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Coastal Erosion and Coastal Integrity Vulnerability at selected Shorelines of Sarawak, Borneo Malaysia

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Department of Aquatic Resources
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Abstract

This study assessed the coastal vulnerability and erodibility of 11 beaches around the Kuching Division-Sarawak state, Borneo Malaysia. The main aim of the study is to judge the feasibility of combined approaches to determine the vulnerability of sampling sites and evaluate further on the crucial erosion events in the study area. The vulnerability assessment comprises the use of the Coastal Integrity Vulnerability Assessment Tool (CIVAT) as a semi-quantitative benchmark in order to compare between single and multiply study sites further supplemented by beach profiling, shoreline tracing with consecutive image analysis in ArcGIS and historical literature research. In addition, an interview with adjunct professor Chou Loke Ming from Singapore was added to evaluate the findings of the study and put it into a more regional context. The results have revealed a massive depletion of sand resources on 4 of the 11 focus areas (Siar Beach, Pandan Beach, Talang Beach and Satang Beach). Erosion rates range between 3.37 % to 15.17 % of beach area per year. While all of the beaches show trends of declining sand resources the CIVAT reveals, besides Permai 1st Beach which achieved a high rating, low to medium vulnerability ratings for all the study sites subject to this study. The feasibility of the "assessment tool" is further discussed and questioned as well as possible reasons for the shoreline recession revealed. Above that, the importance of ecosystem features like the Talang-Satang area as a designated breeding site for endangered turtle species in Sarawak is underscored. The valuation of unique ecosystem services constitutes a key component to initiate conservation action in the areas of focus.

Explanations

Most likelihood classification (MLC)	Digital image procession within ArcGIS which allows to designate a set of training samples in order to classify areas from aerial images
Hedonic pricing	Approach with attempts to estimate the economic value of ecosystem by trying to relate them to economically quantified reference values e.g. (real estate prices)
Ordinary least squares (OLS)	Simple mathematic approach attempting to fit a function by minimizing the sum of squared errors
Width and length of beach	Beach width is defined as the distance between the shoreline and the start of the beach. The beach length refers to its total shoreline distance

Popular summary

This study assesses the current status of beach ecosystems in the Kuching-Sarawak district Borneo, Malaysia. For the focus area information about the condition of the coastline is very limited. Therefore the aim of the study is to produce a basis fundament for introducing long term monitoring to the sites. Within the scope of the study is to assess the present characteristics of 11 local beaches, estimate the ongoing erosion process, rate their vulnerability to different environmental impacts and give future recommendations of how to proceed with the beaches in order to ensure sustainability.

For this purpose a so called "Coastal Integrity Vulnerability Assessment" in combination with a beach profiling and shoreline tracing has been conducted. The approach covers slope measurements of the beach by average determination and standardized questionnaires rating the impact of different environmental impacts on a scale from 1 to 5. The surveys include factors like sand deposition/erosion on the beaches, the adjacent vegetation, anthropogenic activities and developments, coastal communities and susceptibility to tidal changes and local phenomenon like monsoon and typhoon events. As a result of the environmental inventory a rating can be given, judging the overall vulnerability of the site, hence the urgency for human action to preserve it. Above that the area of the beach is assessed by combining Landsat satellite images provided by Google Maps and on site tracked GPS data via mobile GPS device. The so gathered data was used in ArcGIS software to compare it to historic images to assess the development of the beach over time.

The assessment revealed that the outcome of the vulnerability rating differs among the sampled beaches, giving a high vulnerability rating for Permai 1st Beach, a medium rating for Siar Beach and Pandan Beach and a low rating for the remaining sites. However, while the outcome is expected to give clear priority setting for conservation action it becomes evident that the questionnaire does not give credit to single parameters to a sufficient amount. The results of the area calculations have revealed that all of the sampled sites are subject to erosion: 4 of the beaches under focus (Siar, Pandan, Talang and Satang) are threatened to such an extent (3.37 – 15.17 %/year) by the depletion of sand resources, that their sheer existence is endangered in a foreseeable future. However, the outcome of the conducted vulnerability rating gives only low and medium ratings to the concerning sites. Therefore it is important that the design of the vulnerability assessment method is changed to take into account drastic developments more explicitly.

For future management strategies of the focus areas it is advisable to design an integrated coastal management package. The approach has to consider special characteristics of the given sites. The Talang-Satang NP for instance provides nesting sites for endangered turtle species like the Hawksbill turtle. A consecutive economical valuation of these features could give additional support for conservation measurements for the beaches. It is important to raise public awareness in the area and underscore importance features which makes the beaches unique. Ultimately a dedicated and site adjusted approach could connote a key procedure preserving these coastal ecosystems.

Introduction and objectives

According to recent scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report it is most likely that weather patterns will be altered globally in the face of climate change. Basically the frequency and magnitude of monsoon and drought events will tend to increase, resulting in a more unstable and unpredictable climate (IPCC 2014). Besides IPCC global climate model predictions, these tendencies have been verified by real world data (Hansen et al. 2012). This ongoing progress enhances the susceptibility of ecosystems to these external, multi-scaled stressors increasing the rate of exposure and ultimately the vulnerability of the system itself. Particularly vulnerable are coastal communities located in low degrees of latitude, which are subject to sea level rise and extreme globally dimensioned weather events (e.g. monsoon and drought periods) at the same time.

About 23% of the world's population live within 100 km of the coast and below 100 m above sea level (Small & Nicholls 2003). In the case of Malaysia, this applies for 98% of the total population (UNEP/COBSEA 2010), making it especially sensitive to the above mentioned factors. The Malaysian government has declared to counteract the adverse effects of climate change in its recent development plan (10th Malaysian Plan 2011).

The impact and the extent of such progresses can be described by ecological assessments. These surveys account for the current status of ecosystems by conducting a "natural inventory" as well as underscoring site specific features and processes. The outcome of such an approach describes the vulnerability of the ecosystem to site specific external stressors. If monitored regularly the collected data allows future predictions for the status of the site. The outcome of such an approach

Fig. 1: Scope of the study, location of Kuching-Sarawak area (basemap taken from Google Earth 2015)

In the research area of this study (Fig. 1), the surrounding of the city Kuching in the state of Sarawak, the coastal areas are primarily populated by small coastal communities. These communities mainly consist of fishermen, small business holders and workers for the development industry (Fig. 2).

The whole coastline, with exception of the Santubong Peninsular near Permai Beach, is not influenced by tourism. Residents rely strongly on the output of the wood logging, oil palm, agriculture and fishing industry, which is their main source of income.

Fig. 2: Small business settlements in Lundu

However, according to the locals, fish population appears to decline and the surrounding environment is increasingly monetized by e.g. the wood or palm oil industry. Often disregarded in this aspect is the situation at the beaches. Their contribution to the integrity of local ecosystems is often underrated and they did not appear to be an object of prior focus since the tourist industry in the study area is holding off.

Increased exposure of the study site to climate change related effects become more evident. Due to the special geography of the Kuching-Sarawak area, the coastlines are exposed to a big range in tidal magnitude: The local sea level oscillates between magnitudes of 3 to 4 m (Sarawak Marine Department (SMD) 2015)

Above that, the sporadic inundation of the coastal areas found its peak in the beginning of 2015. The Sarawak massive flood event forced 3,201 people to evacuate their homes and many major highways had to be closed (The Star 2015). The present development unveils that the region strongly demands well-elaborated monitoring approach to measure the impacts of the adverse effects of climate change (The Borneo Post 2014).

This study uses the Coastal Integrity Vulnerability Assessment Tool as a semi-quantitative scientific benchmark in order to reveal sensitivity, adaptive capacity and exposure parameters of coastal beach environments and compare multiple study sites. Consecutively the advantages and disadvantages of the approach will be evaluated.

In addition, the study aims for estimating the shoreline erosion at poorly investigated sites, giving further evidence to ongoing erosion claims in the area.

The data collected for this approach comprises shoreline GPS tracing, beach slope profiling, on-site status report within the use of CIVAT, tidal records, digital imagery (Landsat, Google Earth), literature research as well as communication with locals. Further evidence to ongoing erosion claims are assessed using an interview with an expert in coastal integrity

Research site

Sarawak state together with the state Sabah form the Borneo-part of Malaysia. Sarawak state is located between 0° 50’ and 5°N latitude and 109° 36’ and 115° 40’E longitude. The whole state of Sarawak extends over an area of 124,449.51 m² and features three different topographic areas: The coastal lowlands with its river deltas and peat swamp resources, the mountainous inland which goes up to 2500 m and the hilly transformation zone, connecting the other two focus areas.

The research site of this study (Fig. 3) focused around beaches and coasts of Kuching Division and its surrounding area. Most parts of the population in the studied sites concentrate in the capital Kuching, major areas of the coastline besides the villages of Lundu and Sematan remain widely sparsely populated. The yearly temperature averages around 27°C (Sarawak Government 2015)

Fig. 3: Kuching-Sarawak area provides the scope for the study (basemap taken from Google Earth 2015)

Turtle protection programs have a long history in Malaysia and especially in Sarawak. First designated hatching sites were introduced to Sarawak in the early 1950's. The Kuching Division of Sarawak provides breeding spots for Green Turtle, Hawksbill Turtle, Olive Ridley Turtle and Leatherback turtles (Tab. 1). However, populations of these show a steady decline. Reasons are commercial hunting, egg exploitation, decline in fish population and the recession of nesting habitats (Chan 2006). Special protected breeding sites have been assigned in Tanjung Datu National Park, Talang-Satang National Park (introduced 1999) and near Pandan Beach (Fig. 4). The beaches chosen for assessment of vulnerability are crucial for population growth of the above mentioned species. Of particular importance is the Talang-Satang National Park which has been introduced with its primary aim of conservation of Sarawak's marine turtle population. It is estimated, that 95% of Sarawak's turtle landings take place in the 4 islands of the Talan-Satang National Park (Sarawak Forestry Corporation 2014). It has been reported that during the period between April and September 2011 over 3,000 marine turtles had landed and layed around 200,000 eggs in the National Park area (The Borneo Post 2012).

Sarawak has been the first state in Malaysia to update conservation measurements under the Wildlife Protection Ordinance 1998, which prohibits the exploitation and trade of marine turtles, eggs and their derivative parts (Bali et al. 2002). However, another main threat to the turtle populations constitutes the loss in breeding habitats. Marine turtles show an extremely high affinity for their nesting sites and their status is threatened by ongoing erosion events in the research site.

Maintaining these sites and furthermore expanding potential sanctuaries needs to be assured in order to encounter the ongoing decline in turtle populations.

