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Original Paper

STRATEGIES FOR MANGROVE REHABILITATION IN AN ERODED COASTLINE OF *SELANGOR*, PENINSULAR *MALAYSIA*

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ABSTRACT

Continuous mangrove ecosystem degradation and coastal erosion is observed along the coastline of Sungai Haji Dorani, (N 03^{0}38'36.6"; E 101^{0}00'37.3" to N 03^{0}38'37.9"; E 101^{0}00'34.0") Selangor, Peninsular Malaysia. Foreshore mangrove plantation challenges below mean sea level are in progress in this high energy coast. There are interventions of gabion breakwaters and geo-textile tubes to alleviate the wave velocity striking the shore. The area between the breakwaters and coastline is chosen for mangrove plantation. The soil is fluid silt sludge with average clay, silt and sand proportion of 43.03 %, 351.8 % and 5.14 % respectively. The maximum height of the tide recorded onshore was 2.8 m and in the middle of the plantation area the height of the water flooding is ±3.5 daily during tides. Number of plant species on the SAUH concrete revetment is 43 with 12 mangrove species and on the fringe reference mangroves is 27 with 8 true mangrove species. This paper explains the method to identify the potential location for mangrove rehabilitation, possibility of establishing mangroves on the seafront in the chosen area and conservation of the existing strip with 14 mangrove species. Overall sediment accretion since May 2008 is ±0.0037cm per annum which is considerably negligible. Opening out the earthen bunds along the coastline is the actual solution for natural mangrove translocation and stabilization in this particular coastline, however, it is not practically possible. Hence, we have studied an alternative strategy of rehabilitating mangroves at the elevation of +0.5 m to 1m MSL along this shoreline and also in an engineered firm sediment filled zone. We propose carrying out hydrological restoration in the natural habitats for survival and further natural colonization of mangroves.

Keyword: eroded coastline – rehabilitation – mangrove – hydrology

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INTRODUCTION

The purpose of establishing mangroves varies like ecological green belts, economically valuable forest cover, coastal habitat rehabilitation, erosion mitigation, aquaculture effluent treatment and integrated mangrove shrimp farming as in Perunthottam, India (Oswin and Ali-Hussain, 2001). However, the lack of success of mangrove plantation attempts all over the globe underscores the misunderstanding about the mangrove ecosystem functions and autecology of species (Lewis 2005). The earlier attempts at mangrove restoration in many countries met with mixed results with some being successful, while others were doomed from start (Field, 1996 and Erftemeijer and Lewis 1999). Most of the attempts were not based on well understood principles and well defined aims (Bosire *et al*., 2008). In Malaysia, government agencies have joined hands to replant the eroded coastline of Sg. Hj. Dorani, Selangor. In this endeavor both soft and hard engineering technologies were designed and applied. Initial step of wave breaking by University of Malaya (UM) has been tried though installing the L-Block Breakwater (Roslan, 2006) in 2008. Extension of the same in length is also in action which would have a major implication in the sediment settlement pattern along the coastline and survival of the existing mangrove patch. Geo-textile tubes as breakwater has been laid by Forest Research Institute of Malaya (FRIM) in 2006. However, to our understanding there is no indicator parameters fixed or studied to measure the actual effect of both structures in terms of coastal erosion mitigation. As per our observation, these structures in fact induce erosion and destabilize sediment, affecting the meager natural fringe mangrove stand on the coastline. The mangrove plantation site is a stretch of fluid silt sludge. However, further research has to be made before embarking mangrove plantation below mean sea level. After a thorough observation of the ecosystem functioning in this coast, we intend to exemplify the feasibility of mangrove growth along this eroded coastline. This paper will substantiate the potential criteria needed for mangrove rehabilitation and would help the hard engineering technologists to understand and provide a suitable engineered area for mangrove establishment.

