

A Comparison Between ERS-1, JERS-1, and Radarsat-1 Radar Satellite Imaging Systems and Landsat MSS & TM and Spot Optical Satellite Imaging System to Detect and Monitor Mangrove Deforestation in East Kalimantan, Indonesia

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Abstract.—Mangrove forests are one of the primary features of coastal ecosystems throughout the tropical and subtropical regions of the world. Mangroves are very sensitive and fragile resources, and the pressures of increasing population, food production, and industrial and urban development have caused a significant proportion of the world's mangroves to be destroyed. Reliable and timely information is required to manage the remaining mangrove resources. This paper describes a research project to compare the ability of three different radar satellite imaging systems and three different optical satellite systems to detect mangrove deforestation in the delta of the Mahakam River, East Kalimantan, Indonesia.

Mangrove forests are one of the primary features of coastal ecosystems throughout the tropical and subtropical region of the world. They are biologically diverse and have been used for food resources, firewood, charcoal, timber, and other minor products. However, mangroves are very sensitive and fragile resources; restoring damaged mangroves to their original condition requires much effort and time. In recent years the pressures of increasing population, food production, and industrial and urban development have caused a significant proportion of the world's mangrove resource to be destroyed. As the population has risen, the shortage of productive land in coastal regions of the tropics has resulted in the conversion of mangrove swamps to agricultural purposes and to fish and shrimp ponds for commercial production.

Because it is an archipelago, Indonesia has a large area of mangrove (4,250,000 ha are found around the four main islands). There are basically six categories of land use in the mangrove areas: (1) forest reserves, (2) nature conservation, (3) protection forest, (4) production forest, (5) fish/shrimp ponds, and (6) salt production areas. Mangrove forests are traditionally a source of livelihood for the local population. Therefore, the main problems of managing these resources are delineating the area, resolving local community ownership issues.

Information is crucial to assess mangrove deforestation and to monitor the existing mangrove forests for sustainable management. Because of the particular forest structure, composition, and difficult accessibility of mangrove forests, the task of collecting the information by terrestrial/ground inventory is extremely difficult, time consuming, and therefore very expensive. For this reason, remote sensing is an attractive means of obtaining data for defining deforested areas and updating management plans. A serious drawback to using optical satellite images alone for monitoring mangroves in Indonesia has been the unavailability of cloud-free images at the time of interest. The advent of radar systems is expected to resolve this problem. Unlike optical systems, radar systems can be operated day or night; they also have all-weather capability and can therefore penetrate clouds cover, fog, rain, and atmospheric dust. Furthermore, radar energy can penetrate crops and forest canopies and some surface features (dry sand). The objective of this research was to compare the ability of three different radar satellite imaging systems (i.e., ERS-1, JERS-1, and Radarsat) and three optical satellite data (i.e., Landsat TM, MSS, and Spot XS) to detect mangrove deforestation in the delta of the Mahakam River, East Kalimantan, Indonesia.

MATERIALS AND METHODS

The following data were used in this research project: Landsat MSS of 1983, Landsat TM of 1994, and SPOT XS of 1987. Radar data used were from ERS-1 of 1996, JERS-1 of 1996, and Radarsat of 1997. The research methodology is illustrated in figure 1.

