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Identification of Coastal Erosion Causes in Matanchén Bay, San Blas, Nayarit, Mexico

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ABSTRACT

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This work presents an analysis of the erosion processes in Matanchén Bay based on the available historical records; the possible causes were identified and discussed. The bay is located on the Pacific coast of Nayarit state, Mexico; its northern tip is a highly dynamic system that has undergone intense morphological modifications over the last 80 years. At the beginning of the 1940s an unexplained growth in the beach at the northern tip of the bay was observed, while 40 years later, and up to date, erosion processes began adversely affecting small businesses in the area. The primary causes of the erosion are the anthropogenic modifications in the bay and its surroundings, which include the construction of a hydroelectric dam system, new transport infrastructure, tourist facilities, a harbor and several dredging works in the existing port. In this paper the evolution of the coastline at Matanchén Bay and its surroundings is analyzed for the first time and the actual coastline is compared to that predicted under the assumption that no countermeasures against the erosion are adopted.

ADDITIONAL INDEX WORDS: *Coastal erosion, equilibrium bay, sediment transport, Matanchén Bay.*

INTRODUCTION

The municipality of San Blas, Nayarit, Mexico has a population of 43,000 inhabitants according to INEGI. The area is characterized by average temperatures of between 22 and 28 °C, annual rainfall between 1300 and 2000 mm and a warm, humid climate with summer rains. It has an area of 850 km^2 of which 50% is agricultural, 22% jungle, 16% mangrove, 5% forest, 3% grassland and 1% urban, in 1% aquaculture is practiced while 2% is covered by water bodies (INEGI).

Located less than 5 km from the municipal capital, Matanchén Bay is part of a natural protected area, Marismas Nacionales, which is a coastal wetland area with 10-20% of the total mangrove population of the country. It is one of the Mexican RAMSAR sites.

According to Comisión Nacional del Agua (CONAGUA), the bay is located in the Huicicila hydrological region, in the basin of the Huicicila–San Blas river, in the subbasins of the Ixtapa and San Blas rivers. However, the river closest to the bay is the Santiago, whose mouth is 25 km northwest of the bay and in whose course a series of dams have been built.

The main estuaries in the area are El Rey, El Pozo and San Cristóbal, located approximately 7.0, 5.0 and 2.5 km from the bay, respectively.

Matanchén Bay has a beach 7 km long and 30 m wide on average (Figure 1). While it has almost no direct alterations to its beaches, significant anthropogenic modifications over the coastal dune have been made, including the construction of several tourist facilities and the Escuela Nacional de Ingeniería Pesquera of the Universidad Autónoma de Nayarit. Additionally, a disruption of sediment supply to the bay was caused by the dredging works performed at the port of San Blas.

Ortiz, 1999, presented a map showing the condition of the bay in 1785, but the quality is not good enough to determine the physical characteristics of the zone. The map was digitalized and is presented in Figure 2, where it can be seen that El Rey, El Pozo and San Cristóbal estuaries used to discharge directly into the sea and that their mouths had no obstructions and that the northern part of the bay consisted of a small group of islets.

Around 1940, due to unknown causes, the northern tip of the bay began to gain dry beach, a group of tombolos rapidly developed, which eventually joined the islands to the mainland in 1986. From that year to date, an erosion process along the beach in the bay has been reported, causing a coastline retreat of more than 300 m, forming a logarithm spiral beach. Figure 3 shows a summary of the historical evolution of the northern part of the bay taken from aerial photographs.

Together with the natural phenomena, several human interventions have altered the coastal dynamics near the bay, the most relevant of which are shown in Figure 4. For example, the El Rey estuary was closed; the mouth of El Pozo estuary was stabilized with groynes on both sides and the estuary is frequently dredged; and the San Cristóbal estuary was partially blocked by the construction of a bridge. In this paper it is hypothesized that the combination of natural events and human intervention has led to severe damage of Matanchén Bay beach and it will be shown that if no action is taken, the condition of the beach will worsen, endangering tourist activities and even the local population.

