Report

Study of Coastal Mangrove Forest Devastation and Channel Sedimentation: Community-based Solutions Koh Kong Province, Cambodia

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Contents

1. Executive Summary

Mangrove ecosystems provide invaluable protection from climate change impacts and create an environment in which communities can build coastal resilience. They are situated at the interface of ocean water and freshwater sources, where the stable flow of sediment and freshwater allows mangrove forests and associated livelihoods to thrive. One of the largest mangrove forests in Southeast Asia is located in Peam Krasaop Wildlife Sanctuary of Koh Kong Province, Cambodia. It is supported by a 4-km coastal beach barrier and four rivers that are its lifelines.

The sandy beach barrier offers an irreplaceable level of protection to mangrove forests and settlements from coastal hazards, wave energy, and excess saltwater. However, this beach barrier has seen unprecedented rates of landward migration. Since 1973 the beach barrier has moved 390 m, resulting in the loss of 0.60 km^2 of mangrove forest. Migration is accelerating, and the southern portion of the barrier, which shelters the fishing village of Bang Krassop from high wave energy, reached landward migration rates of 90 m per year between 2010 and 2011.

Extensive river sand mining in all nearby rivers since 2008 and dam construction since 2010 is correlated in time with increased rates of beach barrier migration. This has dramatically altered the natural steady flow of sand from rivers to the beach barrier. Over approximately the next 20 years, sediment supply reductions to beaches from upstream sand mining and dam construction will cause further erosion and beach barrier migration, even after the sand mining activities end.

Sediment analyses and ocean current field studies indicate that the Koh Por River provides the most sediment to the beach barrier. Activities in the Koh Por River that alter sand supply to the beach barrier will have the most pronounced impacts on mangrove forest loss associated with beach barrier migration. Sea level rise and changing storm frequency patterns will also continue to contribute to the rapid beach barrier changes.

Sand mining has severely reduced the volume of river sand that stabilizes river banks upstream of the beach barrier. Erosion and river bank collapses have displaced families and caused the loss of hundreds of riparian trees, where river widening has reached 100 m. Dam construction in the Tatai River has increased river turbidity over a 40 km stretch, and sand mining has destroyed fish habitats, resulting in a reduction of 70 - 90% in fish catches.

The Koh Kapik commune is down-current of the Tatai River and faces accelerated channel infilling, due to increased mud supply from dam construction and locally abandoned shrimp farms. Careful excavation strategies during the planned Koh Kapik channel dredging will reduce adverse impacts on the riparian mangrove trees. Excavating the outside of the channel bends during low tide and placing removed sediment on the inside of river bends to a minimal height up the mangrove roots will decrease re-sedimentation rates, which are expected to be 4 - 10 mm per year following excavation.

This study has established priority zones for rehabilitation on the beach barrier, based on beach barrier migration rate. Coastal features, including spits and unvegetated beaches within these priority zones are targeted for intervention. Revegetation of local plant species will prevent further landward migration of the beach barrier and protect livelihoods. During a provincial workshop held on 13 November 2012, community members discussed using these strategies. Alternative sand mining techniques were also described at the workshop, such as dredging away from the outside of river bends, which will reduce river bank collapses and even improve export sand quality.

This improved understanding of the highly connected sediment dynamics, coupled with rehabilitation and erosion prevention strategies, offers a pathway to protect livelihoods and build greater coastal resilience in Peam Krasaop Wildlife Sanctuary.

2. Introduction

Objectives

This study investigates rapid environmental degradation in Peam Krasaop Wildlife Sanctuary (PKWS) of Koh Kong Province, Cambodia (Figure 1) that is a result of accelerated changes in sediment transport dynamics. Livelihoods are threatened by:

i) Coastal mangrove forest devastation (Figure 2)
ii) Severe landward beach barrier migration (Figures 3 and 4)
iii) River bank erosion
iv) Koh Kapik channel infilling

These occurrences are all linked, due to the drift of sand, silt, and clay down-river and along coastal currents. The causes of the ecosystem disruption are inspected in this report and include:

- Sea level rise
- Sand mining
- Dam construction
- Changes in storm intensity
- Abandoned shrimp farms

The Koh Kapik commune of 2900 residents (Sar, 2012), located 12 km south of Koh Kong (Figure 1), both contributes to and is harmed by the impacts of altered sediment transport dynamics. Sedimentation of silt over time in the Koh Kapik channel (Figure 5) has resulted in substantial infilling, which impairs the ability of the community to use boats to support their fishing livelihoods, access drinking water, and escape coastal hazards under recognizable climate change impacts. These problems will be temporarily resolved by dredging, which is planned.

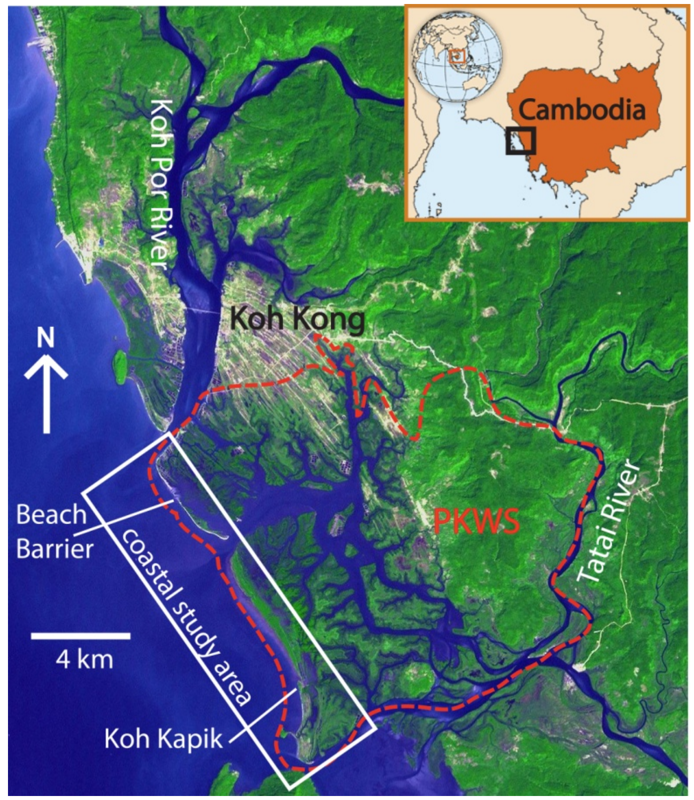

Figure 1: Satellite image of the broad study area, including impacted rivers, mangrove forests, and focused coastal study area (Terralook Landsat image taken 10 January 2002)

Figure 2: Dead trees that formerly thrived in the muddy mangrove environment prior to beach barrier migration.

Figure 3: Aerial photograph of trees stranded in the ocean water on the southern portion of the beach barrier, following beach barrier migration and erosion.

Figure 4: Aerial photograph of beach barrier captured 12 November 2012 by helicopter. The orange line represents the beach barrier location in 1994, during which time the beach was continuous without the current gap.

The state of Koh Kapik channel sedimentation is described and rehabilitation recommendations are provided in this report, including:

- Community sediment contributions
- Expected rates of sedimentation
- Dredging strategies

Study methodologies were both field-based and computer-based with ground-truth comparisons. This includes:

- Satellite analyses
- Scholarly scientific article reviews
- Sedimentary sequence analyses
- Sedimentary component analyses
- Water depth measurements
- Water and soil sampling
- Helicopter survey (courtesy Wildlife Alliance)
- Five community member interviews
- Discussions with local 2 local environmental organizations and 2 eco-lodges
- Multi-stakeholder provincial workshop
- Water usage survey of Koh Kapik (provided in subsequent document)

Figure 5: Koh Kapik channel. Due to infilling, dredging is planned and low-impact strategies should be used to minimimze re-sedimentation.

Significance

Livelihoods of the region, including Koh Kapik and Koh Kong, are heavily dependent on ecosystem health that supports fish habitats, coastal hazard protection, fresh drinking water, and ecotourism. The PKWS and conservation zoning within its boundaries (Figure 6) were established in order to support this natural resource management for sustainable use. It protects the largest mangrove forest in Cambodia, providing habitat to a variety of fish, crustacean, and shellfish species, on which many settlements are dependent (Nong, 2004, p. 1). In 1995 virtually no mangrove trees remained as a result of unregulated deforestation for charcoal production before the implementation of protection became successful in 1998 (Rann, 2012). Although illegal logging still takes place occasionally, conservation measures have progressively improved.

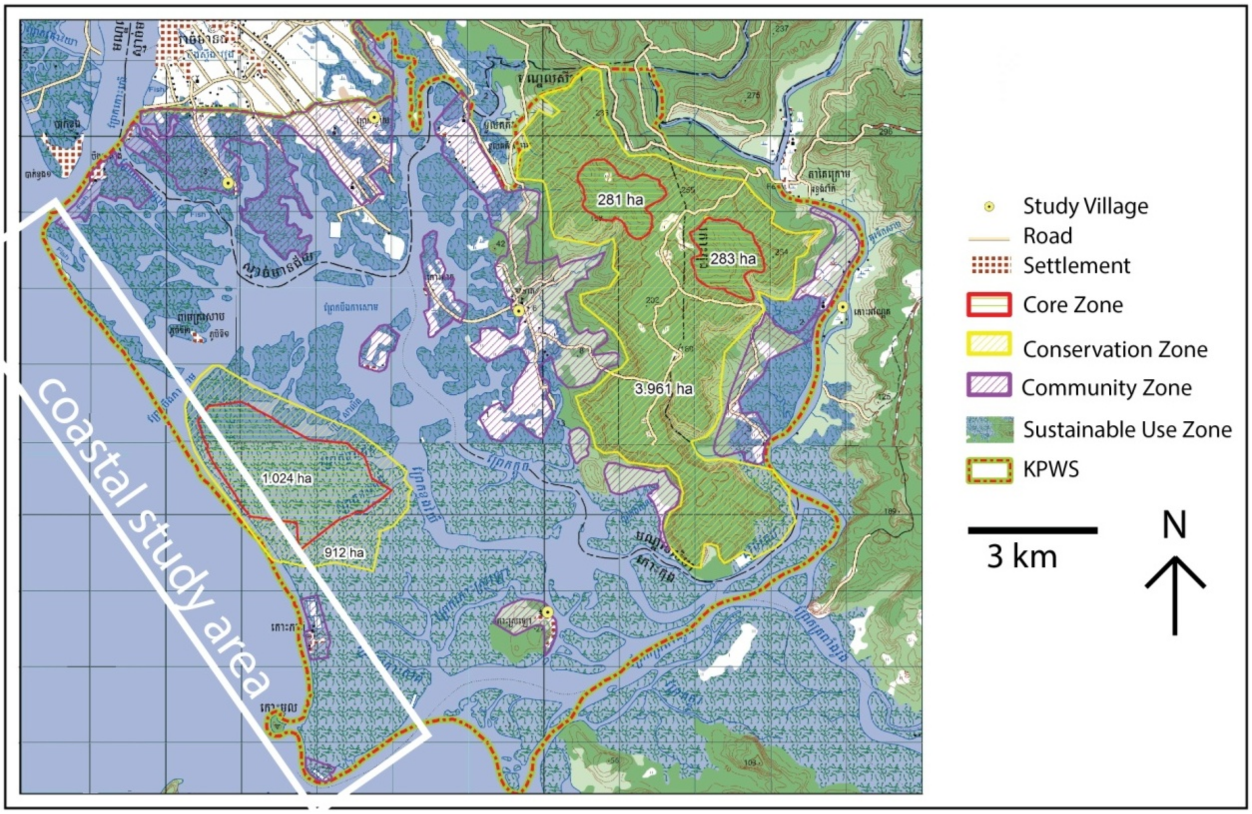

Figure 6: Schematic map of PKWS and conservation zoning (adapted from Kimsreng Kong and Kong Sun).