MATERIALS AND METHODS

Sungai Haji Doraini is situated in Sungai Besar a coastal town in the district of *Sabak Bernam* in *Selangor, Malaysia* (**Fig 1**.). It is situated to the northwest of Selangor. Coastal bunds were built during the years 1932-42 for land reclamation and agriculture extension. Recent developments like resorts and jetties have altered the land use pattern permanently, which has led to further degradation. Proposed mangrove plantation site is (N 03^{0}38'36.6"; E 101^{0}00'37.3" to N 03^{0}38'37.9"; E 101^{0}00'34.0") a narrow strip of coastline with no apparent mangroves at present. However, on both southeast and northwest sides of the plantation site narrow strips of mangrove fringes do occur. Geo textile tubes and L-Block gabion Breakwater (**Fig.2**) were installed in the sea to arrest direct impact of waves on the coast and Department of Irrigation and Drainage (DID) has also constructed SAUH concrete amour units in the year 1991 for a distance of 1.5 km on the coastal bank.

We measured the tidal flooding and topographical elevation of the coastline and reference mangroves using stakes.

We surveyed the vegetation diversity on the revetment and on the reference forests on both sides of the site by standard ecological methods in 80 (20x5m) random plots along the proposed site.

Floral diversity in the reference forest was also assessed in 10 (20x5m) plots in 200m natural forest belt as these are the forest in future would supply seeds for regeneration and rehabilitation of the coast.

Species composition, density, richness and evenness were analyzed using Shannon-Wiener Index. Species density, richness and evenness of plant communities influence the productivity of the ecosystem.

Sediment accretion (Kamali, personal communication) in the plantation area and sediment texture analyzed using L S. Particle Size Analyzer, Beckman Coulter LS 13 320 (Yuyin, personal communication) data was obtained from the researchers working on site.

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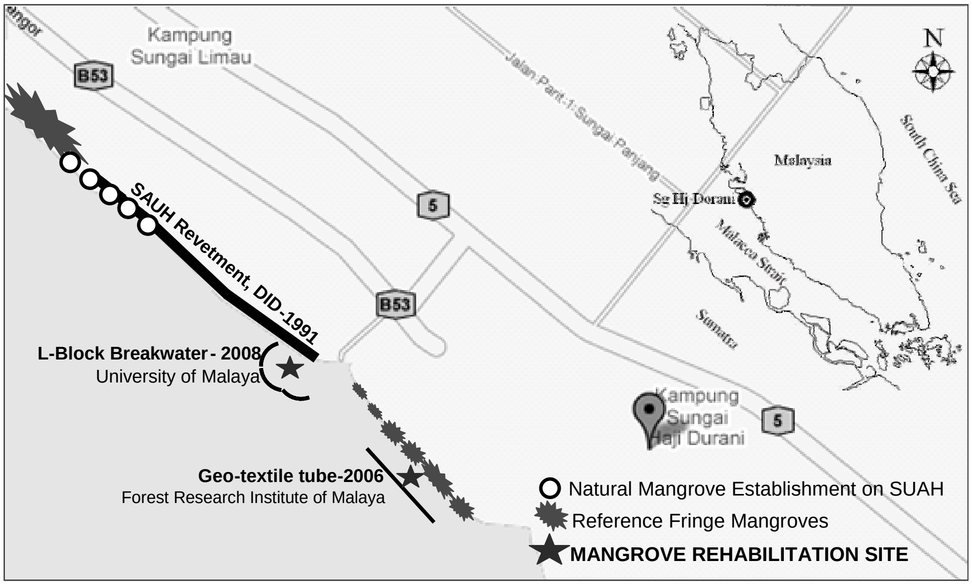

Fig. 1 Map showing the Mangrove Plantation Sites at Sg.Hj.Dorani, Peninsular Malaysia

