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Ernesto Medina
Venezuelan Institute for Scientific Research

Ana Marta Francisco
Venezuelan Institute for Scientific Research

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Natural and man-induced changes in a tidal channel mangrove system under tropical semiarid climate at the entrance of the Maracaibo lake (Western Venezuela)

Ernesto Medina[1], Hortensia Fonseca[2], Flora Barboza[3] & Marta Francisco[1]
[1]*Centro de Ecologíe, Instituto Venezolano de Investigaciones Científicas (IVIC) Aptdo. 21827. Caracas 1020-A, Fax: 582-5041247; E-mail: emedina@oikos.ivic.ve;* [2]*Ministerio del Ambiente y de los Recursos Naturales Renovables, Caracas;* [3]*Instituto para la Conservación del Lago de Maracaibo (ICLAM), Maracaibo, Edo, Zulia, Venezuela*

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Abstract

Caño Paijana is a tidal channel that connected, until recently, the Uruba bay at the mouth of the Limón river, to the Gulf of Venezuela north of Maracaibo, Venezuela. It separated the Island of San Carlos from the mainland. In the last 50 years the channel has been drying out rapidly, to the extent that presently there is no water flow into or from the sea through its mouth opening on the Gulf of Venezuela. This mouth was covered by healthy mangroves (mainly *Avicennia germinans*) until at least 1952. The two extremes of the Paijana water channel differ radically today. At Uruba bay end the channel is fringed by dense mangrove vegetation dominated by *Rhizophora mangle*, while at the Gulf of Venezuela mouth the vegetation cover is mostly constituted by scrubby, scattered trees of *Avicennia germinans*, xerophytic shrubs acting as dune fixers, and halophytic strand vegetation. The process is the result of complex interaction between: a) high frequency of low-rainfall years; b) high dune activity during dry years c) dam construction on tributaries of the Limón river that reduced discharge of fresh water into Uruba bay.

Introduction

Fringe and riverine mangrove systems in semiarid tropical climates grow under quasi-permanent water stress determined by a regime of low, highly variable, and seasonal rainfall. Average temperatures above 25 °C predominate throughout the year, with an incident radiation level surpassing in average the 15 MJ m^{-2} level. In addition, due to low average rainfall, soil salinity increases quickly from the sea shore landwards, worsening water stress conditions. The ecological relationships of these mangroves of arid climates have been described in detail by Cintrón et al. (1978) in the Caribbean, and by Walter and Steiner (1936) on the eastern African coast.

These systems are specially variable, showing advances and regressions in tree cover extension during wet and dry years, respectively. This phenomenon has been reported in particular for *Avicennia germinans* (L.) Stearn communities, the species that usually predominates in back mangroves communities (Lugo and Snedaker, 1974; Smith et al., 1989).

Under these climatic conditions slight changes in the water supply derived from local run-off and/or from river discharges may result in mortality of adult trees and strong restriction of seedling establishment. The Caribbean coast of northern Venezuela presents several examples of the disturbance of coastal mangrove communities under a semiarid climate (Medina et al., 1989). Most frequently the impact is generated by the utilization of river water for agriculture and human consumption.

In western Venezuela the Maracaibo basin is associated with a large and complex estuarine system. A steep south-north rainfall gradient determines a semiarid climate along the Caribbean shores, particularly in the areas around the strait of Maracaibo and the Gulf of Venezuela, and a wet climate more inland