It is clear that great resources and human capital have been invested in the development of PKWS and conservation zoning. Challenges in zoning, however, exist in highly dynamic environments, such as coastlines where impacts in protected areas may be sourced from locations outside of the zoned areas. Ecosystem stability for livelihood prosperity in PKWS is threatened by the changes in sediment flow along the path from the upstream river sediment source to the coast. Optimal zoning would therefore consider the high connectivity of the ecosystem where critical areas upstream are protected from sediment extraction and erosion in order to prevent downstream and down-current environmental degradation.

Sediment dynamics in study area

The study area lies in a location where the physical foundation for ecosystem health is driven by the two main components of river output, including:

i) Freshwater flux
ii) Sediment availability

Freshwater flux

Firstly, mangroves require an optimized balance between freshwater and saltwater to thrive (Semeniuk, 1983, p. 11). The tropical climate of coastal Koh Kong Province, Cambodia provides sufficient rainfall. The unique intersection of multiple rivers in PKWS thereby creates a broad interface between the terrestrial freshwater and marine saltwater for mangrove proliferation.

Sediment availability

Secondly, mangroves require a shallow depth of water and a balanced, constant availability of sediment. Rivers are conveyer belts for the distribution of sediment, including sand, silt, and clay. Over time the output of sediment from up-river builds up, forming a shallow depth of water that extends towards the ocean. Mangrove forests trap sediment, and the trees require an amount of sediment that is neither inadequate nor excessive as not to starve nor smother the trees in sediment. Variability in sediment quantities derived upstream can therefore be harmful enough to kill vast areas of mangrove forests. The beach environment is particularly susceptible to causing this destruction because sand is less cohesive than mud and therefore more mobile. Rapid sand migration is often pronounced over short periods of time, which is the case in the study area's beach barrier.

Geology
The sandstone geology of Koh Kong province is the sediment source for rivers of the study area, naturally generating high volumes of sand that is transported to the coast (Caro and Sokrithy, 2012, p. 1456). Sporadic layers of siltstone are also found in the geology, generating silt and clay that is also transported to the coast.

Coastal sediment movement
Sediment naturally moves along coastlines through *longshore drift*, whereby waves and currents entrain and transport sediment then re-deposit it. Differences in wave energy available at various coastal features (Figure 7) leave some coastal features, such as lagoons with low wave energy, more conducive to mangrove growth. In coastal and river settings, vegetation grows according to intensity of wave energy and sediment size (i.e. gravel, sand, silt, clay). Mangroves prefer sediment finer than sand and relatively low wave energy in order to maintain root strength. They are therefore vulnerable when sand migrates into their environment.

Figure 7: A typical sandy beach barrier (left) and associated features. Vegetation flourishes on the mainland side due to protection by the beach barrier.

Beach Barriers as Mangrove Protection
Beaches are indicative of higher energy environments because sediment size is controlled by the intensity of wave energy by which the sediment is transported. Since mangroves are found between the mainland and ocean, where wave energy is high, beach barriers are critical for the protection of large mangroves areas (Figure 7).

The high wave energy environment of beach barriers allows the beach barrier to migrate over time. Such spatial shifts are expected in the long term in dynamic coastal environments. However, rapid spatial shifts in coastal features and mangrove habits may be caused by anthropogenic changes in sediment movement from up-current. Relative sea-level rise can cause beach barriers to migrate landwards (Leatherman, 1983, p. 415). This is due to either absolute sea-level rise or land subsidence.

The Koh Kong beach barrier is a typical feature, considering the ecosystem, climate, and high sediment availability. However, it is migrating landwards at an unprecedented rate. This study is therefore able to identify which anthropogenic variables, such as sand mining and development, are causing the beach barrier to migrate towards the mainland so rapidly. Lessons learned about the unique geography (natural and human) from this case study can be applied to other beach barrier environments to act as a manual for beach barrier management elsewhere.

3. Results: Environmental Degradation and Ecosystem Changes

Beach Barrier Migration

Key findings

- Maximum beach barrier migration landwards is 390 m between 1973 and 2011 (10.3 m per year)
- Mangrove forest loss due to beach barrier migration is 0.60 km^2 since 1973
- Migration rates progressively increased during four out of five periods since 1973
- The location of the most rapid landward migration is in the southern 1 km section of the beach barrier, reaching 90 m per year
- The most rapid rate of landward beach barrier migration has occurred during the most recent period, coincident with beach barrier erosion, increasing the exposure of Bang Krassop fishing village to coastal hazards
- Three priority zones for intervention to stabilize the beach barrier are identified (1.8 km of coastline), based on vegetation density and migration rate
- Unvegetated beaches and spits (down-current leading beach edges) are most important for rehabilitation

Interviews

Moderate storms during the wet season of 2011 were associated with the migration of the beach barrier (Figure 1). The storms were not thought to have been particularly strong, yet the impact was great. Strips of mangrove trees 1.2 km long with a width up to 40 m have been killed, due to the waves, suffocation by sand, and excessive salinity levels. The beach barrier was breached and concerns were raised that the exposure of the mangroves to high wave energy and mobilization of sand caused destruction of the protected mangroves.

New evidence from interviews with local environmental professionals and community members (Appendix A) suggests that the beach barrier has been migrating for at least the past 10 years. The remains of a concrete foundation for a shrimp farm, once on the landward side of the beach barrier, are now submerged by ocean water 20 m from the beach. Estimates indicate that the beach has migrated here a minimum of 100 m. Local fishermen also explain that mangroves once surrounded by only mud are now covered by over one m of sand.

Sedimentary sequence analyses

Layers of sand and silt were exposed by digging during this study on the beach barrier. Consistent millimeter-scale parallel layering, with decreasing silt content upwards, indicated progressive beach barrier migration (Figure 8). Preliminary interviews indicated that single storm effects may have caused large scale migration. However, the sedimentary analyses indicate that frequent storms, even mild storms, cause migration. The layering was similar at all locations, suggesting that the direction of landward movement is generally consistent along the length of the beach barrier.

Figure 8: Sedimentary sequences contain millimeter-scale laminations, decreasing in silt content upwards, which is indicative of progressive landward beach migration.

Sedimentary component analyses

Comparisons were made between the mineral components of sand collected from the estuary of Koh Por River 1 km south of the bridge, the beach barrier, and Tatai River 0.5 km north of Tatai (Figure 1) in order to constrain the source of beach barrier sediment. The estuary and beach barrier sediment are more similar in the proportion of quartz and feldspar crystals and have similar grain sizes. The absence of iron-oxide staining in the beach barrier sample that is present in the Tatai River sample, suggests that the Tatai river is not the primary source of sand for the beach barrier (Figure 9). This confirms southerly longshore drift. The iron-oxide staining is sourced from the Tatai dam construction.

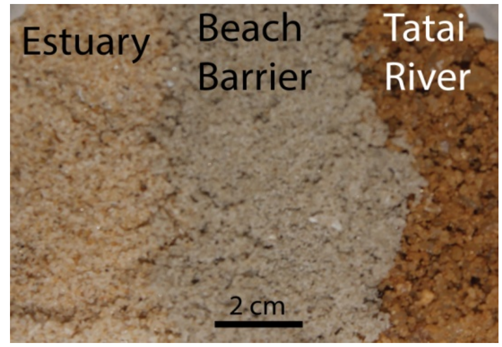

Figure 9: Componentry analysis reveals greater mineralogical similarities between the Koh Por esturary sand and the beach barrier sand, suggesting that the primary source of beach barrier sand is the Koh Por River.

Satellite image analysis
Terraspec Landsat satellite images from as far back as the year 1973 exist for the region and demonstrate changes in shape, length, width, continuity, and migration (Figure 10). Most notably the beach barrier has been divided into multiple sections through breaching events since 2002, while there is no evidence for this prior to 2002. A temporal trend in the increase in sand volume is recognized in the southeasterly direction. Seasonal variability can be excluded as an explanation for differences because all images were captured during the dry season when little geomorphic changes take place.

