COASTAL PROTECTION FOR THE MEKONG DELTA (CPMD)

A Decision Support Tool

Hợp tác Đức
DEUTSCHE ZUSAMMENARBEIT

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FOREWORD

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The 720 km Mekong Delta coastline is under threat, which consequently puts the future of this crucial ecological and economical region at risk. There are many challenges, such as coastal erosion, drought, flooding, and the intrusion of saline water into the Delta. Climate Change does its part to compound these challenges but the decreasing availability of sediment and land subsidence play a big role, too. After almost 7,500 years of growth, the Delta now shows a retreating coastline over more than half of its length. The disappearance of the shielding mangrove belt exposes vulnerable dykes, or even worse, coastal settlements, since dykes do not protect just over 144 km of coastline. With the shrinking mangrove belt, all associated ecosystem services will also disappear with very negative consequences for artisanal fishery and aquaculture. The great socio-economic achievements of the last decades may be at risk. There is no choice, the Mekong Delta with its low elevation and more than 17 million inhabitants must be saved. The Vietnamese Government responded with a plan (P.M. 667) to strengthen the coastal protection system considerably in the coming decades. Looking at comparable situations in Germany, the Netherlands and recently Louisiana (USA), it had to be a catastrophic event that completely changed the planning paradigm for coastal protection towards "space for water". This painful experience should be avoided in Vietnam. The main lesson learned from those disasters was to tackle coastal protection by cross-sectoral planning on a large spatial scale, not focusing on solutions for single local problems at certain sites. **The Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD)** attempts to include those lessons learned in other countries and adopt them to the special conditions and situation in Vietnam.

This CPMD is made for all who have a stake in the coastal zone of the Mekong Delta and need to decide on protection measures and investments which are feasible and effective while minimizing harm to other goods and neighbouring provinces. Even though the CPMD mainly aims to assist decision making, it is meant to present the essentials of coastal protection in a way that is understandable to non-experts, and as such also serves as an effective instrument for communication. The CPMD introduces some innovative ideas, new insights and techniques – the use of lightweight drones is one – into the Mekong Delta and compiles national and international expertise.

The decision to go online (http://coastal-protection-mekongdelta.com/) and develop a digital CPMD was made in order to reach a wide circle of stakeholders and to harmonize the planning process. The online version is an invitation to explore the Mekong Delta, to learn about historical changes of the coastline, to view the current shoreline from the aerial perspective of a “flycam” (lightweight drone), and in particular to identify the recommended measures and respective cost estimates for the protection of different parts of the coast – all in a highly visual and interactive way. It is also an offer to all who would like to contribute with their own research results, observations and experiences. As such the CPDM will become a common good as an information resource base for coastal protection in the Mekong Delta. One special feature of the CPMD is the introduction of the so-called Coastal Protection Units (CPU). In fact, this is the proposal to link water management and land-use in the immediate hinterland behind the

sea-dyke, which comprises a total of 700,000 ha and is home to about 1.9 million people. This zone is identical to the 29 official water management units nearest to the coast, and somewhat a little bit comparable with the polder system in Germany and the Netherlands. It might be considered as a buffer-zone where, for instance, disaster risk preparedness, brackish economy, wind energy, clay extraction sites for sea-dykes, and waterworks get special attention and where the use of water and land is adapted and transformed to increase the resilience of the entire coastal protection system. Coastal protection for the Mekong Delta does not end with the CPMD – as stated in the outlook – since there is still a long way to go for implementers and decision makers to realize stronger and resilient coastal protection while considering the financial and technical challenges that have yet to be solved. The CPMD provides some guidance for all stakeholders and stimulates both an intensive discussion about the best technical solutions and the best ways to organize the urgently needed cross-sectoral planning for the entire region of the Mekong Delta.

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The development team of the CPMD would like to thank the many who contributed with good ideas, concerns, feedback and background knowledge during workshops, conferences, meetings and field tours. Furthermore, we would like to thank all proof-readers of the draft versions and the translators hence we know how tedious this work can be.

The original idea was born during a working visit to the coasts of Germany and the Netherlands in 2014 where the “Master Plan for Coastal Protection for Lower Saxony, Germany” was presented and was received very positively by the participants from the Mekong Delta. Since then, the author of that plan, Prof. Frank Thorenz, head of the Coastal Protection Agency in the state of Lower Saxony (NLWKN), has been providing regular feedback through the entire process of developing this decision support tool. Contributions were provided by national experts from several institutions, such as the Southern Institute for Water Resources Planning (SIWRP), the Southern Institute for Water Resources Research (SIWRR), the Southern Sub-Institute for Forest Inventory and Planning (Sub-FIPI), Can Tho University (CTU) and international experts from Germany, Australia and the Netherlands. We would also like to thank the Government of the Kingdom of the Netherlands for providing funds for looking more closely at often locally disputed questions of setback areas and cost-benefit approaches. Aspects of cross-sectoral and spatial planning and ecosystem-service provision found their way into the CPMD through collaboration with the United Nations Environment Programme (UNEP) and the global GIZ Project ‘Blue Solutions’. The outcome of the Lower Mekong Delta Coastal Zone (LMDCZ) Project contributed important insights into the hydro-dynamic and sediment transport of the Mekong Delta coast. This project was led by the Southern Institute for Water Resources Research (SIWRR) and funded by the Agence Francaise de Développement (AFD) and the European Union (EU). The collaboration with the World Bank (WB) in the course of preparing its new loan for the Mekong Delta (World Bank 9) brought new insights and opportunities to assess investment needs

for the coastline. The Mekong Delta Plan (MDP) - jointly developed by Vietnam and Netherlands in 2013 - also shed light on the approach of this CPMD.

Additional feedback and input on various topics were provided by the Vietnam Administration of Seas and Islands (VASI) under the Ministry of Natural Resources and Environment (MONRE), the Government of the Netherlands represented by the Dutch Embassy in Hanoi, and the International Union for the Conservation of Nature (IUCN).

EXECUTIVE SUMMARY

Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD)

The Mekong Delta (MD) is a key economic region in Vietnam. With a mean elevation of less than 150 cm and an area of about 41,000 km^2, the Mekong Delta produces more than 50% of the rice and more than 65% of the seafood in Vietnam. However, the Mekong Delta is under threat from storm surges, erosion, flooding, land subsidence and saline water intrusion. After about 7,500 years of increasing natural land accretion, the trend seems to be in reverse. More than half of the 720 km coastline of the Mekong Delta is currently eroding. The loss of forest land along the coast is especially sensitive since this green belt stabilizes the dynamic silty coasts by attenuating wave surge and trapping fine sand and clay. Despite great efforts to rehabilitate the mangrove forest belt – on average about 1,600 ha are planted every year – this loss of forest land is continuing. The current sea-dyke system behind the dyke is hardly able to cope with storm surge and rising waters once exposed to the sea without foreland and mangroves. The causes are numerous, ranging from sea level rise to land subsidence. The high urgency along stretches of the coast and the high value of hinterland has led the Vietnamese Government to plan for the upgrade of the coastal protection system in order to safeguard economic development in the Mekong Delta (Prime Minister's Decision No. 667 in 2009 and Resolution 120 in 2017). The protection of the coast is an essential factor in safeguarding the development of the entire Mekong Delta.

The Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD) is an online and print product aiming to assist the planning of coastal protection measures and prioritization of investments. It is based on existing evidence provided by recent studies and the assessment of Vietnamese experts, international consultants, and provincial government agencies under the mandate of the Vietnam Disaster Management Authority (VNDMA), which is in turn under the Ministry of Agriculture and Rural Development (MARD). The CPMD was inspired by several study tours to Germany and the Netherlands – both countries have a long history of success but also failure in coastal protection planning.

The main objective of the CPMD is to harmonize coastal protection planning at regional level. Although being developed for the coastal protection sector, the approach of the CPMD is based on the integration of water management, forest management and land-use planning in the coastal area (Integrated Coastal Management (ICM) approach). The CPMD does not replace official planning documents but is supposed to feed concepts, ideas, and solutions into future regional and provincial planning. The coverage ranges over 7 provinces from Tien Giang (East Sea) to Kien Giang (West Sea).

There are some novelties included in the CPMD such as an innovative classification system of the coast, a compilation of downloadable datasets on design parameters for coastal waterworks and land-use, a critical evaluation of all existing protection measures in the Mekong Delta (Pros & Cons), historical coastline changes since 1904, and the systematic inclusion of lightweight drones (Unmanned Aerial Vehicles – UVA's) in coastal surveys. Several further tools for guiding the planning process for coastal protection are offered. A brief overview and analysis of respective policies on coastal forest, sea-dykes, and coastal environment as well an assessment of the organization, management and funding of coastal protection is also included.

An essential feature of the CPMD is the consequent coastal classification. For the relative uniform coastline of the Mekong Delta (MD) a hierarchical 3-step approach was developed:

- 7 coastal protection regions (CPRs) separated by physical parameters
- 29 coastal protection units (CPUs) based on existing water management units
- 71 Coastal Protection Segments (CPS) indicating four levels of increasing urgency (plus one level for "special zones") for intervention. A total of 262 km is classified as "high to very high urgency for intervention".

The Mekong Delta needs a strong, interlinked system of mangrove protection forest, breakwaters and sea-dykes. Around 77 km of the coastline need quite massive breakwaters in the nearshore area. In order to stabilise the foreshore and intertidal flats (or to restore them), different types of fences, and especially T-shaped groynes, are recommended for about 290 km of coast in coastal segments which are lesser exposed. About 539 km of earthen dyke have to be strengthened, which means they have to be constructed up to the respective design water level with a much milder slope than currently, and with a lifespan of at least 50-100 years. The sea-dykes already exposed – if retreat is excluded – need strong dyke toe protection and other revetments. Currently, this kind of measure would be needed along almost 140 km of coast. This is mainly recommended along the coast of western Ca Mau, south-western Kien Giang, possibly also in Tien Giang and some selected short stretches.

The primary function of sea-dykes is flood protection, not erosion protection. Therefore sea-dykes should never be constructed in front of the mangrove belt. Sea-dykes should be constructed with adaptable profiles which allows additional heightening if needed. The strict implementation of a (legal) space reservation of at least 50 m at both sides of the sea-dyke is urgently recommended. The CPMD provides detailed guidance for design principles of sea-dykes and breakwaters. One essential technical recommendation for sea-dykes is to avoid seaward ditches in front of the dyke for clay extraction but instead to identify clay extraction sites in the hinterland. The most important recommendation for breakwaters is to carefully plan the deployment by proceeding field investigations and numerical and physical modelling, following an obligatory protocol or updated technical guidelines. If possible, reusable construction materials for coastal protection structures (clay, sand, natural stones) should be used for breakwaters. Small-scale natural sediment transported along the shores should be accepted since small short-term erosion-accretion patterns (in the order of a few meters annually) are natural processes for a stable coastline over the long term. A stable and restoring coast needs some space for natural development and should be not cut off from natural sediment supply. By no means should hard protection structures, such as non-permeable, continuous breakwaters without gaps – which completely interrupt sediment transport – or sea-dykes be installed in from of the mangroves.

Recognizing the high importance of mangroves for a number of ecological services, special emphasis is placed on the afforestation, reforestation, selection of suitable species and management of the mangrove belt. ´Building with Nature' is a key element of protecting the coast of the Mekong Delta. The protective function of a mangrove shield is only effective if there is still a closed canopy forest of at least 150 m width. This is the minimum forest width for effective attenuation of wave surge (roughly 50%) also a wider protection forest belt (about 500 m) is desirable as it reaches its optimum of 90 % attenuation for the typical wave spectrum around the Mekong Delta. A reforestation along 290 km of the Mekong Delta coast is probably only possible with support of coastal engineering measures in the nearshore and tidal foreshore as, for example, along the West Sea coast of Ca Mau province. It seems likely that at least 7,900 ha of mangrove protection forest can be rehabilitated in the Mekong Delta even under difficult current conditions if combined with the right structural measures. Detailed information on best practices and newest technical guidelines on multi-species plantation are provided with the CPMD.

The strategic aim until 2030 should be to close all gaps of the sea-dyke system and to create a synchronized spatial water- and land-use plan for coastal protection, mangrove forests, aquaculture, and irrigation at provincial and regional level. Water management behind the dyke is the key of any land-use that is dependent of coastal protection measures. Moreover, these areas are especially prone to dyke breaches but also to saline intrusion and droughts. Therefore, the spatial dimensions of coastal protection planning should exceed the planning of the sea-dyke system and should include resilient livelihood development and disaster reduction measures. The land area adjacent to the sea-dyke and marked out by the existing water management units consists of about 700,000 ha of land inhabited by at least 1,900,000 people. Here, land-use for production and livelihood and measures for coastal protection should be linked. This would mean, for example, the transformation of land-use towards a brackish water economy and the stopping of freshwater drilling in land subsidence-prone areas. Over the long term, the outline of this area (coastal protection regions in the CPMD) might serve as a second line of defence and irrigation measures (inland-dykes, sluice gates, setback areas, water reservoirs) might be planned accordingly.

Although as for now the provincial governments in the Mekong Delta clearly stated that they would not retreat from the current sea-dyke trajectory, there might be situations at some critical stretches of coast where there will be hardly any other options on a long-term perspective other than to plan for setback options. A "digital decision support tool for sea-dyke routing" was developed (only included in the online CPMD) in order to carry out mathematical cost-benefit calculations.

Based on the existing level of baseline data, information, knowledge and guidelines, the CPMD came up with an estimate of a total investment of about 1.4 billion USD for the proposed hard structural and soft measures. This is a minimum estimate of direct costs and should be considered as a rough reference since inflation, price developments and additional costs for local construction feasibility studies, research, disaster risk reduction, capacity development and regional cooperation are excluded. The total costs of mangrove reforestation including restoration of tidal mudflats accounts for only 12 % of the total costs (of 1,4 billion USD). The largest investments with high priority have to be made in Ca Mau and Kien Giang (63 % of the total). Proper prioritizing of interventions by using the indications provided by the coastal classification is crucial in order to implement measures until 2030. Eventually, there might be costs for the relocation of people and assets, and measures to counteract land subsidence and increasing sea level rise. A main recommendation is to coordinate budgeting and prioritization at all three governmental levels, provincial, regional and national, and to tap international climate change funds by concerted actions of neighbouring provinces.

