Landscape transformation in the estuarine region of the Itanhaém river (20 years – period from 1987 to 2007), southern coast of São Paulo State, Brazil

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ABSTRACT. We performed a multi temporal analysis of the landscape scenario in the Itanhaém estuarine region - São Paulo State (Brazil). The data refer to the period between 1987 and 2007, and were provided by the Normalized Difference Vegetation Index (NDVI). The areas were classified as Least Critical (best preserved), Moderately Critical, Intermediate Zone, Critical and Very Critical (most degraded). The results showed an increase in the area corresponding to Least Critical Index, which reflects the recovery of vegetated areas. The abandonment of rural properties and the dynamics of vegetation succession that occurred from 1987 to 2007 represent the degree of effective recovery in the areas. The areas of Critical and Intermediate Zone indexes were enlarged during while the Moderately Critical index had a slight decrease, which indicates continuous expansion and urban densification in consolidated areas with strong interferences, mainly in the seaside zones.

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Introduction

Landscape scenarios result from environmental changes in different regions of the Earth, in several ways, by different people and cultures, according to different social-economic and historical land use processes. However, these processes can generate environmental disequilibrium in various systemic segments; the human activities are the main agent. Fang et al. (2001) reports that the physical and human factors are relevant to environmental analysis. Human impact has become a determining factor to preserve the vegetation cover through activities related to the land use changes.

On the other hand, Forman & Godron (1981, 1986 and 1995), reports that one of the major challenges in land use planning and handling is the sustainable management of the elements that compose the environment. It should be based on transformation dynamics that equally emphasizes environmental and human dimensions of the landscape, considering a time interval that encompasses different human generations. As one of the most significant landscape changes, human occupation has increasing levels of spatial density and lack of structural control in the last decades.

According to the U.S Census Bureau (2009), there were are approximately 6 billion, with a projection of 8 billion people for 2020. An exponential population increase is observed in the world, which consequently requires more areas to be occupied.

In Brazilian coastal regions, mankind faces several forms of spatial restructuring. Flat estuarine areas were once regarded as a matter of territorial expansion; they play a strong attraction to real estate agents who invested in condominia and started the occupation process and urban densification (Yui 2002).

Yui (2002) points out that as coastal areas are naturally attractive land spaces and are located between the shore and the Serra do Mar escarp-

ment, they contribute to the urban expansion phenomenon. Nowadays, urban expansion is considered environmental crime when in areas of multiple interests such as estuaries, springs and watercourses. However, the same author also stresses out that even being considered as Areas of Permanent Preservation (APP, according to Brasil 1965), they are constantly illegally occupied and without any basic infrastructure (water, sewage and electricity). Occupation, according to Villaça (1998), first occurs in the older and better-structured regions of the cities or downstream basins. These areas are in general occupied by higher-income populations. Second, the urban occupation phenomena are then internalized, because the proximity to hilly areas usually directs the occupation of the Environmental Protection Zones such as the Serra do Mar State Park (São Paulo 1997).

The occupation of upstream zones of higher sedimentation, take place in the hydrographic basin landscape scenario, and contributes to a higher inflow of particles due to the removal of the natural cover and the occasional raise of river beds, causing floods and making navigation difficult. The interference on environmental systems has continuously affected the quality and the availability of local water resources and consequently the landscape scenarios of the hydrographic basins that form the Itanhaém River estuary.

The analyses of the systematic changes of the natural cover and their impacts contribute to the understanding and the discussions on the systems and their aspects. The land use coefficient and the subtraction of the standard cover are considered as one of the driving forces of the analysis, which superposed tend to alter the natural environment (Zhang et al., 2003).

A multitemporal study of the spatial cover dynamics is proposed in this paper with the application of NDVI data (Normalized Difference Vegetation Index), prepared for the multitemporal interval between 1987 and 2007. Therefore, the study aims at the characterization of a 20-year landscape transformation to investigate the spatial and environmental changes and their tendencies for the study area.

The objective of this work is to perform a multitemporal evaluation of the landscape transformations both locally and regionally based on NDVI values (Normalized Difference Vegetation Index).

The study area

The study area is located in the hydrographic basin of the Itanhaém River, formed by the connection of the Preto and Branco rivers, and 7 km far from the Itanhaém River mouth, thus including its estuary. Itanhaém region: coordinates S 24º 16' 59" W 46º 47' 20". Fig.1.