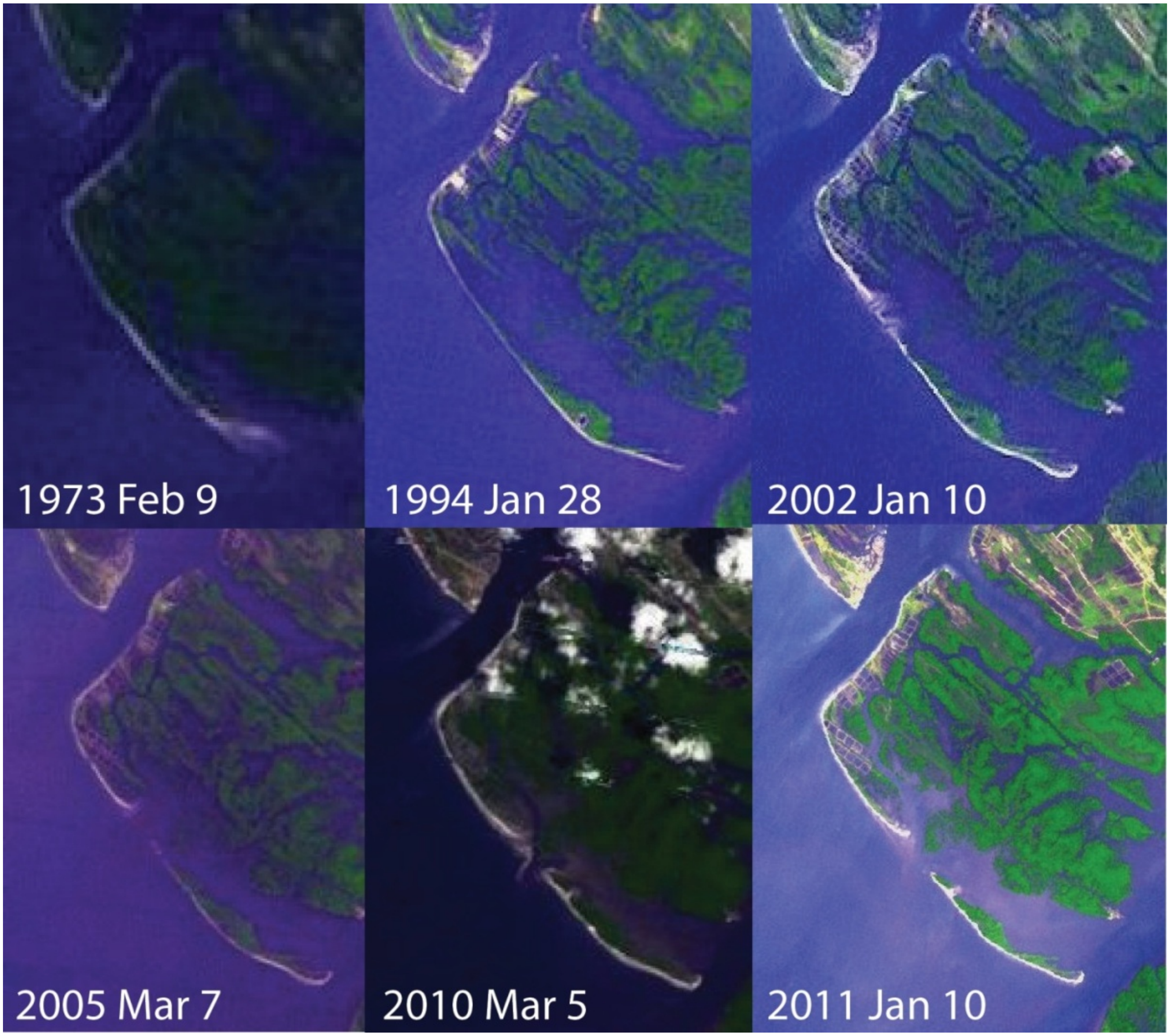

Figure 10: Satellite images (Terraspec Landsat) demonstrating beach barrier changes in morphology, length, width, continuity, and migration.

Beach barrier lengthening in the southeasterly direction provides evidence that longshore drift (the current parallel to the shore transporting sediment) is southeasterly. The direction was confirmed during two field visits when floating objects placed 5 meters from the shoreline floated south. Additionally, waves break from north to south. Knowledge of dominant longshore drift direction will prove useful in understanding the source of sediment. `

Image analysis was completed to quantify beach barrier migration by precisely overlaying images and comparing beach barrier locations between all years available. Figure 11 was produced from this analysis, which confirms landward migration of the beach barrier for every period for which the satellite images are available.

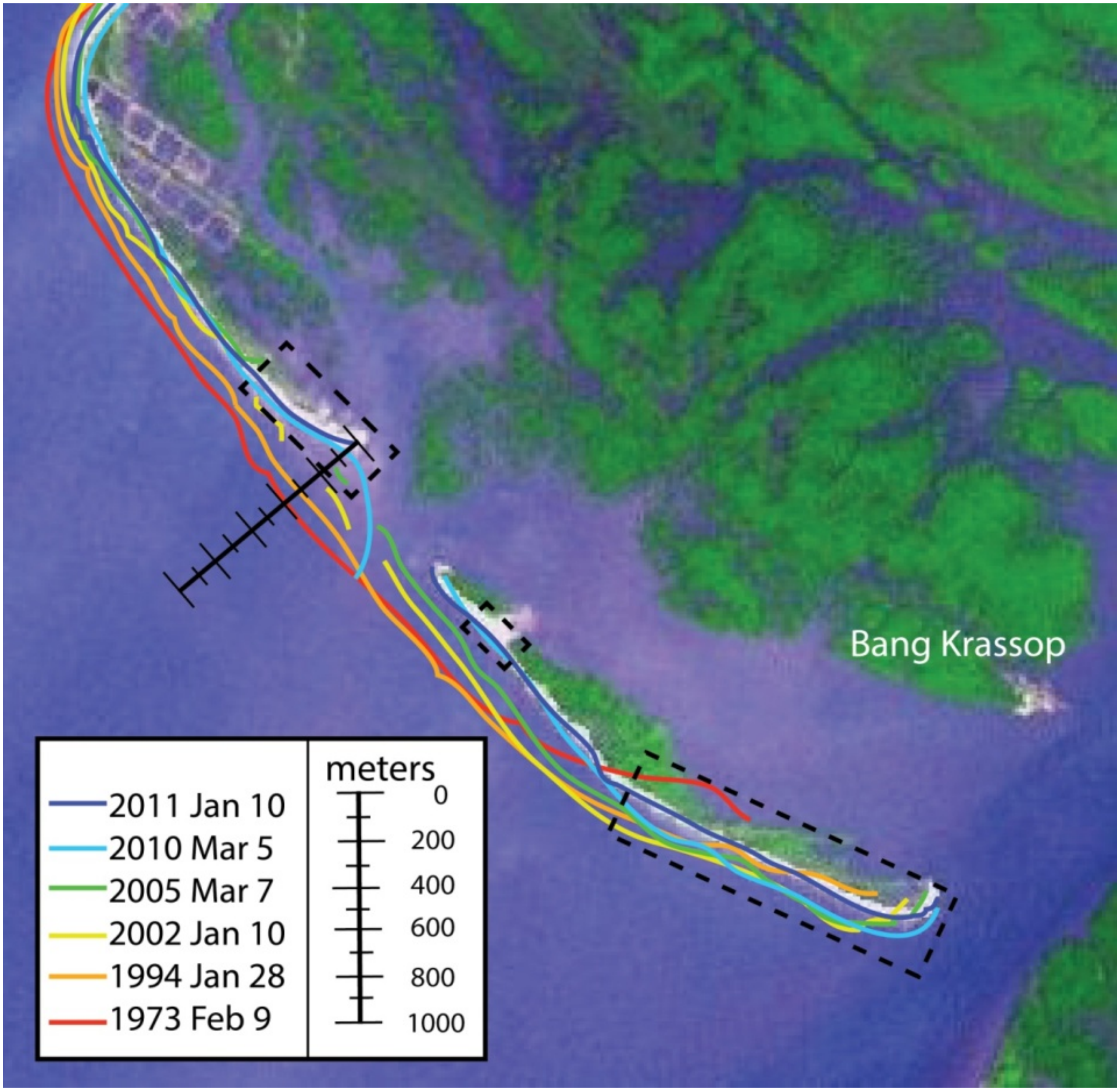

Figure 11: Beach barrier fronts from all available years are indicated in various colors. The visible satellite image is the most recent from 10 January 2011. Between that date and 9 February 1973 migration reached a maximum of 390 m. Dashed boxes represent Priority zones for beach stabilization where landward migration is most rapid and vegetation is sparse.

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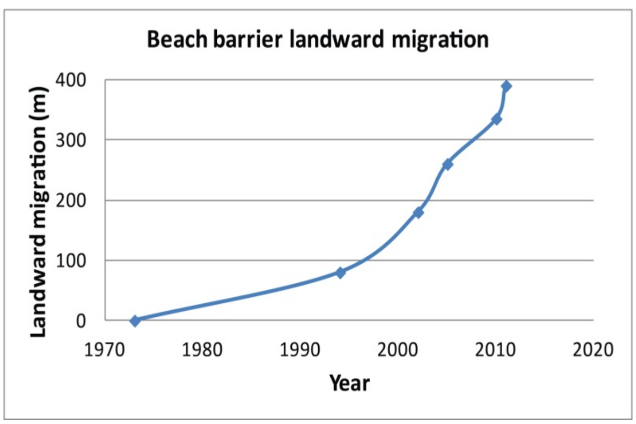
This analysis demonstrates the following findings:

- Beach barrier migration reached a maximum of 390 m from 1973 to 2011, at an average rate of 10.3 m per year
- Mangrove forest loss due to beach barrier migration is 0.60 km^2, considering northerly mangrove forest loss and southerly forest gained since 1973
- The central part of the barrier has migrated most dramatically
- The northern 3 km of the barrier has only migrated landwards an average of 240 m from 1973 to 2011, at an average rate of 6.3 m per year
- The southern 1 km of the barrier has undergone two phases of migration: i) a seaward migration prior to 2005, ii) a landward migration after 2005
- Recent landward migration is most rapid in the southern 1 km, reaching 90 m per year
- The southern tip of the beach barrier eroded from 2010 to 2011
- Areas with little or no vegetation are migrating most rapidly

The record of beach barrier migration rates indicates that the rate of migration will only further increase without intervention. The migration rate has steadily accelerated every period for which data is available, with the exception of the period 2005 – 2010 (Figure 12).

The record of beach barrier longshore growth shows rapid extension during the earliest periods with progressively slowing rates of extension (Figure 13). Since 2010 the barrier length has decreased, exposing Bang Krassop village (Figure 11) to coastal hazards.

Landward migration rate is correlated with longshore growth, both of which have detrimental impacts on the mangrove forests and livelihoods. For four out of five periods of time for which data is available high migration rates are associated with less longshore development. In fact the most recent period has the highest migration rate and the lowest longshore development rate – the beach barrier shortened in length.



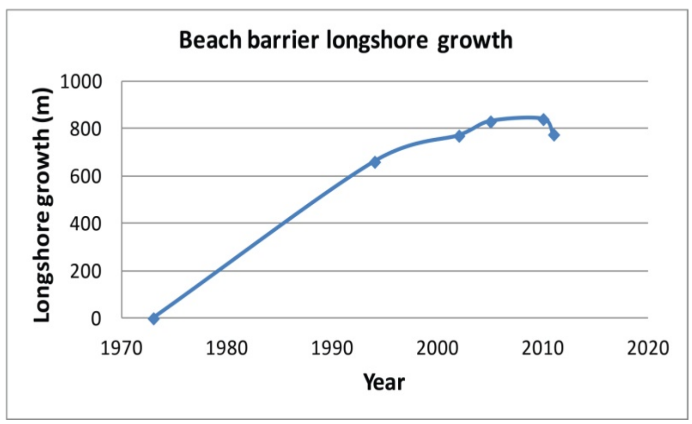


Figure 13: Growth distances southward. Longshore growth rates have generally decreased over time. The most recent period shows net erosion of the southern extension of the beach barrier.

