The Contribution of RADARSAT-1 SAR Imagery to Monitor Land Use in Coastal Areas of Costa Rica and Nicaragua

Nathalie Beaulieu, Grégoire Leclerc and **Alejandro Imbach**
Centro Internacional de Agricultura Tropical (CIAT),
AA. 6713, Cali, Colombia. Phone: 572-445-0000, fax 445-0073
E-mail: n.beaulieu@cgiar.org

Dirk Werle
AERDE Environmental Research, Halifax, NS, Canada

Christian Asch Quirós
Instituto Geográfico Nacional (IGN), Costa Rica

Arturo Sanchez
Department of Earth and Atmospheric Sciences, University of Alberta

Daniel Marmillod
Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica.

Abstract

We present results obtained in a coastal land use monitoring project that relies on the analysis of RADARSAT SAR and other remote sensing data sets acquired over two study areas along the Pacific Coast of Central America. One area is located along the Estero Real estuary of northern Nicaragua, the other area is located around the estuaries of the Terraba and Sierpe rivers in southern Costa Rica. During the initial project phase we compared different RADARSAT SAR imaging modes for identifying different land use features in our study sites. We now present results with regard to the analysis and mapping of land use changes and the updating of land use maps that have been elaborated with electro-optical imagery and aerial photographs. The images have proven useful for mapping the expansion of shrimp ponds and banana plantations; these two production activities, as well as related environmental management practices, greatly affect the ecology of the mangroves. The SAR data have also shown to be useful to map those portions of intertidal mudflats that are colonized by small and low shrub vegetation; this is a difficult task for optical sensors. The analysis of the 1996 and 1998 RADARSAT data set of the Nicaragua test site, with its rapidly expanding aquaculture activities, benefited from ERS-1 SAR images acquired in 1992, SPOT multi-spectral images acquired in 1996, and JERS-1 SAR images acquired in 1995 and 1996. For this site, we are presently updating a land-use map derived from the digital

classification of the SPOT imagery. The Costa Rican site is covered by airborne SAR images from the SAREX'92 mission, a Landsat TM image from 1994 and RADARSAT images of 1996 and 1997. For this site, we are updating a land use map derived from the visual interpretation of aerial photographs taken in 1987.

1 - Introduction

Commercial aquaculture for shrimp production and large agro-industrial operations for the cultivation of banana, rice and oil palm are an important factor in the Central American economy, and they have become part of the landscape in many coastal lowland areas. As many shrimp farms and banana plantations are either expanding or newly established, largely unforeseen environmental side-effects are mounting and are showing their effect on other coastal land use and marine habitat. Mapping and monitoring of shrimp ponds is of primary importance, as these are sometimes illegally established or enlarged before permits are solicited. Secondly, the monitoring of intensive agricultural activities could help estimate the risk of contamination of mangroves by agro-chemicals and excessive production of sediments. Integrated approaches to coastal zone management have stressed the need for resource evaluation and environmental monitoring (Clark 1997, Olsen et al. 1997). Remote sensing has been identified as a potential tool, because it can provide extensive as well as fairly detailed views of coastal regions at a scale and frequency that could not be achieved within reasonable means by conventional and exhaustive field surveys.

For most of these areas, it is possible to find relatively recent optical satellite imagery or aerial photographs, most of which were acquired during the dry period which lasts from December to March on the Pacific Coast of Central America. Detailed maps of forest resources and agricultural land use can be derived from these types of remote sensing data. A relatively new and complementary source of remote sensing data are synthetic aperture radar (SAR) images which, for reasons of operational utility and detection capability, could play a very important role in updating these maps and monitoring of dynamic land use processes during the rainy season. In their review of many routine, high-resolution remote sensing applications to tropical coastal resource management, Green *et al.* (1996) repeatedly mention that cloud cover is the most cited obstacle in numerous investigations which traditionally rely on optical remote sensing methods. In the last few years, the launch of several civilian satellites with SAR sensors has allowed users and researchers to avoid this obstacle and acquire repeated images of cloudy areas. Yet, the key question remains largely unexplored whether satellite SAR data contains the information required for successful coastal resource management.

