A Coastal Classification: A First Step for a Better Coastal Management System in Yucatan?

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Key words: coastal classification, coastal management, morphodynamic, Yucatan

SUMMARY

The coastal areas are very high-dynamic regions. No other landscape unit is eternally affected and permanently formed by geomorphologic processes as the littoral. Furthermore coastal area occur frequently natural hazards. If hurricanes, storm surges, floods etc. happen, they will get stuck as natural disaster in our all memory. Coastal erosion itself is not necessarily a disastrous phenomenon, but problems occur when erosion processes and human activity come into conflict.

World-wide increases the dimension and density of human occupation of shorelines and the vulnerability of the littoral. This necessitate a better management polices imperative. One basic step of a coastal management system is a complete homogenized classification of the coast of Yucatan. The first results of a section are presented in this article.

RESUMEN

Las áreas costeras son regiones muy dinámicas. Ninguna otra unidad del paisaje se afecta continua y es formada permanentemente por procesos geomorfológicos como el litoral. Además en el área costera ocurren riesgos naturales con alta frecuencia; como los huracanes, las oleadas de la tormenta, las inundaciones entre otros, que al pegar ocasionan catástrofes naturales en toda nuestra memoria. La erosión costera, así mismo no es necesariamente un fenómeno desastroso, pero los problemas ocurren cuando los procesos de la erosión y la actividad humana vienen en conflicto.

Aumentos mundiales como la dimensión y la densidad de la ocupación humana en litorales aumentan la vulnerabilidad del mismo, lo que hace necesario un manejo más dominante. Un paso básico de un sistema de gerencia costero es una clasificación homogeneizada completa de la costa de Yucatán. Los primeros resultados de una sección se presentan en este artículo.

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1. INTRODUCTION

The term "Coastal Zone Management" (CZM) is initially used in the United States in its 1972 Coastal Zone Management Act. This term encompasses management of all uses in the coastal zone, but it does not emphasize the relation among uses and polices. Furthermore the initial program emphasized management of land, not ocean, uses in the coastal zone. The Agenda 21 of the United Nations Conference on Environment and Development (UNCED) passed in 1992 underscore the sustainable development and chapter 17 addresses especially to oceans and coasts. Today the term "Integrated Coastal Management" (ICM) is widely used. It is a continuous and dynamic process by which decisions are made for sustainable use, development, and protection of coastal and marine areas and resources. The ICM is multipurpose oriented; it analyzes implications of development, conflicting uses, and interrelationships between physical processes and human activities (CICIN-SAIN et al., 1998).
This manuscript is closer to the original CZM-Concept. The objective of this work is to identify and to characterize the relief units of the coast, distinguish the coastal types, their genesis and to recognize the dynamic of the coast in Yucatan. For this purpose it is necessary to analyze high-resolution satellite images. In this study are used six panchromatic satellite images. These images are supplemented through analog topographic maps in a scale 1: 50,000.

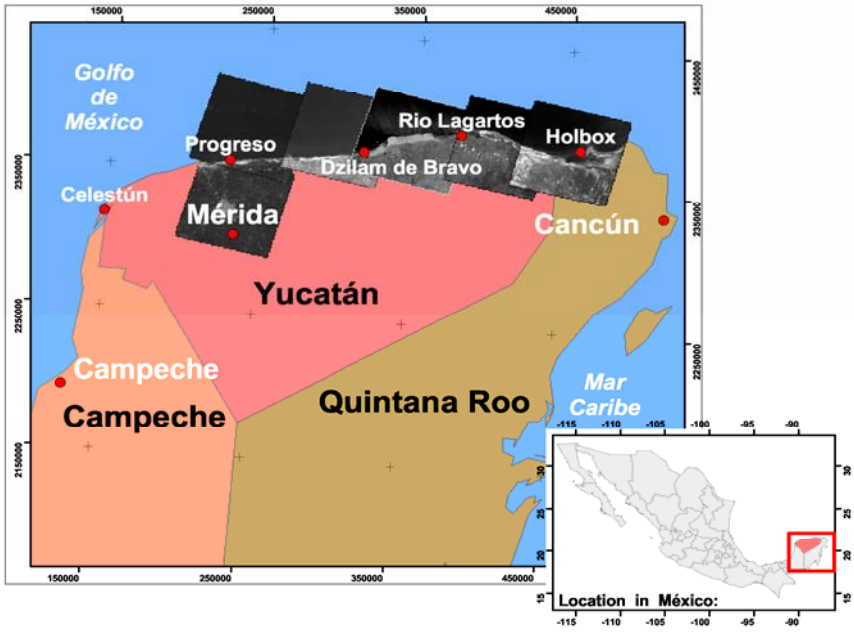

Figure 1: Study area and location of the six satellite images

The study area is the coastal zone of the federal state of Yucatán, México. It includes the area from Progreso to the eastern border line to Quintana Roo. The far western region, around Celestún, is missing in the satellite images.

