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# Ecology of an isolated mangrove lagoon (Playa Medina, Venezuela) and its potential use as sewage pond

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## Abstract

The present study focuses on the hydrochemical conditions of a coastal mangrove lagoon in Venezuela which is completely isolated from the sea, lacking any visible connections such as tidal channels, preventing in this way tidal flushing. These isolation conditions introduced important changes in vegetation, soil salinity and hydrology. The aim of this paper is to relate some of the effects of disconnection, with the potential use of the mangrove as a sewage pond for treated domestic wastewater. Available data are analyzed on soil properties, hydrochemistry and water level fluctuations of surface and groundwater, recorded through a whole hydrological year. Present day mangrove characteristics are examined through the scrutiny of recordable historical disturbances. Finally, the potential effect of treated wastewater to be supplied to the lagoon is estimated, on the basis of local climate trends. It is concluded that the present day surface water quality would be impaired, and the desalinization process of soil and groundwater accelerated. The annual volume of residual water to be supplied would equal a 20% increase in the local precipitation regime, supply that would deeply alter the existing flood/drought regime. It is suggested that recuperating the original mangrove connection to the sea through channel opening may alleviate the impact of wastewater discharge.

**Key words:** eutrophy, ground water, hydrology, hydrochemistry, isolation, mangrove, salinity

**Resum.** *Ecologia d'una llacuna de manglar aïllada (Playa Medina, Veneçuela) i el seu ús potencial com a bassa d'aigua residual*

S'estudien les condicions hidroquímiques d'una llacuna costanera de manglar que es troba actualment aïllada del mar, a la qual li manquen connexions visibles amb aquest com canals o rambles de marea; no està per tant sotmesa a l'acció de la marea. Aquest aïllament ha provocat canvis importants en la composició de la comunitat de manglar, en el contingut de sals del sòl i en les característiques hidrològiques. L'objectiu d'aquest estudi és relacionar alguns dels efectes de l'aïllament sobre la llacuna de manglar i el seu ús potencial com a receptora d'aigües residuals tractades d'un complex hoteler veí. S'analitzen dades disponibles dels sòls, hidroquímica i fluctuacions del nivell d'aigües superficials i subterrànies, registrades durant un cicle hidrològic complet. Les característiques actuals del manglar s'estudien mitjançant dades històriques. Finalment, l'efecte de la incorporació d'aigües residuals tractades a la llacuna s'avalua en base a les tendències climàtiques locals. Es conclou que la qualitat de l'aigua de la llacuna actual podria empitjorar amb la descàrrega de les aigües residuals i que el procés de desalinització existent s'acceleraria. El volum anual d'aigua afegit equivaldria a un increment del 20% de la precipitació actual. Aquest suplement d'aigua dolça podria alterar profundament el règim d'inundació / sequera del present. Per alleugerir l'impacte de la descàrrega d'aigua tractada a la llacuna, se suggereix recuperar les connexions originals del manglar amb el mar.

**Paraules clau:** eutrofia, aigua subterrània, hidrologia, hidroquímica, aïllament, manglar, salinitat.

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## Introduction

Historically, mangroves have attracted much curiosity and scientific attention engendered by their unique adaptations to saline and swampy environments (Lugo & Snedaker, 1974). They are different from other plant communities in that they receive inputs of materials from both land and sea. These contributions embrace fresh water, sediments and nutrients from terrestrial drainage and tidal flushing, saline intrusions and marine organisms from the sea. The dynamic exchange of energy and matter and the high productivity levels allow the establishment in mangroves of a complex and diverse food web composed of large communities of both marine and terrestrial species. These communities are strongly coupled to adjacent coastal and terrestrial areas, often representing nursery sites for fish and crustaceans from near shore habitats (Olson et. al. 1996, Robertson & Duke, 1987). Further, the export of their detritus and fauna biomass has long been considered as an important support for offshore biological production (Lee, 1995).

Environmental biotechnology around the world has focused on the suitability of using mangrove swamps as natural wetland systems for wastewater treatment. Intensive research is being carried out to elucidate the effect of wastewater discharge on growth and production of mangroves, and the mechanisms of retention, mobilization and detoxification of pollutants from wastewater by mangrove ecosystems (Boonsong et al., 2003, Chu et al., 1998, Tam et al., 1998, Yim & Tam, 1999). Till now, hydrological alterations derived from wastewater discharge have received less attention, despite the fact that adverse changes to amounts, locations, and timing of freshwater and marine flows may threat the biological function of mangroves.

The present is a study of a distinct mangrove community which has become isolated from the sea. Visible connections with the marine system such as tidal channels or creeks are lacking and its inland position prevents tidal flushing. As results of water logging, a water impoundment of about 0.36 ha has evolved. No information is available on its hydrologic or limnetic conditions. Yet, this mangrove community has originally developed on the coastal shoreline. Paleoecological studies documented the occurrence of a plentiful "in situ" mangrove community, 9.2 m below present sea level at around 7 000 years before present, this being the oldest Quaternary mangrove community recorded in Venezuela (Rull & Vegas Vilarrubia, 1999, Vegas Vilarrubia & Rull, 2002). But it is also known that humans have used mangroves of the area since 5 000 to 6 000 years before present (Sanoja 1992). Local inhabitants narrate that this mangrove was replaced by the existing coconut crop many years ago. Yet, no rigorous information exists on why and how it has become isolated. In any case, its present condition is unusual and excludes any visible exchange of matter with the sea as a result of disconnection from the marine system. These modifications have possibly led to the uncoupling of many of its ecological functions and to some kind of degradation of the mangrove itself. This apparent disadvantageous situation and its topographic depressed position within the area has attracted the attention of development planners, who explored the feasibility of using the mangrove swamp as a sewage pond for treated wastewater from a projected hotel complex in the neighborhood.

