Land Cover Classification System for the Lower Delta of the Parana River (Argentina): Its Relationship with Landsat Thematic Mapper Spectral Classes

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ABSTRACT

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The Lower Delta of The Paraná River is a tidal freshwater wetland. The land cover characteristics of the Lower Delta of the Paraná River were determined by its hydrologic regime, the geomorphologycal patterns of the islands, and the human activity developed in the region. This paper addresses the development of a conceptual land cover classification scheme and its relationship with classes derived from Landsat/TM satellite imagery. First, a specific conceptual land cover classification scheme is presented based on the definition of delimitation and characterization variables. The regional conceptual classification scheme developed was intended to facilitate comparisons with other systems, and to simplify the use of satellite imagery for land cover map production. Next, the resulting "information classes" were associated to "spectral" classes using a layered classification approach based on the application of an unsupervised classification procedure to a set of multitemporal Landsat/TM imagery. In each step, the spectral classes were subject to careful labeling and recoding based on field work and aerial photography. The final land cover map obtained is the result of combining the different thematic layers obtained. The resulting overall classification accuracy was on the order of 83%. A thorough discussion of the results is presented, where some of the characteristics of this complex area are highlighted together with the advantages and disadvantages of using satellite imagery for this type of product.

ADDITIONAL INDEX WORDS: *Satellite remote sensing, vegetation mapping, coastal ecosystems.*

INTRODUCTION

The Delta of the Paraná River is one of the most important wetland systems in Argentina and South America. It extends along 300 km through the terminal portion of the De la Plata River basin and it covers 17,000 km². The Lower Delta which covers approximately 2,700 km² is characterized by newly formed islands directly connected to De la Plata River and subject to its lunar and wind tides.

From the point of view of biodiversity, the delta is characterized by the coexistence of species from both subtropical and temperate zones. In spite of these features and its closeness to highly populated cities (northern suburbs of Buenos Aires city on one of its sides), no regional land cover map of this region exists. Nevertheless, it is recognized worldwide that inventory and monitoring of wetlands are essential procedures for management and conservation goals. It is also known that a land cover classification scheme is a critical

step toward these goals. Therefore, many studies about wetlands address this need.

There are several important issues in defining a regional land cover classification scheme. First, the scale in which the classification scheme was applied should be defined. This subject has received close attention in recent years since ecosystems may be defined over a range of scales, from an individual leaf up to the whole biosphere (ALLEN and WILEYTO, 1983; O'NEILL, 1989; PICKET and WHITE, 1985). Second, the idea about the discreteness of ecosystems, in particular of plant communities, constitutes, even today, a controversial point among ecologists (KENT and COKER, 1992; COLINVAUX, 1993). Third, it is useful to recall that in 1979 COWARDIN *et al.* pointed out that it was not possible to set up a classification scheme for a given region without imposing boundaries to the ecosystem under study.

Different wetland classifications have been developed according to their vegetative life forms and species composition (MARTIN *et al.*, 1953; SHAW and FREDINE, 1956; ANDERSON *et al.*, 1976). Others based on environmental forcing functions, particularly the hydrologic flow (GOSSELINK and

TURNER, 1978; PRANCE, 1979). More recently, the hydrogeomorphic conditions (BRINSON, 1993) have been used to define a scheme.

During the last two and half decades, satellite imagery has proved successful in detecting a variety of types of wetlands (HARDISKY et al., 1986; RINGROSE et al., 1988; RUTCHEY et al., 1994). One of the common classification schemes used with remotely sensed data for wetlands is that of COWARDIN et al. (1979). KLEMAS et al. (1993), based on ANDERSON et al. (1976) and COWARDIN classification schemes proposed the one utilized by the NOAA Coastwatch Change Analysis Project.

Satellite remote sensing uses information extraction techniques, which rely on the analysis of multispectral reflectance values and on the association of the resultant "spectral classes" with "information classes" derived from conceptual classification schemes based on field data and models (JENSEN et al., 1983). Since digital remote sensing analysis uses spectral reflectance values, in general, as a unique discriminating parameter, classification schemes which employ information variables that are directly related to reflectance values, are more appropriate with remote sensing imagery. Spatial characteristics are also used as additional discriminating features.

Wetland classification schemes based on vegetative cover and/or soil features may have direct application on land-cover map production from remote sensing data. However, products derived from this kind of classification schemes are restricted to a particular ecosystem, and the comparison of data from different regions becomes difficult. Instead, classification schemes based on the functional properties of wetlands, that is, independent of the biogeographic distribution of species, are more suitable for region comparison and conceptual interpretation of the changes observed, but may not be spectrally separable (WEISSBLATT, 1977). Rather than dichotomic, these two possible schemes constitute extreme options. An intermediate approach may be desirable when satellite imagery is used. Even if the vegetation and/or soil types should be used for characterizing spectral classes, an explicit conceptual framework based on the structural and functional comprehension of the ecosystem is desirable, particularly within the field of landscape ecology.

The objective of this paper was to propose a land cover classification scheme of the frontal portion of the Buenos Aires Lower Delta of the Paraná River and to associate this scheme with spectral classes derived from satellite imagery. The classification scheme was based on the hydrologic regime and the degree of human intervention (historical and current) which were considered the main forces that determine the spatial heterogeneity of the area. Features related to spectral response of land cover classes were used as characterization variables in the scheme proposed. Based on the spectral separability of these features, this study used Landsat Thematic Mapper (TM) for discriminating the land cover classes defined in the conceptual classification scheme. The satellite imagery classification approach was based on the use of a multitemporal TM set where three key dates were selected taking into account the phenological differences among land-cover types. As a result, a land-cover map derived from satellite imagery was obtained and evaluated.

This paper addresses two related subjects, the first one deals with the development of a conceptual classification scheme, the second one describes the type of analysis applied to the satellite images utilized.

THE PARANA RIVER DELTA REGION

The Paraná River Delta Region was defined by MALVÁREZ (1993; 1997) as an heterogeneous mosaic of landscape patterns based largely on geomorphic conditions, and in the hydrologic regime. Land forms were derived from past and present processes of different origin such as fluvial ones and marine ingressions and regressions during the Holocene period (IRIONDO and SCOTTA, 1979). The actual hydrologic regime is determined mainly by the dynamics of the Paraná, Uruguay and De la Plata rivers (BONFILS, 1961; MINOTTI et al., 1988).

The high landscape heterogeneity, together with moderate climate conditions (mean annual temperature: 16.7°, annual rainfall: 1,073 mm) allow the coexistence of subtropical lineage and temperate latitude elements. This combination results in peculiar wildlife populations and vegetation community patterns as compared to other areas (RINGUELET, 1961; CABRERA, 1973).

Within this wetland system, only the terminal portion, which covers 2,700 km², is a delta in an aggradation phase (IRIONDO and SCOTTA, 1979). This Delta, called Lower Delta, does not end up in the sea, but in an estuary (De La Plata River estuary), and it differs from most sediment carrying rivers in that it fits to a complex estuary-delta model (PARKER and MARCOLINI, 1992).

Four landscape units were defined in the Lower Delta according to flooding patterns, landscape elements and lowland vegetation (Figure 1) (KANDUS and ADAMOLI, 1993; KANDUS, 1997). Units I and II have a complex landscape pattern, where delta elements coexist with some of the upstream floodplain and the hydrologic regime is determined by the seasonal Paraná River floods and by the De la Plata tides (KANDUS et al., 1997a; KANDUS, 1997). Units III and IV instead, are deltaic islands. Units III and IV have a common geomorphic pattern, a hydrologic regime dominated mainly by moon and wind tides of De La Plata River estuary and, in addition, natural communities correspond genetically to a primary succession scheme (BURKART, 1958; BONFILS, 1961; KANDUS, 1997). In particular, Unit III is formed by pan shaped islands with a perimetral levee and a central depression. The islands are surrounded by water courses that open out like a fan from the two main courses, the Paraná Guazú and Paraná de las Palmas rivers. Unit IV is the prograding portion of the subaerial delta into the De la Plata estuary. According to cartographic documents, the delta front has advanced at an average rate of 70 m/yr over the last 160 years (IRIONDO et al., 1979). Banks, bars and islands with primordial levees were found. Different environmental conditions and vegetation communities have developed through a primary succession process (BURKART, 1958; KANDUS et al.,
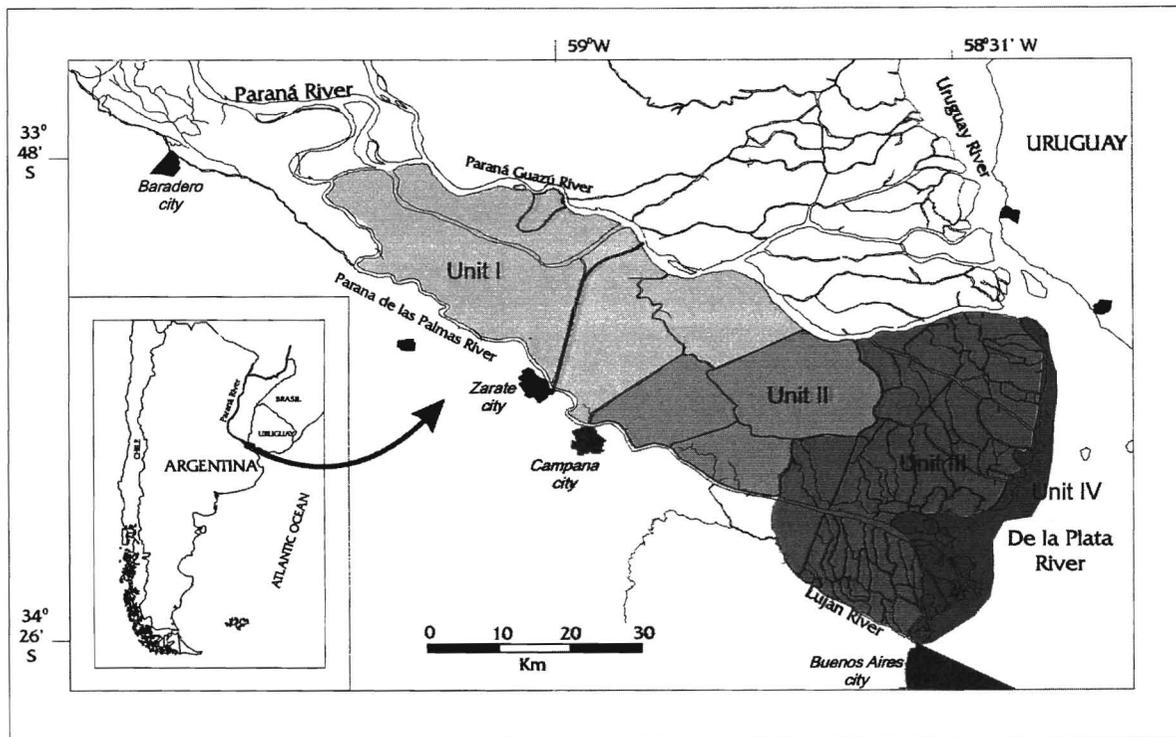
Figure 1. Buenos Aires section of the Lower Delta of Paraná River, Argentina. I to IV indicate landscape units.

