconnaissances and seven ground surveys were performed. The field work was documented by a vast number of field reports and photographs from the air and on the ground.

Some outside reviewers have argued that the extent of field work was somewhat limited, bearing in mind the large land area of the project. Reference is merely made to the above-mentioned tight time schedule and to the fact that the rainy season in the Philippines, which permits no efficient field work by air or on the ground, lasted from June to November-December 1987. Consequently, optimal use was made of time.

A draft classification legend was established at the beginning of the field work. It was refined regularly in pace with the increasing "calibration" experience, and was finally established at the completion of the field work. The initial eleven land cover classes were increased to twenty-two, divided into five main categories, and formed a hierarchic legend structure permitting the classification of the entire land area. This legend appears at the bottom of the resulting land cover maps, and an extract/portion/part/section of one of these maps is shown in Figure 1.

Twenty-one interpreters from NAMRIA and SSC performed the classification by visual interpretation on light-tables. Manuscripts were made on transparent plastic film overlaying the transparent satellite imagery. The initial crucial interpretation was made in the Philippines and the rest in Sweden. The smallest mapping unit was 100 hectares.

The manuscripts were reduced photographically from scale 1:100,000 to 1:250,000, the latter being the scale of presentation prescribed by the World Bank. After mosaicking, the manuscripts were scanned and vectorized into a vector-based GIS in which the layout of the final maps was created. The vectorized map data was transferred to a raster-based system for final plotting of printing originals. Forty-three land cover maps, covering the entire Philippines, were printed in black and white, a reduced sample of which is shown in Figure 1. A generalized color map on a scale of 1:2,000,000 was also compiled, presenting the country on one mapsheet and summarizing the area statistics per region and for the whole country. Figure 2 presents this map in a further generalized and black-and-white form, reduced to a scale of 1:8,000,000.

In the above-mentioned GIS, land cover statistics for the entire country were computed automatically by region and province for each of the twenty-two land cover classes. These statistics are contained in the project report.

The interpretation results showed that 25 percent of the vegetated land area of the Philippines was forest, 41 percent extensive land use, and 34 percent intensive land use. These three main categories constituted 98 percent of the project area. The 25 percent for forest implied an alarming reduction of forest cover, from 40 percent just fifteen years earlier — a loss of one percent, or 300,000 hectares yearly during this period.

The results of the forestry part of the project agreed well with another simultaneous forest study over selected areas of the Philippines. This other study, "Philippine-German Forest Resource Inventory Project," the results of which were "extrapolated" to cover the whole country and thereby permit comparison with the SSC project, was based on more detailed ground surveys and studies of older aerial photos and Landsat imagery, rather than the SPOT data used by SSC.

Forest classes were not entirely the same in the two studies, since in each case they were defined for specific purposes including optimal interpretation of the imagery from which they were studied. Nevertheless, their figures concurred sufficiently well on a regional basis to fully support the conclusions made regarding the alarming reduction in the forest cover.

An immediate result of the SSC-NAMRIA project, and probably also a consequence of the conclusions and results of other studies and information, was the almost total ban on logging in the entire Philippines imposed by President Aquino and the Philipppine government. Obviously, this and other projects, and the ban based on their results, played an important role in the efforts to halt the fast denudation of forest resources. Even if these efforts have not been successful enough to actually halt the denudation, it is regrettable that some outside reviewers of the forestry situation in the Philippines advocate that remote sensing projects in the country have been a failure and have not led to improved forest management, and that the results of the projects have been ignored by the Philippine government. It is also regrettable that these reviewers do not seem to distinguish between research and project work.

On the other hand, it is encouraging for those working within the field of remote sensing that the World Bank, the client for the Philippine project, recognizes its merits. The 1992 Bank report, "Natural Resource and Environmental Information for Decisionmaking" concludes that "The project was remarkable because it clearly demonstrated that under certain circumstances national