Generally, a single frequency (band) single polarization radar image tends to provide comparatively inferior information on land use and forest types compared to multi-spectectral visible and infra-red imagery. If available, aerial photography or Landsat TM or SPOT HRV satellite imagery remain the preferred sources of remotely sensed data for land use and vegetation mapping. A review of the literature suggests that there are several airborne radar investigations that have consistently reported distinct radar backscatter characteristics for certain tropical land use features, particularly banana plantations (Delwig *et al*., 1978, Beaulieu *et al.* 1993), as well as for coastal landforms (Lewis 1977). Some of these encouraging results have been known within the radar remote sensing community for more than 20 years, and coastal areas of Central America were the setting for much of this pioneering work (MacDonald *et al*. 1971).

For our investigation, we have chosen imagery acquired primarily by the Canadian RADARSAT-1 satellite in order to evaluate its potential for pressing coastal land use monitoring needs in Central America. RADARSAT has an advantage over the other satellite SAR systems, because it operates at various spatial resolutions, acquires images at moderate as well as high incidence angles, and can potentially provide data on a weekly basis in tropical latitudes for monitoring tasks. Previous studies conducted elsewhere have shown that satellite SAR images are suited for the monitoring aquaculture ponds and certain agricultural activities; Pigeonnat *et al* (1993) and Beaulieu *et al*. 1993 concluded that one of the most promising applications include mapping and assessment of banana plantations. For further readings, we refer the reader to reviews by Werle (1985, 1994) and to studies reported by Bjerkelund *et al.* (1993) Pons & LeToan (1994).

More specifically, the objective of our investigation is to use RADARSAT images for monitoring changes in the expansion of shrimp ponds and banana plantations in two coastal sites in Costa Rica and Nicaragua where vegetation and land use maps already exist and are available for cross-reference. Secondly, we want to examine the usefulness of different RADARSAT imaging modes to discriminate infrastructure, land use and vegetation features associated with the areas of interest and briefly compare the results with those obtained from the analysis of SAR images from the ERS-1 and JERS-1 satellites as well as optical SPOT and Landsat satellite data.

2 - Study Areas

The Nicaraguan study area covers the Estero Real estuary, an affluent to the Gulf of Fonseca which is shared between three countries, Nicaragua, Honduras and El Salvador, and is the focal point of various sustainable development projects. In this area a Regional Sustainable Development Strategy is being implemented by a consortium of local and national institutions and organizations. The process has already resulted in a regional use plan that is focused on the sustainability of the main productive activities, annual crops, agro-forestry, mangrove forest management, and the conservation of natural areas. In this area, aquaculture operators have recognized the ecological value of mangroves and have constructed their operations onto the associated coastal salt flats, which are quite extensive. But other environmental and socio-economic conflicts arise when the catch of wild shrimp larvae in nearby coastal waters impact local fisheries, as shrimping nets also collect fish larvae as by-catch, thus potentially causing a high attrition rate of fish before they reach adulthood.

The Costa-Rican study area is located to the North of the Osa Peninsula in the South-western part of the country. It includes the lowlands of the Térraba and Sierpe rivers and their estuaries. The mangroves of the Térraba-Sierpe area are much more continuous than in the Estero Real area; aquaculture activities are less prominent but they are on the rise. The local economy is mostly based on tourism, agriculture and marine resource extraction. A description of the mangroves of Térraba-Sierpe can be found in Mainardi (1996). The rapid expansion of banana plantations and the proposed Térraba dam are the main environmental concerns in this area.

The areas have been under study by the DANIDA mangrove project and by the Proyecto para el Desarrollo Sostenible en América Central (OLAFO) at the Centro Agronómico Tropical de Investigación y Enseñanza(CATIE). Remote sensing images and other geo-spatial data has been used in support of land use planning activities and for finding sustainable development strategies with the local population and their institutions.

3 - Imagery and Ancillary Data

The first of a series of eight RADARSAT SAR images were acquired in ascending mode in May, 1996; subsequent acquisitions were made in 1997 for the Terraba-Sierpe area, and in 1998 for the Estero Real area. They were all acquired during ascending orbits to maintain consistent radar look direction, *i.e.* from West toward the East. The image data was delivered in 16-bit unsigned format as “Path Image Plus” (SGX) products. Table 1 shows a summary of the characteristics of these images, as well as other remote sensing images used for comparison purposes.