The effluent to be discharged into the mangrove lagoon would have been previously treated applying conventional techniques: clarification for removal of solids, aeration through biological treatment, disinfection and sludge processing. Therefore, it is expected to come out with an acceptable quality both to be reutilized or to be dumped into the mangrove lagoon. Being water a scarce local resource during the dry season, the effluent would be used to irrigate playing fields, gardens and golf courses of the hotel complex mainly during drought. Excess wastewater would be discharged into the lagoon only during the wet season.

Yet, the consequences of wastewater discharge on any natural wetland not only depend on the biochemical characteristics of the effluent, but also on the structural components of the receiving environment: underlying soils, water quality, hydrologic regime, emergent vegetation and climate (Kadlec & Knight, 1996). In the case of Playa Medina, the unusual condition of isolation of the mangrove ecosystem makes the uncertainty about potential consequences of sewage flow even greater.

The objective of this study was to provide baseline ecological and environmental parameters for the management of this distinct mangrove, and to discuss eventual ecological and environmental effects of using the mangrove swamp as a sewage pond. For this purpose available data were analyzed of soil properties, hydrochemistry (nutrients, salinity, pH, and major ions) and water level fluctuations of surface and groundwater recorded through a whole hydrological year. The present day vegetation composition was compared with local palaecological information. Most of these data have been published elsewhere (Rull & Vegas Vilarrubia 1999, Rull & Vegas Vilarrubia , 2000, Vegas Vilarrubia, 2000, Vegas Vilarrubia & Rull, 2002) but have been combined in this paper to discuss and forecast the expected changes and response of the mangrove ecosystem to the proposed intervention.

## Site description

In the Northeastern Venezuelan coast lies the Playa Medina Bay, a closed basin of the Peninsula of Paria (Fig. 1). It is developed at sea level within an almost continuous cliff formed by the foothills of the Araya-Paria coastal mountain range, where mountain forests develop from below 200 m to 1 300 m a.s.l. The dry season lasts scarcely three months, February to April, while the humid one extends eight months from May to December, showing two precipitation peaks (Fig. 2).

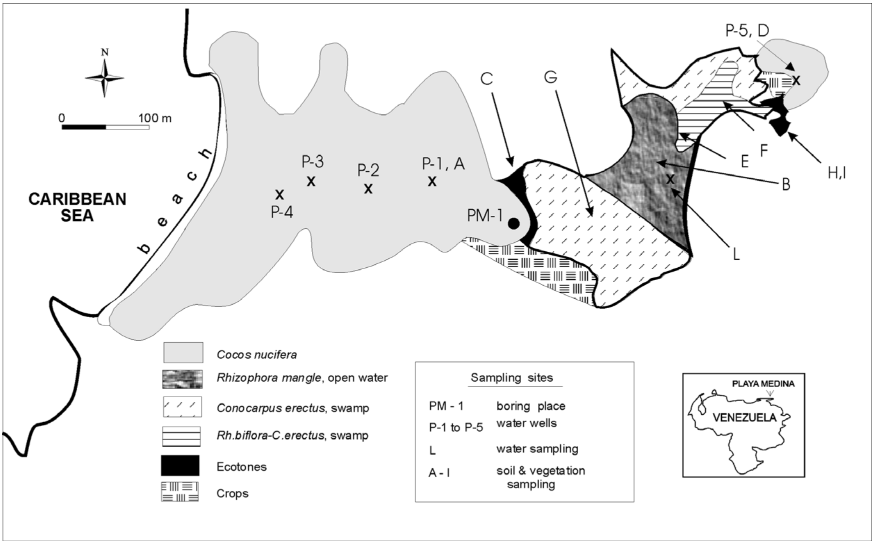

**Figure 1.** Location map, vegetation patterns and sampling points at Playa Medina.

Average total annual precipitation is 818 mm (Rio Caribe meteorological station). Mean annual temperature is 25.5 °C. Permanent water courses are absent in the valley, its drainage consisting mainly of seasonal runoff assembled by the shallow (< 1 m) mangrove lagoon. Open water occupies barely 1/3 of its total area, about 0.12 ha, excluding the marshy zone around the lagoon (Fig. 1). In the ecotone between the lagoon and the surrounding littoral marshy zone grow terrestrial herbaceous and woody species. The mangrove community is first dominated by *Conocarpus erectus* L. (Combretaceae) and then by *Rhizophora mangle* (L.) Presl. (Rhizophoraceae), the latter growing within the open water itself. Coconut crops and areas with secondary vegetation surround the mangrove in the bottom of the basin. Further details can be found in Vegas Vilarrubia (2000). One of the most intriguing features of this mangrove community is the lack of typical mangrove fauna, like oysters, sponges and crabs living on mangrove roots.