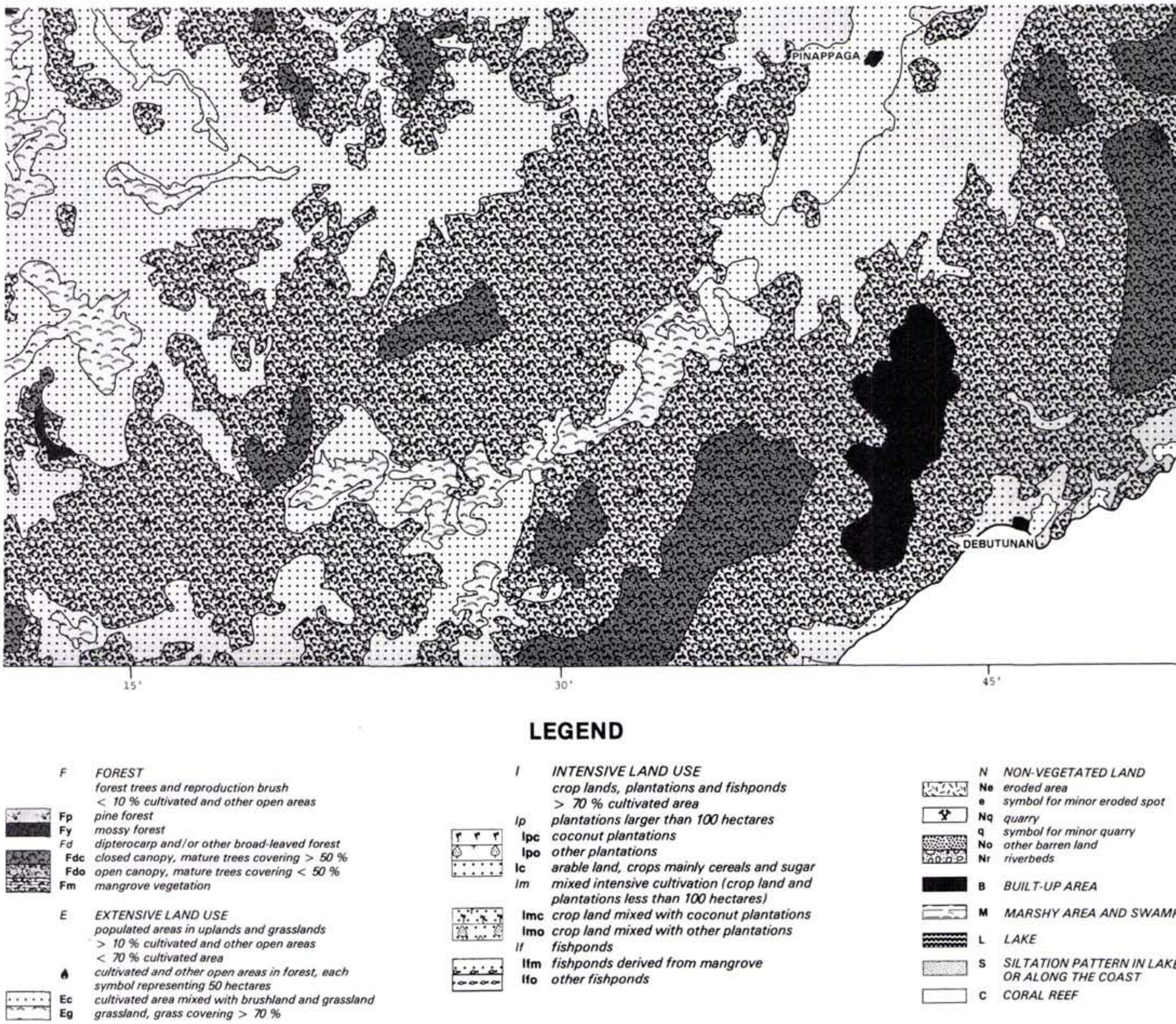

Figure 1. Philippines Land Cover Map.

land resource inventories could be completed in a short time at extremely low cost.... This work could not have been completed in this time frame or at this cost with any other technology."

It is also highly positive that NAMRIA has successfully applied the digital and analogue satellite data delivered from the project in over 80 government projects as well as many non-government projects.

Malawi is experiencing deforestation as forest products are being used for fuelwood or areas are being converted for agricultural uses. The aim of the project was to assess the extent and condition of Malawi's forest resources on a reconnaissance level, as well as land use changes that had occurred from 1972-73 to 1990-91. The Activity Flow Chart is shown in Figure 3.

