Environmental Impact in Mangrove Ecosystems: São Paulo, Brazil

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Abstract

The Baixada Santista is at the moment an intensely occupied area by urban and industrial processes and harbor activities. The physiognomic features of Baixada Santista were constituted by a natural environment with different topographic aspects which had important plant communities as the Mata Atlantica in Serra do Mar cliffs, the resting and the mangrove in the coastal plains. This environment was seriously altered by economic growth. Today, the environment quality of the region is precarious, and still under several kinds of pressures.

Due to the industrialization of Baixada Santista in the mid 1950 there was a great contamination of the region by heavy metals, affecting mainly the Santos estuary. One can still find high concentration of heavy metals in the sediments, mainly the mercury, zinc and plumb.

As for the contamination of heavy metals in the mangrove, the three species (R. mangle, L. racemosa and A. schaueriana) presented an accumulation of these substances in their leaves, mainly in the latter. Furthermore, a correlation between the most contaminated areas and the mangroves with the most degraded forest structures was observed.

The mangroves in the region suffered all kinds of pressures such as: fillings, solid waste, changes in the water bodies, industrial and domestic effluents causing chemical and organic contamination. One of the most harmfully and frequent impacts is caused by oil pollution.

A long-term survey has being carried out in the coast of São Paulo State since 1984 after a spill of 2500 tons of crude oil reached the mangrove following a pipeline burst. The study is in progress and monitoring continues. Results so far show that the forest was seriously damaged. Reduction of the basal area was 40% and 20% of the forest density. Loss of basal area was greater for Avicennia, thus this appears to be the more vulnerable species of the tree present in the area. The three species showed a continuous increase of leaf area after the event that caused an initial high rate of defoliation; increase of leaf area was (R. mangle: 18.5%, L. racemosa: 17.7% and A. schaueriana: 27.2%). There was a reduction of herbivore on the three species.

Leaves showed chronic effects such as withering, necrosis, discoloration malformation. Fissured epidermis, dissecation and necrosis of the stem were frequent. Anomalously shaped prop roots were formed and died off before reaching the sediment's surface.

Propagule density was reduced and was accompanied by atrophy and malformation of the remaining propagules. The impacted area was rapidly colonized by new seedlings that grew up to about 1m high; 100% mortality followed when the nutrient reserves of the propagules were exhausted. The growth of seedling into sapling could not take probably because of the presence of toxic residues in the water and soil of the impacted area.
These observations may be used to develop an impact assessment methodology in events of oil pollution in mangrove areas. First, environmental quality. Second, high density of seedlings does not necessarily represent recovery. A better criterion to this is the presence of rooted saplings.

Furthermore, structural responses of mangrove forest to oil are slower than functional responses and can be divided in four post spill phases as follows:

1. Initial effect: no significant structural alteration
2. Structural damage: high mortality
3. Stabilization: few or none alterations in the studied parameters,
4. Recovery: observations indicate that the mangrove area under study is at the beginning of the recovery stage.

Based on this study it was possible to determine the effects of oil spill on the mangrove ecosystems; to develop an impact evaluation methodology; to develop rehabilitation techniques under the environmental conditions prevailing in the study area.

Resumen

La Baixada Santista es actualmente un área intensamente ocupada por procesos urbanos e industriales, así como actividades portuarias. Los rasgos fisonómicos de la Baixada Santista estuvieron constituidos por un ambiente natural con diferentes aspectos topográficos los cuales tienen importantes comunidades vegetales como la Mata Atlántica en los acantilados de la Sierra del Mar, la restinga y los manglares en las planicies costeras. Este ambiente fue seriamente alterado por el crecimiento económico. Actualmente, la calidad del ambiente de la región es precaria, y continua bajo diversas clases de presiones.

Debido a la industrialización de Baixada Santista a mediados de la década de 1950, existió una gran contaminación en la región por metales pesados, afectando principalmente el Estuario de Santos. Aún pueden encontrarse concentraciones altas de metales pesados en los sedimentos, principalmente mercurio, zinc y plomo.

La contaminación de metales pesados en las tres especies de manglar (R. mangle, L. racemosa y A. schaueriana) presentó una acumulación de estas substancias en sus hojas principalmente en la última especie. Además, una correlación entre la mayoría de las áreas contaminadas y los manglares se observó con la mayoría de las estructuras del bosque degradadas.

Los manglares en la región están afectados por toda clase de presiones tales como: rellenos, desechos sólidos, cambios en los cuerpos de agua, afluentes industriales y domésticos causando contaminación química y orgánica. Uno de los impactos más perjudicial y frecuente es el causado por la contaminación por petróleo.

Un estudio de largo plazo llevado a cabo en la costa del Estado de Sao Paulo desde 1984 después de un derrame de 2,500 ton de petróleo crudo alcanzo los manglares seguidos de una ruptura de cañería. El estudio está en progreso y el monitoreo continua. Los resultados así por mucho muestran que el bosque fue seriamente dañado. La reducción del área basal fue 40% y 20 % de la densidad del bosque. La pérdida del área basal fue más grande para Avicennia, de este modo, parece ser la especie más vulnerable de las tres presentes en el área. Las tres especies muestran un incremento continuo del área foliar después del evento que causo inicialmente una alta tasa de desfoliación; el incremento de el área foliar fue (R. mangle: 18.5%, L. racemosa: 17.7% y A. schaueriana: 27.2%). Existió una reducción de la herborizia de las tres especies.

Las hojas muestran efectos crónicos tales como marchitamiento, necrosis, malformaciones y decoloración. Epidermis fisurada, desecación y necrosis del tallo fueron frecuentes. Anómalamente, la forma de las raíces de sostén fueron formadas y murieron antes de alcanzar la superficie de los sedimentos.

La densidad de propágulos fue reducida y estuvo acompañada por atropía y malformaciones de los propágulos restantes. El área impactada fue rápidamente colonizada por nuevas semillas que crecieron hasta casi 1m de altura; seguida del 100% de mortalidad cuando las reservas de nutrientes de los propágulos fue agotada. El crecimiento de la semilla en el vástago no podía tener lugar probablemente debido a la presencia de residuos tóxicos en el agua y suelo del área impactada.