Figure 12: Migration rates have progressively increased during 4 of 5 periods. The most recent period has the most rapid rate. Distances are sourced from the measurement bar of Figure 11.

Priority zones for intervention
Areas are prioritized for beach barrier stabilization intervention (Figure 11) based on the rate of migration (from satellite images) and vegetation density (from field observations), where a rapidly migrating beach with no vegetation is of the highest priority:

i) Southern Priority zone shows the most rapid migration and the very southern tip has only a thin strip of vegetation
ii) Central Priority zone has low vegetation density and shows sand dispersal suffocating the mangroves behind the barrier
iii) Northern Priority zone has experienced massive sand relocation between 2010 and 2011 and holds only sparse vegetation

The fishing village of Bang Krassop is currently protected by the beach barrier. However, continued erosion, recognized between 2010 and 2011, will expose the village to coastal hazards, including large waves during storms.

Priority beach barrier features for intervention
Some beach barrier features are more susceptible to experiencing overflow, breaching, and migration. For example, the beach in the Northern Priority zone without vegetation (Figure 14) is not able to build up high elevation to prevent overflow. The down-current, growing edge of the beach barrier (known as a *spit*) faces more intense wave energy and therefore migrates more rapidly than other locations. The breached beach barrier has the largest impact on mangroves because the sand has been easily washed landward, suffocating mangrove tree roots. Supporting stable beach barriers with vegetation will prevent these vulnerable features from forming.

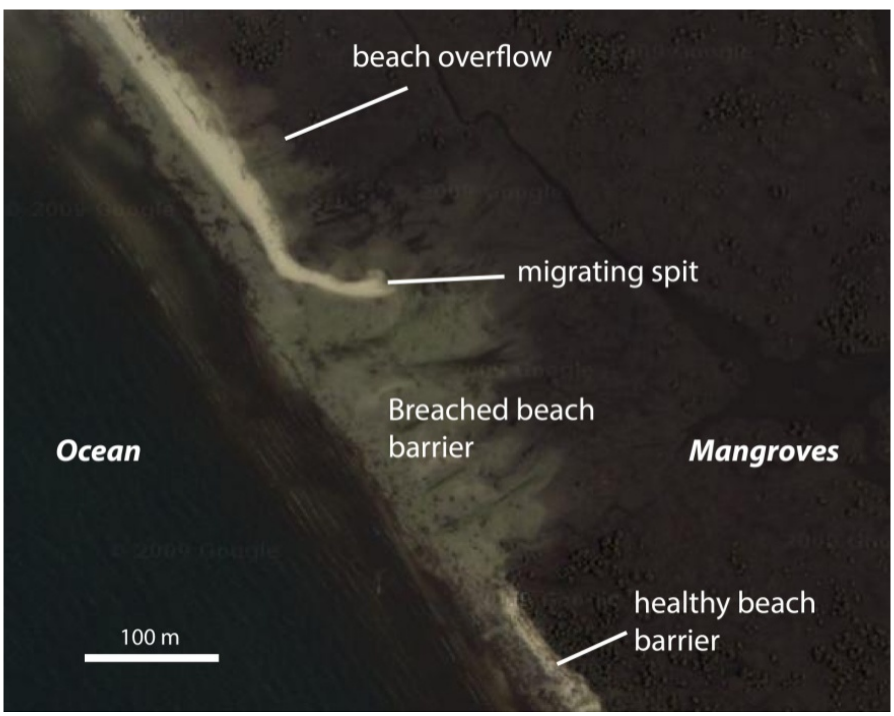


Figure 14: Aerial photograph of the Northern Priority zones in 2001, demonstrating the impacts of beach barrier migration and breaching (Google Earth Pro). Note the cloudy color of the sand suffocating mangroves.

Features in the study area should be targeted according to a balance between i) negative impact potential on mangroves and settlements, and ii) rehabilitation potential. For example, the southern tip of the beach barrier, while most susceptible to migration, is also most difficult to control through revegetation or other rehabilitation techniques.

Table 1 ranks features in the study area accordingly, for which features with high ranking for both categories should be targeted (None - Very high [0 - 5]):

Table 1:

Feature	Impact Potential	Rehabilitation Potential	Score
Unvegetated beach	Moderate	High	**7**
Spit	High	Moderate	**7**
Breached beach barrier	Very high	Very high	6
Vegetated Beach	Very low	None	5

Unvegetated beaches and spits should therefore be of greatest attention for protection and rehabilitation in the priority zones of the study area.

Sand Mining and Dam Construction

Key Findings

- The onset of river sand mining correlates in time with increased beach migration and mangrove devastation, which is consistent with satellite analysis findings
- Sand mining has caused the reduction in fish catches by 70-90% and displacement of many families as shorelines have retreated by 100 m
- Dam construction has increased water turbidity over a 40 km stretch in the short term
- The dam will decrease sand replenishment in the river and beaches in the long term, causing further river bank collapses and beach barrier migration

Sand mining

Sand mining in the Tatai and Koh Por Rivers, within PKWS (Figure 1), began in 2008 and has continued since then, generally increasing over time. Winton Enterprises, a Hong Kong-registered group, was sub-contracted to export the sand to Singapore for land reclamation (Huffington, 2011). Peam Krasaop Director Oul Rann has monitored the dredging and describes the changes in intensity of sand mining in Tatai River as follows:

- 2008: Onset of sand mining in southern Tatai River with constant increase in intensity
- 2009: Operations increased and moved upstream northward
- 2010: Decreased but continued
- 2011: Increased
- 2012: Reached peak, then the largest sand mining vessels were substituted by smaller vessels

Virtually the entire length of the river has been mined of sediment. He believes that at least 100 container ships (Figure 15), equivalent to 48,000 m^3 of sand, have been removed from the Tatai River.

A similar volume is estimated for Koh Por River and the estuary at Koh Kong city, and the timing of sand mining is approximately the same as for the Tatai River. Thus, a minimum estimate of 100,000 m^3 has been established. However, sand can be mined at a rate of 800 m^3 per hour, according to a local boat driver (Appendix A). Sand mining intensity has dramatically decreased for Koh Por in 2012 and there are only seldom reports of sand mining vessels passing through September – October 2012.

The Director also explains that the onset of sand mining corresponded with more intense landward beach barrier migration in the study area.

Figure 15: Photograph of sand mining vessel (top) and transport ship (bottom, from helicopter) 3 km south and 0.5 km south of Tatai commune, respectively.

Dam construction

Construction of the 246-megawatt dam, located 25 km upstream of KPWS began on 29 March 2010 and has caused significant increases in river water turbidity since then (Phnom Penh Post, 2010). The rapid dam construction loosened large volumes of sediment that has become entrained in the river current, giving waters a dark brown color and destroying fish habitat. Despite the 40 km distance to the beaches south of Koh Kapik in this study, sediment at these beaches is largely sourced from upstream of this dam. The dam therefore acts to block sediment that replenishes beaches protecting the mangrove forests.

Ecological and social impacts

The Tatai commune residents have a comprehensive understanding of the environmental degradation caused by sand mining and dam construction. The onset of local sand mining and dam construction correlates with the timing of environmental degradation, including:

- Constant river bank erosion along the length of both rivers, reaching up to 100 m of river widening (Figure 16)
- River bank erosion caused the loss of hundreds of trees and loss of homes
- Cloudy water downstream of sand dredging, killing fish
- The tip of river island eroded away, due to sand starvation
- Death of a fisherman when his small boat was crushed by a sand mining vessel in the night
- Fish habitat loss
- Reduction in fish catches by 70 - 90%
- Displaced families from local company purchasing their land
- Loud noise from sand pumping scares fish away
- Pollution from mining vessels

Figure 16: Estuary erosion (top) left power lines in the water 2 km west of Koh Kong city. River bank collapse 1 km north of KPWS in the sand mining region (bottom).

Priority areas for intervention

River banks exposed to high flow velocity are most likely to erode due to sand mining. The outside of river bends naturally experience high velocity, and channel deepening from mining will further increase this flow velocity.

River bars and islands that are nourished by excess sediment will experience erosion because they are reliant on a critical amount of sediment in flowing waters to build these river features

4. Discussion: Causes of Beach Barrier Migration and Channel Sedimentation

Key Findings

- Without the impacts of sand mining, dam construction, and development, the natural flow of sand from rivers and mud from the mangroves stabilizes beaches and river banks
- In the short term during sand mining and dam construction, mud is supplied from up-river in greater quantities to the Koh Kapik channel and to the coast
- In the long term (year 2020 – 2030), sand shortages in the rivers, caused by sand mining and dam construction, will cause further river bank collapses, coastal erosion, beach barrier breaches, and landward beach barrier migration
- Human activity in the Koh Por River impact the beach barrier far more heavily than activities in the Tatai River, due to the coastal longshore drift that primarily transports sediment southwards
- Accelerated rates of sedimentation in Koh Kapik channel are caused by an increased supply of mud from : i) a locally abandoned shrimp farm, ii) up-current abandoned shrimp farms, iii) loose sediment derived by deforestation in the 1990's, and iv) beach barrier breaching

Natural Conditions

The beaches and river shorelines in PKWS naturally have constant supplies of sediment from rivers. The sandy beach barrier receives a large proportion of sand from the Koh Por River, whereas the coastline south of the beach barrier receives a higher proportion of silt and clay, producing a muddy shoreline (Figure 17). The shorelines are stable and experience low rates of erosion and sedimentation when the sediment supply is constant, without development, sand mining, and dam construction. Beach barriers, however, migrate landward under rising sea levels (Leatherman, 1983, p. 415), although not as rapidly as the beach barrier of this study has migrated.