Tab. 1: Status of Sarawak's turtle populations (IUCN Red List of Threatened Species, WWF Malaysia)

	Scientific Name	IUCN Red List	WWF Malaysia
Green Turtle	Chelonia mydas	Endangered	Significant decrease in Sarawak since 1970
Hawksbill Turtle	Eretmochelys imbricata	Critically endangered	Limited info
Olive Ridley Turtle	Lepidochelys olivacea	Not listed	Declined by more than 95%
Leatherback Turtle	Dermochelys coriacea	Vulnerable	Declined by more than 99%

Fig. 4: Turtle nesting site on Talang Beach (left); green turtle breeding at Pandan Beach (right)

Shoreline erosion in Sarawak

The research area of Kuching division Sarawak experiences ongoing erosion events on its shorelines. This development has been supported by reports of the Malaysian government (Government of Malaysia Department of Irrigation and Drainage (DID) 2009). The process can have several causes and available data for the research site is limited. However, since movement of sand resources on beach systems is a dynamic phenomenon, the Input and Output has to be observed. New deposition of sand mainly comes from inland deposition or from sediment transport from the adjacent river systems. The latter has been consequently influenced by the adverse effects of non-sustainable sand mining in the nearby rivers and channels of the focus area (Fig. 5). Throughout the uncontrolled scooping of rivers the system can be damaged on several trophic levels (Padmalal et al. 2008). On a long-run the disturbance in the organism composition of the river system will raise its susceptibility to external stressors.

Fig. 5: Sand dredging activity in a river system near Tanjung Datu

Relevant for this study is that a speeding up of the sand transport within the river system ultimately affects the sand deposition on adjacent beaches. Since this approach constitutes a pioneer assessment there is no available data to what extent sediment transportation from the adjacent rivers to the beaches subject to this study takes place. However, aerial pictures of the area underscore the importance of sediment transportation of river systems. The Input of peat-draining river sediments into the ocean can be seen by the distinct brownish coloring in close proximity of the estuary. To a certain extent the turbidity can be detected all over the area of research (Fig. 6).

Fig. 6: Sediment Output of a river near Lundu (top) affects the turbidity in the study area (bottom)

Additionally it is to question to what extent sand mining close to the relevant sampling sites has affected the rate of erosion until now. Information on where and to what extent sand has been dredged offshore in the Kuching district Sarawak is not available. However, it can be assumed, that due to the dimension of Singapore's land extension and the proximity and huge sand dredging potential of the study area, relevant offshore dredging activities have been taken place at least until the ban of sand exports by the Malaysian government in 2007 (The New York Times 2007; Sarawak Government 2014). Above that, it is to question if extraction of sand resources is still ongoing. Reports on sand trade from both countries for United Nations' Comtrade database differ significantly, showing an amount of 130 million tons of undeclared sand imports from Malaysia in 2008 (Dredging Today 2010).

Vulnerability

The IPCC defines the vulnerability term in their Fourth Assessment Report (2007) as followed:

> **"***Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change*".
>
> (Intergovernmental Panel on Climate Change (IPCC) 2007)

The definition has been influenced fundamentally by Füssel and Klein (2006) and is widely and homogenously accepted among scientists. However, the complexity of the vulnerability term reveals difficulties to make it quantifiable.

Vulnerability is a dynamic phenomenon, comprising lots of multi-dimensional factors, each interconnected and acting on different scales: Resilience, susceptibility, exposure, sensitivity, adaptive capacity to mention only some of the complex characteristics of the term (Alwang et al. 2001). The attempt to translate it into a quantitative metric often sets apart from what an ecosystem actually represents. Scientific approaches end up converting it to biophysical or socio-economic indicators in order to give them a quantifiable value which in term attempts to deliver a clear statement to decision-makers to act. But a convenient approach to "invoice of natural productivity" does not do justice to the complex term of vulnerability, moreover it abstracts it away from its intricacy and causal implications (Alwang et al. 2001).

Ultimately the vulnerability term with its different components of exposure and potential impact aims to determine specific parameters interacting on multiple levels and scales. To judge the alteration of vulnerability by external stressors like the adverse effects of climate change, the observation has to be progressive and long-term, since events can be continuous and discrete, showing the various facets of this global and dynamic process (Romieu et al. 2010).

The CIVAT approach is used in this study aims for facilitating environmentally driven decisions by the local administration answering the issues stated above.

CIVAT

As indicated above, governments of developing countries show an increased sensitivity to climate change related issues, since decision on environmental sites often results in a dispute between accessing the necessity of action and a lack of institutional capacity to realize them (Adger 2006).

Altering effects of climate change to ecosystems are not easy to assess, since possible impacts are strongly dependent on an almost infinitely diverse actors and multiple stressors working on different scales (Adger 2006). Climate change addresses local phenomena like monsoon and droughts, but also long term effects like a change in temperature and a rise in sea level. The impacts itself can be local and severe, but are mostly slow paced and not recognizable if only watched over a small timespan. The response of local ecosystems exposed to climate change relevant factors is dependent on its susceptibility. The overall resilience is determined by interaction of coastal communities, vegetation cover, tidal movement, sand composition etc. For this reason, when taking mitigation steps, they have to be designed for a specific site, addressing local characteristics and implying the adaptive capacity of the system it got introduced to.

There are a lot of different approaches dealing with this issue and the variety of options to assess often confuses policy makers rather than giving them a clear guidance (Adger 2006). However, the majority of these assessments monitor shifts in regime composition for terrestrial, freshwater and marine systems to a sufficient amount, mostly neglecting the beaches.

Monitoring attempts which are dedicated to these sites often suffer under data limitation, low spatial resolution especially in rural areas. Above that simplistic assumptions of feedback and interlinkage of community effects decreases the efficiency to turn them into trustful decision supporting tools (Hinkel & Klein 2009).

In order to give clear guidance on these coastal environments it is inevitable to introduce long-term monitoring programs, assessing and quantifying core sets of parameters (Defeo et al. 2009). If properly funded and carefully conducted these approaches deliver powerful instruments, considering tons of environmental interactions, dependencies and scenarios. Basically, when addressing climate change related issues, reproducibility, long-term assessments and practicality in even low developed and rural areas is key. However, it has to be acknowledged, that most approaches account for multiple stress factors to a vulnerable systems, neglecting that these accounted stresses influence themselves among each other (Ribot 1995).

The Coastal Integrity Vulnerability Assessment tool (CIVAT) steps aside from overambitious attempts and focuses on the essentials. Through its simplicity it provides a tool which can be used by almost everyone and can be applied to a wide range of different coastal environments. Studies have shown that metrics which provide broad and easy application are considered being the most effective in this field (Luers et al. 2003) and therefore its convenience is a core strength of the approach. Nevertheless the CIVAT approach only becomes a powerful tool in assessing vulnerability of an ecosystem by supplying it with sufficient and consecutive data. If used properly it provides policy-makers guidance on which sites decisions need to be made.

Due to the lack of long-term monitoring data, the work presented here states a pioneering vulnerability assessment, focusing on providing a basis for consecutive research and indicating urgent hotspots for mitigation activities. Subsequent research might also include the involvement of social scientist and economists, producing a better understanding of complex, climate-sensitive systems and prioritizing target formulation of governments (Füssel & Klein 2006). With ongoing enhancements these approaches might even be capable to provide further economical legitimization by calculating financial loss scenarios (Flax et al. 2002).

Methodology

Beach profiling

To measure the profile of the beach CIVAT calls for a simplistic approach (Emery Method) that guarantees the ability to reproduce the data all over the world with little knowledge and low costs. The tools which are needed are an accurate GPS device (e.g. handheld Garmin), three one meter long metal poles with a measure tape attached (= ranging pole), an at least 30 m long measure tape, a camera, a notebook, a pencil and information about the tide level.

To conduct the survey there are at least 2 persons needed: Starting point is a permanent structure like a building or a fence at the beginning of the beach to assure reproducibility in the future. GPS coordinates of the starting point are noted down and the measure tape is rolled out straight to the shoreline. Information about the tide level, weather conditions, type of permanent structure and the daytime are written down in the notebook. The measurement takes place ±1 h of lowest tide level event.

Person A (Fig. 7) moves along the measure tape and places the ranging pole straight up at a set distance X. Person B places the ranging pole at the starting point and aligns their sightline of the horizon with the top of the ranging pole Person A is holding The difference in elevation Δz can be read out at the ranging pole by Person B and is noted down. Afterwards both persons walk down the set distance X along the measure tape and the step is repeated until the end of the beach is reached. If the slope rises, Person B uses a second ranging pole stacked on top of the other one. Δz is now noted down as a negative value. Noticeable changes of the beach profile, like a change of sand particle size, the presence of rock formations and river beds are noted down as well.

Note: Distance between the ranging poles and repetition of the method needs to be adjusted to the timeframe available and the length of the beach. For example: If the beach is comparably small and the slope is mostly even it calls for less repetition of the approach and the distance between the ranging poles are relatively low to increase the accuracy of the output. If the distance between the poles is low, the measurement is very time consuming and therefore it impedes the attempt to cover the full distance of the beach as well as it limits the amount of time available for subsequent surveys like the shoreline tracing.

Fig. 7: Beach profiling at Tanjung Datu

In the end the information about the length of the beach and the difference in elevation can be put together in the data analysis in Excel to calculate the overall slope of the beach. Data can be used to compare the susceptibility to erosion of the different beaches.

Shoreline tracing

The shoreline tracing method of the CIVAT is used to assess the full area of a beach by noting down GPS data of the shoreline area. At low tide level (± 1h) a person walks from the beginning of the beach along the shoreline to the end of it and consecutively notes down the GPS data at least every 50 steps (Fig. 8).

Fig. 8: Shoreline tracing at Tanjung Datu

Digital Processing

The gathered data can be digitalized in Excel and is converted into a *.kml file by KMLCSV converter (earthpoint.us) to be used in Google Earth and ArcGIS later. Using Google Earth, the correct location of the coordinates can be re-verified for the consequent use in ArcGIS. Screenshots from the sampling sites are taken from Google Earth and georeferenced into ArcGIS. The Geographic Coordinate System WGS 1984 has been used for the Data Frame Layer. For georeferencing at least 4 discrete locations (black-white dots) have been placed manually on the screenshot by creating placemarks in Google Earth. The geographic info of all the relevant points have been stored in a separate table.

The available Landsat imagery is used to calculate the overall area of the beach. Using distinct objects like vegetation and development sites to frame the borders of the beach and by linking it to set locations of the shoreline trace, a shapefile can be created (Fig. 9).

Fig. 9: Creating a shapefile in ArcGIS (left); overlay with basemap (right)

In order to calculate the possible recession of the area, historical Landsat images from Google Earth are used as an overlay and new shapefiles have been created, following the former shoreline of the Beach (Fig. 10). Afterwards the Geographic Coordinate System (WGS 1984) is changed into a Projected Coordinate System (WGS 1984 World Mercator) to enable area calculations of the created shapefiles. The calculation can then be conducted by activating the Geometry calculations in the attribute Table of the files.

Fig. 10: Overlay of shapefiles from recent and historic Landsat imagery

Tracking information about the date and time of the available images is strongly recommended to back-calculate the low tide events. Unfortunately the daytime data could not be retrieved. Therefore it was made sure that the consequently used images do not show spring tide events to reduce the impact on the exposure of beach area. Above that the low variability in low tide events is further discussed later on.

