SUSPENDED SEDIMENT DYNAMICS IN MANGROVE AREAS, DONG TRANH ESTUARY, CAN GIO MANGROVE FOREST, HO CHI MINH CITY, SOUTHERN VIETNAM

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Abstract

Mangrove forest, which in Can Gio district, Ho Chi Minh city, Southern Vietnam, covers an area of about 38.664 hectares, plays a special role in supporting fish, crabs, shrimps, shellfish, also in trapping sediment. Suspended sediment transport in this area also plays an important role in the coastal environment evolution. This study outlines field experiments on suspended sediment dynamics in mangrove areas, being of Dong Tranh estuary, Can Gio mangrove forest. From the measurements carried out in two years (2004-2006), experimental results indicate that suspended matter dynamics in this area is strongly governed by tidal action, current velocity and rainfall. The seasonality in redeposition rates with higher erosion and accumulation in the wet season than in the dry season.

Keywords: Suspended sediment concentration, Can Gio mangrove forest, Southern Vietnam.

1. Introduction

Mangrove wetlands fringing tropical shorelines are important interfaces between land and sea. One of their major functions is the protection of the coastal environment and the provision of sediment trapping for suspended particles (Bird 1971, Wolanski *et al.* 1986, Augustinus 1995, Blasco *et al.* 1996, Furukawa *et al.* 1996, Saad 1999, Woodroffe 2002, Thampanya *et al.* 2006, Victor *et al.* 2006).

In order to preserve mangrove forests with their valuable benefits, among others a fundamental understanding of sediment cycling mechanisms, part of it is suspended matters, in this system and its relation to hydrological conditions is needed.

The different measurements were carried in a mangrove forest area as well as in adjacent estuarine channels, tidal creeks and tidal flat areas. The out coming two-year dataset covers a wide spectrum of conditions controlling the sediment and hydrodynamics in the area.

2. Study sites

The actual study area comprises the mud flats and mangrove forests east of the Dong Tranh River. In the north the domain is bordered by the Khe Nhan Creek and in the south by the Nang Hai Creek (Fig.1).

3. Instrumentation, Experimental set-up

The kinds of measurements, methods, and instruments used in the study:

- Measurements: suspended matter concentration, water level, salinity, water temperature, current, topography and sediment redeposition.
- Method: optical backscattering, sonar, leveling, electro mechanical propeller sensor, tracer stick method
- Instrument: OBS, CTD, Seapac 2100, optical level.

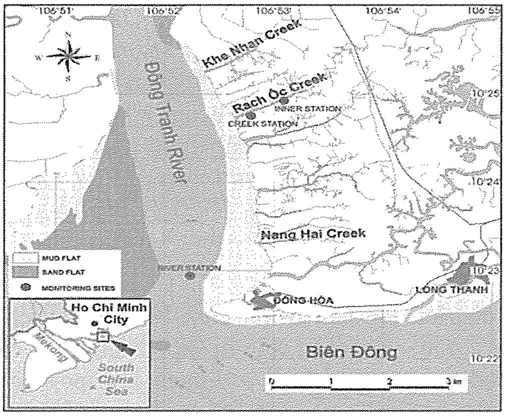

Figure 1 Location of the study area with marked hydrological monitoring stations in the Dong Tranh River estuary

4. Results

4.1 Tidal characteristics

In the mouth of the Saigon River tides are mainly semi-diurnal with a half-daily inequality of varying significance. The tidal range in the investigated area varies between up to four meters during spring tide and approximately one meter during neap tide. In the main channel as well as in the creeks the duration of the ebb phase is markedly longer than that of the flood phase (Fig. 2, 3).

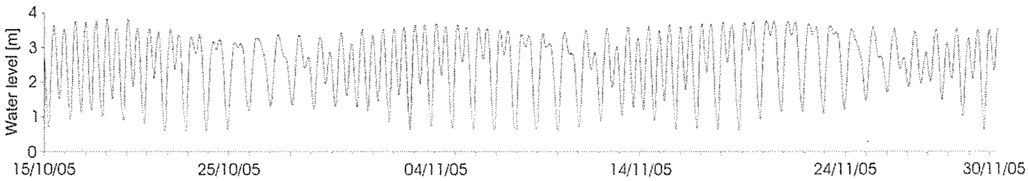

Figure 2 Time-series of water level fluctuations recorded at Creek Station for the period October-November 2005.