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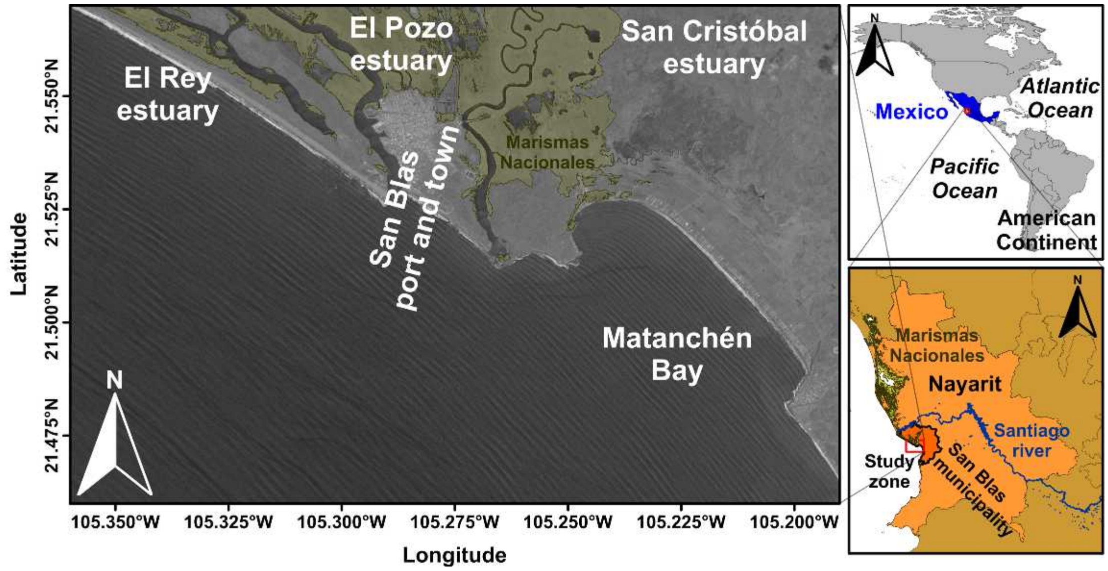

Figure 1. Location of the study zone and its main characteristics: estuaries, Santiago River, Marismas Nacionales and San Blas (Digital Globe, 2008).

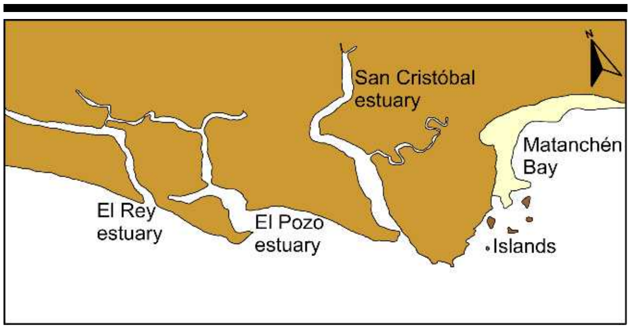

Figure 2. Matanchén Bay in 1785 (Digitalized from Ortiz, 1999).

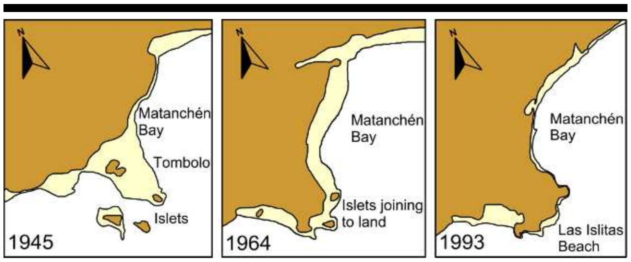

Figure 3. Evolution of the northern tip of the bay (Digitalized from historical photographs by Ortiz, 1999).

Background

In order to identify and understand the mechanisms driving the erosion processes in Matanchén Bay: the anthropogenic actions in the area, the geomorphological conditions, the sediment sources, the weather, the hydrodynamics and the evolution of the coastline were reviewed.

Figure 4. The estuaries systems, 2006 (Digitalized from Google Earth).

Figure 5 shows the major engineering interventions that have modified the original hydrodynamic conditions in the system: the building of six dams along the Santiago River has reduced the sediment available for the whole coastal area and, the little sediment that gets to the coast is dredged to facilitate port activities, the area has a dramatic sediment deficit.