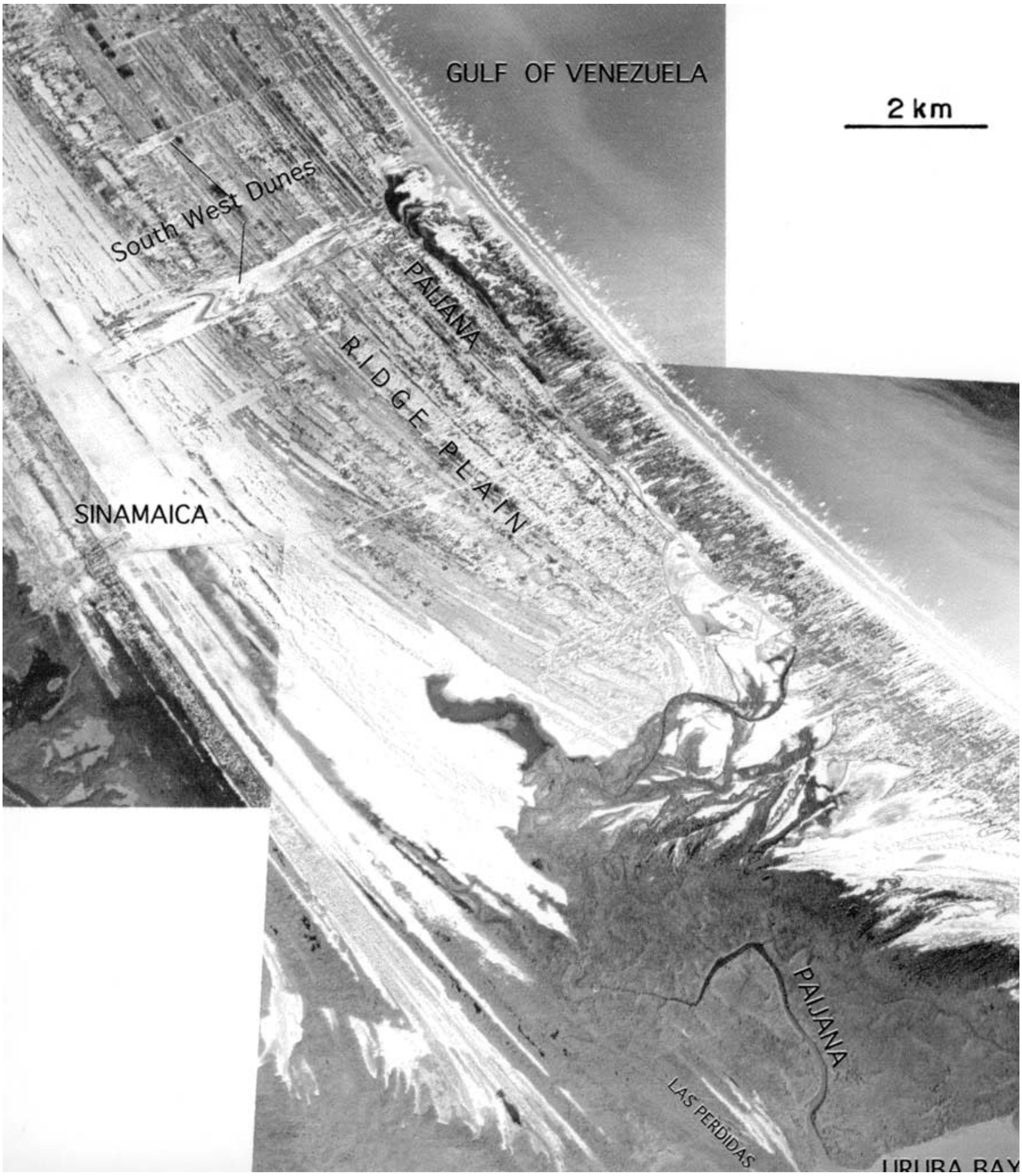


Figure 1. Composite of aerial photographs taken in 1992 showing the course of the Paijana channel between the Gulf of Venezuela and the Uruba Bay. Notice the coastal ridges running parallel to the coast line of the Gulf of Venezuela, and the numerous dunes running south-west cutting the coastal ridges described in detail by Tanner (1971). The town of Sinamaica is indicated as reference for the planimetry shown in Figure 2.

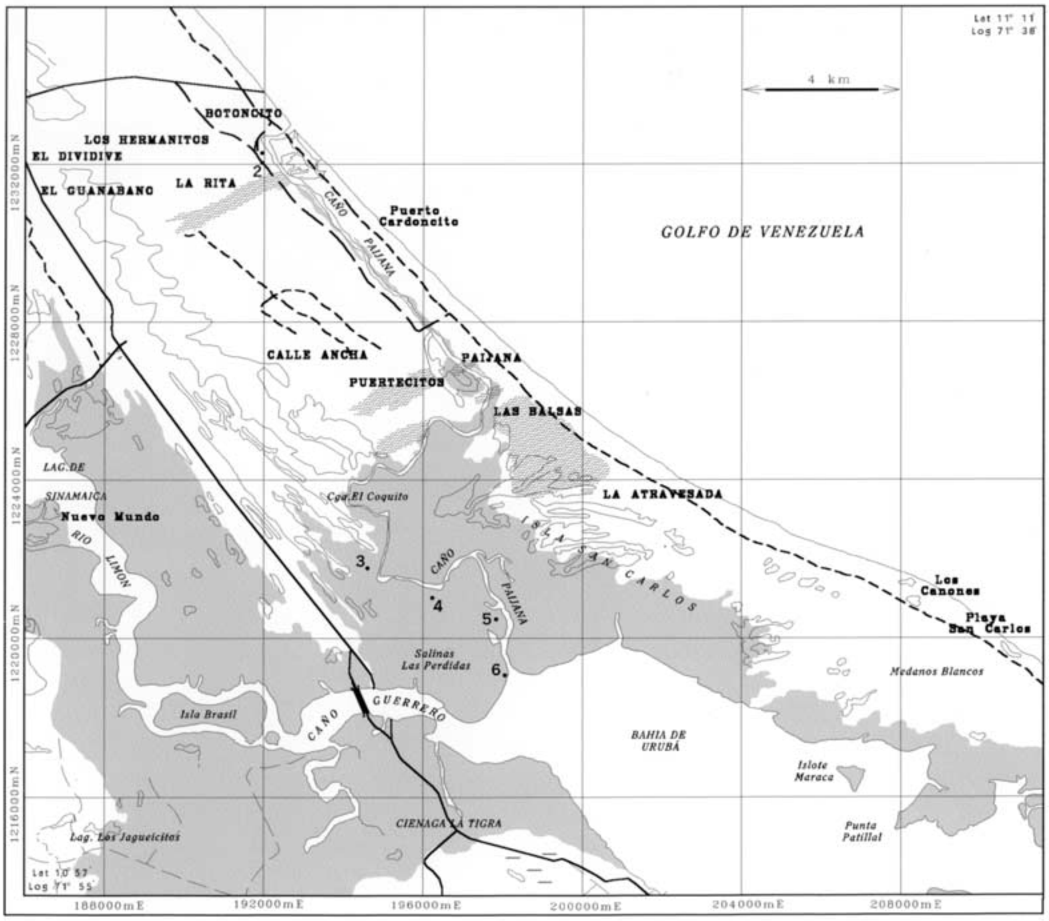


Figure 2. Map of the Paijana channel connecting Uruba bay and the Gulf of Venezuela. Basic maps from Cartografía Nacional (Sinamaica, sheet 3849, 1:100000). The light gray areas indicate the distribution of the mangrove vegetation along the coasts influenced by the Limón river and the Paijana channel. The stippled areas indicate the larger dunes observable in Figure 1. Numbers along the Paijana channel correspond to the location of sampling sites described in the text.