4.2 Flow dynamics

The flow of water masses in the study area is induced and controlled by tidal action. Current velocity is mainly a function of tidal range whereas the temporal variability of current direction depends on the stage of the tides. The measurements show that from the open estuary through the tidal creeks onto the mudflats and finally into the mangrove forest the magnitude of the flow decreases. At the River Station in the main estuarine channel current velocities can reach magnitudes of 1.5 m/s (Fig. 3). In the creeks highest velocities of 0.8 m/s have been measured. On the mudflats the maximum velocities are in a range of only few m/s.

At the River Station highest velocities of the whole tidal cycle can be noticed during the first third of the flood phase (Fig.3). Highest ebb current velocities mostly appear in the last half of the period of falling water levels. This current pattern is in a good agreement with the observed typical estuarine tidal asymmetry with shorter flood phases and longer lasting ebb periods (Fig. 4). The vertical current distribution can be approximated by a logarithmic profile. The spatial and temporal variabilities of the flow at the different measurement points on the cross-section of the creek are depicted in Figure 5,6.

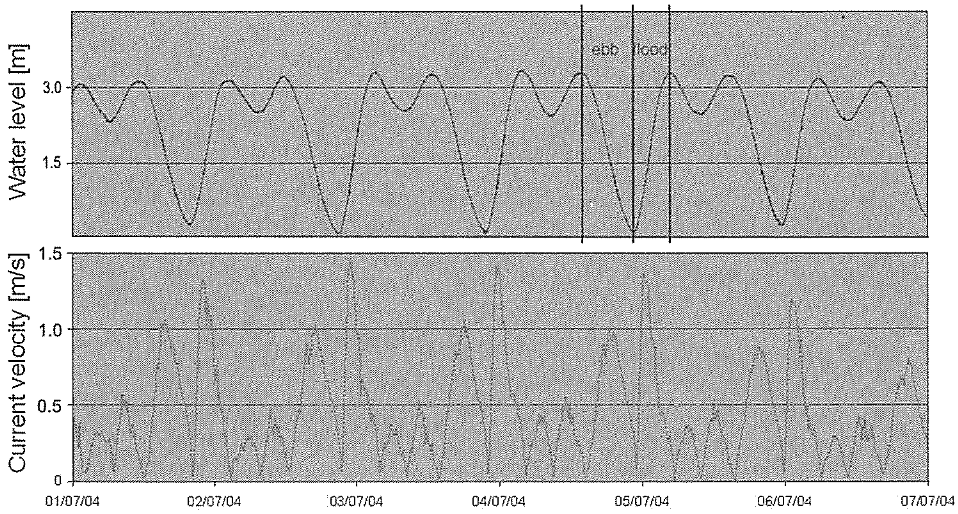

Figure 3 Tide and current velocity records for the River Station

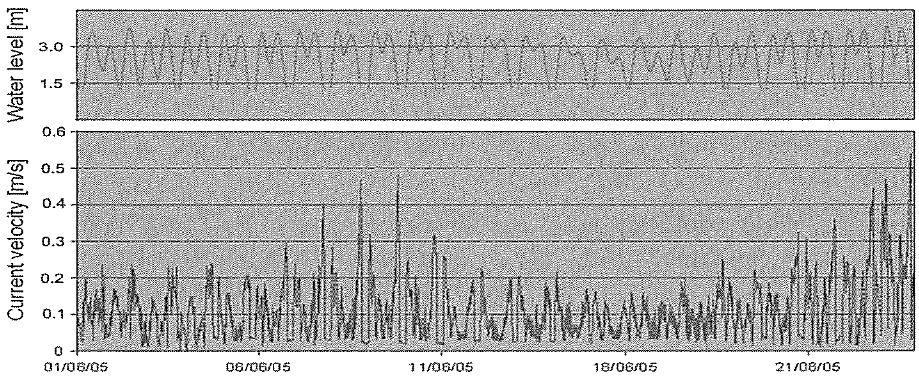

Figure 4 Tide and current velocity records for the Creek Station

4.3 Water discharge