In the case of the Estero Real study area, ground reference data was collected one month before the images were acquired as part of the ongoing CATIE’s DANIDA Manglares project. A multi-spectral SPOT image mosaic of the area was acquired during the dry season in February, 1996, less than three months before the RADARSAT images. The SPOT imagery was classified in order to produce a land use map (Sanchez, 1997, unpublished).

In the case of Térraba-Sierpe in Costa Rica, we are also using a set of reference imagery, *i.e.* a multi-spectral Landsat TM image, acquired in September, 1994 and an airborne C-band SAR image, acquired in 1992 as part of the SAREX'92 mission (Wooding and Zmuda, 1994) and Proyecto Radar Costa Rica/Canada (Elizondo *et al*., 1993). The SAREX and RADARSAT images are used to update a digital geographic database elaborated assembled from 1987 panchromatic 1:20 000 scale aerial photographs and ground surveys (Asch Quiros, 1993).

Unfortunately, five of the first six RADARSAT images revealed technical problems related to a known analog-to-digital converter (ADC) problem which, given certain amount of land-water distribution in the near-range portion of the image swath, manifested itself through radiometric irregularities in the image data. This problem seriously affected and precluded quantitative image analysis of the areas affected; however, it did not affect the visual interpretation of the images in our particular areas of interest, although it has prevented our attempts to calibrate these images. Once made aware of the ADC condition, we specified a fixed gain for the acquisition of the last two images, and the problem did not re-occur.

Table 1: **Summary of characteristics of RADARSAT and other images used in this study**

Sensor	Mode	Resolution (m)		pixel spacing (m)		incident angle (°)		band, polariz.	nominal n. looks	date	site	Project
		range	azim.	range	azim.	nr	fr					
CCRS C-X SAR	wide swath	20	10	15	6.9	45	85	C-HH, C-VV	7	27/04/92	Térraba Sierpe	SAREX 92-Proy.Radar Costa Rica/ Canada
RADARSAT	Fine 5	10	9	3.125	3.125	45	48	C-HH	1	09/05/96		ADRO
RADARSAT	Standard 1	26	27	8	8	20	27	C-HH	4	13/05/96		ADRO
RADARSAT	Standard 7	20.09	27	8	8	45	49	C-HH	4	12/11/97		ADRO
JERS-1		23	20	12.5	12.5	34	42	L-HH	3	16/04/96		GRFM
Landsat TM	Multispectral			28.5	28.5	-	-	7-V,IR	-	3/09/94		REFORMA
RADARSAT	Extended H 5	18.2	27	8	8	56	58	C-HH	4	23/05/96	Estero Real	ADRO
RADARSAT	Standard 7	20.09	27	8	8	45	49	C-HH	4	13/05/96		ADRO
RADARSAT	Standard 1	26	27	8	8	20	27	C-HH	4	15/05/96		ADRO
RADARSAT	Fine 4	8.1	8.4	3.125	3.125	43	46	C-HH	1	20/05/96		ADRO
RADARSAT	Standard 6	22.1	27	8	8	41	46	C-HH	4	21/0798		ADRO
JERS-1		23	20	12.5	12.5	34	42	L-HH	3	8/05/95		GRFM
JERS-1		23	20	12.5	12.5	34	42	L-HH	3	21/07/96		GRFM
SPOT XS	Multispectral			20	20	-	-	3-V,IR	-	25/02/96		DANIDA/ Manglares
ERS-1		26	28	12.5	12.5	20	26	C-VV	4	18/11/92		