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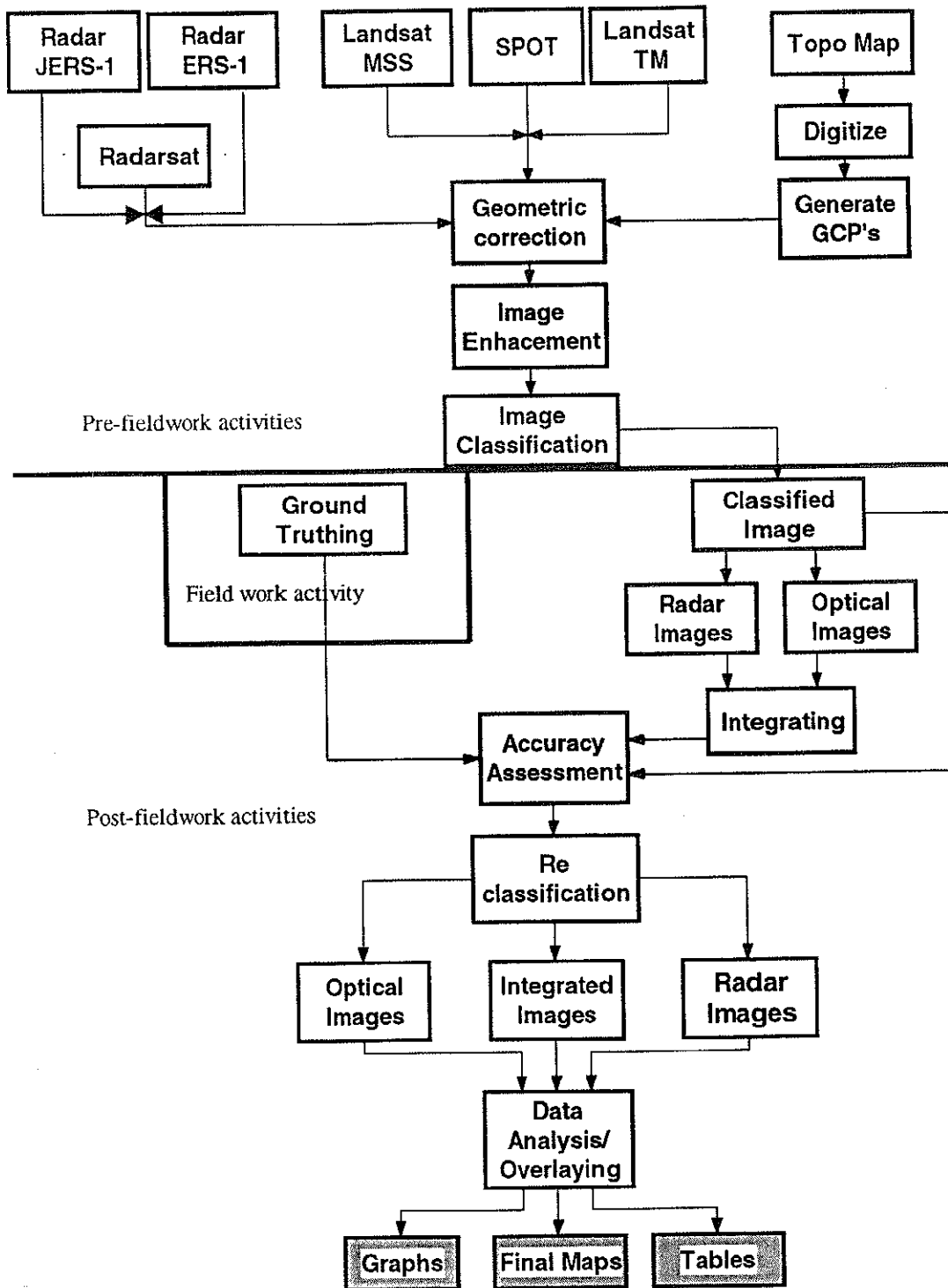


Figure 1.—Methodology flowchart.

Table 1.—Classes detected in each image through supervised classification and visual interpretation

Landsat MSS	SPOT	Landsat TM	ERS-1	JERS-1	Radarsat
Broad-leaved	Broad-leaved	Broad-leaved	—	—	—
Nypa	Nypa	Nypa	Nypa	Nypa	Nypa
Water	Water	Water	Water	Water	Water
Ponds	Dry pond	Fish pond	Fish pond	Fish pond	Fish pond
—	Orchard	Orchard	—	—	—
—	Mixed	Mixed	Mixed	Mixed	Mixed
Agriculture	Agriculture	Agriculture	—	—	—
—	N/A	Clear cut	Clear cut	Clear cut	Clear cut
—	N/A	Half cut	—	Half cut	Half cut
—	—	Swampy	—	—	—
—	—	—	Oil pipeline	Oil pipeline	Oil pipeline