Basically the approach used here takes the available imagery that shows a more exposed beach with a larger area. This way it could be assured if there is ongoing erosion taking place on the site.

Note: The spatial resolution of the available Landsat data is relatively low and a most likelihood classification (MLC) cannot be conducted in ArcGIS.

Surveys

The following tables (Tab. 2 – 6) are from the Guidebook for "Vulnerability Assessment Tools for Coastal Ecosystems" (MERF 2013).They illustrate different parameters which have to be accessed to conduct a CIVAT. Each parameter is given a ranking, summed up it shows the overall impact of that set of parameters for the vulnerability calculation.

The sensitivity analysis (Tab. 2) comprises a set of intrinsic and extrinsic factors. The intrinsic parameters under research focus on the conditions of the beach itself. Hereby it is important to investigate if the beach shows long time developments of accumulating or depleting sand resources. The slope is a decisive factor for the susceptibility to physical stressors like waves and tidal changes. Basically a greater slope means greater resilience to such factors. In addition, a wide and continuous reef flat and a dense coverage by vegetation or coastal communities such as corals, mangroves and seagrasses contributes to the resilience as well. The extrinsic factors take into account anthropogenic activities like the building development on the foreshore with its concrete structures and piers and offshore alteration such as the removal of sand, corals and pebbles. The presence of these actions increase the overall sensitivity of the given site.

The Adaptive Capacity (Tab. 3) determines the actual capability of the system to be subject to adaptation measurements. Hereby it is more important to take a look of the overall development of the site and if prior protection guidelines have been introduced to it. A beach showing long term eroding effects and a lack in continuity of sediment supply has lower adaptive capacity, since it is difficult and expensive to counteract these developments. Above that, if the site in question does not hold any construction restrictions, designated setback zones for recovery and shows high commercial interest, steps for contributing to its integrity are impeded additionally.

The exposure variables analysis (Tab. 4) summarizes the exposure to physical external stressors in the tidal range and wave exposure. Ultimately a big threshold in the tidal range and a relatively great sea level rise increase the exposure of the site. This effect can be dampened by the presence of offshore structures like islands and the beach itself facing away from the ocean to limit exposure to monsoon events.

The results are used to calculate a rating for the given parameters using the CIVAT rescaling Guide (see Appendix). Afterwards the output is summarized by calculating the potential impact (Tab. 5), which reconciles the results of the exposure and sensitivity analysis. The final rating given by the CIVAT shows the overall vulnerability of the site (Tab. 6) and is a result of the potential impact reconciled with the adaptive capacity. This rating combines the above mentioned parameters and translates it into a low, medium or high ranking; judging the structural integrity of the site.

Tab. 2: Sensitivity analysis (MERF 2013, p. 83 Tab. 13)

Sensitivity		Low (1 - 2)	Medium (3 - 4)	High (5)
Intrinsic factors	**Seasonal beach recovery**	Net Accretion	Stable	Net Erosion
	Slope from the shoreline to 20-m elevation (landward slope)	greater than 1:50	1:50 – 1:200	less than 1:200
	Width of reef flat or shore platform (m)	Greater than 100	(50 - 100)	Less than 50
	Beach forest/vegetation	Continuous and thick with many creeping variety	Continuous and thin with few creeping variety	Very patchy to none
	Lateral continuity of reef flat or shore platform	greater than 50 %	(10 – 50)	less than 10 %
	Coastal habitats	Coral reef, mangroves and seagrasses or coral reef and mangroves are present	Either coral reef or mangrove is present	None
Extrinsic factors	**Coastal and offshore mining (includes removal of fossilized corals on the fringing reef and beach**	None to negligible amount of sediments being removes (i.e., sand and pebbles as souvenir items)	Consumption for household use	Commercial scale
	Structures on the foreshore	None; one or two short groins (i.e. < 5 m long) and/or few properties on the easement with no apparent shoreline modification	Short groins & short solid-based pier (5 to 10 m long); seawalls and properties with aggregate length of less than 10 % of the shoreline length of the barangay	Groins and solid-based pier > 10 m long; seawalls and other properties with aggregate length of more than 10% of the shoreline length of the barangay

Tab. 3: Adaptive Capacity analysis (MERF 2013, p. 86 Tab. 15)

Adaptive Capacity	Low	Medium	High
	(1 - 2)	(3 - 4)	(5)
Long-term shoreline trends (m/year)	< -1 (eroding)	-1 and 0	> 0 (accreting)
Continuity of sediment supply	If interruption in sediment supply is regional	If interruption in sediment supply is localized	If sediment supply is uninterrupted
Guidelines regarding the easement (setback zone)	No provision for easement (setback zone) in the CLUP and zoning guidelines	Setback policy is clearly stated in the CLUP and zoning guidelines; with <50% implementation	Implementation of setback policy is at least 50%
Guidelines on coastal structures	CLUP and zoning guidelines promotes the construction of permanent and solid-based structures along the coast	Clearly states the preference for semi-permanent or temporary structures to be built along the coast (e.g., made of light materials and on stilts) is in the CLUP and zoning guidelines	Prohibits construction of solid-based structures; For those already erected, CLUP/zoning guidelines has provision to remove or modify any structure causing obstruction and coastal modification
Type of coastal development	Industrial, commercial, highways, large institutional facility	Residential	Agricultural, open space, greenbelt

Tab. 4: Exposure analysis (MERF 2013, p. 79 Tab. 12)

Exposure variables	Low	Medium	High
	(1 - 2)	(3 - 4)	(5)
Rates of relative sea level change (RSLC; cm/year)	< 0.2	0.2 – 1.5	> 1.5
Wave exposure during monsoons*	Facing away from ocean	Intermediate effect	Facing ocean body
Wave exposure during typhoons* (coming from east)	Islands mitigating the impact of typhoon	Intermediate effect	No islands in front, directly facing typhoon
Tidal range	< 1	1.0 to 2.0	> 2

*after consultation with the local supervisor these parameters have been adapted to fit the sampling site

Tab. 5: Potential Impact calculation (MERF 2013, p. 88 Tab. 14)

Potential Impact				
	Sensitivity			
Exposure		L	M	H
	L	L	L	M
	M	L	M	H
	H	M	H	H

Tab. 6: Overall Vulnerability calculation (MERF 2013, p. 90 Tab. 15)

Vulnerability				
	Adaptive Capacity			
Potential Impact		L	M	H
	L	M	L	L
	M	H	M	L
	H	H	H	M

Interview

Prior assessments of the research area have revealed a depletion of sand resources in the area between Tanjung Datu and mount Santubong (Malaysian Government Department of Irrigation and Drainage (DID) 2009). However, the reasons remain wildly unknown and literature about the sites in question is limited. Adjunct research professor Chou Loke Ming is a leading expert in the field of marine ecosystem integrity in the South East Asian seas. He has published several reports and held various speeches of how the integrity of coastal system is endangered in the face of climate change, anthropogenic pressure and erosion (L. M. Chou (ACSEE) 2014).

Results of this talk should help to reveal possible causes for erosion and give recommendations about adaptation options as well as putting the findings into a more societal and regional context (full interview see Appendix).

Results

The results shown below are a summary of the main findings on the sites. The picture in the top left is a self-taken shot of the actual field site, the date can be found above. The bottom left picture visualizes the location of the beach marked with a star (☆).

The top right picture shows the most recent available image of the sampling site, with the date displayed left from it. The results of the on-site sampling can be seen here. The red flag ( ) shows the GPS location of the starting point for the beach profiling. The results of the beach profiling are displayed in the very bottom left of the figure. The camera ( ) indicates the point where the photography from the top left has been taken. The teal marking ( ) shows the result of the shoreline tracing, each sampling point is noted down. The results of the shoreline tracing should not be confused with the actual image presented here. It is just the reference image for the calculations of the region landwards. The total, GIS calculated area of the beach, can be seen left from the picture. The picture in the bottom right is the available comparison image. It shows a Landsat image where a tidal event has exposed more beach area than in the low tide event during the sampling. The date of the picture and the calculated area are illustrated left from the picture. The results of the CIVAT have been displayed in the center of each figure. Low values of the three main indicators (sensitivity, adaptive capacity, exposure) are indicated in green, medium values in yellow and high values respectively in red. The overall Vulnerability factor can be seen in the very bottom right of the figure.

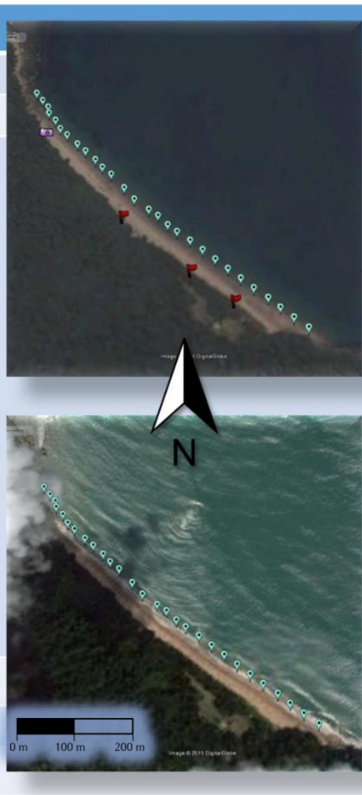
Tanjung Datu 1st Beach

Sample Date: 8.06.2015

Date Landsat Imagery	13.05.2014
Area [m²]	55,715

CIVAT		Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope	1		
	Width	1		
	Vegetation	2		
	Lateral continuity	1		
	Coastal habitats		4	
	Mining	1		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	1		
	Sediment supply			5
	Setback zone			4
	Guidelines	2		
	Coast Development		4	
Exposure	Sea level change	2		
	Exposure monsoon		3	
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	12.04.2002
Area [m²]	57,977



Overall Slope :	-4.90 % ± 0.59	Overall CIVAT Vulnerability:	LOW

Fig. 11: Results Tanjung Datu 1st Beach

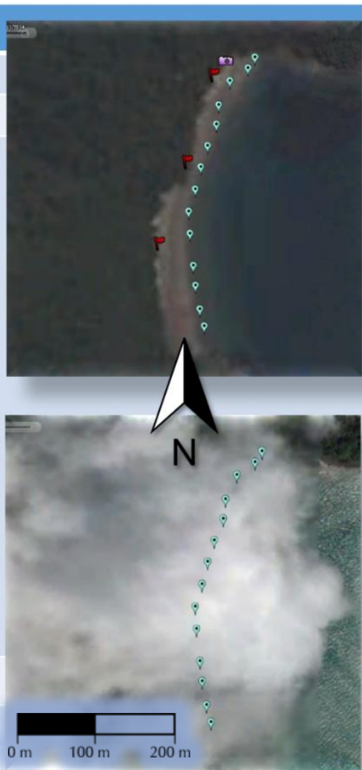
Tanjung Datu 2nd Beach

Sample Date: 9.06.2015

Date Landsat Imagery	13.05.2014
Area [m²]	21,870

CIVAT		Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope	1		
	Width	1		
	Vegetation	1		
	Lateral continuity	1		
	Coastal habitats		3	
	Mining	1		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	1		
	Sediment supply			5
	Setback zone			5
	Guidelines			5
	Coast Development			5
Exposure	Sea level change	2		
	Exposure monsoon		3	
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	18.11.2011
Area [m²]	-