(Rodriguez, 1973). The Limón river running from the mountains in northwest into the semiarid belt, carries a heavy sediment load that has contributed to the formation of large islands such as San Carlos, Pájaros, and Zapara (Figure 2).

Currently the fresh water discharged by the Limón river at Uruba bay, floods the lower half of San Carlos island and feeds the swamp of La Tigra at the southern side of the bay. The discharge maintains a salinity level below that of sea water. The flooded areas are covered by a dense mangrove vegetation with an intricate drainage pattern. The main axis of this drainage is constituted by Caño Paijana, a tidal creek that separates the San Carlos island from the mainland. Until recently this channel connected the Uruba bay to the Gulf of Venezuela. Its mouth on the Gulf of Venezuela was covered by mangroves, and as such it was represented in the map from Cartografia Nacional (Sinamaica, Sheet 3849, 1:100,000, 1963). Archaeological evidence indicates that this caño was actively used during colonial times by smugglers, trying to circumvent the control of the San Carlos castle located at the main entrance of the Maracaibo lake (Alberta Zucchi, Anthropology Department, IVIC, personal communication). Currently the Caño Paijana mouth on the Gulf of Venezuela has been filled up with sand and is partially covered by semi-vegetated dunes.

In this paper we suggest that the final closure of this mouth has been relatively recent, although the process has been progressing steadily at least during the last 200 years. We compared aerial photographs taken in 1952 and 1992 from the two extremes of Caño

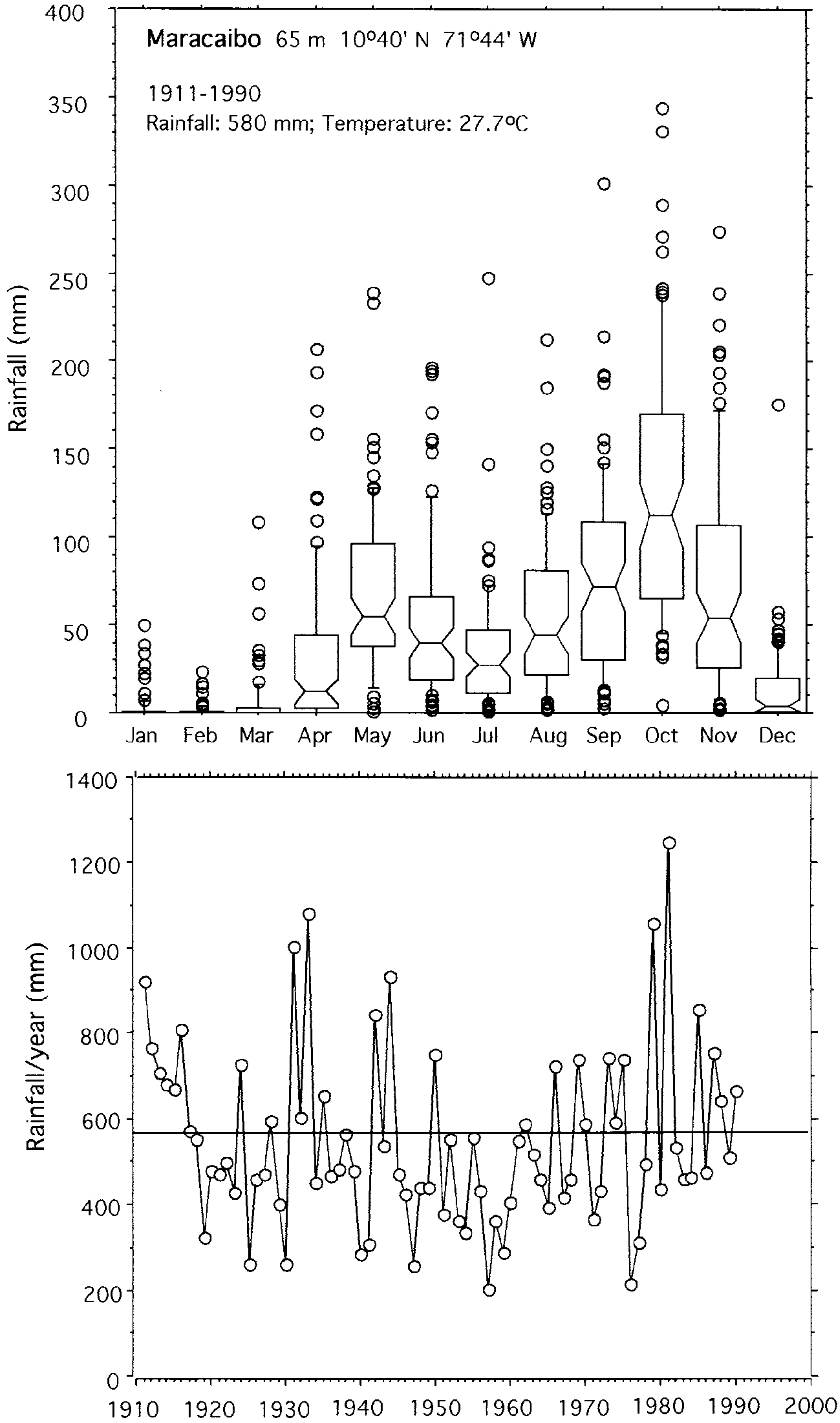


Figure 3. Long-term averages of annual distribution and interannual variation of rainfall (Fuerza Aérea de Venezuela, 1995). The upper diagram contain the box plots showing the percentile distribution (10th, 25th, 50th, 75th, 90th percentiles) and the outliers for each month rainfall (calculated with StatView 5.0 SAS Institute, 1998). This representation conveys the high variability of rainfall in the study area. The lower diagram shows the mean annual rainfall.