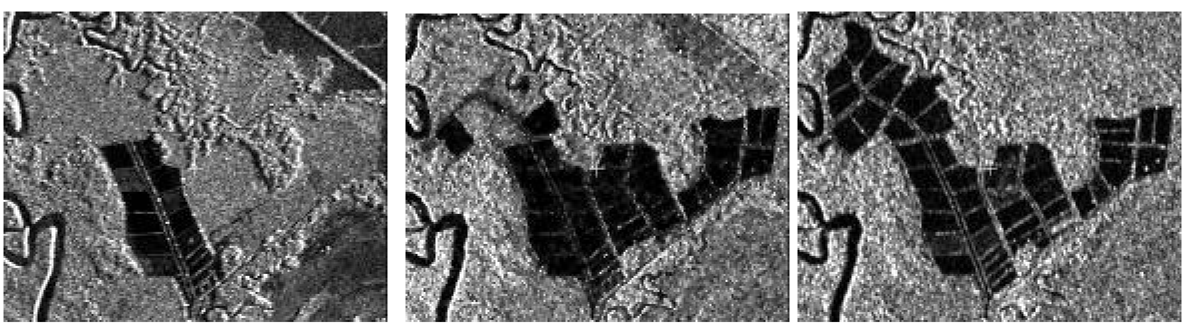
4 - Image Processing

For both sites, we created a geocoded database from the images from the different data sources, using a common pixel spacing. Because of the size of the sites and the availability of complementary images of different resolutions, we used a different pixel spacing for both sites. In Estero Real, we are updating a land-use classification that was based on the SPOT image with a pixel spacing of 20 m. Consequently, we used the same spacing for the geocoded database. The fine mode image was not integrated into this database because it was acquired in a portion of the site that did not contain aquaculture ponds or banana plantations. The Térraba-Sierpe site, where we are updating a land use map made from 1:20 000 scale aerial photographs, is much smaller, and a pixel spacing of 10 m was considered appropriate. The various image data sets were first geocoded to an output image of the same pixel spacing as the original data, using a cubic convolution resampling. This intermediate geocoded image was then re-sampled to be integrated into the geocoded database, using averaging when the output pixel spacing was larger than that of the original image. Ground control points for geocoding were identified from digitized streams on 1:50 000 scale maps, in the case of Estero Real, and from the digital land use map, in the case of Térraba-Sierpe. For both areas, a suitable ‘master’ image was first geocoded and used as reference during the collection of additional ground control points for the other remaining images of the entire data set.

Our preliminary RADARSAT image analysis provided ample evidence that the delineation of shrimp ponds; estuaries and natural lagoons is obvious for all imaging modes collected (Beaulieu *et al*, 1997). Using additional images of different sources and dates, our approach was to map new and expanding shrimp ponds in both sites, through the visual interpretation of the digital images and digitization of the analysis results on the computer screen. Further work will concentrate on mapping the changes in the aerial extent of the banana plantations.

5-Visual Interpretation of the Images

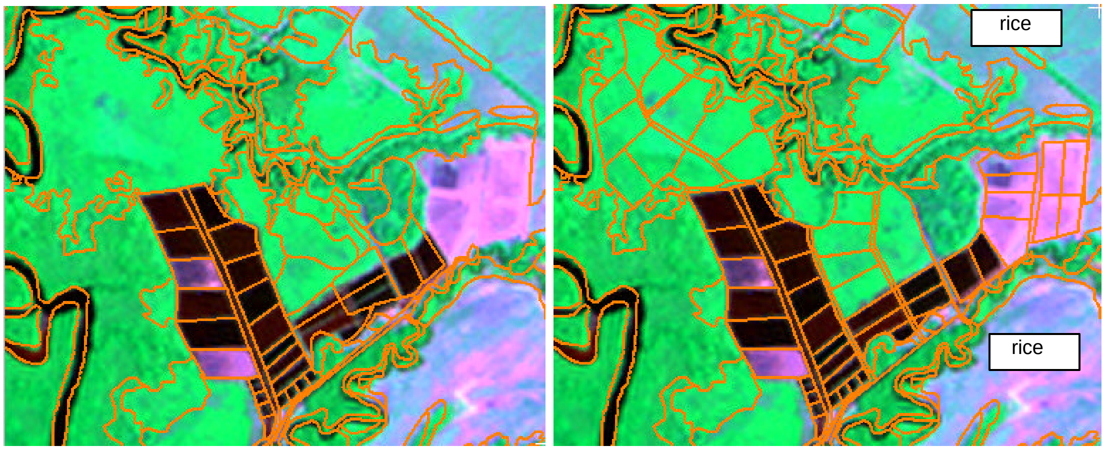
We used visual interpretation of computer-enhanced digital imagery rather than automatic feature extraction routines. In the case of Térraba-Sierpre, the on-screen digitizing allowed us to directly update the land use map by simply adding new features to the existing vectorial coverage. **Figure 1** presents a 3.85 km wide portion of the Térraba-Sierpe test site illustrating the expansion of shrimp ponds. Figure 1(a) shows 1992 SAREX data, figure 1(b) shows 1996 RADARSAT F5 and figure 1(c) shows 1997 RADARSAT S7 data. On the radar images, shrimp ponds are easily separated from surrounding forests on the basis of tone, although drained ponds, or those under construction, tend to provide more backscatter.