1997b). Units III and IV constitute the study area called Frontal Delta.

The De La Plata River is primarily responsible for the regular flooding of the islands belonging to these two units. The Paraná and Uruguay rivers have less influence on flooding regime. De La Plata river has a moon and wind tide regime resulting in frequent but short floods (hours or days) (LATINOCONSULT, 1972). Moon tides have 1 m of normal amplitude (twice a day) but southeast winds can raise the water up to 2.5 m over the mean value. In spite of the tide regime the water is fresh. As a consequence, the study area might be considered a tidal freshwater wetland, as defined by MITCH and GOSSELINK (1993).

The dominant natural species of this area are all perennial, and cover large areas as marshes. The dominant trees of the secondary succession riparian forest are also perennial. A large portion of the natural vegetation was replaced by *Salix* spp. and *Populus* spp. afforestation. The first one begins greening up early in September and the second one in November. The only natural forest that remains in this region is dominated by seibo (*Erythrina crista-galli*) which is leafless until the beginning of the summer (December).

METHODOLOGY

Basis of the Conceptual Classification Scheme

The conceptual classification scheme was based in the use of variables of delimitation, these are, the degree of human intervention, and the flooding regime in natural areas. These variables were considered the main forcing functions which determine the landscape heterogeneity. On the other hand, variables such as floristic composition, vegetation structure and soil type were defined as characterization variables. The selection and use of delimitation and characterization variables was based on the experience derived from field work carried out by the Regional Ecology Laboratory of the Biology Department of the University of Buenos Aires, as well as from data obtained from bibliographic references (KANDUS *et al,* 1992; KALESNIK 1996; KANDUS *et al,* 1997b; KANDUS, 1997; VALLI *et al,* 1992; MINOTTI *et al.* 1988; BURKART, 1958; BONFILS, 1961).

Three levels of human intervention were considered: man made, abandoned land covers, and natural areas where no intervention took place. The main human activities are Salicaceae afforestation and tourist and recreational parks and gardens. These are the major activities not only from the economic point of view (mainly *Salix* spp. afforestation), but also because of the area involved. From the ecological point of view they may be identified as long-term disturbances affecting the natural environment since they completely replace the natural vegetation coverage (GRIME, 1979; AMOROS, 1996). Since a couple of decades ago, afforestation practices have been frequently abandoned mainly due to economic factors. This has led to a secondary succession process, which occurs when pre-existing vegetation is removed by a disturbance and replaced. A developed soil is present, and a biological legacy from the previous vegetation often exists as a seed or seeding banks (GLENN-LEWIN *et al.,* 1992).

Natural habitats were derived from primary succession processes which were defined as the development of vegetation on newly formed or exposed substrate, and proceeds on raw parent material rather than in a developed or modified soil (GLENN-LEWIN et al., 1992). In wetlands, the hydrologic regime is recognized as the major conditioning factor for the installation and persistence of wetland vegetation communities (GOSSELINK and TURNER, 1985; MITCH and GOSSELINK, 1992). In addition, elevation differences across a freshwater tidal mash correspond generally to different plant associations (ODUM et al., 1984; SIMPSON et al., 1983; MITCH and GOSSELINK, 1992). In this area, the local flooding regime was considered the result of the interaction between the regional hydrologic regime (e.g. flooding caused by tides) and the relative topographic position of the sites. In this delta, level of the terrain and flooding could only be established qualitatively since adequate topographic maps were lacking.

With the points indicated above in mind, in this study the following factors were considered for the conceptual classification of natural land cover types (KANDUS, 1997):

● Topographic position was ranked as *highlands* (levees), *relative highlands* (recent deposited bars), *mid slopes* (intermediate between highlands and lowlands) and *lowlands* (depressed areas in the inner portion of the islands, banks of sediments in the streams and estuary).

The flooding regime was described through variables such as: permanence and frequency of flooding, the hydrologic input and hydrodynamics.

● Water permanence and frequency were ranked following COWARDIN et al. (1979) as: *permanently flooded* (surface seldom exposed), *irregularly exposed* (soil permanently saturated, flooded during regular moon tides, high water permanency), *regularly flooded* (soil generally saturated, flooded during tides, moderate water permanency) and *regularly exposed* (flooded only during wind tides, low water permanency).
● The hydrologic input and the hydrodynamic terms are taken from BRINSON (1993) and adapted to this area. The hydrologic input was simplified to two water sources: *groundwater discharge* (inflow through wetland sediments) and *surface inflow* (flooding from tides).
● With respect to the hydrodynamic behavior, three categories were defined: *vertical fluctuation* (evaporation and subsequent replacement by groundwater discharge); *unidirectional flows and bi-directional flows* (surface flows resulting from tides).
● Connection is ranked as: *connected* (habitats in or adjacent to the main course of rivers and streams), *moderately connected* (adjacent to the water courses but with physical barrier that slows down the water flux as for example neighboring vegetation), and *disconnected* (not in contact with water courses, flooded only during tides).

Processing of the Satellite Imagery

Data Acquisition

The satellite imagery used was recorded by Landsat Thematic Mapper sensor on board Landsat 5. This system provided high quality data for vegetation identification and status assessment. It records radiation with a nominal spatial resolution of approximately 30 m for bandas 1–5 and 7, and 120 m for band 6 which correspond to brightness values of vegetation. Three images were utilized: from August 3, 1993 (Winter), October 6, 1993 (Spring), and January 10, 1994 (Summer). However, due to budgetary restrictions only bands 3, 4, and 5 were available for this work. The phenological cycles of the dominant tree species dictated the most appropriate times for remote sensing data acquisition. Even though, on wetland mapping, water level is a critical variable that determines land cover discrimination, in this case, the water level was close to the mean water level for two of the images and lower for the image of October 6, 1993 which was taken as the reference image (Figure 2).

Two other data sources were available: aerial photographs taken during 1989-90 in a 1:20,000 scale, and field work carried out during the same period.

In spite of the difference in time between satellite imagery and the rest of the data sources, they could be used in combination, because, in this area, short time changes in landscape elements were not relevant at the scales considered. The areas affected by occational disturbances, such as fires, were segmented from the images, and therefore, not included in the classification procedures.

Image Pre-Processing Procedures

The images were subject to several procedures to correct for geometric and radiometric distorsions. To remove the geometric distorsions in TM imagery, TM image of October 6, 1993 was geocoded to a UTM Gauss Kruger coordinate system with a pixel size of 28.5 meters using a first order transformation and nearest neighboard resampling. A root-mean-squared error of approximatelly 1.5 pixels was achieved for the fit between TM image of October 1993 and the 1:50,000 scale topographic maps using 40 ground control points gathered from the topographic maps. The other two TM images were then coregistered to the TM image of October 6 using 60 image to image control points. All RMS errors were less than 0.25 pixels for the fit between images. The environment of ERDAS 8.2 system was used for this task.

Images were provided by the ground station of the Instituo Nacional de Pesquisas Espaciais (INPE), Brazil. The conversion from raw counts to radiance was done following the procedures described by CARTAXO MODESTO DE SOUZA (1982). That is, $L = a_0 \, DN + a_1$, where DN is the digital number recorded, L[watt m^{-2} μm^{-1} sr^{-1}], is the radiance measured by the sensor, a_0[watt m^{-2} μm^{-1} sr^{-1} count^{-1}] and a_1[watt m^{-2} μm^{-1} sr^{-1}], are the calibration coefficients provided by the ground station and stored in the header of the tape.

Rather than using radiance L, the bidirectional reflectance was calculated. This is a dimensionless magnitude which is a function of the illumination and observation geometry (TANRÉ et al., 1986, 1990; MILOVICH et al., 1995), and it is given by: $\rho = L \, \pi / I_0^k \cos(\theta_0)$, where θ_0 is the solar zenith angle, I_0^k [watt m^{-2} μm^{-1}] is the irradiance at the top of the atmo-
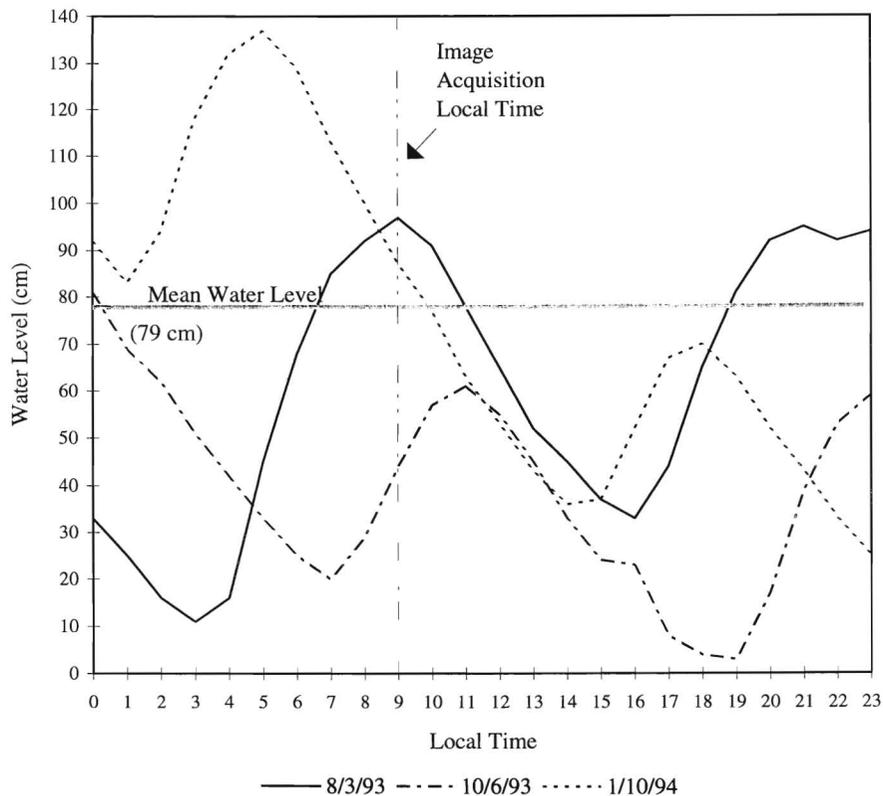
Figure 2. Buenos Aires Port water level as a function of time for the image dates.

sphere corrected for the distance between the Earth and the Sun.

