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Coastal erosion due to long-term human impact on mangrove forests

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Abstract

A coast in southern Vietnam, which is located in a wide and flat alluvial fan and neighbors tidal rivers fringed by wide mangrove swamps, has been eroded continuously by approximately 50 m/year since the early 20th century. Based on field observations and numerical experiments, it is inferred that this large scale erosion is caused by the transition of mangrove vegetation resulting from the long-term impact of humans since the late 19th century. This eroded coast is not in direct contact with mangrove swamps, but is strongly affected by the existence of mangrove forests through the intermediation of neighboring tidal rivers. Thus, with a view to coastal protection, it is argued that the mangrove vegetation in adjacent areas should be managed more sensitively.

Introduction

Mangrove forests fringing tropical coast lines are very important not only from local view points regarding wood resources, food resources and land protection in tropical coastal regions but also from the global view point of earth's total environment (Robertson and Alongi, 1992). Since the late 19th century mangrove forests have been destroyed on a global scale due to human interaction. Consequently, this degradation of mangrove forests has also had a discernible impact on human existence; for example, in South East Asia the deforestation of mangrove areas adjacent to the open sea has sometimes exacerbated coastal erosion from sea waves (Hong and San, 1993; Mazda et al., 1997a). Generally in coastal regions, the interaction between the land and the water is very strong and the ecosystems depending on these physical processes are very sensitive. In order to harmonize the co-existence of humans in coastal mangrove regions, the physical processes and dynamical mechanisms of the interaction should be thoroughly understood (Wolanski et al., 1992; Mazda et al., 1999a).

The findings of the physical processes and hydrodynamics in the area under investigation lend support to the notion of interdependence. Mangroves vegetate in the intertidal area, and experience daily flooding from tidal cycles. The implications of this study are useful not only for the preservation of existing tropical mangrove areas but also in regions where the land may be inundated by tidal cycles as the global sea level rises up to 60 cms within the next 100 years (Field, 1995).

In this paper, we first examine the large scale coastal erosion experienced in southern Vietnam. And then, based on field observations and numerical experiments, we present evidence that this long term, widespread coastal erosion has been caused by changes in mangrove vegetation resulting from long-term human impact since the late 19th century.