The Itanhaém River estuary is located in the southern coast of São Paulo State, Brazil, in the Itanhaém Municipality, forming part of the Baixada Santista. Its characteristics are typical of tropical regions, including social-economic and environmental aspects, mangrove and sandbank vegetation. It is the second largest estuary of São Paulo State, just surpassed by the Ribeira River estuary to the south, close to the boundary of Paraná State. The 3.75 km^2 mangrove area is considered one of the best preserved of São Paulo State, enabling studies of evolution during the Holocene. The Itanhaém River course was modified more than fifty years ago due to the opening of a canal linking the Branco and Preto rivers. Upstream the mangroves, countless sand exploitation sites, many already abandoned, have significantly altered the hydrological profile, forming large lakes (São Paulo 1997).

Consolidated and densified urban occupation, in some localities, has reduced rainfall infiltration, causing floods. Silting may increase the amount of sediments transported from housing lots still being constructed along the riverbeds; the sediments are deposited downstream at the river mouth. This sedimentation contributes to the bottom raise of the canals and during the dry periods it

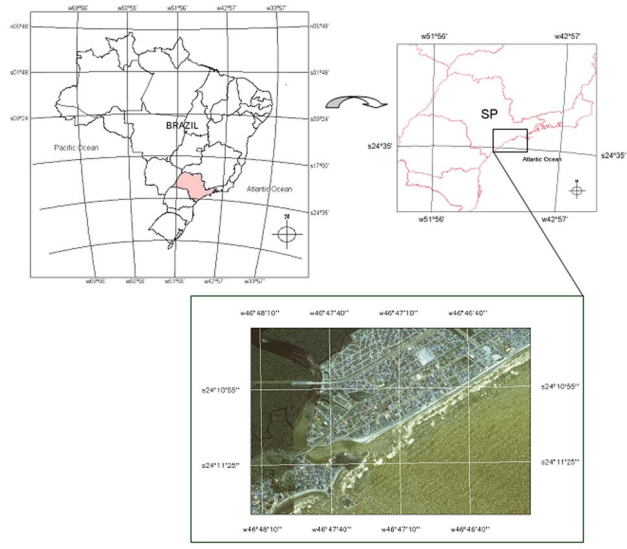

Figure 1. Location of the study area

can promote the influx of saline waters during the tides (very common in the region) in the canals, increases the flooded area. Some parts of the banks of the Itanhaém River and effluents are occupied by thick sandbank vegetation, mostly in primary conservation conditions, which adds plant material (leaves, seeds, pollens, etc.) to the river sediments. In certain areas recent vegetation such as secondary forests and plantations predominate joining the natural mangrove vegetation itself.

The annual average temperature in the whole Baixada Santista exceeds 20 ºC and the annual rainfall varies from 2000 to 2500 mm. The highest annual rainfalls occur during the summer (January to March), being the lowest in the winter (July to August). Despite the absence of a well-defined dry season, the relative humidity in the Baixada Santista is high, averaging 80% (Lamparelli 1999).

In the coastal region of São Paulo State, beaches, mangroves, terraces and isolated massifs occur, are limited to the NW by the Serra do Mar, resulting in contrasting low coastal lands and rocky cliffs. The altitudes in general are lower than 300 m, reaching up to 900 m in parts of the ridge (IPT 1981, Ross & Moroz 1997). According to Zundt et al. (2009), the region is densely urbanized closer to the sea, whereas the Mata Atlântica preservation areas are closer to the Serra do Mar and its escarpments. As a spatial unit, due to its political, social-economic and urban characteristics, it is the second Metropolitan Region of São Paulo State, but was the first to be constituted under the auspices of the 1988 Federal Constitution and the 1989 São Paulo State Constitution.

Method

According to Epiphânio et al. (1990), Vegetation Indexes (VIs) can be defined as linear transformations of spectral bands, generally in the red (R) and near infrared (IRp) ranges. These two bands contain more than 90% of the variation in the vegetation spectral response.