2. GEOMORPHOLOGIC UNITS

The shoreline is not a strictly delimited line; it is rather more a zone of transition between terrestrial and marine ecosystem, which penetrate themselves mutual. The geomorphologic units are definable areas, which can be extracted from the satellite image.
The different geomorphologic units are based on the relief (high relief, transition and low relief zone), the morphology (elevations, isolated elevations, piedmont, costal plains and islands), and the environment (fluvial, costal, deltaic, estuarine, marshes, barrier and barrier islands). Beyond this, there are differences in the type of modulation (erosion, denudation). But some characteristic elements exist in each relief unit (FRAUSTO, 2001).
In the following all geomorphologic units in the study area are defined. The north coast of Yucatan is dominated by Salt Marshes and Barrier Coasts. This coast is part of the longest stretch of barrier coastline that extends along the eastern coast of USA and in the Gulf of Mexico (KING, 1972). We can distinguish in Yucatan:

- **Marshes** corresponds to a plain of coastal accumulation slightly raised by the level of the sea; this slightly slope makes the evacuation of waters difficult and benefit the marsh formation or area with deficient drainage. They are low and uniform coasts that are located in coastal sectors with little deep continental platforms and receive abundant fine sediments. If the coastal dynamic is minima or of loss energy, the zone is covered by vegetation. According to the type of vegetation and altitudinal position of this we differentiate:

    - **higher marsh** is dominated by hydrophilic vegetation (Popal, Tular) and is located in the high sites;
    - **lower marsh** is characterized in the study area by the presence of mangrove;
    - water bodies: **estuaries, channels and lagoons**;
    - accumulation of sand: **beaches** are strips of the coast, weakly inclined towards the sea and composed of sands, pebbles and fractions of mussels. These materials are deposited by the action of the surge. **Sandbanks** are positive forms of the relief with aspect of subaqueous launching slip. It concerns of a loose alluvium accumulations, which is not stabilized and separate the water lamina. They get to emerge in periods from shallow waters or estuaries very marked. By natural dynamics they tend, either to modify themselves, to disappear with any high tide, which the coast frequency occurs, alter there volume in seasonal variations, or to become stabilized they forming small islands. If the disposition lush planted it can be distinguished lateral and average protection;

- **anthropogenic forms** are areas, which are associated to human activity (pier, harbor, settlements).
- **Salt pans** are areas with high salinity. The soils are affected by Solonchaks and extremely hostile for plants. The consequence is, that these areas are either free of vegetation or with intersperse of scrubs with mangrove and other halophilous plants. They are distributed in parallel strip to the coastline.

- **Barrier coast** are submarine accumulative banks which are close to the coast and escaping in an altitude briefly over the level of the sea. They appear parallel to the coast; separating lagoons from the sea, with some times have lengths of kilometers. It is a form of coastal progression, which extends gradual the continent. The forms and elements that constitute to the coastal bar are:

  - **tide channels -** the ascent advance of the tide current and the great energy of reflected waves generating channels, which cut the bar, sectioning it and affects the bottom progressively. The coastal drift causes that the tide channels move laterally, eroding sand in the border and deposit it in the other;
  - a **backwater** lagoon is separated from the sea by a coastal bar, but the backwater lagoon can be connected with the ocean by a tide channels;
  - **lagoons** are water bodies in the coastal plain without a direct connection to the sea. Lagoons can be either permanent or seasonal.
  - **estuaries** are fluvial formed channels which are widened by the influence of the tide;
  - **bays** are a portion of the ocean that penetrate towards the continent. The coastline is characterized by a concave form towards the landside;
  - **islands** are a component of the land, which is completely surrounded by water. **dunes** are mounts of sand, which originate for aeolian accumulation. The main source of materials comes from beaches;
  - **swamps** are a part of the wetlands with insufficient drainage and a constant moisture that causes the appearance of special hydrophilic vegetation and **ponds** are brief depressions or little deep, they can contain small lagoons or pools;
  - **high tide beach** are formed inbound of the bars, by the direct action of the waves;
  - **low tide beach** are formed outbound of the bars. These are sand accumulations due to the currents in sheltered lagoons, bays etc.;
  - **tide delta** is sand accumulations which varied in size and forms. It can be located inside or outside of the coastal bar, and has their origin in a former tide channel. The deposits of the delta are product of the sudden change in the capacity to carry sediments of the tide currents;
  - **tide beach** are beaches between the limits high and low tide, flat surface constituted by deposits of sand, gravel and pebbles.

