Mangrove Erosion in the Mekong delta

1. Introduction

a. Mangrove coast - a balance between different forcing factors

Mangroves are coastal environments frequently observed in the tropical muddy coasts. Coastal mangrove trees grow on mudflat, where fine sediments (silt and clay) are accumulated, in the area of tidal oscillation. As illustrated in figure 1, this ecosystem is the result of a dynamic equilibrium between :

1) the supply of sediment from the continent to coastal shallow waters
2) its redistribution by ocean forcings: wind, waves and currents alongshore
3) the colonization of mudflats by mangrove vegetation.

Depending on coastal environments, the natural cross-shore fluctuation of the coastline (erosion/accretion) can range from a few meters per year to several hundred of meters per year, as is the case along the 1600km long coast of the Guianas, one of the most dynamic muddy coast in the world.

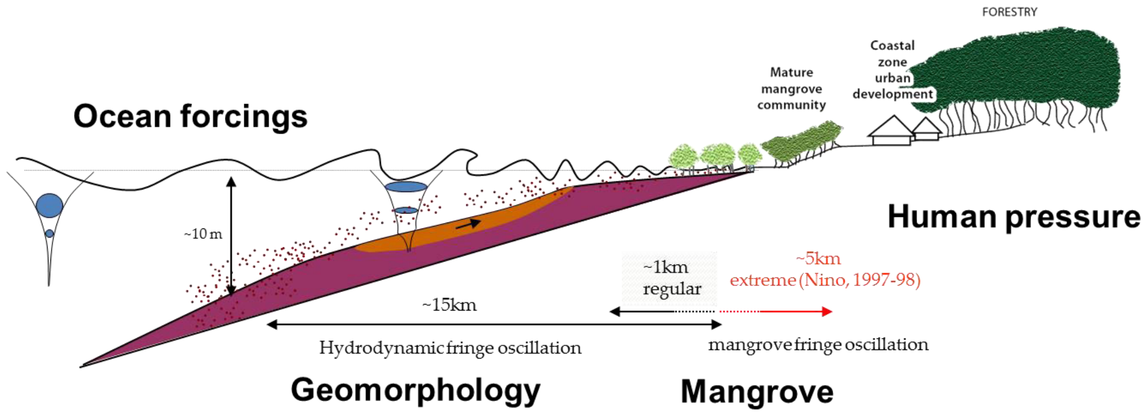

Fig. 1. Mangrove coasts under natural conditions. The mangrove coast results from a dynamic equilibrium between ocean forcings (supply of sediments, waves, currents), the geomorphological forms (mudflat, sand bars, etc.), the vegetation (mangrove trees) and human activity (construction of dykes, aquaculture, use of mangrove trees for coal production. Gratiot and Anthony (2017).

b. Concept of dynamic equilibrium

A dynamic equilibrium means that the natural evolution of a mangrove coastline experiences alternating phases of erosion and recolonization, that depend on the interplay between three processes, namely: the sediment supply, ocean forcing and mangrove colonization.

The concept of dynamic equilibrium, illustrated in Fig. 2 described natural fluctuations of the system around a mean equilibrium position; the resilience capacity allowing mangrove ecosystems to recolonize areas of bare mud after periods of erosion.

The impact of climate change, as well as local and global human changes, can lead to the loss of this capacity for resilience. This is illustrated by a tipping point at time unit 300 in the figure 2. This tipping point can occur if the sediment supply is permanently reduced, or if the oceanic forcing increases for a long period of time. This is also the case if the mangrove fringe is no longer large enough to allow seed dissemination, seed germination and natural recolonization (mangrove squeeze/human pressure).

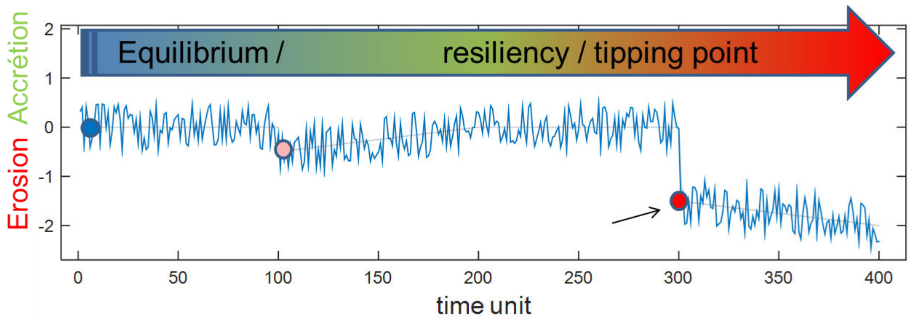

Fig. 2. Sketch illustrating the dynamic equilibrium of mangrove coast. Gratiot and Anthony (2017).