a) SAREX-92, HH polariz. b)Radarsat F5, May 1996 c) Radarsat S7, November 1997

Figure 1: 3.85 km wide portion of the Térraba-Sierpe test site illustrating the expansion of shrimp ponds

Figure 2 shows a color composite of the 1994 Landsat TM image, displaying Bands 3 (in red), 4 (green) and 5 (blue). The orange vectors correspond to the polygons of the 1987 land-use map (Figure 2a) and the map that was updated using the 1997 RADARSAT image (Figure 2b).

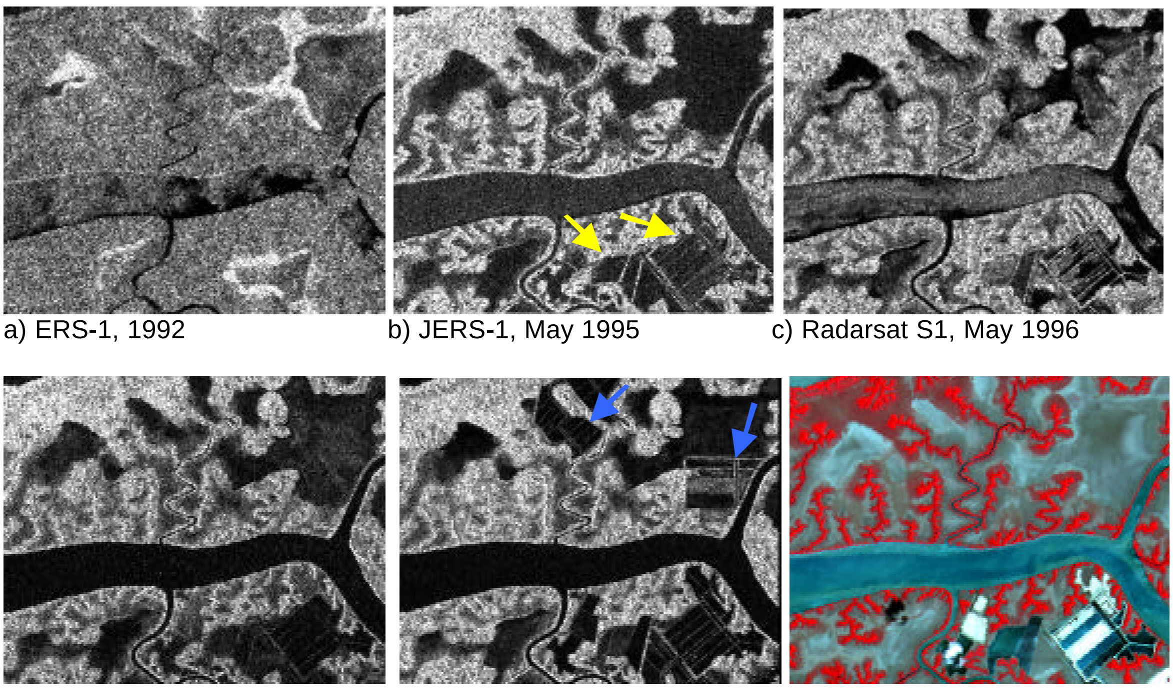


a) b)

Figure 2: Color composite of bands 3, 4, and 5 of the 1994 Landsat TM image, respectively displayed in Red, Green and Blue, for the same area as shown in figure 1. Orange vectors in a) correspond to the 1987 land use map whereas vectors in b) to the map updated with the 1997 RADARSAT image showed in figure 1 c).