These indexes enhance the vegetation spectral behavior correlating it with the vegetation biophysical parameters. The Normalized Difference Vegetation Index (NDVI) proposed by Rouse et al. (1974) is the most used in spatial studies, being defined by the equation 1:

$$NDVI = (IVP - V)/ (IVP + V) \quad \text{(Equation 1)}$$

Where IVP is the spectral response of the pixel in the near infrared band (Band 4), and V is the spectral response of the pixel in the visible band (Band 3).

The result for areas with dense vegetation will be a very high pixel value. Where water is exposed, it will be negative, once the water reflectance is higher in the visible. For degrading areas and areas with no vegetation the result will be a low pixel value. Exposed sandy soils tend to yield very low radiation index, due to their high reflectance in the red and infrared bands.

The NDVI is the most widely used vegetation index in satellite data processing (Myneni et al. 1995), exploring the vegetation spectral properties, such as absorption of visible wavelengths during photosynthesis and strong reflection in the infrared band. It can be an estimator of the radiation used during the photosynthetic process performed by the leaves, and of the seasonal and interannual variations related to the plant (Stöckli & Vidale, 2004; Stöckli, 2005). The Index also responds to changes in the green biomass quantity, estimating harvest and rainfall in semi-arid areas (Liang 2004). This method has been used in several regional and global applications to the study of the vegetation condition (Bannari et al. 1995).

The Georeferred Information Processing System (Câmara et al. 1996) was used to calculate the NDVI, and LANDSAT 5 bands 3 and 4 (Sensor TM) were integrated by Spatial Language for Algebraic Geoprocessing – LEGAL software (Câmara et al. 1996), (Fig. 2).

Qualitative intervals were proposed to understand the dynamics of the NDVI values. The intermediate interval corresponds to the Transition Zone, where data may be positive and negative, but

```
{
//Declaração

Image banda3("1987");
Image banda4("1987");
Image ndvi("1987");

//Instanciação

banda3= Recupere(Nome="B3r_1987");
banda4= Recupere(Nome="B4r_1987");
ndvi= Novo(Nome="NDVI_1987n", ResX=120, ResY=120);

//Operação

ndvi = 127 * (banda4 - banda3)/(banda4 + banda3) + 128;
}
```

Figure 2. LEGAL software used for preparing the map and the numerical grid values of NDVI. (Spatial language for GIS).

susceptible to intervention. The data were ranked according to five Critical levels of spatial degradation and five (Valério Filho et al. 2005).

1. The Least Critical Interval – Corresponds to areas with preserved vegetation cover and negligible spatial degradation.

2. The Moderately Critical Interval – Empty areas characterized by Degraded Areas, Areas with no Vegetation Cover and Areas in Implementation, but crosscut by a road system. It also included in this interval the earthmoving for housing and for medium or large-scale industry implementation, and the interval characterized by Unconsolidated Urban Areas with Low Occupation Rate is, which correspond to urban land lots in initial occupation process and sparse buildings.

3. The Critical Interval – Characterized by Consolidated Urban Areas with Intermediate Occupation Rate. It corresponds to areas with intermediate occupation rate, encompassing high-standard residential areas, institutional areas, large-scale industrial areas, urban parks, and recreation ranches. In this class open spaces are common, such as gardens in industrial and institutional areas.

4. The Very Critical Interval – Characterized by Consolidated Urban Areas with High Occupation Rate. It encompasses areas with high occupation rates and high density almost totally occupied by buildings with paved and dirty roads.

5. The Intermediate Transition Zone Interval. It is a checkpoint for the analysis of data transition, both to positive and negative values.

Thus, the satellite image treatment procedures, such as Selection, Recording, Storage in Data Banks, Filtering, Enhancement of Contrast, Equalization and Generation of Grids of NDVI Values in LEGAL programming (Câmara et al. 1996) were performed to generate classes above cited.

Results

NDVI (Normalized Difference Vegetation Index) for the year 1987.

The NDVI results for the study area and the aggregated values are presented in Figure 3.

The values for spatial analysis obtained in the NDVI numerical grid were plotted in the intervals of 10 to 10 gray levels and evaluated according to their occurrence (Table 1). The center limit for the data was established in the intervals related to pixel 120 and 130.