The land area of Malawi, is approximately 100,000 sq.km. in size. The area was mapped by visual interpretation in the same way as in the Philippine project, but the satellite data originated from the Landsat TM and MSS sensors instead of from SPOT. The TM data (pixel size 30 x 30 metres), from which the "existing situation" was interpreted, was from 1990-91, and the MSS data (80 x 80 metres) from 1972-73. Twelve TM scenes and eleven MSS scenes were utilized to cover Malawi, respectively. In a forest change detection study, a comparison was made between the mapping performed from the two Landsat data sets. Finally, the Biomass Assessment emphasized forestry and was based on the results of the interpretation of the Landsat TM data of 1990-91.

Precision-corrected Landsat TM and MSS scenes were mosaicked and sectioned digitally into ten transparent Satellite Image Maps (SIMs) on a scale of 1:150,000 from each set of data, both covering the area of Malawi. These tranparencies, which were used for the interpretation, had the same geographic coverage as the corresponding ten sheets of the existing topographic maps on a scale of 1:250,000. SIMs were also made to this scale on photographic paper.

Field work for the land cover mapping and biomass measurements was carried out in Malawi from late May to mid-October 1992. Nine field reconnaissances were made by vehicle, visiting almost every land cover class of Malawi, and three reconnaissance flights covered the country from north to south. Field measurements for the Biomass Assessment were made by three biomass teams in parallel with the land cover reconnaissances.

The visual interpretation of the Landsat TM data was carried out at the Department of Forestry in Lilongwe by a joint team of Department and SSC staff. The results were presented gradually to the biomass team.

In the same way as in the Philippine project, the legend was developed after an iterative process in pace with experience gained from the field work. The legend is shown in Figure 4 and on the resulting Land Cover Maps. In all, 25 land cover classes were interpreted. The smallest mapping unit was 100 hectares.

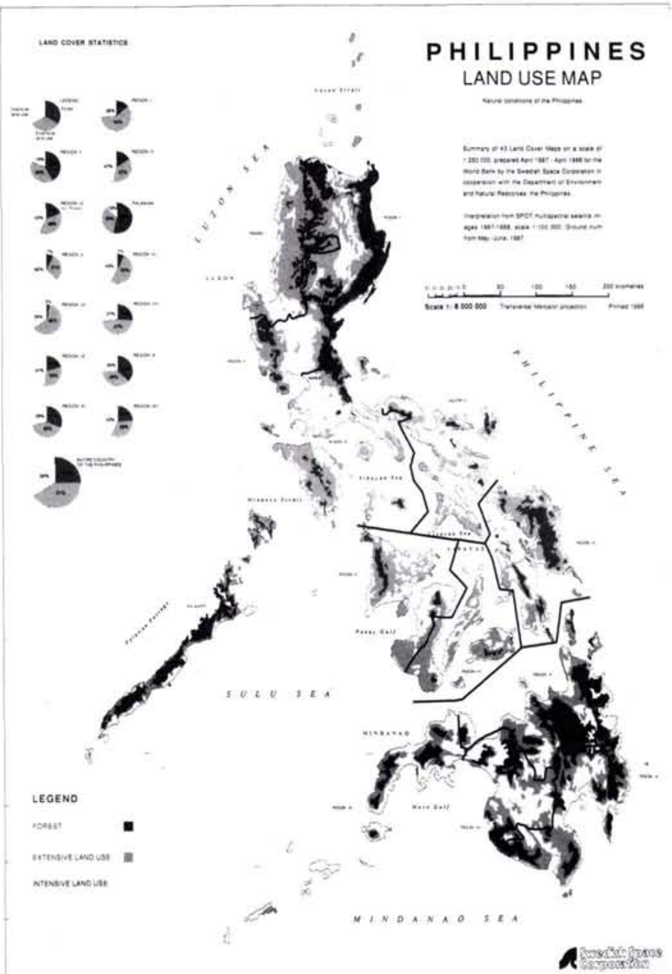

Figure 2. Land Use Map, Philippines.

The interpretation manuscripts were digitized into a vector-based GIS and then transferred to a raster-based system for final plotting of originals for printing in colors. A summary land cover map was also prepared in colors, on a scale of 1:1,000,000. All maps were printed in Sweden.