Besides technical interventions, there are also concrete measures suggested to enhance the capacity for coastal protection planning at three different levels in the Mekong Delta, namely for decision makers, for practitioners and for academic and knowledge institutions. Concerning the scientific base of the planning, investment into up-to-date equipment (autonomous tidal gauges, field measurement campaigns, database compilation and open data service concept) is recommended as well as a periodic recalculation of hydrological and hydrodynamic design parameters (wave climate, sediment transport) every 10 years and regular monitoring of the coastal area (state of sea-dyke and erosion pattern) at least every 2 years, but more effective if on an annual basis. While clearly improved during the period of the CPMD development, the quality and standards of sea-dyke inspection and maintenance could still be further developed at local level. The involvement of resident stakeholders (including Forest Protection Boards and co-management communes) might be helpful for raising awareness, acceptance and support for measures. The use of light-weight drones finds here another field of application.

With a view on organisational aspects, it is recommended to establish regular roundtables and to up-valuate coastal protection planning at provincial level over longer terms. During the development of the CPMD, numerous experiences and lessons learned on coastal protection could be exchanged regularly during informal coastal protection roundtables. It is strongly recommended to institutionalize these roundtables or similar formats to include all coastal Mekong Delta provinces in order to harmonize strategies, raise capacity and increase the efficiency of technical measures. Regarding the character of cross-sectoral planning (especially irrigation, forest, aquaculture, land-use planning, and environment), it might be a consideration to create coastal protection boards with members of each sector organizing cross-visits and combined workshops. Currently, coastal protection is under the sub-department of irrigation at provincial level. On a longer term, an institutional review and potential up-valuation of coastal protection might be considered to reflect the importance of the task for the overall sustainable economic development of the coastal zone and the overall Delta. Because of the importance of coordinating measures, strategic coastal protection planning should be carried out at regional level. Harmonized coastal planning in the Mekong Delta can greatly enhance the process of sea-dyke strengthening. Despite local differences, the problems and solutions in the Mekong Delta are similar and a fast exchange of experiences will raise the capacity of everyone involved at provincial level.

Coastal protection requires close collaboration of national and local governments, agencies and knowledge institutions, residents, and international donors. In particular, the expensive and sophisticated collection of physical parameters, numerical modelling, and for instance the testing of scale models in the flume tank, should be coordinated amongst regional research institutions and universities to substantially reduce costs.

Despite highly sophisticated models for prediction and design development, coastal protection is still a continuous learning experience that benefits from practice worldwide. The planning of the coastal protection of the Mekong Delta does not end with this current work. For the purpose of implementation, detailed feasibility studies at respective sites have to be conducted, and newly collected data, knowledge and evidence needs to be continuously incorporated into the CPMD for its perfection – which is a non-ending process.

1. Introduction

Fig. 1. Typical coastal stretch along the Mekong Delta illustrating the "mangrove squeeze": the erosion of the seaward mangrove belt and the increasing pressure from land-use and aquaculture landwards.

Source: Ca Mau Department of Agriculture and Rural Development

The Mekong Delta – importance and challenges

The Mekong Delta is the economic powerhouse of Vietnam. With more than 17 million inhabitants, a mean elevation of less than 1.50 m and an area of about 41,000 km², the Mekong Delta produces more than 50% of the rice and more than 65% of the seafood in Vietnam. The waters of the Mekong River flow within more than 38,000 kilometres of rivers, waterways, creeks and canals, and are the key driver of fertility and the long history of economic growth. However, the Mekong Delta is under threat.

After 7,500 years of natural land accretion of 550 ha annually and a steady propagation of the Delta in a southeast direction, anthropogenic interventions such as river regulations, dyke construction or construction of dams have reversed this development during the last decades. Nowadays, about 377 km (more than half) of the 720 km Mekong Delta shoreline are eroding, over a length of about 70 km even with rates of more than 20 m annually. Furthermore, larger parts of the Lower Mekong Delta lie below sea level and are prone to flooding and the impacts of global change and sea level rise. Hence, what is needed is evidence-based coastal protection planning and a substantially upgraded Coastal Protection System.

There are numerous causes for eroding shorelines which are interlinked. Just to name few: sea-level rise by 3 mm per year; land-subsidence locally by 25-30 mm per year; substantial reduction of sediment supply through the Mekong River system by probably more than 30% (in the worst case possibly up to 80%) due to dam constructions in the upper river and intensive sand-mining; a history of conversion from mangroves to aquaculture ponds; and, increasing pressure from intensive land use. The natural coastal area is squeezed from both sides, from the sea and from the land. Once erosion of the shorelines and mudflats has started, larger waves are able to reach and destroy recent embankments. Although the trend of converting mangrove areas into aquaculture ponds has been reversed, the erosion is progressing extremely fast in former shrimp ponds and mono-cultures of mangrove species which were once protected by a belt of natural pioneer mangroves.

The high erosion rates along many stretches of the coast and the high value of the hinterland led the Vietnamese Government to plan the upgrading of the coastal protection system (Prime Minister's Decision 667 in 2009) and review existing plans. The protection of the coast is an essential factor in order to save and trigger the development of the entire Mekong Delta. The Technical Guidelines for sea-dyke systems – including the mangrove belt – were developed and coordination among the 13 Mekong Delta provinces – including 7 coastal provinces – were improved. In addition, the Vietnamese Government made efforts to regulate spatial planning in the coastal area and to conserve eco-system services. The efforts of the Vietnamese Government to tackle those challenges in the Mekong Delta is reflected by the "Resolution on Sustainable and Climate-Resilient Development of the Mekong Delta of Viet Nam (no. 120, Nov 2017)".

Objectives and target group of the "Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD)"

The main objectives of this CPMD are to harmonize coastal protection planning on the regional level and to foster interprovincial cooperation regarding the most efficient technical solutions and modern tools for waterworks and mangrove rehabilitation. Although developed for the coastal protection sector, the approach is based on the integration of water management, forest management, land-use planning and budget planning in coastal areas.

The CPMD also offers a bridge between difficult accessible science and local stakeholders in practice, and is supposed to feed into government planning documents. One of the main purposes is to stimulate communication among non-experts and experts of different sectors.

The main users are expected to be planners and implementors at provincial level. However, it is also intended that national and international investors and donors, scientists and other stakeholders will use this knowledge system. It is assumed that the reader is not a scientist or specialist in coastal planning or engineering, but a practitioner or decision maker, or an expert in other fields. The CPMD supports the planning process for coastal protection in relation to all the sectors involved, including coastal engineering, forestry, environment, spatial planning, and budgeting.

What is the "Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD)"?

The CPMD consists of this print document and a comprehensive online version which is hosted by MARD VNDMA. This enables the user to download reports and relevant datasets for new analysis or any purpose and also allows updating. The CPMD is providing detailed technical information and recommendations for the strengthening of the coastal protection of the entire Mekong Delta based on several feasibility studies, reviews, pilot studies and a series of workshops, which were conducted with experts, government agencies and other stakeholders. In addition, the CPMD intends to inform investment parties and therefore includes concrete cost estimates. The recommendations can be considered as a first step towards the construction on site. In addition, guidance is given on cross-sectoral planning, sea-dyke routing, selected practical aspects of designing coastal works such as breakwaters, revetments and dykes and mangrove rehabilitation. The latter are compiled in a so-called toolbox for coastal protection planning in the online CPMD. A synthesis of conclusions and recommendations on technical, institutional and policy aspects, which were compiled and derived from earlier reports and references, is a complement to the CPMD. The coverage ranges from Tien Giang to Kien Giang (7 coastal provinces along 720 km of shoreline) with special emphasis on the southern provinces.

The CPMD does not replace any official planning document but is supposed to feed concepts, ideas and solutions into future regional and provincial planning. Nevertheless, the scope of the CPMD had to be limited, thus highly relevant topics such as human migration, economic livelihood development, disaster management planning and biodiversity conservation are only briefly mentioned in context underlining their crucial importance.

There are some novelties in the CPMD which make it quite unique in respect to innovation and instruments:

- Critical evaluation of mangrove reforestation and waterworks and full acknowledgement of mangroves as an essential element of the coastal protection system
- Innovative classification of the Mekong Delta coast specifically developed for coastal protection and spatial planning (Coastal protection regions, units and segments)
- Compilation of basic design parameters for protection works

- Highlighting the importance of a spatial approach and area management in coastal protection planning
- Analysis of GIS enabled coastline evolution since 1904 based on materials from French archives and satellite images
- Online library with related project reports, legal documents and abstracts of recent scientific literature relevant to coastal protection in English and Vietnamese
- Critical evaluation of existing and proposed technical measures
- Link to water management in the hinterland and conceptual suggestions for a second line of defence
- Inclusion of lightweight drone-based coastal surveys ("flycam" or Unmanned Aerial Vehicle UAV)

The planning approach is evidence-based, cross-sectoral and regional (Mekong Delta region). Special attention was paid on cross-provincial exchange (cross-visits, learning forums, concerted workshops) and on the collaboration of coastal engineering, water management, forestry and spatial planning during the entire planning process. The process involved several stakeholder feedback workshops and an extensive field study programme in the coastal provinces of the Mekong Delta. This approach is considered to foster technical capacity, mutual understanding and to harmonize planning and budgeting for a sustainable coastal area.

The print version of the CPMD provides a brief description of the context and tools for coastal protection planning, the legal framework and the natural setting. Furthermore, a synthesis of general conclusions and recommendations is included. Finally, some specific recommendations on coastal protection measures for the 71 so-called coastal protection segments are provided here, including indicative references for cost estimates of measures.

Fig. 2. Still picture by a drone (UAV) from the coast of Soc Trang at low tide. On the right side, aquaculture ponds are encroaching close to the sea-dyke. There is a channel in front of the dyke which was ditched during the construction of the dyke. Reforested mangrove plantations of different ages are covering the upper intertidal area, which falls dry at low tide. On the seafront, one can recognize undulating sediment accumulations and some probably wild recruitment of mangroves. One can also see marks of fishing gear on the lower tidal mudflats. Source: Soc Trang Department of Agriculture and Rural Development

2. Overview on the institutional and legal framework for coastal protection in Vietnam

Legal framework

Over the past two decades, the development of legal documents on coastal management and protection has received considerable attention from the Vietnamese Government. However, there is no specific legal system for coastal protection. The existing legal documents related to this issue originate from many different ministries. Those together form a comprehensive legal framework which guides and supports the management and protection of coastal areas.

Definition of coastal boundary

The definition of the coastal boundary has been defined and modified in Decision No. 158/2007/QD-TTg dated on 09/10/2007 and Decision No. 2295/QD-TTg dated on 17/12/2014 of the Prime Minister. It was also defined in the Law of Natural Resources and Environment of the Sea and Islands No. 82/2015/QH13 dated on 25/06/2015 of the National Assembly and was clarified by Decree No. 40/2016/ND-CP dated on 15/05/2016 of the Government.

According to Article 8 of Decree 40/2016/ND-CP, the coastal area covers the coastal land and the nearshore area. Coastal land includes all the communes, wards and towns adjacent to the sea. The nearshore is defined as the zone between 6 nautical miles seawards and the line of the lowest astronomical sea level (average calculated from a 18.6-years' time series considering the nodal tide). The Ministry of Natural Resources and Environment also issued Decision No. 487/QD-BTNMT (on 10/03/2016) to publish technical guidance on determination of the average high tide level and the average lowest sea level. This is the most relevant document to determine the coastal boundary.

The so-called coastal protection corridors are defined in the Law on Natural Resources and Environment of the Sea and Islands. MONRE issued Circular No. 29/2016/TT-BTNMT dated 12 October 2016 on technical regulations for the establishment of coastal protection corridors, which stipulates:

(i) A list of areas which have to be established as coastal protection corridors, including special areas for ecosystem protection, erosion areas or areas of high risk of erosion. These are associated with the need to minimize impacts of shoreline erosion and climate change impacts (including Sea Level Rise).

(ii) The technical procedure for determining the width and boundary of the coastal protection corridor.

According to this law, the land within a buffer zone of 100 m from the average high tide level landwards is defined as protection area. All construction activities in this zone are prohibited except important structure for national security defence and coastal protection with permission of responsible authorities. Hence, the intertidal area is not explicitly included in these regulations.

Laws on dykes

There are 2 main laws related to structures for coastal protection, including the Law on Dykes No. 79/2006/QH11 (29/11/2006) and the Law on Water Resources No. 08/2017/QH14 (19/06/2017).

The Law on Dykes was issued on 29/11/2006 and became active on 01/07/2007. It covers the issues of flood prevention and flood control, dyke planning and dyke protection, investment planning, construction guidance, repair, maintenance and improvement of structures. Dykes are divided into 6 grades (i.e. special, and from grade I to V) according to descending level of importance. Sea-dykes are typically categorised under grade I and II while the design for these categories is guided by the Technical Guidelines for Sea-dykes.

Space reservation for dykes

The Law also regulates the boundary of the protection corridors for each dyke grade. For example, special and I-III grade dykes in residential areas, urban areas and touristic areas, require a protection corridor of 5 m width on both sides of the dyke foot. In rural areas this distance from the dyke foot is 25 m towards agricultural land, 20 m towards rivers and 200 m towards the sea. The latter is of high relevance for coastal protection planning, including the foreshore (the area in front of the dyke seawards).

For dyke grade IV and V, the protection corridor is defined by the Provincial People's Committee (PPC) and requires at least 5 m of width on both sides of the dyke.

For dyke design in the coastal area, the "National standard TCVN 9901:2014 on Hydraulic structures - Requirements for sea dyke design" was developed and published in 2014, which inherits and replaces the standard 14 TCN 130 – 2002 on guidelines of sea-dyke design.

The protection boundary of other constructions such as canals, sluices, pumping stations, embankments, ring dykes etc., is regulated in the Law of Water Resources No. 08/2017/QH14, which replaces the Ordinance on the Exploitation and Protection of Irrigation Work (No. 32/2001/PL-UBTVQH10 dated on 04/04/2001).

Disaster prevention

The Law on Disaster Prevention No. 33/2013/QH13 was issued on 19/6/2013 and replaces the Ordinance (in 1993) on Prevention of Floods and Storms. The Law amends and supplements numbers of Articles in the Ordinance. Its content is related to activities of disaster prevention, rights, responsibilities and obligations of agencies, organizations, households and individuals participating in activities of natural disaster prevention. Furthermore, it regulates the management role of the state and provision of state resources which are needed to ensure the implementation of natural disaster prevention.

In this Law, there are requirements on the identification, assessment and zoning of natural disaster risks, the monitoring and supervision of natural disasters, and the level of natural disaster risks determined. Further, there are regulations on formulation, approval and implementation of strategies and plans for natural disaster prevention and control, on construction and management of natural disaster prevention and the organisation of works.

Laws on forest protection

The Law on Forest Protection and Development No. 29/2004/QH11 (dated 03/12/2004) provides rules on management, protection, development, and utilization of forests (including coastal forests) and Decree No. 23/2006/ND-CP clarifies some articles of the Law with recent amendments (see chapter on mangrove forest). According to these, there are three types of forest: i. protection forest, ii. special-use forest, and iii. production forest.