Thinking about coastal protection measures adapted to the Mekong delta system implies to have a good knowledge of the resilience capacity of mangrove coast; which is hard to quantify because of lack of quantitative and long term monitoring of the coastal morphodynamics. During the LMDCZ project, the analysis of satellite images at regional scale provides some information of areas in erosion and/or accretion, by periods of 5 years between 1990 to 2015 (see results of WP3). This is very useful to define areas where the tipping point has been reach and where the dynamic equilibrium is disrupted.

2. Mangrove erosion in the Mekong delta

a. A review of the mangrove dynamics in the Mekong delta (Phan et al., 2015)

In a recent study, Phan et al. (2015) showed a net correlation between mangrove width (in m) and local erosion or accretion (in m/y). The main result is reported in Figure 3. Even if data are dispersed, with large error bars, this positive trend indicates that there may exist a critical mangrove width of

300-500 meters above which mangrove ensure a suitable coastal defence.

In our study, we try to validate or refute the existence of a sustainable mangrove width**.**

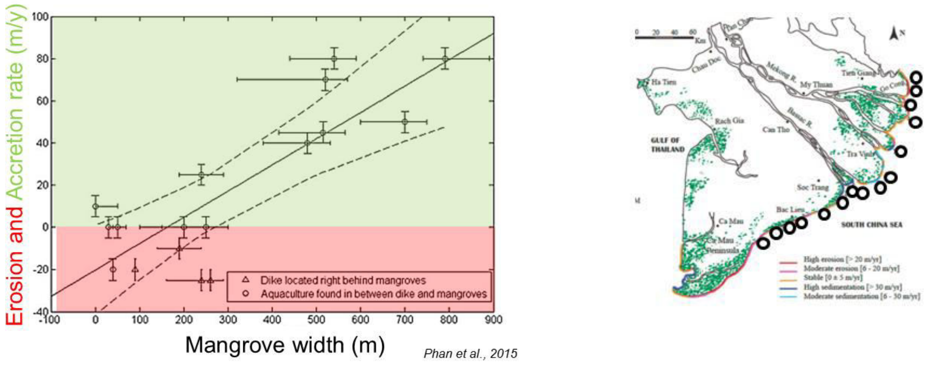

Fig. 3. Impact of mangrove squeeze in the Mekong delta (Phan et al., 2015). Left, variation of shoreline erosion/accretion with mangrove width. Right, location of the point referenced in the figure.

b. Results

Using high-resolution 2003 and 2011 satellite images, we collected 3651 cross shore profiles, spaced 100 m apart along a 379 km-long stretch of the Mekong delta shoreline. The area covered by our study is presented in Figure 4. Based on geomorphological information, it is further divided in two units, namely the Estuary zone and the East coast.