The listing below shows the actual inventory of the northern coast of Yucatan.

Territory unit	Relief unit	Element of the relief
III Low relief type	III.4 Marshes	III.4.a Higher marsh
		III.4.b Lower marsh
		III.4.c Estuaries, channels and lagoons
		III.4.d Beaches, Sandbanks
		III.4.e Anthropogenic Forms
		III.4.f Salt pans
	III.5 Barrier Coasts	III.5.a Tide channels
		III.5.b Backwater
		III.5.c Lagoons
		III.5.d Estuaries
		III.5.e Beaches
		III.5.f Bays
		III.5.g Islands
		III.5.h Dunes
		III.5.i Swamps and ponds
		III.5.j Anthropogenic forms
		III.5.k High tide beaches
		III.5.l Low tide beaches
		III.5.m Tide delta
		III.5.n Tide beaches

Table 1: Listing of geomorphologic units in the coastal area (modified after: FRAUSTO, 2001)

3. GENESES AND DYNAMIC OF THE COAST

In addition to chapter 2, it exist a distinction of the littoral in the morphology, the genesis, and the dynamic. There exist coasts with continental or maritime influence. But the relationship between the coastal relief and the type of coast does not allow knowledge to the dynamic processes. But even this dynamic is significant for any policy management. Erosive and accumulative coasts need distinct monitoring and engagement. In fact the classification consists three parts: Extracting the geomorphologic units (above), the genesis of the coast and the recognition of their dynamic (following).

Analyses of the existing costal classification, compiled by KING (1972), demonstrate a great variance of different systems. The different classifications consider the coast with diverse criteria and different objectives. SHEPARD (1937) emphasized the descriptive criteria without a consideration of the recent morphodynamic. VALENTIN (1952) point out the recent morphodynamic as the most important factor, during DOLAN et al. (1975) the wave movement as the recent process dynamic emphasized. The relative oscillation of the sea level is after VALENTIN (1979) the main factor for the result of the recent process dynamic.
But especially the genesis and formative influences are important for the description of the individuality of each coastal section, during morphodynamic significant criteria for planning, observing and defending the coast contain. Therefore PREU et al. (1988) as well as ORTÍZ et al. (1991) use a combination of different coastal classification.
The classification of the coastal types in this manuscript assemble two parts, one consider the dominant environment and the genesis. The basis of his classification is the distinction between coasts that have been shaped mainly by terrestrial agencies and those that have been modified by marine processes. This classification regards the function of marine processes to be of major significance.

	DOMINATED	GENESIS	
TYPE OF COAST	Primary (continental dominated)	**A. Erosion Coasts**	
			Ria coasts
			Karst topography
		B. Deposition coasts	
		- Fluvial deposition coasts	
			Deltaic coasts
		- Alluvial plain coasts	
			Alluvial plain coasts
			Aeolian deposition coasts
			Dunes
			Paleodunes
			Sand flats
		C. Landslide costs	
			Landslide coasts
		D. Tectonic coasts	
			Fault coasts
	Secondary (marine dominated)	**A. Marine erosion coasts**	
			Wave straightened coasts
			Made irregular by wave erosion
		B. Marine deposition coasts	
			Barrier coasts
			Cuspate forelands
			Beach plains
			Mud flats or salt marshes
		C. Coasts built by organisms	
			Coral reef coasts
			Mangrove
			Marsh grass coasts

Table 2: Type of coasts subdivided to there genesis (modified after: SHEPARD 1937)

The second part considers the morphodynamic processes. The advancing coasts can either be built up through accretion or emergence, while retreating coasts are a result of erosion or submerging. The four processes could themselves superpose or mutual extinguish.
This manuscript distinguishes only in erosion coasts, mixed coasts and accumulation coasts (ORTÍZ et al., 1991). The last one modify into: low sand beaches, patomogenic and marsh costs as well as biogenic coasts.