Overall Slope :	-3.62 % ± 0.77	Overall CIVAT Vulnerability:	LOW

Fig. 12: Results Tanjung Datu 2nd Beach

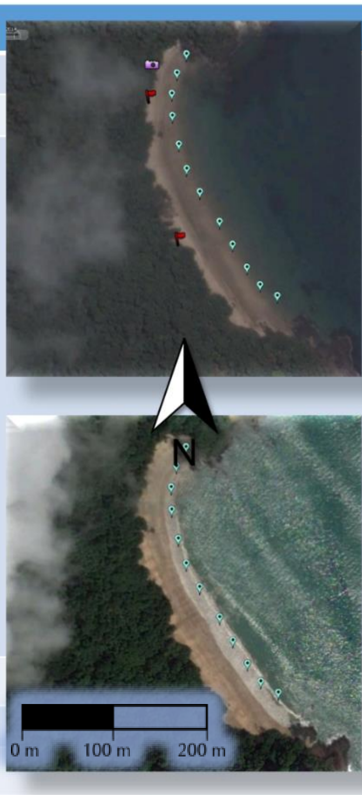
Tanjung Datu 3rd Beach

Sample Date: 9.06.2015

Date Landsat Imagery	13.05.2014
Area [m²]	20,102

CIVAT		Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope	1		
	Width	1		
	Vegetation	1		
	Lateral continuity	1		
	Coastal habitats		3	
	Mining	1		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	1		
	Sediment supply			5
	Setback zone			5
	Guidelines			5
	Coast Development			5
Exposure	Sea level change	2		
	Exposure monsoon		3	
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	18.11.2011
Area [m²]	21,363



Overall Slope :	-4.28 % ± 0.19	Overall CIVAT Vulnerability:	LOW

Fig. 13: Results Tanjung Datu 3rd Beach

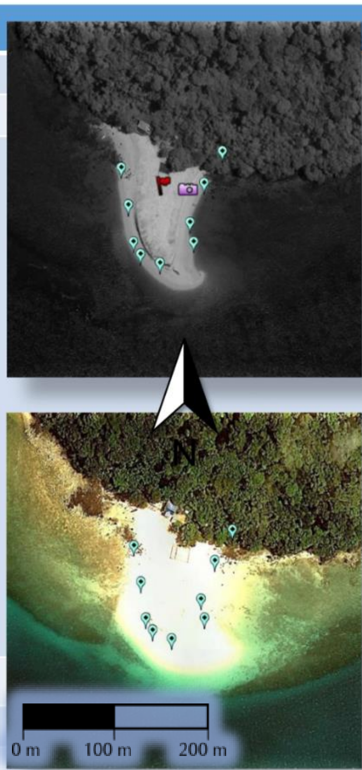
Talang Beach

Sample Date: 10.04.2015

Date Landsat Imagery	26.04.2012
Area [m²]	9,612

CIVAT		Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope	1		
	Width	1		
	Vegetation	2		
	Lateral continuity	1		
	Coastal habitats	1		
	Mining	1		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	1		
	Sediment supply		4	
	Setback zone		3	
	Guidelines		4	
	Coast Development		4	
Exposure	Sea level change	2		
	Exposure monsoon		3	
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	8.11.2010
Area [m²]	29,167



Overall Slope :	-7.57 % ± 1.39	Overall CIVAT Vulnerability:	LOW

Fig. 14: Results Talang Beach

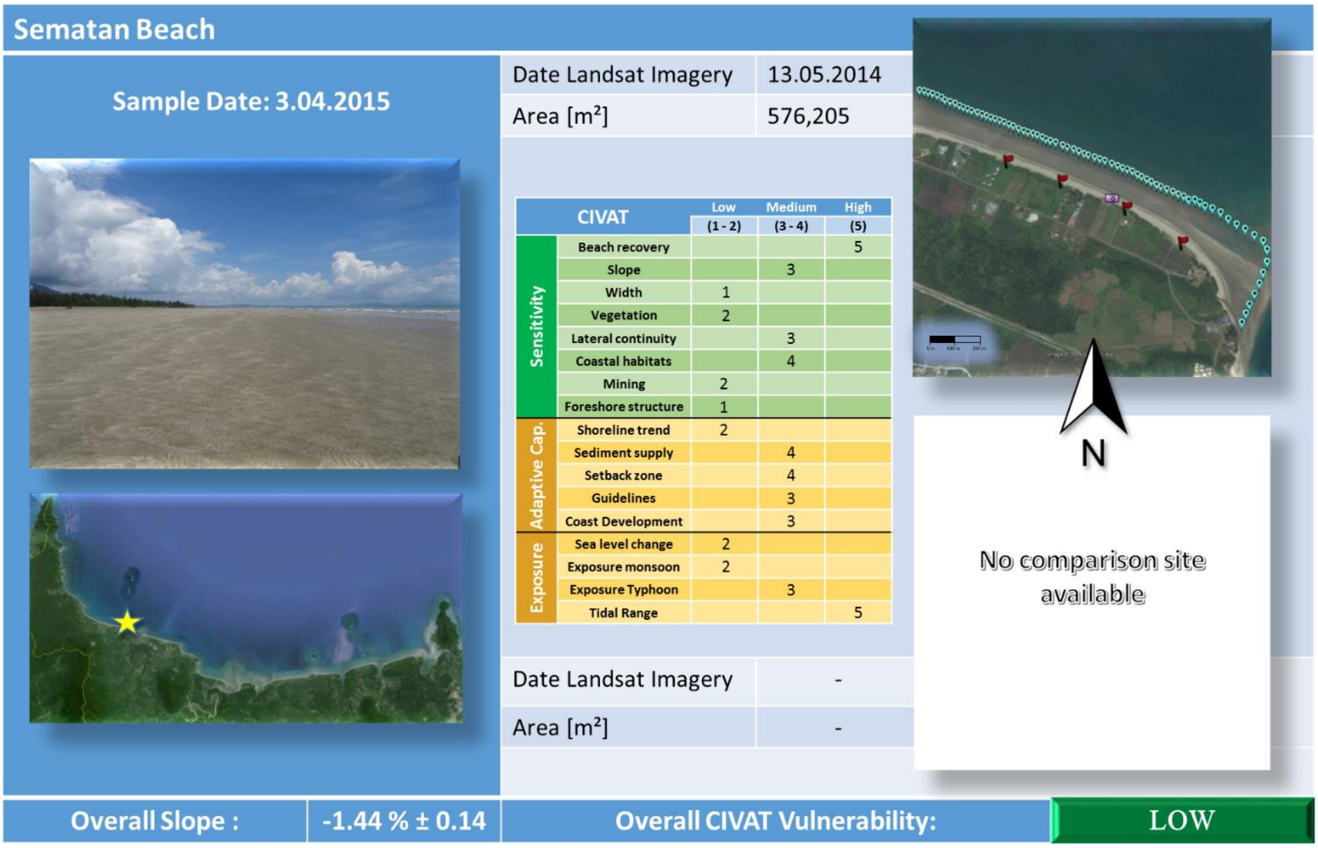


Fig. 15: Results Sematan Beach

Fig. 16: Results Pandan Beach

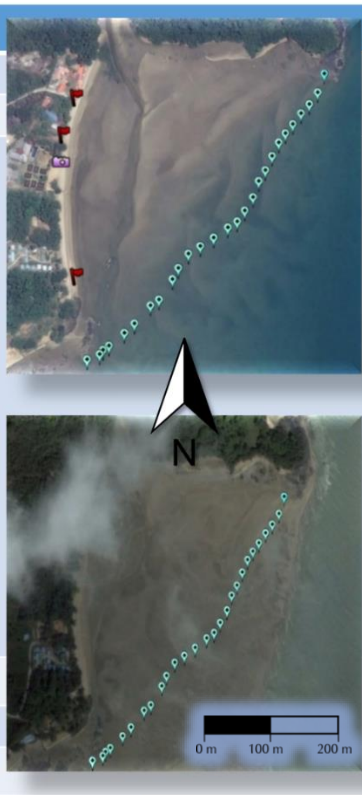
Siar Beach

Sample Date: 4.04.2015

Date Landsat Imagery	25.07.2014
Area [m²]	246,441

	CIVAT	Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope			5
	Width	1		
	Vegetation		4	
	Lateral continuity	1		
	Coastal habitats		4	
	Mining		3	
	Foreshore structure	2		
Adaptive Cap.	Shoreline trend	1		
	Sediment supply			5
	Setback zone		3	
	Guidelines		4	
	Coast Development		3	
Exposure	Sea level change	2		
	Exposure monsoon	2		
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	12.04.2002
Area [m²]	438,207



Overall Slope :	-0.45 % ± 0.04	Overall CIVAT Vulnerability:	MEDIUM

Fig. 17: Results Siar Beach

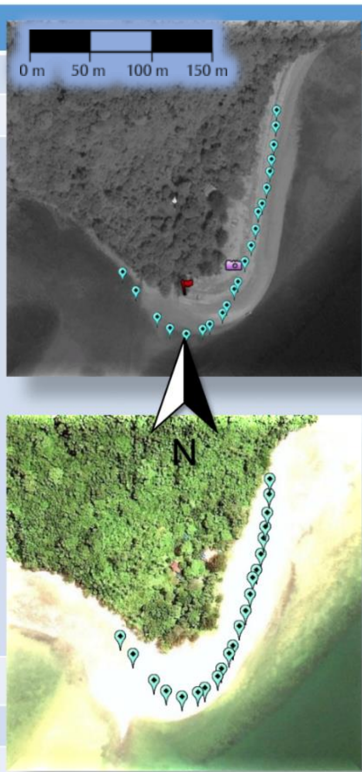
Satang Beach

Sample Date: 24.06.2015

Date Landsat Imagery	02.05.2015
Area [m²]	10,093

	CIVAT	Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope		3	
	Width	1		
	Vegetation	2		
	Lateral continuity	1		
	Coastal habitats		4	
	Mining	1		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend			
	Sediment supply		4	
	Setback zone		4	
	Guidelines		4	
	Coast Development		3	
Exposure	Sea level change	2		
	Exposure monsoon		3	
	Exposure Typhoon		3	
	Tidal Range			5

Date Landsat Imagery	20.06.2010
Area [m²]	26,241



Overall Slope :	-1.2 %	Overall CIVAT Vulnerability:	LOW

Fig. 18: Results Satang Beach

Pasir Panjang Beach

Sample Date: 19.04.2015

Date Landsat Imagery	26.05.2014
Area [m²]	69,799

	CIVAT	Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery			5
	Slope			5
	Width	1		
	Vegetation		4	
	Lateral continuity	1		
	Coastal habitats		4	
	Mining	2		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	2		
	Sediment supply		3	
	Setback zone	2		
	Guidelines	2		
	Coast Development		3	
Exposure	Sea level change	2		
	Exposure monsoon	2		
	Exposure Typhoon	2		
	Tidal Range			5