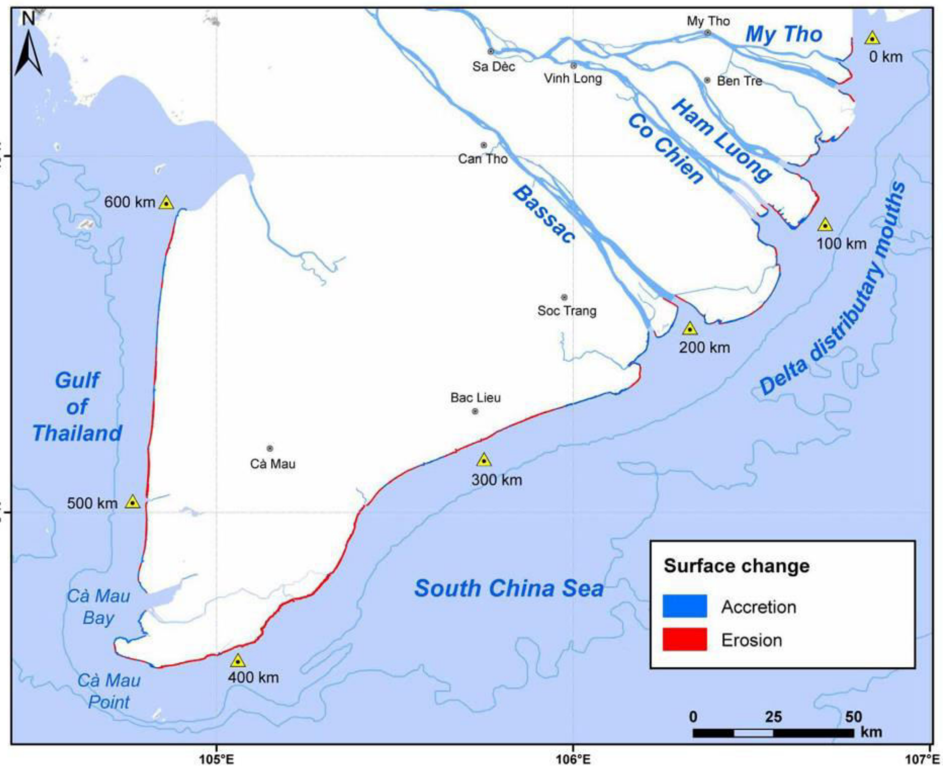

Fig. 4..Map of the Mekong. Location of the two geomorphic units studied. Anthony et al. 2015.

The variation of mangrove width with the rate of cross-shore fluctuations is presented in Figure 5. The mangrove response reveals much more complex than the linear relationship proposed by Phan et al. (2015). **When considering all profiles, no statistical correlations are indeed observed at regional scale** (Fig. 5, left).

Figure 5b shows all profiles by regional units: the Estuary zone (red dots) shows both erosion and accretion with mangrove width between zero and 1500m. Few sectors (see arrows) seem to support the conclusion of Phan et al. (2015), i.e. the existence of a linear relationship between mangrove width and cross-shore fluctuations (see blue arrow). The East coast is largely dominated by erosion (97% of black dots), even if mangrove belt can be wider than 2000m in some sectors.

The lack of mangrove resiliency, even for a mangrove belt larger than 300-500m is in agreement with results of the LMDCZ project on numerical modelling (WP1) and remote sensing (WP3).

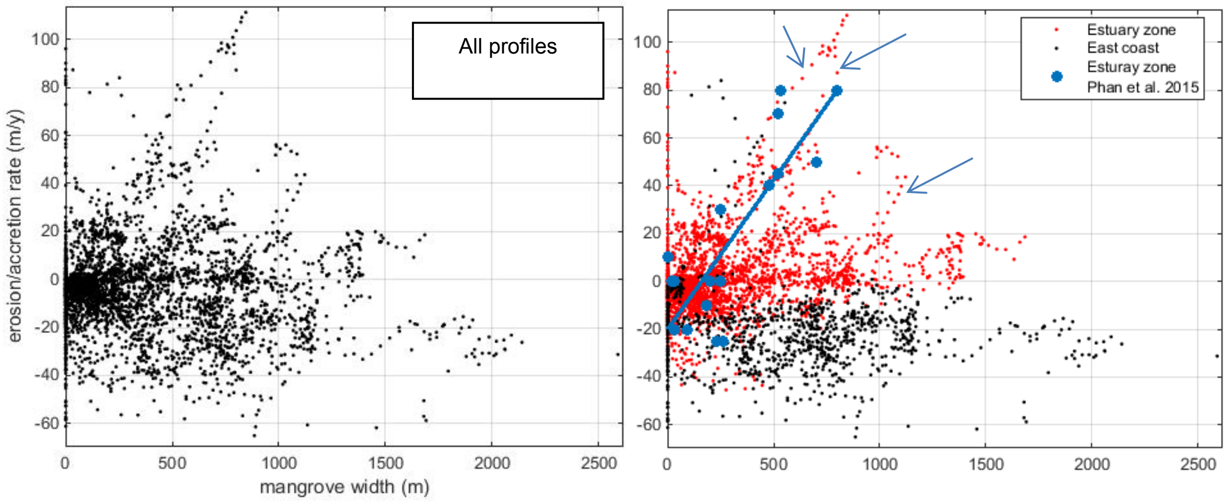

Fig. 5. Left, variation of shoreline erosion/accretion with mangrove width. Right, intercomparison with the work of Phan et al., 2015 and discrimination of the two geomorphic units

To get further in the analysis, we separate the shoreline in segments of 10km (100 consecutive profiles distributed every 100m alongshore) and evaluate whether some correlation exists (or not) between mangrove width and shoreline erosion/accretion at local scale (10km). Results are reported in figure 6. Each line represents segments of coast where a linear trend is observed. The text box gives the kilometric location from the origin shown in Fig. 4.