RESULTS AND DISCUSSION

Identifying the mangrove supporting zone in the inter-tidal area is a challenge before implementing the strategy of plantation. On a spring tide day, the points at which the spring high tide reaches and falls may be marked with a stake, where we arrive at an idea of the breadth of inter tidal zone. The differences in height at the ground level give an idea of the elevation. This is perhaps to be monitored continuously to identify the area without error. The distance between these two points may be divided into tentative three parts as high tidal zone, mid tidal zone and low tidal zone. The high tidal zone is the area which is flushed during the spring high tide and one or two days before and after spring tide. The area which is flushed daily is the low tide area. The low tidal zone where tidal amplitude and wave action are high cannot be considered for mangrove establishment. Mid tidal zone is the potential zone for mangrove rehabilitation. Yet many other factors including sediment texture, substratum and seed limitation would ultimately determine the possibility of mangrove rehabilitation. Considering the topography of the reference forest would assist in locating the potential area for mangrove restoration and species diversity and zonation would help choosing the right species. However, inter tidal zone alone is not the criteria; it should include several appropriate and supportive micro-macro climatic conditions of a mangrove habitat for mangrove rehabilitation.

Hydrology and substratum are the major aspects which offer reference for designing the plan, select species and zone for mangrove rehabilitation. The tides are semi diurnal in Sg. Hj. Dorani with two high waters and two low waters each day. The maximum and minimum tidal variations recorded at Sg Hj Dorani during 2008 are MSL=2.17 m; MHHW=3.40 m; MLLW= 0.6 m (MSL: Mean Sea Level, MHHW: Mean Higher High Water MLLW: Mean Lower Low Water). The maximum height of the tide recorded on the shoreline of the mangrove plantation site was 2.8 m and the tide is up to 2m onshore everyday submerging the L Block breakwater. However, in the middle of the plantation area the height of the waters is ±3.5 daily during tides.

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Mangroves cannot survive below mean sea level, submergence and loose sediment substratum with high energy waves striking the flanking coast. From our measurements it is proved that the reference forest on southeast and northwest sides is ±0.5 to 1.5m topographically higher than the proposed plantation area. The site falls in below the mean sea level which is known to be an elevation that mangroves do not normally grow at worldwide (Lewis 2005).

Species like *Avicennia* prefers a firm substratum hard enough to walk on for example. The soil texture in the mangrove plantation site at Sg. Hj. Dorani showed high silt bound sediment. The average clay, silt and sand proportion (Yuyin, Personal communication) during the seven months from November 2008 to May 2009 is 43.03 %, 351.8 % and 5.14 % respectively and excessive silt dominance confirms the erratic dynamism of the coast. Predominant preference of clay loam soil by *Avicennia marina*, *A. alba*, *Rhizophora apiculata*, *R. mucronata*, *Aegiceros corniculatum*, *Bruguiera gymnorrhiza* in Java (Sukardjo 1989) and Silt clay by *Avicennia marina* and *Aegiceros corniculatum* in Muthupet mangroves, India (Oswin 1998) is reported earlier. In Pichavaram estuarine mangroves of India, luxuriant mixed mangrove stand prevailed in silt clay soil with high water holding capacity and moisture content (Kathiresan, 2002).

The tidal range in the coast is below 20m and restricted by the SAUH revetment. The actual differences in ground surface elevations within the proposed plantation area and the existing reference mangroves are ±0.5 to 1.5m lower than sea level. It can be readily inferred that the natural reference forest area lying topographically higher and the elevation above 0.5m MSL can only support mangrove survival and growth. There is a zone between the reference markers (seaward to landward) + 0.5 to 1m MSL that would be ideal for mangroves, if the sediment is stable (not really soft mud). A similar potential zone with elevations ranging from +0.5 to 1m MSL is present on the revetment in the proposed plantation site, but it is very limited in extent and does not have suitable low energy consolidated sediments. The only answer is to provide good consolidated fill between the breakwater and shoreline, an expensive proposition to be sure.