Geologically speaking, the tips of the bay are composed of extrusive igneous rock, suggesting that they are highly resistant to wave impact, while the interior of the bay consists of sand, indicating that the coastline is influenced by the local hydrodynamic conditions. These features suggest that the most relevant sediment loss from the bay is in the cross-shore direction, but as the sources of sediment are located north from the bay, the littoral cell is not independent and has to be "fed" from outside.

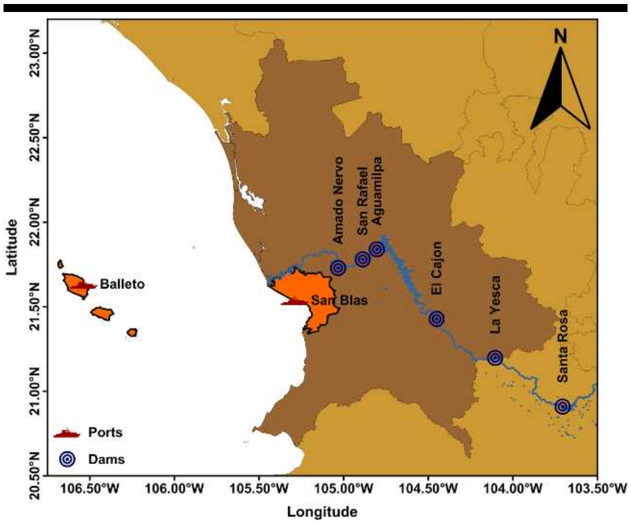

Figure 5. Dams along the Santiago River. Upstream: Amado Nervo dam finished in 1976; San Rafael dam finished in 1994; Aguamilpa Hydroelectric dam finished in 1994; El Cajón Hydroelectric dam finished in 2007; La Yesca Hydroelectric dam finished in 2012; and Santa Rosa Hydroelectric dam finished in 1964. Ports near to Matanchén Bay: San Blas and Balleto.

According to the data provided by the Mexican Servicio Meteorológico Nacional (SMN), from 1970 to 2011, 13 hurricanes of the 152 that passed within 500 km of the study area caused impacts on the state of Nayarit. The worst was hurricane Kenna in 2002 which reached category 3 in the Saffir-Simpon scale, when its center was located less than 70 km from the study zone. Wave heights reported during storm conditions have reached over 12 m.

The main sediment sources in the bay are the Santiago River and the discharge from the estuaries El Rey, El Pozo and San Cristóbal. El Pozo estuary is often dredged for navigation purposes; instead of feeding the beaches, the dredged material is disposed inland on the west side of the port. In addition to this, the construction of groynes on both sides of the estuary mouth has also contributed to the erosion of the bay, blocking the littoral transport and producing accretion on the western part of the system. There is no information regarding any dredging work in the San Cristóbal estuary; however the construction of a groyne to stabilize the mouth has increased the rigidness of the system.

Downstream of Amado Nervo dam a measuring station was located which reported daily data of suspended sediments and hourly records of the Santiago River discharge from 1955 to 2006, these time series are shown in Figure 6. The historical data reveals that before the construction of Aguamilpa and San Rafael dams, the water volume of the river reached more than 2000 m^3/s almost every year and the suspended sediments concentration exceeded 0.40% with peaks of more than 1%; then after the construction of the dams the volume was reduced to less than 1000 m^3/s and suspended sediments were not recorded. It would seem that with the construction of more dams the river volume will be even lower and the sediments that reach the coast will be almost zero.

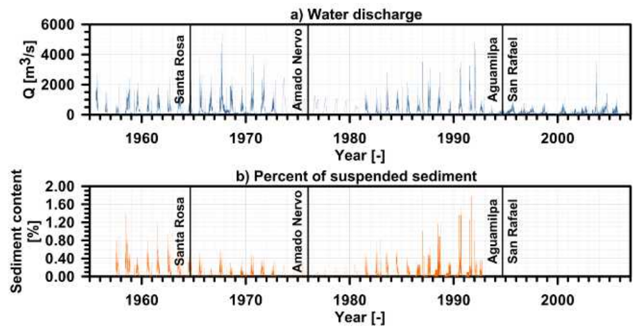

Figure 6. Measurements at the station downstream of the Amador Nervo dam in the Santiago River: a) water discharge; b) suspended sediment (IMTA).