Regarding the coastal area particulary, Circular No. 10/2014/TT-BNNPTNT is relevant, and states the criteria for defining buffer zones of special-use forests (including National Parks) and protection belts of marine conservation areas. According to Article 3, the buffer zones are the areas of forests, land, water surface, coastal and island land, and marine areas within or adjacent to the boundaries of special-use forests and marine conservation zones.

Institutional framework at national level

In coastal management and protection many different ministries are involved. However, the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE) play the most important roles.

According to the Law on Natural Resources and Environment of the Sea and Islands, MONRE is responsible for formulating master plans for sustainable exploitation and utilization of coastal resources and integrated coastal resources management programs, including activities of shore protection and coastal corridor protection. Decree No. 36/2017/ND-CP dated 04/04/2017, which concerns regulations of functions, tasks, powers and organizational structure of MONRE, also indicates that MONRE shall be primarily responsible for elaborating and submitting to the competent authorities for approval and then implementing programs, plans, projects and tasks of integrated management of natural resources in the marine areas and islands according to the provisions of laws. The Administration of Seas and Islands (VASI) has the responsibility to assist MONRE in the identification, monitoring and inspection of coastal protection corridors (Circular No. 29/2016/TT-BTNMT). The coordinating units are the concerned ministries, ministerial agencies, and the People’s Committees of the provinces and cities bordering the sea.

MARD is responsible for the state management of the following sectors: agriculture, forestry, salt production, fisheries, irrigation, natural disaster prevention and control, and rural development (according to Decree No. 15/2017/ND-CP), state management of dykes (the Law on Dykes No. 79/2006/QH11), and forest management and development (Decree No. 15/2017/ND-CP). Details on the organizations and their relationships are described in the diagram below.

Institutional framework at provincial and district level

At the provincial level, the Provincial Peoples' Committee (PPC) is responsible for state management related to coastal protection, a fact that is of high relevance for capacity building. To assist the PPC in managing the coastal zone, the Department of Natural Resources and Environment (DONRE) is responsible for managing and issuing licenses for exploitation of coastal resources in the provincial authorized boundary.

The Department of Agriculture and Rural Development (DARD) has the authority to manage coastal forests and elements of the irrigation system such as dykes, canals, sluices, etc. The direct management unit related to coastal management under DARD is the Department of Irrigation and Flood prevention. There is no specific department for coastal protection.

At district level, the District People's Committee (DPC) is primarily responsible for state management related to coastal protection which is the reason for the many different coastal protection measures implemented at district level. This fact is often overlooked when planning for capacity building. In terms of expertise, the Department of Natural Resources and Environment is responsible for managing issues related to natural resources, environment and coastal areas while the Department of Economics or the Department of Agriculture and Rural Development (DARD) is in charge of irrigation and management of rivers, canals, dikes, sluices, etc.

Some issues for coastal protection planning

The Law on Natural Resources and Environment of Seas and Islands has been in force since 01/07/2016. Its subordinate legal documents include the earlier Circular on the determination of coastal areas and coastal protection corridors. Therefore, there is some confusion in the implementation and also uncertainty on consequences for coastal protection planning, including foreshore and adjacent hinterland of dykes.

There are no regulations or circulars in the legal framework for dykes that clearly guide the design, planning and determination of different types of dyke, such as sea-dykes, river dykes and estuary dykes, which are all relevant for coastal protection. Especially in the Mekong Delta this can lead to high uncertainty for coastal protection planning near the often-critical river mouth.

The reservation for space for coastal protection might become a very important topic for the future in order to safeguard further strengthening of the sea-dyke system but also to ensure the extraction of construction material in a safe way (not in the seaward front of the dyke).

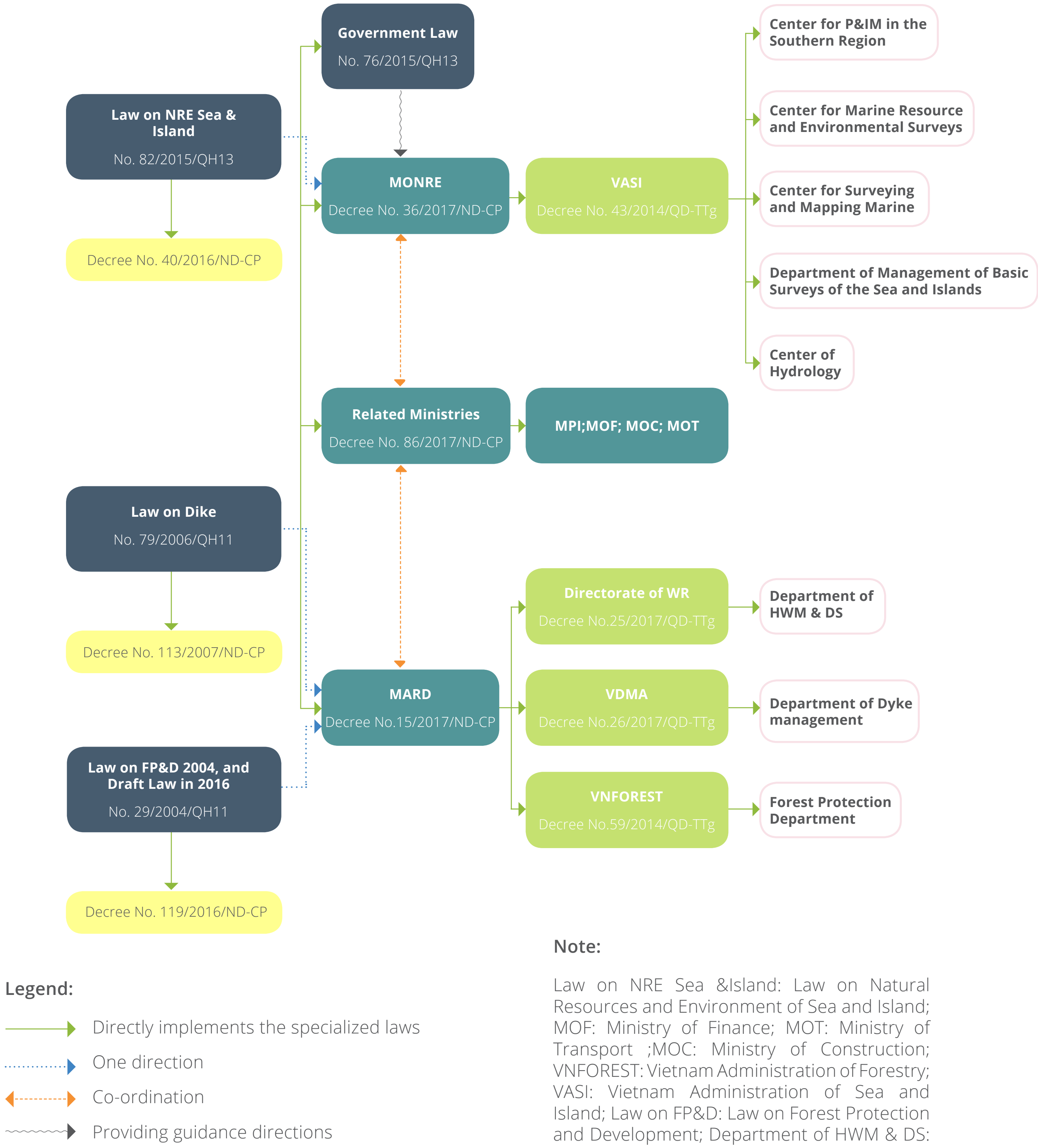
Recommendation

- The issues on overlapping responsibility for coastal protection and the issue on space reservation (see also the chapter on guidance for coastal protection work) might be tackled by a cross-ministerial round table or workgroup with emphasis on harmonising the legal framework for coastal protection.

- Decisions concerning coastal protection work is in practice made on different institutional levels from district to national level and involves at least 3 departments. This should be acknowledged by providing "client-tailored" capacity building on coastal protection to all involved agencies and to support evidence-based decision making and discussion of measures in cross-ministerial round tables.

Abbreviations used in figures 3a-e: *MPI = Ministry of Planning and Investment, MARD = Ministry of Agriculture and Rural Development, MoNRE = M nistry of Natural Resources Environment, MD = The Mekong Delta, CPO = Central Project Office, DCM = Department of Construction Management, PPMU = Provincial Project Management Unit, CMD = Construction Management Division, IWEC = Irrigation Works Exploitation One-Member Limited Liability Company.*

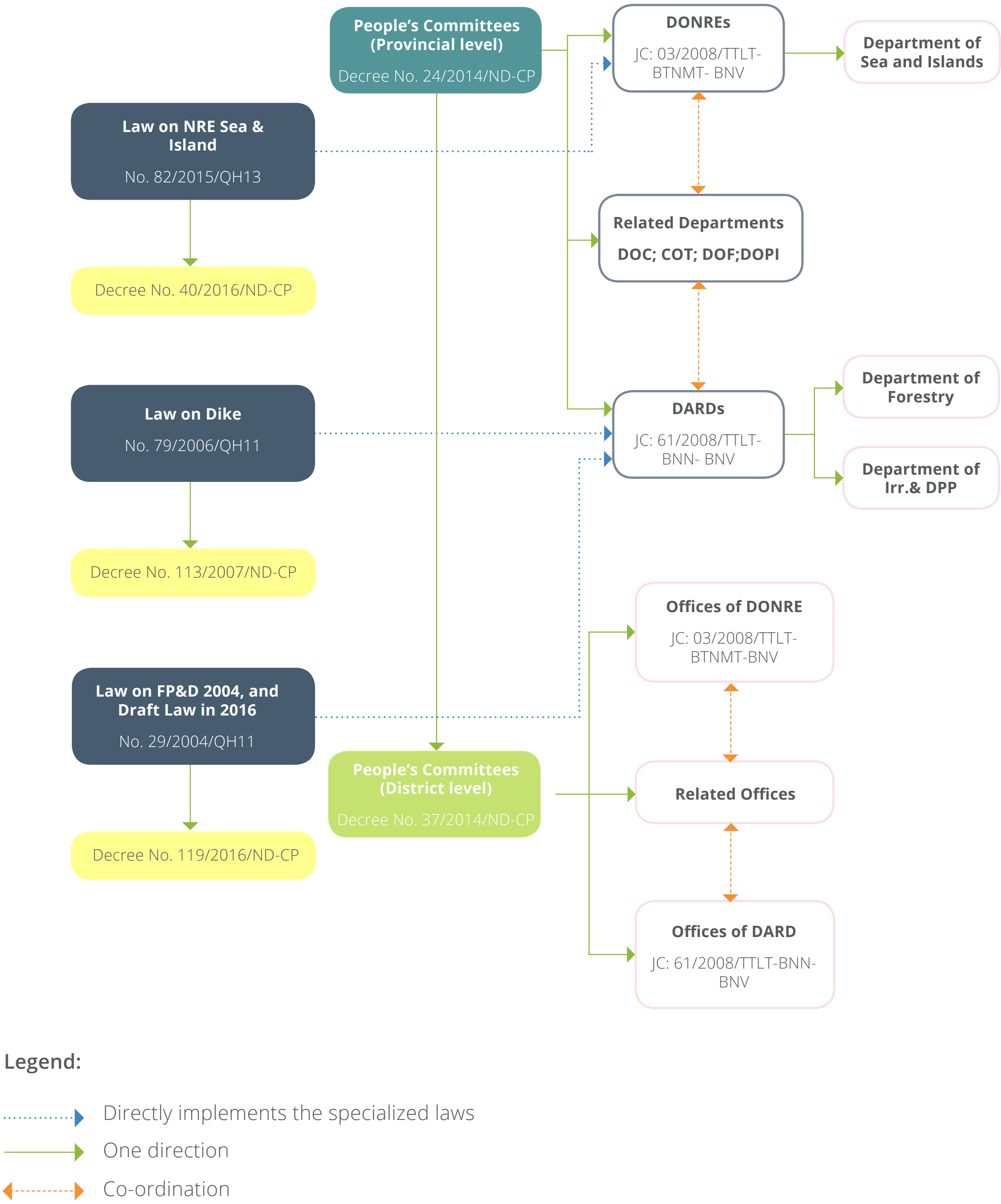
Source: GIZ



Note:

Law on NRE Sea &Island: Law on Natural Resources and Environment of Sea and Island; MOF: Ministry of Finance; MOT: Ministry of Transport ;MOC: Ministry of Construction; VNFOREST: Vietnam Administration of Forestry; VASI: Vietnam Administration of Sea and Island; Law on FP&D: Law on Forest Protection and Development; Department of HWM & DS: Department of Hydraulic work management and Dam safety;Center for P&IMS: Center for Planning &Integrated Management in the southern region

Fig. 3a. Diagram on institutional organisation of coastal protection at national level.
Source: Southern Institute for Water Resources Planning (SIWRP)



Note:

Department of Irr.& DPP: Department of Irrigation and Disaster prevention and preparation; DARDs: Department of Agriculture Development; DONRE: Department of Natural Resources and Environment; JC: Joint Circular; DOC: Department of Construction; DOT: Department of Transport; DOF: Department of Finance; DOPI: Department of Planning and Investment

Fig. 3b. Diagram on institutional organisation of coastal protection at provincial and district levels. Source: Southern Institute for Water Resources Planning (SIWRP)

Source: GIZ

Budget flow in the implementation of water resources, coastal protection infrastructure, and climate change response infrastructure in the Mekong Delta

The following overview on budget flows supports the communication on funding for coastal protection among ministeries and donors.

In general, four ministries (MoNRE, MARD, MoF, MPI) play the main role in the implementation of investment projects related to coastal and water resources management or activities responding to climate change and sea level rise (including works for natural diaster prevention). MoF plays a supervisory role while MoNRE, MPI and MARD have mandates to conduct the investment process.

In terms of budget sources, there are two types: govermental budget and non-govermental budget (ODA, government bonds).

Regarding budget planning and investment procedures (cash flow), the annual budget for each province is decided by the government based on the sectoral master plans and the provincial socio-economic development plans (SEDP). Therefore, the main flows of budget are from MARD to PPCs via CPO, and from MONRE and MPI to PPCs through programs and sectoral plans. There can be a different funding line for irrigation works and coastal protection works:

(i) For irrigation works and responding to climate change works, the budget for such works come from MARD and MPI to PPCs under so-called decision No. 1670/QD-TTg, No. 1397/QD-TTg, and No. 1600/QD-TTg. These decisions consist of name, location, scale and cost of each planned work.

(ii) For the coastal protection works, planned works are listed in decision No. 667/QD-TTg (sea dyke routes) and No. 120/QD-TTg (planting forests).