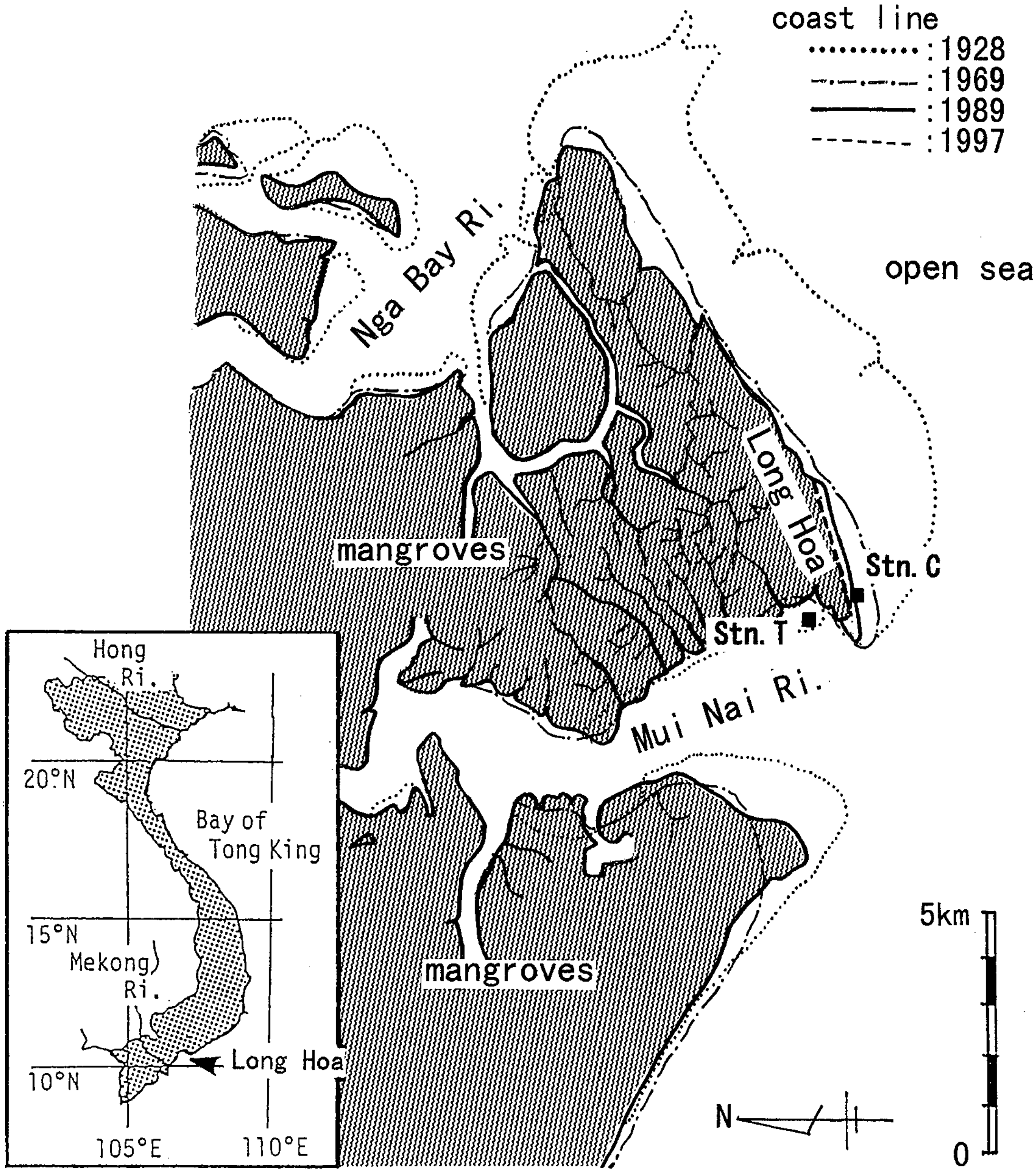

Figure 1. The area map around the Long Hoa coast in southern Vietnam. Four coast lines are drawn based on topographical surveys in 1928 (. . .), 1969 (-·-·-·-), 1989 (———) and 1997 (- - - -), individually.

Large scale coastal erosion in south Vietnam

Figure 1 shows the area map around the Long Hoa coast in south Vietnam, which is located in a wide, flat alluvial fan and lies between two big tidal rivers, the Mui Nai River and Nga Bay River. These rivers are fringed with wide mangrove forests (dominated by Rhizophora species). At present, these mangrove forests don't have direct contact with the open sea; they are separated by a settlement called Long Hoa village, rice paddies, salt farms and aqua-culture ponds. Consequently, at high tide the mangrove forests are inundated by the tidal rivers, but not directly through the coast facing the open sea; this type of mangrove forest is called a riverine forest type (R-type mangal; defined later).

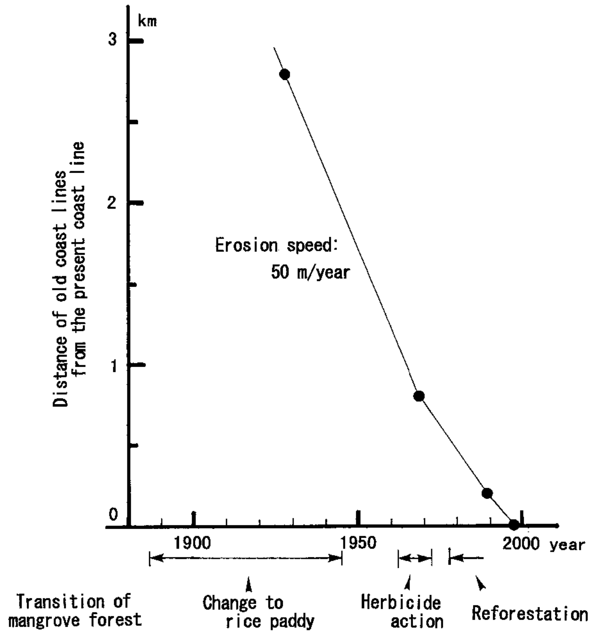

Figure 2. Coastal erosion speed and the historical transition of mangrove forests in Vietnam.