Prior to classification, each image was segmented through a screen digitation procedure following the landscape units defined in KANDUS *et al.* (1994). Units III and IV of Figure 1, were separated from the others (STEWART, and LILLE-SAND, 1995). Also, burned areas were identified and segmented in the three images.

Classification Procedure and Accuracy Assessment

The classification strategy was based on the use of a multitemporal layer classification procedure (WOLTER *et al.*, 1995). One or several land cover classes were obtained from each image depending on the phenology cycle and the spectral response. Due to the complexity of the landscape, and the large number of classes showing patchy characteristics, an iterative clustering technique was used to further improve separation between classes (JENSEN *et al.* 1987, JENSEN, 1993). The final land cover map was the result of combining a set of intermediate layers which were generated after each individual image was classified, labeled and recoded.

For the classification procedure, the ISODATA algorithm available in the software package ERDAS 8.2 was used. Due to the heterogeneity of the region and the patchy characteristics of some of the land covers, a large number of classes was preferred, and unsupervised classifications of 100 classes

were performed. Since the classes were spectrally sorted, the labeling could be done quite rapidly at both ends (high and low spectral returns), but labeling of the central classes required a careful approach. Several tools available in the classification module of the ERDAS package such as alarms, histograms, class profiles, ellipses, contribute to simplify, and make more accurate the labeling process. Finally the identified classes were recode into the categories defined in the conceptual classification scheme.

Between 50 and 100 cluster samples representative of each land cover defined were taken for accuracy assessment. Each sample had 10 pixel or less (CONGALTON, 1988). Field work and aerial photography (scale 1:20,000 and 1:100,000) were used for natural and abandoned land cover sites selection and for the labelling process. The latest forest inventory was used for afforestation samples (Consejo Federal de Inversiones, 1991).

RESULTS AND DISCUSSION

Analysis of the Land cover Classification Scheme Proposed

Figure 3 illustrates a land cover distribution model of the islands. This figure shows a "young island" belonging to unit IV and a "mature island" of unit III. Tables 1 and 2 summarize the main land covers defined in the classification
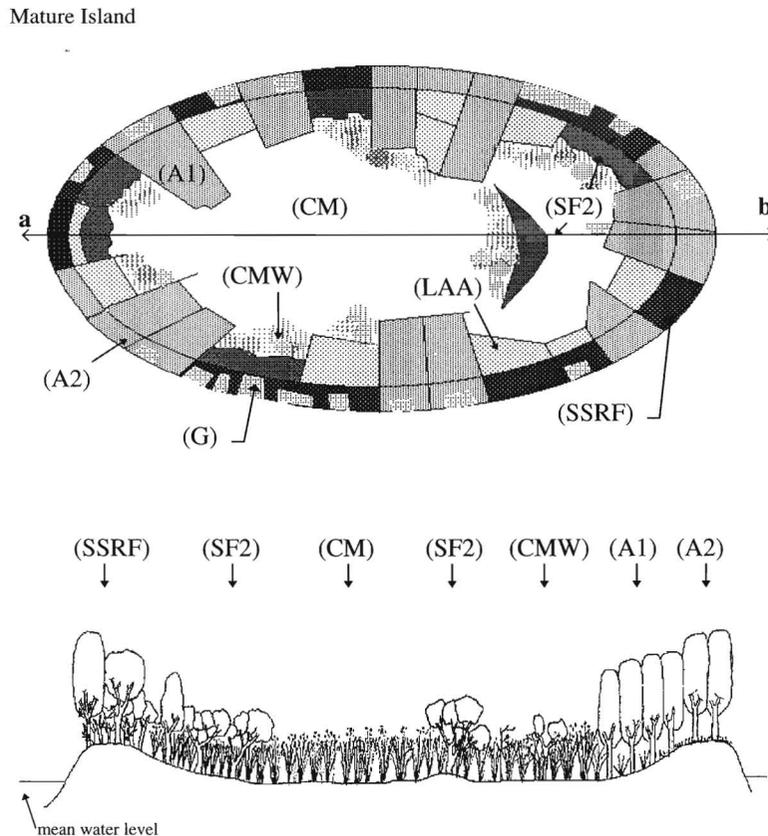
Mature Island

Figure 3. Illustration of typical islands in the frontal portion of the Buenos Aires section of the Lower Delta of Paraná River. Both aerial and cross-sectional views (transects a–b) are showing for a young island from Unit III and a mature island from Unit IV. (S): Sedges, (PS): Protected Sedges, (L): Lagoon, (MM): Mixed Marsh, (CM): Cortadera Marsh, (SF1): Seibo Forest, (SF2): Seibo Forest with *S. giganteus* understory, (FB): Frontal Bar, (A1): Lowland Afforestation, (A2): Levee Afforestation, (LAA): Lowland Abandoned Afforestation, (CMW): Cortadera Marsh with Woody Plants, (SSRF): Secondary Succession Riparian Forest, (G): Parks and Gardens.

scheme. As it is shown in Table 1 natural land cover types were discriminated by flooding regime and topographic position. Main classes are lowlands permanently flooded, lowlands irregularly exposed, relative highlands regularly flooded, mid slopes regularly flooded and highlands regularly exposed. Table 2 lists the land cover classes, their dominant life forms and species, and characteristics such as height, accompanying species, phenology, and soil properties such as texture and organic matter contents. Their main features were:

(1) Lowlands permanently flooded were broken down in different land cover types (subclasses) according to their connection with main streams. *Schaenoplectus californicus* is the dominant species which characterized them. It is the first emergent species that invades areas with high sedimentation rates such as channel mouth banks, and channel margins in the islands (Sedges, S). Sites covered by *S. californicus,* but protected from the direct effect of channel water circulation are richer in life forms and species composition (Protected sedges, PS). Both, S and PS are subject to surface bi-directional flows related to the tide regime. *S. californicus* is also present in lagoons (L) where low energy water fluxes (mostly vertical fluctua-

tion due to groundwater discharge and often surface bi-directional flows due to wind tides) allow a substrate with high organic matter contents which differs from the two previous land cover types. All the remaining land cover types were not directly in contact with the main channel flows except during wind tides because they are inland areas or levees.

(2) Lowlands irregularly exposed occupy the inner portion of the islands. Variation in the aboveground water was mainly related to vertical fluctuation due to groundwater discharge related to regular tides. But, often surface bi-directional flows due to wind tides affect these classes. Low energy water flows, and permanently saturated substrates involve high contents of organic matter. Two main marsh plants associations are found. Mixed marsh (MM) is found in the younger islands of the delta, where *Panicum grumosum, Ludwigia* spp., Typha latifolia., Zizaniopsis bonariensis, Senecio bonariensis and *S. californicus* codominate. Cortadera marsh (CM) instead, is found in mature islands, and *Scirpus giganteus* (cortadera) is the only dominant species. Cortadera marsh with spare woody plants (CMW), constitutes an interface land cover
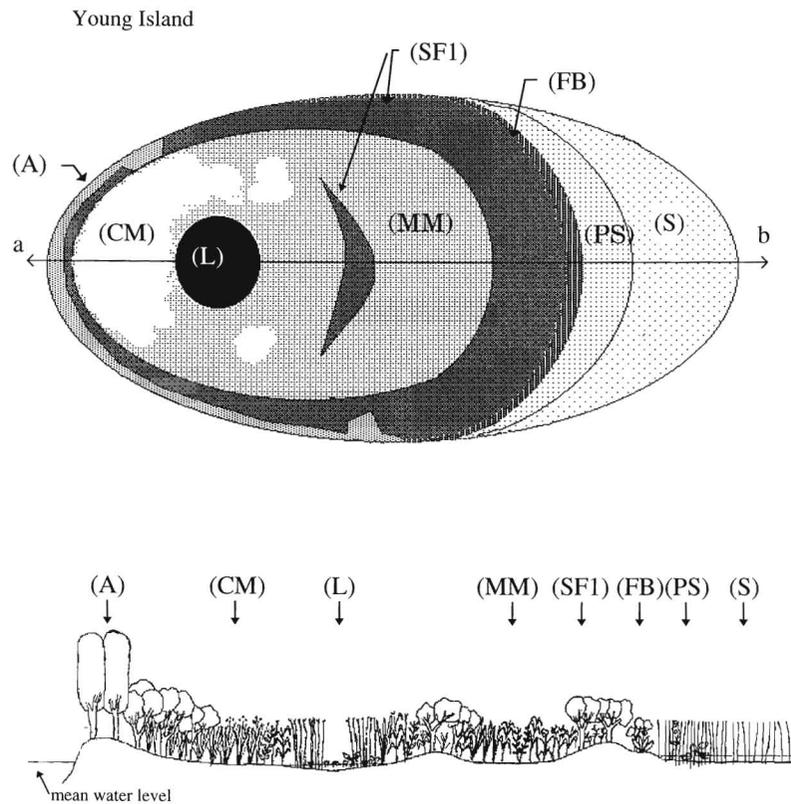
Figure 3. Continued.

type (ecotonal) between Cortadera marsh and *Erythrina crista-galli forest* (Seibo forest). In CMW, individuals of seibo, and different shrub species grow in a dense *S. giganteus* matrix.

(3) Two main land cover types may be discriminated in relative highlands regularly flooded sites: Frontal bars (FB) and Seibo forest (SF1). Both of them are located in the youngest islands of the delta (Figure 3). Frontal bars are found in the distal downstream portion of these islands. Surface and bi-directional flows during wind tides are the distinctive features of the hydrological regime. Different woody and herbaceous species colonize these sites but there is a high percentage of bare soil. *E. crista-galli* is the pioneer tree that colonized these islands, mainly on frontal bars, and also on recently developed levees extending toward the inner portion of the islands. Seibo forms low and open forests (SF1) with an heterogeneous understory mainly composed by species such as Mixed marsh, and other species with shadow habits. It is remarkable that the Seibo forest is the unique primary succession forest remaining at a regional scale in the Lower Delta. In the mature islands (Figure 3) they remain as mid slopes forests with an understory dominated by *S. giganteus* (SF2). These sites are characterized by groundwater inflow and surface unidirectional flows due to overbank discharge.

(4) Highlands regularly exposed were represented by river and stream levees with well developed soils. During strong wind tides, only overbank discharge with bi-directional flows takes place. In the beginning, they were occupied by a highly diversified and structurally complex forest, but at present very few and small patches remain because of human intervention.

(5) Man made land cover types were represented mainly by salicaceae afforestation which replaced the natural vegetation of different land covers. There were *Salix spp.* plantations (A1) in lowlands and mid slope habitats. On highlands both *Salix* spp. and *Populus* spp. plantations (A2) may be found. Nevertheless *Populus* spp. plantations are not frequent in this area. The installation and management of plantations include cutting off, squeezing and burning existing vegetation. In most cases, drain soils are maintained by drainage channels, and in some cases also by polders.