There is overlap between MPI and MARD in the investment of water resources works, for example. the PPCs can request the budget for water resources works or infrastructure directly from the MPI.

Budget flow in the water resources management sector managed by MARD

The budget flow charts below are based on oral interviews with staff from CPO, CPO Unit 10, DCM in Ho Chi Minh City, and DARDs mainly regarding water resources infrastructure managed by MARD via CPO. This is because CPO (Figure 2 illustrates CPO's structure) plays an important and central role in the budget management in the MD. Currently, CPO manages both types of budget; however, non-govermental budget (ODA, government bond) accounts for an increasingly higher share.

The role of the CPO's is to manage the water resources ODA projects; represent MARD and deal with international donors; open or award tenders; choose suitable building contractors; manage, supervise and implement the ODA programs and projects; and

Source: GIZ

to collaborate with PPCs to implement projects. Depending on the scale and specific conditions of projects, MARD will direct the projects to other organizations such as DARD following CPO's suggestion.

Specific references

1- Decision No. 1670/QD-TTg was approved by the Prime Minister and issued on 31/10/2017 on "Approval for Climate Change Response Targeted Program and Green Growth", period 2016-2020 (In Vietnamese: Quyết định số 1670/QD-TTg của Thủ tướng Chính phủ ngày 31/10/2017 về việc phê duyệt "Chương trình mục tiêu Ứng phó với Biến Đổi Khí Hậu và Tăng Trưởng Xanh giai đoạn 2016-2020")

2- Decision No. 1397/QD-TTg was approved by the Prime Minister and issued on 24/09/2012 on "Master Plan of Water Resources and Irrigation Systems for the Mekong Delta in the context of Climate Change and Sea Level Rise" (In Vietnamese: Quyết định số 1397/QD-TTg của Thủ tướng Chính phủ về việc "Phê duyệt Quy hoạch thủy lợi đồng bằng sông Cửu Long giai đoạn 2012 - 2020 và định hướng đến năm 2050 trong điều kiện biến đổi khí hậu, nước biển dâng")

3- Decision No. 1600/QD-TTg was approved by the Prime Minister and issued on 16/08/2016 on "The national target programme for building new-style rural areas".(In Vietnamese: Quyết định số 1600/QD-TTg của Thủ tướng Chính phủ 22/01/2015 về việc phê duyệt "Chương trình mục tiêu quốc gia xây dựng nông thôn mới giai đoạn 2016-2020")

4- Decision No. 667/QD-TTg was approved by the Prime Minister and issued on 27/05/2009 on "Approval for maintaining and improving sea-dyke system program from Quang Ngai to Kien Giang Province".(In Vietnamese: Quyết định số 667/QD-TTg của Thủ tướng Chính phủ ngày 27/05/2009 về việc "Phê duyệt Chương trình củng cố, nâng cấp hệ thống đê biển từ Quảng Ngãi đến Kien Giang ban hành ngày 27/05/2009")

5-(In Vietnamese: Quyết định số 120/QD-TTg của Thủ tướng Chính phủ ngày 22/01/2015 về việc phê duyệt "Đề án Bảo vệ và Phát Triển Rừng Ven Biển Ứng Phó với Biến Đổi Khí Hậu giai đoạn 2015-2020")

6-(In Vietnamese: Quyết định số 578/QD-TTg của Thủ tướng Chính phủ ngày 28/04/2017 về việc "Giao Kế hoạch Đầu tư Vốn Trái Phiếu Chính Phủ giai đoạn 2017-2020")

7- (In Vietnamese: Luật số 49/2014/QH13 ngày 18/06/2017 về "Luật Đầu Tư Công")

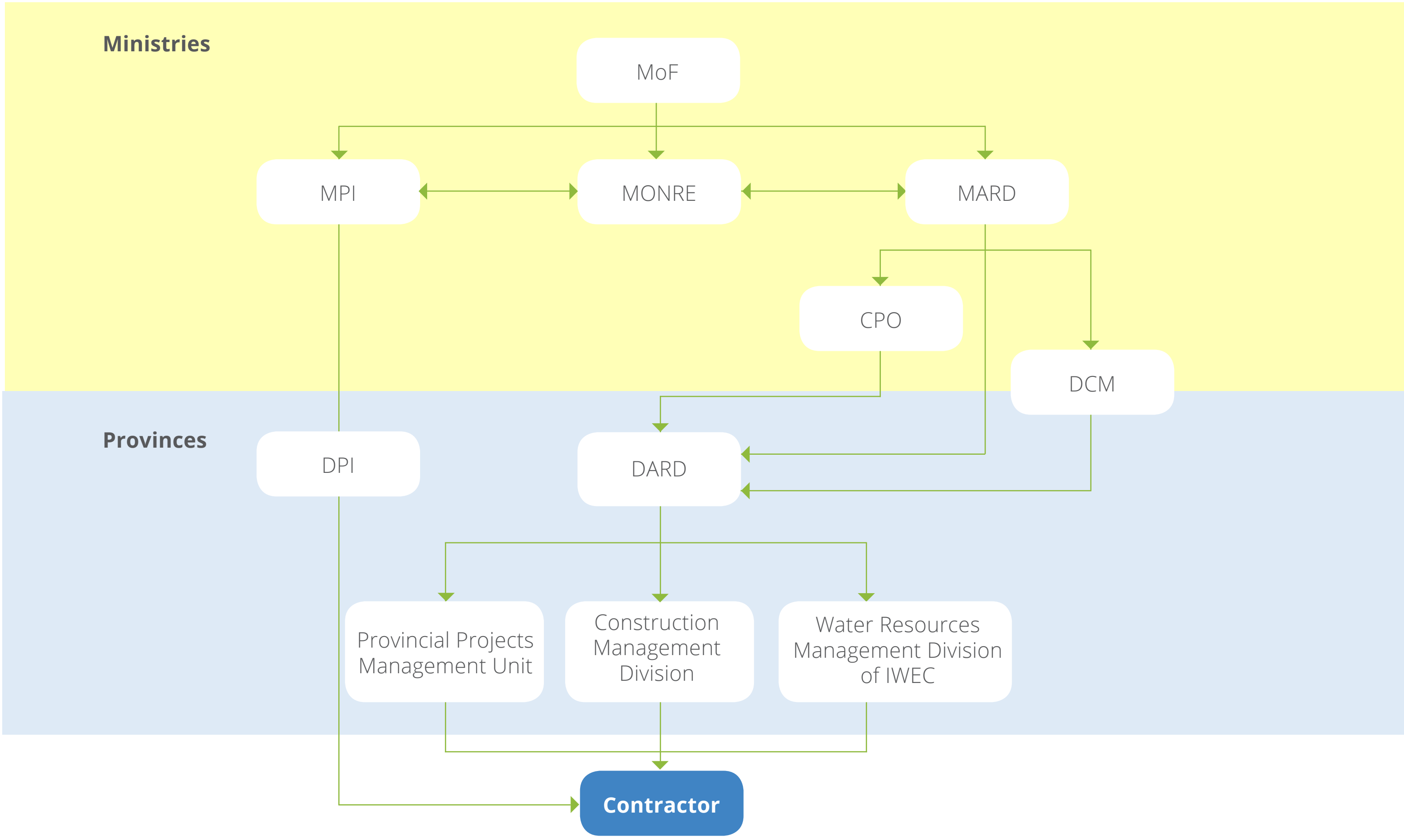
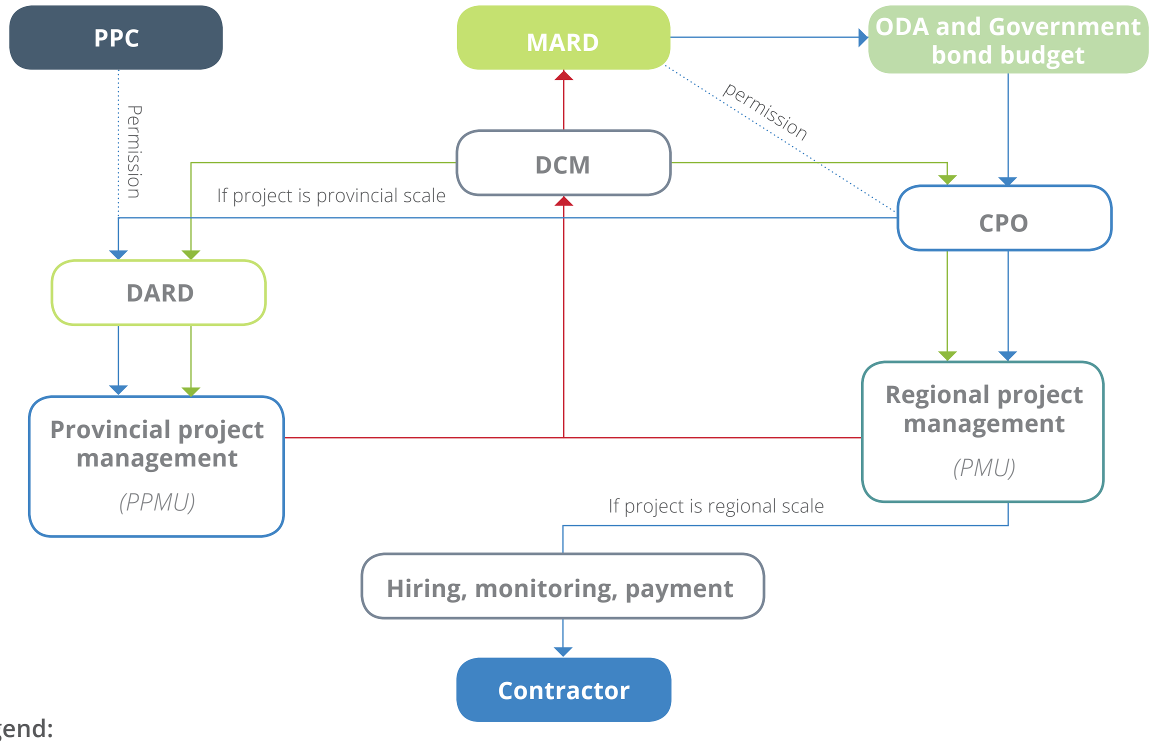


Fig. 3c. Budget flow from the central government to provinces
Source: Southern Institute for Water Resources Planning (SIWRP)

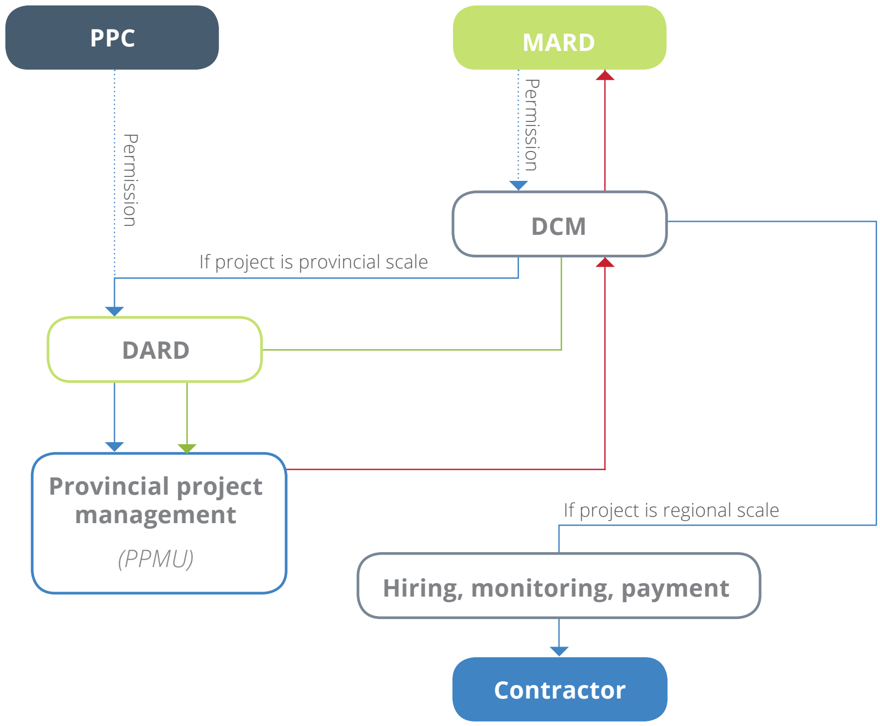


Legend:

Cash flow	→ (blue)	
Reporting process	→ (green)	Constructional process, constructional condition
Policy Guide	→ (red)	Decisions, decrees and law concern about constructional and investment policy

Fig. 3d. Cash flow in the ODA and Government Bond budget projects mandated by MARD
Source: Southern Institute for Water Resources Planning (SIWRP)

Source: GIZ



Legend:

Cash flow
Reporting process — Constructional process, constructional condition
Policy Guide — Decisions, decrees and law concern about constructional and investment policy

Fig. 3e. Cash flow in the Government budget projects mandated by MARD.
Source: Southern Institute for Water Resources Planning (SIWRP)

3. Current mangrove forestry policies and mangrove management in the Mekong Delta

Fig. 4. Mangrove plantation with Rhizophora in the lower intertidal area.
Source: Phan Van Hoang & Luu Trieu Phong

Policies and projects on mangrove forest management, protection and rehabilitation

From 1995 to 2010, the Vietnamese Government issued a number of policies related to forestry land assignment, lease, and contract. The important policies include the Law on Land 2003 and the Law on Forest Protection and Development 2004. The Decrees on forestry land assignment and contract include Decree No. 163/1999/ND-CP dated 16/11/1999, Decree No. 181/2004/ND-CP dated 29/10/2004, and Decree No. 135/2005/ND-CP dated 08/11/2005. Circular No. 38/2007/TT-BNN dated 25/04/2007 guiding the process and procedures for allocation, lease, or withdrawal of forests from organizations, households, individuals, and village communities. At this time, the Mekong Delta provinces also issued their own decisions, for example Ca Mau with Decision No. 19/2010/QĐ-UBND dated 22/9/ 2010, and Kien Giang with Decision No. 51/2005/QĐ-UBND dated 21/11/2005 on policies and regulations on organizing combined production, on benefits and obligations of organizations, households and individuals being assigned, contracts for protection, zoning for regeneration and afforestation for production, protection forest, and barren land.

Being aware of the roles of mangrove forests, policies on coastal forest protection, rehabilitation, plantation, and quality improvement have been recently prioritized, including Resolution No. 24-NQ/TW on "active in response to climate change, improvement of natural resource management and environmental protection". One of its specific objectives is to protect and restore mangroves forests, to promote reforestation, especially coastal mangrove forests. Management and protection of different forest types are specified under different legal documents, for example Decision No. 17/2015/QĐ-TTg dated 9/6/2015 for protection forest, Decree No. 117/2010/ND-CP dated 24/12/2010 for special use forest, and Decision No. 49/2016/ QĐ-TTg dated 1/11/2016 for production forest. The investment policies for coastal forests comply with Decree No. 119/2016/ND-CP dated 23/08/2016 (Sub-FIPI, 2016).