## Material and Methods

### *Vegetation and soils*

Field studies on spatial vegetation patterns and soil salt content were conducted during the peak of the dry season (March 1994). Vegetation species composition and distribution were determined along a W-E oriented transect following the longer axis of the lagoon (Fig. 1). The two ends of this transect were the coconut stand to the West and the inland abandoned crops to the East. Most plants were in flower during the dry season. Current botanical samples were collected for taxonomic identification, which was accomplished by the Herbarium of the Botanical Garden of Caracas (Venezuela). Nine bulk soil samples were collected along the same transect where appreciable differences in topography, granulometry, water logging, and vegetation were observed (Fig. 1, A-I). Several surficial soil shovels (10-20 cm depth) were taken for physical description and chemical analysis in each sampling site. Soil samples were dried at 60 ºC during three days. From them, several aliquots were subjected to binary digestion and the resulting extracts analysed for cations (Na, K, Ca, Mg) using atomic absorption spectrophotometry (EPA SW 846, 1986).

### *Water chemistry*

Hydrochemical measurements were taken in the mangrove lagoon and in the groundwater between it and the sea, covering a complete annual cycle (1993 to 1994). Four groundwater wells of 3 m depth were bored in a straight line from the lagoon to the beach (Fig. 1, P1 to P4), using slotted PVC tubing of 6.5 cm diameter. An existing water well (Fig. 1) located in the crop area at the innermost side of the lagoon was also monitored. In all wells, salinity was measured monthly at the surface and bottom of the water column contained in the tubes. Standard error of salinity values have been calculated by means of a Student´s t for a 0.05 significance level (Parker, 1976). Surface water was monitored in one sampling point with perma-

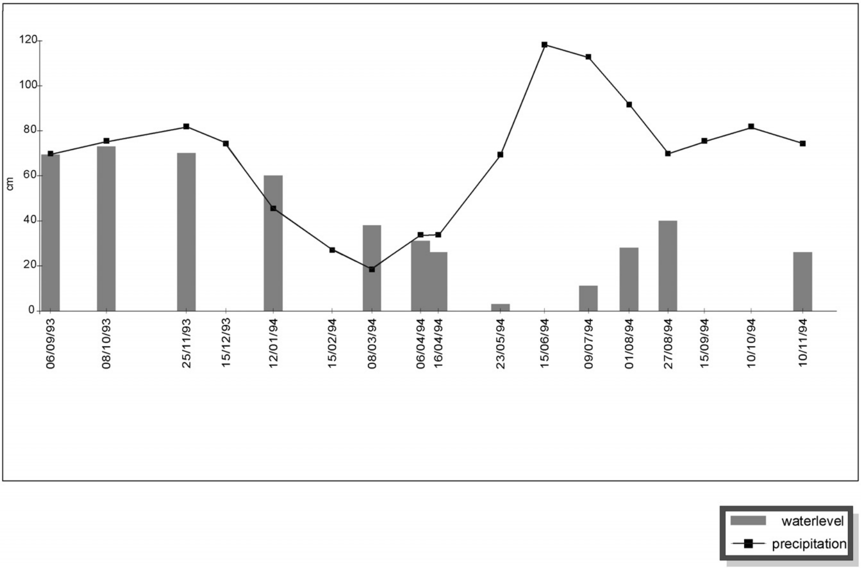

**Figure 2.** Seasonal rainfall and surface water level fluctuations (cm).

nent water located in the deepest zone of the lagoon (Fig. 1, L). In agreement with the very shallow condition of the lagoon (70-80 cm) only surface samples for physico-chemical analysis were taken. Salinity (Sal) and dissolved oxygen ($O_2$) were recorded with a YSI field salinometer and oxymeter, respectively; pH with a Metrohm field pH-meter. Analytical procedures employed to sample amons, cations, organic carbon and alkalinity (Alk) followed standard procedures (Greenberg et al., 1992). Samples were properly preserved and stored at 4 ºC.

### *Water treatment*

The hotel complex to be constructed should extend over 42 ha with a capacity of 356 double and 110 single rooms. A volume 800 $m^3$ $d^{-1}$ of water at a flow of 10 l $s^{-1}$ has been estimated to satisfy the water needs of the complex, which would produce an equal amount of wastewater to be treated. This includes 3 restaurants, discothèque, spa, beach showers, convention rooms for 700 people, swimming pool, 8 tenis courts and 34 500 $m^2$ service areas. Water would be stored in a 1200 $m^3$ storage tank providing a 400 $m^3$ reserve. Of the 800 $m^3$ of water, approximately 100 $m^3$ have been assigned to irrigation and 400 $m^3$ to supply conditioned air. The 300 $m^3$ wastewater surplus should either be stored in a reservoir still to be constructed, or be discharged into the mangrove lagoon. At the same time, the opening of an eco-tourism trail around the mangrove lagoon has been considered. The alternative of converting the mangrove swamp into a sewage pond is obviously the easiest and cheapest one. But before discharge, wastewater needs to be treated to comply with the environmental law in force. The preferred depuration choice is the conventional activated sludge system based on suspended-growth. The general process can be summarized as follows (Henry & Heinke, 1996): produced wastewater is conducted to the treatment plant, where large solids are removed firstly with a screening grit and then suspended solids by settling in the primary setting tank. Once clarified, it is subjected to the biological action of microorganisms in an aeration tank during 4-8 hours. The activated sludge receives further treatment with an anaerobic digester. Afterwards wastewater enters the final tank to settle down the solid loading from the aeration tank and finally, it is disinfected with calcium hypochlorite in the chlorine tank. This treatment should warrant a well aerated effluent without large solids, with an acceptable content of suspended solids, and with a residual chlorine concentration of 1 mg/l. Its resulting quality should attain the standards set by the Venezuelan Environmental Normative in force on the discharge of effluents on water bodies (MARNR, 1992, MARNR, 1994).

