Pole 6 del mer ?

Hydrobiologia **413**: 127–133, 1999.
R.S. Dodd (ed.), Diversity and Function in Mangrove Ecosystems.

Mangrove mapping in North-Western Madagascar using SPOT-XS and SIR-C radar data

Vanina Pasqualini[1,2], Jacques Iltis[3], Nadine Dessay[1], Marc Lointier[1], Olivier Guelorget[4] & Laurent Polidori[1]

[1]*IRD, Maison de la Télédétection, rue J.F. Breton, 34093 Montpellier, France*
[2]*Université de Corse, Equipe ≪Ecosystèmes Littoraux≫, B.P. 52, 20250 Corse, France*
Tel: [+33] 4 95 45 00 55; Fax: [+33] 4 95 46 24 41; E-Mail: pasquali@univ-corse.fr
[3]*IRD, Laboratoire d'Etudes Rurales, B.P. 5045, 34032 Montpellier Cedex, France*
[4]*Laboratoire d'Hydrobiologie Marine, UMR 5556 CNRS, Université Montpellier II, CC 093, Pl. E. Bataillon, 34095 Montpellier Cedex, France*

Key words: mangrove, Madagascar, mapping, remote sensing, SPOT-XS, SIR-C radar

Abstract

Within the framework of an environmental impact study of aquaculture activities in the coastal marsh of Mahajamba (North-Western Madagascar), an assessment of the environmental conditions existing prior to the onset of aquaculture activities (production began in October, 1993) is essential. To this end, the area was mapped using SPOT-XS data, which made it possible to define the main ecodynamic tendencies of the mangroves before the development of the rearing ponds. The aim was then to implement fast, precise and reliable mapping methods, making it possible to follow mangrove alterations resulting from these aquaculture activities. Analysis of the radiometric behaviour of the various plant formations of the marsh, based on SIR-C radar data, revealed that the discrimination between these formations is easier when the frequency used is low and the polarization is crossed. Thematic analysis using textural classification was carried out with the L-band and polarization VH. The results generated are promising insofar as the mapping of mangroves is concerned with a fast treatment time and acceptable precision of the results.

Introduction

Mangroves are regarded as major ecosystems due to their intermediate position between the marine and terrestrial environments, their high level of primary productivity (Amarasinghe & Balasubramaniam, 1992) and their nutritional role for coastal shellfish and fish populations (Laegdsgaard & Johnson, 1995; Kimani et al., 1996; Primavera, 1997). Worldwide, they cover an area of nearly 10 million hectares, thus accounting for approximately 1% of the surface covered by tropical forests. The mangroves have relatively strict ecological requirements (e.g. high air temperature, presence of sheltered and relatively shallow areas, wide tidal range, short periods of immersion and preferential presence of muddy substrates; Chapman, 1974). Also, they are commonly unstable and often in regression as a direct result of anthropogenic disturbances, such as those generated by aquaculture activities, which directly or indirectly destroy the canopy (Dierberg & Kiattisimkul, 1996; Binh et al., 1997).

In Madagascar, aquaculture in mangrove areas started rather tardily, with the setting up of a medium-scale shrimp farm along the north-western coast in the beginning of the 1990s (Mahajamba bay). In order to measure the environmental impact of this farm, an assessment of the environmental conditions before the onset of this auqaculture activity (production beginning in October 1993) was considered essential, as was the periodic monitoring of the environment during the duration of this activity. For this type of environmental assessment, the use of remote sensing produces fast, reliable and precise results. The first objective of the present study was, therefore, to determine the environmental conditions of the period preceding the setting up of the aquaculture activity using SPOT-XS data.