The area of each land cover class was computed automatically in the GIS. The statistics were presented for the three regions of Malawi and for the 24 districts making up these regions. The results for the "existing situation" (Landsat TM from 1990-91) showed that forest areas made up about 28 percent of the land area; extensive agriculture in forest area about 25 percent; and arable land in the main class, intensive agriculture, 29 percent.

With reference to the low resolution of the MSS data (80 x 80 m pixels), it was concluded that some classes, mainly agricultural, could not be subject to the same criteria when interpreting the MSS imagery as those used for the TM data. Since the emphasis of the change study was on forestry, however, we judged that this short-fall was insignificant.

With the GIS, ten forest change maps were plotted in a raster-based system on transparent film as overlays, with the same coverage and scale (1:250,000) as the corresponding land cover maps.

The area computation in the GIS showed that the extent of Brachystegia forests had declined drastically. In 1972-73 these forests occupied 45 percent of the total land area of Malawi while in 1990-91 the figure was 25 percent, implying that between 1972-73 and 1990-91 the area occupied by these forests declined by 44 percent.

One overall conclusion that can be drawn from the results is that the higher resolution of Landsat TM data proved its definite superiority over MSS data for land cover interpretation. If the project only had access to MSS data, considerably less information would have been extracted from the interpretation than was in fact the case.

The Biomass Assessment part of the project aimed at describing the major land cover classes in terms of wood biomass. The estimation was made from measurements on sample plots, laid out systematically in cluster arrangements in five selected land cover classes which contained considerable volumes of natural forest.

Each cluster was made up of twelve sample plots. On each plot, a sample tree was selected, and the tree and stem heights were mea-

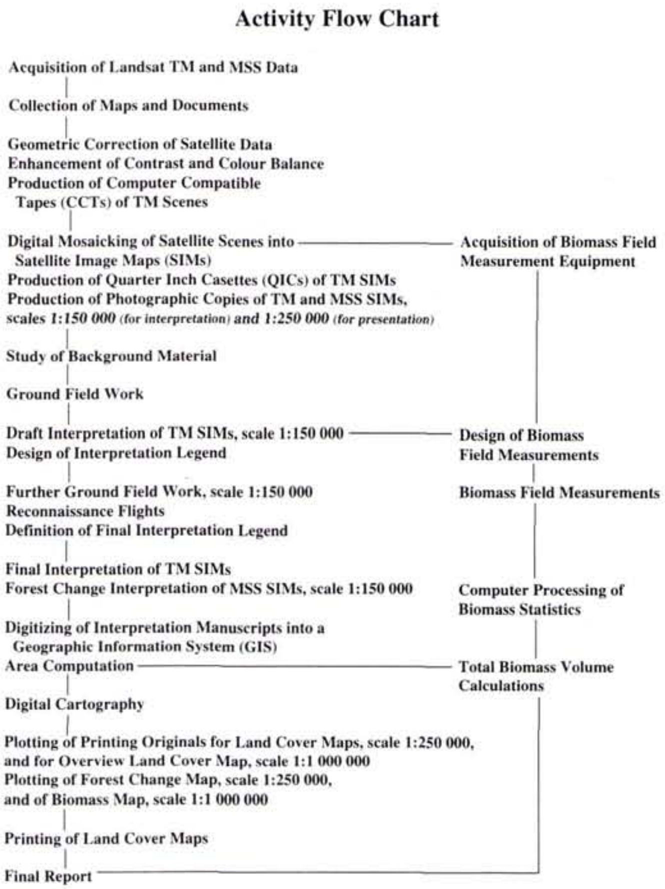

Figure 3. Forest Resource Mapping and Biomass Assessment for Malawi.

sured and recorded. On one sample plot per cluster, the sample tree was felled for measurement of the tree volume. Based on the data from the trees felled, a regression analysis was performed to express the tree volume as a function of diameter and height.

The estimate of volume per hectare by land cover class and region gave a figure for Brachystegia forest in hilly areas varying from 123 cubic metres per hectare in the Northern and Central Regions to 81 cubic metres per hectare in the Southern Region. In flat areas the figures for this forest class were about 20 percent lower. The estimated total biomass in natural forest in Malawi in 1990-91 was about 460 million cubic metres of which some 47 percent fell in the Northern Region, 31 percent in the Central Region, and 22 percent in the Southern Region.