Based on topographical surveys taken in 1928, 1969, 1989 and 1997, the transition of the coast line is shown in Figure 1. It is notable that the coast facing the open sea has been severely eroded compared to the inside of the river mouths. The coast of Long Hoa village has been eroded continuously by approximately 50 m/year since the early 20th century (Figure 2). Furthermore, as seen in Figure 2, the speed of erosion does not appear to be decelerating.

Generally, the progression of the coastal erosion depends on two necessary conditions. Firstly, the current flow has to be strong enough to move bottom sediment, and secondly, the supply and disappearance of bottom sediments due to the flow are not in balance with each other. Thus, in order to prevent further erosion in this area, the mechanism of the above two conditions needs to be analyzed.

Current velocity along the coast

Field observation

Current velocity at Stn.C (Figures 1 and 3) located at 150m offshore and 300 m from the tip of the spit of the river mouth was measured at 5 cm above the bottom floor during three tidal cycles from 17 to 18 Sept. 1997 (Figure 3). Unfortunately the tide level was recorded only for a short period at the beginning of the observation, because a tide gauge set near the shore of the river mouth (Stn.T) was uprooted by the strong tidal current.

Comparing the current velocity with the tidal elevation in Figure 3, it is apparent that coastal waters flow westward with flood tides, then reverse with ebb tides. This tidal current along the coast has an amplitude over 70 cm/s, sufficient to move bottom sediment composed of fine, silty sands. The tidal flow is asymmetric between the flood and ebb periods. A curious current pattern can be observed after every high tide. As schematically shown in Figure 4, this curious current pattern represents the typical fate of an eddy which occurs behind the steep spit due to a strong ebb flow, then moves downstream along the coast line. This eddy sucks up bottom sediment (Itosu et al., 1995), and moves it. As a result, the tidal flow asymmetry causes one-way transportation of sediment, that is, coastal erosion. In our experience, such a strong tidal flow is rarely seen in other wide, flat alluvial fans (for example, see Mazda et al., 1997a). Considering that both sides of the Long Hoa coast neighbor two big tidal rivers, the Mui Nai River and Nga Bay River, the above mentioned strong tidal flow along the coast is inferred to be generated by the existence of wide mangrove areas which are flooded by tidal action through these rivers, as schematically shown in Figure 5. The flooding volume into wide mangrove swamps due to tidal action (Figure 5b) causes a huge amount of tidal flow at the river mouths compared to the case without flood plains (Figure 5a), resulting in a strong tidal current along the neighboring coast. This inference is confirmed in the following numerical model experiments.

Numerical experiments

Two simplified models, A and B, were compared. Model A has a tidal river with no flood plain. The river has no land discharge but a tidal flow through the river mouth. Model B has similar physical qualities to Model A but with fringing mangrove swamps (flood plains), that is, Model B is a typical R-type mangal. As the swamps are inundated with water at high tide through the river, the tidal prism volume in Model B is expected to be considerably large compared to Model A. The plane view of the river is shown in Model A in Figure 6; the river length is 40 km, the water depth is 4m, the widths of the river at the mouth and at a point 8 km from the mouth are 2 km and 250 m