(6) Parks and gardens (G) for touristic and recreational goals may be found on rivers and stream's levees. They constitute a very heterogeneous land cover because they depend on particular man decisions about extension and composition, and management activities.

(7) The consequences of giving up afforestation on levees are different from those on lowlands and midslopes. On levees, a secondary succession riparian forest (SSRF) is generally well developed. This multicanopy forest is dominated mainly by perennial exotic species. In lowlands

Table 1. *Land cover classification scheme showing the main factors that determine different land cover types. Thin arrows show land cover replacement. Hydrologic input: (sf) surface flows, (gw) ground water flows. Hydrodynamic: (v) vertical, (bd) bidirectional, (ud) unidirectional.*

Flood regime / Topographic position (natural habitats)		Degree of Human Intervention		
		Natural land covers (Primary succession)	Man made land covers	Abandoned land covers (Secondary succession)
Lowlands Permanently flooded	connected (sf) (bd)	(B) Non Vegetated Banks		
		(S) Sedges		
	moderately connected (sf) (bd)	(PS) Protected Sedges		
	unconnected (gw,sw), (v,bd)	(L) Lagoon		
Lowlands Irregularly exposed Permanently saturated soil	(gw,sw), (v,bd)	(MM) Mixed Marsh		
	(gw>sw) (v>bd)	(CM) Cortadera Marsh		
	(gw>sw) (v>bd)	(CMW) Cortadera Marsh with Isolated Woody Plants	(A1) Willow Afforestation (lowland, midslopes)	(LAA1) Open Willow Forest
				(LAA2) Cortadera Marsh with Isolated Woody Plants
Relative highlands Regularly flooded	(sf), (bd)	(FB) Frontal Bars.		
Mid slopes Regularly flooded	(sf), (bd,ud)	(SF1) Seibo Forest		
	(sf>gw), (ud,v)	(SF2) Seibo Forest with Cortadera Understory		
Highlands (river and stream levees). Regularly exposed	(sf), (bd)	(PSRF) Primary Succession Riparian Forest (Mostly perennial species)	(G) Parks and Gardens for tourist and recreation	(SSRF) Secondary Succession Riparian Forest (Mostly perennial exotic species)
			(A2) Salicaceae Afforestation	

and midslopes instead, restoration of hydrological conditions determines the recovery of natural vegetation, particularly marshes dominated by *S. giganteus*. Nevertheless these land cover types could be divided into different classes ranging from Open Willow Forest (OWF) to Cortadera marsh (LAA1-2). They form a mosaic of patches. The patches variability depends on land use history, plant conditions at the time afforestation was abandoned, and the time elapsed since.

The goal of the classification scheme proposed was to understand the interaction between the natural and man made ecosystems that coexist in the delta islands. This was

achieved through the analysis and definition of conditioning factors (mentioned above), that permit a consistent description of the Paraná's delta and have the additional advantage of enabling comparisons with other wetland systems.

In the case of natural land covers, the approach utilized makes a consistent use of delimitation variables (hydrologic regime), and of characterization variables (structural properties of the ecosystems: physiognomy, dominant species, and soil properties such as texture and organic matter contents). These delimitation variables have a functional character, are independent of biogeography, and allow comparisons between regions. On the other hand, characterization variables address specific properties of the region and their relation with

Table 2. *Land cover features that may influence spectral response in remote sensing imagery. Life forms are defined according to Barkman's classification (1988), soil features are described following Bonfils (1961) and vegetation characteristics are defined according to Burkart (1957) and field work.*

Land Cover	Vegetation					Soil	
	Dominant Life Forms	Dominant Species (%cover)	Dominant Vegetation Height (m)	Other Species (%cover)	Dominant Species Phenology	Texture	Organic Matter (%)
Sedges (S)	equisetoids	*Schinoplectus californicus* (50% aprox.)	2.5	—	perennial	Silt loam	very low
Protected Sedges (PS)	equisetoids, rooted and errants aquatic plants and climbers	*S. californicus* (>70%)	2.5	*Eichhornia* sp., *Pontederia* sp., *Sagitaria* sp., *Mikania* sp., *Ludwigia* sp., etc.	perennial	Silt loam	very low
Lagoon (L)	equisetoids, rooted and errant aquatic plants	*S. californicus* (<50%)	2.5	*Lemna* sp., *Miriophyllum* sp., *Azolla* sp., *Salvinia* sp., *Eichhornia* sp., etc. (%variable)	perennial	Clay - Silty clay	high
Mixed Marsh (MM)	graminoid herbaceous and herbs	*Panicum grumosum, Ludwigia* spp., *Senecio bonariensis, Zizaniopsis bonariensi, Typha latifolia* (80%)	1.5–2	—	perennial	Clay - Silty clay	high
Cortadera Marsh (CM)	graminoids herbaceous	*Scirpus giganteus* (100%)	1.5–2.0	—	perennial	Clay - Silty clay	high
Cortadera marsh with isolated woody plants (CMW)	graminoids herbaceous, shrub and trees	*S. giganteus* (100%)	1.5–2.0	*E. crista-galli, Aeschinomene montevidensis, Baccharis* spp. etc. (<10%)	perennial	Clay - Silty clay	high
Frontal Bars (FB)	herbaceous, shrubs and trees	*Eryngium pandanifolium, Senecio bonariensis, S. californicus* (<40%) (60% bare soil)	less than 2.0	—	perennial and annual	Silt loam	low
Seibo Forest (SF1)	trees, herbs and climbers	*Erythrina crista-galli* (>40%)	ap to 6.0	Understory: *Ludwigia* spp., *Polygonum* spp., etc. (less than 80%)	deciduous	Clay - Silty clay	high
Seibo Forest (SF2)	trees and graminoids	*E. crista-galli* (>40%)	ap to 6.0	Understory: *S. giganteus* (100%)	deciduous	Clay - Silty clay	high
Primary Succession Riparian Forest (PSRF)	trees	*Ocotea* sp., *Nectandra* sp., *E. crista-galli, Rapanea* spp. and others (100%)	8.0–12.0	—	perennial	Loam	low
Lowland Afforestation (A1)	trees	*Salix* spp. (80%)	up to 12.0	variable	deciduous	Clay - Silty clay	low
Highland Afforestation (A2)	trees	*Salix* spp. or *Populus* spp. (80%)	up to 12.0	variable	deciduous	Loam	low
Parks and Gardens (G)	graminoids, shrubs and trees	Different exotic ornamental species	variable	variable	variable	Loam	low
Lowland Abandoned Afforestation (LAA)	graminoids or trees	*Salix* sp. (<40%), *S. giganteus* (up to 100%)	variable	variable	perennial and deciduous	Clay - Silty clay	low
Secondary Succession Riparian Forest (SSRF)	trees	*Ligustrum sinence, L. lucidum* (100%)	less than 10.0	Understory: *Lonicera japonica, Rubus* spp. and others	perennial	Loam	low

neighboring regions. These last variables are determined by biogeographic position, species colonization, composition of the Paraná River sediment charge, and the Rio De la Plata properties. Comparison of these elements through regions is difficult, but they can be adequately associated with the spectral classes that result from the analysis of satellite images, thus enabling the production of a land cover map, a basic instrument for monitoring and management goals.

In the case of abandoned land covers, one of the main features from the ecosystemic point of view corresponds to the recovery of the natural hydrologic regime during the process of secondary succession. When the man made activity is abandoned, the delimitation of land use parcels is determined by the cadastral system. But, transformation with time of these parcels into marsh systems in lowlands or secondary forests in the levees modifies their spatial configuration, creating fuzzy boundaries among them. This is why the areas subject to the processes of secondary succession could be classified in a greater detail (as in the case of natural land cover types), but this is beyond the scope of this work.

The situation of sites where man made activities are in progress is quite different. In this region, forest plantations and recreational units are activities which introduce strong modifications in the natural ecosystem. In other words, a complete replacement of the natural vegetation habitats occurs, as well as a modification of the hydrological regime. This work addresses a land cover scheme instead of a land cover/land use scheme because the term land cover helps to understand the different ecosystems and their interrelationships in a conceptual frame that includes the structural and functional characteristics of the region.

Spectral Signature Analysis

The land cover features that affect the spectral responses observed in the satellite imagery are summarized in Table 2. As it is clear from this table, the high vegetation coverage constitutes the key element in spectral land cover classification. The spectral signature of each land cover class identified was distinctive. Even if they looked rather similar at a certain date, a good discrimination was obtained when the multitemporal data set was used. Figures 4, 5 and 6 present the main characteristics of the land cover spectral signatures. They show spectral class patterns using three bands of Landsat/TM imagery at three different dates.

(1) Figure 4 represents lowland permanently flooded land covers, where the most important and frequent species among these is *S. californicus*. This is a perennial equisetoid herbaceous plant. Sedges (S), and protected sedges (PS) were differentiated mainly by the abundance of *S. californicus*, and by the presence of aquatic plants (*Pontederia cordata, Echinodorus grandiflorus, Sagittaria montevidensis*) and vins (*Mikania* spp.). The spectral pattern of the lagoon was similar to that of the sedges, but the observed general reduced reflectance in all bands may be due to greater contents of soil organic matter and less suspended sediments. Differences between sedges and open water are maximal in the TM-near infrared band of October 6.