Estas observaciones pueden ser utilizadas para desarrollar una metodología de evaluación del impacto en eventos de contaminación por petróleo en reas de manglar. Primero, el área basal y la densidad del bosque son los indicadores más reales de la calidad del ambiente. Segundo, la alta densidad de semillas no necesariamente representa una recuperación. Un mejor criterio de esto es la presencia de vástagos enraizados.

Además de la respuesta estructural de los bosques de manglar al petróleo es más lenta que la respuesta funcional y pueden dividirse en cuatro fases post-derrame como sigue:

1. Efecto inmediato: sin alteraciones estructurales significativas
2. Daño estructural real: alta mortalidad
Introduction

Throughout the Brazilian coast there is a great variety of wetland ecosystems, however, most of them are suffering a fast and intense process of environmental degradation caused by the urban and industrial settlements. Out of the 25 metropolitan areas in Brazil 14 are situated in estuaries in which the main petrochemical centers and portuary systems of the country and industries lie, causing a major damage to those important ecosystems (Diegues 1987). It is worth pointing out that ecosystem such as the estuaries, lagoons and closed bays where the mangrove dominates, are the most sensitive to environmental impact.

The mangrove area in the coast of the state of São Paulo is 231 km² and 42.5 % of them are located in the Baixada Santista (Herz, 1987). Despite their degradation level and their ecological importance (Rodrigues et al., 1987), there is still a great pressure to convert those wetlands to human uses as agriculture, urban expansion and other activities that cause different environmental impacts.

This region is within the most degraded Brazilian coastal areas because of the presence of a major industrial and portuary center as a result of a fast growth due to economic demands. Although these mangrove areas still present some structural and functional alternations provoked by human activities they do perform an important role in the retention of sediments and toxic substances. Actually, this region benefits from their location for not only does the mangrove retain part of the pollutants released in the rivers but also in the estuary, preventing them from reaching the coastal waters.

According to Lugo (1987), the study of degraded regions is as important as the one preserved ecosystems, once they enable one to understand the ecosystem responses to different kind of stresses. Thus, this knowledge might be applied to prevent, minimize, and evaluate other impacts and even to correct previous ones.

In view of this, the aim of this chapter is present an updated picture of the degradation of the mangrove areas in Baixada Santista in the central coast of São Paulo state, as well as the results of a long-term study of environmental impact.

A summary of the physiognomy of Baixada Santista will be made together with an analysis of the historical development of the land use. In addition, the environmental alterations related to heavy metal and oil contamination will be described. To conclude the chapter a study case is presented describing the long term effects of oil spill on a mangrove ecosystem and discussing an impact evaluation methodology.

The Coast of São Paulo: Features of the Region

Location of Baixada Santista

The Baixada Santista is located on the coast of São Paulo state in the southeast of Brazil, under the Tropic of Capricorn (between 24° 50'S, 46° 45'W and 23° 45'S, 45° 50'W). The so-called Baixada Santista is the region that goes from Bertioga, in the northeast, to Mongaguá, in the southwest and from Santos, on the coast, to the interior, until the cliff of Serra do Mar (Goldenstein, 1972).
Climate Features

The region presents hot and wet coastal climate as indicate the yearly average temperature of 22°C, and the high rainfall rates between 2,000 and 2,500 mm. The temperature ranges from 38°C to below 10°C.

The relative humidity of air is high, reaching more than 80% during the year. The rainfall is higher in the summer (January-March) decreasing in the winter (from July-August), but without a real dry season (Santos, 1965) (Fig. 2).

Geological and Topographic Features

The Santos Coastal plain forms a crescent 40 km long and up about 15 km wide that is limited by the Mongaguá mountains to the south and the rocky portion of the Santo Amaro Island to the North. In the central and northeastern parts, the coastal plain drained by lagoonal and tidal channel systems that isolate São Vicente and Santo Amaro Island (Suguio and Martin, 1978).

Practically in all the extension of this part of the Brazilian coastline there are uncontestable records of ancient sea levels higher than the present. These records can be correlated to two different transgressives episodes: the Cananéia transgression (120,000 years BP) and the Santos transgression (8,000 years BP).

During the first regression the sea reached as far as the foot of the Precambrian crystalline rocks along the entire coastline. Shallow marine sands were deposited within extensive bays located at the present sites of Santos and other coastal plains. During the following regression, hydrographic systems established on these deposits eroded deep valleys. When the last transgressive phase occurred, the sea initially penetrated into these lower-lying zone thereby
creating lagoonal systems. Simultaneously, the higher portions were eroded by the transgressive sea and the products of this erosion contributed to the Holocene marine deposits (Suguio and Martin, 1978).

The combination of these events gives to the Baixada Santista two different kinds of geomorphological compartments. There is a sharply contrasting topography which is composed by high cliffs together with coastal plains (Fig. 3). The first one is constituted by crystalline basement and the second one is a result of recent marine and riverine sedimentation processes. These quaternary deposits receive the fresh water input of the rivers that run down from the Serra do Mar (Goldenstein, 1972).

**Hydrology**

The proximity to the Serra do Mar makes the rivers flow fast and intensely, losing this energy when reaching the coastal plains which have little or no declivity, slowing down the flow. As a result, streams and creeks are formed making a complex hydrological network, transforming vast regions in wetlands. That is where mangrove lies (Goldenstein, 1972).

**Vegetation**

There are three main plant communities in the coastal area which occupy adjacent environmental areas with different features: the Mata Atlantica, the restinga and the mangroves (Fig. 4). The Mata Atlantica occurs in the Serra cliffs that overlook the sea, whose topography acts as a climate barrier where the high relative humidity and rainfall remain. The main feature of this rain forest is the fact of being exposed directly to the maritime influence. In this forest the covering is dense and continuous. Most of the trees are 20 to 30 m high. The other strata are less representative. There is also a great number and variety of epiphytes and vines.