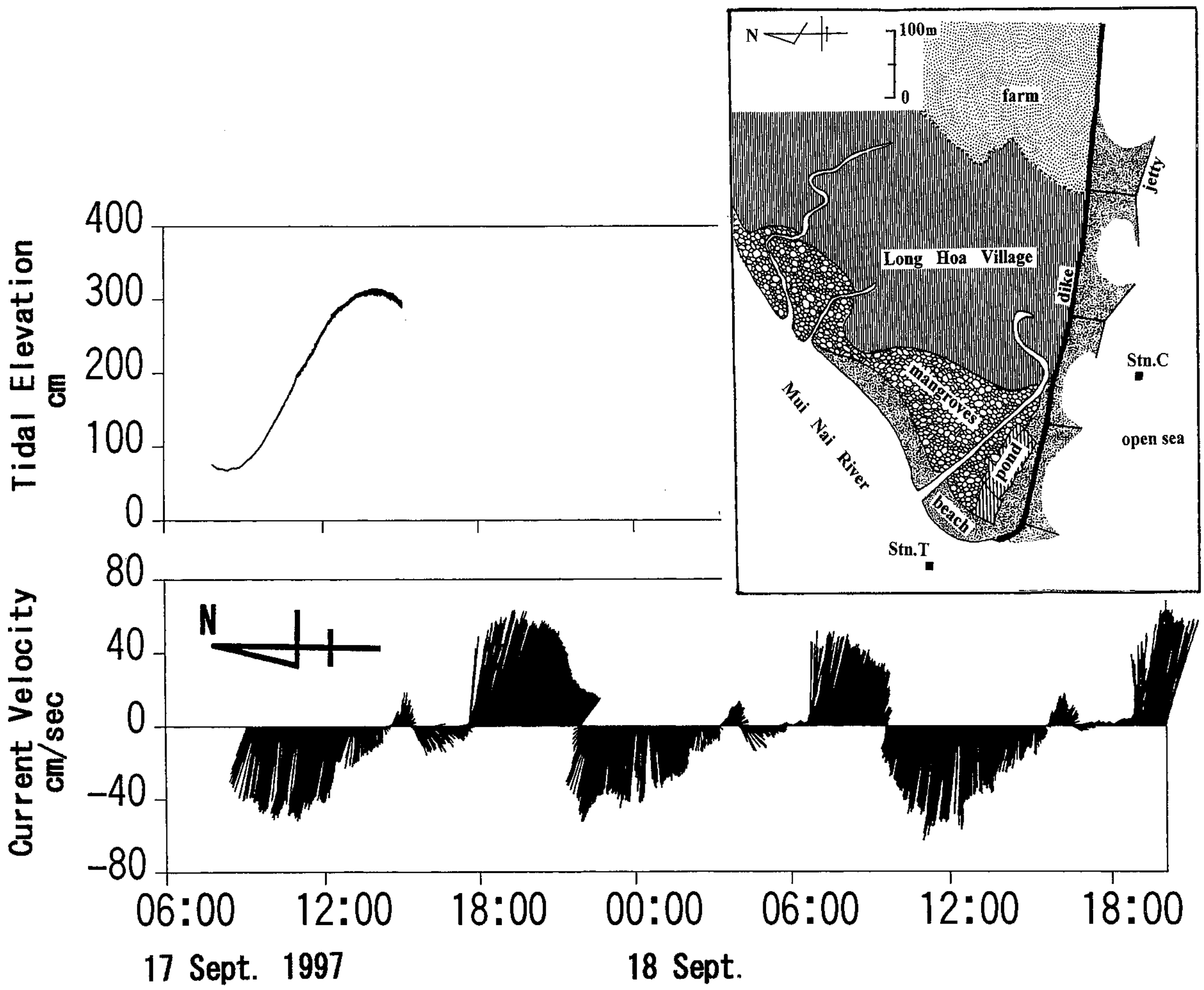

Figure 3. Time series plots of current velocity vector at Stn.C and tidal elevation at Stn.T.

respectively, and the tidal amplitude in the open sea is 1.5 m. In Model B, the slope of the flood plain is 1/3000. These dimensions are roughly based on actual field measurements. The method of numerical computation implemented in the experiment is similar to that used by Mazda et al. (1995) and Mazda et al. (1999a), as follows; the depth-averaged momentum and continuity equations are

$$\frac{\partial uh}{\partial t} + \frac{\partial u^2 h}{\partial x} + \frac{\partial vuh}{\partial y} = -gh\frac{\partial \varsigma}{\partial x} - \gamma^2 u\sqrt{u^2 + v^2} \quad (1)$$

$$\frac{\partial vh}{\partial t} + \frac{\partial uvh}{\partial x} + \frac{\partial v^2 h}{\partial y} = -gh\frac{\partial \varsigma}{\partial y} - \gamma^2 v\sqrt{u^2 + v^2} \quad (2)$$

$$\frac{\partial \varsigma}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = 0 \quad (3)$$

where u and v are the vertically-averaged velocities in x- and y-directions, respectively, t the time, ς the elevation of water surface, h the water depth, g the acceleration due to gravity and γ^2 the drag coefficient. In the creek γ^2 is 0.0026 as well as the usual value in coastal regions and estuaries. In the flood plain, γ^2 varies corresponding to mangrove species and their vegetation densities.