(2) The dominant species of irregularly flooded lowlands are also perennials. Spectral patterns were relatively stable along the three dates, showing a lower response in TM-band 3 and a higher response in TM-bands 4 and 5 (Figure 5). *S. giganteus* is the unique dominant species in Cortadera marsh. It covers 100 percent of the surface and reaches a height of about 2 meters. Low water content in *S. giganteus* leaves may explain the high spectral response in TM-mid infrared band. This also occurs with Mixed marsh (MM) although species with variable anatomy and morphology coexist: species with high content of aerenchima in tissues (such as *Typha* sp. *Zizaniopsis bonariensis, Echinodorus grandiflorus, Sagitaria montevidensis*), species with lower content of aerenchima (such as *Panicum grumosum*), and species with mesophitic leaves (*Senecio bonariensis, Ludwigia* spp.). In addition, plants of MM shows a lower ground coverage (80%), and the exposed saturated soil has a high content of organic matter. These factors may cause the lower general reflectance pattern observed. Cortadera marsh with isolated woody
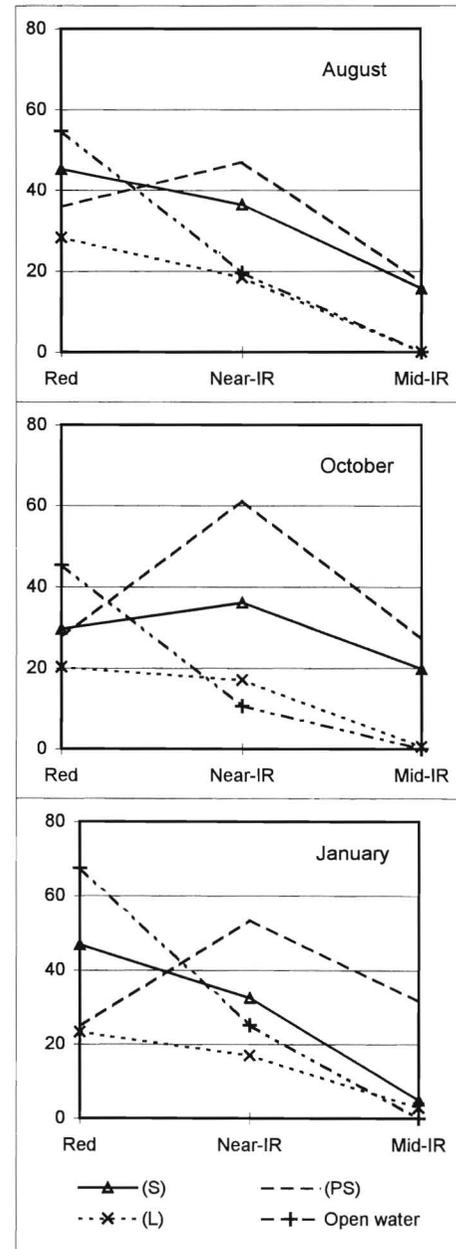
Figure 4. Spectral pattern of lowland permanently flooded land cover types and open water for the three dates analyzed. y-axis represents reflectance mean values, x-axis is Landsat TM bands.

plants had a pattern similar to Cortadera marsh in August 3 and October 6, but Seibo leaf production allows their discrimination in January 10, when a decrease in the mid-IR wavelength response occurs, possibly due to the mesophytic features of these leaves.

(3) Forested land covers are shown in Figure 6. As it is indicated in the literature (WOLTER *et al.,* 1995), low reflectance in TM-band 3, high values in TM-near infrared band and moderate ones in TM-mid infrared band char-
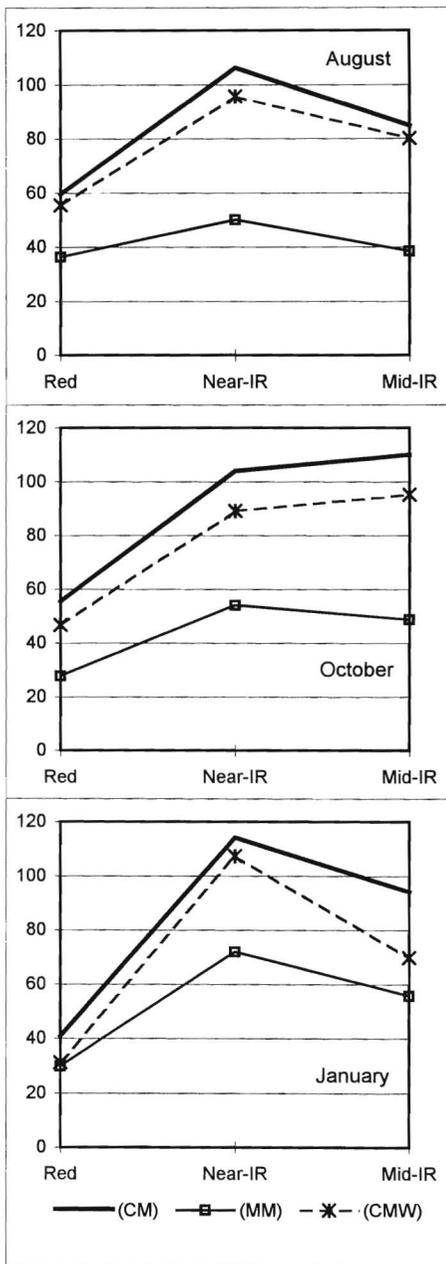
Figure 5. Spectral pattern of lowland irregularly exposed land cover types for the three dates analyzed. x and y-axis as described in Figure 4.
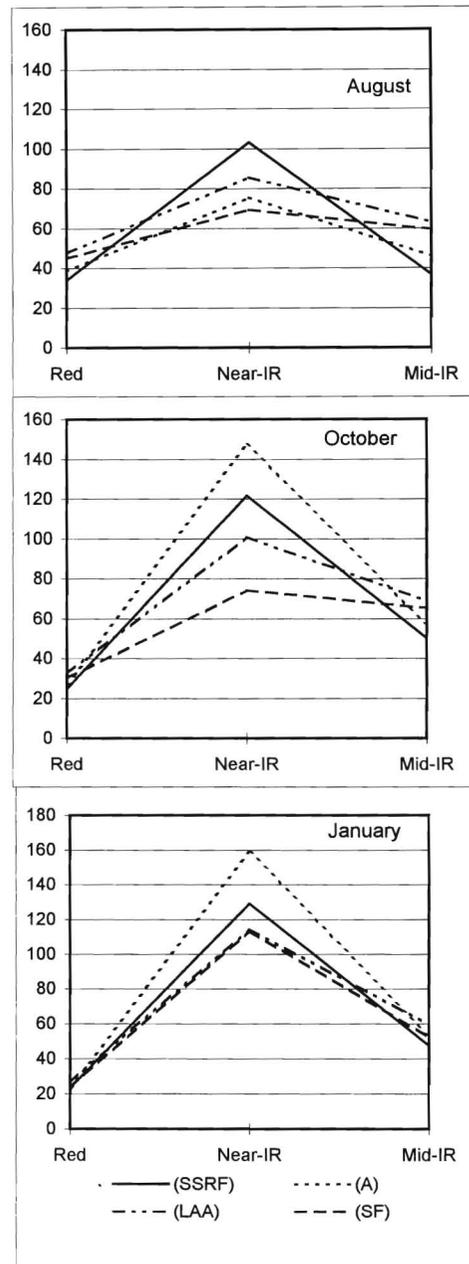
Figure 6. Spectral pattern of forested land cover including natural, man made and abandoned, for the three dates analyzed. x and y-axis as described in Figure 4.

acterize forest cover. Differentiation among forest types strongly depends on the dominant species phenology. Secondary succession riparian forest (SSRF) had a distinct pattern in August due to some of the most important dominant trees such as *Ligustrum sinence* and *L. lucidum,* that are perennial. Dominant species of the other habitats are deciduous. Willow afforestation is green in October and Seibo forest is green in January.

The spectral definition of Lowland abandoned afforestation was somewhat "noisy" since it is a class that names a land cover type that represents dynamic plant communities, as it was described above. High environmental heterogeneity due to different abandonment conditions determines a high spectral variability which makes it difficult to identify a unique spectral signature for this class.

Table 3. *Imagery dates and the corresponding thematic layers derived.*

TM-Image Dates	Thematic Layer Derived
August 3rd., 1993	Secondary Succession Riparian Forest (SSRF)
October 6th., 1993	Land/Water Mask
	Non Vegetated Banks (B)
	Salix spp. Afforestation (A1)
	Lowland Abandoned Afforestation (LAA)
January 10th., 1994	*Populus spp.* Afforestation (A2)
	Seibo Forest (SF)
	Cortadera Marshes (CM)
	Cortadera Marshes with Woody Plants (CMW)
	Mixed Marshes (MM)
	Sedges(S)
	Protected Sedges (PS)
	Lagoon (L)

An intermediate stage of succession was considered here consisting of a *S. giganteus* matrix (covering 100 percent of the surface) with sparsely *Salix* spp. plants (approximately 40 percent of the surface). Among forests, the increase in spectral separability in TM-near infrared band as compared to TM-bands 3 and 5 was determined mainly by leaf production. Nevertheless, a higher near-IR response would be expected for secondary succession riparian forest since a higher biomass, and meshophytic conditions are found. As indicated by BRONDIZIO *et al.* (1996), complex and multicanopy vegetation create large areas of shadow and spectral traps which reduce the amount of energy returning to the sensor, particularly in TM-near infrared band. This can also explain why the afforestation signature showed higher TM-near infrared band values than the secondary succession riparian forest (SSRF). Afforestation is less complex, less likely shadowed, has less moisture content and is less likely to trap incoming or outgoing energy.

The secondary succession riparian forest class showed the best spectral separability in August, when other forests types were leafless. *Salix* spp. plantation and lowland abandoned plantations were best discriminated in October, when Seibo has no leaves yet. All the remaining classes representing primary succession land covers may be discriminated in January.

The other classes proposed in the land cover classification, such as frontal bars, parks and gardens for touristic and recreational goals, primary succession riparian forest and *Populus* sp. plantations were not discriminated. In this case, TM spatial resolution plus the spectral heterogeneity of some of these land cover types were the main limiting factors.

Analysis of the Multitemporal Spectral Classification

As it was described in the methodology section, the strategy of the classification was based in a multitemporal TM set where each classified image provided one class or several classes according to the phenology cycle of the different species and their spectral responses. This is summarized in Table 3, where the thematic layers derived from August 3, October 6 and January 10 images are listed. Since the water

level of the image of October was the lowest, it was used to derive the water mask and the non vegetated banks in water (Figure 2). An unsupervised classification of 100 classes was run and recoded into land or water. Transitional classes from water to land were closely analyzed to assign land/water categories. Considering the interest for future change detection studies in young islands, a very careful labeling was performed. After applying the water mask to the three images, the image of August 6 was used to obtain the secondary succession perennial forest (SSRF) class. Next, this category was masked in October and January images. *Salix* spp. afforestation and lowland abandoned afforestation were obtained from the October image. These classes were masked in the image of January.

In order to attain a better understanding of the relationship between characterization variables and spectral classes within natural land cover types, an unsupervised classification of 200 classes was performed in the TM scene of January 1993, after masking the classes mentioned above. This classification allowed the discrimination of all natural land cover types. Its main objective was to determine whether it was possible to detect the characteristics of the intra and interclass spectral variability, and to determine whether such variabilities were associated with characterization variables.

The derived spectral clusters were plotted in a bi-spectral feature space where the x-axis represents the near infrared band and the y-axis represents the mid infrared band (Figure 7). Two main gradients may be observed in the spectral response. Axis (A) indicates the range from land cover with less vegetation coverage and permanent flooded soils such as sedges, protected sedges and lagoons (low to medium values in the near infrared band and low values in the mid infrared band) to land cover types with a dense vegetation coverage with high reflectance values in the near infrared band. This axis may be interpreted as related to a subyacent gradient of soil water content. Axes (B) shows a second gradient, from Cortadera marsh (higher mid infrared values) to Seibo forest (lower mid infrared values) and could be related to differences in leaf morphology and leaf water content.