The reference for NDVI is inverse to the spectral target responses. In this matter, the greener areas in the map will be close to the maximum

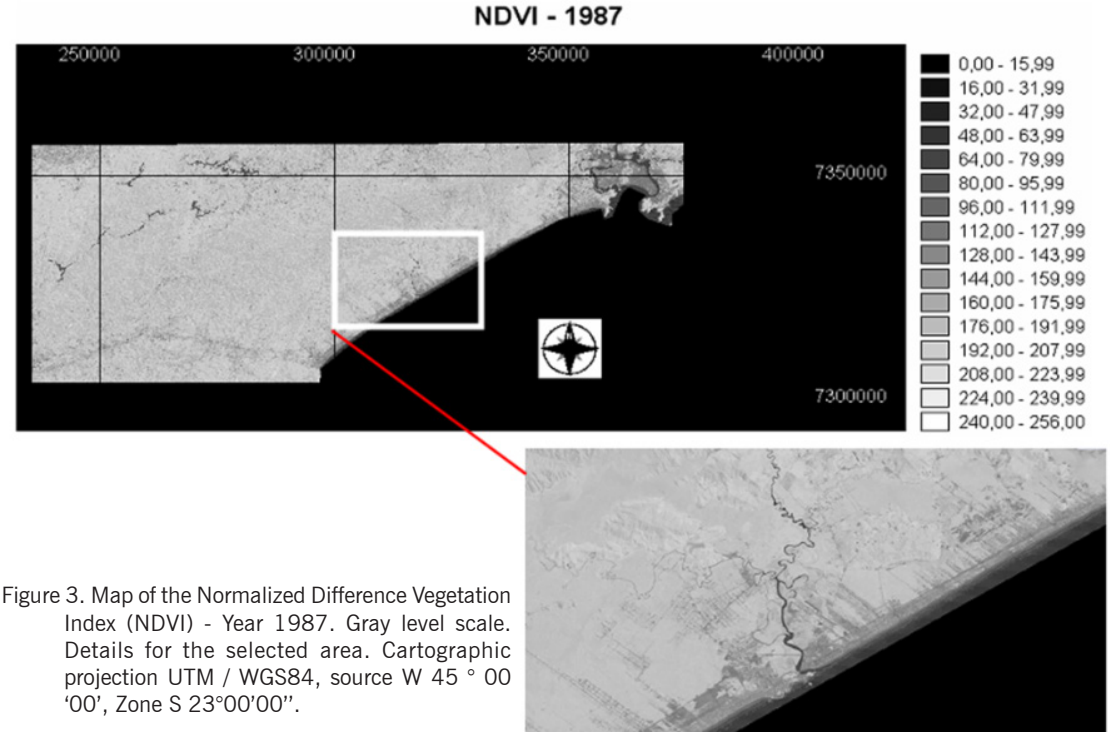

Figure 3. Map of the Normalized Difference Vegetation Index (NDVI) - Year 1987. Gray level scale. Details for the selected area. Cartographic projection UTM / WGS84, source W 45 ° 00 '00', Zone S 23°00'00''.

Table 1. Normalized Difference Vegetation Index (NDVI) - Year 1987

Interval – Year 1987 (Grey level scale)	Class	Lower Limit	Upper Limit	Frequency	%
Water bodies (black)	0	0	9,9999	43381774	87,93
Very Critical (dark grey)	1	10	19,99	26	0,00
	2	20	29,99	42	0,00
	3	30	39,99	110	0,00
	4	40	49,99	398	0,00
	5	50	59,99	10886	0,02
Critical (grey)	6	60	69,99	45491	0,09
	7	70	79,99	50046	0,10
	8	80	89,99	30102	0,06
	9	90	99,99	14619	0,03
	10	100	109,99	13361	0,03
	11	110	119,99	35730	0,07
Intermediate or Transition Zone (light grey)	12	120	129,99	57280	0,12
	13	130	139,99	75881	0,15
Moderately Critical (white)	14	140	149,99	92642	0,19
	15	150	159,99	131121	0,27
	16	160	169,99	219663	0,45
	17	170	179,99	551289	1,12
	18	180	189,99	1451813	2,94
	19	190	199,99	2313415	4,69
	20	200	209,99	830119	1,68
Least Critical (white)	21	210	219,99	30253	0,06
	22	220	229,99	26	0,00
	23	230	239,99	0	0,00
	24	240	249,99	0	0,00
	25	255	259,99	2	0,00

gray level values — 255 and tending to white. The areas with higher spectral response will correspond to lower gray levels than those representing darker colors. The central limits 120 and 130 represent the Intermediate or Transition Zone, so the more the data tend to minimum gray level values, more densified and degraded the areas will be. The opposite will indicate the recovery of such areas.