Although the data acquisition systems of multispectral data, such as SPOT or LANDSAT, represent suitable tools for mapping mangroves and assessing their overall condition (Dutrieux et al., 1990; Green et al., 1996, 1998; Long & Skewes, 1996; Ramsey & Jensen, 1996), their use in tropical coastal areas is often limited due to an almost permanent cloud cover. Thus, recent research efforts have turned to the use of remote sensing radar (Hery et al., 1993; Mougin et al., in press; Proisy et al., in press), as this image acquisition system is not hindered by cloud cover. Based on SIR-C radar data of the marsh of Mahajamba, the radiometric behaviour of the mangroves, as evaluated from their densities, was examined and compared to other tropical plant formations. Remote sensing of the mangroves, using radar data, is generally carried out using a purely radiometric approach. Thematic analysis using radiometric and textural classifications was also considered here in order to define mangrove mapping methods. The long term goal of this study is to generate a fast and reliable tool to be used in the monitoring of mangrove habitats subjected to anthropogenic activities.

Materials and methods

The study site is located in North-Western Madagascar, between latitudes 15° 10′ S and 15° 45′ S, and longitudes 46° 45′ E and 47° 20′ E (see Figure 1). Mahajamba bay is the point of convergence of two large coastal rivers: the Sofia (in the east) and the Mahajamba (in the south; see Figure 2). Mean annual precipitation is in the order of 1500 mm, occurring for the most part between November and April (Chaperon et al., 1993). Local tidal amplitude is 4–4.50 m during the spring tides.

SPOT-XS imagery (20 m pixel), taken on 21 April 1993 (10 h15 standard time, tide of +2.02 m), and composed of 3 rough channels (XS3, XS2, XS1), was analyzed using GEOimage® software. A low level of cloud cover was present on this date, although some clouds can be observed to the south-east and smoke is perceptible in the centre of the image. A pretreatment was first performed, the purpose of which was to carry out radiometric and geometrical corrections to the rough image. The geometrical correction consists of transferring onto the image, and subsequently onto the reference document (topographical maps to the 1/100 000: N-39, 1953; O-39, 1956; N-38, 1953; O-38, 1953), several reference points; the relative coordinates of which are recorded in each reference mark. These coordinate lists generate a polynomial model, making it possible to pass from the reference mark on the image to that of the map. The projection system used is of the Madagascar Laborde type with international 1967 ellipsoïde. Distinguishing between the immersed and terrestrial areas was made possible using a plant index so as to avoid mistaking slightly immersed areas and mangroves. The terrestrial zones were mapped using supervised classification (maximum probability) with XS3/XS2/Plant Index channels, by successive masks on the mangroves, swamps and terrestrial ecosystems. Manual corrections were carried out based on field data obtained between 1993 and 1995.

SAR radar imagery (Synthetic Aperture Radar) from the satellite ERS-1, type SIR-C (Spaceborne Imaging Radar-C), taken on 7 October 1994 (11 h15 standard time, tide of +0.34 m), presents a portion of the study site, and in particular the mouth of the Sofia and Mahajamba rivers. This multifrequency data was obtained as C-band (5.35 GHz or 6 cm) and L-band (1.25 GHz or 23 cm) with VV and VH polarization (Resolution: 15 m; Width of sweep: 35–100 km; View angle: 15–60°; Length of aerial: 12.1 m). Each image pixel represents the amplitude of the retrodiffused signal. This numerical data (DN) was transformed so as to obtain the retrodiffusion coefficients (dB) for each pixel (dB=−40.2+0.2DN; Pers. comm.: NASA). A filtering was then applied to the images in order to reduce the shimmer phenomenon (speckle). Thematic analysis using radiometric classification was carried out by directed classification (maximum probability), on the basis of both the L-band associated with two polarizations and the C-band associated with crossed polarization, namely L-VH, L-VV and C-VH. Thematic analysis using textural classification was carried out using the L-band associated with cross polarization and the PAPRI software (Borne, 1990; CPIS, 1996). The choice of the L-VH channel is explained by the fact that low frequencies cross natural mediums with more ease, and cross polarization accentuates discrimination between the plant formations. This method makes it possible to threshold the image in a supervised manner, based on the textural heterogeneity of the structures. Image analysis was carried out using a pixel window. For a given window, the closest landscape and the distance (distance between the theoretical composition of the landscape and the real composition of the window) were calculated. Image analysis was carried out on a set range of window