Examples of the current velocity distributions are shown in Figure 6. The flooding over the swamps is seen in Model B (the tidal changes of the current distribution is analogous to Figure 2 in Mazda et al., 1999a). In Figure 7 the tidal changes in current velocity at the river mouth are shown accompanied with tidal levels. The magnitude of tidal current at the center of the river mouth in Model B reaches three times as large as that in Model A. Since the bottom topography of this

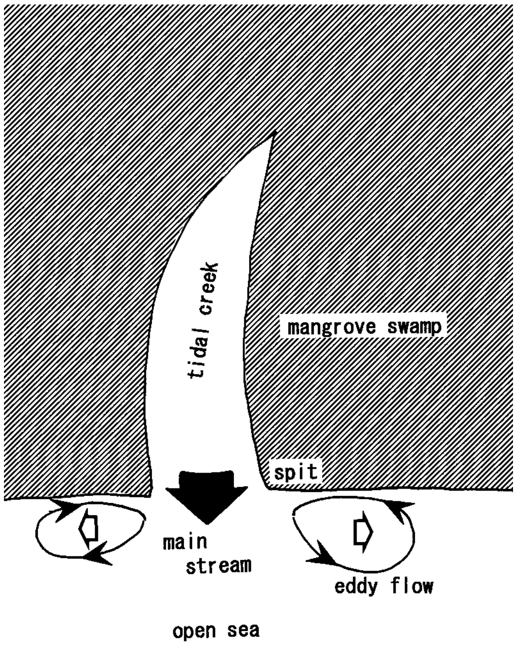

Figure 4. Schematic view of eddy flows occurring behind spits.

model does not approximate actual conditions in the field (especially that outside the river mouth including the coastal area) because of computational techniques, we cannot confirm the rate of current velocity along the coast which goes round the spit of the river mouth. However, this experimental result suggests that water inundation in the background mangrove area along the river considerably strengthens the tidal current along the coast neighboring the river mouth.

The transition of mangrove vegetation

Mangrove areas in Vietnam have been exposed to human impact since the late 19th century (Hong and San, 1993). In particular, mangrove swamps have been eradicated and developed into rice paddies by an intentional governmental policy (since the late 19th century to the middle 20th century). In addition, mangrove trees were severely damaged by the herbicides used in the Vietnam War (1962–71). In recent years, a degree of reforestation has been undertaken by local people and the Vietnamese government (these events are shown in Figure 2). Even so, the mangrove forests behind Long Hoa village were extensively damaged by the introduction of salt farms and herbicides used during the Vietnam War. From these facts it is inferred that the density of mangrove vegetation in this area has considerably changed since the late 19th century.

Changes in vegetation density of mangroves causes changes in tidal prism volume flooding into the forest. This occurs due to the tidal flow inundating the forest encountering drag force from the vegetation as described in the next section. Accordingly, long term changes in vegetation density in wide mangrove forests should have impacted on tidal flow in the rivers.

Water flow depending on the mangrove vegetation density

Mazda et al. (1995) have discussed the dependency of tidal flow in R-type mangal on the vegetation density of mangroves. Figure 8 shows the results of the numerical experiment for various drag coefficients in the flood plain in Model B, highlighting the amount of flood water over the mangrove forests during one tidal period. Case B1 is the case without vegetation on the flood plain ($\gamma^2 = 0.0026$). Case B4 is for $\gamma^2 = 4.0$ which corresponds to natural vegetation conditions (Mazda et al., 1999a). Cases B2 and B3 are for $\gamma^2 = 0.2$ and 1.0, respectively, which lie between Cases B1 and B4. As seen in the figure, the amount of water inundation on the flood plain changes with the drag coefficient, i.e. the vegetation density (Mazda et al., 1997b). This finding suggests that the magnitude of tidal flows in the Mui Nai River/Nga Bay River, and in turn, the current velocity along the coast neighboring these rivers, has changed gradually according to the transition of mangrove vegetation in this area since the late 19th century.