As a result of the devastation for land uses in State of Sào Paulo approximately 5% of the original rainforest remains due to its location on the steeper cliffs. There are also some remaining areas in the inland sectors. The Mata Atlantica in Sào Paulo State occupied originally 753 km$^2$, occurring in 55% of the Baixada Santista area. There is still 43% (319 km$^2$) which has preserved its original characteristics, and 232 km$^2$ of them are located in the Bertioga region representing 73 % of all the remaining...
original Mata Atlântica in the Baixada Santista. Besides, 31% (226 km$^2$) of the original forest is now replaced by secondary forest in an advanced state of succession, mainly in the areas where there were banana crops, 142 km$^2$ of which are located in Santos and 74 km$^2$ are very degraded. Furthermore, 116 km$^2$ which correspond to 16% of the original Mata Atlântica area are occupied by urban, industrial and other human activities. Generally speaking, the areas of Mata Atlântica which remain preserved are located mainly in the mid and high cliffs of the Serra do Mar an the secondary forests and degraded areas are located in the low cliffs and the isolated hills in the coastal plain (CETESB, 1991). As a result of the devastation for land uses approximately 5% of the original rainforest remains due to its location on the steeper cliffs. There are also some remaining areas in the inland sectors.

As for the restinga, the plant communities are varied, sharing the same sandy soil, poor in organic matter and clay and located close to the beaches, beach-ridges, dunes or lagoon banks. There are restinga forests mainly in the larges plains such as Juréia and Itanhaém, on the south coast.

The restinga forests are from 6 to 15 m high without a defined stratification. Near the sheltered beaches the trees are smaller and shaped by the marine spray effects, whereas near the larger beaches there is a dense transitional shrub strip, and close to the sea there is an herbaceous vegetation which colonizes the dunes.

There is still (90 km$^2$) 22% of the original restinga forest of Baixada Santista that remain with the same physiognomic structure and species composition. From these, 88 km$^2$ are located in the Bertoga Coastal plain. The remaining 78% (232 km$^2$) are very degraded and 78 km$^2$ are at the secondary succession stage with arboreal size; 83 km$^2$ are very degraded mainly due to deforestation, sand extraction and to the industrial pollution, presenting only shrubs and herbaceous vegetation. The other 162 km$^2$ are occupied by urban, industrial and rural activities (CETESB, 1991).

The constantly flooded lands, mainly by the tides and also by the rivers, constitute an appropriate area for the development of mangroves. This condition occurs due to the great amount of rivers on the coastal plain under the influence of the tides and the high rainfall which increases the input of sediments and nutrients, besides reducing the salinity. The location of the region close to the south limits of the Brazilian mangrove distribution (Laguna 28° 30' S in Santa Catarina, Cintron and Schaeffer Novelli, 1983) has to be taken into account once it makes the mangrove structure less developed, probably related to lowest temperatures.
Figure 4. Alterations in the plant communities of the Baixada Santista (modified after CETESB, 1991)
The total extension of Baixada Santista is 1329 km² and 10% of this area was tidal plains originally occupied by mangrove forests. At the present moment 40% of these forests are well preserved and they are mainly located in Bertioga’s region, and some in São Vicente’s region (CETESB, 1991). The degraded mangroves totalize 31% (42 km²), mainly in Santos region. The most degraded mangrove forests whose alteration is clearly related to industrial pollution are concentrated in the region of Santos estuary. The degradation of this region is mainly due to oil spills and the influence of the Cubatao and Mogi rivers whose waters receive a great load of industrial and urban effluents and the waters of the Billings, coming from the power plant of Henry Borden (CETESB, 1990a).

Mangrove Features

A study carried out from 1982 to 1986 in 33 different mangrove sites has shown that forest height ranges from 4.50 m to 13.20 m, the average being 8 m. The forest density varied according to the degradation of areas, ranging from 600 to 3,800 trees per hectare and from 900 to 5,800 number of stems per hectare. As for the average diameter, a variation of 3.60 cm to 12.75 cm was observed together with a total basal area of 3.593 to 31.126 m² per hectare. The large range of variation was observed among the seedlings and saplings density, being from 0 to 23,200 and from 0 to 5,200 per hectare respectively (CETESB, 1988).

As for the leaves size, the average lengths in the different sites ranged from 7.6 to 11.38 cm for R. mangle, 5.91 to 10.66 cm for L. racemosa and 6.20 to 8.83 cm for A. schaueriana. The average widths for each species were 3.48 to 5.26 cm for R. mangle, 2.91 to 4.35 cm to L. racemosa and 2.86 to 4.24 cm to A. schaueriana. The average leaf areas were 20.65 to 36.46 cm² for R. mangle, 12.54 to 27.94 cm² for L. racemosa and 10.49 to 18.75 cm² A. schaueriana. (CETESB, 1988)

The cluster analysis of the different mangrove sites of Baixada Santista, according to these structural features showed groups of mangrove forest with different degrees of degradation. The analysis of the distribution of these groups indicated that elements of the same group are not found necessarily close to each other although there is a concentration of them in some places in particular.

It followed from this observation the delimiting of a transverse area (direction northeast-southwest) between the region of São Vicente and Santos estuary (Fig. 5), which presents a higher concentration of highly degraded mangrove areas, whereas the south of the São Vicente estuary and to east, near Bertioga, there is less degraded areas. It is hard to tell to what extent the human activities affect this distribution once this region is exposed to several impacts. It is worth mentioning that Cubatao is in the very heart of the area where the most degraded mangroves are. Beside that, the rivers that cross the main industrial complex situated in the north of this area flow directly into it.

![Figure 5. Distribution of less degraded mangrove forest (groups 1 and 4) and the highly degraded mangrove area (groups 2 and 3) with the industrial complex of Cubatão](image-url)
Taking this into account one could assume that the precarious state of conservation of the mangroves situated in this area is a consequence mainly of the environmental changes caused by the existence of this industrial complex.

The plant community in this region is thus highly altered by human activities. To have a clearer view of the causes of these alterations in natural ecosystems, mainly the mangroves, a brief historical background of the human occupation in this area will be described in the next item.

**Land Conversion to Human Uses**

In the last century the Baixada Santista has been going through deep changes, with marked influence in the economic and social picture, not to mention alterations in the landscape and environmental quality. A brief description of this process is made below, based mainly on the information given by Goldenstein (1972) and Branco (1984).