Figure 3 contains an even larger set of radar images for a portion of the Estero Real area. In 1992, no shrimp ponds were operating in this particular area, as can be seen on the ERS-1 image. New ponds constructed between 1992 and 1995 are indicated by a yellow arrow in the JERS-1 image. New ponds constructed between 1996 and 1998 are indicated by blue arrows in the RADARSAT S6 image. In the case of Estero Real, the radar backscatter of the ponded water surface does not provide a strong contrast against the surrounding tidal flats, which also appear in radar-dark tone. However, the most important recognition elements of the aquaculture ponds are the artificial drainage channels and raised embankments which provide strong radar return and appear as bright linear features. **Figure 3 f)** shows a SPOT color composite of the same area for reference purposes, with bands 3, 2 and 1 respectively displayed in red, green and blue.

The comparison of the RADARSAT data set with ERS-1, and to some degree with JERS-1, showed significant differences in information content; we attribute this mainly to incidence angle and polarization differences. Small incidence angle imagery, for example RADARSAT Standard 1 or ERS-1 SAR data, would be less suitable for automatically distinguishing land from water, because the radar return of wind-roughened water reduce contrast between the two types of surfaces. The very bright areas on the ERS-1 image correspond to depressions; they could be caused by significantly higher moisture after the tide has moved out. The strips of tree vegetation along the streams are not noticeably bright on the ERS-1 image, whereas they do appear quite clearly on the other SAR images. These tree strips appear in bright red (stands dominated by the Rhizophora gender) and in dark brown (stands dominated by the Avicennia gender) on the SPOT composite shown in figure 3 f). The intertidal mudflats between these streams are partially colonized by short shrubs, which cause intermediate to bright tones on all RADARSAT images. The short vegetation is more clearly distinguishable from the tree vegetation on the JERS-1 image, because it produces a darker tone. The identification of short shrubby vegetation on the intertidal flats remains a difficult task for optical sensors because this vegetation often offers very incomplete ground cover. Nonetheless, they are important to detect because in certain cases they correspond to mangrove regeneration, although in other cases the dwarf vegetation simply corresponds to unfavorable conditions for tree growth.