Conclusion and remarks

Mechanism of coastal erosion on the Long Hoa coast

The existence of wide mangrove forests, which floods in tidal cycles, impacts on the strong tidal flows in the mouths of the Mui Nai River/Nga Bay River. These strong tidal flows move bottom sediments along the coast of Long Hoa neighboring the river mouths. This is the first necessary condition causing coastal erosion in this area. In addition, changes in mangrove vegetation density due to human intervention have prevented the amplitude of tidal flows from becoming steady. This is the second coastal erosion condition. Due to these two conditions, long-term transitional coastal

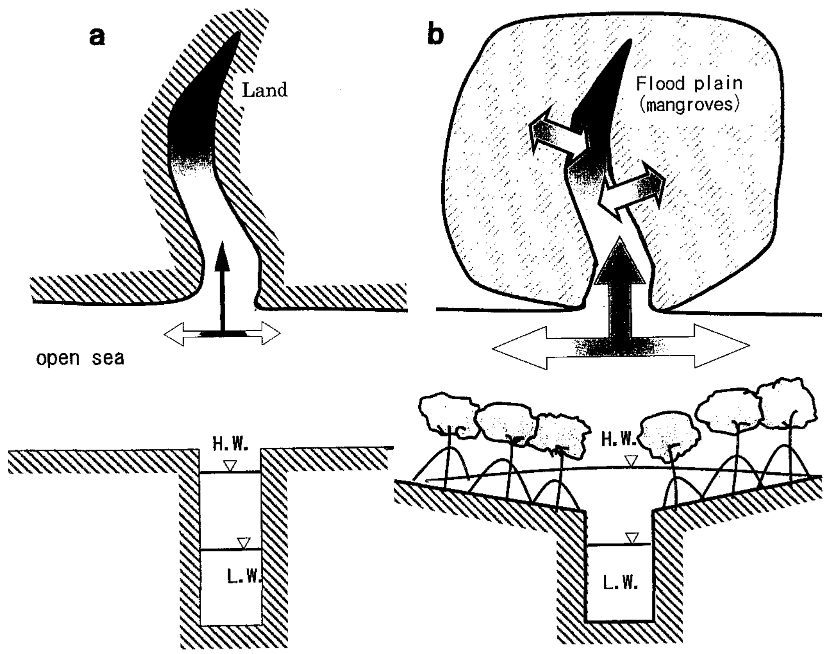

Figure 5. Schematic views of tidal river with/without flood plains and tidal flows around the river mouth.

