Int. J. Environ. Res., 10(4):481-490, Autumn 2016
ISSN: 1735-6865

Environmental Variability of Tropical Sandy Beaches Across an Anthropic Gradient: The Case of Central Veracruz (Southwestern Gulf of Mexico)

Hidalgo, G.[1,4*], Castañeda-Chávez, M.R.[2], Granados-Barba, A.[3] and Sánchez-Domínguez, B.E.[1]

[1]Postgrado en Ecología y Pesquerías, Universidad Veracruzana (UV), Independencia 30, Pisos 1 y 2. C.P. 94290, Boca del Río, Veracruz, México

[2]Instituto Tecnológico de Boca del Río (ITBOCA), Veracruz, México

[3]Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana (ICIMAP-UV), Veracruz, México

[4]Instituto de Oceanología, Agencia de Medio Ambiente del Ministerio de Ciencia, Tecnología y Medio Ambiente (IDO-CITMA), 1ra. 18406 entre 184 y 186, Playa, C.P. 11600, La Habana, Cuba

Received 2 June 2016; Revised 19 Aug. 2016; Accepted 25 Aug. 2016

ABSTRACT: In a coastline with growing urbanization, we examined the condition of water and sediments in sandy beaches within a gradient of uses and modification, in contrast with a reference unmodified beach, to assess different disturbance sources and environmental impact grades. The gradient was analyzed depending on beaches proximity to the urban nucleus, accessibility, tourism and recreation activities, and construction of breakwater structures. Using an integrated approach, some physical, chemical, microbiological and morphodynamic parameters were measured during two sampling campaigns. The results indicate a higher content of organic matter in sediments of the beaches near to the Veracruz Reef System with respect to the reference beach, and in the cold fronts season than in rainy season. This temporal variation can be explained by the regional pattern of surface circulation, favoring downwelling in cold fronts season and upwelling in rainy season. Water temperature, salinity and dissolved oxygen concentrations also accounted for seasonal variations. The stress gradient was evident in the granulometric characteristics of sediments, fats and oils, total solids, and enterococci concentrations in pore water. Intertidal slopes and littoral currents indicated not only a marked seasonality of these parameters, but differences between unmodified and modified beaches by breakwaters. All parameters are discussed, particularly those that accounted for the perturbation gradient, increased by the presence of breakwaters. This study serves as baseline of the environmental spatial-temporal variation in intertidal of the sandy beaches of central Veracruz, and as a reference in assessments of other beaches worldwide with similar conditions.

Key words: Beaches, Intertidal environment, Gradients, Environmental impact, Breakwaters

INTRODUCTION

Exposed sandy beaches are increasingly perturbed by human activities in most urban and industrial coastal zones of the Gulf of Mexico. The Veracruz-Boca del Rio littoral tourist corridor is located nearby a major seaport, exposed to fluvial and pluvial outfalls and wastewater discharges in some areas, transformed with breakwater structures and used for recreational purposes. The sandy beaches of the Veracruz metropolitan zone are semi-protected by numerous reef structures that belong to the Veracruz Reef System National Park (PNSAV) and are frequently visited by domestic and international tourists (Sánchez-Domínguez *et al.*, 2015).

The presence of breakwaters indirectly modifies environmental characteristics by limiting the natural beach dynamics (Bulleri and Chapman, 2010; Valadéz-Rocha and Ortiz-Lozano, 2013). Beach sand is considered a possible linkage between wave energy level and water quality, as a pervasive nonpoint source that tends to harbor more bacteria in the low-wave-energy environment (Feng *et al.*, 2016).

*Corresponding author E-mail: gemahidrod@gmail.com

García-Fuentes *et al.* (2014) reported that pathogenic bacteria in this zone come from coastal point sources of pollution, and affect PNSAV coral reefs. Water pollution from production and other anthropogenic activities (*e.g.* agriculture, animal husbandry, fisheries and aquaculture, industry and human settlements) has also led to deterioration of water quality in aquatic systems of the hydrological network by altering the concentration of some physical, chemical, and biological parameters of water beyond the permissible limits established by Mexican Federal Government standards (Landeros-Sánchez *et al.*, 2012). Heavy metals have been found in marine sediments of PNSAV in concentrations that exceed Federal limits associated with prevailing grain texture, particularly for fine sediments (Zamudio-Alemán *et al.*, 2014).

In this zone winds are natural disturbance sources influencing the coastal morphodynamics. Winds frequently exceed 40 km per hour during meteorological events, such as cold fronts from October to March (Ortiz-Pérez and De la Lanza-Espino, 2006), and 100 km per hour during the less frequent but devastating tropical storms or hurricanes from June to November (Carrillo *et al.*, 2007), generating storm surges that cause floods in lowlands, beach erosion and sediment transport in different directions, with predominant movement of sand from North to South. Extreme events can even cause sedimentation processes and estuarinization of coastal waters.

There are few comparative studies in intertidal zones of Veracruz that integrate data on multiple environmental parameters. Mendez-Ubach *et al.* (1985) analyzed the textural characteristics of sediments and their relationship to benthic macrofauna in 29 beach localities along the Veracruz littoral. Kasper-Zubillaga *et al.* (1999) studied petrography and geochemistry of Holocene sands and its implications for provenance and tectonic setting. Moreno-Casasola (2006; 2010) also included several aspects of these zones in her important compendia on coastal ecology. As part of the Clean Beaches Program in Mexico, monitoring of the sanitary quality of sea water for recreational use is done three times a year in 16 sandy beaches of the Veracruz coast.

Given the complexity of this coastal environment, interdisciplinary studies have been indicated as a top-priority, especially because natural and anthropogenic phenomena often exceed the carrying capacity of ecosystems (Carranza-Edwards *et al.*, 2004; Elko *et al.*, 2014). Nevertheless, there are no comprehensive surveys of multiple parameters in time and space to estimate the effects of the combined influence of uses and modification on beaches. In order to assess disturbance sources and environmental impact, the present study analyzes the intertidal physical, chemical, morphodynamic and microbiological conditions in three sandy beaches across a gradient of uses and modification at the Veracruz metropolitan zone, in comparison with a reference outer beach.