In this region the indian has always made a living from fishing, shellfish harvest as shown by the "sambaquis" or shell-midden (archaeological site where shells and skeletons were found) hunting and some roots crops (mandioca). The Portuguese brought the cattle, cane and cereals cultivation and sugar mills.

Later with the development of cattle raising to slaughter, tanning spots started to crop up, specially in the region of Cubatao, close to the mangroves, particularly on the grounds of the tannin organic compound, found in the leaves and bark of the mangrove and still largely used in leather preservation due to its bactericidal properties although recently substituted by synthetic products.

In spite of the inadequate soil, the large extension of lands available and the low demographic density favored the installation of fruit crops mainly the banana. The banana turned out to be the most important product of the region, occupying large extensions of lands and the local labor force and being the raw material in the manufacturing of sweets. These factories belonged to a first industrial period of the region together with the tannin, aniline, fertilizers and paper factories.

In the early 60s, the urban and industrial boom together with the building of new roadways gradually took over the banana crops (Franca, 1965). The Santos port played an important role to the development of the region acting as a compulsory way to all the goods to be commercialized, enhancing the area as a whole.

Through the port the export of sugar started to flourish being the main product until the 1850's. Later there was an expansion of coffee crops in São Paulo State, becoming this a main export product in Santos port until 40's, this situation being changed by the industrial development.

In 1949, the government decided to build a large oil refinery, with capacity of 45,000 barrels per day. The Baixada Santista was chosen for a number of reasons. The existence of roadways, railways and sea, the proximity to the biggest consumers spot of the country, the electrical facilities and finally the political reasons.

Twenty years later the refinery of President Bernards doubled its capacity, reaching the production rate of 115,000 barrels per day. Needless to say it brought together the establishment of chemical industries, constituted by a group 20 factories, most of which had as its raw material products or subproducts of the refinery and some being located there only because of the proximity to the port.

In 1959, the COSIPA works (Companhia Siderurgica Paulista), i.e. steelworks, were launched. This huge establishment was located in a plot of 5 million square meters, between the Serra do Mar, the estuary (Largo do Canu) and the mangrove. Part of this area was constituted by dry soil, most of which was used to grow banana and palm trees, the main activity in Piaçaguera region. As for the mangrove areas, there was an expensive and harmful process of filling, due to the technical difficulties.

Much in the same way as all the previous big enterprises in the area, non attention was given to the environmental and social impacts that might have happened. As a result, there was a great migration, with a great influence on local customs, society and on the landscape itself.

By the end of the building works, the area was left with a great number of unemployed, homeless and poor people and environmental problems. Therefore, the Baixada Santista was loaded by social problems, mainly habitational ones. It all started in the late 40's, with the building of the first modern roadway which linked São Paulo to Santos, being increased by another roadway in the 70's. It followed from that an increasing process of inappropriate occupation starting in the Serra do Mar cliffs with most of the people living in slums and spreading to unhealthy spots in the mangrove, frequently flooded.

The Baixada Santista has shown an intense urbanization as a result of the industrial, the portuary and the tourism development. Cubatao has 84 industrial spots at the moment, 30 of which are regarded as highly pollution by CETESB. In Santos and São Vicente the most important urban concentrations of the Baixada are found, with no primary industries besides the
Santos and São Vicente bays normally have an increased population at the weekends and on holiday, mainly during the summer. This particular feature of the region brings about serious problems to the basic services and overloads the sanitary infrastructure worsening the organic fecal pollution in the area. (CETESB, 1978a).

One has to consider another important aspect, the atmospheric conditions, extremely unsuitable for the pollutants dispersion. This fact is worsened by the topography that is, the cliffs which surround the valleys, where the city and industries lie. It is clear to see the lack of social and environmental plan in the industrial installation, resulting in a totally altered landscape. There is also a political choice for the sake of a fast development at the expense of the environment and its natural resources.

Heavy Metal Contamination

The inorganic industrial waste composed basically by heavy metals do not degrade and although they can be diluted in the long run they will always be responsible for an environmental damage even if the source has ceased to operate. The intense occupation and industrialization of the region has launched an enormous amount of waste into the environmental, amongst which the heavy metal. If found in high rates they can be harmful to the organisms and bioaccumulation can occur in the several levels of the food web. Thus, a historical background to this contamination will be described in the three regions of the Baixada: Santos and São Vicente estuaries and Santos bay.

Sources of Heavy Metal Pollution

The installation of Presidente Bernades refinery in Cubatao and consequently of other industries in the region in the mid 50's, started a serious problem of environmental contamination. The inorganic industrial waste composed mainly by heavy metals was released in the water bodies of the region, most times without any kind of treatment.

This industrial complex which is composed by several activities the chemical (Hg and Cr), paper (Hg), fertilizers (Cu, Pb, Hg and Cr), chlorine (Hg), styrene (Hg and Cr) and steelworks (Cd, Pb and Zn) constitute the main sources of heavy metals (CETESB, 1978a, b).

The first studies concerning the environmental contamination by heavy metal in the region started in 1974 and showed a high level of contamination (Pereira et al. 1975; CETESB, 1978a; Tommassi, 1979; Tables 1 and 2). The metals whose values presented themselves beyond the aquatic organisms' preservation criteria were the Hg and Pb for the water and the Cu, Hg and Zn for the sediment. As for the sediment, it can observe a negative gradient concentration for the three metals from Santos estuary to São Vicente and Santos bay.

Five years later, the mercury concentration in the water was also high (Boldrini and Pereira, 1987) with average values beyond the aquatic organisms preservation criteria for brackish waters which is 0.1 μg/l (CONAMA, 1986; Table 2). As for the sediment, there was a contamination in the region by cooper, zinc and mercury, once for the these metals the values went beyond the aquatic organisms preservation criteria (Tables 1 and 2). One could also observe a gradient of decreasing concentration of metals in the sediment from Santos estuary to São Vicente and Santos bay.

Thus one can observe that for five years, the picture of contamination in Baixada Santista has not been largely altered. It was not before the state government got alarmed by this high level of pollution in the waters of Baixada Santista, that there had to be a better control of industrial waste, maximizing the usual monitoring mainly after 1984. Based on the data from CETESB (1987), as far as the quality of the waters in the watershed of Cubatao river are concerned, there were significant reduction in the amount of waste released in the waters, from 1984 to 1986.