Figur
shrim

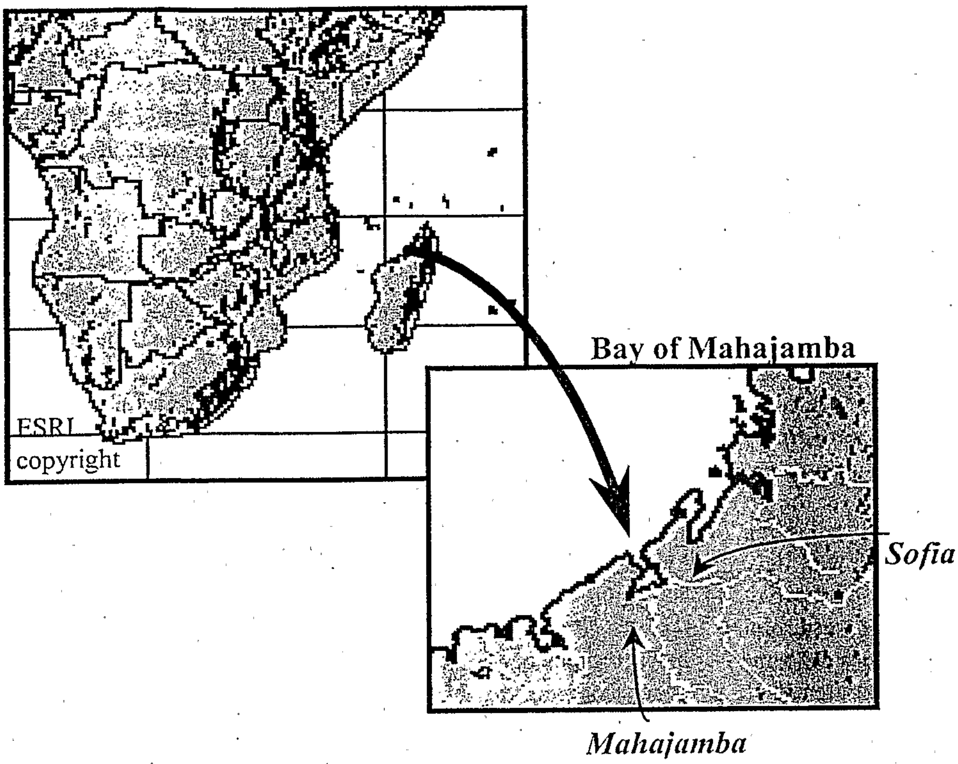

Figure 1. Geographical location of the study site.