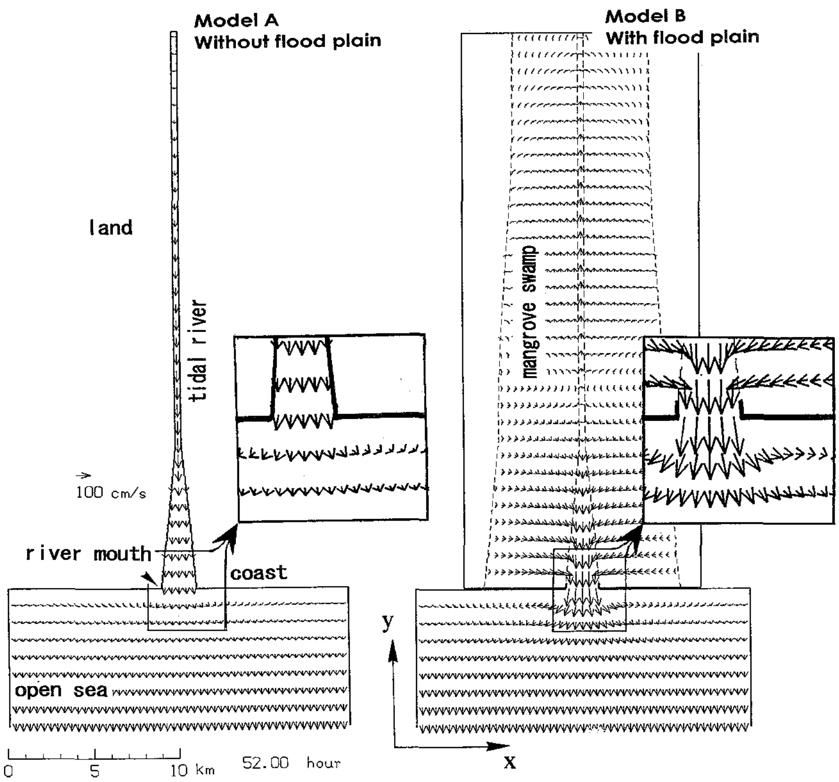

Figure 6. Velocity distributions in Models A and B. The velocity vectors show the distributions at a tidal phase when the velocity at the river mouth is at its peak value (see Figure 7 for the tidal phase). This is the case with no vegetation in the flood plain (i.e. both of the drag coefficients in the flood plain and in the river are $\gamma^2 = 0.0026$). left: Model A without flood plain; right: Model B with flood plain.

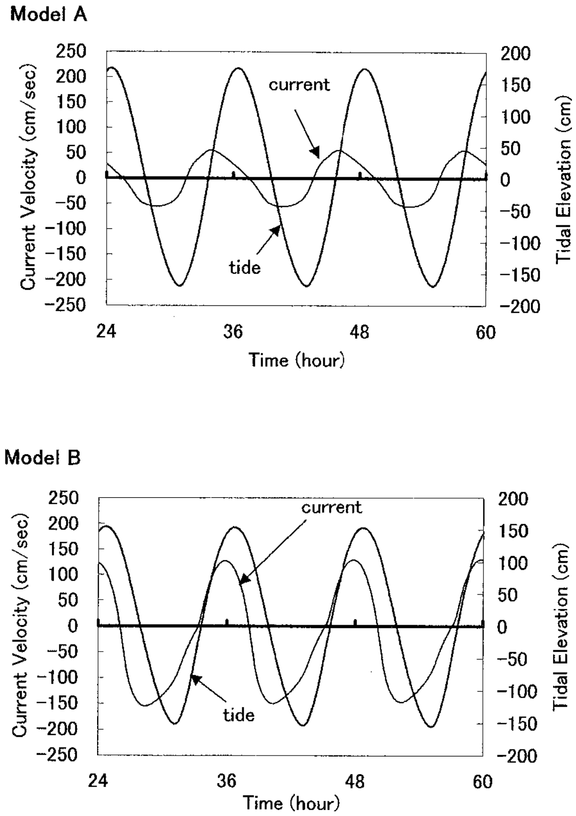

Figure 7. Tidal flows and tidal levels at the river mouth in Models A and B. This is the case with no vegetation in the flood plains.

erosion is still occurring in this area. However, it is not simply a matter of whether the coastal erosion is caused by cutting or reforesting the mangroves because the erosion and accumulation also depend on various delicate changes in the topography of the coast floor.

Coastal erosion due to indirect human impact

According to Cintron and Novelli (1984), mangrove forests are divided into three types; the riverine forest type (R-type mangal; this forest is found on a flood plain along a tidal river, and is inundated by most high tides), the fringe forest type (F-type mangal; this forest is directly exposed to the open sea, and thus attacked by sea waves), and the basin forest type (B-type mangal; this forest is a partially impounded depression, thus it is inundated by few high tides during the dry season, and by high tides during the wet season). It is well known that coasts in deforested F-type mangals are severely eroded by sea waves. The hydrodynamic functions of F-type mangal preventing coastal erosion due to sea waves have been analyzed by Furukawa and Wolanski (1996), Mazda et al. (1997a) and Massel et al. (1999). The R-type mechanism stated in this paper is an important new addition to understanding coastal erosion. In the case highlighted here, the erosion is not due to wave action, but to tidal forces. Further, notwithstanding that the eroded coast does not have direct contact with mangrove swamps (R-type mangals), it is strongly affected by the existence of mangrove swamps through the intermediation of the tidal rivers neighboring the coast. In other words, not only the deforestation of the F-type mangal, but also the deforestation of the R-type mangal (which doesn't have contact with the open sea) causes coastal erosion. This suggests that to prevent coastal erosion, it is important to manage human interactions in the background (or inland) area more sensitively.