Paijana, the mouths on the Gulf of Venezuela and on the Uruba bay. Examination of those pictures showed that 40 years ago water was still flowing into the Gulf of Venezuela, and a healthy mangrove community occupied both mouths of the Caño. To document the present levels of salinization we collected soil and leaf samples in six sites along the Caño Paijana.

Study area

The study area is a marine swampy plain located along the western coast of the Gulf of Venezuela (Figure 1). The Paijana connects the Uruba bay about 1 km north of the mouth of the Limón river in the southeast, with the Gulf of Venezuela toward the northwest. The coordinates limiting the Paijana plain are 11°00′–11°10′ N and 71°37′30″–71°52′30″ W (Figure 2).

The region includes a swampy intertidal zone along sandy beaches, and coastal dunes. The water channel is fringed by mangrove vegetation (Figures 1 and 2). Wind activity is considerable and the trade winds blow steadily throughout the year, predominantly from the NNE with average velocities of 3.8 m/s and maximum velocities ranging from 16.5 in December to 30.7 m/s in August (averages for the period 1961–90, Fuerza Aérea, 1993). Sand mobilization from dunes is possibly associated with dry years, because low water availability during the period August-October may affect vegetation vigor when wind activity is at its peak.

Climate

The study area is located within the semi-arid climatic type of Thornwaite (Petróleos de Venezuela, S.A. 1992). The most representative climatological station for this semi-arid area is Maracaibo airport, with the longest record in western Venezuela (Fuerza Aérea, 1993). Average rainfall in Maracaibo amounts to 580 mm with temperatures averaging 27.7 °C. Average rainfall distribution is bimodal with a small peak in May and a larger peak in October. However, variability is quite large and rainfall below 5 mm has been recorded for every month during the measuring period (Figure 3, upper panel). The frequency of rainless periods is higher from December through March and also in July, when a distinctive short dry season may be discerned from the data. Rainfall per year shows also a large variability with 19 out of 80 years showing rainfall below 400 mm, and 9 years with rainfall above 800 mm (Figure 3, lower panel). Evaporation measured in Tank A is high reaching 1826 mm per year. Monthly evaporation is always higher than rainfall except in October. The radiation climate in Maracaibo shows two well defined and similar peaks, one in March and a second in July, reaching values of 17.5 MJ/m^2 in average. Evaporation peaks during the same months, however, the first peak is higher (7 mm/day) than the second (5.4 mm/day).

Geomorphology

The landscape corresponds to a depositional marine coastal environment in the shape of filled up coastal lagoons with terminal expansion axes (Coplanarh, 1974). It is constituted by a large and well-developed beach ridge plain (Tanner, 1971; Ellenberg, 1978) (Figure 2). In the area between Paraguaipoa and Sinamaica 50–100 beach ridges trending northwest and southeast can be easily detected in conventional air photographs. Average spacing between ridges is close to 100 m. Tanner (1971) described five parallel sand strips each of which is marked at the seaward edge by considerable dune activity. The widest strips located near the sea shore do not taper at either side, indicating the off-shore origin of the sand (Figure 2).

Vegetation

Three main types of vegetation are present:

a) mangrove vegetation along Caño Paijana, dominated by *Avicennia germinans* from the middle portion up to the mouth on the Gulf of Venezuela, and *Rhizophora mangle* L. from the middle down to the mouth on Uruba bay. *Laguncularia racemosa* (L.) Gaertn. f. is also frequent at this side of the Caño.

b) xerophytic vegetation covering the beach ridges towards the interior represented mainly by *Prosopis juliflora* (Sw.) DC, and some dune fixing species such as *Coccoloba uvifera* (L.) L., and

c) halophytic herbaceous vegetation along the littoral with *Sesuvium portulacastrum* (L.) L. and *Sporobolus virginicus* (L.) Kunth.

The current vegetation cover of Caño Paijana differs markedly between the extremes. The fringes around the entrance in Uruba bay are covered by a well developed mangrove community dominated by *Rhizophora* in an environment heavily influenced by the fresh water supply from the Limon river (Figure 2). The areas around the mouth on the Gulf of Venezuela