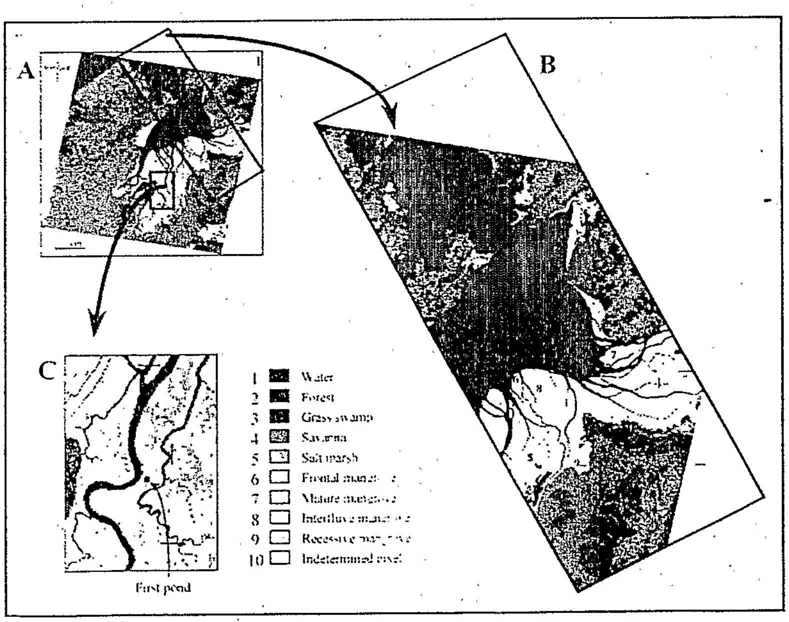

Figure 2. Mapping of the tropical plant formations by image processing of SPOT-XS: (A) of Mahajamba bay, (B) of the area surrounding the shrimp farm and (C) at the mouth of the Mahajamba and Sofia rivers.

sizes, in order to provide the best possible classification of each structure to be mapped. Three tests are realised with 3×3 and 5×5 windows, with 29×29 and 31×31 windows and from 3×3 to 31x31. A geometrical correction was then carried out based on image reference points using the SPOT data and this was done in order to render them strictly superposable.

Results and discussion

The analysis of SPOT-XS imagery made it possible to map Mahajamba bay in April 1993 and revealed the presence of several different environments: mangrove ecosystems, terrestrialecosystems (savannahs and forests) and swampy areas (see Figure 2A). The surface area covered by the coastal marsh is 56 400 ha, of which 43 700 ha is made up of mangroves. These mangroves are well developed in the southern and eastern regions of the bay, at the mouth of the Sofia river and in the western parts. Some small mangrove islands are present to the north. Four types of mangroves have been identified: two types from morphological parameters (frontal, interfluvial) and two other types from dynamic parameters (mature, recessive). This zonation is characteristic of the mangrove ecosystem's dynamics in Madagascar (Lebigre, 1990). The levels of fluvial and sedimentary input determines the spatial evolution of the mangroves. At the mouth of the Sofia river, in the eastern part of the bay, fluvial input is high and the mangrove map shows intensive hydrosedimentary dynamics in this region (see Figure 2B). Large quantities of laterite mud accumulate in the shallow waters and almonds of sediments are formed as one approaches the sea. Pioneer mangroves (e.g. *Sonneratia alba, Avicennia marina*) can then develop, allowing a fast propagation. In the mouth of the Sofia, the mature mangroves (*Rhizophora* spp.) are well developed (see Figure 2B), revealing the intensive dynamics present at this site. A previous study of the spatiotemporal evolution of mangroves in the mouth of the Sofia would tend to confirm this result (Lebigre. 1990). Conversely, in the central part of bay, at the mouth of the Mahajamba, mature mangroves are less developed (see Figure 2B), which would suggest more reduced dynamics. Most of the waters of the Mahajamba basin are artificially contained upstream of the coastal plain (Chaperon et al., 1993). Beyond the mature mangroves and in the region of the interfluvial mangroves, many salt marshes (brine ecosystems without vegetation) develop (see Figure 2C). In April 1993, the first of the shrimp farming ponds was set up in one of these marshes (see Figure 2C). This aquaculture activity currently occupies several hundred hectares, installed primarily on salt marshes and some mangrove areas.