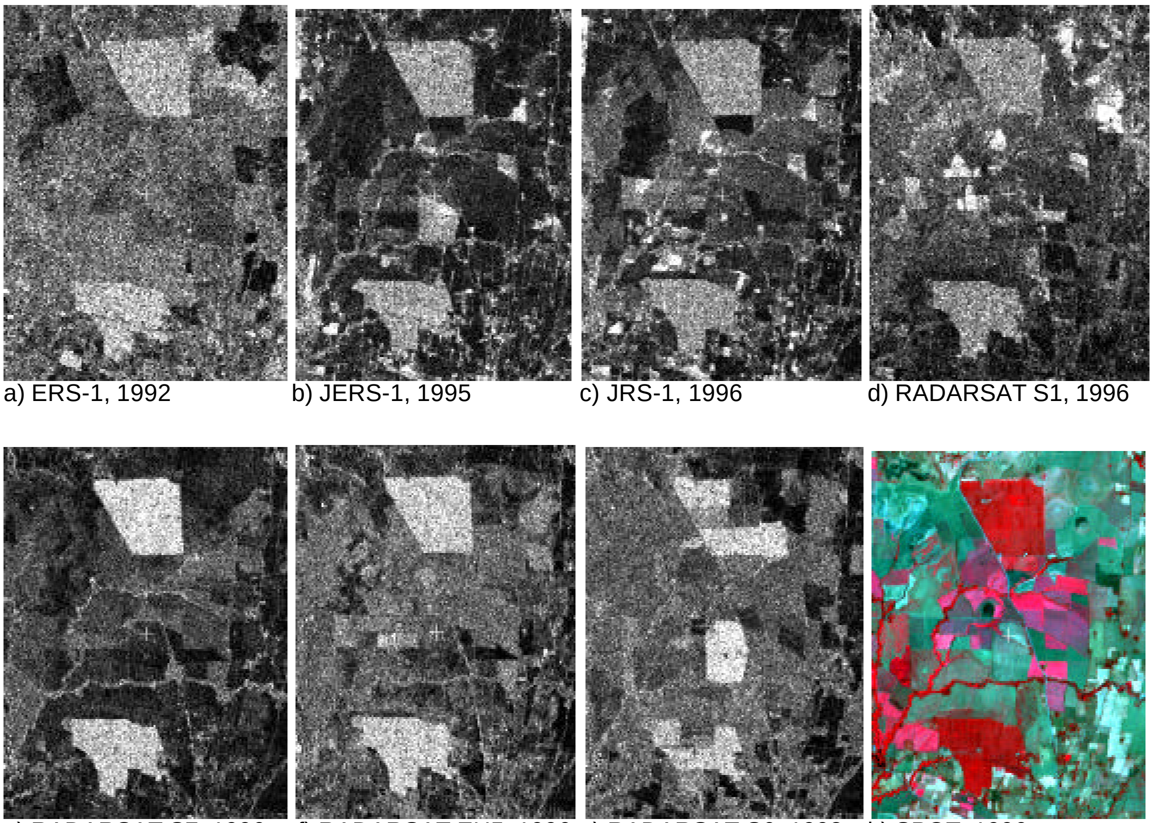


a) ERS-1, 1992 b) JERS-1, May 1995 c) Radarsat S1, May 1996

d) Radarsat S7, May 1996 e) Radarsat F6, July 1998 f) SPOT, february 1996

figure 3: Series of image subsets of a 7.7 km wide portion of the mangroves of the Estero Real site, showing new shrimp ponds in the 1995 image and then in the 1998 image. The SPOT composition shown in h) has bands 3, 2 and 1 displayed in red, green and blue.

In **figure 4**, we present examples of image subsets showing banana plantations near Estero Real at different dates and as seen by different sensors. These examples illustrate the operational usefulness of RADARSAT as well as the SARs on the ERS and JERS-1 satellites for monitoring banana plantations. Unfortunately, the fact that we do not know the moisture and crop conditions for all image acquisitions prevents us from drawing conclusions from the comparison of the images' capacity to distinguish the banana plantations from surrounding crops. But the analysis of the individual RADARSAT scenes and other SAR data reveals that banana plantations can be detected and identified without difficulty as a result of a very strong radar return. Compared to the surrounding land use in the flat coastal plains, the plantations tend to be larger in size and fairly homogeneous in terms of their image tone and even texture. In optical imagery such as SPOT, banana plantations often show similar spectral signatures to those of forests, whereas on all our SAR images, they have shown to be brighter than inland forests.



a) ERS-1, 1992 b) JERS-1, 1995 c) JRS-1, 1996 d) RADARSAT S1, 1996

e) RADARSAT S7, 1996 f) RADARSAT EH5, 1996 g) RADARSAT S6, 1998 h) SPOT, 1996

Figure 4: Series of images of banana plantations near Estero Real, Nicaragua, acquired by different sensors, as indicated. The SPOT composition shown in h) has bands 3, 2 and 1 displayed in red, green and blue.

6 - Conclusions and Plans for Future Work

Through our application, we have demonstrated the usefulness of RADARSAT images for operational monitoring of rapidly evolving shrimp ponds and banana plantations along the Pacific coast of Central America. We are using visual interpretation of computer-enhanced digital imagery rather than automatic feature extraction routines, directly adding the features on the screen to our digital land use maps. However, backscattering differences between the agricultural areas used for banana plantations and their surroundings are usually sufficient to allow effective automatic extraction. Automatic extraction of aquaculture ponds surrounded by mangrove forests should also be feasible, although drained ponds or ponds under construction show higher backscatter. When the ponds are built on intertidal mudflats which also have a low backscatter, visual interpretation or automatic extraction of linear features are necessary. Low incidence angles such as the ones used by the ERS-1 SAR and the low-angle RADARSAT modes are more sensitive to wind-roughened water and may thus reduce the chance of successful automatic extraction of shrimp ponds. RADARSAT images have proven useful to detect the presence of short shrubby vegetation on the mudflats, and the addition of JERS-1 images helps distinguish short vegetation from tree vegetation.

IGN in Costa Rica will continue to exploit this data in the scope of the GLOBESAR-2 program. We hope to shortly complete the process of updating the land-use maps for both sites.

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