Along the 379km of shoreline analyzed, we identify seventeen segments of coast showing a relationship between mangrove and cross-shore evolution. Each segment has an alongshore length comprises between 500 and 8,000 meters. These segments represent a cumulative length of 35.3 km, i.e. ~9.3% of the total length of the shoreline (379km).

In Fig. 6, we can see that a majority of these segments (13 over 17, i.e. 76%) match with the law proposed by Phan et al. (2015) (the blue area). The 4 remaining segments are located at 150, 160, 190 and 370km from the origin, which corresponds to the southern section of the Estuary coast and the East coast. Interestingly, all profiles almost show the same slope between mangrove width and the rates of erosion/accretion. This may be interpreted as a sign of a similar mangrove resiliency all along the coast.

We can also observed an outlier line (represented with a dotted line), located in the erosion sector of Camau (370km). Even if located in the erosion quadrant, a linear relation between the rate of erosion and mangrove width is observed. This means that even if erosion dominates a regional unit, there are some specific places where the effect of shore protection by mangrove is still efficient and can be directly observed. In other word, a mangrove coast under erosion remains an active defense shore protection and efforts should be done to maintain it, even during eroding phases.

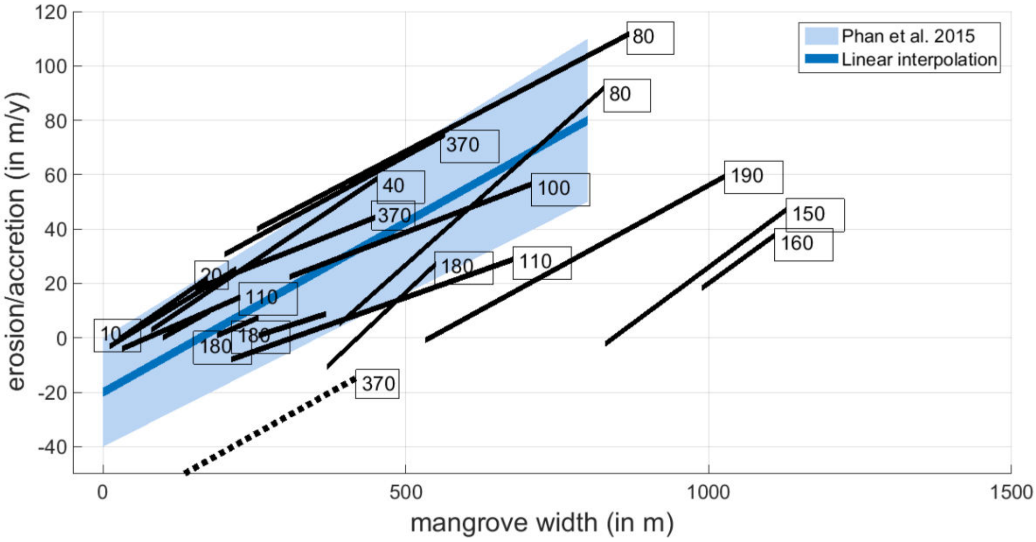

Fig. 6. Synthesis of areas presenting a significant correlation between mangrove width and erosion/accretion.

3. Mangrove erosion in the Mekong delta

a. The Estuary coast (0 to 280km) shows alternate signs of erosion and accretion even at small scales (sectors of 10km in length). This indicates that the coast is highly dynamics and resilient. The sediment supply from the river mouths is redistributed by the ocean forcings with some adjustment and feedbacks of the mangrove vegetation. Only 11% percent (32 km over 280 km) of the shoreline shows a direct linear relationship between mangrove width and the rate of erosion/accretion. For the remaining 89% of shoreline, the hypothesis of Phan et al. (2015) is not valid and the dynamic equilibrium is not dominated by mangrove resiliency, but by another driving factor: ocean forcings and/or human pressure and/or a variation of the fluvial sediment supply.