A) Erosion coasts

Cliffed erosion coasts are directly infected by waves and the currents above the coastline. The principal characteristic is the advance of the coastline against the land. The energy of the waves and the current shape a cliffed, if the lithology and the structure it allows. Normally this type is located at abrasions platforms or high relief coasts.

B) Mixed Coasts

Abrasive-accumulative coasts are a result of erosion and accumulation at the same location. The reason of the contrasting processes is given in the general form of the coast, in the type and hardness of the material and the presence of fractures and flexures. Furthermore relevant is the alternation of the energy, the incidence of the waves, and the currents, or a combination of both.

C) Accumulation coasts

Low sandy beaches are represent accumulative coastal strips, from continental dominated (coastal plains, deltaic plains, fluvial plains) or marine dominated (barrier coasts and barrier islands). The coastline advanced against the sea.

Patomogenic and marsh costs are coastlines with low energy but with accumulation of fine material. Typical for this coasts are estuaries, and mangrove. This type of coasts stand for slow advanced of the coastline against the sea.

Biogenic coasts are constructed by biological material. They build up by chalky skeletons or similar materials, secreted and harden by marine organism, which live in colonies.

COASTAL DYNAMIC	
A) Erosion coasts	
	Cliffed erosion coasts
B) Mixed coasts	
	Abrasive-accumulative coasts
C) Accumulation coasts	
	low sandy beaches
	patomogenic and marsh costs
	biogenic coasts

Table 3: Coastal Classification according to morphodynamic Criteria (after ORTÍZ et al. 1991)

4. METHODOLOGY

The result of this study should be a complete coastal classification in a medium scale for the northern coast of Yucatan. The following methods were applied: georeferencing of satellite images, for using them in a Geographic Information System (GIS), visual interpretation on the satellite images in combination with topographic maps in a scale 1: 50,000 as well as an on-screen digitizing of the extracted geomorphologic units.

The visual interpretation based on six panchromatic satellite images of the French SPOT-System (**S**ystème **P**robatoire d'**O**bservation de la **T**erre). The images can be received optional in XS-mode (multispectral) and P-mode (panchromatic). Panchromatic images have a higher geometric resolution (10 m); therefore they are used for the interpretation, throughout multispectral data with the near infrared channel are very helpful for the interpretation of vegetation. An interpretation of aerial photos for the complete coastal area of Yucatan with a length of more then 350 km could not be handled.

Satellite images are more up-to-date then any other vector data or topographic maps. For this reason satellite images support the interpretation. Georeferencing of the satellite images is necessary in order to use them in a GIS. The raw format images were transferred into a geodetic coordinate system. In Mexico is used the **U**niversal **T**ransverse **M**ercator (**UTM)** projection. The UTM coordinates are measured from the topographic maps. The identification and the measurement of the control points are essential for the accuracy of adjustments to the UTM coordinates to combine with other layers of information. For the resulting resampling of the satellite image, the original cell size was retained. The images were only used for visual interpretation, so the cubic convolution procedure takes the best optical result. A greytone-

CODE			INTERPRETATION			VERIFICATION	
			SPOT (panchromatic)			Vectorial Data: Topographic maps (INEGI)	Cartography of the Biotope types (Inventario Nacional Forestal)
			Grey tone, saturation	Texture, pattern	Form, size, topology		
III	4	a) **Higher marsh**	medium grey	irregular	Large sized	No specification	Mangrove, Popal, Tular
			dark grey (rare)	regular	circular	"Islands" of dense vegetation	semi-evergreen tropical rain forest
		b) **Lower marsh**	dark grey	regular	larger than III.4.a)	Inundation and flooded land	mangrove
			medium grey with white spots	irregular	close to the transition zone		Halophilic and gypsophilic Vegetation
		c) **Estuaries, channels and lagoons**	black or grey with channel	irregular	well delimited	Channel water body	water body
		f) **Salt pan**	white	regular	close to the water body	marsh (rarely used)	Areas without vegetation
			White with gray spot	irregular, with circular structures	close to the water body		Areas without vegetation or with pseudo "hammocks"
III	5	a) **Tide Channels**	black to light grey (variable)	striae (depend on the deepness and particles in suspension)	vertical to the coast	water body	water body
		b) **Backwater**	black, rarely light grey	irregular with tide structures	extended , circulate	water body (perennial)	water body
		c) **Lagoons**	Dark grey to light grey	irregular with striae	circulate	water body (intermittent or perennial)	water body
		d) **Estuaries**	black to gray	regular to irregular with striae	extended, parallel to the coast	water body (perennial)	water body
		e) **Beach**	white	regular	Strip, very narrow	sandy zone: sand	
		f) **Bays**	black	regular	semicircular	water body	
		g) **Islands**	depend on the type of vegetation	irregular	circular		
		h) **Dunes**	Variance of greytons	Lineaments at close quarters,	extended	Sandy zone: dunes	Vegetation of the coastal dunes
		i) **Swamps and ponds**	white	regular	close to the water body	Marsh	Areas without vegetation
		j) **Anthropogenic forms**	dark tones with an evident spectral edge	Recognizable by rectangular blocks and streets	coherent	Urban areas	Urban area
		k) **High tide beaches**	white	regular, between two bars inbound	extended		
		n) **Tide beaches**	white	regular, without perceivable direction	extended		