As for the concentration of heavy metals, it was reduced in 97 % in the period analyzed, falling from 4,000 to 120 kg/day. This value remained the same after 2 years (CETESB, 1990b).

Due to the improvement in the quality of the waters in the Cubatao River, fish, shrimps and other aquatic organisms started to flourish which was worrying because of its unsuitable food value (Boldrini et al., 1989). Previous studies had already shown the accumulation of these metals in organisms in the Baixada Santista. Concentration beyond the human consumption criteria for Cu, Hg, Zn and Cd (Nauen, 1983 in CETESB, 1990a) were found in the fish muscles and viscera, from 1979 to 1980. Thus other measurements of heavy metal in Cubatao River and Santos estuary (CETESB, 1990a) were made and values of concentration of Cd, Pb, Cr, Fe and Hg beyond the aquatic organisms preservation criteria were found for the water and as for the sediment some spots were regarded as highly polluted, according to Bowden classification (in Prater and Anderson, 1977) concerning the Ar, Pb, Hg and Zn.
### Table 1. Calculated average values in study sites from cited references

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### Table 2. Calculated averages values of Hg in study sites from cited references

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1. Pereira et al. (1975) data from 1974; 2- CETESB (1978) data from 1974; 3- Boldrini and Pereira (1987) data from 1979; 4- Tommasi (1979) data from 1974; 5- CETESB (1990a) data from 1989. EC - Established criteria for the aquatic life preservation; ND= not detected; + = only one sample; (a) CONAMA (1986); (c) Vucetic et al. (1974 in SEMA, 1980)
An analysis of the average data in the concentration of mercury and zinc in the sediment of Santos estuary showed that both have gone beyond the aquatic organisms preservation criteria (Tables 1 and 2). As for the aquatic organisms, values of concentration of Cu, Hg, Zn, Cs and Pb were found in the fish muscles and viscera that have gone beyond the minimum human consumption criteria established by national and international laws.

The metal found in high concentrations in sediments since 1974 as the Cu, the Zn and the Hg, were also high in aquatic organisms. This shows how important it is to consider the concentration of metals in sediments once, generally speaking, the highest concentration is found in Santos estuary, next in São Vicente estuary and Santos bay. This is due to the location of the sources of industrial waste which are placed mainly next to the high Santos estuary, reaching also São Vicente estuary. Santos bay, because of its further location from the pollution sources is least affected region.

Furthermore, one could observe that even after the reduction of the release of heavy metal from industrial sources, this problem, which started decades ago with the industrialization of Baixada Santista is still present in the region and will continue for quite a long time.

Heavy Metals Concentration in Mangroves

The metals reach the mangrove in two main interchangeable forms: diluted fraction and particulate fraction. The physical-chemical features of this environment cause several transfers between the two fractions.

The increase of the water pH and its ionic power and salinity, together with a decrease in the speed of the river flow when reaching the coastal area, causes the precipitation of several diluted metals and accelerate the deposition of particles (Lacerda and Rezende, 1984). Thus, the mangrove can concentrate these metals in the sediment.

Studies carried out by CETESB from 1982 to 1986 (CETESB, 1988) in mangroves of Baixada Santista (Santos estuary, São Vicente and Bertioga regions) show concentrations of heavy metals such as Cr, Cu, Cd, Pb, Hg and Zn, in the sediment (Table 3) and leaves of the mangrove (Table 4).

This study shows that the concentrations of Hg were higher than the criteria established for marine sediment of 0.1 μg/g (Vucetic et al., 1974 in SEMA, 1980) in 97% of the sample sites, the highest ones being found in Santos estuary mainly for the sites next to the industrial complex of Cubatao, reaching 1.60 μg/g in Cascalho river.

As for the concentrations of Zn in the sediment it was shown that in 76% of the sites they were higher than the criteria established for marine sediments of 20.0 μg/g (Chester, 1975 apud SEMA, 1980), the highest ones being 188.0 μg/g in Santos estuary.

As for the concentration of Pb in the sediment, it was observed that in 45% of the sites they were higher than the criteria established for marine sediments of 20 μg/g (Chester, 1975 in SEMA, 1980). Although this contamination was found in a larger number of sites in São Vicente, the highest concentrations were found in samples collected next to Cubatao, in Santos estuary, reaching 76.2 μg/g.

The concentrations of chrome in the sediment for the three studied areas varied from 0.62 to 40.60 μg/g, the highest one being found in Onça river in Santos estuary.

In the same site, the highest concentration of Cu (29.6 μg/g) was found and among the sample sites in only 12% of them the criteria established for marine sediment of 10 μg/g (Chester, 1975 in SEMA, 1980) was surpassed.

The concentration of cadmium in the sediment was below the criteria established of 5 μg/g (Chester, 1979 in SEMA, 1980).

The analysis of average concentrations in the three studied areas (Table 3) shows that in Santos estuary, where the industrial complex lies, the highest levels and variability were found.

The mangrove sediments contamination by heavy metals was also observed in other regions of the Brazilian coast as Rio de Janeiro, where some of them presented higher values than the Baixada Santista. In Enseada das Graças for instance the Cd concentration was 0.50 μg/g and as for the Zn in Coroa Grande it was 188.0 μg/g (Lacerda and Abrao, 1984). As for the Cu and Cr in rio Irajá the values reached 15.4 and 80.5 μg/g respectively (Lacerda, 1982).

As the concentration of heavy metals was high both in the waters and sediments of the mangroves, this also happened to the leaves of the three species. According to table 4 one can observe that the species which presents highest concentration values of heavy metals was A. schaueriana. As for the other two species, L. racemosa concentrated more Pb, Cr and Zn whereas R. mangle presented higher concentrations for Cd, Cu and Hg. It’s worth pointing out that cadmium concentration were similar for the three species.
Studies about heavy metal concentration in mangrove leaves (Lacerda et al., 1986) carried out in southeast coast of the three species when compared to Baixada Santista values showing that the mangroves of this region are very polluted by this metal as for the Zn the concentration were similar for the two regions. On the other hand the Pb values for the Baixada Santista mangrove leaves were lower.