The amount of water going in out by the tides through Rach Oc creek was calculated for the cross-section. During the dry season experiment discharge - depending on the tidal stage - varied from 1 m^3/s to 16 m^3/s (March 2005). During the rainy season (August 2005) discharges were ranging from 1 to 20 m^3/s. The differences in discharge are mainly a function of current velocity and therefore a function of the tidal range. However, from time to time current velocities in the creek can be clearly influenced by fresh water runoff. This is especially the case in heavy precipitation happens at phases of low water level. Under these circumstances the runoff of the rain water from the forest areas is canalized in the creeks what leads to pronounced discharge peaks.

4.4 Suspended matter dynamics

The suspended matter in the study area predominantly consists of flocculated very fine grained organic and inorganic material. Numerous particle size analyses of thoroughly homogenised samples revealed that the basic components are clay and fine silt sized particles with a mean diameter in the range of 4-5 μm (Fig.7). In this context it is noteworthy that the particle size composition of the basic components of the suspended

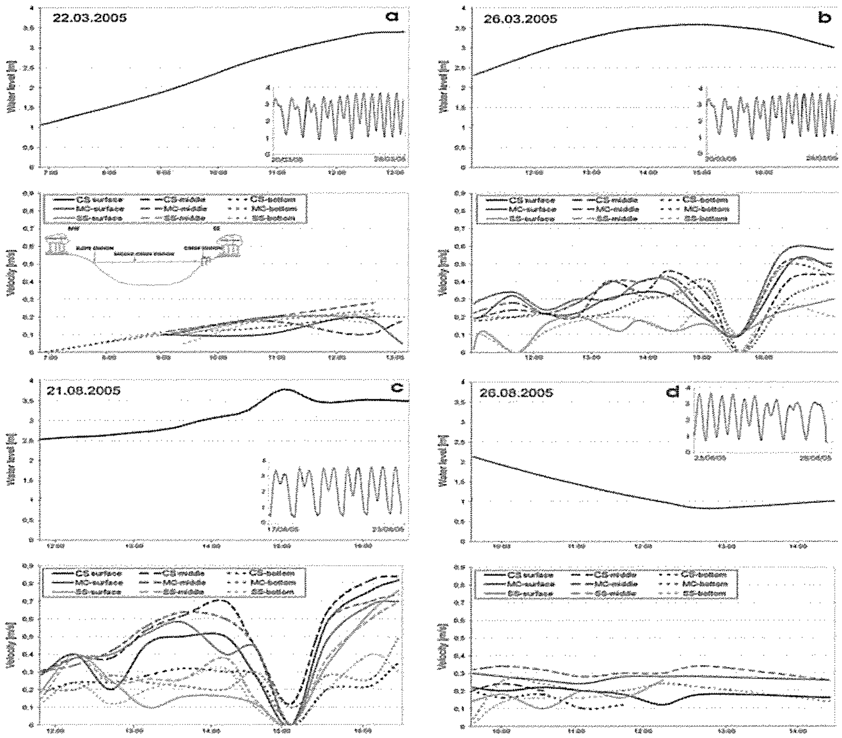

Figure 5 Current velocities and water level records for the Creek Station (CS), Middle-Creek Station (MC) and Slope Station (SS) in the Rach Oc Creek from (a) dry season with low velocities increasing during a flood phase, (b) dry season with high velocities during flood phase and maximum velocities during ebb tide, (c) wet season with high velocities during flood phase and maximum velocities during ebb, (d) wet season with low velocities during ebb phase.