Wave velocity is tremendously high and SAUH revetment positively aid in mitigating the force of waves hitting the coastline. The substratum between the breakwater and the SAUH revetment is extremely muddy and during the tidal inundation it becomes 2 m deep fluid mud. Structures like poles and sticks planted for plot demarcation are often lost due to floatation during tides. The depth of muddy sediment during the low tides is above 1 m (**Fig 3**). The recorded sea level change during the years from 1961 to 2003 is 1.8mm/yr; 1993 to 2003 is 3.1 mm/yr and 1986 to 2006 is 1.25mm/yr (DID, 2007). The subsequent sea level rise also would render more submergence of the area. The possibility of mangrove translocation landwards adjusting the natural change is however restricted by the earthen bund creating a frontier to the existing narrow fringe of mangroves.

Natural Vegetation along the coast in the reference ecosystem on both sides southeast and northwest sides of the plantation site have the species composed of mangroves and terrestrial associates. The vegetation structure depicts a total of fourteen (14) mangrove species namely *Avicennia marina, A. alba, A. officinalis*, *Bruguiera cylindrica, Aegiceras corniculatum, Lumnitzera racemosa, Soneratia ceseolaris, Xylocarpus molluccencis, Scyphiphora hydrophyllacea, Nypa sp, Excoecaria agallocha, Rhizophoracea mucronata, Sesuvium portulacastrum* and *Achrosticum aureum* the mangrove fern and 36 (thirty six) identified associated flora dominated by species such as

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Thespesia populnea, Caesalpinia bonduc, Cocus nucifera, Leucaena leucocephala, Scaevola taccada, Tamarindus indicus, Paspalum distichum, Bidens pilosa, Ruellia tuberosa, Cyperus odoratus and Chloris barbata.. The vegetation is of the open accreting shores where, the pioneers are *Avicennia marina* and *A. alba* followed by *Bruguiera cylindrica* with limited species diversity, density, compact substratum, disrupted internal drainage and regular loads of wave washed sand, shells or calcareous deposition (**Fig. 4**). The vegetation on the 1500m SAUH revetment accounts 43 species of plants including 12 species of mangroves (*Avicennia marina, A. alba, A. officinalis, Bruguiera cylindrica, Aegiceras corniculatum, Lumnitzera racemosa, Soneratia ceseolaris, Xylocarpus molluccencis, Scyphiphora hydrophyllacea, Excoecaria agallocha, Rhizophoracea mucronata* and *Sesuvium portulacastrum*). The species density, evenness and richness in the overall concrete revetment are -2.62, -0.7 and 5.39 respectively. In the reference fringe forest with 27 plant species including 8 mangrove species (*Avicennia marina, A. alba, A. officinalis, Bruguiera cylindrica, Xylocarpus molluccencis, Nypa sp, Excoecaria agallocha, Sesuvium portulacastrum* and *Achrosticum aureum*) the species density, evenness and richness is -2.54, -0.31 and 3.76 respectively. The naturally established vegetation on the SAUH coastal concrete revetment represents maximum species diversity and density in terms of mangroves and associates than the reference forest which is in the verge of degradation (**Fig. 5**). The rich plant diversity proves that SUAH concrete revetment is efficiently contributing to biodiversity enhancement and erosion mitigation.

Diversity is a function of species richness and of species evenness. Plant species richness is thought to influence primary productivity and other ecosystem processes via mechanisms that favor species with particular traits (non-complementarity) and promote niche differentiation or facilitation between species (complementarity) (Tilman *et al.*, 1997; Loreau 1998, 2000, Wayne *et al*., 2003). Species richness determines the range of trait variation present in a plant community (Tilman *et al.*, 1997; Loreau 2000). Evenness and plant density may influence the expression of this variation by defining its relative distribution among plants and the intensity of plant–plant interactions. Decline in diversity would threaten the productivity of any ecosystem.