MATERIALS & METHODS

The Veracruz metropolitan zone, as defined by the Mexican institute of statistics and geography (INEGI), is situated in the middlemost part of the coastal State of Veracruz (southwestern Gulf of Mexico). Siemens *et al.* (2006) pointed out the historical process of expansion of the city in the environmental and landscape context, with implications for dunes and wetlands ecosystems.

This study was conducted in three sandy beaches (Villa del Mar, Mocambo and Arroyo Jiote) of the Veracruz metropolitan zone (Fig. 1), and a reference beach located in the natural reserve La Mancha (19º35’28"N, 96º22’41"W), about 50 km Northwest to the Veracruz port. The four beaches of this case study are exposed to the three types of wave regime present in the Gulf of Mexico according to Lankford (1977): waves and storm surges associated with tropical cyclones, waves and storm surges associated with cold fronts, and waves and storm surges generated within the fetch of winds on the gulf surface. The proximity of three of them to Veracruz Reef System, a coral reefs system which protect from the joint effect of wind and waves, as well as its orientations on the coastline, can modify both the fetch of wind and the magnitude and direction of incident waves.

Prevailing winds are gusting constant Northeast trade winds throughout the year, generating waves with typical periods of between five and seven seconds and 1.5 m high, according to Ortiz-Pérez and De la Lanza-Espino (2006). From October to March recurrently affect dry cold North winds, generating waves that can reach more than three meters and periods of ten seconds.

Human use and modification of beaches were analyzed based on their relative location to the urban nucleus, the presence of access roads, incidence of tourism and recreation, and construction of breakwater structures (Table 1).

Samplings were carried out in March (representative of cold fronts season) and September (representative of high temperature and precipitation) of 2013, at low tide conditions, in the days of the month with lower tidal variation (less than 0.35 m) according to the prediction models obtained from the National Tidal Service data station located at 19°11.5’N and 96°7.4’W. At low tide, almost all of the fauna are buried,

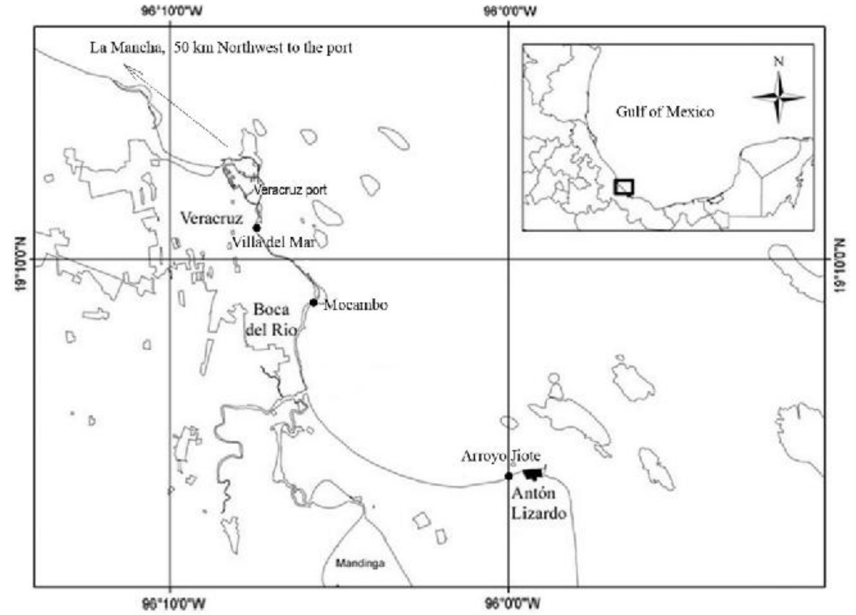

Fig. 1. Map of the study stations marked as dots

Table 1. Some differences regarding modification and human use of the study beaches

	La Mancha	Villa del Mar	Mocambo	Arroyo Jiote
Location relative to the urban nucleus	Rural (about 50 km)	Urban (<1 km)	Urban (<10 km)	Rural (<30 km)
Accessibility	Partially limited (unpaved path)	Broad (main road)	Moderate (side street)	Partially limited (unpaved path)
Incidence of tourism and recreation (No. persons per 100 m^2)	Relatively small groups for periods (<100)	Massive almost all year (>300)	From scarce to massive for periods (<300)	Relatively small groups for periods (<100)
Modification by breakwater structures	unmodified	modified	modified	unmodified

least mobile and structural features of the beach are most evident (Schlacher *et al.*, 2008).

Two sites with different configuration of intertidal slope (cusp and horn) were settled at each beach, away from their natural or artificial boundaries, to include different local morphodynamic conditions. Sediment samples per site were taken using a cylindrical PVC corer of 10.5 cm internal diameter, 0.01 m^2 area and inserted 10 cm into sediment, from a transect at three levels of tidal range for analysis of the main granulometric parameters following Buchanan (1984), and percentage of organic matter using the method of weight loss ignition by Dean (1974).

Textural parameters of sediments were analyzed according to the criteria of Folk and Ward (1957), using the SysGran 3.0 program (Camargo, 2005) with particle sizes in phi (x) notation of the geometric Wentworth scale, where $x = -\log_2 d$, and d= diameter (mm). Organic matter results were compared at each beach per sampling campaigns by Kruskall Wallis tests using Statistica 7.0 software (StatSoft, Inc., 2004).

Temperature, pH, salinity, and dissolved oxygen concentrations in water were registered at each site with a YSI 556 multiparameter probe, with precision of 0.01 for each parameter. Water physical chemical parameters were also compared per sampling campaigns using Kruskall Wallis tests.