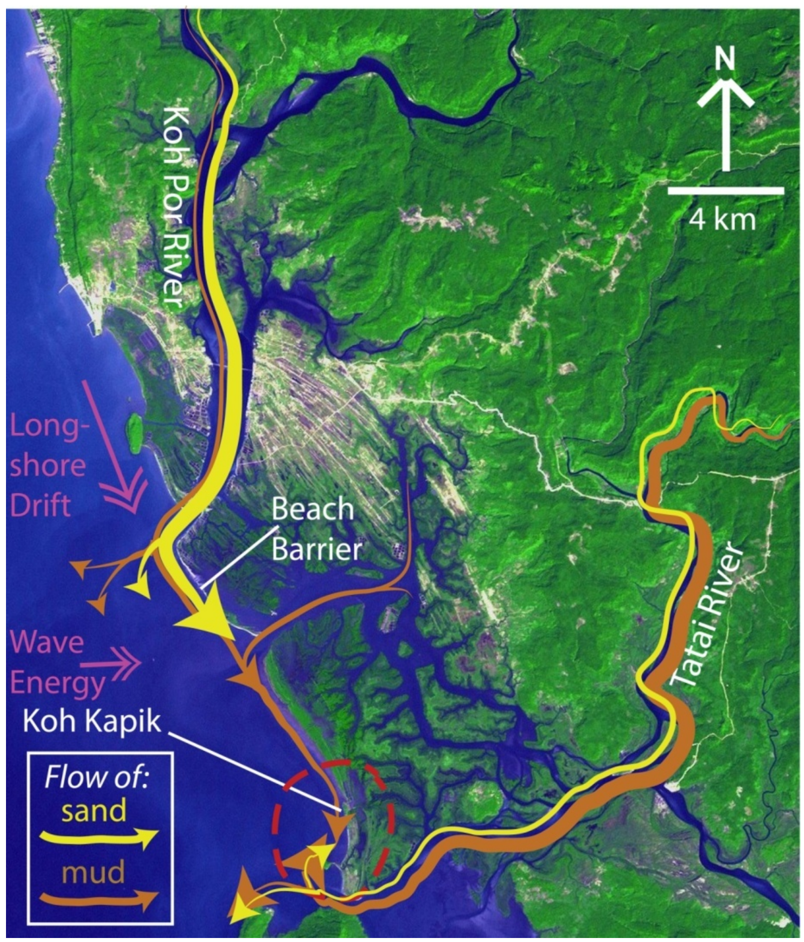


Figure 17: The sediment movement from rivers to coastlines, then following longshore drift. The red circled area indicates a beach south of Koh Kapik, where sediment supplies meet, causing magnified coastal erosion/sedimentation variability from sand mining and dam construction.

Future Ecological Impacts

Sand mining and dam construction cause variability in downstream impacts over time. In the short term, sand mining causes an uneven and rough river bed that entrains sediment, making river water cloudy. The impacts on the coast are rapid because silt and fine sand flows quickly in suspension downstream. In the long term, downstream areas will recognize similar impacts from sand starvation because the combined removal of sand from mining and the halting of sediment flow from the dam will prevent sediment that is generated far upstream from reaching downstream areas. The coast, which is nourished and supplied with sand from the rivers, will experience erosion.

Sand mining on the Koh Por River has taken place 4 – 12 km upstream from the beach barrier of this study, while sand mining on the Tatai River has taken place 8 – 20 km upstream of the beach south of Koh Kapik. The beach barrier will therefore recognize erosion and landward migration before the southern beach. Research on the beach impacts from upstream sand supply depletion shows that similar rivers recognize a lag of 5 –15 years from sand removal until heightened beach erosion is recognized (Huang, 2011, p. 27). For the beaches of PKWS the lag time may be a few years greater, due to the low gradient of the rivers.

1) ***Short term (present – continued sand mining):***
    a. <u>Local erosion upstream</u>: Localized river bank collapse causes intense river widening.
    b. <u>Sedimentation downstream and on coast</u>: Increased sedimentation in downstream and coastal areas is recognized by more sediment on river bars and more sand on beaches
2) ***Long term (year 2020 – 2030)***
    a. <u>Widespread erosion upstream</u>: As sediment in the river moves downstream to compensate for sediment-starved areas in the river, bank erosion will affect further areas.
    b. <u>River bar and island erosion downstream</u>: These features form in low-velocity river flow zones when sediment supply is high, and the features will therefore degrade with a lower sediment supply.
    c. <u>Coastal erosion</u>: Beaches are fed by sediment sourced upstream of dam construction and sand mining areas. They will therefore experience sediment shortages, eroding in beach height and length. This will **expose mangrove forests to greater wave energy and cause further landward beach barrier migration**.

Beach Barrier Migration

The causes of beach barrier migration are complex with interconnected variables. Considering all areas of this study, the beach barrier will experience the most significant changes. Beach barriers in general are vulnerable to both landward and seaward migration. Sand mining, climate change, and dam construction cause changes in the following variables, all of which promote landward migration and erosion of the beach barrier in the long term:

- <u>Sediment supply</u> shortages at the beach barrier, caused by the extraction of river sand, prevent the beach barrier from building height and length, thereby causing erosion and greater landward movement during storms
- <u>Grain size</u> reductions of the beach barrier sands, caused by:
    i) the mobilization of fine sediment during sand mining, and
    ii) the preferential extraction of large grain-sized sediment by mining companies

    will mobilize beach barrier sand under wave energy that formerly kept the barrier more stable
- <u>Sea level rise</u> is known to cause landward migration (Leatherman, 1983, p. 415). Sea level rise in the Gulf of Thailand is rising 3 - 5.5 mm per year (Trisirisatayawong, 2011, p. 137)
- <u>Storm frequency</u> increases associated with climate change will also increase the wave energy that pushes the beach barrier landwards

The early impacts of sand mining from 2008 to the present have increased sediment supply (visible in Figure 10) and decreased grain sizes of the sediment. Yet, this period has seen the most rapid landward beach migration (Figure 12), demonstrating the high control that sediment size has on beach barrier stability.

The beach south of Koh Kapik (Figure 17) has experienced noticeable variability in beach sediment over the last 4 years (Appendix A), due to sand mining and dam construction. It will likely experience further erosion due to grain size reductions in the short term, sediment supply shortages, sea level rise, and increased storm frequency in the long term.

The mudflat shoreline between the beach barrier and Koh Kapik (Figure 17) experiences net land growth instead of erosion because the cohesive properties of slit and clay minimize incision. Additionally, the low angle shoreline that mud creates allows wave energy to dissipate over a greater distance, weakening wave energy and therefore reducing erosion.

Koh Kapik Channel Sedimentation

Understanding of the sedimentation processes is useful in identifying strategies to prevent infilling and the need for future dredging. Coastal mangrove ecosystems like that which surrounds Koh Kapik naturally experience more sedimentation than erosion. Fine particles of silt and clay from upstream rivers are trapped by mangrove roots (Kathiresan, 2003a). Tidal fluctuations transport sediment into deeper channels.

Figure 18: Koh Kapik commune. The channel wraps around the abandoned shrimp farm, which had a dike built around it in 2012 (left).

Disturbances in mangroves may prevent full soil stabilization, accelerating the transport of sediment into channels, thus causing rapid channel infilling. The abandoned shrimp farm adjacent to Koh Kapik commune left high volumes of mobile sediment that has contributed to the shallow depth of the eastern side of the channel, although a barrier was built in 2012 to reduce further sediment flow (Figure 18).

Mud from up-current, particularly in the central area of the mangroves (Figure 17), is also reaching the Koh Kapik channel. This silt and clay flows out of the mangroves during tidal fluctuations (Figure 4) and drifts southward into Koh Kapik channel, particularly during storms when longshore drift is strong.

Volumes of mud exiting the mangrove system are large (Figure 4), due to:

- Abandoned shrimp farms, which are unvegetated with mud that mobilizes during extreme tidal fluctuations and storms
- Loose sediment generated during the period of extreme deforestation for charcoal, during the 1990's
- Beach barrier breaching events that initially took place 1994 – 2002 (Figure 11), and continues to offer a pathway for mud to escape the mangrove system and drift down the coastline towards Koh Kapik

5. Beach Barrier and River Protection Strategies

Key Findings

- Vegetative rehabilitation methods are most sustainable in this high sediment flux ecosystem
- Structural engineering solutions provide rapid remedies to erosion, but often cause further erosion down-current, and should only be used for the protection of homes and infrastructure, if ever needed
- Native species should be replanted on beach barrier spits, unvegetated beaches, and sparsely vegetated beaches within Priority zones (Figure 11) to allow the beach barrier to grow vertically and to slow further migration
- Regulating human traffic in Priority zones will improve beach barrier stabilization, reducing the rate of beach barrier migration and erosion
- Water coconut and bamboo tree planting has stabilized river banks and should be further utilized to protect homes from sand mining and dam impacts
- Revised sand mining strategies that extract sand less frequently and away from river banks, particularly on the outside of river bends, will minimize river bank collapses and even improve export sand quality

Vegetative rehabilitation strategies are more highly recommended than structurally engineered designs, because mangroves, rivers, and beaches are so highly connected by the flow of water and sediment. Rapidly trapping sediment on one beach or river bank location would starve the area down-current of sediment, thus transferring erosion to another location. Rehabilitation to a more natural state will instead offer benefits to down-current areas.

Beach Barrier Rehabilitation

It is critical to promote vertical and longshore growth of the beach barrier in order to prevent further mangrove loss and exposure of Bang Krassop to coastal hazards. It will, however, be a challenge because a reduced sand supply and landward migration will be the tendency under climate change, dam, and sand mining impacts.

Allowing the beach barrier to grow vertically will prevent further beach barrier breaches during storms. The beach barrier will additionally develop more mass this way, adding strength against landward push during storms. Vegetation traps sand on higher beach elevations when large waves and wind push sand landwards (Figure 19). Engineered structures on the coast would, in this way, be counterproductive because they would prevent this critical sediment movement and beach development.

Figure 19: Vegetation on the beach barrier (the Beach Morning Glory *Ipomoea pes-caprae, Ipomoea biloba*), secures and traps sand, building up the height of the beach barrier (right).

Structurally engineered techniques may, however, be appropriate in the future if the cost-benefit analysis favors a structure. For example, if beach barrier migration threatens the Bang Krassop commune, bamboo breakwater structures can be used to reduce wave energy and trap sediment for land growth.

Supporting beach barrier species

Rehabilitation of the beach barrier through support of vegetation on the highly ranked beach barrier features (Table 1) in the priority zones (Figure 11) will reduce the rate of landward migration. The area around the sandy beach has greater plant biodiversity than elsewhere, due to the rapid landward transition from saltwater to brackish water. Landward species are reliant on ocean-side species to hold together soil and prevent sand from moving landward.