The different heavy metal contents in the leaves of the three species can be accounted by their physiological adaptation to develop in substrates of high salinity, with different mechanisms of osmotic regulation (Mizrachi et al., 1980).

The low concentration of metals in R. mangle tissues can be related to its capacity of excluding salt other substances in the root absorption. However A. schaueriana performs only a partial exclusion in the roots, completing its osmotic regulation by releasing the salt through the leave surface. Thus, this mechanism facilitates the transport of metals to the leaves,
which would account for the high concentration of these substances found in this species.

Analysis of contamination of heavy metals and structural features of mangrove forests showed that the most contaminated forests (Fig 6), (CETESB, 1988) show most degraded structures.

Moreover, highest concentrations of heavy metals of the region were found in the transverse area of the most degraded mangroves delimited through a cluster analysis. This confirms the fact that these areas receive large amounts of industrial waste, which reinforces the hypothesis suggested (in vegetation) that its present state of degradation is mainly a consequence of this situation.

It is worth pointing out that the least degraded sites are located in the mid and low estuaries, which could be related the minor influence of pollution sources and a bigger action of dispersion due to the tides.

**Oil Contamination**

Due to the great frequency of oil spills on the Brazilian coast its main sources and causes will be described and analyzed in this item together with a study case where the oil effects on mangrove have been registered through a long term monitoring. This analysis is based on data of the forest structure and field observations registered in 7 years.

**Sources of Oil Pollution**

On the coast of São Paulo state, there are several sources of oil pollution, mainly in the ports and oil terminals. The oil release in the sea can happen in many ways, some through the loading and unloading of the ships which are regarded as ordinary and represent 96% of oil spills. The remaining 4% are caused through accidents (Branco and Rocha, 1980).

It is in Baixada Santista that most of the accidents in São Paulo estate happen, reaching 19% of the total, being Santos and Cubatao the most affected by this kind of pollutant (Awazu, 1985). From January 1980 to February 1990, 71 accidents involving oil and derived were reported in this region (CETESB environmental accident file), from which only 45% had an estimate of quantity of oil released, which amounts to 5,300 m³.

The ships themselves were responsible for 59% of the accidents whereas the pipelines, the reservoir-ships and industries for 11.5% each. Besides the accidents, which release great amount of oil in the environment, one cannot forget the continuous input of oil and grease from industries.

Once the mangroves are placed near the coast, where the most of the spills happen, they are constantly affected by this pollutant. Based on studies of the oil spill effect in coastal areas. Gundlach and Hayes (1978) classified the main coastal environments according to their vulnerability to oil. This classification is based on the residence time of oil in the environment and takes into account the initial biological impacts. Sheltered coastal areas as mangrove are regarded as the most sensitive to this kind of impact for being seriously affected by oil. This is due to the residence time of oil in mangroves which can be more than 10 years with a estimated recovery time of 20 years. In order to better understand the ecosystem response to the oil impact a long term monitoring in the mangroves in Baixada Santista was carried out and will be described below.

**Oil Effect on Mangroves: a Case Study**

A long term survey was initiated in the coast of the São Paulo state after a 2,500 ton pipeline crude oil spill in 1983 reached the mangrove. The aim of this study was to determine the effects of oil spill on the mangrove ecosystem. The results presented in this chapter are from the first 6 years monitory (1984-1989).

Bertioga, situated at 23°51'S 46°08' W, where this study is being carried out, has large mangrove area which when compared to Santos, Cubatao and São Vicente (in Sources of heavy metal pollution) are less degraded.

Bertioga Channel is the main water course, around 25 km long. This tidal channel has its west mouth in the Porto Channel, situated in the mid estuary while, next to Bertioga city its east mouth, the tidal, connects with the ocean, making the tidal flow more intense in this area (Fúlfaro and Ponçano, 1976). The border of this channel is dominated by large mixed mangrove forest of three species: *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia schaueriana*.

In the border of Santo Amaro island (Fig. 6) there is a narrow band and very little is left of the original forest, mainly due to the fillings for the construction of harbors. On the other hand, the continental border which is large, and more difficult to get to, has mangrove areas spreading along the river banks with developed and more conserved forest.

In order to carry out this research, a sample area in the left bank of Iriri river, which was strongly affected by the oil spill which even drained through the land, was chosen. Moreover, as this spill occurred during the high tide, a great amount of oil reached the inner part of the forest.
Two 10×10 m plot were limited in the fringe one next to the river bank (outer plot) and the other 20 m further towards the inner part (inland plot). These plots were permanently tagged in 1986. In order to monitor the seedling growth, 1 × 1 m plots were also limited established.

For the structural and functional findings the methodology described by Schaeffer-Novelli and Cintrón (1986) and was utilized and the sampling started 4 months after the oil spill. Structural analysis of the forest was based on data related to the tree density, diameter of breast height (DBH) and tree height. From these parameters the specific basal area, the average diameter of the forest and the species frequency were worked out (calculated). As for the functional characteristics, 50 green leaves and 50 senescent leaves of the three mangrove species were collected at random, the first measured width and lengthwise and the latter being measured on the leave area and the grazing rate were measured on the latter.

These data sets are time series through which the moving averages were calculated, in order to identify the trends of each parameter at study.

During the field work, the immediate effect of the oil spill that could be noticed was the withering of the leaves and an increased defoliation. At the same time, an overwhelming mortality of seedlings and sapling was observed. These alterations were called initial effect. However, the mortality of seedlings and sapling...
could also be observed after the event, thus constituting the long term effects (CETESB, 1989).

After a high initial defoliation followed a milder one for some months. The same phenomenon was reported by Cintrón et al. (1981) and Teas et al. (1987) in mangrove areas affected by oil.

In the remaining leaves and in the new ones morphological alterations as spots, speckles, perforations, fading, twisting and necrosis were observed. RPI (1984) also mentions these symptoms for leaves under the oil stress.