Accuracy Assessment

For the final map, the total number of classes of Table 1 was reduced to ten classes. Some of the classes (gardens and parks, frontal bars and primary succession riparian forest) were not included because of their spectral and spatial characteristics already discussed in the previous section. Others, were collapsed as follows: A1 and A2 as A, SF1 and SF2 as SF, and LAA1 and LAA2 as LAA.

Figure 8 shows the final land cover map obtained. Within the islands, the spatial distribution of the land cover spectral clases agrees well with the profile presented in Figure 3. This is observed in Figure 9 where transects were drawn across the spectral classes of a mature island and a young island of the final map.

The accuracy assessment of the final classification is summarized in Table 4. Overall map accuracy was computed by taking the total number of correctly classified samples (diagonal cells of the matrix) and dividing by the total number

* Cortadera Marsh with Woody Plants
● Cortadera Marsh
+ Sedges
△ Protected Sedges
◆ Lagoon
○ Mixed Marsh
■ Seibo Forest
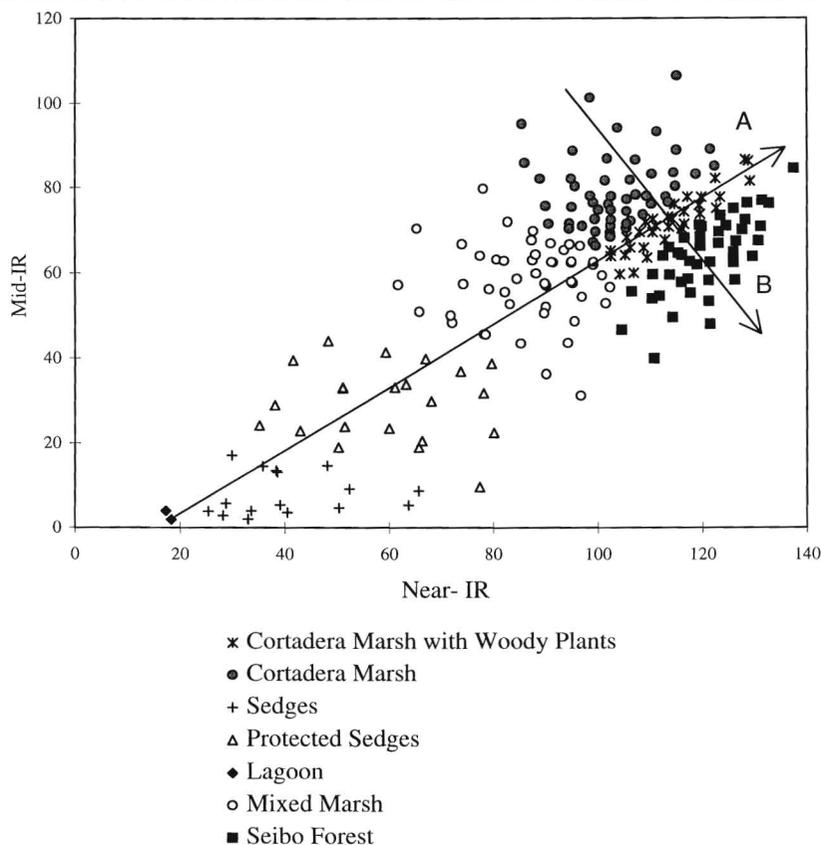
Figure 7. Two dimensional feature space classes of unsupervised classification from primary succession land cover data. Class distributions illustrate a principal gradient from permanently to regularly flooded conditions indicated by arrow (A). Arrow (B) shows a vegetation gradient from Seibo Forest to Cortadera Marsh classes related to an underlying topographic-flooding gradient.

of samples. A value of 83.5 percent was obtained. The user's accuracy, calculated as the number of correctly classified samples divided by the row total provides a measure of the value of the map for a particular user. It indicates the probability that the class assigned to a location on the map is the class that would be found at that location in the field (JANSSEN and VAN DER WEI, 1994). By dividing the number of corrected classified samples by the column total the producer's accuracy is obtained: it indicates the percentage of samples of a certain reference class that were correctly classified. Individual class user's accuracy ranged from 65.9 percent for Abandoned afforestation and 66.8 percent for Cortadera marsh with woody plants to 98.3 percent for Cortadera marsh. Producer's accuracy instead, ranged from 75.6 percent for secondary succession riparian forest and 76.3 percent for Cortadera marsh to a top value of 98.4 percent for afforestation.

The greatest amount of user's accuracy confusion occurred in three environmental conditions: (1) classes that represent dynamic plant communities such as Abandoned afforestation; (2) land covers that represent ecotones such as Cortadera marsh with woody plants, and (3) land covers

that are mostly differentiated by the proportion of dominant elements such as lagoons, particularly the borders of them in relation with sedges and protected sedges. In the first case, the abandonment process generates fuzzy boundaries among landscape elements, that differ from active plantations which have very clear cut limits. This was due to the fact that the restoration process of vegetation and hydrologic regime results in a collection of patches abandoned at different times, subject to different management systems and belonging to different topographic situations. All these elements generate confusion not only about the stage of the recovery process, but also about the surrounding land covers.

Most vegetation in natural habitats in this delta had distinct boundaries (with thin ecotones) in agreement with ODUM's description (1984) of other tidal freshwater marshes. In spite of this, Cortadera marsh with woody plants may be considered as the ecotone between Cortadera marsh and Seibo forest or as a land cover depending on the resolution scale. Whatever may be considered, great confusion occurs because of the spectral response of CMW that corresponds mainly to *S. giganteus* matrix. Additional satellite systems
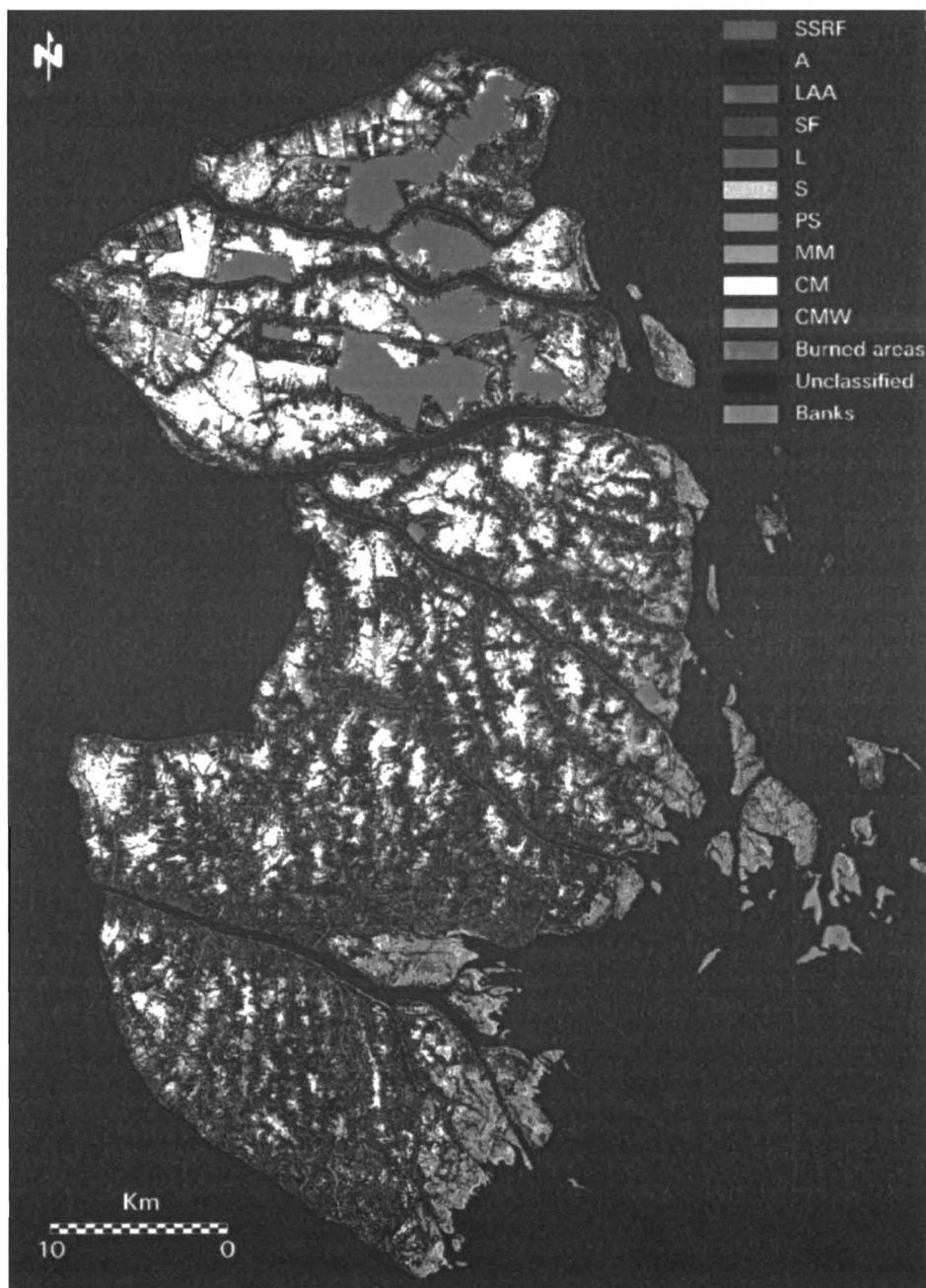
Figure 8.   Ten land-cover classes produced from a multitemporal unsupervised classification of the study area on the Lower Delta of Paraná River, using Landsat TM data from August, October and January, 1993/94. S: Sedges, PS: Protected Sedges, L: Lagoon, MM: Mixed Marsh, CM: Cortadera Marsh, SF: Seibo Forest, A: Afforestation, LAA: Lowland Abandoned Afforestation, CMW: Cortadera Marsh with Woody Plants, SSRF: Secondary Succession Riparian Forest.

such as those that provide radar imagery might help improving results since the backscatered signal depends of the structure of the vegetation canopies.

Within permanent flooded land covers, classes labeled as external sedges also include lagoons. In this case the avail-

ability of TM blue and green bands would have helped to discriminate between them.