Decree No. 119/2016/ND-CP concerns policies on sustainable management, protection, and development of coastal forests to cope with climate change. At the same time, the government requested provinces to review and change the use purpose of coastal land planned for planting of production forests or other land suffering from soil erosion into land planned for planting of coastal protection forests; and to relocate construction works which affect or pose threat to the protective purposes of coastal forests to the outside of the planning area for important and very important coastal protective forests, and coastal protection corridors. Mangrove plantation and rehabilitation shall support environmental protection, climate change response and green growth. This is a priority area for ODA funds and concessional loans of the government according to Decree No. 16/2016/ND-CP dated 16/3/ 2016 on management and utilization of ODA funds and concessional loans from foreign sponsors.

Mangroves in the Mekong Delta

Currently, the Mekong Delta is one of the regions most affected by climate change. According to forecasts, 39% of the Mekong Delta could be underwater if the sea level rises by 100 cm, affecting nearly 35% of its population and losing 40.5% of its rice production (MONRE, 2016). In this context, protected and sustainably managed mangrove forests are able to contribute to improve the climate resilience of coastal communities. The total area of mangrove forest (excluding Melaleuca swamps) in the Delta is 65.894 ha, including 11.274 ha of special use forest, 38.426 ha of protection forest, and 13.103 ha of production forest. 3091 ha of mangrove forest are scattered across other land types (Sub-FIPI, 2016). Natural forest totals around 35% of the total area, and the rest is plantation forest. The main species for plantation forests are Rhizophora sp., Sonneratia sp. and Avicennia sp.

In 2016, the total forest area of the Mekong Delta covered only 5,6% of the total area. Compared to the 2017 Decree on social economic development (National Assembly, 2016), forest coverage of the entire country of Vietnam should total 41,45%. Compared to this target, forest coverage in Mekong Delta is rather low.

Programs and projects of mangrove management, protection and rehabilitation

Since 1995, a lot of activities on mangrove protection and rehabilitation have been implemented through national programs such as the Program 327, Program 661, and through international cooperation projects, such as those conducted by the World Bank and GIZ. These programs and projects have contributed to protect, rehabilitate, and improve the quality of mangrove forest and mangrove management (SubFIPI, 2010).

The Integrated Coastal Management Programme in the Mekong Delta (GIZ-ICMP, phase 1, 2011-14) provided technical assistance for mangrove rehabilitation by supporting communities in mangrove management and awareness raising. The Program also supported the development of technical documents on coastal mangrove forest protection and policy (phase 2, 2015-18).

Funding mangrove rehabilitation

In the period 2016 - 2020, about 44 projects related to mangrove forest protection and development in the Mekong Delta have been deployed or are under preparation within the framework of Decision No. 57/QĐ-TTg dated 9/1/2012, Decision No. 120/QĐ-TTg dated 22/01/2015 of the Prime Minister and international cooperation projects. 13 projects are financed according to Decision No. 57/QĐ-TTg dated 9/1/2012, 20 projects are financed by funds for Climate Change response, and 2 projects are financed by funds for sea-dyke maintenance, protection and upgrading. Another 9 projects are recently proposed to be financed by ODA funds or concessional loans in the period 2015 - 2020. Some forest-related production projects are being incorporated into projects of the protection forest management boards and forestry companies. However, implementation of forest rehabilitation is still facing many challenges. Coastal mangrove forest in the Mekong Delta is still declining in terms of both quality and quantity because of natural disasters and human activity.

Difficulties and challenges of mangrove rehabilitation in the Mekong Delta

In general, policies on mangrove forest protection and development are fragmented and issued by different agencies. There is little linkage between various sectors. Currently, forest management is mainly undertaken by management boards of special use forest and protection forest and by state-owned enterprises. In the Mekong Delta, 75% of the region's forest is managed by such units, the other 13% is managed by households and the remaining is managed by the army. Local state budget invested for mangrove forest protection and development is very limited, mostly relying on the central state budget. Forest management boards lack equipment and modern tools for implementation. Mangrove forest monitoring and evaluation is conducted in the framework of the national forest assessment program by provinces, but most of the provinces are faced with poor monitoring equipment and digital tools for spatial data collection and analysis (GIS). Furthermore, there is a limited capacity of central information and data management. Province agencies are reporting a lack of participation by communities and local stakeholders in monitoring forest resources.

There are no sufficient results available on the value of the 70:30 regulation in Kien Giang and the 40:60 regulations in Ca Mau. This ratio provides the relation between protected forest area and aquaculture use in the protection forest zone. From the standpoint of coastal protection, this model is not favourable since the resilience of respective forest against erosion is very low. The potential of organic aquaculture is not fully realised since there are unsolved problems with hatching facilities, water pollution, logistics, and high initial investment. The size of forest areas assigned to households is rather small for livelihood development. Co-management approaches, such as those piloted in Soc Trang and Ca Mau are promising but face skepticism from the government side. At this moment it appears very difficult to create sustainable livelihood models in the mangrove forests. In many cases, people lived in respective areas before regulations on protection forests and national parks were implemented. Payment for ecosystem service (PES) policies have not been applied for coastal forests yet but might offer some potential. It is necessary to promulgate the policies and technical guidelines for their development; for instance, co-management models, forest ecosystem-based management and climate change adapted farming systems for mangrove forests. Private enterprise should be encouraged to link with forest protection communities to develop, for instance, sustainable organic aquaculture models. There is no strategic coastal planning for coastal forest protection and development in the context of climate change. With a retreating coastline and pressure from aquaculture intensivisation, the land-use for production forest areas and the extension of protection forest should be regularly evaluated and re-considered in the future.

Other challenges are of a technical nature. Survival rates of forest plantation is low due to poor selection of plantation sites and the use of inappropriate seasons. New plantations are often affected by strong waves and young seedlings are buried by silt before the regular planting season. The capacity for better planting techniques and management models is especially lacking at commune level.

Some general recommendations related to mangrove forest policies and management

Mangrove forests play an important role in protecting the Delta from natural disasters and ensure environmental security for social economic development. The following recommendations are provided based on project evaluations in the Mekong Delta during past years:

- Current policies relating to mangrove forest and coastal resources should be reviewed in order to eliminate described conflicts and overlaps
- A complete and specific policy should be developed for planning, managing, protecting, and restoring mangrove ecosystem in Mekong Delta

- The participation of respective community and private sectors in forest protection and management should be encouraged
- Strengthening of capacity for state management organisations from central to commune level in developing planning under current conditions, with emphasis on monitoring and mangrove restoration
- Re-structure of coastal forest protection management in order to enhance the collaboration between management organisations, provinces and regions for consistent and efficient coastal resource management
- Developing legal tools and technical guidelines on database management and spatial planning and strengthening capacity on GIS enabled techniques
- Upgrade technical equipment (UAV, GIS tools, etc.)
- Implement the policy of payment for forest environment services (PES) for mangrove forests after successful piloting
- Develop specific guidelines to promote community-based forest management (Co-management). The values and benefits of forests should be shared in a certain way with local communities and stakeholders
- Provide sufficient conditions for local communities and stakeholders to participate in forest protection and restoration activities through long-term contracts with communities and household groups

Fig. 5. Dense mangrove plantation using 11 different species in the arboretum of Bac Lieu province. Source: Stefan Groenewold

4 Natural conditions and state of the coast in the Mekong Delta

4.1 Wave climate, currents and sediment transport around the Mekong Delta

Tidal regime

According to the classification of DAVIS & HAYES (1984) the coasts of the Lower Mekong Delta are a mixed-energy (tide-dominated) environment affected by the discharge regime of the Mekong River and its sediment load, the tidal regime of the Vietnamese East Sea and the Gulf of Thailand as well as coastal long-shore currents driven by prevailing monsoon winds and the corresponding wave conditions (DELTA ALLIANCE, 2011). The East Coast from north of Ben Tre Province to the Cape Ca Mau is influenced by the irregular semi-diurnal tide of the East Sea with a tidal amplitude of 3.0 - 3.5 m. From the Cape Ca Mau to Kien Giang along the West Coast, the tides are irregular diurnal with a tidal range of approximately 0.8 - 1.2 m (DELTA ALLIANCE, 2011).

The shoreline of the Ca Mau peninsula is influenced by a complex interaction of two tidal regimes: The regime of the Vietnamese East Sea affects the area from Ganh Hào to Mui Ca Mau, the southern tip. The West Coast of Ca Mau is dominated by the regime of the Vietnamese West Sea (ALBERS ET AL., 2013). The tidal range decreases from 3 m at Ganh Hao to 1.0 m at Mui Ca Mau. The regime of the West Coast is characterized by a diurnal tide with a tidal range of about 0.8 m.

Fig. 6. Sediment sampling (left photo) and measurements on currents and wave regime with an ADCP (Acoustic Doppler Current Profiler, right photo) in West and East Sea around Ca Mau Province. Source: Stefan Groenewold

In the Mekong Delta, the monsoon cycle, with seasonal variations in the wind and pressure systems and in precipitation levels, leads to seasonal variations in water levels, especially at gauges in the mouths of the Mekong branches with peaks at the end of the rainy season. Strong monsoon winds can lead to higher water elevations in the Mekong Delta. In combination with a spring tide, this produces a storm surge with water levels that are elevated by up to 0.9 m.

Wave climate

The dominant wind climate induces a corresponding characteristic wave climate. The monsoon climate is characterised by prevailing seasonal wind directions. In Southeast Asia, the summer monsoon is referred to as the SW-monsoon, and is warm and humid. The winter monsoon, which is referred to as the NE-monsoon, is relatively cool and dry. The East Coast of the Mekong Delta is predominantly exposed to waves during the NE-monsoon (PHAM, 2011).

Monsoon winds are relatively moderate and persistent for each monsoon season. This means that the corresponding wave climates are also seasonal.

Offshore wave data, e.g. from Con Dao Island 230 km southeast of Ho Chi Minh City, show two main wave directions, which are induced by the northeast monsoon and southwest monsoon, respectively. In winter, a larger quantity of higher waves from the northeast dominate the wave climate. During summer, the waves approach from the southwest and the appearance of larger waves is reduced. However, strong SW monsoon winds occasionally create waves of up to 3 m in height (DAT & SON, 1998).

These offshore wave conditions are transformed due to shallow water processes when the waves approach the coasts of the Mekong Delta. The corresponding wave heights on the East Coast can be up to 2 m nearshore during the northeast monsoon (ADB, 2011). When winds blow from the southwest, especially Ca Mau peninsula is downwind of a considerable fetch and is subject to higher waves. The same is the case for strong northeast winds. Cape Ca Mau is therefore especially exposed and vulnerable to storm surges from strong monsoon winds coming from both southwest and northeast wind (ADB, 2011).

Tropical cyclones (typhoons) are characterised by wind speeds exceeding 32 m/s and they give rise to very high waves, storm surges and cloudbursts. Tropical cyclones occur as single events, peaking during September in the northern hemisphere. They are rare and therefore recording programmes seldom document the resulting waves (SCHWARTZ, 2005). The Mekong Delta has not been hit regularly by severe typhoons in recent times. However, there have been some significant events. The most catastrophic of these was typhoon Linda (or storm no. 5) on 2 November 1997. The typhoon killed more than 3,600 people and injured more than 850 (GIANG, 2005). It destroyed more than 200,000 homes and caused severe damage across the provinces of Soc Trang, Ca Mau, Bac Lieu and Kien Giang. It resulted in flooding, damage to mangrove forests and inundation including associated damage to agricultural production. More than 200 km of dykes were damaged or destroyed completely (DILLION & ANDREWS, 1997). This destruction was accompanied by severe coastal erosion (TRUONG & KETELSEN, 2008). The accompanying wave field had a long fetch, which meant that waves of over 3 metres were directed onto the shore (ADB, 2011).

Fig. 7. Erosion in action reaching the dykeline in Ca Mau during stormy weather.
Source: Stefan Groenewold

Morphodynamics and sediment transport

The entire coastline of the Lower Mekong Delta is characterised by a dynamic process of accretion and erosion. In some areas, loss of land of up to 30 m per year due to erosion has been recorded, while in other areas land created through accretion can reach up to 64 m per year (PHAM ET AL., 2009; JOFFRE, 2010; PHAM ET AL., 2011).

Offshore sandbanks (cheniers) and mudflats form a natural protection system that reduces the incoming wave energy. In this complex environment, patterns of erosion and accumulation of sand and mud change in time and space and are significantly influenced by the migration of the sandbanks.

Where the cross-section of a river widens at the mouth, the flow velocities decrease (due to the continuity equation) and the transported sediments start to settle. In general, sediments with a larger grain size are deposited closer to the mouth than finer sediments.

Due to complex patterns of the bathymetry (i.e. underwater topography) in the foreshore area, sandy shorelines and silty or clayey shorelines may change independently from the general pattern. Especially in sheltered areas, e.g. in the lee side of islands or peninsulas, muddy sections may occur. While the coasts of Soc Trang and Bac Lieu Provinces are further away from the mouths of the Mekong and mostly dominated by mud, the characteristics of the coasts of Ben Tre and Tra Vinh are more diverse due to their location.

The tidal wave proceeds along the East Coast from northeast to southwest, and thus tidal currents have a strong long-shore component. Those currents are increased during the northeast monsoon season. Suspended sediment concentrations are mainly affected by the velocity of the tidal currents and by wave action. Stronger currents and higher waves increase the amount of transported sediments. Due to the tidal long-shore currents, sediments are transported along the coastline to the southwest and to the southernmost spit of cape Ca Mau. Here, this described sediment transport band is interrupted. The sediment transport at the West Coast is characterized by the tidal currents and waves of the West Sea. Its direction and amplitude depend on the tidal phase and the season, and is directed to the north or the south along the coastline.

Generally, the largest values of the long-shore sediment transport are reached at the end of the rainy season due to high sediment freights in the Mekong branches in that season. In winter, while the sediment plume of the Mekong is less pronounced and less material is available, the northeast monsoon winds cause increased erosion especially on the East Coast.