The SPOT-XS data made it possible to characterize the Mahajamba bay environment prior to the development of the aquaculture ponds. These data will be used to monitor the evolution of this region over time. However, the use of SPOT data presents several disadvantages. Firstly, the use of this data is not always possible, due to an almost permanent cloud cover. The size of the pixel (20 m in multispectral mode) also represents a limiting factor in the precise monitoring of mangrove evolution. Lastly, the mapping of tropical areas using SPOT data can lead to a number of confusions and requires that a classification using masks be performed which tends to confer a large amount of subjectivity to the manipulator. The radiometric behaviour of the mangroves, as determined using SIR-C data, has, therefore, been determined based on the density of these ecosystems, which can be compared to the other plant formations present. The variation in mangrove density is easily detectable using SIR-C radar data (Proisy et al., in press). This analysis (see Figure 3), carried out on the four channels available, reveals a similar general tendency in the channel response for the four channels considered. The use of cross polarization, however, accentuates this discrimination between the plant formations at lower frequencies. For the L-band, the dense mangroves are easily identifiable. As for the diffuse and regressive mangroves, they can be distinguished only on the L-VH channel. The C-band would appear to be of interest in differentiating between forests and swampy meadows. It seems that these answers are influenced by the water or humidity present beneath the plant formations and will differ according to the wave length emitted. Savannahs are easily identifiable regardless of the frequency of the signal and even under HH polarization (Proisy et al., in press). Moreover. the value of the retrodiffusion coefficient increases as a function of the density of the plant formations (see Figure 3) and thus as a function of biomass (Proisy et al., in press).

On the basis of these observations. thematic analysis using radiometric classification was carried out using the L-VH, L-VV and C-VH channels (see Figure 4). These results reveal a certain amount of confusion in the interpretation. Indeed. recessive mangroves cannot be distinguished from the forests, nor the dif-

