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Sediment re-deposition in the mangrove environment of Can Gio, Saigon River estuary (Vietnam)

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ABSTRACT

Sediment re-deposition in mangrove environments is usually attributed to marine and estuarine hydrodynamics - rainfall as a driver was not considered yet. However, combined with annual water level variations, tropical rainfall can play a significant role for sediment re-deposition. Inside mangroves, current velocities induced by rainwater runoff during low tide conditions can be much stronger than tide-induced currents. Along the Saigon River Estuary and the Mekong Delta coastline, rainfall is high from May to October and low from December to April. To study processes controlling sediment re-deposition, data of current and suspended matter concentration have been combined with sediment re-deposition rates. All investigations have been carried out in the Can Gio mangrove reserve, Saigon River mouth. Based on a 19-year data set (1991 – 2009), strong annual variability in water level heights and tidal range are observed, with a mean maximum high tide level of 3.34 m during the rainy season and 3.73 m at the beginning of the dry season. Maximum tidal range is reached during the rainy season coinciding with the lowest annual average sea level. The highest parts of the mangrove forest are not inundated by tides during these periods. Only heavy rainfall during these times can lead to mangrove soil mobilisation, induce strong currents between the mangrove roots and cause erosional gullies. Depending on the amount of precipitation, this sediment mobilisation and the amount of suspension load in the forest can be much stronger than sediment transport induced by tidal currents.

ADDITIONAL INDEX WORDS: Mangrove forest, Saigon River estuary, suspension solid concentration,

**Investigation area**

The forest in the Can Gio reserve is a hybrid between a fringing (F-type) tide dominant and a river dominant (R-type) mangrove forest (Ewel et al., 1998). The study site is embedded in the Dong Tranh estuary (Figure 1), a branch of the Saigon River. The tide is mixed, dominantly semi-diurnal. Tidal range varies between almost four metres at spring tide and about only one metre at neap tide. Superposed on daily tidal fluctuations are spring/neap-tidal cycles and monsoon-driven variations in mean water levels (Nguyen, 2012). The depositional environment is characterized by silty sediments. From the banks of the Dong Tranh River and from the banks of the creeks (Figure 1), a morphological gradient exists with a rising bottom towards the inner forest. After the Vietnam War, mangroves have been reforested successfully since 1978, but coastal erosion continued with rates up to 50 m/year in some places (Mazda et al., 2002).

![Figure 1. Investigation area with marked hydrological monitoring stations in the Dong Tranh river mouth estuary.](image)

**Instrumentation and experimental setup**

Measurements of suspended matter concentration (SMC), salinity and temperature were done using optical backscatter sensors (OBS) and stationary conductivity, temperature and water level probes (CTD). OBS (Seapoint Sensors Inc., 2000) transmit an optical signal into the water column of which the wave length is near to infrared light (wave length 880 nm). The intensity of the backscattered light, expressed as a change in output voltage, is understood as measure for the amount of SSC in the water-column. A sensor’s response not only depends on the number of scatters but also on the composition and size of the suspended particles. Therefore for precise turbidity measurements an "on site calibration" is needed. The aim of this calibration is to mathematically formulate a close relationship between the sensor's mV response to concentrations of site specific particle composition (mg/l). In our case, prior to a measuring campaign, all available sensors are installed close to each other (Figure 3) at one location for which it is assumed that characteristics are comparable to those of the investigation sites. Calibration lasted for 1 tidal cycle with water sampling every 30 minutes. Samples are filtered (0.63 μm filters) and dried to calculate the total dry mass of suspended matter per volume unit water.

![Figure 2. Positions of 9 OBS sensors at the creek station (see Figure 1) in the forest of the Rach Oc Creek. CTD probes are installed in the creek and in the forest. Red arrows mark OBS-positions at the viaduct.](image)

![Figure 3. Sensor-array for the calibration and inter-calibration of OBS sensors and CTD-probes in the field (upper part of this figure). Best fit curves for two OBS sensors from the creek station are shown below.](image)
The relationship between the real concentrations and the sensor's signal strength mostly result in a linear best fit line (Figure 3). The fit equations allow all indirect sensor readings to be converted into real concentration values. The field calibration procedure is also used to inter-calibrate all sensors (Figure 3) and to detect shortcomings of any single sensor.