METHODOLOGY

To evaluate the erosion rate in the bay, the historical coastline position was taken from Landsat satellite images. In Figure 7 the coastline locations in 1986, 1990, 1995, 2000, 2005, 2010 and 2013 are shown, together with detailed time series in selected points. It can be seen that the most affected area is the north of the bay (profile C) with a retreat of 380 m in 24 years. The erosion rate in this point was of almost 20 m/year between 1986 and 2005 and only 1 m/year from 2005 to 2013. The coastline at point B had severe erosion (100 m by 2000) but its present position is very close to that of 1986. Points A and D show accretion of around 140 and 100 m, respectively.

Although the erosion rate in the bay and its surroundings has reduced, it seems relevant to investigate whether the system is close to reaching a state of equilibrium, or if any action is needed to stabilize the system to protect the coastal population and activities. A simple means to evaluate how close the beach is to a stable shape, specifically in the area around profile C in Figure 7, can be obtained with the equation of Hsu and Evans (1989):

$$\frac{R_n}{R_\beta} = C_0 + C_1\left(\frac{\beta}{\theta_n}\right) + C_2\left(\frac{\beta}{\theta_n}\right)^2 \quad (1)$$

where

β = obliquity of the incident wave

θ_n = angle to determine the R_n value

R_n = radius from the control point (diffraction point) to the beach line at angles θ_n ($\theta_n > \beta$)

C_0, C_1, C_2 = coefficients that depend on β

R_β = control line from the up coast diffraction point to the down coast limit of the bay, where the tangent to the beach is parallel to the incident wave crests

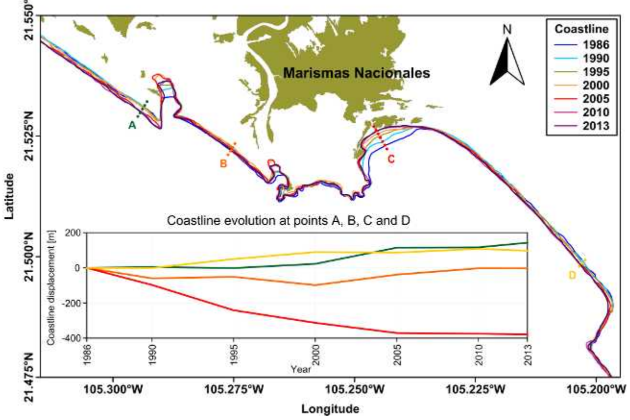

Figure 7. Historical coastline positions 1986-2013.

Parameters C_0, C_1 and C_2 depend on β (Raabe *et al*., 2010):

$$C_0 = 0.0707 - 0.0047\beta + 0.000349\beta^2 - 0.00000875\beta^3 + 0.00000004765\beta^4 \quad (2)$$

$$C_1 = 0.9536 - 0.0078\beta + 0.0004879\beta^2 - 0.0000182\beta^3 + 0.0000001281\beta^4 \quad (3)$$

$$C_2 = 0.0214 - 0.0078\beta + 0.0003004\beta^2 - 0.00001183\beta^3 + 0.00000009343\beta^4. \quad (4)$$

Equation (1) was used because of its simplicity and accuracy even when little data is available. To determine the diffraction point needed to apply eq. (1) the WAPO model by Silva *et al*., 2005 was used. This model solves the Modified Mild Slope Equation in its elliptic form. To get a better view of the hydrodynamics within the bay the COCO model by Silva *et al*., 2010 was applied. This model solves the Nonlinear Shallow Water Equations to estimate wave induced currents.

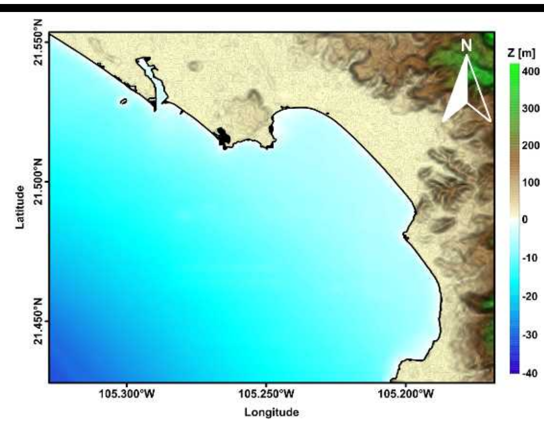

Figure 8. Topography and bathymetry in the study zone (Digitized from a nautical chart).