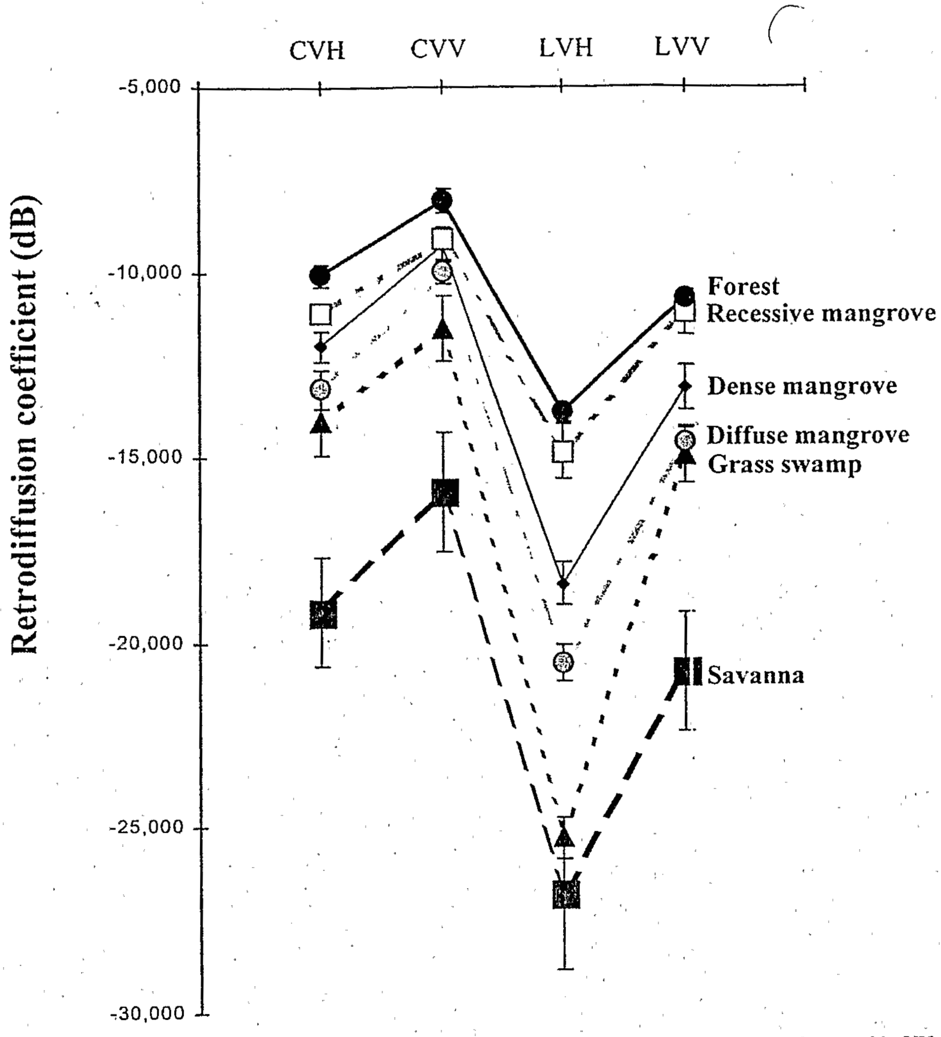

Figure 3. Radar responses concerning the tropical plant formations in the L-band and C-band associated with VH and VV polarizations (Retrodiffusion coefficient depends on the amplitude of retrodiffused signal and is expressed by the relation: retrodiffusion coefficient=(*K***R*4*Pr)/*Sr*; with *K*=wedging coefficient. *R*=cible distance. Pr=received power, *Sr*=area of observed surface).

fuse mangroves from savannahs, the salt marshes from swampy meadows and water from swampy meadows. Thematic analysis using radiometric classification of the SIR-C radar data, therefore, does not appear to be a reliable method for precisely mapping mangroves and other tropical plant formations. Thematic analysis using textural classification was thus carried out using only the L-VH channel (see Figure 5). The test carried out, with 3×3 and 5×5 windows (see Figure 5A). provides interesting results in terms of the identification of dense mangroves, water and swampy meadows, with values in the confusion matrix higher than 84%. Using 29×29 and 31×31 windows (see Figure 5B), most of the structures can be identified, with the exception of forests and salt marshes. As the salt marshes are totally confused with water, it is assumed they have the same texture. The forest is, in places, confused with the recessive mangroves; they thus have the same texture and, consequently, the same density. Moreover, the delimitations of the different plant formations are not very distinct (see Figure 5B). Consequently, a third test is considered using a larger window from 3×3 to 31×31 (see Figure 5C). This treatment allows us to more clearly distinguish the delimitations of the plant formations, but does not reduce the overlapping of salt marshes and forests. Thematic analysis using textural classification of SIR-C radar images, therefore, generates promising results in terms of the precise mapping of mangroves and other tropical plant formations, with the exception of forests and salt marshes.

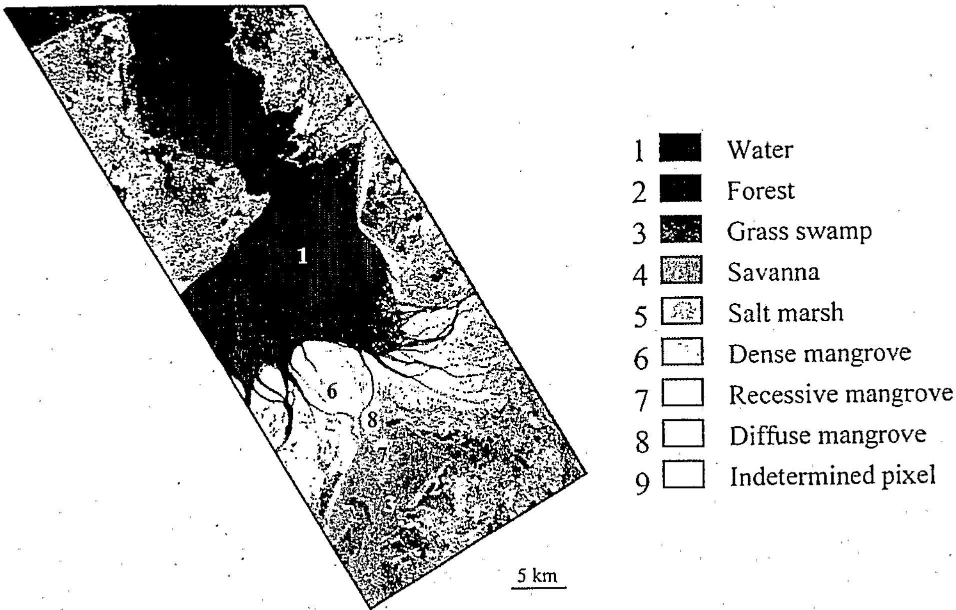

Figure 4. Mapping of the tropical plant formations in the mouth of the Mahajamba and Sofia rivers using radiometric classification of SIR-C radar images.