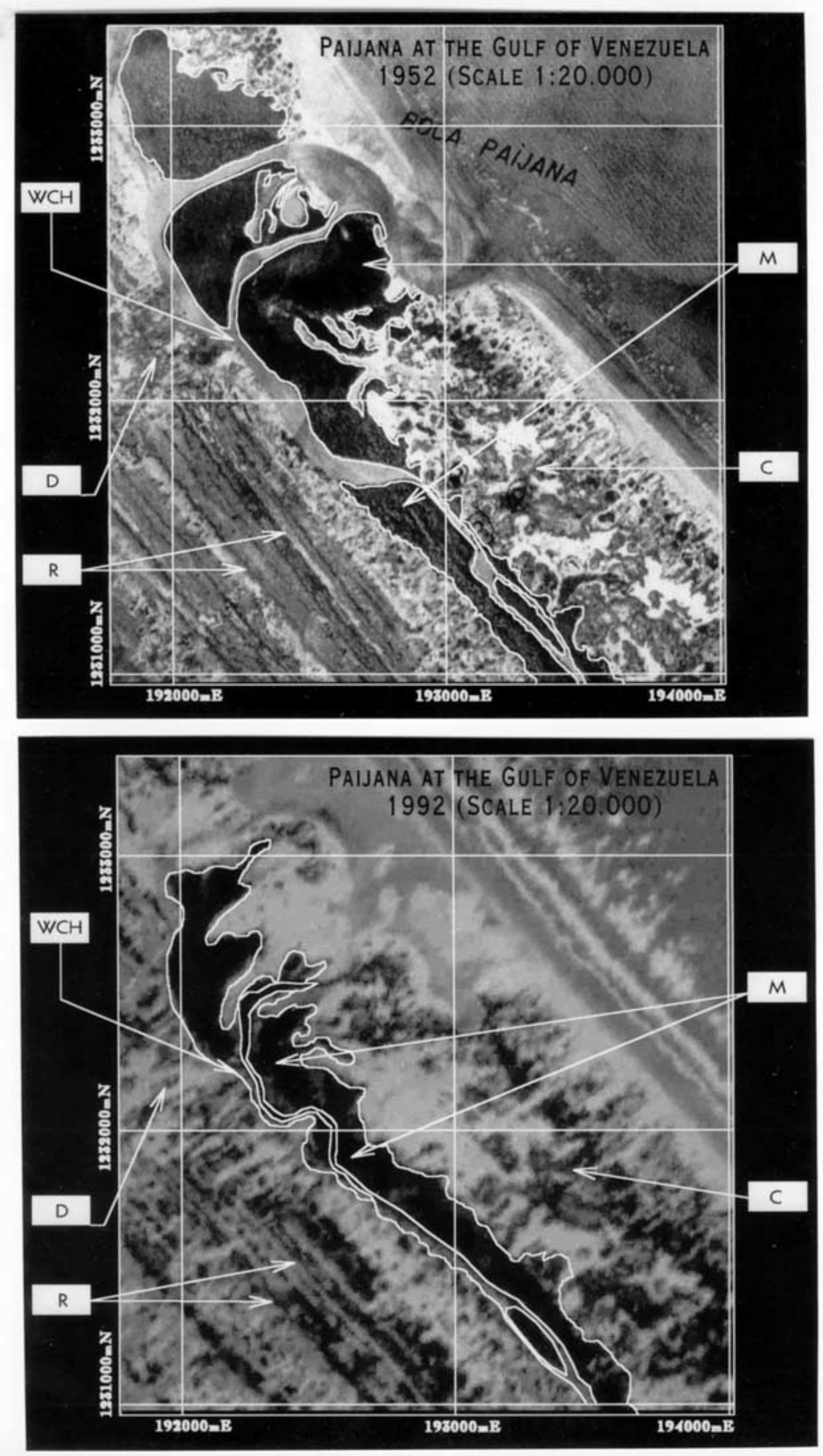


Figure 4. Comparison of conventional aerial photographs taken in 1952 (upper) and 1992 (lower) of the Paijana mouth on the Gulf of Venezuela. Actual scale is 1:20000, the distance between the UTM coordinates is 1 km. Notice the differences in the extension of the mangrove cover (dark continuous patches, M) and the large dune in the southwest direction (D). R, coastal ridges; C, xero-halophytic coastal vegetation; WCH, water channel.