Data sets provided by the CPMD for the Mekong Delta

The online CPMD offers detailed information on the wave climate around the Mekong Delta based on hydrological survey at 58 stations in 2016/17 (SW and NE monsoon). The following parameters are reported: maximum wave height, significant wave height, wave period, current speed and direction, and tidal range. The survey was conducted at a distance of 5 to 10 km off-shore at a depth of 5-10 m under the Lower Mekong Delta Coastal Zone (LMDCZ) Project funded by the French Development Service (Agence Francaise Developpement AFD) and the EU. These data were used for calibration and validation of models. Data were compared and validated with earlier field surveys and model results and considered as representative and reliable. There is still a lack of a long-term series of wave data but data from national stations such as Bach Ho, Con Dao, Phu Quy, and Phu Quoc were used earlier for calibration in addition to available wave data from NOAA or ERA-Interim daily data on the website of the European Centre for Medium-Range Weather Forecasts (ECMWF).

For a proper modelling of wave propagation from deep water to the shallow water zone there is still a lack of hydrological measurements in the very shallow water. In general, regular long-term observations and model validations are urgently needed in order to update and improve the data on wave climate.

At this moment, there are no data on sediment (seabed or suspended) nor bathymetric available for download in the CPMD. However, because of the high importance of these data for coastal protection planning an inclusion of respective data sets is a key aim. An overview on coastal depth profiles, bathymetry and sediments around the Mekong Delta is provided, for instance, in these two reports (below) and scientific literature which are provided in the library of the online CPMD:

(i) Coastal Engineering Consultancy in Ca Mau province (Albers et al., 2014)

(ii) Shoreline Management Guidelines - Coastal Protection in the Lower Mekong Delta (Albers et al., 2013)

4.2 Climate change and sea level rise scenarios

The inclusion of climate change scenarios and especially sea level rise (SLR) is of highest relevance for coastal protection planning in the Mekong Delta. The projected scenarios for the Mekong Delta (MD) exacerbate the challenges for coastal protection in the MD. The highest percentage area of inundation is expected in the Mekong Delta (38.9%) by 2100 if the sea-dyke system is not strengthened. Although the number of typhoons might not increase, their severity probably will. The projected SLR is higher for the southern coast of Vietnam and depending on the scenario, at least 18 cm can be expected by 2040 and 55-77 cm by 2100. For proper planning of sea-dyke systems not only SLR is relevant but also the combined scenarios of storm surges with high tidal waves around the MD. According to the report (IMHEN, 2016) this can double the direct impact of SLR. For the design of sea-dyke systems, the highest storm surge ever observed and the highest storm surge that may occur under the projected scenarios for SLR are of highest relevance. The combination of these scenarios with local down-scaling for the MD is not sufficiently regarded in current protection planning. The strong indications for increasing land subsidence in the MD are also of great concern since the rates of subsidence are much higher than the current SLR. Urgent action is requested with emphasis on ground-water conservation in the coastal areas. This underlines also the need for a concerted management of water landwards behind the dyke line and coastal protection. How should the outcome of these scenarios be included in the CPMD in the future? There is no straight answer yet but food for thought which has to be considered in the near future.

Three documents are presented in the online-CPMD in full length for a quick overview on these issues:

- Climate Change and Sea Level Rise scenarios for Viet Nam – summary for policy maker (IMHEN-MONRE, 2016)
- Delta subsidence and groundwater system in the Mekong Delta – state of knowledge and uncertainties (Pechstein & Minderhoud, 2018)
- The relation between Adaptation to Climate Change and the Coastal Protection Tool (CPMD) – how the use of Climate Services (CS) will support to avoid loss and damage and minimize future costs (Baumert et al., 2018).

4.3 State of the sea-dyke system along the Mekong Delta

Fig. 8a. *Earthen sea-dyke along the West Sea coast of the Mekong Delta. There is still mangrove forest seawards (in the photo left side) protecting the dyke from direct wave impact. The maintenance road for light motor vehicles is next to the dyke crown. However, the dyke is not high enough to protect for flooding and the berm seawards is very steep which makes the dyke vulnerable and leads to unwanted wave reflection. More detail is provided in the chapter on guidance for coastal protection works.* Source: Stefan Groenewold

The current sea-dyke system behind the forest is hardly able to cope with storm surge and rising waters once exposed to the sea without dyke foreland and mangroves. The sea-dyke system shows many gaps and was never constructed to deal with the current harsh conditions in exposed areas. Dyke breaches and flooding threatens the densely populated hinterland. Secure coastal protection is of highest importance for the 17 million inhabitants and the economic future of the Mekong Delta, and only a completed sea-dyke line without gaps but with a controlled discharge of water by sluice gates, can control the risk of flooding. Currently there are sea-dykes along the Mekong Delta with a total length of 637 km. In the south of Ca Mau peninsula there is a gap of roughly 90 km (depending on the dykeline and connection to estuary dykes) without a sea-dyke. The deep intrusion of salt-water into ground-water and more pronounced droughts add to these problems by harming both the economy and mangrove regeneration. Over wide stretches, there is an earthen dyke with crest heights of 2.1-3.5 m along the East Sea coast and about 2 m at the West Sea. Usually the slope of the current sea-dyke is quite steep with crest-foot ratios of 1:2-2,5. At certain stretches the sea-dyke has been strengthened by armouring (dyke revetments) and heightening (at U Minh, Ca Mau).

Further aspects are described in the chapter on guidance for coastal protection works. A general overview on sea-dykes in the Mekong Delta is provided by the following reports, which are available for download in the library of the online CPMD. The issues described in these reports range from official technical guidelines, local case studies, advice on design to reviews and specific recommendations for capacity building (especially in Schuettrump, H. & Froehle, P., 2015).

- Reviewing seadyke planning from Quang Ngai to Kien Giang (SIWRP, 2017)
- Technical standards for seadike design (MARD, 2012)
- Emergency sea dyke rehabilitation in Soc Trang Province, Vietnam (Roos et al, 2009)
- Case study: Dyke design, construction and maintenance in Kien Giang (Heiland, M. & Schuettrumpf, H. 2013)
- Dike Survey Report - Results of an initial dike inspection in the Ca Mau Province (Scheres, B. 2014)
- Dyke Design at Mo O in Tran De District, Soc Trang Province / Viet Nam (Albers, T., 2013)
- Coastal Protection Mekong Delta, Vietnam (Schuettrump, H. & Froehle, P., 2015)
- Coastal protection in the Mekong Delta - Wave load and overtopping of sea dikes as function of their location in the cross-section for different foreshore geometries (Tas, S., 2016)
- Seadikes in Germany (Schuettrumpf, 2014/17)

Fig. 8b. Earthen sea-dyke along the West Sea coast of the Mekong Delta in Kien Giang province. The dyke crown is cultivated with banana trees and other crops since berm and crown are less harmed by saline water intrusion. However, certain crop cultivation with deep root systems and trees might lessen the stability of the dyke surface and should be avoided.

Source: Stefan Groenewold

Fig. 8c. Heavily armoured sea-dyke along the West Sea coast in Ca Mau province using interlocked slabs. Armouring or revetment of dykes is expensive and critical issues were found during the field studies for the CPMD concerning missing filter layers under the slabs and insufficient dyke toe protection at some sites.

Source: Stefan Groenewold

Fig. 8d. Earthen sea-dyke along the West Sea coast of the Mekong Delta. This sea-dyke will be strengthened in the near future. An unsolved problem are the settlements on the dyke crown or berm along several stretches particularly at the West Sea. The site of the settlements are offering some safety for people living on resources in the dyke foreland and nearshore but makes the dyke itself very vulnerable.

Source: Stefan Groenewold

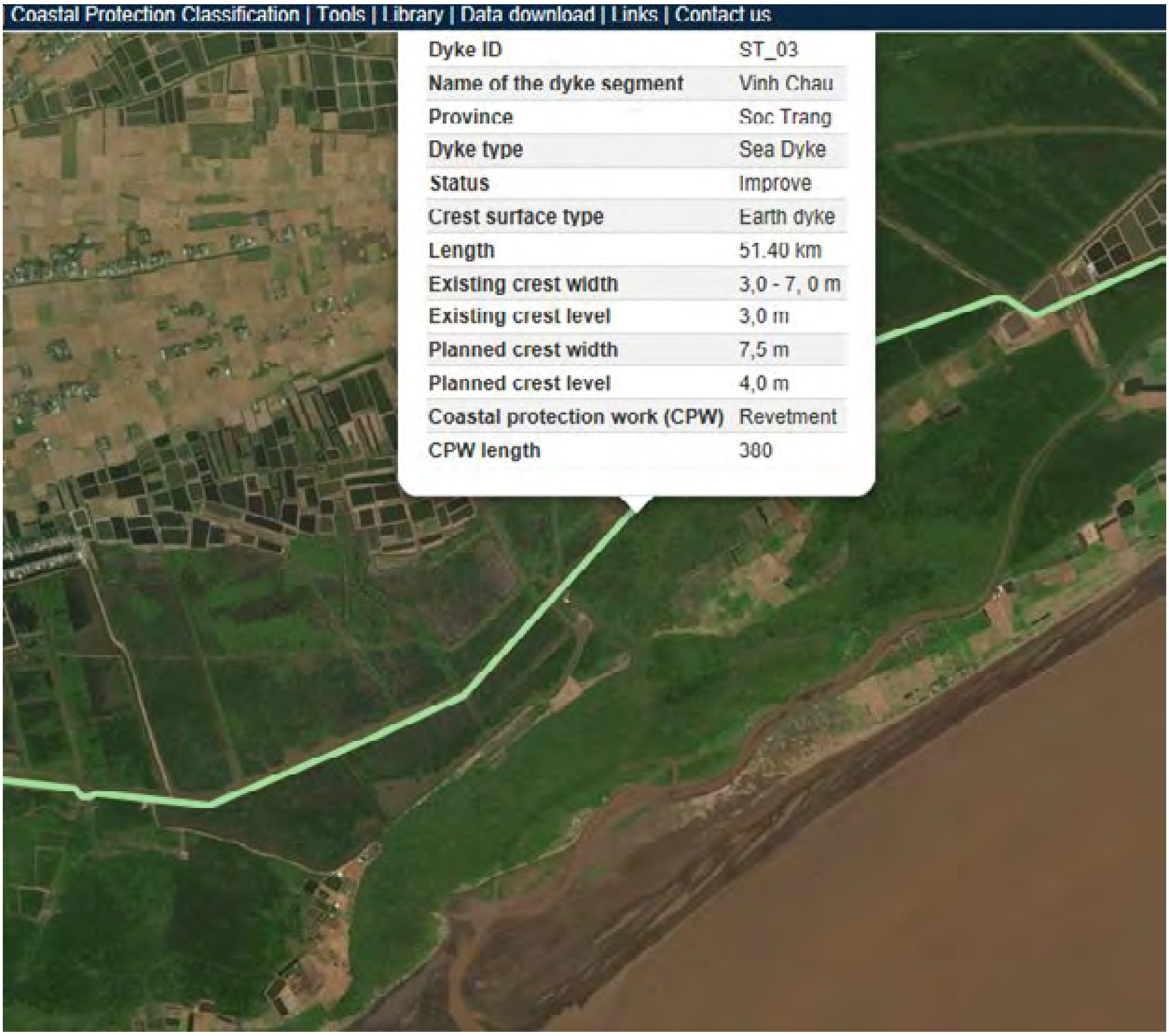


Fig. 9. The online CPMD offers detailed data on all dyke stretches and other coastal protection work. Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

4.4 State of knowledge on morpho-dynamics in the Mekong Delta

Not every detail of the complex Mekong Delta system and its evolution is understood yet but there is certain agreement about the following facts which have direct consequences for coastal protection planning:

- About 80% of the sediment discharge of the Mekong River into the East Sea is trapped on the subaqueous (= underwater) Delta area within 20-30 km offshore.

- The peak of sediment discharge takes place in August - November while during the stormy period from January - April the sediment is re-suspended and distributed mainly through an underwater channel system relatively close to the shore (within ca. 20 km), (Nittrouer et al., 2017).

- Roughly a third of this sediment is deposited near the northern and southern Delta (proximal deposits) front east of Ben Tre, Tra Vinh, Soc Trang and northern Bac Lieu provinces. Between 40-66% of the sediment is transported south-eastwards and deposited southeast (distal deposit) near Cape Ca Mau and to some lesser extent near the Bay of Kien Giang at a water depth between 5-20 m (Unverricht, 2014; Liu et al., 2017a, b).

- For the sediment supply shorewards along the West Sea coast re-suspension processes and cross-current transport plays a role, too, although it cannot be fully quantified yet (LMDCZ, 2017).

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- A decrease of sediment supply to the mentioned sediment deposits will under-nourish the sediment demand of the coast (Nittrouer et al., 2017).

- The discharge of sediment by the Mekong River system into the East Sea was estimated at 150-160,000 tons per year before the period of dam and reservoir construction and is now decreasing. However, there is disagreement about the amount since a time lag of effects and inconsistent data impede analysis. Currently the discharge of sediment is estimated to have decreased to 110,000 tons per year (Milliman & Fainsworth, 2011), and a sharper decrease is expected after the dam construction works in the upper Mekong region are finished.

- The trapping of sediment particle is not only a physical process but is strongly determined by biological and chemical aggregation processes. An important aggregation process takes place during the so-called estuarine circulation where the discharge of freshwater by the Mekong River is causing a coastwards counter current that transports oceanic water and sediments towards the shore. Due to an increasing SLR this coupling is diminished and the trapping efficiency is decreasing. The SLR and land subsidence also lead to deeper channel beds resulting in even lower sediment trapping efficiency (Allison et al., 2017).

- There is high agreement by different sources of the fact that the erosion trends along the Mekong Delta coast is accelerating (Anthony et al., 2015). While in the period between 1973-95 there was still an accretion of 7,2 m annually (on average), the accretion rate fell to about 2,8 m annually in the period 1995-2005 and even became negative (which means erosion) between 2005-15, estimated at -1,4 m annually (Liu et al., 2017a, b). Erosion occurs over about half of the entire coastline. This agrees with the following analysis using historical coastlines going back to 1904. The erosion rate is one main criteria for the coastal classification in the CPMD.

- There is also agreement by cited studies about the main causes for the increasing erosion: Decreasing sediment discharge by the Mekong River; sand mining in the middle and lower Mekong River; land subsidence in coastal areas caused by groundwater extraction; SLR (sea level rise); and destructive land-use in the mangrove belt.

4.5 Changes to the coastline since 1904

Based on historical maps from the French National Overseas Archives (1904-1953), U.S. Army Map Services (map series L7014, 1965-1993), satellite images (Landsat, 1988-2017), and GPS tracks, a collection of a total of 131 historical coastlines were reconstructed after careful digitalization and rectification of the data. With this, the changes of coastlines of the Mekong Delta between 1903 and 2017 could be reproduced and the rates of changes in meters per year could be calculated. The collection forms a unique dataset that reaches further back than data from satellite imagery only. The derived rates of change for the last decades (10 and 30 years) and indicated trends over the past century were the main criteria for classification of the 71 Coastal Protection Segments (CPSs) of the CPMD.