The values for the Very Critical interval, characterized by more degraded landscapes resulting from the impact of human activities, reached 11,462 occurrences or 0.02% of the total. It is relevant that 87.93% of the values or the equivalent to 43,381,774 of the cases correspond to the 0 - 9.99 interval established for gray level values that characterize water bodies, flooded terrains and seawater. Only 12.07% of the values compose the series to be analyzed according to their spatial transformations in the proposed scale.

The Least Critical level reached 30,281 occurrences or the equivalent to 0.06%. The areas ranked with the Moderately Critical qualitative indicator

Table 2. Normalized Difference Vegetation Index (NDVI) - Year 1987. Percentage of qualitative values

Interval – Year 1987	%
Very Critical	0,02
Critical	0,38
Intermediate or Transition Zone	0,27
Moderately Critical	11,34
Least Critical	0,06

and characterized by Areas in Implementation, Degraded Areas and Areas with No Vegetation Cover yielded the highest values, reaching 5,590,062 in 1987 or 11.34% of the total.

The areas ranked with the Critical indicator summed up to 189,349 occurrences or 0.38%. The Intermediate Zone represents 0.27% of the total. Table 2 summarizes the spatial relationships of occurrences of qualitative values.

The procedure adopted to elaborate the NDVI map for the year 1987 was used for the year 2007 (Fig. 4).

The NDVI values for the year 2007 are listed in Table 3. The data described compose the spatial universe of the local and regional landscape scenarios for 2007.

The values of the Least Critical interval summed up to 36,429 or 0.07% of the total occurrences. The Very Critical level corresponded to 4,559 or 0.01% of the total occurrences.

The Moderately Critical level reached 5,545,367 occurrences or 11.08% of the total.

The Critical interval corresponded to 200,610 occurrences or 0.4% of the total. The Intermediate Zone represents 0.33% of the total. Table 4 summarizes the spatial relationships among occurrences of qualitative values.

Comparative analysis for the years 1987 and 2007

The areas classified as Very Critical showed a drop of 0.01% in the global values with a total frequency of 11,462 for 1987 and 4,559 for 2007.

The values for the Least Critical level increased 0.01% being 0.06 for 1987, and 0.07 for 2007 with 30,281 cases in 1987 and 36,429 cases in 2007 showing an increase of areas recovered.

The vegetation recovery is attributed to the abandonment of agricultural activities and the regain of the natural cover (Fig. 5). The Critical interval varied *ca*. 0.02%, from 189,349 occurrences in 1987 to 200,610 in 2007. The Intermediate Zone values also correspond to an increase in occurrences of approximately 0.05% of the total, with 133,161 cases in 1987 and 167,335 in 2007 due to the insertion of new degraded areas in the local environment.

The values for the Moderately Critical interval decreased from 5,590,062 in 1987 to 5,545,367 occurrences in 2007. Figure 6 presents a graph