A shallow water sample per site was taken with a two-liter bottle of PVC, and preserved in refrigeration for determination of fats and oils, and total solids, according to the national standards. The fats and oils of both campaigns were tested for significant differences and post-hoc comparisons among beaches. Before the analysis, data homogeneity of variance was proved by Levene test [$F(3,12)=2.65$, $p = 0.09$]. All analysis of variances and post-hoc tests of multiple comparisons were performed with significance level of $p<0.05$.

Pore water samples were collected with sterile serological pipettes and poured into sterile labeled bags that were transported in a container at 4 °C to the laboratory. Enterococci concentrations in pore water were determined in the March campaign as described in Sánchez-Domínguez *et al.* (2015) using the chromogenic substrate method Enterolert IDEXX, and were compared among beaches by a Kruskall Wallis ANOVA test and multiple comparisons of mean ranks for all groups. In this month, increased persistence of these microorganisms would be expected due to lower temperatures (Whitman *et al.*, 2014).

The intertidal slope was measured according to Emery (1961). Beach morphodynamics were assessed by Dean's parameter $\Omega = Hb \cdot 100/Ws \cdot T$ where Hb is breaker height (m), Ws is sand fall velocity (cm s^{-1}) and T is wave period (sec) (Short, 1996). Direction and magnitude of littoral current were registered by a drifting buoy with a Garmin GPS, taking records every 30 seconds.

RESULTS & DISCUSSION

Villa del Mar and Mocambo are urban beaches modified by breakwater structures, while Arroyo Jiote and La Mancha are rural and virtually unmodified beaches. Accessibility and recreation incidence decrease from Villa del Mar to Arroyo Jiote, the last one being similar to La Mancha considering these two characteristics.

Sediment size and sorting of sediments varied along the gradient of uses and modification, from very fine sand and well sorted in Villa del Mar to medium sand and poorly sorted in Arroyo Jiote (Table 2). The granulometric parameters in La Mancha beach were similar to those of Arroyo Jiote. These generally are mainly due to the interaction of local morphodynamic processes (Calliari *et al.*, 2003), but in this case were clearly influenced by the use and modification factors analyzed. The intervention differences regarding accessibility and incidence of tourism and recreation activities likely have influenced textural characteristics of sediments; as they involve different grades of impacts that can reduce the sediment budget, *e.g.* foreshore area reduction, sand trampling, regular beach cleaning or grooming, construction on and degradation of coastal dunes (Defeo *et al.*, 2009).

The organic matter content in sediments was low as expected in the highly hydrodynamic environments of the swash zones, where the effects of wave action keep phytoplankton populations at a relatively low level (Steele and Baird, 1988). The percentages of organic matter were lower during September than in March in all four beaches, with significant differences between sampling campaigns in Villa del Mar and La Mancha, and significantly higher in Villa del Mar,

Table 2. Granulometric parameters (Φ) of the study beaches

	La Mancha	Villa del Mar	Mocambo	Arroyo Jiote
Textural group	Medium sand	Very fine sand	Fine sand	Medium sand
Mean particle size	2.45-2.72	2.91-2.99	2.72-2.84	2.57-2.67
Median particle size	2.38-2.69	2.92-2.99	2.77-2.86	2.58-2.67
Sorting	Poorly sorted (0.8-1.1)	Well sorted (0.6-0.7)	Moderately sorted (0.7-0.8)	Poorly sorted (1.1-1.4)

Mocambo and Arroyo Jiote compared to the reference beach (Fig. 2).

The seasonal variations found in organic matter content seem to be explained by the pattern of surface circulation in this area, depending on the stress component of parallel wind to the coast, favoring downwelling in winter and upwelling in summer (Zavala-Hidalgo *et al.*, 2003, Dubranna *et al.*, 2011). In this sense, there have been found sedimentation rates in PNSAV significantly higher during winter, with values of over 2 kg m^{-2} day^{-1} (Pérez-España *et al.*, 2012).

Moreover, the impact of weather events, such as cold fronts, causes the breakdown and deposition of corals and other organisms (González-Gándara, 2011; Armstrong-Altrin and Natalhy-Pineda, 2014). The decomposition of those organisms contributes to the increase and hauling of organic matter to the beaches, explaining the differences between the organic matter content in sediments of beaches nearby PNSAV with respect to La Mancha, farthest from reef system.

The Veracruz metropolitan zone receives a load of terrigenous sediments from fluvial systems, like the rivers Papaloapan, La Antigua, and mainly Jamapa (Salas-Pérez and Granados-Barba, 2008; Ortiz-Lozano and Bello-Pineda, 2012). There have been found surface seawater suspended sediments concentrations up to 22-32 mg L^{-1} in the southern reefs (Carriquiry and Horta-Puga, 2010), increasing turbidity during the rainy season from July to October (Horta Puga *et al.*, 2015). Nutrient inputs due to these fluvial and groundwater discharges (Finkl and Krupa, 2003) and high mean annual sedimentation rates of ~250 g m^{-2} day^{-1} (Pérez-España and Vargas-Hernández, 2008) may explain the greater percentages of organic matter in sediments of beaches located in the metropolitan zone compared to the reference beach.

Water temperature, salinity, and dissolved oxygen concentrations were similar across beaches, but varied significantly between sampling campaigns, evidencing its dependence on seasonal pattern (Fig. 3). Water temperature was higher, and salinity and dissolved oxygen concentrations were lower in September sampling. All pH values in water were very similar in all beaches and campaigns, averaging 7.5 in March and 7.7 in September.

These variables were according previous descriptions of the physicochemical coastal and littoral parameters in the area (Nava-Martínez *et al.*, 2015; Perales-Valdivia *et al.*, 2015). There may be local variations of these parameters in pore water, and the upper tidal level may have lower dissolved oxygen and salinity, but there were not found spatial differences in shallow water.