stretch is done individual by the histogram. After the adjustment of the images they can be displayed all together in a GIS with other layers of information.

Table 4: Matrix for the visual interpretation of the SPOT-Images

The cognition of objects in a satellite images is a complex process, based on a lot of factors. Greytone, saturation, texture, pattern, form, size and topology are the main factors (ALBERTZ, 2001). Knowledge of these is elementary for any visual interpretation. A matrix for all geomorphologic units and there concurrency factors are shown in Table 4.
With the help of the matrix it is easy to identify and delimit all geomorphologic units in the satellite images. The areas are performed directly on-screen by digitalization. This file could be combining with all other georeferenced data set.
For verification serves two other data sets: a) vector data set from INEGI (is widely identical with the topographical maps in a scale 1: 50,000) and b) the inventory of biotope types (Inventario Nacional Forestal).

5. FIRST RESULTS

The execution of the interpretation with Table 5 is easily accomplished; nevertheless the digitizing is very time-consuming, so that the coastal classification is still in progress. Figure 2 shows a small part of the coastal classification of the far east of the study area (closed to the border for Quintana Roo). This area is dominated by a coastal bar and low sand beaches. Accumulation and dislocation of sand and shell has shaped the littoral. This sparsely populated area is low vulnerable. Inundations threaten salt pans and marshes were neither people live nor any human use is relevant. The dislocation of sand and pebbels can be a problem for the local coasting trade. The harbor of El Cuyo with its defending pier and wall changed lasting the natural dislocation of sand. The normally straight coastline gets a significant kink. El Cuyo itself is situated in the "Reserva Especial de la Biosfera Ría Lagartos", which was founded in 1979. It is protected for his climate, his special geohydrology and accommodates one of Méxicos largest Flamingo colony. Inside the Reserve live only 4,600 people (VALDEZ-CASILLAS, 1993).
The inundation in Louisiana initiated by the hurricane "Katrina" or the devastating storm surges in 2002 in Yucatan let ask for an effective coastal protection. Normally a shoreline, which is undisturbed by mankind will develop its own defences against the permanence of the wave activity. A berm can absorbing the wave energy and stabilized the coastline hereby. Sand dunes preventing overwash and preserve the interior from floods and inundations. Barrier islands and beaches are breached from time to time by storm surges. In unsettled or low populated areas the marine erosion and storm surges are without any significant effects to human life's and goods. The problems occur, when human activity and coastal protection come into conflict. In these cases are controlled protection, sensible planning and meaningful management necessary. ALEXANDER (1999) emphasized the following adjustments for coastal protection: coastal zoning, building codes, storm warning and forecasting system as well as dunes stabilization.
A critical coastal management policy has to go beyond that. BEATLEY et al. (2002) call it "the challenge of sustaining the coast". The population and the development pressure lead to a number of critical problems. Therefore issues are necessary like coastal storm mitigation, shoreline erosion, strategic retreat, beach reinforcement, protection of coastal wetlands, protection of coastal waters, energy development, biodiversity and habitat conservation as well as marine and fishery management. Nevertheless the issues should consider also soft

factors: access to beaches and shorelines, social equity, coastal sprawl, land use pressures, and quality of life.