The instruments are installed in the Rach Ôc tidal creek (Figure 1), at the rim of the forest and in the forest. Time series measurements covered at least one spring/neap tidal cycle. To calibrate the OBS sensors and to carry out particle size analyses, during the field campaign additional water samples were taken every hour at every sensor for at least 1 tidal cycle during neap-, intermediate-, and spring tide. The SMC measurements were combined with assessments of sediment re-deposition in the mangrove forest by applying the “tracer stick method” (Schwarzer and Diesing, 2001). This method is based on injecting a rectangular stick (length: 10 cm, width: 2 cm) vertically into the sediment. The stick is made up of artificially coloured fine sand which is bound with water-soluble glue. The upper end of the stick coincides with the sediment surface. Upon contact with moisture, the glue dissolves after approximately 5 minutes. The tracer sticks remain in the mangrove soil until recovery where they are subjected to hydrodynamic influences. Erosion and deposition are calculated by measuring the length of the remnant stick with a centimetre scale (Figure 4) immediately after recovery. This method was applied for a 2-year period on 54 stations along the Khe Nhan-, Rach Ôc- and Nang Hai creek (Figure 1). The time the sticks remained in the sediment varied between 2 weeks and 5.5 months.

Data of water level variations were provided by the Southern Regional Hydro-Meteorological Center (SRHMC) which operates an official tide gauge at Vung Tau, located approximately 20 km east of Can Gio. These data were correlated with our own data, allowing us to extend site specific water level data for a longer period. According to the tidal classification by Courtier (1938), the mixed semi-diurnal tide is characterised by different water levels: two high waters (higher high water (HHW) and lower high water (LHW)) and two low waters (higher low water (HLW) and lower low water (LLW)). In addition to these parameters, tidal range (TR) and the mean sea level (MSL) were analysed for the period from 1991 to 2009.

RESULTS

Depending on the monsoon, variations of the considered tidal levels MHHW, MHW, MSL, MLW, and MLLW occur (Figure 5). During the wet season, sea levels are lower than during the dry season. Lowest levels are recorded in June/July (3.34 m), and the highest levels are measured in November (3.73 m). On average, the seasonal differences between highest and lowest MHHW and MLLW are approximately 45 cm and 53 cm, respectively. These values indicate a higher and longer inundation of the mangrove environment during the dry season. On the other hand, due to generally lower high water levels, the highest parts of the mangrove forest will not be tidally flooded during the wet season. This increases the chance for sediment re-deposition in the course of heavy rainfall events.

High variability in current velocities, water mass exchange, salinity, suspended matter concentration and sediment erosion and accumulation were found to be attributed to the monsoon cycle. Compared with the dry season, stronger currents combined with more water mass exchange are observed during the wet season, which in addition to intensive rainfall, cause an increase in suspended matter concentrations (Figure 6). If heavy
rainfall happens during ebb phase, and the forest soil has already fallen dry, erosion happens and sediments are exported from the forest flats. This is clearly observed in the higher SMC at the creek- and the forest station (Figure 7, sensor b and c). Rainfall during the flood phase does not show any pronounced signal of higher suspension load in the creek. During these phases, either remobilized sediment in the higher part of the mangrove forest due to rainfall will remain in the forest and be distributed there, or the water-level has already reached a height that hampers the ability of raindrops to induce re-suspension.

Tracer stick data revealed an increase in sediment dynamics combined with higher erosion and accumulation in the mangrove forest during the wet season. Turnover reaches approximately 0.2 cm/day during the wet season, while during the dry season turnover amounts to approximately 0.15 cm/day. The sediment balance during the dry season is negative in the forest with a loss of approximately 0.03 cm/day, while during the wet season the sediment balance in the forest is nearly in equilibrium. During the transitional seasons (May and October/November), the sediment balance is slightly positive with 0.01 cm/day. These findings, combined with the results of SMC measurements at the creek station, indicate that sediment which is washed out from the forest will be transported towards the inside of mangrove forest. Therefore, there is in general a positive sediment budget for this part of Can Gio Mangrove forest.

DISCUSSION

There are only few studies combining investigations of sediment redistribution in mangrove creeks and in mangrove forests. While Horstmann et al. (2013) focus mainly on topographical variation and the impact of the vegetation system on flow velocities, we show the impact of monsoon-dependent rainfall combined with seasonal water level fluctuations on sediment mobility. It is known that tidal currents in a mangrove forest rarely reach 0.1-0.2 m/s (Massel, 1998; Furukawa et al., 1997; Wu et al., 2001). Their ability to initiate short-term high sediment re-deposition rates is small. However, even if the sediment balance is equalized and no changes seem to appear, the sediment turnover, indicating sediment dynamics, can be very high (Figure 4). This turnover might have high implications for geochemical and nutrient cycles in the mangrove environment. Rainfall as a driver has been neglected so far, but should be included in future studies.
CONCLUSIONS
Sediment re-deposition in the mangrove environment of Can Gio shows seasonality in tidal- and water level fluctuations and precipitation. When rainfall happens during ebb tide, strong currents are initiated all over the mangrove environment as rain-water follows the morphological gradient, creating small gullies. This current induced sediment mobility and the amount of suspension load can be much higher compared to tide induced suspension load in the forest. Sediment turnover (see Figure 4) is an indicator for sediment dynamics. Even if the sediment balance is close to zero, sediment dynamics can be rather high.

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LITERATURE CITED