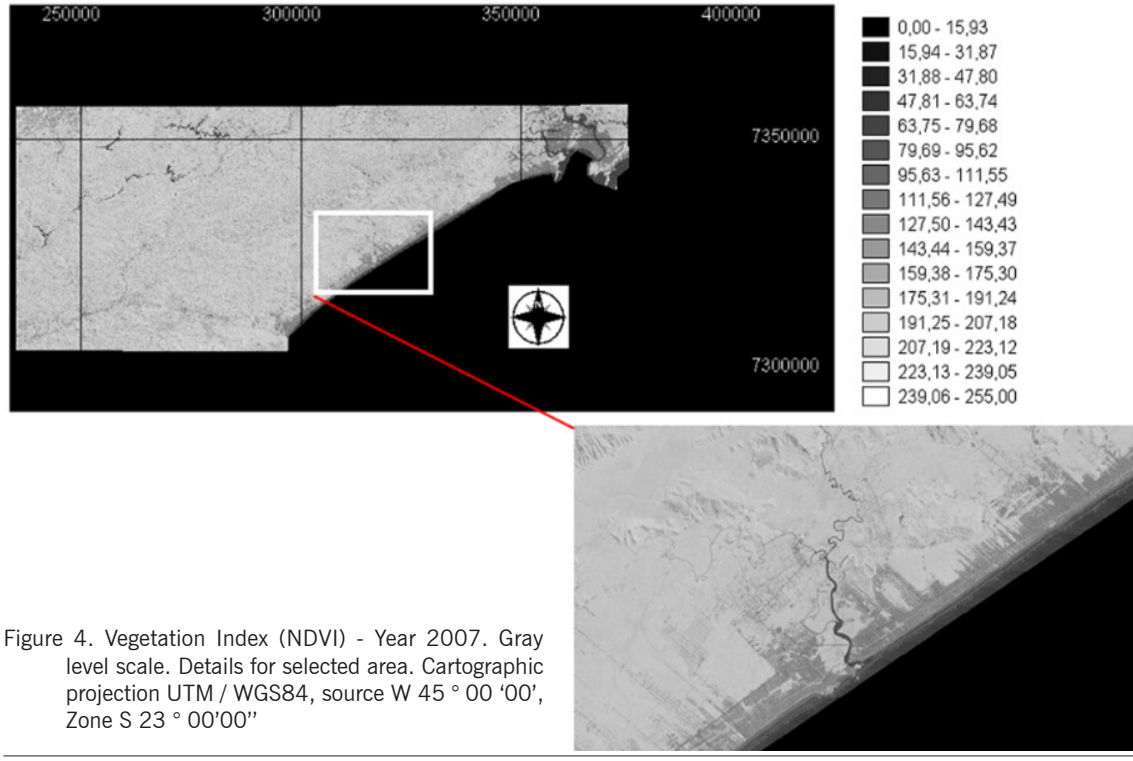

Figure 4. Vegetation Index (NDVI) - Year 2007. Gray level scale. Details for selected area. Cartographic projection UTM / WGS84, source W 45 ° 00 '00', Zone S 23 ° 00'00''

Table 3. Values for NDVI for the Year 2007

Interval – Year 2007 (Grey level scale)	Class	Lower Limit	Upper Limit	Frequency	%
Water bodies (black)	0*	0*	9,9999*	44133100*	88,11*
Very Critical (dark grey)	1	10	19,9999	31	0,00
	2	20	29,9999	21	0,00
	3	30	39,9999	124	0,00
	4	40	49,9999	365	0,00
	5	50	59,9999	4018	0,01
Critical (grey)	6	60	69,9999	22733	0,05
	7	70	79,9999	51412	0,10
	8	80	89,9999	45876	0,09
	9	90	99,9999	19966	0,04
	10	100	109,9999	16019	0,03
	11	110	119,9999	44604	0,09
Intermediate or Transition Zone (light)	12	120	129,9999	91325	0,18
	13	130	139,9999	76010	0,15
Moderately Critical (white)	14	140	149,9999	77622	0,15
	15	150	159,9999	116924	0,23
	16	160	169,9999	231304	0,46
	17	170	179,9999	573529	1,15
	18	180	189,9999	1216412	2,43
	19	190	199,9999	2202966	4,40
	20	200	209,9999	1126610	2,25
Least Critical (white)	21	210	219,9999	36087	0,07
	22	220	229,9999	299	0,00
	23	230	239,9999	13	0,00
	24	240	249,9999	7	0,00
	25	250	259,9999	23	0,00

Table 4. Normalized Difference Vegetation Index (NDVI) - Year 2007. Percentage of qualitative values

Interval – Year 2007	%
Very Critical	0,01
Critical	0,4
Intermediate or Transition Zone	0,33
Moderately Critical	11,08
Least Critical	0,07