The input data for both models is only the bathymetry and the wave conditions. The bathymetry was taken from a nautical chart with data from 2005 and is shown in Figure 8. The wave data was obtained from the Maritime Climate Atlas of the Mexican Pacific, Silva *et al*., (2008) which reports data from re-analysis for 1948 to 2007. Figure 9a shows the exceedance probability for wave height and period, from where the significant mean regime wave height is 1.11 m with a period of 5 s. Figure 9b shows that the predominant wave direction is WNW.

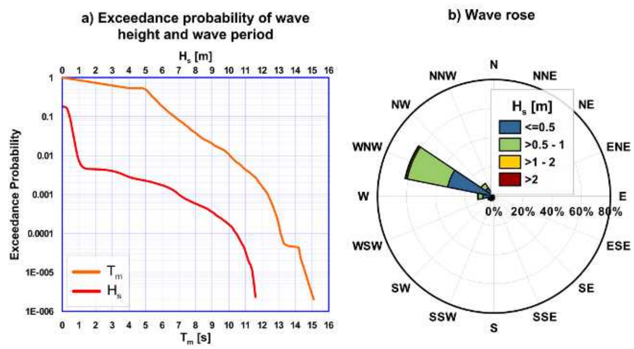

Figure 9. Annual statistics for medium regime: a) Exceedance probability of wave height and wave period; b) Wave rose.

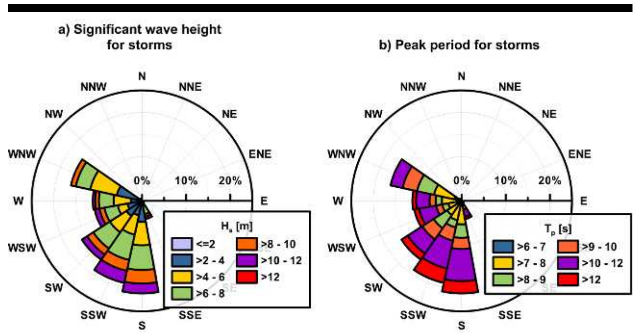

Figure 10. Extreme conditions statistics: a) Wave rose; b) Period rose.

The results for extreme conditions are shown in Figure 10 where the roses for wave height and period are presented in panels a and b, respectively. From those data the most relevant storm conditions are from S, SSW, SW and WNW with wave heights between 4 and 12 m and periods between 7 and 12 s. According to SMN, from 1970 to 2011, 13 hurricanes affected the state of Nayarit; however according to the database of NE/NC Pacific HURDAT2 of the NOAA from 1949 to 2012, 235 hurricanes passed within 500 km of the study zone and 11 within 100 km, which means that on average 3.5 hurricanes affect the study area every year.

The tidal data was obtained from the Red Nacional Mareográfica of the Mexican Secretaría de Marina, 1999 – 2007, the mean high tide level was 1.00 m, which corresponds to microtidal regime, therefore this level is considered in the analysis presented as it is considered the worst case.

Considering all the information gathered, mean regime values and four storms were selected (Table 1) to investigate the hydrodynamic conditions imposed by waves on the beaches of Matanchén Beach.

Table 1. *Wave conditions for the selected scenarios.*

Scenario	Wave height (m)	Wave period (s)	Wave direction	Tide level (m)
1	1	5	WNW	1.00
2	7	12	WNW	1.00
3	7	12	SW	1.00
4	7	12	SSW	1.00
5	7	12	S	1.00

RESULTS

To facilitate the numerical calculation, the 5 m squared cells grid (721x961 cells) containing the bathymetry was rotated 45° clockwise. It is important to note that due to the size of the domain, the wave propagation was performed in two steps, first the deeper part was computed with a parabolic version of the Mild Slope Equation and then the shallower part was calculated with the WAPO model. The wave induced currents were only computed at lower depths as their magnitude is only relevant close to the breaking zone. Finally, eq. (1) was applied to the northern part of the bay using a diffraction point from which the diffraction seems to be governed in the WAPO results. Figures 11 to 15 show the numerical results, and panel a) shows the instantaneous wave field, panel b) the wave induced currents and panel c) the instantaneous free surface together with the result of applying eq. (1) to the north of the bay.