b. The East coast (281-379 km) is dominated by a large scale erosion (97%), even if this coast has the largest mangrove belt, up to 2000m. Results of numerical simulation conducted in (WP2) shows that the dominating factor is a large scale (hundreds of km) readjustment of the geomorphological forms under the ocean forcings. In this sector, the interplay of wave, tides, currents and wind do not supply enough sediment along shore. The lack of sediment limits the natural development of mudflats; the mud topography remains too low to offer optimal conditions for mangrove growth. While the severe erosion in this regional unit results from natural geomorphic readjustment, we should bear in mind that mangrove, even under erosion, contributes actively to the shore defence. In other words, the rate of erosion would have been even more intense without mangrove fringe.

c. Go-cong suffered chronic erosion during the last 20 years (not any phase of accretion, the dynamic equilibrium is disrupted). The mangrove is very scarce and the sand mud mixture is not necessarily the better environment for mangrove restauration. In the light of geomorphic and modeling results, we may hypothesized that erosion is predominantly due to a reduction of sediment fluxes from the Saigon Dong-Nai system. Sediment supply being a key factor, measures of mangrove restoration would probably be inefficient if they are not associated with sand and mud nourishments.

d. The West coast suffers mangrove squeeze, mainly because of aquaculture activity. While the coast has been eroding over the last years without strong geomorphological adjustments (the coast remains linear) ; we may hypothesized that mangrove squeeze enhance erosion. From the literature, we identify two possible factors: mangrove is not large enough to ensure wave dissipation, turbulence decrease and flocculation (see WP see Anthony and Gratiot, 2012 and WP3); the presence of aquaculture farms and/or dykes limit the tidal prism with negative effects on sediment trapping (Winterwerp et al., 2013).

4. Recommendations

The study shows that **a mangrove width of 500m** is required to promote natural resiliency. This condition is necessary but not sufficient. As mangrove ecosystem results from an equilibrium dynamic between sediment supply, ocean forcings, mangrove and human pressure, all of those parameters can disrupt the coastal resiliency.

A monitoring strategy based on remote sensing at regional scale and few sites of long term monitoring: An appropriate understanding of coastal evolution and resiliency require a monitoring at high spatio-temporal frequency. Remote sensing is an important tool to evaluate coastal changes at regional scale, while some pilot study sites should be selected for a deeper understanding of the processes. In particular mudflat topography and its connection with mangrove growth. Mudflat topography is a key factor for mangrove growth. Some tens centimeters of difference between two sites can lead to success or not. Monitoring the tidal signal, sedimentation and the seed arrival and mangrove growth has been particularly relevant along the Guianas coast. The same methodology could be deployed at a reasonable price on some chosen sites. Knowledge about local tidal fluctuations and mud bank topography may help in determining the appropriate temporal window for replanting. Regular drone observations and cameras could also help in identifying whether seeds arrival are naturally sufficient or if human replanting should be considered.

Promote soft engineering techniques except for Go-Cong site. Along the Estuary coast, we have a very dynamic system with erosion and accretion that operate jointly on segments of 10km. It means that the natural resiliency of this geomorphological unit is active and should be preserved.

A soft engineering techniques combining sand/mud nourishment, bamboo fence and mangrove replanting should be best efficient, as it will promote wave dissipation, the damping of residual turbulence and currents, and flocculation. Two points merit to be emphasized:

1) The ultimate dissipation of flow in the mangrove fringe is believed to promote actively flocculation by differential settling. Laboratory experiments indicate that flocculation by differential settling in settling column can increase sediment trapping by more than 100 times. The actual coastal defence techniques do not consider this process. Some test should be conducted in the field to evaluate the efficient of flocculation by differential settling in situ.
2) Protection measure would be best efficient if they are conducted all along the cross shore profiles, from the shallow water area where waves propagate to the muddy beach, where mangrove developps. This because the equilibrium dynamic depends on ocean forcings (need to reduce wave), sediment supply (need to promote quiescent conditions) and mangrove growth (need mangrove replanting and/or seed dissemination; three processes that operates at different cross shore locations.

REFERENCES

Anthony, E. J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., Nguyen V.L. 2015. Linking rapid erosion of the Mekong River delta to human activities. Sci. Rep. 5, 14745; (2015).

Gratiot, N. and Anthony, E.J. 2017. The mangrove mud coast under human pressure. LMDCZ workshop, 25 May 2017. Hoi An, Vietnam.

Phan, L.K., van Thiel de Vries, J.S.M. and Stive, M.J.F. 2015. Coastal mangrove squeeze in the Mekong Delta. Journal of Coastal Research, 31(2), 233-243.