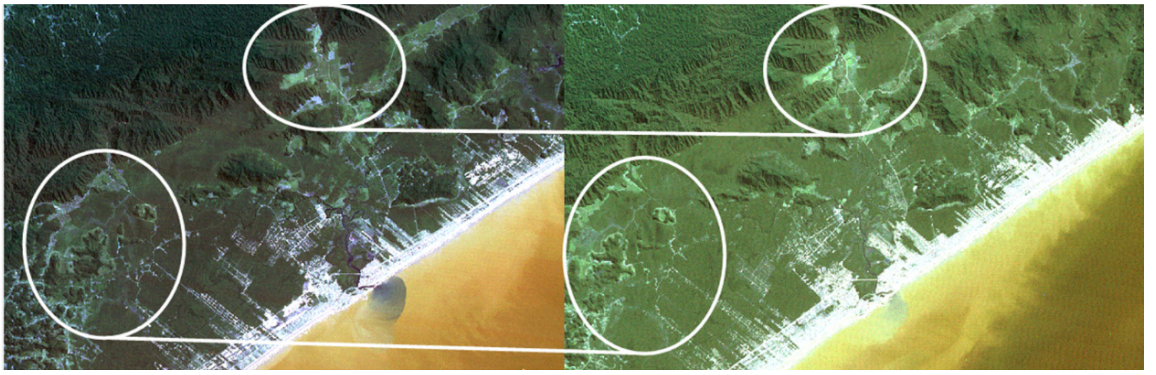

Figure 5. Recovered areas in the landscape scenarios - 1987 / 2007

with the variation of occurrences for 1987 and 2007 respectively.

The total values varied according to the spatial changes of the natural vegetation cover. Between 1987 and 2007, there was an increase in the qualitative indicators in the Critical and Intermediate Zone intervals.

By applying the NDVI method, we observed a tendency to urban densification in areas already consolidated.

The decrease in the Moderately Critical interval values indicates the migration of areas in implementation to densely urbanized and consolidated areas. The increase in the values in the Intermediate Zone can represent the transition of these areas.

The NDVI data indicate that the urban expansion occurs within the already consolidated areas and areas in consolidation. Figures 7 and 8 demonstrate some spatial changes in 1987 and 2007.

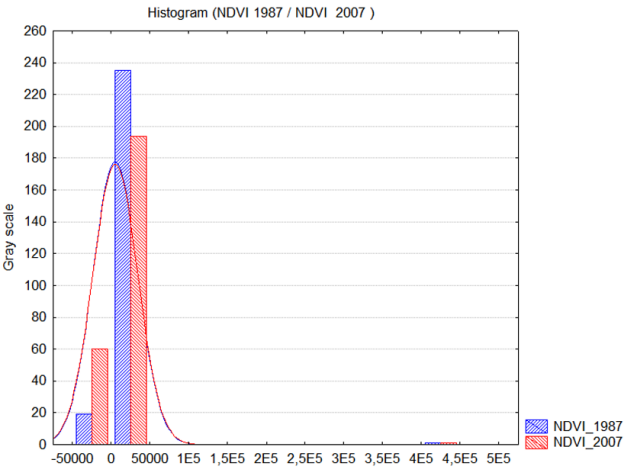

Figure 6. Bar graph representing the volume of records for the years 1987 and 2007

Final considerations and conclusions

Along the 1987-2007 period, there has been a significant change in the landscape scenario; it was well defined by the method adopted in this study, despite attenuations given by the Mata Atlântica exuberance and the distance Serra do Mar – Tide Limit. The urban scenarios are in continuous expansion and show strong inference from densification, mainly in seaside zones characterized by economically more valued areas.

The abandonment of rural properties and the dynamics of the vegetation succession in these areas are expressed by the effective recovery of the buffer zones of the Conservation Units, as well as a

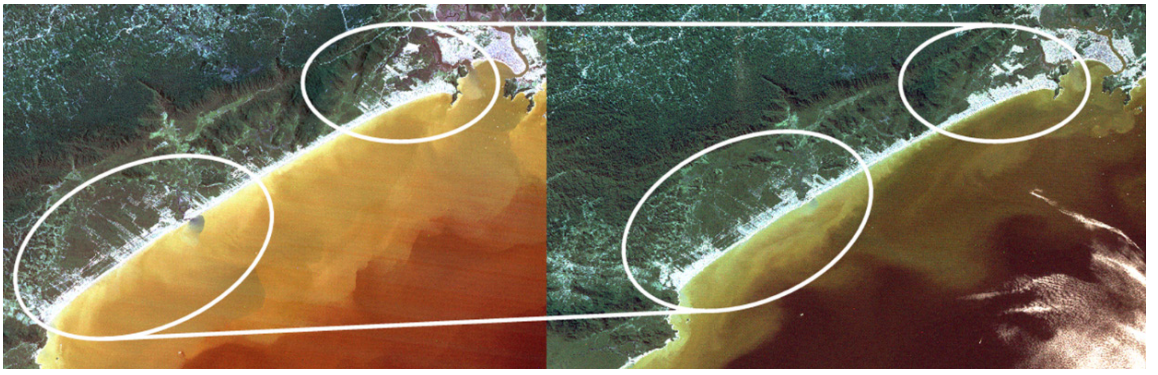

Figure 7. Selected area for comparing the changes of landscape scenarios - 1987/2007. Note the high density of urban areas on coastal strip