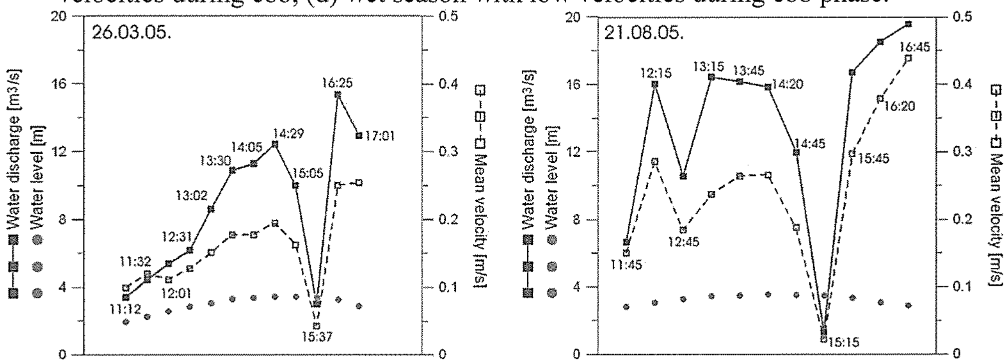

Figure 6 Water discharge and mean velocity measured at the cross-section in the Rach Oc Creek. Timing of current velocity and water level measurements is indicated in the plots.

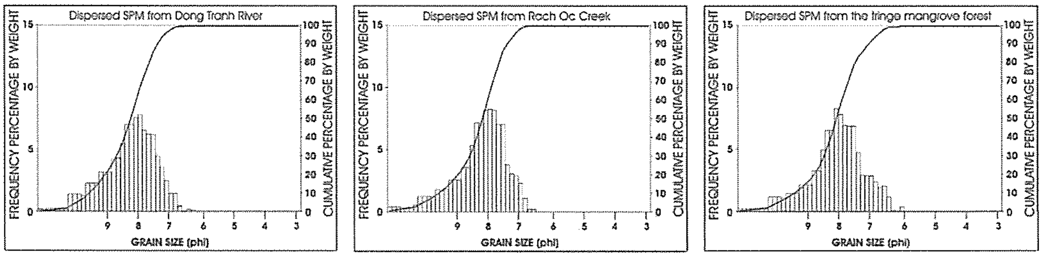

Figure 7 Examples of dispersed suspended matter from: Dong Tranh River (10°24.809'N 106°52.120'E), Rach Oc Creek (10°24.837'N 106°52.373'E) and fringe mangrove forest adjacent to the Rach Oc Creek.

sediments hardly differs between samples from the open estuary and those from tidal creeks or from inundated mangrove forest areas.

Suspended matter concentration is mainly controlled by tidal currents. With the exception of minor phase shifts the amount of suspended solids in the water directly follows the current magnitude (Fig.8). At the River Station this leads to a run of the concentration time

series curve with highest values at the first third of the flood phase and a second lower but longer lasting maximum at the end of falling tide. Lowest values can be observed during high water slack. This typical estuarine pattern is superposed by variations due to the daily and weekly (neap-spring-cycle) inequalities of the tides respectively the tidal range and the corresponding tidal currents.

In this context it is relatively easy to recognise that suspended matter concentrations directly responses to the 14 days neap-spring tidal cycle. The generally lower tidal ranges during neap tides result in less sediment suspended in the water column (Fig. 9).

This periodicity is superimposed by daily changing suspension loads. The magnitude of this variability depends on the ratio of diurnal to semi-diurnal characteristics of the controlling tides. The complex patterns of the temporal SPM distribution can be attributed to specific tidal situations (see Fig. 10, 11).

Mainly diurnal tides with a subordinate semi-diurnal constituent result in the comparably low mean concentrations. SPM peaks are present only at the diurnal phases of high tidal range. During the low semi-diurnal rising and falling, the SPM concentrations are not effected.

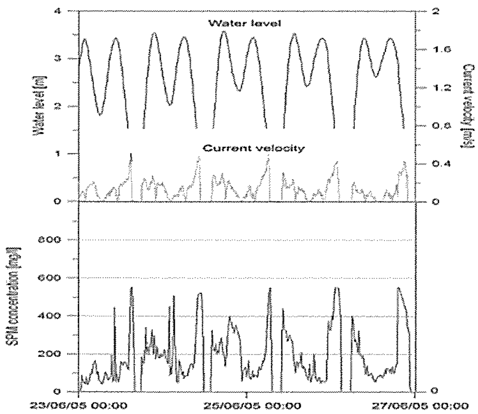

Figure 8 Water level, current velocity, SPM concentration records showing increases in SPM concentrations due to raises in current velocities with increasing tidal range (current measurements from Seapac instrument; data from OBS middle sensor; Creek Station, June 2005).