The regional variations in biomass volume per hectare and land cover class were shown on a transparent Biomass Map on a scale of 1:1,000,000. Estimates were made of the standard deviation and the standard error for each land cover class by region. The relative variation differed significantly between land cover classes. The most homogeneous land cover class was Brachystegia forest in hilly areas where the relative variation was low in all three regions (about 40 percent), and the error comparatively low.

It was concluded from the *Biomass Assessment* that the five selected land cover classes had a fairly unique distribution of species and that, consequently, they had been adequately interpreted and delineated in the land cover maps.

Differences in results between projects or studies may depend on their respective levels of generalization. A detailed and costly survey performed over many years and based on a great number of data will, for many reasons, have a high degree of accuracy. On the other hand, it will by nature also contain uncertainties in comparison with a project for which recent data is used. The balance between these two aspects, and differences in costs and degree of accuracy, must be considered by clients when drawing up terms of reference for projects with long and short execution times. In comparison with aerial photographs, satellite data offers the decisive advantage for many projects of comprising recent data in both analogue and digital

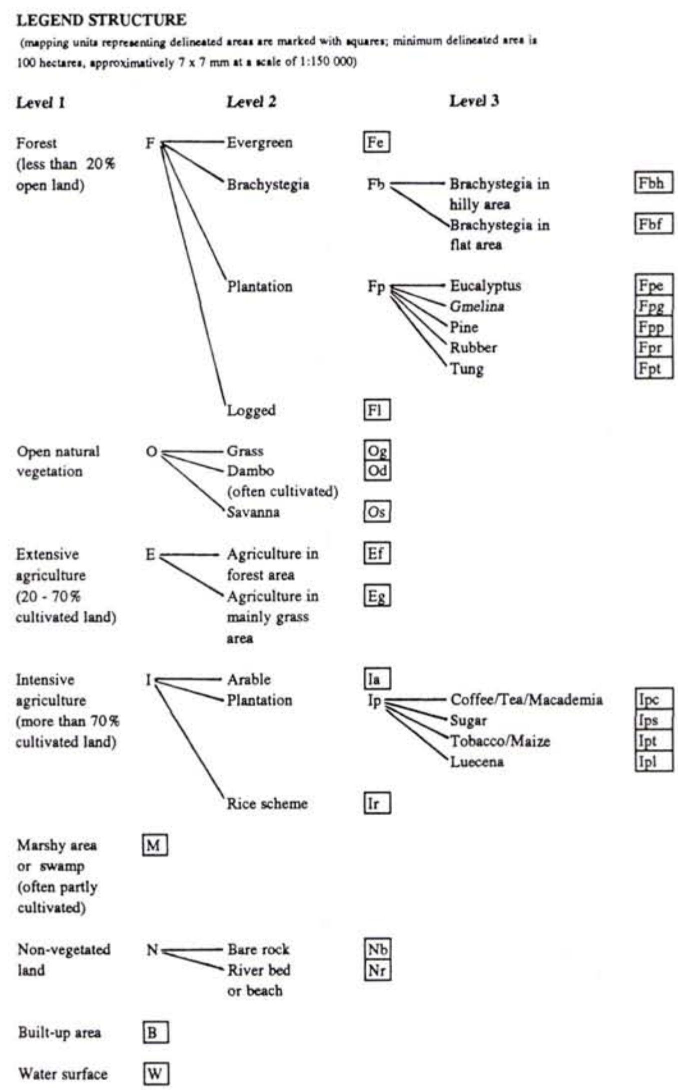

Figure 4. Malawian Legand Structure.

This work could not have been completed in this time frame or at this cost with any other technology.

form at a low cost, and of permitting further processing of the digital data by the client. On the other hand, aerial photos may have higher degree of interpretability and can be used on larger scales than satellite data. Therefore, these two types of information should be regarded as supplementing, rather than conflicting with each other.

In order to make optimum use of a certain type of specified information within a project, such as SPOT or Landsat, definitions of land cover classes may differ from those used in earlier studies, thereby seemingly giving differences in results. This divergence in definitions should be borne in mind when comparing results between surveys in which the names of classes resemble each other. In fact, the usefulness of the results of different projects can be increased considerably in many cases if, in a constructive way, the results are regarded as supplementing each other rather than, in a negative academic way, as opposing each other.