Within the next 100 years, the sea level is expected to rise 60cms on a global scale. As this occurs, many coastal areas, even those without mangroves, may suffer a similar fate as that described in this paper.

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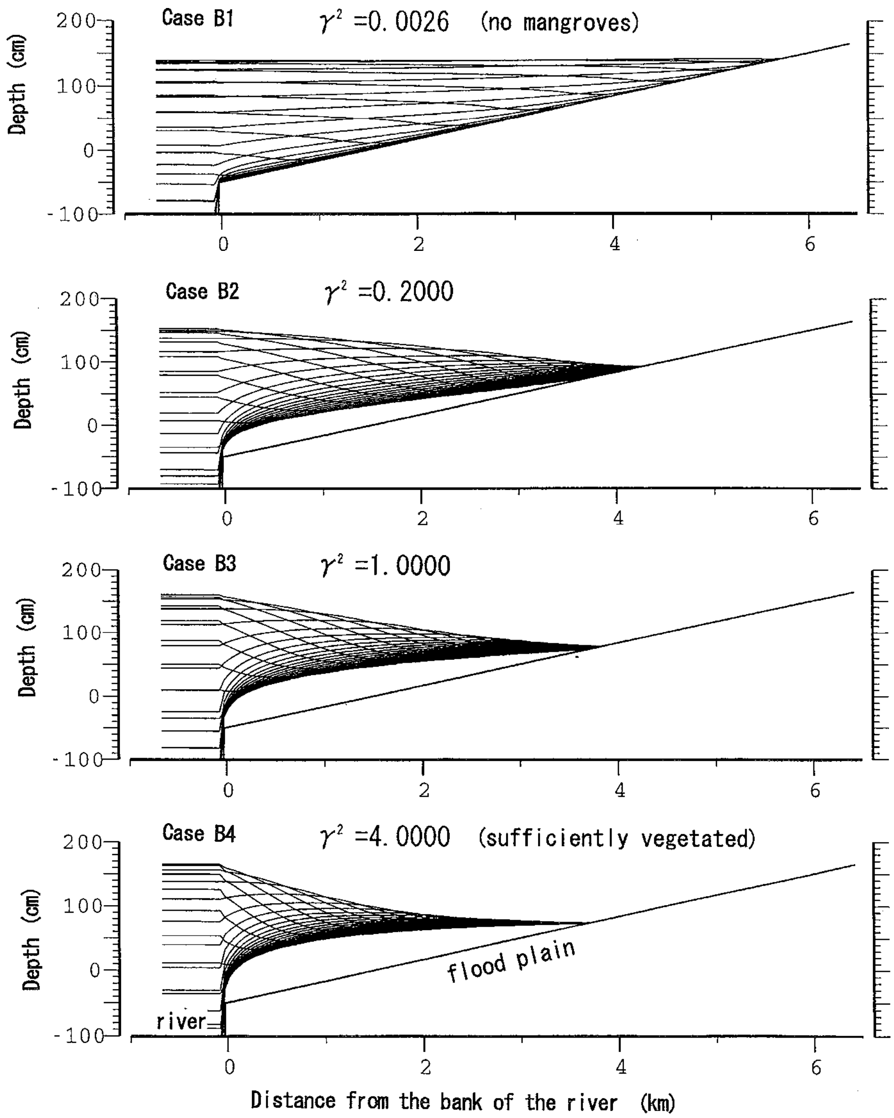

Figure 8. Tidal changes of the water surface along a line perpendicular to the river bank between the center of the river and the head of the flood plain. Curves drawn in each case show the water surfaces with 0.5 hour intervals in one tidal cycle. Differences of the pattern between Cases B1 to B4 are due to the magnitude of the drag coefficient γ^2 in the flood plain (see the text).

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