The greatest amount of producer's confusion, occurred in secondary succession riparian forest. This may be due to a mature active afforestation without a clean understory which

Mature Island
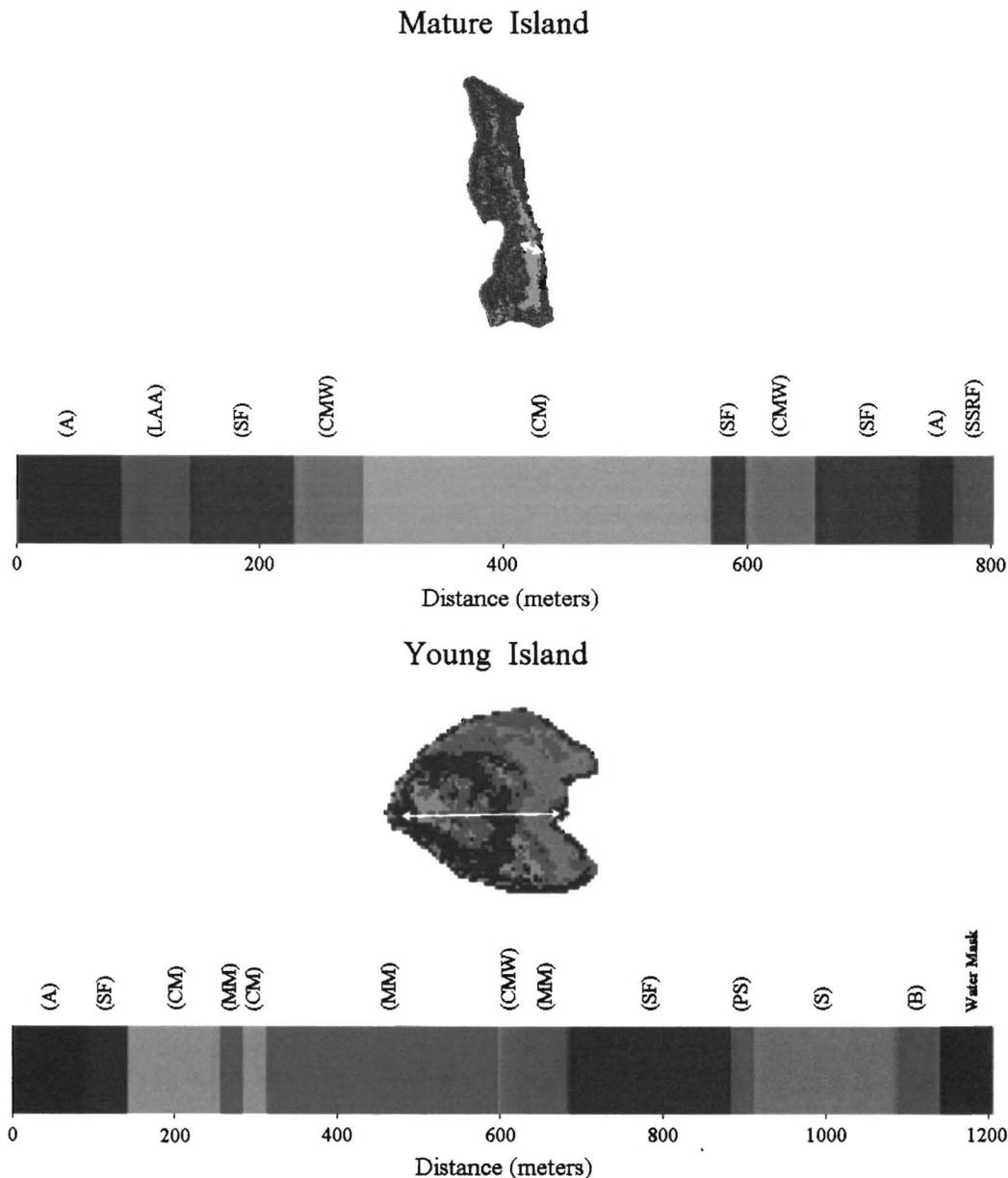
Young Island

Figure 9.   Spatial profile of land-cover classes of a young and a mature island from the map of figure 8. Abbreviations as indicated in Figure 8.

may have the same perennial species as the first one. In the case of Cortadera marsh (producer's accuracy 76.3 percent), the result is related to the ecotonal situation of Cortadera marsh with woody plants, as discussed above.

CONCLUSIONS

This paper addressed the development of a conceptual land cover classification scheme for the Frontal Delta of Parana River, and its relationship with classes derived from Landsat/ TM satellite imagery. The regional conceptual classification scheme developed was intended to facilitate comparisons with other systems, and to simplify the use of satellite imagery for a land cover map production.

For management considerations, formulation of environmental policies, or research purposes (change detection studies, comparison between wetlands of different regions) it was necessary that the discriminated land cover classes could be directly related to functional aspects such as water, nutrients, organic matter, and information fluxes. Also, temporal processes such as primary or secondary successions had to be considered. Both, spatial and temporal dimensions determine the landscape heterogeneity, and they also helped to define

Table 4. *Error matrix for the overall classification. S: Sedges; PS: Protected Sedges; L: Lagoon; MM: Mixed Marsh; CM: Cortadera Marsh; CMW: Cortadera Marsh with Woody Plants; SF: Seibo Forest; A: Afforestation; LAA: Lowland Abandoned Afforestation; SSRF: Secondary Succession Riparian Forest.*

Classified data	Reference Data										Row data	User's Accuracy
	(S)	(PS)	(L)	(MM)	(CM)	(CMW)	(SF)	(A)	(LAA)	(SSRF)		
(S)	769	10	16	2							797	96.49
(PS)	111	427	5	25						1	569	75.04
(L)	45	23	154	1				1	3	2	229	67.25
(MM)			1	514	13	1			1		530	96.98
(CM)					918	8					926	99.14
(CMW)				9	246	708	94		3		1060	66.79
(SF)				17		9	996	2			1024	97.27
(A)		1		32	4	1	4	778		156	976	79.71
(LAA)				23	22	51	123	102	627	4	952	65.86
(SSRF)		1		2			1	64	3	505	576	87.67
Column data	925	462	176	625	1203	778	1218	947	637	668	7639	
Producer's Accuracy	83.10	92.42	87.50	82.20	76.30	91.01	81.67	82.20	98.43	75.60		

Overall accuracy = 83.5   Diagonal Total = 6396

the conceptual framework necessary to interpret classification results and their scope.

In the scheme presented, the definition of characterization variables allowed the linkage between information classes, functionally defined, and the spectral classes derived from satellite imagery. A layered classification approach based on the use of a progressive unsupervised classification procedure was applied to a set of multitemporal Landsat/TM imagery. In each step, the spectral classes were subject to a careful labeling and recoding based on field work and aerial photography. The final land cover map was the result of combining the different thematic layers obtained.

The overall classification accuracy, of the order of 83%, was quite satisfactory. Through the analysis of the error matrix, it was possible to explain the confusion of certain classes in relation to the environmental factors of the landscape, such as fuzzy limits in abandoned sites, ecotones, and land covers which differ only in the relative abundance of species.

The classification scheme presented is not only flexible from the conceptual point of view, in the sense that it allows aggregation or desegregation of land covers as more specific studies are required, but it is also flexible from the quantitative point of view since it was not defined for a particular satellite system. Follow on studies will consider the use of a complete TM set (seven bands) and the inclusion of satellite systems where textural elements could be added for class discrimination. Also, the use of images of better spatial resolution than that of Landsat/TM could help in the discrimination of some of the land covers not included in the final map such as those for cadastral and touristic use.

Due to the closeness of this area to large urban centers such as Buenos Aires, important infrastructure developments are planned or in progress such as Hidrovia Paraguay-Paraná, the bridge Rosario-Victoria, or large polder systems. These developments may heavily influence the regional hydrologic regime. Also, the expansion of forested areas, the establishment of small towns, even if their influence may be of less magnitude, they will also modify the natural conditions reducing the areas usually kept for mitigation of flooding events.

From this point of view, the land-cover map obtained, the first for this region, may constitute a benchmark against which futures conditions could be compared utilizing image processing and change detection techniques with the purpose of defining conservation and management practices for this area.

ACKNOWLEDGEMENTS

LITERATURE CITED

ALLEN, T. F. H. and WILEYTO, E. P., 1983. A hierarchical model for the complexity of plants communities. *Journal of Theoretical Biology,* 101, 529–540.

AMOROS, C. and WADE, P. M., 1996. Ecologycal Succession. In *Fluvial Hydrosystems.* G. E. Petts and C. Amoros (ed.). Chapman and Hall, London. pp. 211–239.

ANDERSON, J. R.; HARDY, E. E.; ROACH, J. T., and WITMER, R. E., 1976. A land use and land cover classification system for use with remote sensor data. *U.S. Geologycal Survey Professional Paper 964,* Washington, D.C. 28p.

BARKMAN, J., 1988. New systems of plants growth forms and phenological plant types. *In: Plant Form and Vegetation Structure.* M. A. J. Werger; P. J. M. van der Aart; H. J. During, and J. T. A. Verhoeven (eds.). The Hague: SPB Academic Publishing.

BONFILS C., 1962. Los suelos del Delta del Río Paraná. Factores

generadores, clasificación y uso. *Revista. Investigación Agrícola. INTA* 16(3), 257–270. Buenos Aires, Argentina.

BRINSON, M. M., 1993. *A Hydrogeomorphic Classification for Wetlands.* Wetland Research Program Technical Report WRP-DE-4. US Army Corps of Engeneers, Waterways Experiment Station. Washington, D.C.

BRONDIZIO, E.; MORAN, E.; MAUSEL, P., and WU Y., 1996. Land Cover in the Amazon Estuary: Linking of the Thematic Mapper with Botanical and Historical Data. *Photogrammetric Engineering and Remote Sensing,* 62(8), 921–929.

BURKART, A., 1957. Ojeada sinóptica sobre la vegetación del Delta del Río Paraná. *Darwiniana,* 11(3), 457–561. Buenos Aires, Argentina.

CABRERA, A. and WILLINK, A, 1973. *Biogeografía de America Latina.* OEA Serie Biología. Monografía 3.

CARTAXO MODESTO DE SOUZA, R., 1982. INPE Landsat-D Thematic Mapper computer compatible tape format specification. INPE *Technical Report.* INPE-2553-PRE/207, 2nd. Version.

CONGALTON, R. G., 1988. A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. *Photogrammetric Engineering and Remote Sensing,* 54(5), 593–600.

COLINVAUX, P., 1993. *Ecology II.* New York: Willey 688p.

CONSEJO FEDERAL DE INVERSIONES, 1991. Informe final de la actualización cartográfica, Provincia de Buenos Aires. Programa de desarrollo integrado del Delta del Río Paraná. *Technical Report.*

COWARDIN, L. M.; CARTER, V.; GOLET F. C., and LAROE, E. T., 1979. *A classification of Wetlands and Deepwater Habitats of the United States.* Washington, D.C.: U.S. Government Printing Office, Office of Biological Service, U.S. Fish and Wildlife Service, FWS/OBS-79/31, 103p.