## Results

### *Vegetation patterns*

Following the transect W-E from the back of the beach to the crops located on the hill foot (Fig. 1), nine different plant communities were distinguished. The associated floristic inventory (Table 1) assembled 36 plant species belonging to

**Table 1.** Floristic inventory of the mangrove community at the lagoon of Playa Medina (Vegas Vilarrúbia, 2000). A-I : sampling sites (Figure 1).

| | **Species** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|---|
| Acanthaceae | *Aphelandra pulcherrima* (Jacq.) H.B.K. | | | X | | | | | | |
| Acrostichaceae | *Acrostichum aureum* L. | | | | | | X | X | X | |
| Aizoaceae | *Sesuvium portulacastrum* L. | | | | | | | | | |
| Amaranthaceae | *Alternanthera lanceolata* (Bentham) Schinz. | | X | X | | | | | | |
| Araceae | *Phylodendron* sp. | | | | | X | | | | |
| Araceae | *Anthurium crassinervium* (Jacq.) Schott | | | X | | X | | | | |
| Arecaceae | *Cocos nucifera* L. | X | | | | | | | | X |
| Apocynaceae | *Rhabdadenia biflora* (Jacq.) Muell. – Arg. | | | X | X | X | X | X | | |
| Asclepiadaceae | *Sarcostema clausum* (Jacq.) R. & P. | X | | | | | | | X | |
| Asteraceae | *Wedelia fruticosa* Jacq. | | X | | | | | | | |
| Bromeliaceae | *Tillandsia usneoides* (L .) L. | | | | | X | | | | |
| Bromeliaceae | *Tillandsia juncea* (R. & P.) Poir. | | | | | X | | | | |
| Bromeliaceae | *Tillandsia fasciculata* Sw. | | | | | X | | | | |
| Bromeliaceae | *Tillandsia sp.* | | | | | X | | | | |
| Bromeliaceae | *Aechmea aquilega* (Salisb.) Griseb. | | | | | X | | | | |
| Cactaceae | *Hylocereus lemairei* (Hook.) Britton & Rose | | | | | X | | | | |
| Cactaceae | *Epiphyllum phyllanthus* L. Haw. | | | | | X | | | | |
| Combretaceae | *Conocarpus erectus* L. | | | X | X | | | X | X | |
| Commelinaceae | *Commelina cf. erecta* L. | X | | | | | | | | |
| Convolvulaceae | *Ipomoea asarifolia* (Desr.) R. et Sch. | | X | X | | | | X | | |
| Cyperaceae | *Cyperus cf. imbrincatus* Retz. | | | | | | | X | X | |
| Cyperaceae | *Cyperus cf. digitatus* Roxb. | | | | | | | X | X | |
| Haloragaceae | *Myriophyllum sp.* | | | | | X | | | | |
| Leguminosae | *Senna sp.* | | X | | | | | | | |
| Lemnaceae | *Wolffia sp.* | | | | | X | | | | |
| Malvaceae | *Malachra alceifolia* Jacq. | | X | | | | | | | |
| Malvaceae | *Pavonia spicata* Cav. | | | | | | | X | | |
| Orquideaceae | *Orchidae* sp. | | | X | | X | | | | |
| Poaceae | *Graminea* sp.1 | | | | | | | X | | |
| Poaceae | *Graminea* sp.2 | | | | | | | X | | |
| Poaceae | *Graminea* sp3 | | | | | | | X | | |
| Poaceae | *Graminea* sp.4 | | | | | | | X | | |
| Polypodiaceae | *Campyloneurum phyllitidis* (L.) Presl | | | X | | | | | | |
| Rhizophoraceae | *Rhizophora mangle* L. | | | | X | X | X | | | |
| Sapindaceae | *Paullina cf. pinnata* L. | | | | | | | X | X | |
| Sterculiaceae | *Guazuma ulmifolia* Lam. | | X | | | | | | | |
| Myrtaceae | *Psydium guajaba* L. | | | | | | | | | X |

26 families. The dominant one was *Conocarpus erectus* (Mangle botoncillo) surrounding the mangrove community behind the shoreline in more elevated, drier soils. *C. erectus* stands were being colonized by herbaceous taxa, especially the halophytic beach fern *Acrostichum aureum* L., which is common in disturbed mangrove areas (Chapman, 1976) with high rainfall and frequent desalinization of the upper soils (Medina et al., 1990, Walter,1977), and by the halophytic rooted climber *Rhabdadenia biflora* (Jacq.) Muell.-*Arg*. (Bejuco lechero). *Rhizophora mangle* (Mangle rojo) grows in the more intensively flooded, deepest zone of the lagoon. Epiphytes are conspicuous on their trees. Other typical Caribbean mangrove-tree genera, such as *Avicennia* (Mangle negro) and *Laguncularia* (Mangle blanco), were absent. In the early Holocene, the mangrove of Playa Medina was more diverse and dominated by *Avicennia* or co-dominated with *Rhizophora*. Since then, a relative sea level rise (Rull, 2000) has been the most important natural disturbance suffered by the mangrove community, together with the arrival of European colonizers and the subsequent expansion of cultivated crops (Rull et al., 1999). Three water weeds were found floating, but only *Myriophyllum* sp. formed dense, submersed beds covering the water surface from shore to shore during the rainy season, and decaying progressively from the end of it. The transitional zone between the lagoon itself and the littoral marshy zone was composed of terrestrial herbaceous and woody species such as *Guazuma ulmifolia* Lam. (Guácimo), *Ipomoea asarifolia* (Desr.) R. et Sch (Batatilla), *Alternanthera lanceolata* (Bentham) Schinz. (Lancetilla), *Wedelia fruticosa* Jacq. (Mirasol), *Commelina erecta* L. (Hierba del pollo) *Malachra alceifolia* Jacq. (Malva), *Senna sp*. and several Cyperaceae. The mangrove of Playa Medina was not pure and contains 43% of terrestrial and non-halophyte species. More detailed information on vegetation patterns can be found in Vegas Vilarrubia (2000).