The reference forests on both sides are filled with rotting wood, plastics and litter; the area opposite to Geo-structure pillow tube accumulates the majority of the litter consisting of poly bags, tins, cans, damaged or broken wooden poles and supports, coir-logs (from several previous planting attempts which failed), uprooted trees, etc. Clearing litter would enable tidal flushing and revival of tidal flow in the entire area and future survival of the existing mangroves in the east. At present in many locations the seeds/propagule which falls from the mother tree has to fall in the dry to semi-dry land with litter where there is limited to no chance for germination and further growth. The reference forest next to the D'Muara Resort and opposite to Forest Research Institute of Malaysia (FRIM) is flooded and waterlogged.

There is no outlet for the water to drain from mangroves and hence the mangroves are dying. The fate of the existing mangroves, the speed of degradation and ignorance or negligence in conserving the existing natural resource is substantiated in the **Fig. 6 and Fig. 6a**. Unless the hydrology of that area is restored there will not be any mangroves in near future either to protect the shoreline or to provide seeds for future forest establishment. Differential survival and growth of mangrove species studied to date are related to the depth, duration and frequency of flooding and soil .

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Fig 4. Photograph showing the calcareous deposits on the shore and revetment indicating current erosion and littoral drift

Fig. 5 Photograph showing the effect of coastal erosion on the fringe mangroves – the reference forest patch available to understand the natural vegetation profile is at the verge of extinction

saturation (*Nickerson and Thibodeau (1985), McKee and Mendelssohn (1988), McKee (1993), McKee (1995),* and *McKee and Faulkner (2000a, b)* . Ultimately, the critical periods of inundation and dryness govern the health of the forest (*Kjerfve, 1990*). For these reasons, any engineering works constructed near mangrove forests, or in the watershed that drains to mangroves, must be designed to allow for sufficient free exchange of seawater with the adjacent ocean or estuary, and not interrupt essential upland or riverine drainage into the mangrove forest. Failure to properly account for these essential inputs and exchange of water will result in stress and possible death of the forest.

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There is a site specific erosion and deposition occurring along the Sg. Hj Dorani coast due to construction of resort and installation of engineering structures like Geo Textile Tubes and L Block Breakwater. After the construction of breakwater in May 2008, the sediment accretion is ±0.0037cm per annum which is considerably negligible in dynamic patches (Kamali, Personal communication) in mud flat where plantation is carried out (Fig 7&7a). The presence of the large grain size shell hash along the coast indicates that the shoreline is still experiencing some major wave and current erosion. The area prior to the breakwaters being installed was quite deep and has collected fine grain mud over time with the reduced wave action. Along the coastline curvature in few locations sand deposition is observed towards landward side, which fragments mangroves for a small distance up to 100 to 150m. Damage to the mangroves strongly affects sediment budgets and promotes coastal erosion (Kamaludin and Woodrofee, 1993). The eroded sediments may cause further damage to the mangroves. For example, Young and Harvey (1996) showed that sediment accretion interferes with root aeration in *Avicennia marina var. australasica*. Similarly, movements of sand in mangroves habitats on Portuguese Island, Moszambique have caused high mortality of *Ceriops tagal*. This has altered the mangrove species composition and depleted the crustaceans and mollusks from the mangroves (Hatton and Couto, 1992). The proposed plantation site is experiencing sand erosion that is deposited to the sides, but it could be more complicated than that. Certainly, where sand accumulates to the right elevation (east), mangroves colonize. Where it does not accumulate or erodes, the elevation is too low and hence volunteer mangroves do not exist and planting or replanting will not overcome this limitation.

Attempts of installation of a geo-fabric tube (about two meters in diameter and a hundred meters long) filled with sand followed with subsequent plantation in an exposed mudflat located near Pulau Sayap in the State of Kedah by the Forestry Department and the Forest Research Institute Malaysia has failed earlier. The geotube was located just above the lowest tide mark, parallel to the shore. The reason for the installation of this geotube was to form a barrier to break the on-shore waves as well as encourage sedimentation on the shoreward side of the tube. The use of this rather expensive (~$75,000 per 100 meters) geotube has been described by Chan (2008). Another observation was that there was apparently no significant increase in sedimentation on the shoreward side of the geo-tube or any reduction in relative sea-level (Tan and Ong, 2008). However, repeated trials of the same method in many other locations of Malaysia are surprising.