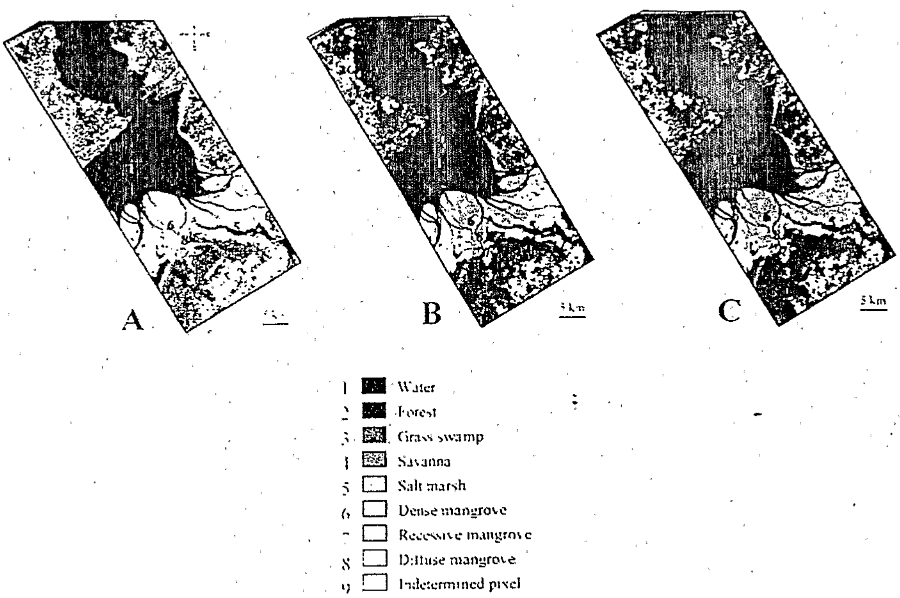

Figure 5. Mapping of the tropical plant formations in the mouth of the Mahajamba and Sofia rivers using textural classification of SIR-C radar images: (A) with 3×3 and 5×5 windows, (B) with 29×29 and 31×31 windows, (C) from 3×3 to 31×31.

Conclusions

The mapping of Mahajamba bay, using SPOT-XS data, made it possible to characterize the evolutionary dynamics of the mangroves present within the bay prior to the setting up of aquaculture rearing ponds. The mouth of the Sofia river is characterized by intensive dynamic conditions in its frontal area. Conversely, the central part of the bay exhibits a more reduced evolution. Analysis of the radiometric behaviour of the mangroves and other plant formations in Mahajamba bay, as determined from SIR-C radar data, reveals that these formations are more easily identified when the frequency used is low and when polarization is crossed. Thematic mapping using radiometric classification did not generate satisfactory results. Conversely, textural classification using the L-VH channel provided interesting results, insofar as the precise mapping of mangroves and other tropical plant formations is concerned. Results for forests and salt marshes using this technique, however, were not satisfactory. In order to monitor the environmental evolution of mangroves in relation to the development of aquaculture activities in Mahajamba bay, the textural analysis of SIR-C radar images appears to be the technique most adapted to our objectives, with the added advantage of possessing a short treatment time.

Acknowledgements

We make a point of thanking Christian Reynaud, researchers at the Laboratory of Marine and Continental Hydrobiology in Montpellier (France), for the interest they showed in this work. Our thanks also go to Frederic Borne, researcher at the CIRAD Laboratory, Centre for Remote Sensing (Montpellier) and André Beaudoin, researcher at the CEMAGREF Laboratory, Centre for Remote Sensing, for their valuable advice and help in the completion of this study.