The results for scenario 1, which corresponds to mean regime conditions are presented in Figure 11, where panel a) indicates that waves coming from WNW enter all along the bay reaching its southern part, but very little energy is arrives at the northern part; panel b) shows very small currents with an area of concentration at the center of the bay and in panel c) it can be seen that the predicted equilibrium shape has almost been reached in the eastern part but at the West, on Las Islitas beach, erosion is expected to continue.

The results for scenario 2 are presented in Figure 12; panel a) shows that the shallowness of the bathymetry makes waves break far from the coast, although as wave direction is from the WNW, more energy reaches the south of the bay (waves close to 3 m). On the other hand waves, of less than 1.5 m arrive at the north of the bay. A similar effect is seen in panel b) where stronger currents occur at the south and almost null sediment transport is expected from the north; in panel c), the predicted equilibrium shape shows that Las Islitas beach may be further eroded.

Figure 13 shows the results for scenario 3. In this case waves comes from the SW, which is the direction normal to the straight part of the bay, which means the energy of the waves is evenly distributed along the bay (panel a), with waves scarcely higher than 3 m along almost all the beach, except for the protected area at the north where waves only reach heights of 1.5 -2.0 m. As the waves break far from the coast, panel b) shows low intensity currents in all of the domain. The predicted equilibrium shape, drawn in panel c) indicates that Las Islitas beach would be totally eroded if the system were left to reach that condition.

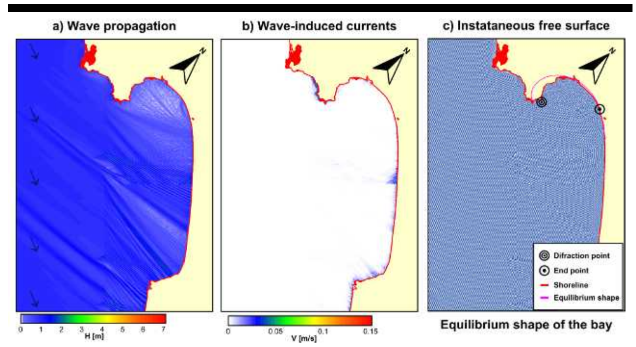

Figure 11. Scenario 1 results (a) Wave propagation; (b) Wave-induced currents; (c) Free surface and predicted equilibrium shape.

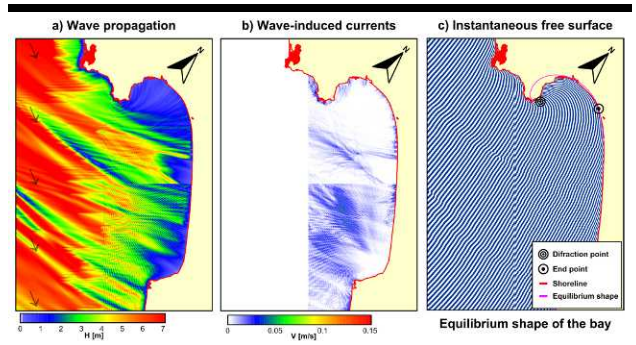

Figure 12. Scenario 2 results (a) Wave propagation; (b) Wave-induced currents; (c) Free surface and predicted equilibrium shape.

Storm conditions coming from SSW define scenario 4, which results are presented in Figure 14. Panel a shows slight variations from the previous case in terms of the energy that reaches the coast despite a low decrease in the wave heights and wave induced currents along the bay (panel a and b). Regarding the predicted equilibrium shape, the erosion at Las Islitas beach is noticeably lower and similar to that seen in scenarios 1 and 2.

Finally, Figure 15 shows the results for scenario 5; storm waves coming from the South. Panels a) and b) indicate a relevant increase in the wave heights and currents at the northern part of the bay but far from expected, the equilibrium shape is almost the same as in the previous cases (scenarios 1, 2 and 4). These numerical results suggest that the trend of the coast at Las Islitas beach is continued erosion, occurring in both mean conditions and during storms.