Fats and oils ranged between 164.75 mg L^{-1} in La Mancha and 739.5 mg L^{-1} in Villa del Mar, on average across campaigns (Fig. 4). Total solids fluctuated from 30.65 g L^{-1} in Arroyo Jiote and 39.2 g L^{-1} in La Mancha, to 41.25 g L^{-1} in Mocambo and 49.5 g L^{-1} in Villa del Mar during the September campaign. In March sampling, this gradient was not evident.

Concentrations of enterococci in pore water ranged from 1428.5 in Villa del Mar to 13.8 in Arroyo Jiote; La Mancha had intermediate values between those of Mocambo and Arroyo Jiote (Fig. 5). The textural characteristics of sediments were inversely related to densities of bacteria, as can be expected (Arrocena and Conde, 1999).

Therefore, the stress gradient was also evident in the values of enterococci concentrations, fats and oils and total solids in September, after an increase of the tourism activity, as stated by the Tourism Secretariat.

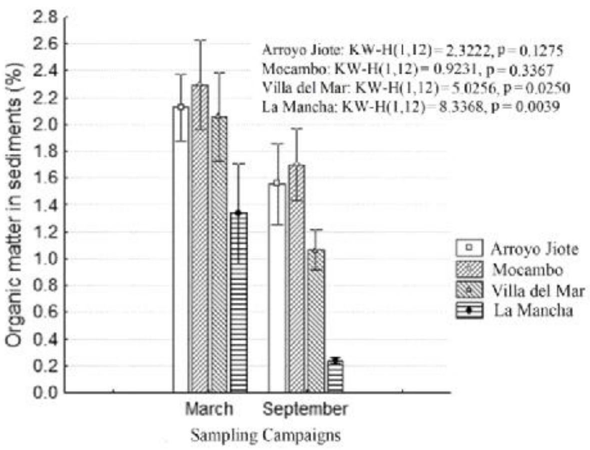

Fig. 2. Organic matter in sediments (mean±se) per sampling campaigns at each beach and results of Kruskall Wallis tests

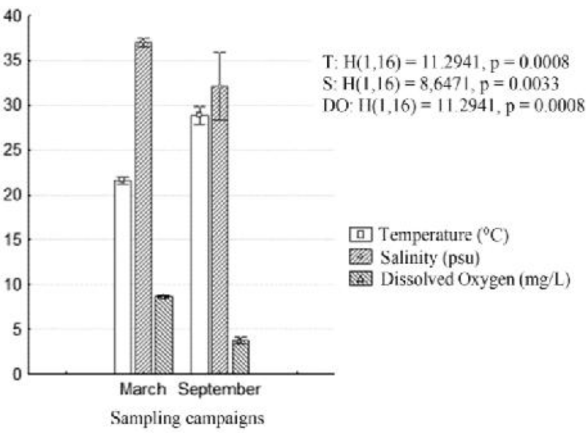

Fig. 3. Water physical-chemical parameters (mean±se) per sampling campaigns and results of Kruskall Wallis tests

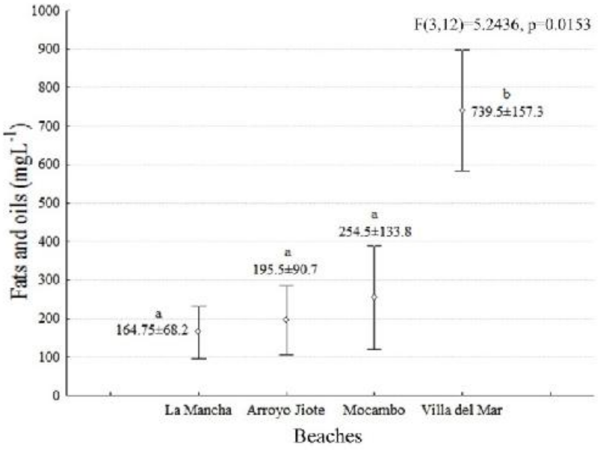

Fig. 4. Fats and oils (mean±se) per beach. Results of ANOVA and post hoc test

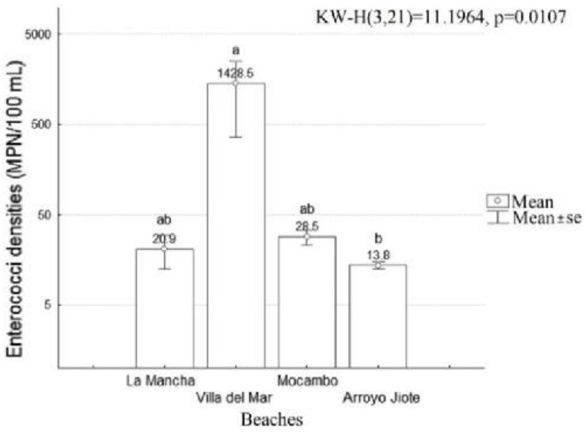

Fig. 5. Enterococci densities (mean±se) at each beach. Results of Kruskall Wallis test and multiple comparisons of mean ranks

Urban beaches are more exposed to chronic poor hygienic conditions and environmental problems, such as the pollution of coastal waters by sewage drains without treatment or with incomplete treatment (Ortiz Lozano, 2012). In Villa del Mar, enterococci concentrations in pore water surpassed the threshold (most likely number (MLN) higher than 200 in 100 ml) of the health and quality criteria for recreational use, based on the National Water Commission of Mexico (2010).

March intertidal profiles in Villa del Mar and Mocambo were broader and less steep than in September (Fig. 6). In contrast, in Arroyo Jiote and La Mancha they were steeper in March than in September. The intertidal slopes of the four analyzed beaches varied between samplings, indicating a seasonality of this parameter, as well as morphological differences between "natural" and modified by breakwaters. Differences between the intertidal profiles of both sites of the same beach were less evident. The intertidal slopes ranged from 0.0498 in Arroyo Jiote in September (horn site) to 0.1992 in La Mancha in March (cusp site), which is consistent with that reported by Shepard (1973) for different mean sand particle sizes.