Changes were also observed in leaf size, measures of leaf area showed an increase of leaf size for all three mangrove species. A two-way ANOVA was used to analyze species and year effects. For this test, we used only the data for a single month. The results showed that there is a significant difference among leaf area of the three species. A. schaueriana has a smaller leaves with a leaf area average of $17.2 \pm 6.5\text{cm}^2$. L. racemosa leaf area average was $25.2 \pm 8.5 \text{cm}^2$ and R. mangle was $31.3 \pm 9.2 \text{cm}^2$.

There were also significant differences among years and a significant interaction between years and species. Leaf area measurements showed different curves for each species. R. mangle had a significant increase ($p<0.05$) of 25.9% of leaf size from 1984 to 1986. L. racemosa also showed an increase (43.4%) from 1985 to 1987 ($p<0.06$). Only A. schaueriana continued showing a significant increase (64.5%) of leaf area from 1984 to 1991 ($p<0.09$).

To test the statistical validity of these increasing trends, we used auto-regressive models, ARIMA (Box and Jenkins In: Morettin and Toloi, 1981) adjustment and a t-student test for $p<0.05$. R. mangle showed a significant increase from September 1984 to December 1986 (Fig. 7a), L. racemosa showed a significant increase from December 1984 until the last observation in March 1992 (Fig. 7b). Leaves of both species started to increase approximately one year after the oil spill in October 1983. Only A. schaueriana showed a continuous increase of leaf area since the beginning of the monitoring in 1984 (Fig. 7c).

Other studies in the same area also reported an increase in the leaves of the three species, almost doubling its original leaf size in A. schaueriana and L. racemosa (Ponte et al., 1987). On the other hand, the literature reports a reduction of the leaf surface related to stressing chronic factors as oil and others (Cintrón and Schaeffer-Novelli, 1983; Getter et al., 1985). To account for this controversy, the reduction in our study occurred in the first months, the increase being then a mere recovery of its original size, as the long term effect was weakening (Rodrigues et al., 1989).

The grazing rates on the leaves decreased for all the species mentioned, lowering to as little as 5% of the total leaf area, which is regarded as a healthy forest value. This findings clash with the hypothesis mentioned by Schaeffer-Novelli and Cintrón (1986), that impacted forests have a higher herbivory.

The reduction of the grazing rate (Rodrigues et al., 1989) can be attributed to the migration of herbivores to other places in search of food, due to the leaf fall. Another possibility would be the release of aromatic fractions and the storage of other substances inhibiting their consumption. In addition, oil could also interfere in the development at some stage in the life of some insects and other herbivores, which would decrease its population.
To sum up, the leaves response to the stress was fast, shown by the overwhelming defoliation and the reduction of leaf size in the first months after the impact. Afterwards, there was a continuous increase of leaf size, in some cases stationary, which would show the leaves have already recovered their original size. However, the structural parameters behaved distinctly, requiring a longer period to respond. Therefore a longer period of sampling is needed, one year at least.

The mangrove structure was seriously affected by the oil impact. After three years the forest density was reduced from 2435 trees/ha to 1936 trees/ha, which represents a 20% reduction. This high loss in trees occurred mainly one year after the oil spill (Fig. 8a). The reduction in forest density caused a reduction of the total basal area, from 15.9 m²/ha to 9.5 m²/ha, which corresponds to a 40% reduction (Fig. 8b). It is worth pointing out that this reduction was mainly due to the higher mortality of *A. schaueriana* (Fig. 8c) once its frequency was highly altered (Rodrigues et al., 1990). It is thought that this species is the most sensitive to oil, which according to Getter et al. (1985) is due to its mechanism of the osmoregulation wich apparently facilitates the oil to reach the leaves.

These reductions are statistically valid according to the results of the regression analysis of these dummy variables (Draper and Smith, 1981), shown in Table 5, which reveals that the findings before the response to the impact are statistically different from the previous level. As for the average diameter, the trend curves did not show great alterations, only a slight decrease. This fact is due to the reduction of both values: the basal area and forest density, resulting in a stable ratio.

Based on the reported alterations, it could be said that the oil impact in the mangrove caused a disruption of the normal structural development pattern. According to Cintrón and Schaeffer-Novelli (1984), in the normal development of a forest, the expected alterations are reduction in the forest density and increase in the basal area and average diameter, as result of room competition.

The tendencies of a continuous decline observed for the structural parameters in Rio Iriri forest, indicate a long term effect, without signs of stabilization or recovery, until the fourth year of sampling. Yet, that analysis of the data of the last two years which corresponds to the 5th and 6th years after the oil spill indicates a tendency of stabilization in all the structural parameters. This behavior suggests that in the 5th year after the oil spill, the effects tend to get weaker. It is believed that from the 7th year, the recovery of the forest might start, which will be confirmed in future sampling if the parameters happen to show signs improvement.

Until the 6th year after the spill the sites were rapidly colonized by new seedlings which grew approximately up to 1 meter high. Thereafter their mortality rate was 100%, for once depending exclusively on the sediment water and nutrients they were presumably affected by the remaining toxic substances present in it.

Besides, in addition to low propagule density they also exhibited atrophy and deformations. The rapid colonization was probably due to propagules from other places and although the presence of seedlings apparently indicates recovery it was not the case.

Nine years after the oil spill the presence of seedlings and juveniles will suggest the beginning of the ecosystem recovery, indicating that the seedlings are managing the survive and grow.

The analysis of the trend curves of the structural parameters reveals that all of them show a similar behavior with the same sequence of stages, which corresponds to successive phases of the community response to impact (Fig. 9). It is worth pointing out that these phases are related to the community response as a whole.
These phases could be called and described as follows:

1. Initial effect. The structural responses of the ecosystem to oil are not immediate, and there is, therefore, the first phase after the impact when no structural alteration can be measured. During this phase, only seedlings and sapling died. This phase lasted one year.

2. Structural damage. High mortality is observed, the oil impact on the ecosystem can be measured in terms of major structural alteration. This phase lasted a little more than three years.

3. Stabilization. After major alterations, a stabilization period starts, with none or few alterations in the structural parameters. During this phase, it is possible to observe saplings. This phase lasted for five years.