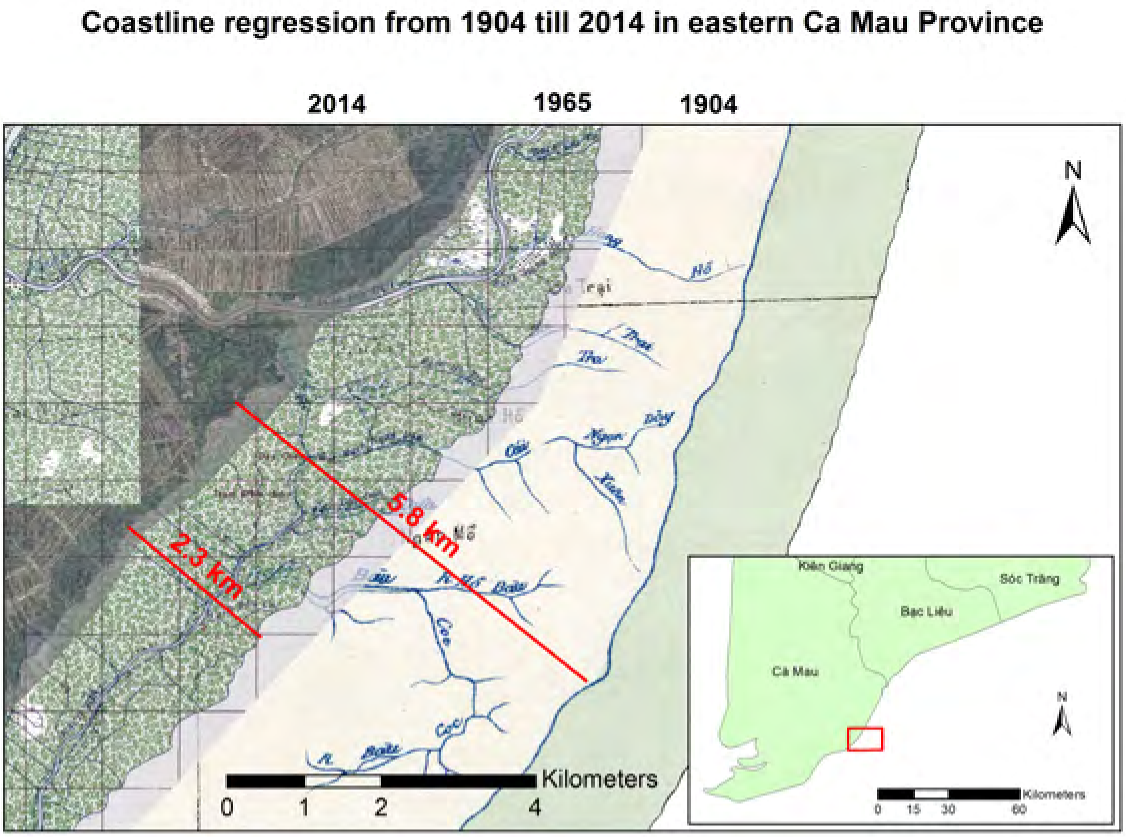

Fig. 10a. Coastline regression from 1904 until 2014 in eastern Ca Mau Province based on georeferenced historical maps and recent satellite images. Between 1904 and 2014 about 5.8 km of coastal land was lost (on average 52 m per year).Source: Roman Sorgenfrei

The use of historical maps and satellite images for detecting coastline changes

In order to understand the morphological development of coastlines, the analysis of historical maps, aerial images, and satellite images is of highest value (Albers et al., 2013). For coastline change analyses including the calculation of regression and transgression rates, the ArcGIS 10 extension DSAS – Digital Shoreline Analysis System (U. S. Geological Survey, 2018a) was used. To remove uncertainties regarding the coastline and shoreline, here a brief definition of the two is given. Even though they differ, they are often interchanged in literature:

- In international literature the shoreline is mostly defined as the line of the Mean Tidal High Water.
- The coastline is usually (depending on the context) defined as the boundary of terrestrial vegetation and the sea, or the line of the Mean High-Water Spring Tide on beaches or the cliff foot at rocky coast.

These definitions are not handled consistently among policy makers and legal frameworks in Vietnam. Along flat coasts the different vertical references can lead to horizontal differences of several dozens of meters.

A detailed description of the workflow can be found in the online CPMD library (Sorgenfrei, 2016).

Application of the programme "Coastline change analysis system (DSAS)"

A general dataset with a collection of coastlines spanning the entire available time from 1903/04 to 2017 and covering the complete Mekong Delta was created for overview analyses.

Therefore, the coastlines of the georeferenced historical maps from 1903/04, 1951/53 and the map series L7014 were digitised. The complete dataset can be downloaded via the online CPMD. A collection of 14 coastlines spanning the complete time can be displayed in the online CPMD under Surveys -> Historical coastlines.

At least two coastlines from different time steps are necessary to calculate change rates with the DSAS, which offers several statistical calculation methods (U.S. Geological Survey, 2018b). The most frequent cited methods are EPR (end point rate) and LRR (linear regression) (Thi et al., 2014). This is because they are the least expecting for the data input (for example no accuracy information is needed). Both methods were used for coastline analysis (Sorgenfrei, 2016).

While it is not possible to allocate values of accuracy for the old historical maps, it would be possible for the Google Earth satellite images as well as for the map series L7014. Because of this, and because both used calculation methods don't use accuracy information during calculation, the accuracies of the single coastlines were not considered in the conducted analyses. For further analyses of the more recent data, for which accuracy can be allocated, other statistical methods, like weighted linear regression (WLR), can be used in DSAS (U.S. Geological Survey, 2018b).

Using the Landsat satellite images, two extra coastline change calculations were conducted covering the complete Mekong Delta for transects every 100 meters along the coast. The results for all transects surrounding the Mekong Delta coast can be displayed in the online-CPMD (layers are in Surveys -> Coastline changes over 10/30 years). The change rates were classified into 6 classes.

Some selected results on coastline changes in the Mekong Delta

The results of the aforementioned analysis of the erosion rate (EPR) over 10 years for transect every 100 meters along the complete Mekong Delta coast show that only 10% of the coastline is currently still accreting, while more than 50% is eroding. More than 70 km is eroding at rates between 20 and 50 meters per year (see Table 1a).

Table 1a. Result overview of the coastline change analysis using EPR (end point rate) in DSAS for the period 2005-2015

EPR 10a in m/year	Count	Km	%
> +40	304	30,4	4,3
Từ +20 tới +40	322	32,2	4,6
Từ 0 tới +20	2607	260,7	37,2
Từ -20 tới 0	3040	304,0	43,4
Từ -40 tới -20	637	63,7	9,1
< -40	94	9,4	1,3
Total sum	**7004**	**700,4***	**100**

** Of the total 720 km long coastline the harbour development in Song Doc, Ca Mau, land reclamation in Rach Gia, Kien Giang and the canal and thermal power plant in Duyen Hai, Tra Vinh, which account for a total 20 km of coastline, were excluded.*

On average the coastline change rate along the complete Mekong Delta coastline in the period from 2005 to 2015 was -0.25 m/year; the Delta is therefore shrinking. Looking at the results of the analysis for the period 1988 to 2015 (EPR 30), the average coastline change rate was 2.08 m/year. In Table 1b, further results are aggregated for the latter period.

Table 1b. Result overview of the coastline change analysis using EPR (end point rate) in DSAS for the period 1988-2015

EPR 30a in m/year	Count	Km	%
> +40	324	32,4	4,6
Từ +20 tới +40	578	57,8	8,3
Từ 0 tới +20	2744	274,4	39,2
Từ -20 tới 0	2716	271,6	38,8
Từ -40 tới -20	552	55,2	7,9
< -40	93	9,3	1,3
Total sum	**7006**	**700,6***	**100**

** Of the total 720 km long coastline the harbour development in Song Doc, Ca Mau, land reclamation in Rach Gia, Kien Giang and the canal and thermal power plant in Duyen Hai, Tra Vinh, which account for in total 20 km of coastline, were excluded.*

The following figures show the shoreline change of the Mekong Delta. More detailed illustrations can be displayed in the online CPMD (Surveys ▶ Coastline changes over 10/30 years and Surveys ▶ Historical Coastlines).

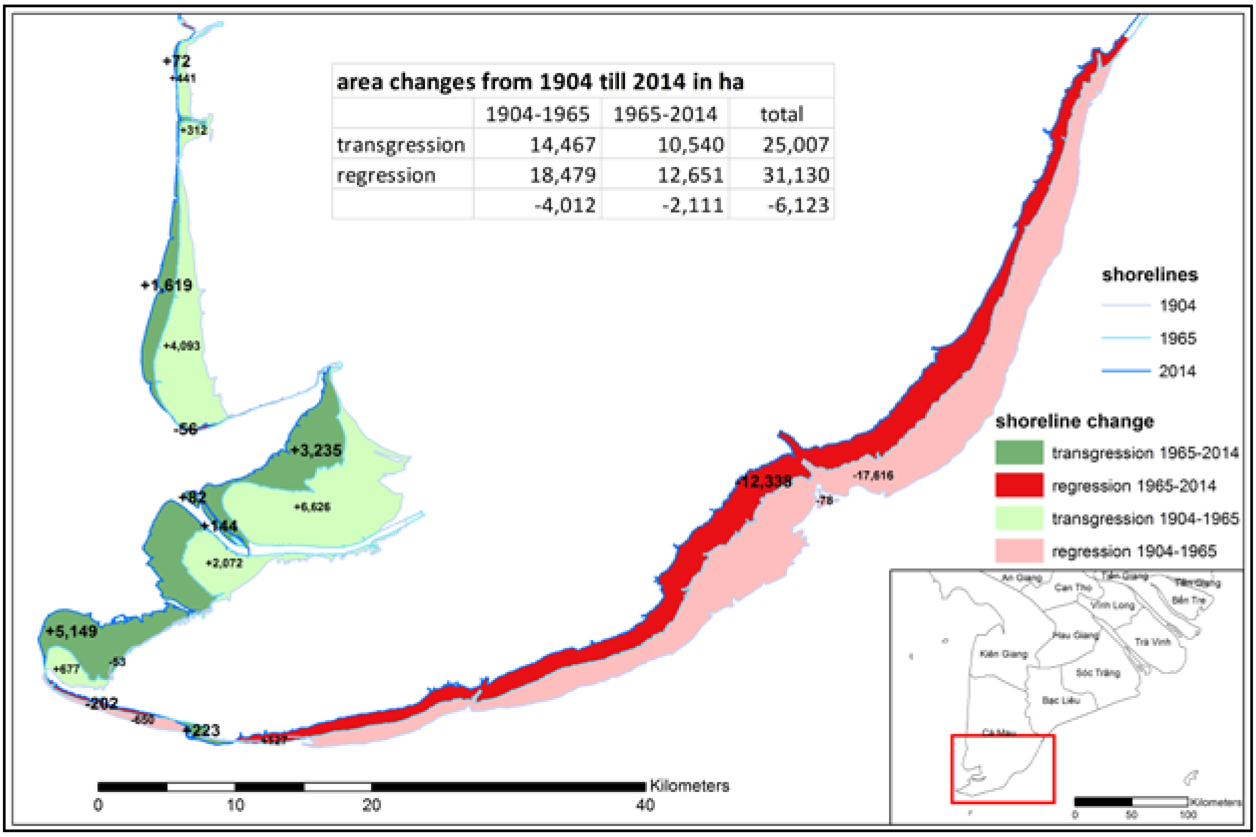

Fig. 10b. The larger spatial scope including the area pictured in Fig. 10a. It is obvious that very high land loss due to erosion since 1904 along the East Sea coast (Ca Mau and southern Bac Lieu) contrasts with large accretion along the West Sea coast north of the spit. Despite uncertainty, it can be assumed that this trend will continue and indicates constant sediment starvation along the SE coast (CPR 5). GIS analysis also provides an estimate of the land area lost and gained: the southern coastal stretch along the East Sea lost land persistently since 1904. Source: Roman Sorgenfrei

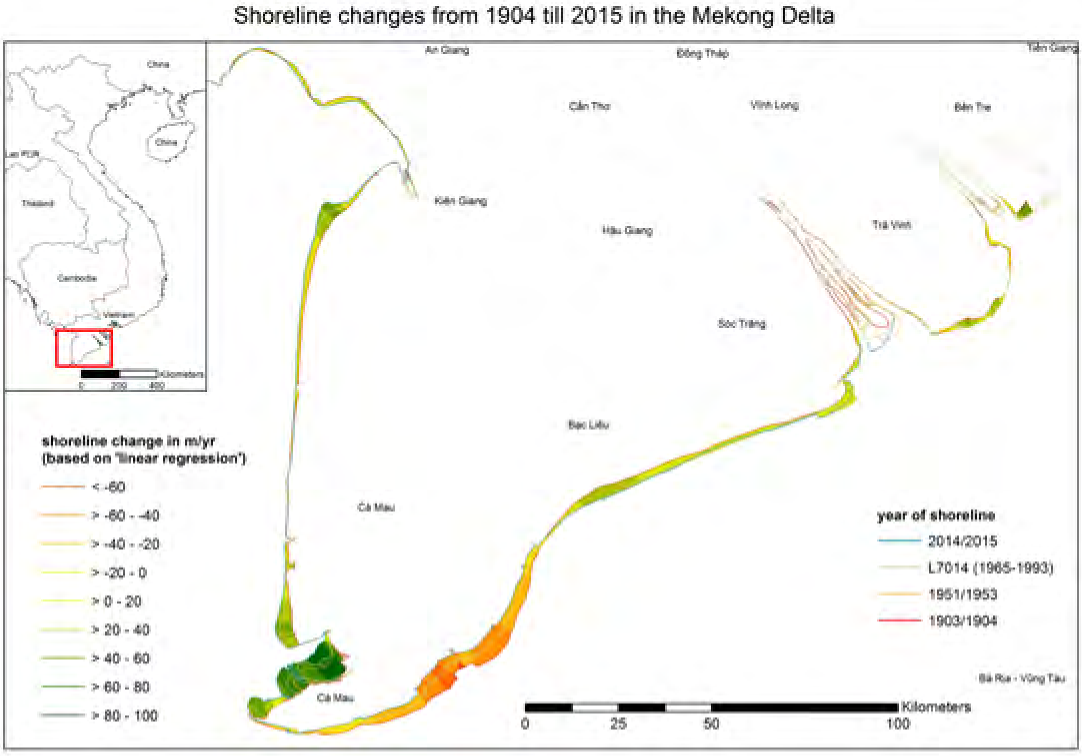

Fig. 10c. Changes of coastlines in the Mekong Delta from 1903/4 to 2015. Huge change rates of more than 60 m/year erosion as well as more than 100 m/year accretion can be seen in this analysis. Major accretion during the last century was along the coasts of Tra Vinh, Soc Trang and Bac Lieu Provinces. While the East Coast of Ca Mau Province had the highest erosion rates during this period, during the same time the West Coast had the highest accretion rates. In western Ca Mau close to and across the border with Kien Giang, no larger changes can be observed over the last 110 years despite the losses during the last two decades. Source: Roman Sorgenfrei

Main conclusion

The analysis of historical coastlines allows deriving trends from a broader database in space and time in order to recognise patterns which are not visible from short-term erosion hotspots and one-time surveys. The entire Mekong Delta is highly dynamic and constantly exposed to changing hydrological forces, and by including not only satellite imagery but also historical maps, a much deeper insight into these dynamics can be achieved.