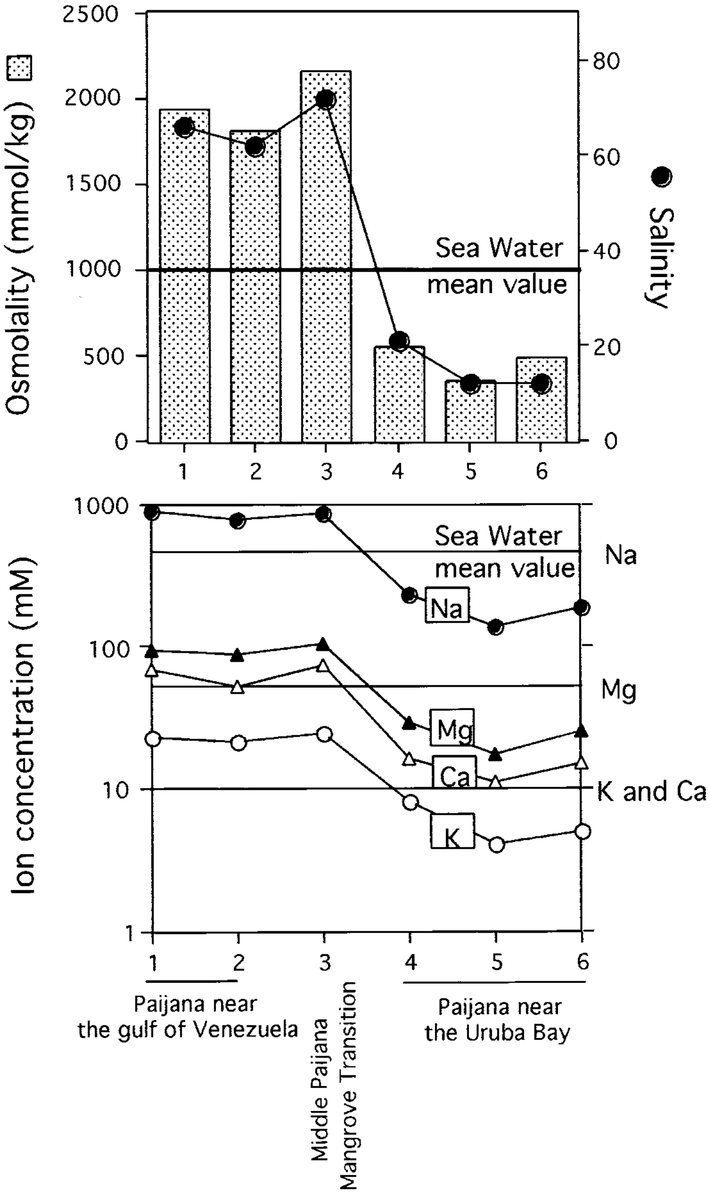
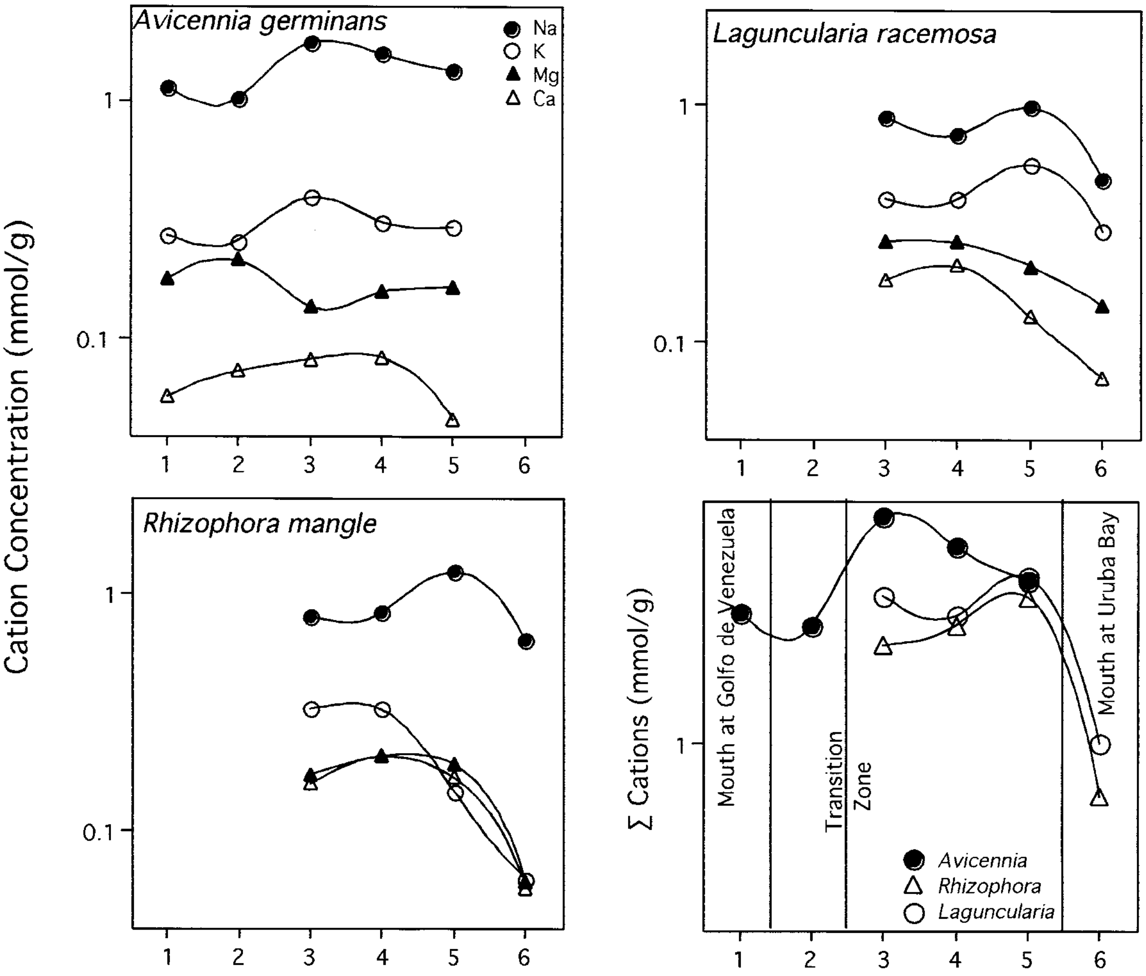


Figure 5. Salinity and cation concentrations in interstitial water collected along the Paijana channel. Each point in the upper diagram represents the average of three replicates.

are covered by a sparse vegetation, with narrow, discontinuous fringes of pure stands of *Avicennia* along the water channel, and scattered trees isolated within the old flood plain (Figure 2). The remains of the original channel can be observed, but the communication to the sea has been cut off for a time long enough to allow the formation of dunes between the flood plain and the sea. Xero-halophytic vegetation mostly dominated by *Sporobolus* is found scattered in the plain.