Lewis (2005) noted the importance of assessing the existing hydrology of natural mangrove ecosystems, and applying this knowledge to first protect existing mangroves, and second to achieve successful and cost-effective ecological restoration, if needed. He also states that research has documented the general principle that mangrove forests worldwide exist largely in a raised and sloped platform above mean sea level, and inundated at approximately 30%, or less of the time by tidal waters. More frequent flooding causes stress and death of these tree species. Prevention of such damage requires an understanding of the mangrove hydrology of a particular area. The processes involved are complicated and no single factor applies to all mangrove zones, but observations and data collection across transects through mangroves from low to higher elevations indicate that the higher-elevations sites were infrequently flooded over the soil surface, whereas the lower elevation sites near the shoreline were inundated twice daily.

Tidal amplitude and water velocity decreased strongly with increase in distance

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Fig. 6. Photograph showing the water-logging, drying and loss of mangroves in June 2009 in front of FRIM's mangrove plantation site substantiating ignorance to conserve existing mangroves

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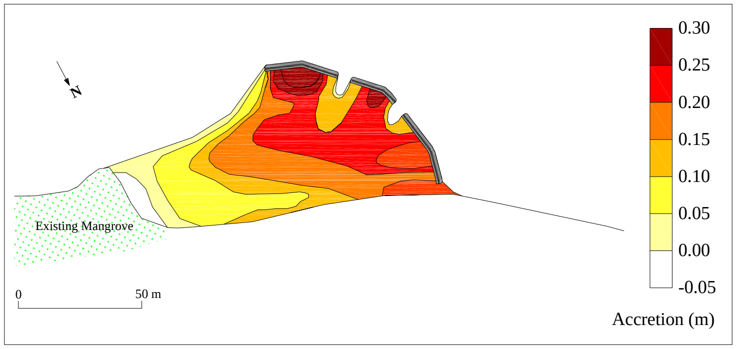

Fig 7. Rate of Sediment accretion at the mangrove plantation site in October 2008, 4th month after construction of L Block Break water

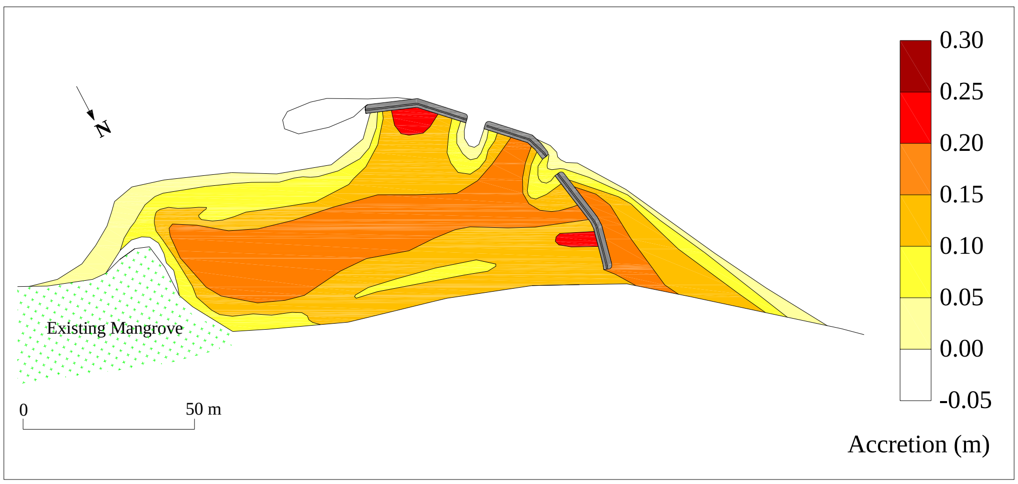

Fig 7.a. Rate of Sediment accretion at the mangrove plantation site in February 2009, 8th month after construction of L Block Break