4. Recovery. A period of recovery of the ecosystem follows, when it is possible, to measure improving alterations of the structural parameters. However, the ecosystem might not fully recover to its original state. We believe this phase only begins after nine years.

The duration of each phase might vary depending on environmental conditions, the local features of the place where the oil spill occurred, and the amount and kind of oil spilled. Still, it is assumed that this community response pattern, constituted by this succession of phases described above, should occur in other mangroves affected by oil pollution.

Comparing these post-spill phases to the ones described by Snedaker (1985), where he distinguished three phases: mechanical suffocation, chronic chemical toxicity, and recovery, one could say that the author used the oil action on the mangrove as a major criterium and in this study the criterium was the community response to this action.

It is worth pointing out that to each action there is a correspondent effect that characterizes a response phase so that a relationship can be established between the two classifications. Consequently the first and the last phases described by Snedaker (1985) correspond to the initial effect and recovery phases of this study.

However, during the chronic effect phases, or long-term one, two phases were observed: the first showing a significant structural damage and the other of a relatively long stabilization. It follows from that, therefore, that after the initial effect the structural response does not occur slowly and continuously until the recovery. What happened then was a relatively abrupt alteration in a short span followed by a longer period of stabilization before the recovery itself.

In the literature concerning the oil spill effects on mangroves, a different terminology is used. The effects described are generally classified in three ways: 1) acute and chronic (Davis et al., 1980; Getter et al., 1981; Jernelóv and Linden, 1983 and Lewis, 1983); 2) immediate or initial and chronic (Jackson et al., 1989); 3) short and long term (IUCN, 1982; Krebs and Burns, 1977).

Beside this, these concepts vary from author to another and sometimes they are not clearly defined. In some cases the acute effect is the one which occurs during the first month (Lewis, 1983). To other authors the same phase can last months (Davis et al., 1980). One can also find the term acute effect related to the high mortality of trees which actually happens initially in most cases (Snedaker, 1985). The long term or chronic effect is the one which happens after the acute one.

In this study the major mortality rate does not coincide with the initial or acute effect. Therefore, the alterations observed and measured during the first year after the oil spill will be called initial or short-term effect, whereas the other alterations observed in the following years including the high mortality rate of the second and third years will be called long-term effects.

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### Table 5. Results of the Regression Analysis of dummy variables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before Level</th>
<th>Effect</th>
<th>Present Level</th>
<th>Statistical Significance</th>
<th>Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal Area A. schaueriana</td>
<td>0.70</td>
<td>-0.64</td>
<td>0.076</td>
<td>0.0</td>
<td>-89.28</td>
</tr>
<tr>
<td>Total Basal Area</td>
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<td>-0.63</td>
<td>0.96</td>
<td>0.0</td>
<td>-39.78</td>
</tr>
<tr>
<td>Relative density L. racemosa</td>
<td>70.49</td>
<td>17.31</td>
<td>87.81</td>
<td>0.0</td>
<td>24.55</td>
</tr>
<tr>
<td>Relative density A. schaueriana</td>
<td>29.50</td>
<td>-17.31</td>
<td>12.19</td>
<td>0.0</td>
<td>-58.67</td>
</tr>
<tr>
<td>Tree number.</td>
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<td>-49.91</td>
<td>193.64</td>
<td>0.0</td>
<td>-20.49</td>
</tr>
<tr>
<td>number</td>
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<td>-147.44</td>
<td>222.56</td>
<td>0.0</td>
<td>-39.85</td>
</tr>
</tbody>
</table>
Figure 9. Post spill phases of the structural response of the mangrove forest

Due to the oil impact on mangrove areas, initial effects in the first months and long-term effects, until the fourth year, were observed. The stabilization of these alterations in the last two years suggested that after six years the effects started to weaken, which might indicate the beginning of recovery. This study confirms that the time residence of oil in mangroves is long and that the ecosystem requires a long period to recover. This calls for an urgent oil pollution control, by preventive action, besides the elaboration of emergency plans to protect these ecosystems effectively.

Conclusions

The mangrove in the region suffered all kinds of pressures such as: fillings, solid waste, changes in the water bodies, industrial and domestic effluents causing chemical and organic contamination, not to mention the successive oil spills.

However, they still perform an important ecological role such as the retention of sediments in the estuary, protection of the coast line, as well as a retention of toxic substances as heavy metals, preventing them from reaching the coastal area. Ecological and environmental impact studies are invaluable for they help to understand the ecosystems responses to the stress factors, which will be extremely useful in other estuary regions in the tropical America which are facing similar problems.

The conclusions drawn from the case study, concerning the oil effects in the ecosystem can be seen in Figure 10 and are described as follows:

- as for leaves the initial effects was the withering and high defoliation. The long-term effect was the alteration of the shape and color of the leaf, besides perforations and necrosis. It was also observed an increase of the leaf area and a decrease in the herbivory for the three species.

- the oil impact caused an interruption of the normal process of development expected for a forest, due to the reduction of the numbers of trees and stems and the total basal area.
- A. schaueriana was the most sensitive species to the oil effects.
- the responses of the mangrove to the oil impact can be divided in four successive phases called: initial effect, real structure damage, stabilization and recovery.
- the oil effects on the mangrove were more evident one year after the oil spill, with higher mortality rate as from this period. These effects persisted four years after the oil spill. The stabilization of the structural parameters in the last two years suggests that after six years the weakening of the effects might be a sign of recovery.
- the high density of seedlings does not necessarily indicate a recovery of the ecosystem. A more adequate criterium for this would be the presence of saplings.
- the presence of some saplings in the last year of sampling is a clear signal of recovery of the forest, which confirms the tendencies of structural parameters.

These results enabled one to confirm the importance of long-term studies, making it possible to compare different situations, once it is believed that these four phases of the mangrove responses to oil can occur in other cases. It also reinforces the need to develop researches concerning the functional aspects of the ecosystem once the functional responses occur faster than the structural ones and can be measured in a shorter period of time.

In view of this, long-term studies of productivity are recommended in order to obtain more information about degraded ecosystems through the identification of yearly environmental patterns so as to compare to non degraded ecosystems. The aim of this approach is to implement a methodological standardization and to produce ecological information management oriented.

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