As tide variation was not relevant in this study, the sediments conditions and waves patterns were the main characteristics influencing morphodynamic profiles. Granulometric characteristics of sediments varied along the anthropic gradient and were similar between the unmodified beaches. Regarding waves influence, breakwaters are wave energy barriers that alter circulation patterns, flushing conditions and littoral sediment transport and dispersion. They induce longshore gradations in breaker wave height through

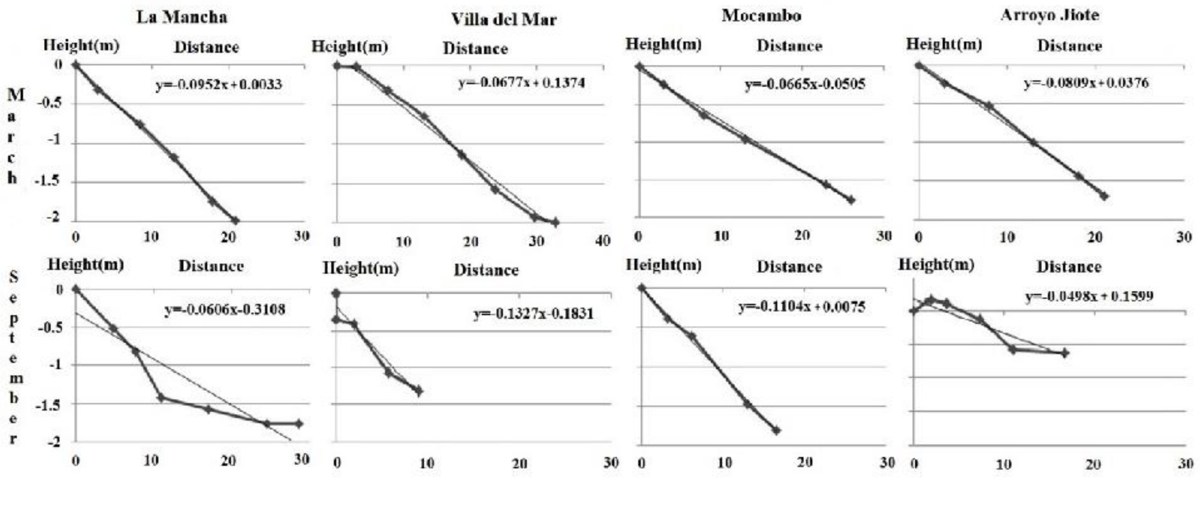

Fig. 6. Intertidal slopes per beaches and sampling campaigns

both wave attenuation and refraction (Short, 2006). Consequently, the typical modified beach is relatively short, with lowered waves at the shore in summer and more curvature in the beach through wave refraction. This could induce the formation of rip currents (Dalrymple, 1978) that create an erosive pattern in September. In March, the influence of longer period incident waves and trapped edge waves along the breakwaters (Dalrymple *et al.*, 1986; Dean and Dalrymple, 2004) could be important in generating the observed dissipative profiles in modified beaches.

The magnitudes of littoral currents obtained in March and September, were 0.36 and 0.08 m s^{-1} in La Mancha, 0.18 m s^{-1} and 0 in Villa del Mar, 0.24 and 0.01 m s^{-1} in Mocambo, 0.15 and 0.11 m s^{-1} in Arroyo Jiote, respectively (Fig. 7). The predominant direction obtained was southwest. Average Dean's parameter (&!) per beaches in March was 21.08, 11.91, 9.45 and 7.93 in Villa del Mar, Mocambo, Arroyo Jiote and La Mancha, respectively. In September sampling this gradient was not so evident, and varied from 10.76 in La Mancha to 5.19 in Villa del Mar, with intermediate values in Mocambo and Arroyo Jiote.

Even though sandy beaches are one of the most resilient dynamic types of costs, because of its ability to absorb wave energy (McLachlan and Brown, 2006), humans are having an increasingly adverse impact on many beach systems, threatening their suitability for conservation or recreation (McLachlan *et al.*, 2013). Breakwaters and other coastal structures, such as jetties and groynes, contribute to modify wave-sediment processes in surf zones, as they change wave energy and direction, and limit shore normal sediment transport (Charlier *et al.*, 2005; Dugan *et al.*, 2011). This was evident in the two urban beaches modified by breakwaters, where there was virtually no littoral current in September sampling, although our spot metering does not allow making inferences about values of this variable. The temporal variability of currents in northern Veracruz coral reefs is dominated by strong episodic southeastward currents during autumn–winter, reaching more than 1 ms^{-1} and associated with the intrusion of atmospheric high-pressure systems into the Gulf of Mexico, some episodes of strong southeastward currents in spring–summer forced by low-pressure systems (tropical storms), and weak northwestward currents predominant from May to August, with speeds lower than 0.40 ms^{-1} (Allende-Arandía *et al.*, 2016).

Even though the proximity of the beaches located in the metropolitan zone to a coral reef system oriented Northwest-Southeast, may partly protect against the combined effect of wind and waves, and influence circulation patterns (Salas-Monreal *et al.*, 2009), the modification by breakwaters still seems to influence morphodinamic conditions, particularly in September. In Villa del Mar we found the greatest morphodynamic variability, with dissipative profiles in March (Ω Index higher than 20) and intermediate conditions in September sampling (given the &! Index lower than 6). Intermediate beaches have values of &! ranging from 1 to 6 and are characterized by bar and rip morphology (Masselink and Short, 1993).