Changing aspects of the Paijana channel

During the 80 years for which reliable rainfall data is available, it appears that frequency of relative dry years in the area predominates. Out of 80 years in the record 47 years had rain below, and 24 above average, among the latter 4 years with rainfall above 1000 mm (Figure 3, lower panel). Within the measuring period,



Sites:

1-2 Paijana at Golfo de Venezuela; 3. Middle Paijana, Mangrove transition; 4-6. Paijana towards and in the vicinity of Uruba bay

Figure 6. Cation concentration in leaf tissues of mangrove species along the Paijana channel. Observe that *Avicennia* is the only species occurring at sites 1–2, and absent from site 6. The y-axis is given in a logarithmic scale to convey the variation of the four cations together.

there are eight sequences of 3–5 relatively dry years interrupted by 1–2 relatively wet years.

In addition to the higher frequency of relatively dry years, the discharge of the Limón river into the Uruba bay has decreased as a result of the construction of two large water reservoirs, about 100 km NW from Maracaibo, that impound the waters from two of the main tributaries of the Limón river (MARNR, 1995). They are the Cachiri-Colorado dam (Tulé dam) built between 1964–1971, and the Socuy dam built between 1973–1978. These water reservoirs supply water to Maracaibo and neighboring towns, to the El Tablazo Petrochemical Complex, and are used to irrigate about 12 km^2 of agricultural fields. Finally, the sediment load has increased because of the extensive deforestation for agricultural developments in the upper basin of the Limón river. These processes have affected the amount of fresh water flowing through Caño Paijana from Uruba to the Gulf of Venezuela, resulting in a large scale vegetation die-back, and interruption of the water channel by sand deposition.

Comparison of aerial photographs taken in 1952 and 1992 (Figure 4) shows a clear reduction in the vitality and extension of the mangrove vegetation at the Gulf of Venezuela mouth. The picture taken in 1952 shows a dense mangrove vegetation forming three large patches covering the inter-channel areas of this mouth of the Paijana. These three units and the dark areas covering the lower border of the water channel were constituted exclusively by *Avicennia*. This assertion is based on the observation that all wood sections of dead stems that we examined at the Paijana mouth have the characteristic false ring structure of this species (Tomlinson, 1986). This picture shows two free water exchanges between the mouth channels and the sea. A large dune extends southwest interrupting the parallel beach ridges described by Tanner (1971) (see also Figure 1). The 1992 picture (Figure 4, lower panel), although it has lower resolution than the previous one, shows clearly that the extent of the mangrove vegetation has been markedly reduced. The beach ridges remain similar, but the vegetation located between the Paijana channel and the sea-shore has also retreated.

Inspection of the 1992 set of aerial photographs covering the whole extension of the Paijana showed the presence of two large and one small dunes that have interrupted, some time in the past, the flow of water through the Paijana, resulting in a complex pattern of deviation of the water flow. The location of these dunes is indicated in the map of Figure 1.

Interstitial soil salinity and ion concentrations in soils and plants

Water and plant samples were collected near both extremes of Caño Paijana near the Gulf of Venezuela (sites 1–2) and near Uruba bay (site 6) located about 14 km apart, the transition zone between the *Avicennia* dominated to *Rhizophora* dominated zones (site 3), and the middle-lower section of the channel sites 4–5 covered by dense *Rhizophora* dominated forest (see Figure 1).

Interstitial water samples were collected using a plastic tube that is inserted in the mud down to 30 cm. Interstitial water from 10 to 20 cm depth drained through perforations into the tube was collected for determination of salinity (refractometer), osmolality (Wescor dew point osmometer), and concentration of dissolved cations (K, Na, Mg, Ca) (atomic absorption spectrometry). Mature leaves from the dominant species were also collected in the field, thoroughly cleaned with moist tissue paper and dried in a ventilated oven at 60 °C until constant weight. Leaf material was homogenized in the laboratory using a modified coffee-bean grinder. Soluble elements were extracted from leaf powder with hot water (90 °C) for 2 hours. This extract was used for the determination of soluble cations by atomic absorption spectrometry.

Interstitial water

Salt concentration of interstitial waters appreciably changes from the Gulf of Venezuela to Uruba bay. At the blind end and in the transition zones salinity and osmolality amounts to nearly twice the concentration of normal sea water (Figure 5, upper panel). Towards the Uruba bay concentration fall below half of standard sea water. Concentration of cations shows the same dilution pattern, Na being the most important cation followed by Mg, Ca and K in all sampling sites. The measured cation concentrations, however, differ from the predictible dilution effect. Using standard sea water cation concentrations as a basis, it may be calculated that the most abundant cations in sea water, Na and Mg, follow the dilution pattern indicated by both salinity and osmolality (Table 1). However, K was about 0.2 to 0.5 times higher than expected, while Ca was about 3.5 times higher than expected. These higher ratios point to a terrestrial source of these cations, possibly associated with run-off or underground waters.

Leaf tissues

Avicennia was sampled in the first 5 sites, while *Rhizophora* and *Laguncularia* were sampled only in sites 3 to 6. Sodium was the predominant cation in all species, but *Avicennia* had higher concentrations than the other two. Soluble calcium was particularly low in *Avicennia* because this plant produces oxalate that renders Ca insoluble (Popp, 1984). The rank of concentrations in the three species was Na>K>Mg>Ca. The higher rank of K in the plant tissue compared to interstitial water reflects its selective absorption by plants (Rains and Epstein, 1967). The Mg/Ca ratios in plant tissues showed a comparable value to that of the interstitial water (1.5–1.7 in water, 1.1–2.6 in plants) while the Na/K ratios decreased from 33–37 in interstitial water to 1.9–5.9 in leaf tissues. It is remarkable that *Avicennia* leaves had higher cation concentration in leaves

Table 1. Concentration ratios interstitial water/standard sea water (n = 3). Ratios were calculated dividing measured parameters by standard sea-water values: Salinity 35‰; Osmolality 1000 mmol/kg; 459.4 mM Na; 52.3 mM Mg; 9.7 mM K; 10 mM Ca.