The following species grow on the beach barrier transect (from ocean-side to landward-side):

- Zone 1: ***Ipomoea pes-caprae*** *(*Beach Morning Glory) grows rapidly on sand, offering the first layer of stabilization with shallow roots, and extending to the ocean front (Figure 19). It protects the beach from both water and wind erosion.
  - Most highly recommended for supporting and replanting on spits, unvegetated beaches, and poorly vegetated beaches because of its high survival potential and sand stabilizing abilities.
- Zone 2: ***Casuarina*** species grow in sandy soil on the higher elevations of the beach barrier, stabilizing the middle and rear sections of the beach barrier.
  - Also recommended for poorly vegetated beaches where *Ipomoea pes-caprae* has already added a level of sand stabilization.
- Zone 3***: Avicennia alba*** colonizes new ground in muddy areas with a root system that holds fresh sediment deposits.
  - Known to be challenging to replant. The community agrees that conditions should be supported to grow the species rather than planting it.
- Zone 4: ***Rizophora mueronata*** grow in brackish water on the landward side of beaches in muddy soils. It is commonly used to prevent coastal erosion.
  - Supporting Zones 1-3 closer to the beach front will create conditions favorable for the species.

Replanting *Ipomoea pes-caprae* will most likely have the highest payback in beach stabilization because it requires little more than sand to survive. Sandy beaches, including spits, are also most highly prioritized. Thus, it is recommended to plant *Ipomoea pes-caprae* (Beach Morning Glory) on beaches that are isolated from the species. This will accelerate natural beach-stabilizing processes.

Human traffic reduction

Unvegetated and sparsely vegetated areas of the Priority zones (Figure 11) require the closest attention to human traffic because they have the potential to increase beach stability if vegetation density increases. Due to the scarcity of soil, it is difficult for plants to thrive here. Sparse vegetation is therefore vulnerable to disturbances and must be protected in order to increase vegetation density. Tourist groups and local fisherman are known to frequent these locations. Regulating activity in the Priority zones and designating sparsely vegetated areas as off-limits will accelerate the growth of beach-stabilizing vegetation, thereby reducing the rate of beach erosion and landward migration.

River Rehabilitation

Water coconut trees

The communes on the Tatai River recognize the value of riparian water coconut trees (Figure 20) in the prevention of river bank erosion. These trees grow naturally and the communities also plant the trees in target locations to protect their shorelines. They do not appear to be invasive, and protect shorelines particularly well where the water level is relatively shallow.

Figure 20: Water coconut trees (*Nypa fruticans*, fringing Tatai River) have been planted by locals to buffer shorelines from erosion and bank collapse.

Bamboo trees

The community finds that these trees are better suited to protect shorelines where a steep drop exists between the shore and the river bed. Residents generally feel that the trees are an advantage to protecting their land from giving way to the river.

The only recognized drawback is that the plants may block river access. Further utilization of the water coconut and bamboo trees will provide resilience against imminent sand mining impacts. Support by IUCN for this may be considered.

Revised sand mining strategies

Alternative mining techniques can reduce ecosystem and livelihood impacts while increasing the economic viability of the industry. Local residents have explained that the sand quality has been inadequate for export standards at times during the last two years. The grain size of the sediment has not been sufficiently uniform. This is often caused by the incorporation of river bank sediment, which consists of fine grains, during bank collapses. Thus reducing the frequency of river bank erosion will both protect the environment as well as the quality of exported sand. This can be done using the following strategies:

- <u>Mining away from river banks</u> will prevent some bank collapses because mining creates pockets without sediment. As sand moves downstream the voids migrate short distances to areas adjacent to fragile river banks, which might cause bank collapses. Mining near the center of the river provides more space for sand levels on the river bed to even out, thereby maintaining sand next to river banks that supports the banks.
- <u>Mining away from the outside of river bends</u> will further prevent bank collapses because the outside of river bends are naturally prone to erosion, even without sand mining. In fact, rivers naturally migrate towards the outside of river bends because the velocity of river flow is highest there. Mining in this location accelerates that process unsustainably.
- <u>Reducing the frequency of mining</u> in a single location will allow sediment supplies to regenerate to levels that can quickly fill in pockets lacking sediment, which would otherwise also cause bank collapses.

6. Koh Kapik Channel Rehabilitation Recommendations

Key Findings

- The naturally shallow depth of the Koh Kapik channel faces further infilling of sediment sourced from dam construction and commune waste
- Dredging on the outside of river bends will reduce the volume of excavated material because the channel is naturally deeper there and it will experience lower rates of re-sedimentation there
- Placing excavated material on the inside of river bends during low tide will reduce the chance of re-deposition of that same material into the channel
- A minimum amount of the mangrove root length should be covered by excavated material
- When necessary, the construction of barriers and dikes will prevent loose sediment from reducing the depth of the channel
- The Koh Kapik channel can expect re-sedimentation rates of 4 - 10 mm per year following dredging

The Koh Kapik channel is critical for the transportation of water, food, and materials. The fishing livelihoods of the village are naturally dependent on constant access to the ocean to the west and mangrove forest to the east (Figure 21). Coastal hazards, particularly under climate change, present a significant risk, therefore necessitating access to the east. However, infilling of the channel with sediment prevents the community from accessing the eastern side of the channel by boat during low water levels. During workshops with the Koh Kopik community 12-14 March 2012 the community prioritized dredging the channel in order to build livelihood resilience (Kimleong, 2012, p. 1).

Natural Depth

The section of the Koh Kapik channel that is planned to be dredged naturally has a shallow depth. While the commune has contributed sediment through shrimp farm abandonment and solid waste, the stream morphology of the mangroves maintains shallow depth. Two comparable streams to the north of Koh Kapik channel (Figure 21) become even shallower. Care must therefore be taken to avoid accelerating natural sedimentation rates through human activity.

Infilling Prevention Strategies

A dike was built in 2012 to prevent sediment from entering the channel from an adjacent abandoned shrimp farm (Figure 22). This strategy is useful here and further recommended for locations where the volume of potentially mobile sediment exceeds the volume used to construct the dike because the sediment of the dike can become mobilized as well.

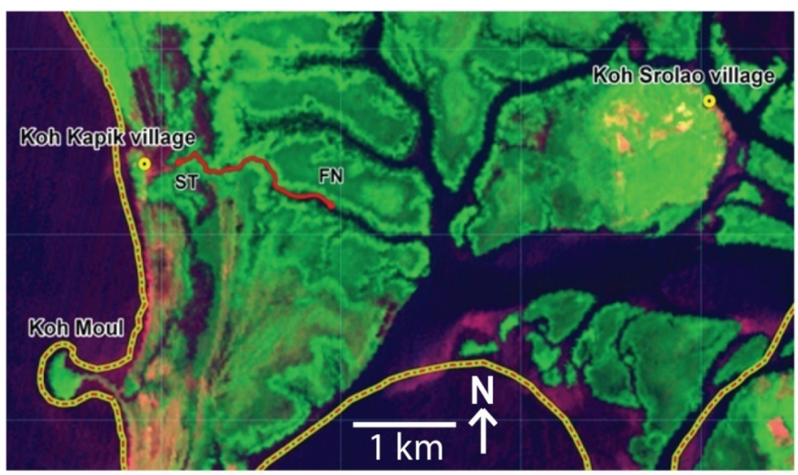


Figure 21: Koh Kapik and the planned 2-km dredging length (in red). Koh Sralao village is the primary source of water during the dry season (modified IUCN image).

Sedimentation Rates

Annual sedimentation rates in mangrove forests range from 1 to 8 mm, often associated with the expansion of land seaward (Bird & Barson, 1977). Channels, however, are more susceptible to human-induced sedimentation rate variability.

They can demonstrate higher rates, because sediment can more easily fall downwards into the channel, as well as lower rates because the faster velocity of water can accelerate erosion.

During the weeks following dredging, re-sedimentation rates are expected to be markedly higher than the longer period thereafter, due to disruption of the channel floor and the unnatural, uneven surface of the channel floor caused by dredging. The months following dredging will also experience heightened re-sedimentation rates during storm events. For these reasons as well as sediment contributions from dam construction and the commune, sedimentation rates after dredging of 4 - 10 mm per year are predicted.

Dredging Recommendations

Excavation

Dredging from the outside curve of bends in the stream will reduce the volume of sediment that must be dredged. These locations are naturally deeper because flow velocity is greater here. Higher flow velocity accelerates erosion, helping the channel to maintain depth after dredging. Dredging should therefore take place 0.5 - 1 m towards the outside of the deepest location (Figure 22).

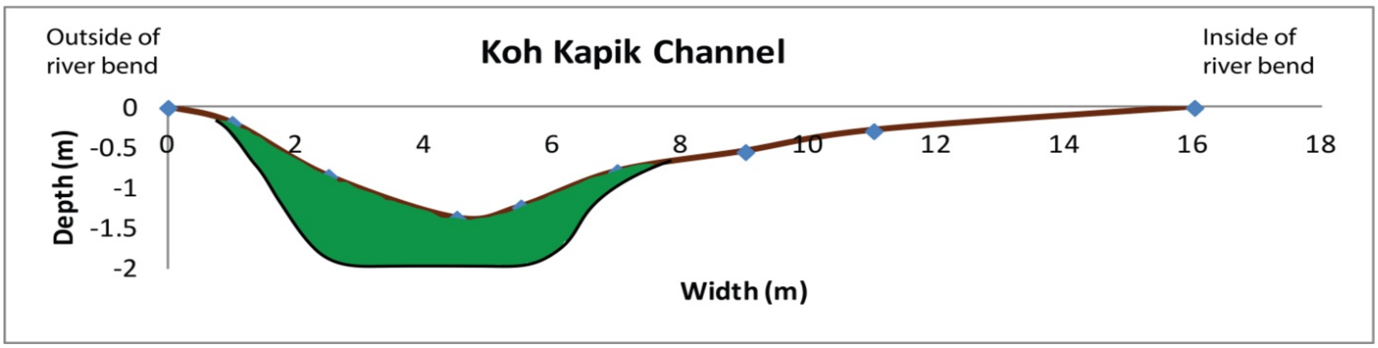


Figure 22: Cross section profile of the Koh Kapik channel measured in October 2012 at the most western bend of the planned dredging length (Figure 21) in brown. The area in green represents the suggested excavation area location where the majority of the sediment removed is sourced from the outside of the stream bend.