Conversely, La Mancha had almost intermediate morphodinamic state in March (Ω=7.93) and dissipative in September (Ω=10.76), reflecting a natural pattern. These contrasting patterns can be explained because high energy events like cold fronts can cause different short term environmental changes on microtidal exposed sandy beaches, depending on the

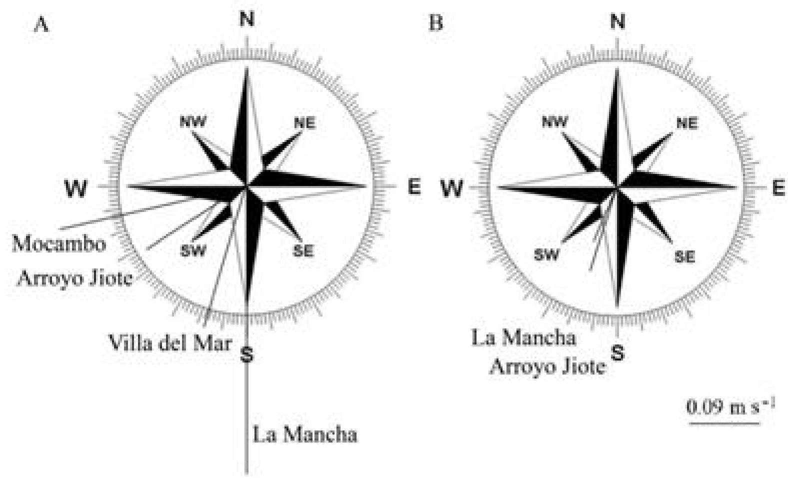

Fig. 7. Directions and magnitudes of littoral currents measured in samplings of March (A) and September (B)

morphodynamic state, so erosive processes can operate more slowly and progressively in dissipative beaches, with a reduced capacity for recovery and rapid restoration of the beach profile (Short and Hesp, 1982; Dos Santos-Alves and Pezzuto, 2009).

CONCLUSIONS

This study provides a baseline of the environmental spatial-temporal variation in intertidal of sandy beaches of central Veracruz. Using this integrated approach, we found that some of the measured parameters accounted for the anthropic gradient, increased by the presence of breakwaters as a factor contributing to modify the natural morphodynamic conditions, and others accounted for natural variations. As stated by Lucrezi *et al.* (2016), integrated beach assessments are beneficial, in that they allow the establishment of a basic framework onto which new and different visions can be engrafted, according to the specific beach considered. Our study demonstrates how beach use and modification conditions are associated with more instability and lower system resilience, reflected as less capacity and rapidity to counteract human perturbations.

ACKNOWLEDGEMENTS

Special thanks to all colleagues that helped us during sampling campaigns and further processing at the Research Laboratory of Aquatic Resources of the Technological Institute of Boca del Río, Veracruz, and to the reviewers of the manuscript. To Secretariat of Foreign Affairs of the Mexican Government and CONACYT-Mexico for the scholarships granted for concluding PhD studies. This research was conducted under the Project: Bases for analysis and synthesis of coastal systems of Veracruz, of the RASZCOVPromep network.

REFERENCES

Allende-Arandía, M.E., Zavala-Hidalgo, J., Romero-Centeno, R., Mateos-Jasso, A., Vargas-Hernández, J.M. and Zamudio, L. (2016). Analysis of Ocean Current Observations in the Northern Veracruz Coral Reef System, Mexico: 2007–12. Journal of Coastal Research, **32(1),** 46-55.

Armstrong-Altrin, J.S. and Natalhy-Pineda, O. (2014). Microtextures of detrital sand grains from the Tecolutla, Nautla, and Veracruz beaches, western Gulf of Mexico, Mexico: implications for depositional environment and paleoclimate. Arabian Journal of Geosciences, **7(10),** 4321-4333.

Arocena, R. and Conde, D. (1999). Métodos en Ecología de Aguas Continentales; con ejemplos de Limnología en Uruguay. (Montevideo: DIRAC/FC/UdelaR)

Buchanan, J.B. (1984). Sediment Analysis. (In: Holme, N.A. and McIntyre, A.D. (Eds.), Methods for the Study of Marine Benthos (pp. 41-63). Oxford: Blackwell Scientiûc Publications.)

Bulleri, F. and Chapman, M.G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology, **47(1),** 26-35.

Calliari, L.J., Muehe, D., Gemael-Hoefel, F. and Toldo Jr., E. (2003). Morfodinâmica praial: uma breve revisão. Revista Brasileira de Oceanografia, 5l(único), 63-78.

Camargo, M.G. (2005). SysGran 3.0. Análises e gráficos sedimentológicos. (www.cem.ufpr.br/sysgran).

Carranza-Edwards, A., Rosales-Hoz, L., Caso-Chávez, M. and Morales de la Garza, E. (2004). La Geología Ambiental de la Zona Litoral. (In: Caso, M., Pisanty, I. and Ezcurra, E. (Eds.), Diagnóstico Ambiental del Golfo de México (pp. 571-601). México D.F.: SEMARNAT-INECOL-INE-HRI.)

Carrillo, L., Horta-Puga, G., Carricart-Ganivet, J.P. (2007). Climate and Oceanography. (In: Tunnell Jr., J.W., Chávez, E.A. and Withers, K. (Eds.), Coral reefs of the southern Gulf of Mexico (pp. 34-40). Corpus Christi: Texas A. & M. University.)

Carriquiry, J.D. and Horta-Puga, G. (2010). The Ba/Ca record of corals from the southern Gulf of Mexico: contributions from land-use changes, fluvial discharge and oil-drilling muds. Marine Pollution Bulletin, **60(9),** 1625-1630.

Charlier, R.H., Chaineux, M.C.P. and Morcos, S. (2005). Panorama of the history of coastal protection. Journal of Coastal Research, **21(1),** 79-111.

Dalrymple, R.A. (1978). Rip currents and their causes. Coastal Engineering Proceedings, **16(1),** 1414-1427.

Dalrymple, R.A., Kirby, J. and Seli, D. (1986). Wave trapping by breakwaters. Coastal Engineering Proceedings, **20(1),** 1820-1830.

Dean, W.E. Jr. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. Journal of Sedimentary Petrology, **44,** 242-248.

Dean, R.G. and Dalrymple, R.A. (2004). Coastal Processes with Engineering Applications. (Cambridge University Press).

Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M. and Scapini., F. (2009). Threats to sandy beach ecosystems: a review. Estuarine, Coastal and Shelf Science, **81,** 1-12.

Dos Santos-Alves, E. and Pezzuto, P.R. (2009). Effect of cold fronts on the benthic macrofauna of exposed sandy beaches with contrasting morphodynamics. Brazilian Journal of Oceanography, **57(2),** 73-96.

Dubranna, J., Pérez-Brunius, P., López, M. and Candela, J. (2011). Circulation over the continental shelf of the western and southwestern Gulf of Mexico. Journal of Geophysical Research, 116(C8), C08009. doi:10.1029/2011JC007007 PubMed.

Dugan, J.E., Airoldi, L., Chapman, M.G., Walker, S.J. and Schlacher, T. (2011). Estuarine and coastal structures:

environmental effects, a focus on shore and nearshore structures. (In: Wolanski, E. and McLusky, D.S. (Eds.), Treatise on Estuarine and Coastal Science (pp. 17-41). Waltham MA: Academic Press.)

Elko, N., Feddersen, F., Foster, D., Hapke, C., McNinch, J., Mulligan, R., æzkan-Haller, H.T., Plant, N. and Raubenheimer, B. (2014). The future of nearshore processes research. Abstract OS22A-08 presented at 2014 Fall Meeting, AGU, San Francisco, California.

Emery, K.O. (1961). A simple method of measuring beach profiles. Limnology and Oceanography, **6,** 90-93.

Feng, Z., Reniers, A., Haus, B.K., Solo-Gabriele, H.M. and Kelly, E.A. (2016). Wave energy level and geographic setting correlate with Florida beach water quality. Marine Pollution Bulletin, **104(1-2),** 54-60.

Finkl, C.W. and Krupa, S. (2003). Environmental impacts of coastal-plain activities on sandy beach systems: hazards, perception and mitigation. Journal of Coastal Research, SI **35,** 132-150.

Folk, R.L. and Ward, W.C. (1957). Brazos river bar: A study in the significance of grain size parameters. Journal of Sedimentary Petrology, **27,** 3-27.

García-Fuentes, J.L., Galaviz-Villa, I., Lango-Reynoso, F. and Castañeda-Chávez, M.R. (2014). Pathogenic Bacteria in Corals from Veracruz Reef System National Park. International Journal of Modern Engineering Research, 4(5), 29-36.

González-Gándara, C. (2011). Amenazas al ambiente marino veracruzano. (In: Cruz-Angón, A. (Ed.), La biodiversidad en Veracruz: Estudio de Estado (pp. 341-347). Veracruz: Comisión Nacional para el conocimiento y Uso de la Biodiversidad (Conabio), Gobierno del Estado de Veracruz, Universidad Veracruzana, Instituto de Ecología A.C. México.)

Horta-Puga, G., Tello-Musi, J.L., Beltrán-Torres, A., Carricart-Ganivet, J.P., Carriquiry, J.D. and Villaescusa-Celaya, J. (2015). Veracruz Reef System: a hermatypic coral community thriving in a sedimentary terrigenous environment. (In: Granados-Barba, A., Ortiz-Lozano, L.D., Salas-Monreal, D. and González-Gándara, C. (Eds.), Aportes al conocimiento del Sistema Arrecifal Veracruzano: hacia el Corredor Arrecifal del Suroeste del Golfo de México (pp. 181-208). San Francisco de Campeche: Universidad Autónoma de Campeche.)

Kasper-Zubillaga, J.J., Carranza-Edwards, A. and Rosales-Hoz, L. (1999). Petrography and geochemistry of Holocene sands in the western Gulf of Mexico: implications for provenance and tectonic setting. Journal of Sedimentary Research, **69(5),** 1003-1010.

Landeros-Sánchez, C., Lango-Reynoso, F., Castañeda-Chávez, M.R., Galaviz-Villa, I., Nikolskii-Gavrilov, I., Palomarez-García, M., Reyes-Velázquez, C. and Mínguez-Rodríguez, M.M. (2012). Assessment of water pollution in different aquatic systems: aquifers, aquatic farms on the Jamapa river, and coastal lagoons of Mexico. Journal of Agricultural Science, **4(7),** 186-196.

Lankford, R.R. (1977). Coastal lagoons of Mexico: their origin and classification. (In: Wiley, M. (Ed.), Estuarine Processes (pp. 182-215). New York: Academic Press Incorporation.)

Lucrezi, S., Saayman, M. and Van der Merwe, P. (2016). An assessment tool for sandy beaches: A case study for integrating beach description, human dimension, and economic factors to identify priority management issues. Ocean & Coastal Management, **121(3),** 1-22.

Masselink, G. and Short, A.D. (1993). The effect of tide range on beach morphodynamics and morphology: A conceptual beach model. Journal of Coastal Research, **9(3),** 785-800.

McLachlan, A. and Brown, A.C. (2006). The Ecology of Sandy Shores. (Burlington MA: Academic Press)

McLachlan, A., Defeo, O., Jaramillo, E. and Short, A.D. (2013). Sandy beach conservation and recreation: Guidelines for optimizing management strategies for multi-purpose use. Ocean & Coastal Management, **71(1),** 256-268.

Méndez-Ubach, N., Solís-Weiss, V. and Carranza-Edwards, A. (1985). La importancia de la granulometría en la distribución de organismos bentónicos. Estudio de playas del Estado de Veracruz, México. Anales del Centro de Ciencias del Mar y Llimnología, **457,** 45-56.

Moreno-Casasola, P. (2006). Entornos veracruzanos: la costa de La Mancha. (Xalapa Ver.: Instituto de Ecología A.C.)