from the shoreline and lead to restricted water movement and incomplete drainage of interior areas. In such areas narrow matrix of water channels and the area with proper inclination for drainage may be given. In examining the correlation of measured environmental variables across transects with different dominant species of mangroves, Lewis (2005) confirms that, flooding "had a high negative loading of relative elevation and a high positive loading of sulfide and in such cases constructing channels would be beneficial. Sulfide tends to accumulate in waterlogged soils, a process that is promoted in low elevation areas where water levels may not fall below the soil surface during a tidal cycle. The point of all of this is that flooding depth, duration and frequency are critical factors in the survival of both mangrove seedlings and mature trees.

The single most important factor in designing a successful mangrove restoration

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project is determining the normal hydrology (depth, duration and frequency, and of tidal flooding) of existing natural mangrove plant communities (a reference site) in the area in which you wish to do restoration. Vivian-Smith (2001) and Sullivan (2001) for example recommended the use of a reference tidal marsh for restoration planning and design. Mangrove planting for coastal management has two major ecological concerns i) mangrove species – site incompatibility and ii) the conversion of other habitats, particularly mudflats, sand flats and sea grass beds in to mono specific plantations (Erftemeijer and Lewis 2000). These mud flat, sand flat and sea grass beds are usually located at sea fronts (and thus exposed to stronger mechanical wind stress and wave action) and are frequently within the low inter tidal zone (Samson and Rollon, 2008). These are areas often mistaken as potential sites for mangrove plantation and chosen wrongly for habitat conversion and thus failure.

CONCLUSION

Health of the existing mangrove forest is crucial in coastal rehabilitation planning. Collection of established seedlings from underneath the parent trees to develop coir logs or similar experimental techniques may be avoided. Perhaps seeds during the seed fall season be used to develop nursery, because extensive seedling removal from the natural establishment is detrimental to the future of existing mangroves. The reference forests along the coast need to be restored prior to plantation activities. The site selected below the mean sea level with high flooding and wave velocity would neither sustain plantation nor support mangroves. It is meant to be a mud flat during low tides, as the sediment structure, tidal energy and the topography confirms the fact. In this coast, mangroves have started moving to occupy different locations as the original hydrology and topography has been modified. The process of sediment loading has been altered and the shore line is in a transitional shift. Beach nourishment activity in the shoreline by resort developers will have major implications. Planting mangroves on the proposed site between the breakwaters and coast need to be reconsidered with viable alternatives. Such expensive and labor intensive mangrove plantation efforts are going to offer little ecological gains (Samson and Rollon, 2008) as they are unlikely to succeed. The reference mangroves on both sides of the coastline are yet not fragmented greatly and efforts could be made to facilitate hydrology and elevation. Therefore, the possibility of seed provision for natural rehabilitation on the coastline would increase. The ultimate success of the rehabilitation efforts and survival of the rehabilitated vegetation depends on the understanding of the ecosystem and prioritizing the conservation strategies based on the most current ecological mangrove restoration science. To us intuitively, the best way to ensure seafront mangroves exist is to deal well with land use issues inland the mangrove ecosystem as a whole. Establishing only a thin coastal green belt where mangroves have disappeared and coastal geomorphology altered is source consuming endeavor that will fail more than succeed. Knowledge of the routes and rates of littoral drift is a prerequisite to predict the probable effects of near shore engineering structures on the maintenance of the coastal stretch. A case study needs to be designed to study the prevailing littoral drift to delimit the long-term patterns of erosion and accretion in order. Complicated shoreline littoral drift patterns are in play that makes it difficult to have the complete prospect of this particular coastal belt. But, as of now the proposed site may not support mangrove plantation unless it is engineered simulating the natural forests

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topographical elevation and with firm sediment substratum.

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