Placement of sediment

Sediment removed from the stream bed should be placed on the inside river bends' banks, due to the natural stream migration towards the outside of the stream bend and the higher velocity there. During high tide and flooding, this will reduce the volume of sediment that becomes entrained by stream flow and falls back into the stream bed. The moderate sinuosity of this channel allows this technique to be used for approximately 15% of the dredging length.

Figure 23: The root systems of *Rhizopora* species along Koh Kapik stream require exposure to oxygen for survival and should therefore have minimal root height covered by mud from dredging.

Maximum root height coverage

Excavated sediment should be placed on the outside of the channel such that mangrove roots are covered at a minimal height to reduce impacts on riparian mangroves. The dominant species of *Rhizopora* fringing the stream has stilt roots, which require exposure to air for aerobic processes to take place (Figure 23). Mud coverage would create highly anaerobic conditions and suffocate the trees. Full coverage would certainly cause the trees to die, while partial coverage of the root length may provide sufficient oxygen for survival.

Tidal considerations

Dredging should take place during low tide of low amplitude tidal lunar cycles to reduce the depth of water that encounters fresh unconsolidated material. This will again reduce the volume of sediment that falls back to the stream bed because it is estimated that sediment is 25% less likely to be entrained in flow during low tide (Kathiresan, 2003a, p. 355).

Barriers and dikes

Sediment containment constructions will be useful for areas of loose sediment that are created by the dredging process. They have already been built by the commune to prevent sediment of the abandoned shrimp farm from entering the channel (Figure 24).

Figure 24: Koh Kapik channel, before (A) and after (B) dike construction (red box). The dike has successfully prevented loose sediment from the abandoned shrimp farm (background) from resedimenting in the channel.

7. Multi-stakeholder Collaborations

Provincial Workshop on Sediment Flow Issues

IUCN Cambodia conducted a half-day workshop on 13 November 2012 about local ecosystem protection to prevent adverse changes in local beach and river erosion/sedimentation. Thirteen participants from agencies of the line departments, local authorities, and Peam Krasop Wildlife Sanctuary (Figure 25) discussed community-based solutions to support livelihoods during the workshop at the Peam Krasop community meeting hall.

Figure 25: Participants of the workshop titled *PKWS Ecosystem Protection: Current Issues and Solutions to Support Livelihoods*

During the workshop, findings were discussed as well as the importance of maintaining a steady flow of sediment from rivers to the coast. Participants shared their understanding of downstream impacts on livelihoods from unsustainable actions upstream. In this way, the high level of connectivity of the watershed was illuminated.

Participants worked together to identify solutions to river and coastal erosion. Local knowledge was contributed about native plant species that can be used in particular environments for rehabilitation. Plans are now being made to apply the lessons learned during the workshop to improve the health of the mangrove ecosystem and protect local livelihoods from coastal hazards associated with climate change in Koh Kong Province, Cambodia.

Meeting: Biodiversity Conservation Corridors Project (BCCP) – Asia Development Bank (ADB)

During the International Consultant's field work in Koh Kong Province, he coincidentally met the team working on BCCP. A meeting was attended, during which time potential collaborations between the project and IUCN became visible (Figure 26). It will be important that synergies rather than unnecessary overlaps are established between the organizations.

Figure 26: Meeting participants included ADB staff, Mekong Think Tank staff, Wildlife Alliance staff, and local authorities.

8. Upcoming Community-based Ecosystem Protection

Since the provincial workshop held on 13 November 2012, communities in PKWS are gaining an understanding of the interconnectedness of the rivers and beach, namely the importance of stabilizing sediment transport dynamics. With this, they recognize that ecosystem rehabilitation strategies must be coupled with erosion prevention strategies:

Rehabilitation:

Communities living on eroding river banks had already utilized the bank-stabilizing characteristics of water coconut and bamboo species. Stakeholders whose livelihoods are based near the beach barrier are now looking into planting native vegetation to slow the rate of beach migration and erosion. Future work should further investigate case studies of the usage of plant species described in this study to control erosion and beach migration. Replanting should then take place in the priority zones outlined in this study.

Prevention:

During the provincial workshop, a provincial leader from the Ministry of Industry, Mines and Energy increased his awareness about the mutual benefit of preventing river erosion for both communities and the quality of sand to be exported. Strategies as simple as mining away from the outside of river bends will prevent river widening. In this way, further educating those involved in the mining industry will protect livelihoods of PKWS communities.

9. Conclusion

Local activities in PKWS have pronounced impacts on sediment flow dynamics that stabilize the rivers and protective beaches of the mangrove ecosystem. Climate change further exacerbates the effects, namely the expansive loss of coastal mangroves as the beach barrier migrates landward. In the short term, river bank erosion near sand mining operations will present challenges to those living near the river. In the long term, the reduction in sand volume flowing downstream may accelerate beach barrier migration. However, communities have knowledge about rehabilitation strategies that can be utilized to build resilience to these impacts.

Specific native flora species can be planted in priority zones of the beach barrier to increase beach height, which will slow the migration rate. Support should also be provided to families who would like to prevent the loss of land next to rivers, where sand mining has caused river bank collapses and the displacement of families. Controlling this erosion upstream will improve not only beach health, but also reduce the rate of sedimentation in Koh Kapik channel, which may otherwise soon again require dredging. Using the recommended channel excavation strategies will additionally stabilize mangrove sediment and reduce down-current impacts.

Rehabilitative and preventative approaches are economically beneficial for all stakeholders. The use of more sustainable mining techniques will protect the land and even improve the quality of exported sand. Concerted efforts are required. Community-based resilience against the impacts of dam construction, sand mining, and climate change can be improved by strengthening collaborations to protect the rivers, beaches, mangrove ecosystem, and ultimately the livelihoods within PKWS.

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Appendix A: Summarized interview notes

Interview 1: Changes in PKWS Ecosystem Stability with Director Oul Rann

- 10 October 2012
- Lead by Brian Kastl, notes taken by Supanuth Chuerattanakul, translation by Sun Kong

1. Biggest problem in PKWS?
    - By observation, there is no net erosion in PKWS. It has been impacted by storms with ample sedimentation; beach does not erode; beach moves seaward and landward at the location where the mangroves die
    - Channels 1 – 5 are blocked by sedimentation south of the study area
    - In Koh Moul the water eats the land; beach getting shorter and shorter. Behind Koh Mu there is also erosion

2. Other significant problems?
    - Beside climate effects, there are some impacts by humans, example sand dredging
    - But few activities now, and it leaves the strong impact
    - In 2 location, 1st is near the shrimp farm (and it' affect the water flow & sand dredging)
    - 2nd location (Koh Samah), 2-3 hectare of erosion, 60m of sand erosion each on both side
    - The sea is not clear anymore, cloudy water
    - Another problem is loss of fisheries and fishing zones

3. Is the sand taken from deep or shallow?
    - Normally the company takes the sand in the area that has a lot of sand. And there is sand everywhere
    - 800 cubic meters per hour from the faster pumps

4. What about the location and timing of the dredging in the year?
    - (he draw it on the map)
    - Since 2008 (so there is no dredging before 2008).
    - In 2009 increase, 2010 decrease, 2011 increase, 2012 peak, and more in future

5. Are they still dredging up stream?
    - He saw the ferry, still activities
    - Location: very closed to bridge.
    - On the map, activities start in the beginning 2012, but stop now already on lower end of Tatai River

6. How much of the total available sand does he think has been taken?
    - At least 100 ferries, equivalent to around 1 million cubic meters

7. Does he think that there is an change in sedimentation in Koh Kapik?
    - From Channel 1 to Koh Kapik, there is no change, just normal sedimentation
    - But below the area, he saw more sand and mud

8. Is erosion/sedimentation seasonal?
    - Mostly seasonal, (wet season = sand – windflow from open sea and take some from there)
    - In 2010, he saw the most mud
    - This year on the south beach, it is sandy and a little muddy

9. <u>Can he describe the movement of the beach inland and the mud filling here, and can he comment on the timing?</u>
   - He doesnt know why, he thinks some are from the wind taking the compose to there
   - Before he noticed that along the coast there are some sand , in some year, he saw the sand, in some year he doesn't see, => sometimes it deposits from open sea, sometimes the open see bring it in.
   - Before 2008, the current wave flow the sand to the beach and take the sand out
   - After 2008 (more movement, more coastal change) extreme weather, bring more sand in, it eventually caused the trees to die

10. <u>Can he comment specifically on the year, from 2008 to 2012 on the amount of beach movement?</u>
    - (refer to graph in map)
    - no decline, 2012 is when the extreme event (more storms)
    - o More sand from year to year deposited

11. <u>Can you draw the graph of what happen before 2008?</u>
    - He can remember up to 2002 (beginning of the impact) events get a little bit more extreme each year, but the extreme events started in 2008.
    - In 1999, the community chief gathered the people who live in the mangrove forest, to stay in one area – near the shrimp farm, (before the people cut the mangrove for chacoal, illegal cutting) but now the beach move

12. <u>When did the deforestation stop?</u>
    - In 2009, all illegal activities such as deforestation stopped completely
    - From 1999 till 2002, there are some activities still going on
    - In 2000 - 2001, established CPA community protected area
    - In 1995 to 200, there are no mangroves (you can see from PKWS office) so you can even see the island (Koh Sraloa and even Koh Kapik)

13. <u>Was there a change in biodiversity after the mangrove came back?</u>
    - Since 1998 – 2000, there are no fishing (no interest, no market) because people are busy cutting mangrove
    - Before people only have one trap, after 1 or 2 hours, take the trap out and get the food
    - But when no more mangrove, it lead to dirty water, no more fishing or crab
    - People start to realize that this is not sustainable, and some even start to move

14. <u>Impact of shrimp farming on sedimentation</u>
    - 1 problem, after they catch, they clean the area, and the sedimentation wash out into the freshwater

15. <u>After the shrimp farm is abandoned is there along of sedimentation that is washed into the river?</u>
    - His idea, he compare 3 things, (1) shrimp farm- sedimentation flow, (2)erosion from mangrove tree/ leave, (3) the area that the people plant the green mussle,
    - Thus a lot of sedimentation comes to this area
    - Before there are some erosion from the mountain, no more now
    - What about deforestation in 1995 – 1996, does it cause more sedimentation to the sea or less?
    - During 1999, there are no more mangroves , more erosion

16. <u>Is there still sand dredging up north?</u>
    - Last month he saw the ferry, moving sand south

BUT according to boat driver, it stop 3 month ago

17. Thoughts on water issues in Koh Kapik?
    - Kong: send water from the mountain, but need about 1 million USD. Not really worth since it's a small town
    - The chief: "desalination and need to research and feasibility study on ground water

18. Other comments?
    - Funding scarcity, although people still participate
    - Only 30 USD provided per month from the government even for the Director and Park Ranger.