Moreno-Casasola, P. (2010). Veracruz. Mar de arena. (Xalapa Ver.: Comisión Organizadora del Estado de Veracruz de Ignacio de la Llave para la Conmemoración del Bicentenario de la Independencia Nacional y del Centenario de la Revolución Mexicana / Secretaría de Educación-Gobierno del Estado de Veracruz)

National Water Commission of Mexico. (2010). Statistics on water in Mexico. (México D.F.: SEMARNAT)

Nava-Martínez, G.G., García-Salgado, M.A., Román-Vives, M.A., Lopez-Huerta, I, Rangel-Avalos, M., Dor, A. and Samos, E. (2015). Evaluación de técnicas de viveros y trasplantes para la restauración del coral *Acropora palmata* (Anthozoa:Scleractinia) en el Sistema Arrecifal Veracruzano. E-Bios, **2(8),** 106-123.

Ortiz-Lozano, L.D. (2012). Identification of priority conservation actions in marine protected areas: Using a causal networks approach. Ocean & Coastal Management, **55(1),** 74-83.

Ortiz-Lozano, L.D. and Bello-Pineda, J. (2012). Escenarios propiciatorios de las inundaciones en la zona costera de Veracruz: el caso de la cuenca del Río Jamapa. (In: Tejeda, A. (Ed.), Inundaciones 2010 en el estado de Veracruz (pp. 158-177). Veracruz: Consejo Veracruzano de Investigación Científica y Desarrollo Tecnológico.)

Ortiz-Pérez, M.A. and De la Lanza-Espino, G. (2006). Diferenciación del espacio costero de México: un inventario regional. Geografía para el siglo XXI. Instituto de Geografía, UNAM, Serie Textos Universitarios, **3,** 138 pp.

Perales-Valdivia, H., Sanay-González, R. and Marín-Hernández, M. (2015). Variación temporal de la estructura termohalina en el Parque Nacional Sistema Arrecifal Veracruzano. E-Bios, **2(8),** 124-137.

Pérez-España, H., Santander-Monsalvo, J., Bello-Pineda, J., Gómez-Villada, R.S., Ake-Castillo, J.A., Lozano-Aburto, M.A., Román-Vives, M.A. and Marín-Hernández, M. (2012). Caracterización ecológica del Parque Nacional Sistema Arrecifal Veracruzano. (In: Sánchez, A.J., Chiappa-Carrara, X. and Brito-Pérez, R. (Eds.), Recursos costeros del sureste Vol II (pp. 581-601). Mérida: Unicornio S.A.)

Pérez-España, H. and Vargas-Hernández, J.M. (2008). Caracterización ecológica y monitoreo del Parque Nacional Sistema Arrecifal Veracruzano: Primera Etapa. Informe final SNIB-CONABIO Proyecto No. DM002. (México D.F.: Universidad Veracruzana, Centro de Ecología y Pesquerías)
Salas-Monreal, D., Salas de León, D.A., Monreal-Gómez, M.A. and Riverón-Enzástiga, M.L. (2009). Current rectification in a tropical coral reef system. Coral Reefs, **28(4),** 871-879.

Salas-Pérez, J.J. and Granados-Barba, A. (2008). Oceanographic characterization of the Veracruz reefs system. Atmósfera, **21(3),** 281-301.

Sánchez-Domínguez, B.E., Granados-Barba, A., Castañeda-Chávez, M.R. and Bernal-Ramírez, R.G. (2015). Enterococci presence in interstitial water in intertidal areas of sandy beaches from Veracruz-Boca del Río, Gulf of Mexico. Global Journal of Biology, Agriculture and Health Sciences, **4(1),** 28-31.

Schlacher, T.A., Schoeman, D.S., Dugan, J., Lastra, M., Jones, A., Scapini, F. and McLachlan, A. (2008). Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts. Marine Ecology, 29(Suppl. 1), 70-90.

Shepard, F.P. (1973). Submarine Geology. (New York: Harper and Row)

Short, A.D. (1996). The role of wave height, period, slope, tide range and embaymentisation in beach classifications: a review. Revista Chilena de Historia Natural, **69,** 589-604.

Short, A.D. (2006). Australian Beach Systems-Nature and Distribution. Journal of Coastal Research, **22(1),** 11-27.

Short, A.D. and Hesp, P.A. (1982). Wave, beach and dune interactions in southeastern Australia. Marine Geology, **48,** 259-284.

Siemens, A.H., Moreno-Casasola, P. and Sarabia, C. (2006). The metabolization of dunes and wetlands by the city of Veracruz, Mexico. Journal of Latin American Geography, **5(1),** 7-29.

StatSoft, Inc. (2004). STATISTICA version 7 data analysis software system. (www.statsoft.com).

Steele, J.H. and Baird, I.E. (1968). Production ecology of a sandy beach. Limnology and Oceanography, **13,** 14-25.

Valadéz-Rocha, V. and Ortiz-Lozano, L. (2013). Spatial and temporal effects of port facilities expansion on the surface area of shallow coral reefs. Environmental Management, **52(1),** 250-260.

Whitman, R.L., Harwood, V.J., Edge, T.A., Nevers, M.B., Byappanahalli, M., Vijayavel, K., Brandão, J., Sadowsky, M.J., Wheeler-Alm, E., Crowe, A., Ferguson, D., Ge, Z., Halliday, E., Kinzelman, J., Kleinheinz, G., Przybyla-Kelly, K., Staley, C., Staley, Z. and Solo-Gabriele, H.M. (2014). Microbes in beach sands: integrating environment, ecology and public health. Reviews in Environmental Science and Biotechnology, **13(3),** 329-368.

Zamudio-Alemán, R.E., Castañeda-Chávez, M.R., Lango-Reynoso, F., Galaviz-Villa, I., Amaro-Espejo, I.A. and Romero-González, L. (2014). Revista Iberoamericana de Ciencias, **1(4),** 159-168.

Zavala-Hidalgo, J., Morey, S.L. and O'Brien, J.J. (2003). Seasonal circulation on the western shelf of the Gulf of Mexico using a high-resolution numerical model. Journal of Geophysical Research, 108(C12), 3389. doi:10.1029/2003JC001879