RESULTS AND DISCUSSIONS

Table 1 summarizes the classes identified on each image using supervised classification

Three types of mangrove deforestation were found to occur in the study area:

1. deforestation caused by establishment of agriculture and/or orchard
2. deforestation caused by establishment of oil pipeline networks
3. deforestation caused by the establishment of shrimp ponds

Deforestation resulting from the establishment of agriculture crops or orchards can be detected by Landsat TM 1994 and SPOT_XS 1987. However, radar data (JERS-1, ERS-1, and Radarsat) cannot detect this type of deforestation. Mangrove deforestation caused by establishment of an oil pipeline network cannot be detected on any of the optical images. On average, the oil pipelines are around 15 m wide, and they are surrounded by water and swampy vegetation. The spectral and spatial resolutions therefore prevent them from being imaged on optical images.

However, pipelines are visible on all the radar images because they behave as corner reflectors as a vertically standing object on the ground. Mangrove deforestation caused by establishment of shrimp ponds can be detected on all optical and radar images, although ponds under construction, in which only about half of Nypa palm have been cut, can be detected only on the Landsat TM, JERS-1, and Radarsat images. ERS image could detect ponds and pipelines because of its short wavelength, small incidence angle and it is VV polarization. Since JERS radar image collected with longer wavelength, HH polarization and medium incidence angle while Radarsat is image collected by the same short wavelength of ERS, although with HH polarization and a medium incidence angle, it is believed that incidence angle played the

important role to detect ponds and pipelines. The SPOT_XS 1987 image does not cover any areas with fish ponds.

The accuracy of each classification was assessed by comparison with data collected at sample points on the ground and compiling error matrices. To determine accuracy assessment for the deforested area (agriculture and/or orchards, ponds, and pipe line), all the corrected number of pixels in these classes were added, divided by the total number of pixels (correct + incorrect) in these classes, and the result multiplied by 100.

Based on data collected at sample sites in the field, the classification accuracy of each image to detect deforested mangrove area was as follows:

- 76% for Landsat MSS 1982, with 5 classes
- 89% for SPOT_XS 1987, with 7 classes
- 88% for Landsat TM 1994, with 9 classes
- 83% for ERS 1996, with 6 classes
- 85% for JERS 1996, with 7 classes
- 84% for Radarsat 1997, with 7 classes

CONCLUSIONS

Results of this research show that it is possible to differentiate between mangrove forest and non-mangrove cover types with all optical types of remotely sensed data. Specifically, it was found that:

- ◆ all optical data were able to differentiate fishponds,
- ◆ Landsat MSS and Spot XS data were able to differentiate only one agriculture class,
- ◆ Landsat TM data were able to differentiate two agriculture classes, and
- ◆ none of the optical data were able to differentiate oil pipeline establishment.

Using radar data to detect deforestation type, it was found that:

- ◆ all radar data were able to differentiate fishponds and clearcut areas,
- ◆ all radar data were able to identify the establishment of oil pipelines (using both spatial and backscatter information),
- ◆ none of the radar data were able to differentiate any agriculture classes, and
- ◆ JERS-1 and Radarsat images were able to differentiate partly cut Nypa palm (fish ponds under construction).

Given the accuracy percentage and the number of classes that resulted from these classifications, it seems that Landsat TM, Spot XS, and all radar images, especially JERS-1 and Radarsat, all give reasonable results in detecting deforested areas. There were no significant differences between the accuracy of these five data sets. However, Landsat MSS shows a significantly lower accuracy. It is possible that if optical data are fused with radar data, they may even give better results. Further research is therefore required to investigate whether optical and radar data can complement each other in detecting deforested mangrove areas.