<u>Interview 2</u>: Sand Dredging Impacts during River Tour with Oudom, Boat driver of 4 Rivers Hotel

- 12 October 2012
- Led by Brian Kastl and Supanuth Chuerattanakul

1. <u>How often do the boats mine the sand?</u>
   - One week in a month, then wait for the big boat to transport the sand.
   - But for the small boat, once the vessel is filled up, transport to the coast near by.

2. <u>How do you feel about sand mining? Does it affect you?</u>
   - I feel very upset. Actually the villagers are all very upset. There was once an accident that the sand boat crushed into a small fishing boat. The man was found dead the next morning, but the company takes no responsibility.
   - Sometimes, the sand boat will run over the fishing net and destroy it.
   - Not only that there is no economic benefit to the village, the sand they took also cause coastal erosion, trees fall into the water along the river.
   - The operation itself is also very noisy and the staffs working always pollute the river with their trash.

3. <u>How much do you they have taken the sand?</u>
   - They took a lot of sand, there is no sand left, now they have to move somewhere else.
4. <u>But there are some sand left in the ground, what do you mean when you say there is no more sand?</u>
   - They have taken all the good quality sand, the good sand is on the side of the rivers, there is no more.
5. <u>How do you define good quality sand?</u>
   - The good sand is the large grain one.

Interview 3: Climate Variability in Koh Kong with Eric Renard, General Manager of Koh Kong Bay Hotel

- 21 October 2012
- Lead by Brian Kastl

1. How long have you been the manager at Kong Kong Bay Hotel?
   - 8 years, and I was previously manager of a hotel nearby on the coast of Thailand

2. I noticed that high tides in the last days have flooded the restaurant seating areas. Can you comment on this?
   - Annually during the end of October the lunar cycle creates exceptionally high tides
   - Because the timing overlaps with the end of the rainy season wave action intensifies the impact

3. Can you describe any climatic changes you have recognized here in the past eight years?
   - During the early part of my eight years here, the rainy was predictable with distinct beginnings and ends. Now it is unpredictable when it will start and stop
   - As a result, the storms and precipitation are less consistent

4. Has the storm intensity been variable or consistent over the past eight years?
   - Although the storms occur at different times of the year now, the intensity has remained variable; sometimes they are strong, sometime they are weak
   - They have, however, not generally intensified over the years

<u>Interview 4</u>: Tatai River impacts from sand mining with 75 year-old local woman, living in village of 80 people 4 km downstream of Tatai village

- 3 November 2012
- Lead by Brian Kastl

1. <u>When did you begin noticing changes to river erosion and stability?</u>
   - I have lived here all my life along the shores of the Tatai River
   - The impacts have been recognized for the last 2 to 3 years
   - Within months of sand mining beginning, the banks of the river began collapsing near the areas where sand mining was taking place
   - Later on, the banks downstream of the sand mining began to collapse

2. <u>What are the changes you have noticed?</u>
   - Prior to sand mining, fisherman would consistently catch 10 kg of lobster per day; now it is consistently 0-3 kg of lobster
   - The profit was 30,000 - 40,000 baht per day from fishing; now it is only 1000 baht
   - It has not improved at all yet, despite the amount of sand mining decreasing
   - Over this 4 km stretch of river, 300 coconut trees and 15 durian trees have fallen in the river
   - Here, the river is now 100 m wider
   - The local Dragon Fish species is now endangered in this river

<u>Interview 5</u>: Governance Challenges in Controlling Sand Mining with UNDP staff Phat Phy and Icuntheara Tep

- 5 November 2012
- Lead by Brian Kastl

3. <u>Is UNDP aware of sand mining, particularly in the Peam Krasaop Wildlife Sanctuary?</u>
   - Yes, we have been aware of the issues for quite some time and know a lot about the companies that have been involved

4. <u>Are you familiar with the impacts of the sand mining on local livelihoods?</u>
   - Yes, many of our colleagues have heard the reports of houses being lost due to river erosion, the noise complaints, as well as some of the ecological impacts

5. <u>Does UNDP have any control over the situation?</u>
   - Unfortunately no intergovernmental agencies nor local authorities are able to stop the sand mining due to the structure of power

6. <u>What is the root problem of the governance that prevents any limitations to be put on sand mining?</u>
   - The problem is 3-fold:
     - The central government gains direct benefits from the sand mining that are not recognized in the rest of society: corruption
   - The central government pressures the provincial governments to do as the central government wishes
   - This ultimately leaves the provincial government with no control over the local issues that negatively impact their people

Appendix B: Surveys

Survey template 1: Water usage and wastewater generation in Koh Kapik, Koh Kong Province

- 9 October 2012
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Questions for households:

1.	Gender:	2.	Age:
3.	Occupation:	4.	How many people are in your household?
5.	Monthly income:		
6.	Where do you buy your water?		
	a. How many litres does your household buy per month (wet vs. dry season)?		
	b. What percentage of your water is purchased?		
	c. What is the cost of water per litre?		
	d. What is the water quality (potable, only for bathing)?		
	e. Is all of the water purchased the same quality?		
	f. What is the source of the remainder of the water?		
7.	Do you attain water from a well?		
	a. How many litres does your household buy per month (wet vs. dry season)?		
	b. What percentage of your water comes from a well?		
	c. What is the cost per litre?		
	d. What is the quality (potable, only for bathing)?		
	e. Is all of the water the same quality?		
8.	Do you have a rain catchment system?		
	a. Litres caught per month (wet season vs. dry season)?		
	b. What percentage of your water is captured by catchment system?		
	c. Type of design?		
	d. Rooftop surface area?		
	e. Functionality of system?		
	f. What is the water quality (potable, only for bathing)?		
	g. Tank design?		
	h. Tank volume?		
	i. Tank cost		
9.	What percentage of households do you think have rainwater catchment systems?		
10.	What percentage of households do you think use well water?		
11.	How many liters are used in your household per day during the dry season for:		
	a. Drinking (bought vs. captured vs. well) ?		
	b. cooking (bought vs. captured vs. well)?		
	c. Bathing (bought vs. captured vs. well)?		
	d. Toilets (bought vs. captured vs. well)?		

	e. Washing dishes (bought vs. captured vs. well)?
	f. Washing clothes (bought vs. captured vs. well)?
	g. Washing fish (bought vs. captured vs. well)?
	h. Other (bought vs. captured vs. well)?
	i. Total (bought vs. captured vs. well)?
	j. What is the percentage increase in usage during the wet season (bought vs. captured vs. well)?
12.	Estimated graywater production (wastewater from b-c, e-g above)
13.	Estimated total wastewater production (blackwater & graywater).
14.	Where does wastewater go?
15.	What is the water quality of the Koh Kapik channel (healthy for swimming, bathing)?
16.	Additional comments

Site assessments:

17.	Record the % of homes with catchment system
18.	Estimate the surface area and percentage of village rooftop surface area that:
	a. catches and contains water
	b. tries but fails to catch and contain water
	c. is structurally capable of catching and containing water
	d. is structurally not capable of catching and containing water

Post-processing:

19. Calculate estimated graywater production.
20. Calculate estimated wastewater production (blackwater & graywater).
21. Identify low-cost, low-tech household (or community level) solutions for water conservation and pollution prevention ranked based on ease to install and operate.

Appendix C: Workshop Information

Workshop on PKWS Ecosystem Protection: Current Issues and Solutions to Support Livelihoods

Koh Kong Province residents discuss mangrove ecosystem protection strategies

16 November 2012 | Article

IUCN Cambodia conducted a half-day workshop on 13 November 2012 about local ecosystem protection to prevent adverse changes in local beach and river erosion/sedimentation. Thirteen participants from agencies of the line departments, local authorities, and Peam Krasop Wildlife Sanctuary **discussed community-based solutions to support livelihoods during the workshop at the Peam Krasop community meeting hall.**

Peam Krasop Wildlife Sanctuary in Koh Kong Province, Cambodia includes one of the largest mangrove forests in Southeast Asia. The forest is situated between the base of four major rivers and the Gulf of Thailand, providing it with ample brackish water for the mangroves to thrive. River bank and coastal beach stability are critical to the long-term health of the mangroves. However, recent erosion of river banks and landward migration of a protective beach barrier have left the forest vulnerable to further climate change impacts, particularly during the last five years.

As part of the Europe Union funded Building Coastal Resilience (BCR) project, a field study was conducted September – November 2012 to identify ecosystem changes and community-based solutions to improve livelihood resilience. During the workshop, findings were discussed as well as the importance of maintaining a steady flow of sediment from rivers to the coast. Participants shared their understanding of downstream impacts on livelihoods from unsustainable actions upstream. In this way, the high level of connectivity of the watershed was illuminated.

Participants worked together to identify solutions to river and coastal erosion. Local knowledge was contributed about native plant species that can be used in particular environments for rehabilitation. Plans are now being made to apply the lessons learned during the workshop to improve the health of the mangrove ecosystem and protect local livelihoods from coastal hazards associated with climate change in Koh Kong Province, Cambodia.

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Source: http://www.iucn.org/news_homepage/news_by_date/?11739/Koh-Kong-Province-residents-discuss-mangrove-ecosystem-protection-strategies

Workshop Invitation:

You are hereby cordially invited to a seminar and discussion at Peam Krasaop Wildlife Sanctuary (PKWS) on November 13, 2012 to share knowledge about harmful changes in the ecosystem and its impacts on livelihoods.

Rapid beach migration has resulted in the loss of large areas of coastal mangrove forests. The International Union for Conservation of Nature (IUCN) has carried out field studies to identify whether these changes are due to alternations in coastal and river sediment transport. The findings will be explained and further insights are sought from participants. We look to identify further strategies to prevent mangrove loss to protect livelihoods.

Lunch will be provided and your logistics costs will be covered. Below you will find a schedule of the event.

Please RSVP by November 6, 2012.

We look forward to hearing your knowledge and investigating solutions to promote a healthy ecosystem for everyone.

- Brief introduction of participants and IUCN studies
- Participant concerns and experience with ecosystem degradation of PKWS
- Presentation describing changes in PKWS, including beach migration and sedimentation
- Discussion of questions, concerns, and participant knowledge on the issues
- Lunch
- Discussion on ways to prevent and slow further beach migration and mangrove devastation
- Closing