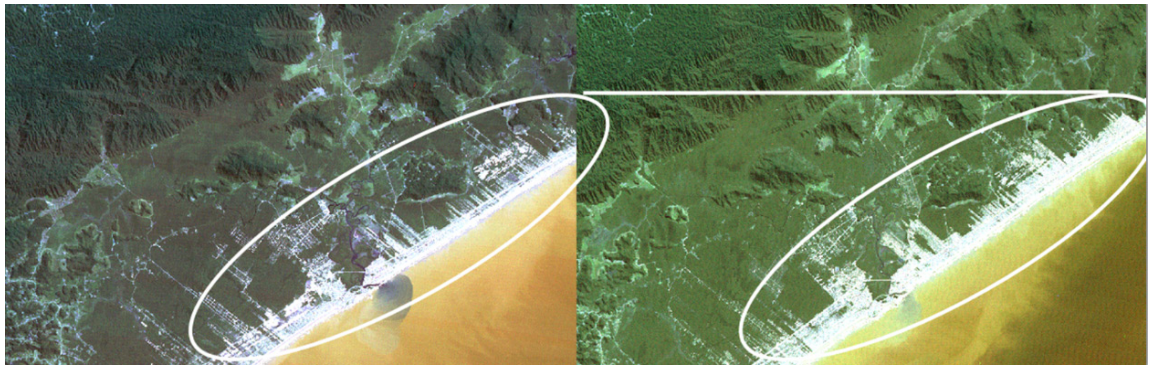

Figure 8. Selected area for comparing the changes of landscape scenarios - 1987 / 2007 - Areas showing an increase of urban density in coastal strip in 2007

change in the economic pattern of the region (from agricultural/extractive characteristics to outsourced activities such as tourism and recreation). On the other hand, there are no public policies regulating occupation and urban housing development, as predicted by the Estatuto da Cidade (Brasil 2001). However, the viability of oil exploration of the Pre-Salt field could alter significantly the local economy dynamics.

According to São Paulo (2010), dozens of enterprises, projects and investment are expected next years, mainly along Baixada Santista and Northern Coast. The implementation and full operation are planned to occur until 2025, amounting R$ 209 billion; introducing approximately 200,000 direct jobs.

The profound spatial transformations can be predicted for local and regional landscape, due to the migration flow that should be recorded with the insertion of these large-scale enterprises. The oil and port demands converge as a major driving force in terms of economic values, technology, generation of jobs and income, which significantly alters the existing local and regional dynamics. However, the request for an effective public policy is fundamental to optimize the process and to provide minor damage to the population, and a better life quality for the present and future generations.

In this sense, the NDVI method is an useful instrument for planning and monitoring the transformations with low cost and effective results.

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RESUMO. Foi realizada uma análise multitemporal da paisagem na região estuarina da Itanhaém - Estado de São Paulo (Brasil). Os dados referem-se ao período entre 1987 e 2007, e foram fornecidos pelo Índice de Vegetação por Diferença Normalizada (NDVI). As áreas foram classificadas como: Menos Crítico (melhor preservada), Moderadamente Crítico, Zona Intermediária, Crítico e Muito Crítico (mais degradada). Os resultados mostraram um aumento na área correspondente ao Índice Menos Crítico, o que reflete a recuperação de áreas vegetadas. O abandono das propriedades rurais e as dinâmicas de sucessão vegetal que ocorreram 1987-2007 representam o grau de recuperação efetiva nas áreas. As áreas de índices Crítico e Zona Intermediária foram aumentadas enquanto que o índice Moderadamente Crítico teve uma ligeira diminuição, o que indica expansão contínua e adensamento urbano em áreas consolidadas com fortes interferências, principalmente nas zonas balneares.

Palavras-chave: análise multitemporal, cenários de paisagem, NDVI, região estuarina.