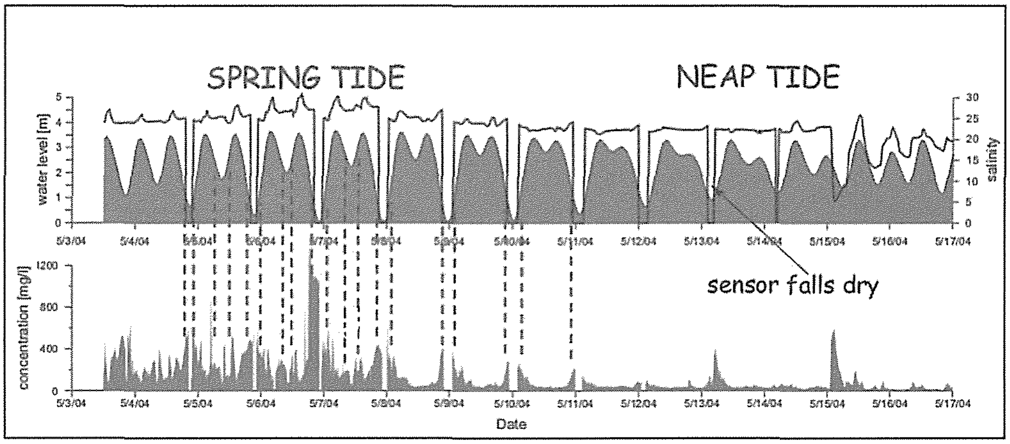

Figure 9 Time-series of water level, salinity and SPM collected at Creek Station (May 2004).

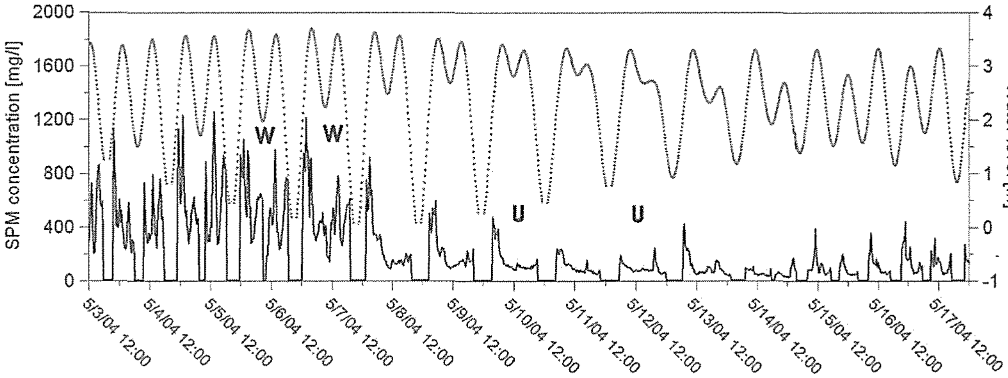

Figure 10 Time series of the SPM concentration and water level at the Creek Station at the end of dry season. (OBS lower sensor)

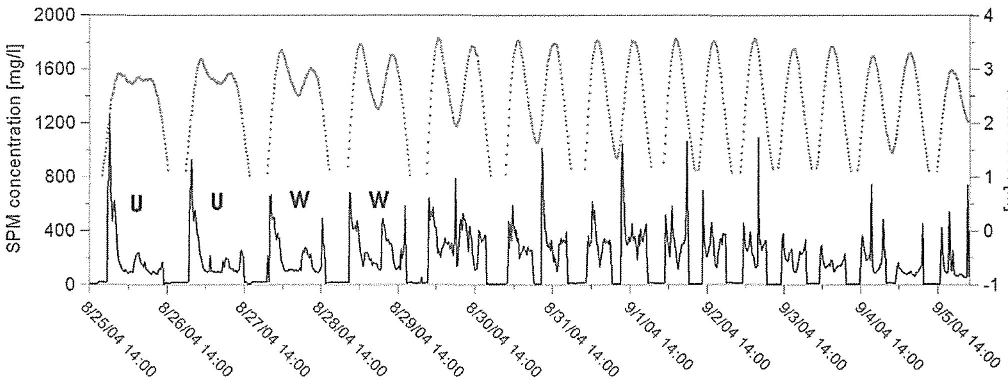

Figure 11 Time series of the SPM concentration and water level at the Creek Station during the wet season. (OBS lower sensor)