### *Soil salinity*

Field testing revealed that soils were mostly organic and clayey, except for the sandy soil underlaying the coconut crop. Table 2 showed differences in $Na^+$, $K^+$, $Ca^{++}$ and $Mg^{++}$ concentrations of soil samples (Fig. 1). Calcium was the most abundant in all of them and $K^+$ the least abundant. Sodium was higher in soils from *C. erectus* stands. The concentrations found allowed the soils to be classed, on average, from moderate to low saline. Results were grouped according to their ratio (Cs) between alkaline (Na+K) and earth-alkaline metals (Ca+Mg), in order to test some spatial pattern based on salinity, assuming that soils under marine influence would account for higher ratios. In all cases (Table 2) the ratio was $Cs < 1$ ranging between 0.01 and 0.47 indicating that Ca+Mg prevailed over Na+ K. Lower Cs ratios may be explained by a more intense leaching of salts, which depends both upon the prolongation of waterlogging due to subtle differences in topography, and soil texture. Higher ratios were found on soils subjected to a less prolonged flood and to annual periods of drought. Further details on mangrove soils are given in Vegas Vilarrubia (2000).

**Table 2.** Soil salinity in meq / 100g and monovalent/divalent ratio Cs (Vegas Vilarrúbia, 2000) A-I : sampling sites (Figure 1).

| Sample site | K mg/l | Mg mg/l | Na mg/l | Ca mg/l | Na + K | Ca + Mg | Cs |
|---|---|---|---|---|---|---|---|
| A | 0.15 | 2.38 | 0.33 | 44.6 | 0.48 | 47.0 | 0.01 |
| D | 0.24 | 5.54 | 7.96 | 47.0 | 8.2 | 52.5 | 0.16 |
| C | 0.99 | 5.96 | 40.0 | 81.6 | 41.0 | 87.6 | 0.47 |
| B | 0.37 | 4.85 | 17.4 | 78.7 | 17.8 | 83.6 | 0.21 |
| E | 0.19 | 2.27 | 3.48 | 48.2 | 3.67 | 50.5 | 0.07 |
| F | 0.23 | 4.19 | 7.35 | 58.9 | 7.58 | 63.1 | 0.12 |
| G | 0.74 | 6.08 | 19.6 | 90.2 | 20.3 | 96.3 | 0.21 |
| H | 0.33 | 4.69 | 8.41 | 52.3 | 8.74 | 57.0 | 0.15 |
| I | 0.48 | 6.35 | 32.6 | 98.2 | 33.1 | 105 | 0.32 |

### *Groundwater salinity*

During the whole year, ground water was near the surface ranging from 0.70 to 1.70 m depth, but never overflowed. Minimum and maximum levels coincided with drought and the two precipitation peaks, respectively. Salinity values showed brackish conditions, with bottom layers more saline (5 ‰- 23 ‰) than surface layers (1 ‰- 17 ‰) within the water column. Salinity values also showed differences among wells, depending on their proximity to the mangrove or to the sea, being P3 and P1 less saline than P4. Table 3 shows average salinity values and standard error for each well.

### *Hydrochemical features of the lagoon* (Table 4)

Water level fluctuations of the lagoon were strongly influenced by seasonal evaporation / precipitation patterns. The dry season led to progressive decreasing water levels and at the end of it, the water body became reduced to a few small, shallow

**Table 3.** Average salinity of upper and bottom groundwater well measurements during 1993-1994.

| | Surface samples | | Bottom samples | |
|---|---|---|---|---|
| Well | Average °/oo | Standard error | Average o/oo | Standard error |
| P-1 | 3.53 | 1.61 | 9.3 | 1.29 |
| P-2 | 3.83 | 2.16 | 18.8 | 0.82 |
| P-3 | 2.45 | 0.57 | 15.6 | 1.06 |
| P-4 | 11.9 | 3.25 | 20.5 | 1.16 |
| P-5 | 4.3 | 1.4 | 7.4 | 4.4 |