Date Landsat Imagery	-
Area [m²]	-

No comparison site available

Overall Slope :	**-7.99 % ± 0.46**	**Overall CIVAT Vulnerability:**	**LOW**

Fig. 19: Results Pasir Panjang Beach

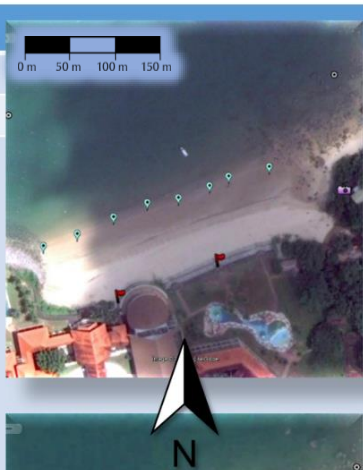
Permai 1st Beach

Sample Date: 9.05.2015

Date Landsat Imagery	26.05.2014
Area [m²]	11,103

	CIVAT	Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery		4	
	Slope		3	
	Width	1		
	Vegetation			5
	Lateral continuity	1		
	Coastal habitats		4	
	Mining		4	
	Foreshore structure		3	
Adaptive Cap.	Shoreline trend	2		
	Sediment supply		3	
	Setback zone	1		
	Guidelines	1		
	Coast Development	2		
Exposure	Sea level change	2		
	Exposure monsoon	2		
	Exposure Typhoon	2		
	Tidal Range			5

Date Landsat Imagery	8.03.2003
Area [m²]	13,712



Overall Slope :	**-1.57 % ± 0.12**	**Overall CIVAT Vulnerability:**	**HIGH**

Fig. 20: Results Permai 1st Beach

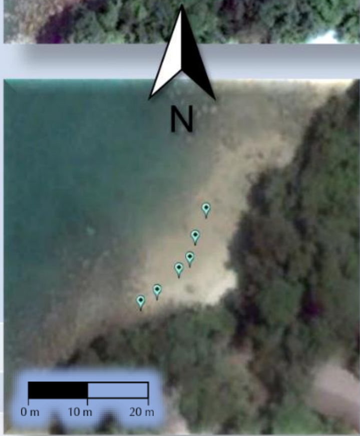
Permai 2nd Beach

Sample Date: 8.05.2015

Date Landsat Imagery	26.05.2014
Area [m²]	735

CIVAT		Low (1 - 2)	Medium (3 - 4)	High (5)
Sensitivity	Beach recovery		3	
	Slope	1		
	Width			5
	Vegetation	1		
	Lateral continuity	1		
	Coastal habitats		4	
	Mining	2		
	Foreshore structure	1		
Adaptive Cap.	Shoreline trend	2		
	Sediment supply		4	
	Setback zone			5
	Guidelines			5
	Coast Development			5
Exposure	Sea level change	2		
	Exposure monsoon	2		
	Exposure Typhoon	1		
	Tidal Range			5

Date Landsat Imagery	8.03.2003
Area [m²]	892



Overall Slope :	-10.55 %	Overall CIVAT Vulnerability:	LOW

Fig. 21: Results Permai 2nd Beach

The results of all of the 11 beaches under investigation (Fig. 11 – 21) show between minor up to massive erosion events over the last years. For three of the mentioned sites (Tanjung Datu 2nd Beach, Sematan and Pasir Panjang) there was no imagery Landsat data available. This is due to distortion or cloud cover. Above that, the muddy sediment at Pasir Panjang made it impossible to trace the shoreline to the very end. However, detection of net erosion of sand resources in the Kuching Division-Sarawak has been reported by the Malaysian Government Department for Irrigation and Drainage (Malaysian Government Department of Irrigation and Drainage (DID) 2009). Therefore this finding is incorporated in the shoreline trend of the CIVAT. The sampling conditions were the same everywhere: sunny and calm. The number of samples for the beach profiling have been adapted to the structure of the beach and the available timeframe.

The results of the CIVAT give a medium vulnerability ranking to two sites (Pandan Beach and Siar Beach) and a high ranking for Permai 1st beach. The remaining 8 beaches show a low vulnerability rating. The sensitivity rating is medium for Permai 1st beach, Pandan Beach and Siar Beach, for the remaining ones there is only a low sensitivity given.

The adaptive capacity gives for all the beaches besides Permai 1st at least a medium rating, only the aforementioned one shows a low level of possible adaptation impacts.

The exposure rating shows a medium result for all the sampling sites under research.

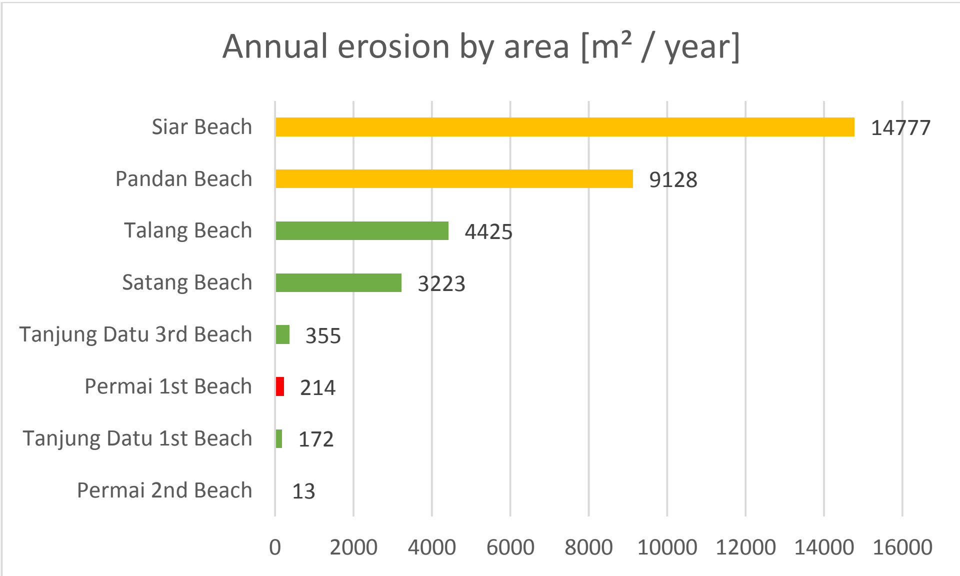


Fig. 22: Annual erosion by area in m² per year (CIVAT rating indicated by the respective bar color)

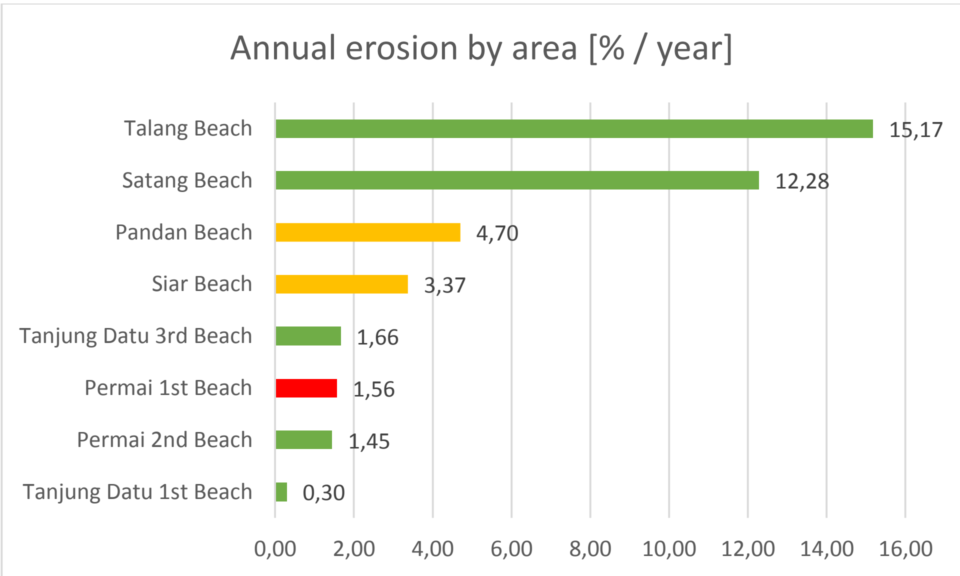


Fig. 23: Annual erosion by area in % of total beach catchment per year (CIVAT rating indicated by the respective bar color)

While comparing the annual erosion by area per year (Fig. 22) it becomes quite evident that at least 4 of the beaches (Siar Beach, Pandan Beach, Talang Beach and Satang Beach) show massive depletion of sand resources over the last years. The annually decrease of beach area of Siar beach actually translates into the area of 2 soccer fields (~2.07) disappearing each year.

When putting the same data in a different view and having a look at the percentage of disappearing beach in relation to its overall area (Fig. 23) a different ranking can be seen. It is still the same four beaches underscored from the previous figure which show a crucial development. But in relation to its overall size, Talang Beach (15.17 %) and Satang Beach (12.28 %) show an annually decline which endangers their existence in the coming years.

The interview has underscored ongoing developments in the Kuching Division Sarawak and revealed possible conservation approaches for the future. Therefore it is important to implement a holistic, integrated coastal management approach. A package considering the vulnerability assessment like CIVAT enhanced by economical quantification measures to make the issue apparent and negotiable for associated policy makers.

Developments in this area are fundamentally driven by the economic interest of the logging and palm oil industry. If the valuation of the beaches is not presented by analytical assessments, no profound conservation action will take place. Consequent mitigation options would only be maintained by introducing long-term monitoring of the sites and in-depth revision of the UN Adaptation Fund system to assure to the point financing. Above that the approach should feature a policy harmonization between federal and marine government to make such issues legally addressable on water and land likewise. In case that the issue will be ongoing and neglected by local governments, ecosystem services will disappear and remain unrecoverable for the future.

The results until now only give a hint of possible causes of the massive erosion events. Nevertheless the interview supports the claim that the integrity of the beach systems under research is substantially influenced by sand dredging activities within the river systems, the alteration of inland vegetation by the logging and palm oil industry as well as former offshore activities in the area by the state of Singapore. To what extent this development takes place, if it constitutes a recent or an over decades ongoing event can only be determined if long-term monitoring in the area takes place.

Discussion

Technical considerations

The results of the study have revealed massive depletion of sand resources of at least some of the focus areas. However, basically the results should be analyzed carefully before judging the overall susceptibility of the site.

First and probably most important, the historical Landsat imagery available on Google Earth provides only a rough reference to what extent the erosion takes place. The timespan between the reference pictures varies greatly due to limited availability and quality/resolution of the aerial imagery. It was a common issue that a lot of pictures in these mostly less developed areas lack these kind of characteristics. The reference picture of Permai 2nd Beach (Fig. 21; bottom right) for instance showed a slight lateral distortion while putting it into the WGS 1984 reference system in ArcGIS. Further re-adjustments of the image overlay decrease the accuracy of the approach. Above that, the Pasir Panjang site showed very muddy characteristics making it impossible to trace the shoreline by foot. The data gathered here cannot be used for consecutive studies, showing a demand for an alternative technique.