The transport of suspended matter in the river and especially in the tidal creeks follows complex rules. The situation in the mangrove forest itself is far less complicate. In a first order here the transport of mineral components depends on the water level respectively the elevation of the area. Deposition only can happen if the water level is high enough that the area gets inundated and sediment loaded water

reaches the location. Figure 12 depicts that the forest area was not inundated during neap tide conditions but only at spring tides. Since most of water enters the forest through the tidal creeks and only at high water levels close to high water slack only water with comparably low amounts of suspended solids reaches the forest. With the exception of the first water that enters the forest resuspending loose material on the forest floor and sometimes forming a kind of intertidal mud front the concentrations in the forest are barely higher than the already background concentrations of approximately 30 mg/l. However, Very high concentration can occur as a consequence of heavy rainfalls. Due the fine grained composition and little permeability of the forest floor the rain does not ooze away. Instead it discharges overground and is canalized between the roots and trunks of the mangrove trees. That can lead to strong erosion becoming visible in high suspended matter concentrations in the discharging fresh water masses.
Long periodical variabilities in salinity and suspended matter concentration can be correlated with seasonal monsoon cycle. During the dry season salinity was relatively stable on the level of 20, while during rainy season it was fluctuating in the range from 14 to 17 (Fig. 15). An estimation of the mean SPM concentrations also shows seasonal characteristics. During the dry season the concentration level of suspended sediments is generally lower compared to the rainy season. In the latter season intensified fresh water runoff either locally or in the whole catchment area of the river in combination with more frequent storms leads to the mobilisation of sediments (Fig. 13).
In addition to the concentration measurements calculations of the sediment flux through the Rach Oc tidal creek were carried out for at dry and rainy season conditions. The results are shown in Figure 14.
During dry season, measured suspended sediment fluxes show values up to 1.5 kg/s (March 05), while during wet season maximum measured fluxes reached 8.5 kg/s (August 05). The higher flux in rainy season results on the one hand from higher water mass exchanges at that time and on the other hand from higher suspended matter concentrations.

5. Discussion

Investigated mangrove swamps are inundated during periods of high tide by water directly from the river (fringing *Avicennia* forest) and additionally by water from the tidal creek (further inland *Rhizophora* forest). A complex mangrove system is regularly inundated by sediment-laden waters. The most important factors accounting for the increased suspended matter concentrations in the investigated mangrove forest are: tidal range, currents velocity and rainfall.

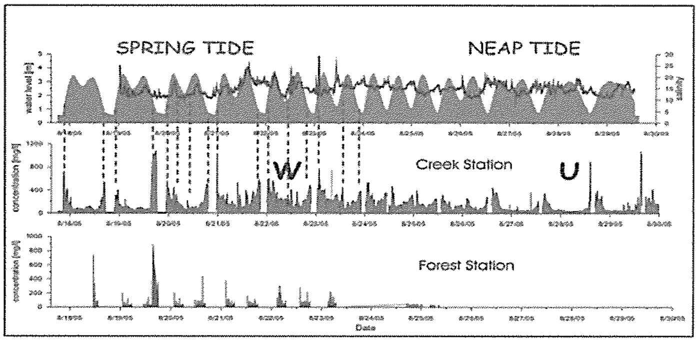

Figure 12 Water level, salinity and SPM concentrations for the Creek Station and Forest Station.

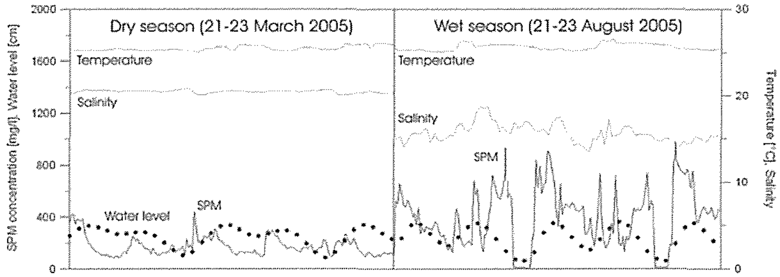

Figure 13: Examples of temperature, salinity and SPM concentration time series in the dry and the rainy season.