**Table 4.** Hydrochemical features of the lagoon from september 93 to novermber 94.

| Date | Temp °C | pH | Sal 0/00 | Cond µS cm$^{-1}$ | Cl mg l$^{-1}$ | TP mg l$^{-1}$ | TN mg l$^{-1}$ | TOC mg l$^{-1}$ | $O_2$ mg l$^{-1}$ | $H_2S$ mg l$^{-1}$ | $SO_4^{-2}$ mg l$^{-1}$ | Alk meq l$^{-1}$ | Na mg l$^{-1}$ | K mg l$^{-1}$ | Ca mg l$^{-1}$ | Mg mg l$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6-sep-93 | 24.5 | 7.25 | 2.5 | 3 550 | 788 | 0.07 | 0.180 | 182 | 1 | 0 | 25.2 | 5.53 | 190 | 178 | 224 | 33.7 |
| 8-oct-93 | 24.8 | 7.48 | 1.5 | 2 600 | 310 | 0.203 | 0.656 | 8.9 | 1 | 0 | 4.59 | 5.80 | 182 | 144 | 237 | 49.6 |
| 25-nov-93 | 23 | 7.11 | 1 | 2 250 | 606 | 0.111 | 1.83 | 275 | 2.65 | 9.54 | 4.50 | 5.10 | 193 | 125 | 204 | 30.4 |
| 12-jan-93 | 26.3 | 7.22 | 1 | 4 000 | 606 | 0.36 | n.d. | 1.37 | 0 | 0 | 3.50 | 3.60 | 201 | 148 | 132 | 51 |
| 8-mar-94 | 22.2 | 7.21 | 2 | 2 850 | 1 553 | 0.27 | 1.86 | 14.8 | 0.6 | 6.68 | 8.20 | 4.20 | 206 | 50.1 | 216 | 41.3 |
| 6-apr-94 | 26 | 7.45 | 4.5 | 7 500 | 1 708 | 0.356 | 17.5 | 169 | 1.75 | 8.36 | 6.00 | 7.20 | 1950 | 920 | 240 | 245 |
| 16-apr-94 | 26.3 | 6.93 | 4 | 7 000 | 2 284 | 0.085 | 2.36 | 133 | 1.25 | 21 | 52.4 | 8.00 | 530 | 89.2 | 350 | 583 |
| 23-may-94 | 32 | 7.9 | 11.5 | 18 500 | 8 850 | 2.72 | 14.6 | 118 | 6.95 | 19.4 | 2018 | 7.65 | 1000 | 154 | 861 | 559 |
| 9-jul-94 | 24.6 | 6.94 | 2.5 | 4 700 | 1 872 | 1.8 | 3.36 | 1.8 | 3.65 | 0 | 222 | 3.74 | 880 | 52 | 198 | 90.1 |
| 1-aug-94 | 25.4 | 7.15 | 3.5 | 6 000 | 1 304 | 0.955 | 1.26 | 14.4 | 0 | 3.77 | 61.7 | 3.74 | 670 | 257 | 208 | 66.1 |
| 27-aug-94 | 25.7 | 6.86 | 2.5 | 4 150 | 932 | 1.05 | 2.24 | 24.4 | 0.7 | 4.5 | 4.4 | 2.72 | 478 | 42.7 | 127 | 48.1 |
| 10-nov-94 | 26.3 | 6.83 | 3 | 5 000 | 1 491 | 0.86 | 5.94 | 26.3 | 0.55 | 14.7 | 168 | 4.76 | 1466 | 258 | 337 | 91.6 |
| **average** | 25.6 | 7.2 | 3.3 | 5 675 | 1 859 | 0.7 | 4.7 | 80.7 | 1.7 | 7.3 | 215 | 5.2 | 662 | 202 | 278 | 157 |
| **standard deviation** | 2.4 | 0.3 | 2.8 | 4 368 | 2 280 | 0.8 | 5.8 | 91.7 | 2.0 | 7.6 | 572 | 1.7 | 573 | 237 | 195 | 202 |

puddles of a meter or less of diameter. During the rainy season, water level variations roughly reflected the two precipitation peaks. Water composition varied accordingly and reflected the alternation of dilution/concentration processes linked to climate. Salinity varied from 1 to 11.5 ‰, indicating the prevalence of a brackish aquatic environment. Minimum values occurred between November and December coinciding with the second precipitation peak of the year (Fig. 2). Subsequently salts became concentrated by progressive evaporation, reaching a maximum salinity by May. These salinity values are low when compared with similar mangrove lagoons along the Northern coasts of Venezuela that maintain their natural connections with the sea (Okuda & Benitez-Alvarez, 1985), which range between 0.31 and 95.1 ‰. Conductivity varied widely throughout the year, ranging from 2250 µS/cm by November 1993 to 18500 µS/cm by April 1994, coinciding with water level variations. Chloride (Cl) concentrations were closely related to salinity and conductivity, reaching a maximum value of 8850 mg $l^{-1}$ by May and a minimum of 310 mg $l^{-1}$ in October 1993. Concentrations of Na, K, Ca and Mg were also high and variable and followed different trends. As in the surrounding soils, earth alkaline metals dominated on alkaline ones. Values of pH ranged from 6.83 to 7.90; no clear trend could be observed. Total phosphorus (TP) concentrations were fairly high, shifting from 79 to 2270 µg $l^{-1}$. No clear seasonal trend could be noticed, except for the high concentrations in May coinciding with the drying up of the lagoon. Total nitrogen concentrations (TN) were also very variable showing three peaks, a weak one in November 1993, the second in early April, followed by a sudden decrease in the middle of April, and the third in May probably related to the drying up of the lagoon. When compared with other mangrove lagoons located on the North-Eastern coast it came out that both TP and TN were much higher than the averages recorded at the Tacarigua, Píritu and Unare lagoons (Okuda & Benítez-Alvarez, 1985). In October 1993 and January 1994 a significant decrease in TOC and TN took place, coinciding with the rapid expantion of the weed *Myriophyllum* sp. Later increases in TOC and TN in the water column coincided with Myriophyllum leaf breakdown. Conditions of low dissolved oxygen and high hydrogen sulphide concentrations, common in eutrophic environments, where found throughout the year.