GLENN-LEWIN, D. C. and VAN DEL MAAREL, E., 1992. Patterns and processes of vegetation dynamics. *In: Plant Succession Theory and Prediction.* D. C. Glenn-Lewin; R. K. Peet, and T. T. Veblen (eds.). Chapman and Hall Population and Community Biology Series 11. University Press, Cambridge, pp. 11–44.

GOSSELINK, J. G. and TURNER, R. E., 1978. The role of hydrology in freshwater wetland ecosystems. *In: Freshwater Wetlands: Ecological Processes and Management Potential.* R. E. Good; D. F. Whigham, and R. L. Simpson (eds.). New York: Academic, pp. 63–78.

GRIME, J. P., 1979. *Plant Strategies and Vegetation Processes.* Chichester, England: Wiley, 222p.

HARDISKY, M. A.; GROSS, M. F., and KLEMAS, V., 1986. Remote Sensing of Coastal Wetlands. *Bioscience,* 36(7), 453–460.

IRIONDO, M. and SCOTTA, E., 1979. The evolution of the Paraná River Delta. *Proceedings of the 1979 International Symposium on Coastal Evolution in the Quaternary.* (Sao Paulo), pp. 405–418.

JANSSEN, L. L. F. and VAN DER WEL, J. M., 1994. Accuracy Assessment of Satellite Derived Land-Cover Data: A Review. *Photogrammetric Engineering and Remote Sensing,* 60(4), 419–426.

JENSEN, J. R., 1986. *Introductory Digital Image Processing. A Remote Sensing Perspective.* Englewood Cliffs, New Jersey: Prentice-Hall, 379p.

JENSEN, J. R., 1993. An evaluation of the CoastWatch Change Detection Protocol in South Carolina. *Photogrammetric Engineering and Remote Sensing,* 59(6), 1039–1046.

JENSEN, J. R.; MACKEY JR., H. E.; CHRISTENSEN, E. J., and SHARITZ, R., 1987. Inland Wetland Change Detection Using Aircraft MSS data. *Photogrammetric Engineering and Remote Sensing,* 53(5), 521–529.

KALESNIK, F. and MALVAREZ, A. I., 1996. *Los bosques secundarios en el Bajo Delta del Río Paraná.* Technical Report. Universidad de Buenos Aires, 30p.

KANDUS, P. and ADAMOLI, J. M., 1993. Freshwater marsh vegetation response to flooding patterns in the Lower Delta of the Paraná River. *Wetlands Ecology and Management,* 2(4), 213–222.

KANDUS, P., 1997. Análisis de patrones de vegetación a escala regional en el Bajo Delta Bonaerenje del Río Paraná (Argentina). Tesis Doctoral. Universidad de Buenos Aires, Argentina.

KANDUS, P.; BORGO, L.; KALESNIK, F., and MALVAREZ, A. I., 1997a. Spatial pattern and temporal changes in the Paraná River Delta

(Argentina): The Botija Island Study Case. Technical Report. Universidad de Buenos Aires, 28 p.

KANDUS, P.; MALVAREZ, A. I., and CAGNONI, M., 1997b. *Vegetation and Landscape Patterns in the Lower Delta of Paraná River Islands (Argentina). A Primary Succession Model.* Technical Report. Universidad de Buenos Aires, 30p.

KENT, M. and COKER, P., 1992. *Vegetation Description and Analysis.* London: Belhaven, 363p.

KLEMAS, V. V.; DOBSON, J. E.; FERGUSON, R. L., and HADDAD, K. D., 1993. A coastal land cover classification system for the NOAA Coastalwatch Change Analysis Project. *Journal of Coastal Research,* 9(3), 862–872.

LATINOCONSULT ARGENTINA, 1972. *Estudio integral para el desarrollo del Delta del Río Paraná bonaerense,* I. Ministerio de Economía de la Provincia de Buenos Aires, Argentina.

MALVAREZ, A. I., 1993. El Delta del Río Paraná como región ecológica. *In: El Holoceno en la Argentina.* M. Iriondo (ed.). Ediciones del CADINQUA, 2, 81–93.

MALVAREZ, A. I., 1997. *Las comunidades vegetales del Delta del río Paraná Su relación con factores ambientales y patrones de paisaje.* Tesis Doctoral. Universidad de Buenos Aires. Argentina, 183p.

MARTIN, A. C.; HUTCHKISS, N.; ULHER, F. M., and BOURN, W. S., 1953. *Classification of Wetlands of the United States,* U.S. Fish and Wildlife Service Special Science Report-Wildlife 20, Washington, D.C. 14 pp.

MILOVICH, J. A.; L. A. FRULLA, and D. A. GAGLIARDINI, 1995. Environment contribution to the atmospheric correction for LANDSAT-MSS images. *International Journal of Remote Sensing,* 16(14), 2515–2537.

MINOTTI, P. G.; KANDUS, P., and VALLI, S., 1988. Zonificación de patrones de paisaje en el Bajo Delta del Río Paraná. In: *Condicionantes ambientales y bases para la formulación de laternativas productivas en la región del Delta del Río Paraná.* Technical Report. Subsidio UBACyT Nr. 135. Universidad de Buenos Aires. Buenos Aires, Argentina, 145p.

MITCH, W. and GOSSELINK, J., 1993. *Wetlands.* New York: Van Nostrand, 722p.

O'NEILL, R. V., 1989. Perspectives in hierarchy and scale. *In:* Rougharden, J.; May, R. M., and Levin S. A. (eds.), *Perspectives in Ecologycal Theory.* Princeton, New Jersey: Princeton University Press, pp. 140–156.

ODUM, H. T.; COPELAND, B. J., and MCMAHAM, E. A., 1974. *Coastal Ecologycal Systems of the United States.* (Four volumes). The Conservation Foundation, Washington, D.C.

ODUM, W. E.; SMITH III, T. J.; HOOVER, J. K., and MCIVOR, C. C., 1984. *The Ecology of Tidal Freshwater Marshes of the United States East Coast: A Community Profile.* U.S. Fish and Wildlife Service, FWS/OBS-87/17, 177p.

PARKER, G. and MARCOLINI, S., 1992. Geomorfología del Delta del Paraná y su extensión hacia el Río De La Plata. *Revista de la Asociación Geológica Argentina,* 47(2), 243–249.

PICKET, S. T. A. and WHITE, P. S., 1985. *The Ecology of Natural Disturbance and Patch Dynamics.* Orlando, Florida: Academic.

PRANCE, G. T., 1979. Notes on the vegetation of Amazonia. III. The terminology of Amazonian forest types subject to inundation. *Brittonia,* 31, 26–38.

RINGROSE, S.; MATHESON, W., and BOYLE, T., 1988. Differentiation of Ecologycal Zones in the Okavango Delta, Botswana by Classification and Contextural Analysis of Landsat MSS Data. *Photogrammetric Engineering and Remote Sensing,* 54(5), 601–608.

RINGUELET, R., 1961. Rasgos fundamentales de la zoogeografía de la Argentina. *Physis* (Buenos Aires, Argentina), 22, 150–170.

RUTCHEY, K. and VILCHECK, L., 1994. Development of an Everglades vegetation map using a Spot image and the Global Positioning System. *Photogrametric Engineering and Remote Sensing,* 60(6), 767–775.

SHAW, S. P. and FREDINE, C. G., 1956. *Wetlands of the United State, Their Extent, and their Value for Waterfowl and other Wildlife,* U.S. Department of Interior, Fish and Wildlife Service, Circular 39, Washington, D.C. 67p.

SIMPSON, R. L.; GOOD, R. E.; LECK, M. A., and WHIGHAM, D. F.,

1983. The Ecology of Freshwater Tidal Wetlands. *BioScience*, 33, 255–259.

STEWART, J. S. and LILLESAND, T. M., 1995. Stratification of Landsat TM data, based on regional landscape patterns to improve land cover classification accuracy of large study areas. *Proceedings, ACSM/ASPRS 1995*, 3, 826–835.

TANRÉ, D.; DEROÓ, C.; DUHAUT, P.; HERMAN, M.; MOCRETTE, J. J.; PERBOS, J., and DESCHAMPS, P. Y., 1986. *Simulation of the Signal in the Solar Spectrum (5S). User's Guide. First draft.* (U.S.T. de Lille, 59655 Villenueve d'asq, France: Laboratoire d'Optique Atmosphérique).

TANRÉ, D.; DEROÓ, C.; DUHAUT, P.; HERMAN, M.; MOCRETTE, J. J.; PERBOS, J., and DESCHAMPS, P. Y., 1990. Description of a com-

puter code to simulate the satellite signal in the solar spectrum: the 5S code. *International Journal of Remote Sensing*, 11(4), 659–668.

VALLI, S.; KANDUS, P., and MALVAREZ, A. I., 1992. Freshwater recovery related to landscape patterns in the Lower Delta of Paraná River (Argentina). *INTECOL'S IV International Wetlands Conference.* Columbus, Ohio.

WEISSBLATT, 1977. A Hierarchical Approach to Satellite Inventories of Coastal Zone Environments. *Geoscience and Man*, XVIII, 215–227.

WOLTER, P. T.; MLADENOFF, D. J.; HOST, G. E., and CROW, T. R., 1995. Improved Forest Classification in the Northern Lake States Using Multi-Temporal Landsat Imagery. *Photogrammetric Engineering and Remote Sensing*, 61(9), 1129–1143.

□ RESUMEN □

El Bajo Delta del Rio Paraná constituye un humedal dulceacuícola sometido a mareas. Los ambientes presentes están determinados por la expresión local del régimen hidrólogico en relación con los patrones de paisaje naturales y la actividad antrópica desarrollada. El objetivo de este trabajo es la presentación de un esquema de clasificación conceptual de ambientes y su vinculación con clases obtenidas del análisis de imágenes satelitales provistas por el sistema Landsat/TM a fin de obtener un mapa de coberturas vegetales. Primero se presenta un esquema específico para esta región basado en la identificación de variables de delimitación y de caracterización. El esquema de clasificación conceptual de caracter regional fue desarrollado a fin de facilitar la comparación con otros sistemas y de permitir un uso más adecuado de las imágenes satelitales. Las clases de "información" resultantes se vinculan con las clases "espectrales" obtenidas al aplicar el método de superposición de mapas temáticos que resultan de la aplicación de procedimientos de clasificación no supervisada a un conjunto de tres imágenes Landsat/TM. En cada paso, las clases espectrales obtenidas son cuidadosamente identificadas y recodificadas teniendo en cuenta fotografía aérea y trabajo de campo. El mapa final de coberturas es el resultado de la combinación de varios mapas temáticos. La evaluación de exactitud de la clasificación es del orden del 83%.

Finalmente, se discuten los resultados obtenidos destacando algunas de las características de este area compleja y se señalan las ventajas y desventajas de los datos satelitales para este tipo de objetivos.