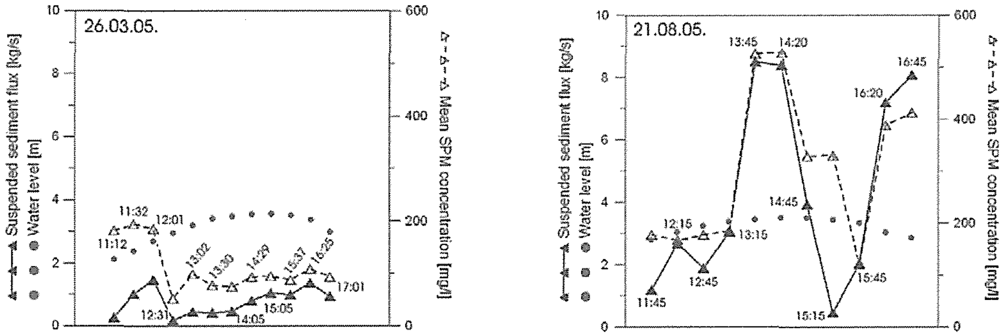

Figure 14 Suspended sediment flux and mean SPM concentration measured at the cross-section in the Rach Oc Creek. Timing of current velocity and water level measurements is indicated in the plots.

It was observed that current velocities and suspended matter dynamics are strongly controlled by tidal action. Investigated mangrove creek system has tidal currents which are ebb-dominated (Fig. 4, 5). Tidal asymmetry between the flood and ebb water velocity for the mangrove creeks and its importance has been highlighted by Pethick (1980), Wolanski *et al.* (1992), Mazda *et al.* (1995), Mohd-Lokman (2004). Increasing tidal range leads to the increase in the current velocity and to the increase in inundation of the mangrove forest. The increase in SPM concentrations as well as in sediment transport occur due to increasing tidal range (Fig.10 and 13) and thus increasing current velocities (Fig. 11). It enables that the particles are deposited under lower velocity conditions when turbulence vanishes near slack high tide and at ebb tides the water currents are too small to re-entrain this sediment (Furukawa *et al.* 1996). Golbuu *et al.* (2003) estimated that about 15-30% of the riverine fine sediment is deposited in the mangroves during river floods. Higher current velocity in the creek during the ebb phase was found to result in a greater discharge of water during periods of maximum ebb flow. Ebb-domination in the tidal creek results in a tidal asymmetry between the tidal phases, what causes the circulation within the creek (Massel 1998). The SPM concentrations at spring tide are higher than during neap conditions (Fig.10). Furukawa *et al.* (1997) estimated that about 80% of the suspended sediment brought at spring tide is trapped in the mangroves.

The forest gets less suspended matter than is present in the tidal creek. Similarly, Anthony (2004) noticed lower SPM concentrations over the mangrove swamp than those in the creeks, what is connected with the circulation of SPM between the creek and mangrove forest modulated by the duration of flooding which exerts a determining influence on settling potential (Anthony 2004). This potential may be considered in terms of the amount of SPM and the settling time of SPM on the mangrove surface (Reed *et al.* 1992, Anthony 2004). Tidal currents in the mangrove forest rarely reach 0.1-0.2 m/s (Massel 1998, Furukawa *et al.* 1997, Wu 2001) due to the weakening processes caused by the vegetation-induced friction (Furukawa *et al.* 1996, Furukawa *et al.* 1997, Mazda *et al.* 1997b).

Seasonally, stronger current velocities take place in the wet season, what accounts for higher water discharge in the wet season. Flood tide brings water from the river with higher concentrations of suspended material, what increases SPM concentrations during wet season in comparison with dry season. The potential for SPM transport by high-discharge river, flooding of the mangrove swamps and consequently higher SPM concentrations in the mangrove forest is enhanced during the wet season by rainfall. Diffuse wet season flow through the estuarine mangrove swamp with higher SPM concentrations accounts for rainfall influence on the suspended sediment dynamics (Anthony 2004). Additionally, lower salinity during the wet season is less favourable to flocculation (Owen 1970, Dyer 1995), which can lead to more rapid settling (Anthony 2004). Inverse correlation between salinity and SPM concentrations was also found by Victor *et al.* (2006). Changes in rainfall regimes have been linked to changes in surface water salinity and by Clarke *et al.* (1967) to soil salinity, mangrove survivorship and the expansion of mangroves into saltmarshes.