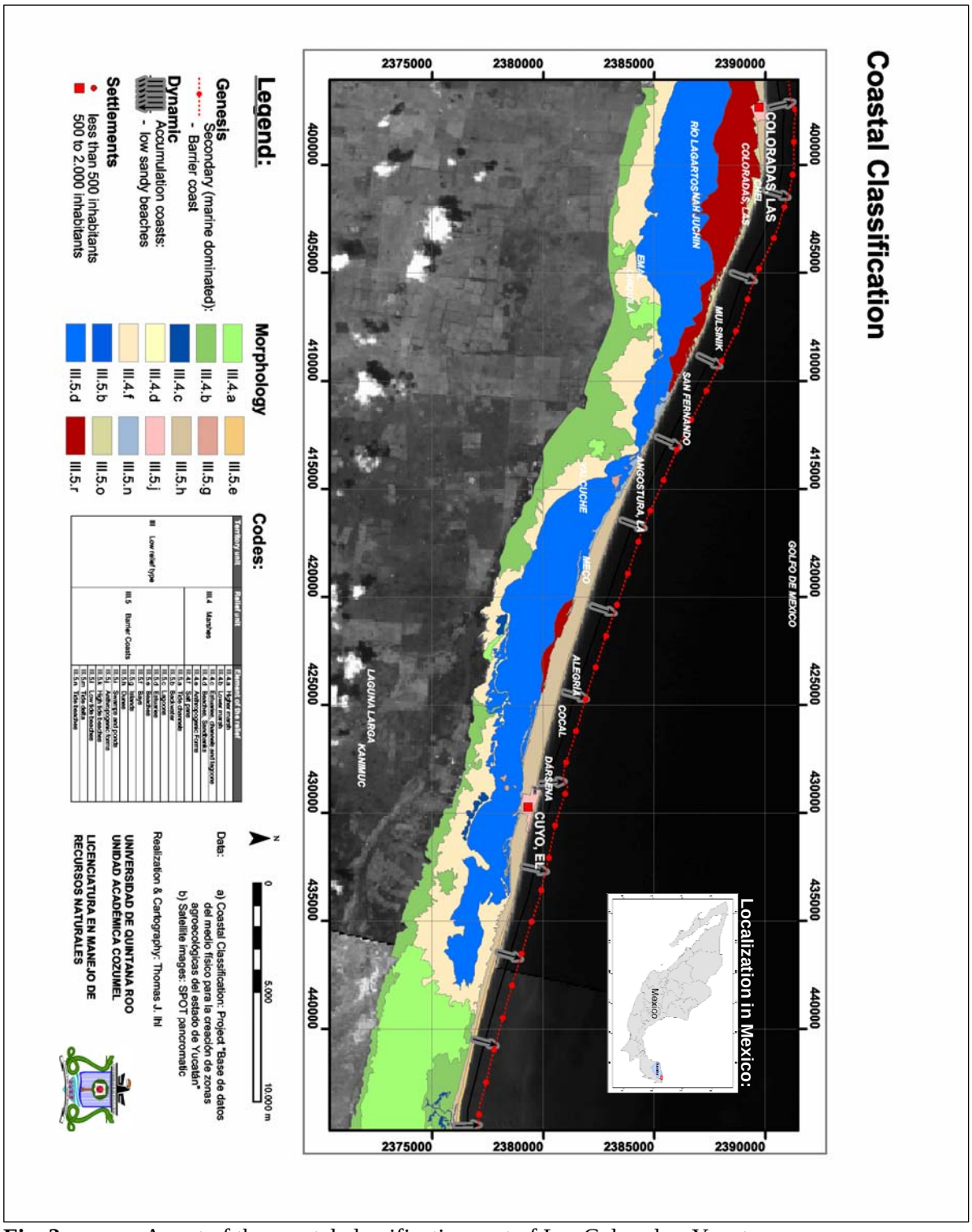

Fig. 2: A part of the coastal classification east of Las Coloradas, Yucatan

All these facts make a critical coastal management unavoidable. A coastal classification, which includes an inventory of the morphologic units, the morphodynamic processes and the genesis of the section can focus on critical regions and give hints for prevention. Through the digital technique it is possible to use the coastal classification includes the geomorphologic units directly in a GIS. Integration of further more specific or thematic data like Digital Elevation Model, protected areas, sanctuaries, development plans, etc., could easily implemented, to built up a complex information system, that related to a helpful tool for the goals of the "integrated coastal management".

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