	Salinity ‰	osmolality mmol/kg	Na mM	K mM	Mg mM	Ca mM
Vicinity of the Gulf of Venezuela						
Sites 1–3	1.9 (0.1)	2.0 (0.2)	1.8 (0.1)	2.3 (0.2)	1.8 (0.2)	6.5 (1.2)
Vicinity of Uruba Bay						
Sites 3–6	0.4 (0.1)	0.5 (0.1)	0.4 (0.1)	0.6 (0.2)	0.4 (0.1)	1.4 (0.2)

of plants occurring in intermediate sites (3–4), than those of hypersaline sites 1–2. The smaller trees in sites 1–2 possibly express more severe water stress and reduced transpiration. Curtailment of salt transport in the transpiration stream may have resulted in lower concentration of soluble cations per unit dry weight.

Conclusions

The evidence presented here indicates the progressive disappearance of the Paijana creek, that functioned formerly as a permanent, and later as an intermittent tidal water channel connecting Uruba bay and the Gulf of Venezuela. The causes of this process have not been yet definitively established, however, several converging factors seem to have had a preponderant influence:

1. Although the rainfall record for the study area is not long enough to establish a clear pattern, the available data indicate that for the period 1911–1990 the number of years with below average rainfall predominates. Sequences of relatively dry years result in higher levels of water stress, particularly during the dry seasons, and slows down salt leaching in coastal areas during the rainy season. In addition, lower average water run-off diminishes further the discharge into the channel.
2. The western coast of the Gulf of Venezuela is under the permanent influence of the trade winds blowing predominantly from the NE direction. The capability of these winds to transport sand and to mobilize fine sediments increases during drier years, partially as a result of the lower vegetation vigor preventing effective cover of exposed areas. We hypothesize that the 5 events of heavy dune activity detected by Tanner (1971) are associated with sequences of years with rainfall below average. Some of these events may be present in the available record. The periods 1919–1928; 1935–1940; 1952–1960 were clearly periods of dry years that may have contributed to increase the dune activity.
3. The main supply of fresh water to Uruba bay is the discharge of the Limon river. This river is formed by the convergence of the rivers Guasare, Socuy and Cachiri. The latter two have been impounded to build water reservoirs providing water for human consumption and agricultural purposes. These works have certainly reduced the fresh water influx into the Uruba bay, further diminishing the amount of water available to flow into the Paijana channel.

Acknowledgements

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References

Cintrón, G., Lugo, A.E., Pool, D.J. and Morris, G. 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. Biotropica 10: 110–121.

Coplanarh. 1974. Inventario Nacional de Tierras. Región Lago de Maracaibo. Caracas.

Ellenberg, A.L. 1978. Coastal types of Venezuela – an application of coastal classifications. Zeitschr. Geomorph. 22: 439–456.

Fuerza Aérea Venezolana. 1993. Estadísticas Climatológicas de Venezuela Período 1961–90. Publicación Especial No. 5. 1era. Edición.

Lugo, A.E. and Snedaker, S.C. 1974. The ecology of mangroves. Ann. Rev. Ecol. Syst. 5: 39–64.

MARNR. 1995. Grandes Presas Venezuela. Revista El Agua. Tomo 1. Edicion Especial. Caracas.

Medina, E., Cram, W.J., Lee, H.J.S., Lüttge, U., Popp, M., Smith, J.A.C. and Díaz, M. 1989. Ecophysiology of xerophytic and halophytic vegetation of a coastal alluvial plain in northern Venezuela. I. Site description and plant communities. New Phytol. 111: 233–243.

Petróleos de Venezuela S.A. 1992. Imagen de Venezuela. Una visión espacial. 272 pp. Editorial Arte, Caracas.

Popp, M. 1984. Chemical composition of Australian mangroves I. Inorganic ions and organic acids. Zeitschr. Pflanzenphys. 113: 395–409.

Rains, D.W. and Epstein, E. 1967. Preferential absorption of potassium by leaf tissue of the mangrove, *Avicennia marina*: an aspect of halophytic competence in coping with salt. Aust. J. Biol. Sci. 20: 847–857.

Rodriguez, G. 1973. El Sistema de Maracaibo. Instituto Venezolano de Investigaciones Cientificas. Caracas.

Smith, J.A.C., Popp, M., Lüttge, U., Cram, W.J., Díaz, M., Griffiths, H., Lee, H.S.J., Medina, E., Schäfer, C., Stimmel, K.-H. and Thonke, B. 1989. Ecophysiology of xerophytic and halophytic vegetation of a coastal alluvial plain in northern Venezuela. VI. Water relations and gas exchange of mangroves. New Phytol. 111: 293–307.

Tanner, W.F. 1971. Growth rates of Venezuelan beach ridges. Sediment. Geol. 6: 215–220.

Tomlinson, P.B. 1986. The Botany of Mangroves. Cambridge Tropical Biology Series. Cambridge University Press.

Walter, H. and Steiner, M. 1936 Die Ökologie der Ost-Afrikanischen Mangroven. Zeitschr. f. Bot. 30: 65–193.