Additionally it is to question if the historical reference imagery actually shows low tide events. If this is not the case, the erosion of the beach could be even more evident than stated in the results. Actual daytime data of the comparison site could not be retrieved and an approach to estimate the daytime by judging the shading of trees and buildings had to be neglected due to low image resolution. Above that, the presence of the new moon event has an impact on the tidal range as well (Hammons 1993). Therefore, to increase the overall accuracy of the approach, on site sampling has been conducted at least two full days apart from full/new moon events. In addition the low variability of low tides over the years should be considered (Fig. 24) as well as the expected level in sea level rise in the coming years (Ercan et al. 2013). Despite the fact that the variation in low tides in the graph (Fig 24.) appears to be relatively high, only a few actual data points come into consideration. For example, when taking the latest available low tide tables from 2014 and excluding spring tides (± 2 days) as well as low tides events during the night, the overall standard deviation is relatively low: 1.68 m ± 0.24 m for the respective sampling period between April and July (Director of Marine Sarawak 2014).

The data is consequently used to verify the claim of erosion in the focus areas by weakening other factors which could have possibly influenced the exposure of beach surface on the satellite images.

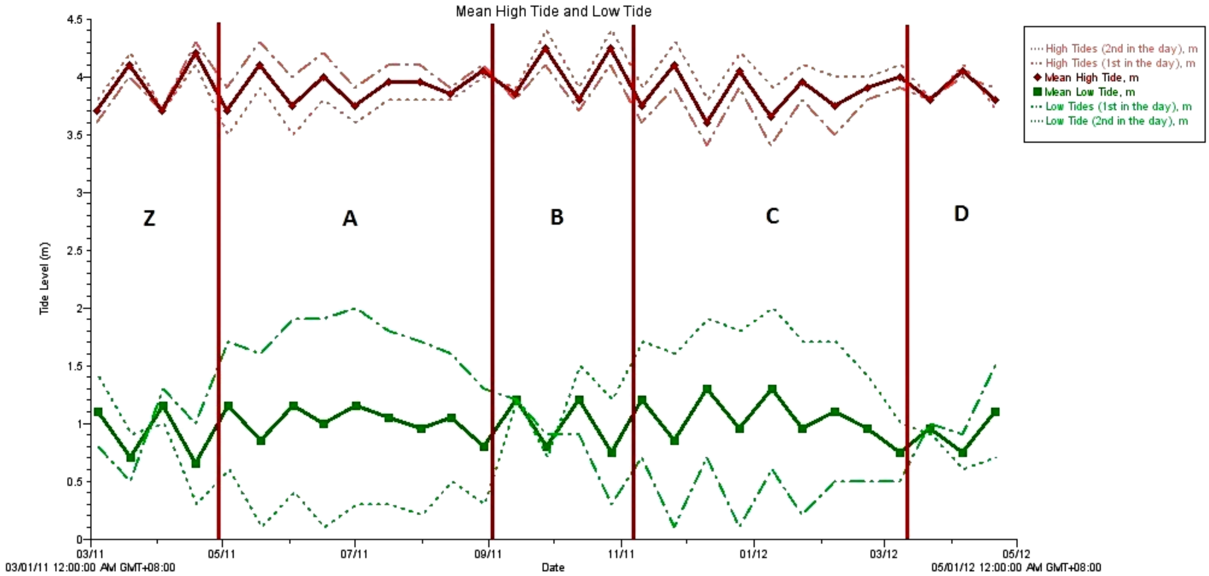


Fig. 24: Mean low and high tides from March 2011 to May 2012 in Sematan. Reproduced with permission. (Ng Chiew-Tyiin 2012)

Where the shoreline tracing showed great accuracy of the mobile tracking device and reproducibility by application into different software, the beach profiling revealed clear weaknesses. For beaches which show a broad width and an even slope as characteristics like the Tanjung Datu Beaches (Fig. 11 - 13), Sematan Beach (Fig. 15) and comparable sites the approach is absolutely accurate and gives a clear idea of the susceptibility to waves and tidal variability in the studied sites. However, when it comes to beach profiles which show an uneven gradient like Talang Beach (Fig. 14) and Satang Beach (Fig. 18; top right) the approach does not properly reflect the given characteristics of the site. For instance the latter shows after 51 m a slope of -0.79 %, but the remaining 9 m show an increase in slope to -9.65 %. Displaying the overall slope with –1.20 % does not represent an accurate indicator to judge the susceptibility of the site. Above that, due to the very uneven shoreline course it is to question if additional profiling attempts of the beaches would increase the accuracy of the tool. This also affects the comparability between beaches, which can only be made if both samples show a very even slope.

When projecting the current development of the sites in the face of erosion and relate it to the CIVAT vulnerability rating; the approach, in the present state does not indicate higher than medium need for action in the most crucially eroding sites: Siar Beach, Pandan Beach, Talang Beach and Satang Beach. Furthermore, future monitoring approaches would most probably not raise the rating on these sites. The CIVAT approach used in this study gives a broad set of parameters applicable for the sites, but does not allow the necessary step here to prioritize certain factors by giving them additional weighting.

The erosion factor (= shoreline trend) is just 1 of 5 parameters in the adaptive capacity rating (Tab. 2), which itself is just 1 of 3 parameters adding up to the actual vulnerability rating (Tab. 3). The approach lacks the opportunity to prioritize certain factors in order to point out key developments for the focus areas. For instance, a slight amplification of a single indicator can already have a big impact: As mentioned in the introduction, the Kuching Division due to its coastal geography is subject to large oscillation of low and high tide events (Sarawak Marine Department (SMD) 2015). Due to that fact the tidal range in the exposure rating (Tab. 4) receives 5 points and is 1 of a total set of 4 parameters all the exposure ratings have been raised to an at least medium scaled rating in that regard.

Possible causes of erosion

The results have shown that the ongoing beach erosion is the major concern of the study sites. This development has to be questioned and possible causes need to be faced as soon as possible. Besides the river dredging activities, which have been mentioned earlier, the integrity of coastal beach systems is further threatened by the intensive alteration of the Inland of the Kuching division Sarawak. Due to a boom of the logging and consecutively oil palm industry in the 1970's (Fig. 26) the area has experienced a decrease in tropical rainforest which is without comparison even when put in a worldwide perspective: Over the last decades Sarawak has lost over 90% of its primary tropical rainforest (The Economist 2012). The forest stand, especially the mangrove vegetation in Sarawak, is a crucial factor for sustaining the integrity of local beach ecosystems by protecting them from erosion (Bennett & Reynolds 1993). It is important to acknowledge this factor has influenced the coastal integrity, but to measure the actual impact is beyond the scope of this study.

Fig. 26: Oil palm plantation in Sarawak

Additionally it is to question to what extent sand mining close to the relevant sampling sites has affected the rate of erosion until now. As mentioned earlier, available data here is limited. Former off-shore sand mining activities could have caused permanent disruption in the stability of the sites sand resources. Basically the common response of a beach system to off-shore mining is forming a dissipative profile in order to cope with the enhancement of the horizontal penetration of waves. As a result the overall surface and slope will be flattened and lowered (Nordstrom 2000). Sematan Beach, Siar Beach, Pasir Panjang Beach and Permai 1st Beach showed a remarkable resemblance of this type of response. This trend could be supported by statements of local inhabitants. Nevertheless, it is recommended to conduct further research on the mentioned sites to gather a better understanding of the development which causes the flattened profile of the beach. Deep off-shore intervention of sediment transport is followed by a hysteresis effect which is a strong characteristic response of coastal beach systems. The initial erosion period is thus followed by a persistence consecutive loss of sand resources of the studied beaches, accumulating in the low-tide platform (Borges et al. 2002).

The reaction mentioned above is the direct effect altering the profile of a beach. The indirect effect is more difficult to estimate. It constitutes an interrelation between the change in offshore depth affecting the size and movement of waves and ultimately changing the sediment transport to the beach. Hereby the depth of the dredged hole thus has a bigger influence than its cross-shore length and its impact is virtually independent to its longshore width. Therefore a recommended approach is, if offshore dredging cannot be avoided, to scoop at the deepest spot in the ocean to minimize impacts on local shoreline deposition (Hüseyin 2004).

In the future this development has to be addressed throughout a policy harmonization as suggested in the interview. Only by making land and sea issues legally tangible at the same time the impact of dredging activities can be restricted.

Above that, the sea level rise, which comes along with progressing climate change could show a reinforcing effect on the beaches response to form a dissipative profile: Malaysia's geographic location and climate makes it subject to greater sea level rises than predicted in the worldwide average scenarios (NAHRIM, 2010). However, in national comparison the expected sea level rise of the study site remains relatively low. Until 2040 the Kuching-Sarawak area shows a rise in sea level of 0.161 m and until 2100 it adds up to 0.592 m (Ercan et al. 2013). The response of a sandy beach ecosystem to this development is a recession of local mangrove resources as well as an adaptation of the beach profile itself. The so called bruun rule describes the effect: The face of the beach is building up vertically but retreats landwards in order to maintain an equilibrium in profile (Harvey & Woodroffe 2008). This could have been a further development increasing the physical response of the beach in order to cope with the altered hydraulic patterns afflicting the sandy ecosystem.

Results Landsat Imagery and GIS

The results have shown, that a combination of recent and historical Landsat images from Google Earth and subsequent use of GIS to determine the surface area of the beach, constitute a powerful tool to assess the overall beach erosion. This has been proven by prior studies and could here be verified (Anfuso et al. 2009).

The overall expenditures are relatively low and the data procession can be made far off from the site. The gathered data facilitates easy reproducibility and it provides a starting point for long-term monitoring. For future projection of the development of the surface area additional data collection is indispensable. The collected data can be updated periodically and gives consideration for describing a dynamic process. Hereby it would be of great interest to investigate the evolution of the beach before and after monsoon events or great storms.

Possible CIVAT Alternative

Besides the mentioned limits for the CIVAT approach, literature about vulnerability assessments and in general theoretical knowledge about coastal ecosystems and its valuation options is expanding greatly (Brander et al. 2012). On the other side, experience in applying these assessments in development countries and moreover rural areas is very limited (Schwarz et al. 2011). The practicality in these areas can only be improved by expanding the scope of application for these kind of approaches.

Besides it is to question if there is an actual best solution: One which incorporates a chosen set of parameters and weighting of each; considering enough details to cope with local diversity while being general enough to allow broad scaled application. The progress of developing such a powerful tool is still in its infancy. State of the art research provides a long list of well-elaborated approaches, but lacks the actual homogeneity it needs for linking and comparing sites.

The coastal vulnerability index (CVI) is one of these alternative approaches which finds broad application today and has been fundamentally influenced by Gornitz in the early 90's, by trying to find a way to create a vulnerability database for coastal ecosystems (Gornitz et al. 1994). Basically the CVI is calculated as the square root of the product of the ranked variables divided by the total number of variables. The variables and their distinct ranking process can be entirely different from study to study and therefore can show high dedication to certain ecosystems and their comparability among each other (Boruff et al. 2005; McLaughlin & Cooper 2010).