References

Amarasinghe, M. D. & S. Balasubramaniam. 1992. Net primary productivity of two mangrove forest stands on the northwestern coast of Sri-Lanka. Hydrobiologia 247: 37–47.

Binh, C. T., M. J. Phillips & H. Demaine. 1997. Integrated shrimp-mangrove farming systems in the Mekong delta of Vietnam. Aquacult. Res. 28: 599–610.

Borne, F., 1990. Méthodes numériques de reconnaissance de paysages. Thèse de 3ème cycle. Université Paris VII: 213 pp.

Chaperon, P., J. Danloux & L. Ferry. 1993. Fleuves et rivières de Madagascar. ORSTOM Paris: 874pp.

Chapman, V. J., 1974. Mangrove biogeography. In Walsh G., S. Snedaker & H. Teas (eds), Proc. Inter. Symp. Biol. Management of Mangroves, Honolulu, Hawaï, U.S.A: 3–22.

CPIS, 1996. Classement Paysager d'Images Satellites; Guide de l'utilisateur. CIRAD-INRA (eds): 32pp.

Dierberg, F. E. & W. Kiattisimkul, 1996. Issues, impacts and implications of shrimp aquaculture in Thailand. Envir. Mgmt 20: 649–666.

Dutrieux, E., J. Denis & J. Populus, 1990. Application of SPOT data to a base line ecological study of the Mahakam delta mangroves (East Kalimantan, Indonesia). Oceanol. Acta 13: 317–326.

Green, E. P., C. D. Clark, P. J. Mumby & A. C Ellis, 1998. Remote sensing techniques for mangrove mapping. Int. J. Remote Sensing 19: 935–956.

Green, E. P., P. J. Mumby, A. J. Edwards & C. D. Clark, 1996. A review of remote sensing for the assessment and management of tropical coastal resources. Coast. Mgmt 24: 1–40.

Hery, P., D. Ducrot-Gambart, A. Lopes, E. Mougin, G. Marty, F. Fromard, F. Blasco, J. P. Rudant, M. Lointier & M. T. Prost, 1993. Cartographie de la végétation tropicale et suivi de la dynamique des mangroves de Guyane par SPOT et ERS-1. In Cépaduès eds, De l'optique au radar, les applications de SPOT et ERS, Mai 1993, Paris, France: 329–341.

Kimani, E. N., G. K. Mwatha, E. O. Wakwabi, J. M. Ntiba & B. K. Okoth, 1996. Fishes of a shallow tropical mangrove estuary, Gazi, Kenya. Mar. Freshwat. Res. 47: 857–868.

Laegdsgaard, P. & C. R. Johnson, 1995. Mangrove habitats as nurseries: Unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. Mar. Ecol. Progr. Ser. 126, 1–3: 67–81.

Lebigre, J. M., 1990. Les marais maritimes du Gabon et de Madagascar. Thèse doct. Géographie, Univ. Bordeaux III: 704pp.

Long, B. G. & T. D. Skewes, 1996. A technique for mapping mangroves with Landsat TM satellite data and Geographic Information System. Estuar. coast. shelf. Sci. 43: 373–381.

Mougin, E., C. Proisy, G. Marty, F. Fromard, H. Puig, J. L. Betoulle & J. P. Rudant, 1999. Multifrequency and multipolarization radar backscattering from mangrove forests. IEEE Transact. Geosci. Remote Sensing 37(1): 94–102.

Primavera, J. H., 1997. Fish predation on mangrove-associated penaeids – The role of structures and substrate. J. Exp. Mar. Biol. Ecol. 215: 205–216.

Proisy, C., E. Mougin, F. Fromard & J. P. Rudant, 1998. Télédétection radar des mangroves de Guyane Française. Photo-interprét., Images spatiales et aériennes, num. Spéc. in press.

Ramsey, E. W. & J. R. Jensen, 1996. Remote sensing of mangrove wetlands: relating canopy spectra to site-specific data. Photogramm. Engin. Remote Sensing 62: 939–948.