## Discussion and Conclusions

The results clearly pointed to three outstanding consequences of mangrove isolation, which should be carefully considered before dumping wastewater into it, because of their significance for present day life at the lagoon. They are 1) gradual shift to freshwater conditions; 2) nutrient overloading and 3) the installation of a drought/flood hydrological regime drown exclusively by seasonal rainfall and evaporation in the absence of marine inputs.

It could be shown that a marine subsurface water svedge penetrates landwards till the mangrove and becomes mixed with precolating freshwater supplied by precipitation and runoff, resulting in a progressive dilution of ground water. Within the mangrove lagoon, water was brackish too and level and stagnancy seemed to be controlled only by seasonal precipitation and topographic conditions, while once tidal fluctuations were probably important in this regard. Consequently, soils were subjected to different degrees of leaching due to precipitation and water logging. In the absence of any replacement of salts by tidal action, this process might produce, in the mid time, non-saline soils throughout. The mangrove community still kept some relationship with the sea through groundwater. The latter offered a permanent salt provision to the system, counteracting the effect of gradual soil desalinization. Current desalinization process allowed terrestrial plants to grow at the periphery of the mangrove community, while typical mangrove species and aquatic and semi-aquatic plants occupied more central positions within the ecosystem. Further spaces may be colonized by terrestrial plants, if soil salt losses continue. On the other hand, the input of treated wastewater may only accelerate the ongoing soil desalinization process and water dilution, creating favorable conditions for a progressive substitution of mangroves trees by freshwater species.

Mangroves are known to enhance water quality by extracting nutrients from the water column. They diminish nitrate and phosphorus concentrations in contaminated water through denitrification and soil-nutrient burial (Ewel et al., 1998). However, the potential of mangroves to "clean" water is limited. Nutrient concentration at Playa Medina was elevated and very fluctuating. The lagoon even reached hypereutrophic conditions that are TP > 0.100 mg / l (Wetzel, 1984), but its nutrient concentrations were below the permitted limits set by the environmental norms for effluent quality in force: 10 mg/l for TP and 40 mg/l for TN (MARNR, 1994). This means that, assuming compliance with the norm, the treated effluent from the Hotel complex would be of worse water quality as the receiving water itself, representing an additional input of P and N to the lagoon.

The permanence and depth of water in the lagoon and flood area throughout the year were critical factors for the development and distribution of plant species. The seasonal evaporation / precipitation cycle establishes the alternation of aquatic and terrestrial stages, which in turn determine and condition the biological cycles of many species living in the mangrove. The question is whether a discharge of 300 $m^3$ $d^{-1}$ of wastewater into the lagoon during the wet season is about to interrupt this cycle, prolonging the presence of water during the dry season. No evacuation of wastewater from the lagoon is possible due to the absence of drainage channels. Infiltration is probably very low regarding the daily water volume to be discharged and the evaporation rate will remain the same. Therefore the installation of permanent flood is a likely scenario and would represent a significant hydrological change. A projection can be made of the significance 300 m3 $d^{-1}$ of a water supply in terms of precipitation. This volume is equivalent to 109 500 $m^3$ $y^{-1}$, or 1 009 l $m^{-2}$, if divided by 109 400 $m^2$ of receiving terrain (lagoon + flood zone). In terms of precipitation this represents 1 009 mm $y^{-1}$, or 83 mm $month^{-1}$. From a climatic point of view, this would equal an average yearly precipitation increase of about 20%, which may result in a likely shortening or elimination of the dry, terrestrial phase of the lagoon, and in an asynchrony between seasonal evaporation / precipitation and biological cycles. Additionally, a 20% increment of pluviosity would be enough to promote important vegetation changes. Bush (1994) stated that a 20% decrease of effective precipitation due to climate change would facilitate the expansion of dry savanna forest in lowland Amazonia, but would not be sufficient to oust the tropical rain forest. In Playa Medina it is straightforward that *C. erectus*, the dominant beach mangrove and other terrestrial species growing on dryer soils, would experiment a retreat with the expansion of permanently flooded terrain, or with a significant shortening of drought.

Summarizing, on the one hand the proposed wastewater discharge of 300 $m^3$ $d^{-1}$ into the lagoon during the rainy season is expected to worsen water quality. On the other hand, it would introduce changes in the current hydrological regime comparable to those forecasted from a pluviosity increase due to a climatic change, but much more faster. The expected changes would produce the suppression of seasonality in the hydrology, and consequently in the biological cycle and survival probability of many species.

Yet, recuperating the original mangrove connection to the sea through channel opening may alleviate the impact of wastewater discharge. The effluent would be evacuated to the sea, and sea water and marine organisms would enter the mangrove. In this case, the normal relationship with the tidal influence on the mangrove would be restored, helping the ecosystem to recover. Restoration or rehabilitation may be recommended when a system has been altered to such an extent that it cannot self-correct or self-renew (Lewis & Streever, 2000). This seems to be the case of the mangrove Playa Medina. A good approach to restoration might be working with natural recovery processes to reestablish mangrove habitat, reestablishing appropriate hydrological conditions. With a proper restoration design and good environmental management, the mangrove of Playa Medina might be conserved and its ecological functions improved, while solving the discharge needs of the Hotel Complex.