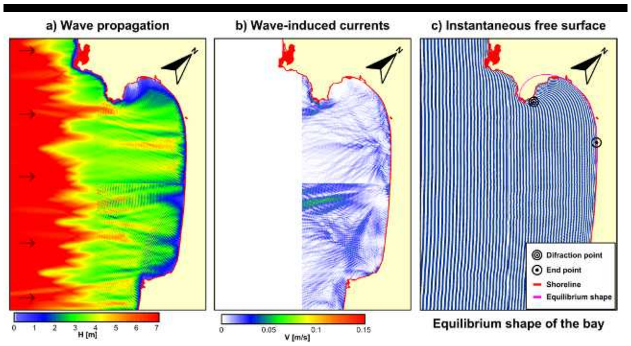

Figure 13. Scenario 3 results (a) Wave propagation; (b) Wave-induced currents; (c) Free surface and predicted equilibrium shape.

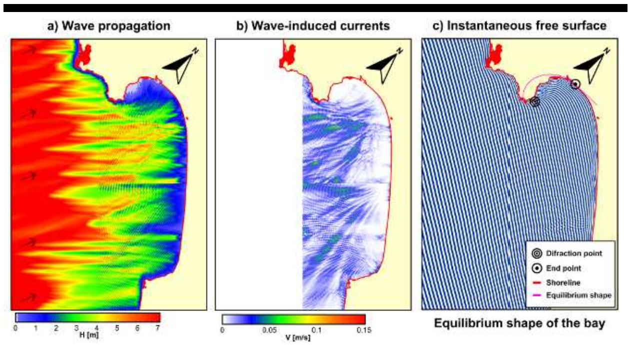

Figure 14. Scenario 4 results (a) Wave propagation; (b) Wave-induced currents; (c) Free surface and predicted equilibrium shape.

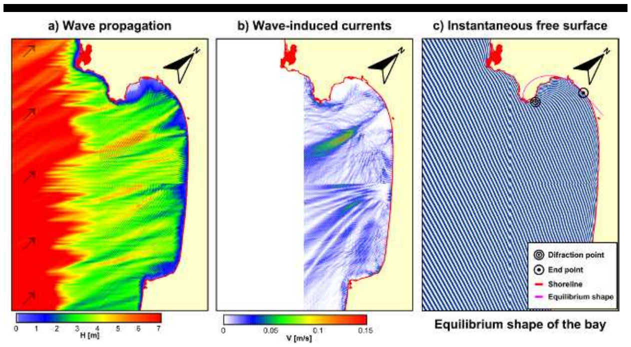

Figure 15. Scenario 5 results (a) Wave propagation; (b) Wave-induced currents; (c) Free surface and predicted equilibrium shape.

DISCUSSION

The analysis of the present dynamics in the bay show that the system is reaching a stable state, furthermore it can be said that the central and southern parts of the bay are already in dynamic equilibrium while the northern part is still evolving; rapidly from 1986 to 2005 and slowly since then. While it is still unknown what caused the sedimentation that turned the islets into Las Islitas beach, we do know is that nowadays the system has a severe sediment deficit.

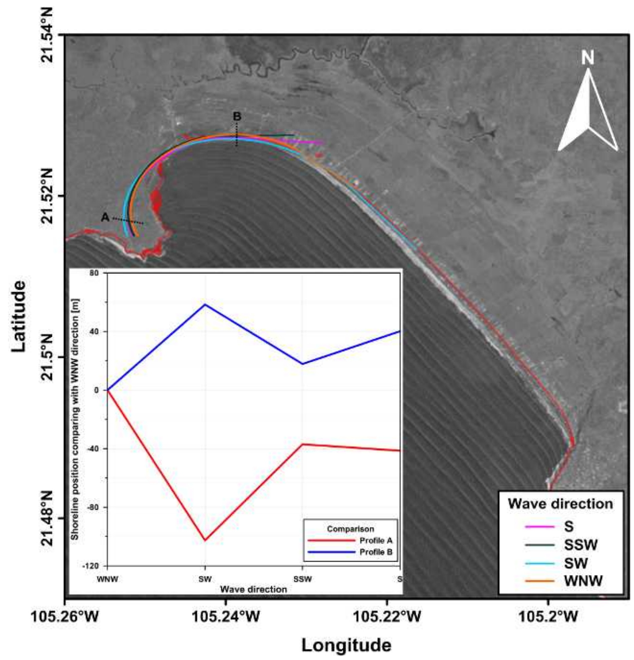

Figure 16. Comparison of results for equilibrium shape of the bay.