This attempt has been further re-shaped and enhanced consecutively by many to project it to different coastal environments (e.g. Vittal Hegde et al. 2007). Above that, the weighting process has been re-evaluated and more recent approaches consider sub-indices which dedicate to the socio-economic framework where the adaptation measurement are being introduced to (McLaughlin & Cooper 2010). The latter is a decisive factor to assess the feasibility of the whole approach. If the results of the assessment provides clear recommendation e.g. prioritization of certain sites, but it cannot be sufficiently translated into legal action, the whole project loses its relevance. Basically the socio-economic circumstances of the area is the key fundament where action should be adjusted to. However, also for this factor it is critically discussed to give explicit values. Socio-economic systems are sensitive to changes in global economics or policies (McLaughlin et al. 2002). This dynamic component impedes the process of making it accessible for such an assessment. This occurrence is to some extent comparable to the effect climate change has on the assessed vulnerability parameters given by the CIVAT approach. The impacts can be calculated to a certain extent by assuming different scenarios, but the future dynamics of the system cannot be completely understood by present approaches.

The way CIVAT and CVI work is very akin, they are just likely to take into account different parameters and indices and weight them differently. It is important to acknowledge that the flexibility of the CVI tool impedes its function to create global comparability of beach ecosystem. At a certain degree, a coastal assessment becomes simply too site specific. Further re-evaluation of the approaches and testing their robustness by sensitivity analysis can provide more evidence, but is not within the scope of this study. However, in order to make the tool more powerful it should be considered if the inclusion of non-environmental related factors makes sense here.

As underscored in the interview, developments of the study site are mainly driven by the economic interest of big industries. Therefore is important to recognize the socio-economic component as a part of the assessment, improving its overall applicability. Mechanics would tackle more efficient here if the approach is not considered an analytical tool as a stand-alone. An integrated coastal management approach should on the one hand consider all the environmental aspects but on the other hand also take into account that these steps call for a proper translation into local conditions. At the end of the day it is about introducing a different way to access resources and development issues by governments as well as individuals (Luers 2005).

Mitigation options

Taking a view to a more global perspective it has to be acknowledged that the issue itself is additionally branded by a worldwide development, going along with a more and more industrialized and globalized world: There is a so called double inequity between responsibility/capability between first world and development countries (Füssel 2010). This means that Malaysia's rural populations are in the position that due to their proximity to the equator area they suffer the most of the adverse effects of climate change even though they are not responsible for its causes. The country itself has increased its sensitivity and exposure level to these changes by altering natural habitats due to extensive fishing, logging and palm oil industry activities. Based on this initial position the effects which go along with climate change are more subtle, hard to grasp and leaves locals with a feeling of powerlessness behind (Grothmann & Patt 2005). Having this general development considered, a holistic approach (Gornitz et al. 1994; Hennecke et al. 2004) has to provide a powerful tool in empowering the locals. Basically the whole step is to enable a consistent translation of robust and measurable indices of resilience and vulnerability into well-adjusted adaptation measurements for local sites. However, as already underscored by Adger, there is a missing link of turning the outcome of the research into legal practice (Adger 2006). For that matter one has to acknowledge that managing such rural and less developed areas requires different approaches than for tourist areas, where such action could simply be funded by taxation of hotels and recreational activities.

During the work on the focus areas, interviews with people in Lundu and Sematan have shown, that the locals are well aware of their declining ecosystem services. However, they feel incapable of taking action and see themselves as powerless minorities (Grothmann & Patt 2005). This draws a link to comparable situations worldwide, despite the fact that native tribes enjoy a lot of rights and respect in most development countries.

The above mentioned development can be counteracted: Studies have shown that by gaining a better understanding of community-level governance and creating social cohesion down to the individual scale, the collective action might enhance the perception of people being able to cope with change. (Schwarz et al. 2011). This social consensus has to be created and maintained, especially when it comes to managing rural areas.

It is to question which measurements would be most advisable to the sites, especially the ones suffering from large erosion events (Siar Beach, Pandan Beach, Talang Beach and Satang Beach). Basically the objective should be handled with care, since it is most likely that certain responses like the erosion of the sites might be a result of a certain stressor which has been the case on a comparable site. However, a link between an external stressor and a certain response is not applicable globally since the effect alters with space and time (Tol & Yohe 2007). Therefore the following recommendations should be revised thoroughly before introduced to the area.

One possible option to tackle the progressing erosion is to shift the processes down drift by introducing hard structures to the area. However, it is questionable to what extent such an encroachment constitutes an adverse effect to the ecosystems virtually unaffected by anthropogenic activity until now (e.g. Tanjung Datu). Above that and even more a concern, to what extent the introduction of hard structures can actually alter the sand movement mainly characterized by the sand input from adjacent riverine and upland systems and the aftermath of former offshore dredging activities. Ultimately the implementation of hard structures affects regional species diversity. It alters hydraulic patterns, affects the sediment deposition and grain size and contributes to habitat heterogeneity (Airoldi et al. 2005). Before such an approach is operated the possible impacts on short and long term susceptibility of the site should be investigated.

Another approach would constitute the refilling of sand resources from local supplies. However, results of related studies question the long-term effect of beach nourishment for mitigating the adverse effects of climate change (Gopalakrishnan et al. 2011). In general this approach is not sustainable and will constrain the budget available for treating these sites. In the case of virtually untouched sites (Tanjung Datu) a different approach might be more viable:

A sustainable conservation approach should be introduced to the studied sites in order to protect the coastal flora and fauna without deep human interferences of the sites. A transitional solution, as suggested in the interview, could be the designation of the sites as marine reserves (MRs) and marine protected areas (MPAs). This method has not been common practice until now for sandy beach ecosystems. The idea behind that method is that part areas could be converted into special protection zones excluding anthropogenic activities. Basically this would provide refugium for coastal organisms threatened by the increasing commercialization of the area by the logging and oil palm industry. The approach would maintain integrity of the ecosystems and its efficacy could be traced easily since these ecosystems mainly consist of short-lived invertebrates (Defeo et al. 2009).

Therefore first of all low cost approaches have to be developed highly adapted to the sites to dampen the effects of erosion. The introduction of hard structures constitutes a feasible measurement for areas which are not designated National Park areas like the offshore islands and Tanjung Datu. They are cheap and easy to realize with local manpower under a community level government project. For the Tanjung Datu area the comparatively erosion is small, nevertheless monitoring should be continued to observe seasonal effects as well as impacts of global phenomena of El Niño to inland vegetation and anomalous monsoon events (Slik 2004; Chongyin 1990). For the special protected areas within the Talang-Satang NP it is recommended to introduce approaches highly dedicated to the sites. The special importance as a turtle breeding area needs to be underscored, mitigation measurements should not impair the species high affinity for nesting sites. Therefore it is recommended to conduct further steps carefully and assess behavior patterns of the turtle species.

Basically it is to question how to fund more advanced mitigation techniques and future assessments in the focus area. One viable option in this case is to ask the UN adaptation fund board. The special status of the Talang-Satang NP as a turtle breeding site for even critically endangered species like the Hawksbill turtle legitimizes this option. The state of Malaysia as being one of the 192 countries who ratified the Kyoto Protocol and therefore is eligible to ask for funding for climate change adaptation projects. Above that as a development country which is particularly vulnerable to the adverse effects of climate change it inherits a priority status. In order to apply for funding, a proper management plan has to be presented, comprising a project which is within the technical and economical feasibilities of the country. The plan has to be endorsed by the designated government authority (UN Adaptation Fund Board (AFB) 2014).

However, despite the fact the adaptation fund board is constantly reviewing its prioritization pattern it still struggles with translating it to the subnational level (Persson & Remling 2014). That in term means that there is a lack of a control instance on national scale. In order to assure a sufficient funding process it has to be traced by an UN subordinated entity that the money the government receives for such a project is spend completely in this regard. Due to the fact that this control mechanisms is not completely given yet, the effectiveness of such a step considering the administrative barriers given, has to be evaluated.

Despite that, fundamental action by the Malaysian government will only take place if the economic interest in the conservation of the focus areas of this study is given. Therefore, in order to legitimize adaptation measures, an economical quantification of beach characteristics is recommended.

Ecosystem services at the investigated beaches

Recent studies have shown that the economic value of the beach resource has been underestimated for a long time. Hedonic pricing calculations with the OLS method have shown, that the actual beach width correlates way more to its economic value than previously assumed (Gopalakrishnan et al. 2011). This results could give new input into a justification process for mitigation options. However, a proposed development plan would still face the issue that the area is not of touristic interest. By having a look of management proposal for such tourist areas partial ideas could be adapted.

Recent studies of coastal urbanized areas have underscored, that the correlation between shore-line retreat and increase in remaining beach area value is significant. Certainly the decline in the coastal property can be tackled by well adapted risk assessments in combination with a cost-benefit analysis within the scope of a sustainable beach management plan. All funded by an increase in rental values of the beach sites (Alexandrakis et al. 2015).

Admittedly and as already stated, the above mentioned approach cannot be applied to most of the areas in question subject to this study. Though, the study points out the possibility of linking outcome-based scenario calculations and economical quantification to the present ecosystems subject to this study. Taking this into the consideration as a part of such an assessment the outcome can complement and enhance decision making by local governments (Brooks et al. 2005).

If the valuation of the beach itself does not provide evidence to claim for mitigation steps, the importance of certain ecosystems has to be underscored. Basically the problem here is to give valuation to nature's inventory and to account for local phenomena rather than providing a standardized approach. However, ultimately approaches ends up being a benefit and loss calculation, legitimizing conservation action in the area (Boyd & Banzhaf 2007). Of major importance in the research area is the Talang-Satang NP: The provision of a habitat for endangered turtle species is a unique key feature of the site. The outcome of the interview suggested to apply for funding from the UN adaptation fund board or trying to declare the unique turtle nesting islands as UN World Heritage Sites. However, considering the acuteness of the erosion process, further research suggested a different approach:

Economical valuation of the beaches can be assessed by the calculation of annual willingness to pay (WTP) for securing the reproduction habitat of turtles. The approach typically estimates the benefits for local citizens (Loomis & White 1996), but the benefits can also apply for people in richer nations (Mazaris et al. 2014). Putting an incentive payment for marine conservation on a global scale is not common practice yet, but has proven to show remarkable success when applied in conservation of turtle nesting sites with low annual expenditures (Ferraro & Gjertsen 2009).

Conclusions

Within the study the CIVAT has been tested and evaluated. The assessment in combination with the shoreline tracing and beach profiling showed good practicability and can provide easy to reproduce data at low costs. The results revealed extensive beach erosion especially in the Talang-Satang NP and at Siar and Pandan Beach endangering nesting habitats for local sea turtle species. However, the CIVAT approach as a stand-alone analytical tool did not flag the mentioned sites with a high priority status. For further research it is suggested to re-evaluate the weighting process of the assessment and consider the implementation of socio-economic parameters to account for site specific processes.