As is gradually becoming more recognized, the cost of satellite data is low per unit area covered. Furthermore, the cost of the data is often a comparatively low component of the overall cost of projects involving many other ingredients – in some cases, even a marginal cost. It is, therefore, strongly recommended that a project should not contain only one set of satellite data, such as SPOT or Landsat, but both, or even more sets whenever possible. This "generous supply of input" will provide many advantages, not only during the interpretation stage of the project, but also during the client's future use when refining or extending the project work or making use of the data for other projects. Different sets of data can offer higher geometric resolution which influences the interpreta tion scale (SPOT vs. Land-sat); more spectral bands facilitating the distiction between certain vegetation types (Landsat vs. SPOT); the coverage of different seasons (leaves on vs. defoliation), etc. On the other hand, a crucial aspect may be that one set of data is much more readily available than others, such as SPOT in the case of the Philippine project.

The difficulty of acquiring cloud-free data in certain regions should be recognized at an early stage of the project. Where distinct cloud-free seasons are regular, the time schedule for the project must take such seasons into consideration. On the other hand, the aim of mapping the vegetation may not focus on the situation during these seasons (due to defoliation, etc.), and in such cases, as well as in regions without cloud-free seasons, project time schedules should make due provision for the time required to receive cloud-free imagery.

Figure 5. President Corazon Aquino

A project on interpretation and mapping of land cover cannot be executed as a desk study without performing an essential part of the work in the project country. Cooperation between local expertise and interpretation specialists is required to permit the optimum "calibration" between the image and the actual countryside discussed earlier in this article. Such cooperation, taking the form of on-the-job training in many cases, also provides the necessary technology transfer for a smooth transition to the post-project situation. Furthermore, collegial in-country cooperation ensures efficient use of existing information contained in maps, aerial photos, literature, etc.

It is recommended that interpretation be made from Satellite Image Maps (SIMs) rather than from precision-corrected satellite scenes. SIMs are made from scene data by digital mosaicking and sectioning into map-sheets on the same scale and with the same geographic coverage as existing topographic maps of the area. This gives the interpreter considerably better familiarity and more efficient and economical use of the imagery than if satellite scenes were to be used. It is recognized that SIMs are somewhat more costly than satellite scenes.

For projects incorporating the land cover mapping of large areas or regions for the first time, visual (manual) interpretation is superior to digital classification in many aspects. It is a simple method from the practical point of view, including training, and requires no sophisticated equipment for the crucial element of manuscript preparation. It is also much more "clever" and gives more diversity and better results than digital classification which cannot compete with the human brain during first time interpretation. A descriptive example is the many stages (signals/colors in the imagery) of a rice area (wet, partly or fully covered by green matter, moist, dry, newly harvested, barren, etc.) which presents no difficulty during visual interpreation but which has to be calibrated extensively for digital classification. Finally, visual interpretation is far less costly.

Project planning should start from the assumption that no work in the host country should be commenced until a substantial

Conclusions: A project takes longer to execute than is planned.

portion of the imagery to be interpreted, such as SIMs, is at site. Time and effort have been wasted in past projects when this assumption is ignored.

The establishment and common use of an interpretation legend, and of a useful key to the application of this legend, is the most important activity of a project. Failure to accept this fact and to act accordingly, will result in confusion, conflicts, delay, and project failure. Rushing into the field for ground truthing in an unplanned way must be avoided. Instead, by adopting the iterative interpretation/field work process described earlier for the Philippine and Malawian projects, efforts, conflicts and costs will be minimized.

The future use of land cover maps resulting from an interpretation project should determine the "degree of sophistication" of the cartography of these maps. It may not be necessary in all projects to produce maps to the highest cartographic mapping standard plotted from a raster-based system. Instead, it could sometimes even be *sufficient merely to copy* the interpretation manuscripts. In other cases, it could be enough to go "half-way" by plotting maps from the GIS into which the manuscripts have been scanned and/or digitized and in which the input data has been edited.

Finally, a project always takes longer time to execute than is planned.

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