The erosion measured in the investigated mangrove forest show higher rates during wet season in comparison to the dry and transitional seasons, although the erosion was relatively high also in the dry season. The accumulation rates were higher in the wet season, two times than accumulation in the dry season and three times than accumulation in the transitional season. Consequently, the greatest sediment dynamics took place in the wet season.

The seasonality in redeposition rates with higher erosion and accumulation in the wet season correlate with the increasing rainfall, stronger current velocities (Figure 14) and higher SPM concentrations during the wet seasons. Higher sediment rates in the wet seasons compared to the dry seasons were found by many researchers. For instance, Saad (1999) found the average accretion in the mangrove swamps for the monsoon season to be significantly higher than the non-monsoon season.

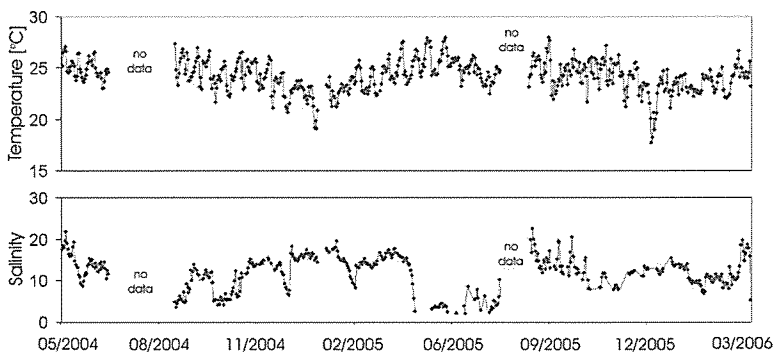

Figure 15 Time-series of temperature and salinity at Creek Station during the field study (May 2004-April 2006).

6. Conclusions

From the measured data, the following conclusions have been obtained:

(1) Tides are the dominant cause of water movement and processes acting in the investigated mangrove estuary environment. Dong Tranh River is flood-dominated, while the tidal creek is ebb-dominated. Increasing tidal range leads to the increase in the current velocity and to the increase in inundation of the mangrove forest. Higher current velocities in the creek during the ebb phase result in a greater discharge of water.

(2) The suspended matter dynamics is strongly governed by tidal action, current velocity and rainfall. The increases in SPM concentrations occur due to increasing tidal range and current velocities. The SPM concentrations at spring tide are higher than during neap conditions. The forest gets less suspended matter than is present in the tidal creek. Seasonally, due to stronger currents and intensive rainfall in the wet season, the SPM concentrations are higher than in the dry season.

(3) Deposition rates are affected by proximity to the tidal creek, river, by kind of mangrove forest and by the seasonality. The seasonality in redeposition rates with higher erosion and accumulation in the wet seasons than in the dry seasons was noticed. The greatest sediment dynamics was found on the mangrove edge of a tidal creek and smaller further inland. The highest dynamics appeared in the *Avicennia* forest, the zone fringing the river. The highest redeposition rates among three investigated creeks occurred in the forest adjacent to the Rach Oc Creek and Nang Hai Creek, located in the south of the investigated area, while the lowest were noticed in the areas adjacent to the northern Khe Nhan Creek.

(4) The seasonality in redeposition rates with higher erosion and accumulation in the wet season than in the dry season correlate with the increasing rainfall, decreasing salinity, stronger current velocities and higher SPM concentrations during the wet season.

(5) The prevailing homogeneous sediment concentrations and the dominance of very fine suspended particles in the water column was noticed. Clay and silt fractions dominate both suspended matter and surface sediments. Distinction in the grain size was found between the mangrove swamps (fine silt) and the tidal flat of estuary (coarse silt). The trend of finer sediment occurring in the north and coarser sediment in the south of the investigated Dong Tranh River and in the mangrove forest was noticed. The tendency of a decrease in the particle size from the *Avicennia* forest with more coarse sediment fringing the estuary to the *Rhizophora* forest with finer sediment further inland was found.

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