Further mitigation steps in the Kuching division Sarawak call for an integrated coastal management approach including a policy harmonization by the government. Current issues can only be addressed adequately by making anthropogenic activities in the focus area legally tangible on land and sea likewise.

To facilitate action in the area it is suggested to underscore the unique characteristics of the Talang-Satang NP as a breeding hotspot for endangered sea turtle species. Economic valuation can be established by promoting incentive payments for the maintenance of the turtle habitat on a global scale. This approach can create financial backup over the full period of long-term management plans. The longevity of the measurement is an important factor. Only by carrying forward monitoring based on the outcome of this pioneer study the full extent of ongoing processes like the acuteness of the erosion can be determined with greater accuracy.

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Appendixes

CIVAT rescaling Guide

Guide for rescaling the total scores for the Exposure, Sensitivity and Adaptive Capacity components into Low-Medium-High rating

If the no. of criteria = 2

Maximum score	(2 x 5) = 10
Minimum score	(2 x 1) = 2
Total range	[max - min] = 8
Intervals	8 ÷ 3 = 2.7 or 3
Interval	8/3
	2.7

Rating	Range
Low	2-4
Medium	5-7
High	8-10

If the no. of criteria = 3

Maximum score	(3 x 5) = 15
Minimum score	(3 x 1) = 3
Total range	[max - min] = 12
Intervals	12 ÷ 3 = 4
Interval	12/3
	4.0

Rating	Range
Low	3-7
Medium	8-11
High	12-15

If the no. of criteria = 4

Maximum score	(4 x 5) = 20
Minimum score	(4 x 1) = 4
Total range	[max - min] = 16
Intervals	16 ÷ 3 = 5.3 or 5
Interval	16/3
	5.1

Rating	Range
Low	4-9
Medium	10-15
High	16-20

If the no. of criteria = 5

Maximum score	(5 x 5) = 25
Minimum score	(5 x 1) = 5
Total range	[max - min] = 20
Intervals	20 ÷ 3 = 6.7 or 7
Interval	20/3
	6.7

Rating	Range
Low	5-11
Medium	12-18
High	19-25

If the no. of criteria = 6

Maximum score	(6 x 5) = 30
Minimum score	(6 x 1) = 6
Total range	[max - min] = 24
Intervals	24 ÷ 3 = 8
Interval	24/3
	8.0

Rating	Range
Low	6-14
Medium	15-22
High	23-30

If the no. of criteria = 7

Maximum score	(7 x 5) = 35
Minimum score	(7 x 1) = 7
Total range	[max - min] = 28
Intervals	28 ÷ 3 = 9.3 or 9
Interval	28/3
	9.3

Rating	Range
Low	7-16
Medium	17-26
High	27-35

If the no. of criteria = 8

Maximum score	(8 x 5) = 40
Minimum score	(8 x 1) = 8
Total range	[max - min] = 32
Intervals	32 ÷ 3 = 10.7 or 11
Interval	32/3
	10.7

Rating	Range
Low	8-18
Medium	19-29
High	30-40

If the no. of criteria = 9

Maximum score	(9 x 5) = 45
Minimum score	(9 x 1) = 9
Total range	[max - min] = 36
Intervals	36 ÷ 3 = 12
Interval	36/3
	12.0

Rating	Range
Low	9-21
Medium	22-33
High	34-45

If the no. of criteria = 10

Maximum score	(10 x 5) = 50
Minimum score	(10 x 1) = 10
Total range	[max - min] = 40
Intervals	40 ÷ 3 = 13.3 or 13
Interval	40/3
	13.3

Rating	Range
Low	10-23
Medium	24-37
High	38-50

If the no. of criteria = 11

Maximum score	(11 x 5) = 55
Minimum score	(11 x 1) = 11
Total range	[max - min] = 44
Intervals	44 ÷ 3 = 14.7 or 15
Interval	44/3
	14.7

Rating	Range
Low	11-26
Medium	27-41
High	42-55

If the no. of criteria = 12

Maximum score	(12 x 5) = 60
Minimum score	(12 x 1) = 12
Total range	[max - min] = 48
Intervals	12 ÷ 3 = 16
Interval	48/3
	16.0

Rating	Range
Low	12-28
Medium	29-44
High	45-60

If the no. of criteria = 13

Maximum score	(13 x 5) = 65
Minimum score	(13 x 1) = 13
Total range	[max - min] = 52
Intervals	52 ÷ 3 = 17.3 or 17
Interval	52/3
	17.3

Rating	Range
Low	13-30
Medium	31-48
High	49-65

Fig. 1: CIVAT rescaling Guide (MERF 2013, p. 89 Tab. 13)

Interview

According to the COBSEA report published, 98% percent of Malaysia's population live in 100km proximity of the Ocean. The governments states in their plans (9th and 10th report) that there will be major conservation steps assuring sustainable management of the environment.

The erosion of the beaches in the area near small villages like Sematan and Lundu is apparent and has now been highlighted by the results of my studies. Besides major wood lodging activities and the massive growing palm oil industry there is no action taking place to protect these areas. The Malaysian plan should have at least introduced long-term monitoring to the site to justify its self-imposed preventive measure policy.

Well I think this is a common thing happening in those areas. The government will say that they have all this major conservation and Malaysia has got EIA process to minimize the impact to the environment. You find that when big major players come in, the business people. They want to setup plantations, so they can easily just get a permit and just go ahead. There are restrictions on the different levels of government. Federal government that handles the sea and marine environment, state government handles anything that is on land: Land development. For what is happening on the sea there is no sort of policy, so there is a conflict on different levels of government.

When you go down to more localized levels of government. What do you think there plan is? They want to develop their economy. That's quite a common problem. So what is really driving this is economic development which any level of governments wants, that goes on. That's we have seen in this area.

So what are actions which could take place here? For instance the UN adaptation fund established in the Kyoto protocol provides money to treat such sites. But despite the fact the adaptation fund board of the UN is constantly reviewing its prioritization pattern the process still struggles with translating it to the subnational level (Persson, Remling 2014). Is that one of the main concerns while trying to introduce sustainable management practices to rural sites?

Besides, economical interest is comparably low in the area, what could be a way to set incentives for the conservation of the sites?

That is something they should consider. Once they end up with funds and partition it out. There is no proper follow on, an accounting system which says what goes on. You need a long term monitor system which is very important. For example when you designate a world heritage site then the concerning country has to follow certain guidelines. If you are not managing the site carefully then UNESCO can just take it off the list. You need mechanics like this to enforce, to make sure the necessary action is taken.

It's the economic interest that drives all this. Even though the countries have all the EIA laws and regulations but it is very easy for a business man to engage actions here.

What is or could be the major factor driving the erosion along Sarawak's coastline? Coastal development does not seem to be a major cause here. Is it a combination of different exposure factors going along with climate change?

We have to see, if there is not much coastal development. We still have to move further upland and see what is happening there. If you have development further up and that will easily change the intensity of run-off and that can also create changes to the coastal morphology. But if it is just something that has developed during the last 10 years. If the rate of erosion has increased over the last 10 years then obviously that it is not something that is part of a natural process (e.g. tidal change). It definitely has to be attributed to something that anthropogenic activity going on either further upland or the offshore dredging.

Sand dredging in the riverine systems of Sarawak, does it affect the sand deposition in the sampling site?

Once you clear the upland forest, it will change the amount of runoff coming down and that will cause erosion. Depending how the land is managed and that will all eventually transmit right now. Dredging definitely will have a major impact.

What would your recommendation for long-term monitoring of the sites be? Does the CIVAT approach state a viable option for priority setting? Is it the recommended approach in this area (urbanized SEA / rural in general)?

There is one thing that can sort of prevent this thing from happening. In order to make sure that it does not happen all of the sudden is having a proper management approach? I think that is where integrated coastal management is important. Because then you get to analyze impacts from uplands and in general within the catchment area that will have an effect. Integrated coastal management if it is in place it will at least address this kind of problems. Long term monitoring is just monitoring the impact. ICMF will help to reduce the impacts. But still, long term monitoring is necessary to assess all these environmental management issues.

When we have a look at integrated management of coastal sites. The difference between urbanized and rural areas to be more precise, the CIVAT does not really distinguish between those sites. For instance my research has shown that the Siar Beach area is a major eroding site, but it is not on the high priority list. What could be a possible adaptation here?

ICMF also has application in rural areas. Rural areas, the land or the sea is just open for big business corporations. If you have an ICMF for the entire coastal area, rural areas will also benefit. For the ICM approach what you are doing is getting the different levels of government into policy integration. The federal government takes care of the sea and the state government will take care of the land. The impacts from land coming to the see cannot be addressed. An ICM approach is important because you get this policy harmonization across different levels right down to the local government. Rural area erosion is going very fast and they come to realize that they will never get back how it used to be. Once you have this kind of erosion, a lot of ecosystem services will just disappear. This will have a big impact on coastal rural communities.

In the documentation you have played a part in (Sand Wars, 2013) it has been mentioned that there are huge ships transporting sand to Singapore every day, even though it has been banned almost everywhere. Do you think it is more viable to give recommendations and set limits to the sand mining industry rather than preventing it at all?

First of all Singapore stand is that they purchase the sand and then the sand that comes in, whoever brings the sand in has to prove that the sand is not illegally brought in. What actually happens is a commercial thing, you can buy the sand and as long as people can show that the sand is not illegal - they can bring it in. A lot of surrounding countries like Malaysia and Indonesia have banned such offshore activity. Sand that is taken from the inland that is still not a problem. So also Singapore is getting sand from Vietnam, it is dredged from the rivers. You see that all over Vietnam and it is happening every day, but the sand supply which comes down from the river still continues. So some of that sand is being shipped to Singapore. Singapore will just buy from wherever they can get sand, even from Myanmar river systems. Because these rivers discharge a lot of sand.

The deep intervention of sediment transport offshore is followed by a hysteresis effect which is a strong characteristic response of coastal beach systems. The initial erosion period is thus followed by a persistence consecutive loss of sand resources of the concerning beaches, accumulating in the low-tide platform (Borges et al. 2002). To what duration can such a hysteresis effect last? Is the erosion on the sites a result of former or ongoing dredging activities?

If the amount of sand is dredged up and creates big cavities then this will continue for a long time. Sand from the beaches will all be dragged down with time. The shore sand enrichment is just not enough, the loss of beach sand in this dredge areas will be exceeding the shore enrichment. That nourishment comes from rivers and longshore drift. Also I think when you do dredging on a scale like this close to the shore this will also alter the hydromechanics patterns. This will affect the longshore drift and the amount of sand which is transported across the shores.

Studies have shown that the shoreline response is extremely sensitive to the water depth of the dredging location. Therefore placing the pit in the deepest water that is practical and minimize both the change in depth due to dredging and the side slopes of the pit is recommended (Hüseyin 2004).

When you go deeper areas it calls for more expensive equipment and also it is more difficult. A common technique is to do dredging over a wide area. Economic feasibility will limit the approach.