The application of eq. (1) to the northern part of the bay showed that the system is not far from becoming stable but some considerations have to be stated: a) the predicted equilibrium shape is quite similar for all the wave conditions tested but the final position of the coastline may vary by 60–100 m from one to another (see Figure 16) which is not a small consideration; b) the land that still has to be eroded to reach stability is approximately 700 000 m^2, most of it occupied by woods, but there is also some tourist and transport infrastructure which would be lost; and c) this predicted equilibrium shape is based on the assumption that no more alterations will be made in the system, which is unlikely.

There are two main management options for the future of Matanchén Bay:

Leaving the system to reach its new equilibrium with the considerations stated before. This option entails the loss of land surface, but presents the advantage of turning the system back to the condition where Las Islitas beach was a group of islets that used to let the sediment into the bay. Taking into account that neither the cause of the sedimentation, nor the source of the material is known, this might be a feasible solution. Of course, on the other hand, there are economic and social actors involved that may influence the decision. It is also important to note that the coastline has moved very little from 2005 to date, possibly meaning that a hard element (rock) has been reached, this would modify the equilibrium shape and is not considered in the application of eq. (1). Further fieldwork is needed to verify this possibility and therefore the "do nothing" scenario might be justified.

Disregarding any hard engineering solution, the bypass of sediment from the system of dams (especially from Aguamilpa), from the dredging of San Blas Port and from the groyne at El Pozo Estuary may be a solution to deal with the coastal erosion in the bay. For this solution to be successful, it is necessary to estimate the volume of sand that must be placed in the beach for the action to have the largest possible life and for the maintenance resources to be gathered. It would be even better to construct and implement a permanent bypass system.

CONCLUSIONS

It is concluded that Matanchén Bay is close to reaching a new equilibrium state, because the rate of erosion has been reduced dramatically. However, the amount of land that may still be eroded suggests that an intervention, which may be an artificial sediment supply to the system, may be recommendable.

It is clear that a strict management plan needs to be implemented as the vulnerability of the system has been evidenced and what may be natural processes of a very long period may change the understanding we have of the area.

Additionally, the norms which are intended to protect natural areas should consider not only the activities and infrastructure permitted within the area but also should regulate actions taken outside it that may affect the equilibrium of the protected area.

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LITERATURE CITED

Hsu, J.R.C., and Evans, C., 1989. Parabolic bay shapes and applications. *Proc. Institution of Civil Engineers*, London (Part 2), 87, 556-570.

Instituto Mexicano de Tecnología del Agua (IMTA). www.imta.gob.mx

Instituto Nacional de Estadística y Geografía (INEGI). www3.inegi.org.mx/sistemas/mexicocifras

Ortiz, M., 1999. *Evidencia documental de los cambios en la línea de costa por sedimentación rápida en la bahía de Matanchén, Nayarit, México*. Investigaciones Geográficas, Boletín 40, 58-70 (in spanish).

Raabe, A.; Klein, A.; González, M., and Medina, R., 2010. MEPBAY and SMC: Software tools to support different operational levels of headland-bay beach in coastal engineering projects. *Coastal Engineering*, 57, 213-226.

Silva, R., 2005. *Análisis y descripción estadística del oleaje.* Instituto de Ingeniería UNAM. Serie Docencia 49, ISBN 970-32-2813-5, 145-170 (in spanish).

Silva, R.; Borthwick, A., and Taylor R., 2005. Numerical implementation of the harmonic modifies mild-slope equation. *Coastal Engineering*, 52, 391-407.

Silva, R.; Ruíz, G.; Posada, G.; Pérez, D.; Rivillas, G.; Espinal, J., and Mendoza, E., 2008. *Atlas de Clima Marítimo de la Vertiente Atlántica Mexicana*. Universidad Nacional Autónoma de México (in Spanish).

Silva, R.; Baquerizo, A.; Losada, M., and Mendoza, E., 2010. Hydrodynamics of a headland-bay beach-near shore current circulation. *Coastal Engineering*, 57, 160-175.