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## References

Boonsong, K., Piyatiratitivorakul, S., Patanaponpaiboon, P. 2003. Use of mangrove plantation as constructed wetland for municipal wastewater treatment. Water Sci Technol. 48 (5):257-66.

Bush, M.B. 1994. Amazonian speciation: a necessarily complex model. J. of Biogeogr. 21: 5-17.

Chapman, V.J. 1976. Mangrove Vegetation. J. Cramer. Vaduz. Federal Republic of Germany.

Chu, H. Y., Chen, N. C., Yeung, M. C., Tam, N. F. Y. & Wong, Y.S. 1998. Tide-tank system simulating mangrove wetland for removal of nutrients and heavy metals from wastewater. Water Sci. & Technol. 38: 361-368.

Greenberg, A.E., Cleresci, L.S. & Eaton, A.D. 1992. Standard Methods for the Examination of Water and Wastewater. Ed. APHA, AWWA, WEF, Washington, DC 20005.

EPA (Environmental Protection Agency). 1986. Test Methods for evaluating Solid Waste. Office of Solid Waste and Emergency Response, Washington D.C. 20460.

Ewel, K.C., Twilley R.R. & Ong, J. E. 1998. Different kinds of mangrove forests provide different goods and services. Glob. Ecol. Biogeogr. Lett.. 7: 83-94.

Henry, J.G. & Heinke, G.W. 1996. Environmental Science and Engineering. Prentice Hall, New Jersey.

Kadlec R.H. & Knight R.L. 1996. Treatment Wetlands. Lewis Publishers. New York.

Lee, Y.S. 1995. Mangrove outwelling : A review. Hydrobiol. 295: 203-212.

Lewis, R.R. & Streever, B. 2000. Restoration of mangrove habitat. WRP Technical Notes Collection (ERDC TN-WRP-VN-RS-3.2), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/wrp (active on the Internet June 2004).

Lugo, A. & Snedaker, S. C. 1974. The ecology of mangroves. Annual Review of Ecol. Syst. 5: 39-64.

MARNR. 1992. Decreto 2224. "Sobre la regulación de descargas de vertidos a cuerpos de agua." Ley penal del ambiente y sus normas técnicas. Ministerio del Ambiente y de los Recursos Naturales Renovables. Caracas,Venezuela.

MARNR, 1994. Decreto 883. "Normas para la clasificacion y el control de la calidad de los cuerpos de agua y vertidos o efluentes liquidos". Ley penal del ambiente y sus normas técnicas. Ministerio del Ambiente y de los Recursos Naturales Renovables. Caracas,Venezuela.

Medina, E., Cram, W.J., Lee, H.S.J., Lüttge, U., Popp, M., Smith, J.A.C. & Díaz, M. 1990. Ecophysiology of xerophytic and halophytic vegetation of a coastal alluvial plain in Northern Venezuela. New Phytol. 111 : 233-243.

Okuda, T. & Benítez-Alvarez, J. 1985. Evaluación comparativa de las condiciones hidroquímicas en el sistema lagunar Tacarigua-Unare-Píritu, Venezuela. Bol. Oceanogr. Univ. Oriente, 24: 199-211.

Olson, D., Dinerstein, E., Cintrón, G. & Lolster, P. (editors) (1996.) Report from WWF's Conservation Assessment of Mangrove Ecosystems of Latin America and the Caribbean. Workshop, December 2-4, 1995, Washington, D.C. USA.

Parker, R.E. 1976. Estadística para Biólogos. Cuadernos de Biología. Omega, S.A. Barcelona.

Robertson, A.I. &. Duke, N.C. 1987. Mangroves as nursery sites of fishes and crustaceans in mangrove and other near shore habitats in tropical Australia. Mar. Biol. 96: 193-205.

Rull, V. 2000. Holocene level rising in Venezuela: a preliminary curve. Bol. Soc. Venez. Geol., 25:32-36.

Rull, V. & Vegas Vilarrubia, T. 2000. Chrysophycean stomatocysts in a Caribbean mangrove. Hydrobiol. 428: 145-150.

Rull, V. & Vegas Vilarrubia, T. 1999. Surface palynology of a small coastal basin from Venezuela and potential paleoecological applications. Micropaleont. 45: 365-393.

Sanoja, M. 1992. Wetland ecosystems and the management of cultural heritage. In: A.E. Lugo and B. Bayle (eds.), Wetland management in the Caribbean and the role of forestry and wetlands in the economy. Institute of Tropical Forestry, Río Piedras, Puerto Rico.

Tam, N. F. Y., Wong, Y. S., Lan, C. Y. & Wang L. N. 1998. Litter production and decomposition in a subtropical mangrove swamp receiving wastewater. J. of Exp. Mar. Biol. Ecol. 226: 1-18.

Vegas, Vilarrubia, T. 2000. Zonation pattern of an isolated mangrove community at Playa Medina, Venezuela. Wet. Ecol. Manag. 8: 9-17.

Vegas, Vilarrubia T. & Rull, V. 2002. Natural and human disturbance history of the Playa Medina mangrove community ( Eastern Venezuela). Carib. J. Sci. 38 : 66-76.

Yim, M.W. &. Tam, N. F. Y. 1999. Effects of Wastewater-borne Heavy Metals on Mangrove Plants and Soil Microbial Activities . Mar. Poll. Bull. 39: 179-186.

Walter, H. 1977. Zonas de vegetación y clima. Omega S.A., Barcelona.

Wetzel, R.G. 1981. Limnología. Blume. Barcelona.