5. Pros & cons of coastal waterworks

This section provides a brief overview and evaluation (PROS & CONS) on different coastal water works against shoreline erosion in the MD. We included successful and less successful solutions since coastal engineering builds on both comprehensive scientific studies and lessons learned from applications on the spot. Coastal engineering builds heavily not only on predictive models but on experiences and existing local knowledge of local systems.

Detached pillar-riprap breakwater

Fig. 11. Detached riprap pillar breakwater along the West Sea coast of Ca Mau. The version below right is the most recent, using larger blocks of stones and partly retractable parts. Source: Frank Thorenz

Length	Several hundreds of metres in different versions of the basic constructions at distances of 160-230 m off the shoreline between 2011-2017.
Location (*exact values in online CPMD)	West Sea, Ca Mau province
Costs (VND) per m	18,000,000-22,000,000++ (earlier versions were more expensive, the latest version with retractable parts costs about 18 million VND.
PROS	The breakwater efficiently reduces the wave energy and accelerates the process of sediment accretion for mangrove forest planting and sea-dyke protection. The character of the sediment accumulated is almost identical with non-protected reference areas nearby. The transmission coefficient is sufficient and was tested in the laboratory (TUHH). For high waves the transmission is 13 %, meaning an attenuation of 87 % of the wave height. The transmission for lower waves is 72 % which still corresponds to an attenuation of 28 %. The results from the field measurements attest to the breakwater's high wave-damping-abilities. The breakwater leads to wave attenuation for high and small waves. The damping by the breakwater in all cases produces waves on a non-harmful scale.
CONS	A critical issue is the relatively high costs (which could be reduced considerably through the efforts of DARD Ca Mau) and the so-called far-field impact on the leeside of the main sediment transport (lee erosion, downdrift erosion) and on the disruption of longshore sediment transport. The breakwaters were over-dimensioned in the early versions, but the size was reduced adequately in 2016/7. A mild slope seaward instead of the vertical wall might increase the durability and resistance against storm surge. The functional aspect is not fully understood despite sediment accretion between breakwater and shoreline. A close field monitoring and a more detailed numerical modelling is recommended.
Conclusion	This pile breakwater is principally recommended since the structure took up several critical concerns and is a clear improvement compared to earlier structures. Although principally recommended because the functionality is proved, this breakwater could still be modified. A mild slope seaward instead of the vertical steep profile might increase durability and resistance against storm surge. The functional aspect is not fully understood despite sediment accretion between breakwater

	and shoreline. A close field monitoring on far field impacts and a more detailed numerical modelling is recommended. A continuous construction parallel to the shoreline over wide stretches without leaving larger gaps might enhance negative effects (interrupting longshore transport of sediment)
Further comment on construction and functionality	The general construction consists of two rows of precast reinforced concrete piles. They have a diameter of about 0.35 m and an axial distance of about half the size of the diameter. The distance between the two rows is 2.5 m in cross direction. The newer constructions show a reduced axial distance of 0.50 m in order to save construction costs. The poles are fixed with one concrete binding beam for each pile row and cross beams with an axis distance of about 2.0 m. The binding beam and the cross-beam mark sections with a spacing of about 2 x 2 m. The estimated height of the construction is 1.0 m above mean high water level. This pile breakwater is principally recommended since the structure took up several critical concerns and is a clear improvement compared to earlier structures. As mentioned in the table, the functionality is already proofed but not fully understood. This breakwater could still be modified and improved. A mild slope seaward instead of the vertical steep profile might increase the durability and resistance against storm surge. This might be achieved by deployment of larger boulders at the seaward side of the structure. Physical models could help to identify the optimal structure. A close field monitoring on far field impacts and a more detailed numerical modelling is recommended. More information at the online CPMD library (Master Thesis by Philipp Jordan (2015), TUHH (in English only but with Vietnamese summary). A combination with light nearshore T-shaped fences might further increase the functionality since any groyne elements perpendicular to the coast are missing.

Detached breakwater; hollow concrete structure filled with rock stones, “hollow dyke”; about 200 m off the shoreline

Fig. 12. Detached “hollow dyke” breakwater. Source: Frank Thorenz

Position	About 200 m off the shoreline
Location (*exact values in online CPMD)	West Sea; Ca Mau province, deployed in 2016
Costs (VND) per m	22,000,000
PROS	This hollow breakwater is prefabricated on land than installed at the site. Therefore, the quality can be controlled. The single elements appear to be quite stable.
CONS	Earlier deposition of this construction got toppled by moderate to strong wave impact. Therefore, they were filled with natural stones (riprap). The interconnection of the single elements is considered a critical weak point in the construction. There is no ground layer used, the construction might sink into the soft mud soil after some time. The accumulation mechanism for sediment is not proven.
Conclusion	At this stage, structures of this design are not recommended for other stretches of the Mekong Delta coast. Further testing of complete physical scale models is recommended to prove functionality. The structure was only stable in first field tests after the hollow space was filled with heavy rock material. Although the prefabrication of single elements has some advantages concerning structural quality, there are serious concerns about the interlinking of elements, the missing ground layer on the seabed and the resistance against high wave surge which was also the main issue for enforced T-shape fences along the West Sea coast.

Breakwater with concrete pillar frame, riprap filling and paved promenade on the top

Fig. 13. Breakwater with promenade on top. Source: Stefan Groenewold

Position	At about 50-60 m off the shoreline
Location (*exact values in online CPMD)	Southern tip of the peninsula of Ca Mau Province (erected in 2011)
Costs (VND) per m	33,000,000
PROS	There is sediment accumulation within the sheltered area. The erosion of the shoreline is halted. This breakwater structure was placed quite close to the eroding shoreline and is easily accessible for visitors (tourists).
CONS	High costs.
Conclusion	Since Cape Ca Mau is an important part of the Vietnamese cultural heritage, the costs balance the protection values and the aim of this structure was also to trigger eco-tourism. For any extension, a modified version might be considered allowing for higher permeability and thus conservation of all ecosystem services provided by the mangrove forest. For any extensions, the modified type of pillar riprap breakwater is strongly recommended in order to keep the mangrove forest intact and healthy. Less permeable structures are not recommended in the southern tip of Ca Mau because of the unforeseen effects on sediment transport.

Detached geotextile breakwater - a geotextile tube filled with sediment

Fig. 14. Detached geotextile breakwater. Source: Frank Thorenz

Position	At about 150 m from the shoreline
Location (*exact values in online CPMD)	East Sea, Bac Lieu
Costs (VND) per m	About 5,000,000
PROS	Quick and relatively low cost, high flexibility in functional design (positioning!)
CONS	Geotextile used up to now shows very low durability and leached within weeks or months. Another problem is damage by human activity.
Conclusion	In this version, textile geotubes are not recommended for muddy coasts in the Mekong Delta as breakwaters. With the use of higher quality materials and a proper functional design, geotubes have potential for sites where flexible short- and mid-term solutions are required.

Mixed type of shore parallel breakwater with seawards gaps and perpendicular groynes (groyne fields); T-shaped fences made of natural bamboo materials and Melaleuca bushwork filling

Fig. 15. Mixed breakwater and groyne fields.
Source: Phan Van Hoang & Luu Trieu Phong

Position	100 – 180 m off the shoreline
Location (*exact values in online CPMD)	East Sea, Soc Trang province, also in Bac Lieu. Attempts in the West Sea at Ca Mau have failed up to now (2017). For details see "T-fence story".
Costs (VND)	1,200,000 (light)-2,400,000 (if strengthened with concrete piles)
PROS	At suitable sites, T-shaped fences achieve effective sediment accumulation. Low costs, using natural and local materials. In principle, T-shaped fences can be extended seawards if the site shows successful sediment accumulation.
CONS	Few. Not suitable for sites with high exposure to waves and currents, steep gradient of foreshore and sand dominated environments. Details on limiting conditions can be read in the chapter on "The T-fence story" and further reports in the online CPMD library.
Conclusion	Recommended with some restrictions. Along coastal sections without any mangrove belt, bamboo T-fences are an effective coastal erosion and protection measure for restoring floodplains and creating conditions for mangrove regeneration. Their wave transmission effect is sufficient to reduce wave heights significantly and stimulate sedimentation on the landward side. The construction is cost-efficient and often more feasible than massive structures on the soft soil. However, the application of T-Fences has clear limits. If the location exceeds a certain degree of exposure to waves and a certain duration of submergence, the effort for maintenance significantly increases before the application becomes impractical.

Sediment trapping double-fence, Kien Giang

Fig. 16. Sediment trapping double-fence. Source: Stefan Groenewold

Length	About 30-60 m off the shoreline
Location (*exact values in online CPMD)	West Sea, Kien Giang province
Costs (VND) per m	1,100,000-2,400,000
PROS	The sediment trapping fences are quite effective at certain sites with low exposure, in particular in the very shallow northern bay of Rach Gia. Especially if combined with mangrove plantation, the seedling and saplings benefit from the attenuation of waves by the double-fences although the rate of sediment accumulation was in most cases low to moderate. Community supported measure!
CONS	Not suitable for exposed sites; short lifespan; Melaleuca wood is prone to woodboring shells (Teredo sp.) in the seawater. While benthic productivity and diversity appeared not to be harmed, these fences are barriers for larger organisms. Little is studied about the impact on the subtidal profile beyond the fences.
Conclusion	Recommended where these fences were already successful (shallow bay of Rach Gia). Finally, these structures protect mangrove plantations but play minor role in restoring wider tidal mudflats. The structures do hinder the exchange of larger fauna in the mangroves (crabs, fish). Principally, structures showing higher permeability or layout with gaps are recommended. Modified T-shaped fences might be more effective in the same area and should be tested.

U-shaped fence; groyne field-like structure made mainly of bamboo

Fig. 17. U-shaped, groyne field-like fence. Source: Stefan Groenewold

Length	About 150-400 m off the shoreline
Location (*exact values in online CPMD)	West Sea, Kien Giang province
Costs (VND) per m	1,200,000-3,400,000
PROS	Certain protection of seedlings and planted saplings of mangroves; protection against destructive bottom fisheries. Use of natural materials is encouraged.
CONS	Not suitable for exposed locations as all kind of fences made of less durable natural materials. There are no strong indications yet for any sediment accumulation within the fences. Some U-shaped fences were extended in front of the existing mangrove edge which lowers the survival of plantations considering the low elevation of the seabed.
Conclusion	Although some features of the U-shaped fences are similar to other types of fences, the critical issue is the lack of sediment accumulation. The basic idea to support mangrove plantation is recommended but not in the current positioning and design. Newer versions leave gaps at the seaward side and seem to be more successful.

Mangroves – natural growth or planted; coastal protection shield

Fig. 18. Natural and planted mangroves. Source: Stefan Groenewold

Width	At least 150m width
Location (*exact values in online CPMD)	West Sea, Ca Mau National Park
Costs (VND) per m	Planting 1 ha of mangrove forest in the seafront pioneer zone costs 172,000,000 per ha. In order to compare directly with structural work, the cost per m of a 150 m wide mangrove belt is: 2,580,000 VND/m.
PROS	Natural accumulation of sediment and elevation of seabed. High attenuation of waves especially in the short- and mid-wave length spectrum. Very high ecosystem services (fish and shrimp production and natural nursery ground, eco-tourism, other uses, >2,700 USD annually per ha in Ngoc Hien).
CONS	Mangrove plantation in exposed sites needs additional engineering support; sites with low elevation are not suitable and have to be restored before any planting attempts.
Conclusion	Recommended for most locations along the Mekong Delta with low exposure to waves and recommended as highly durable, effective measure for erosion prevention, especially if combined with engineering measures.

Riprap revetment of embankment; rubblemound-like construction of rock stones

Fig. 19. Riprap embankment protection.
Source: Holger Schuettrumpf & Peter Froehle

Position	Close to shoreline
Location (*exact values in online CPMD)	West Sea, Ca Mau
Costs (VND) per m	About 10,000,000
PROS	Rip-rap revetments provide ad-hoc protection of severely eroded sites. They can be constructed at short notice. Feasible as emergency response method.
CONS	Instability, high weight on soft soil induces settling; it is only a temporary solution with a short lifespan. Since natural stones are relatively expensive materials, their use should be restricted to more durable structures such as described in wavebreaker (no. 1, 2).
Conclusion	Revetments along the funnel-shaped erosion areas at the mouth of most channels and creeks especially as an ad-hoc method in case of severe erosion. The funnel-shaped erosion pattern is natural.

Gabion, concrete breakwater-like construction with steel fence

Fig. 20. Gabion breakwater. Source: Phan Thanh Tinh

Position	Close to shoreline up to 30 m
Location (*exact values in online CPMD)	West Sea, Ca Mau province
Costs (VND) per m	22,000,000
PROS	Little benefits for short periods
CONS	Gabion structures were corroded (the steel net cages) within a year at all sites and had to be replaced. Missing bottom layers or seabed filter were missing, heavy constructions were sinking quickly into the soft muddy soil.
Conclusion	Gabions of this design are not recommended for any segments of the Mekong Delta coast.

Gabion embankment revetment

Fig. 21.Gabion revetment. Source: Phan Thanh Tinh

Position	Close to shoreline
Location (*exact values in online CPMD)	West Sea, Ca Mau province
Costs (VND) per m	7,000,000
PROS	Little benefits for short periods
CONS	Gabion structures were corroded (the steel net cages) within a year at all sites and had to be replaced. Missing bottom layers or seabed filter were missing, heavy constructions were sinking quickly into the soft muddy soil.
Conclusion	Gabions of this design are not recommended for any segments of the Mekong Delta coast.

Coconut lumber seawall

Fig. 22.Coconut lumber seawall. Source: Phan Thanh Tinh

Position	At shoreline
Location (*exact values in online CPMD)	West Sea, Ca Mau province (2010)
Costs (VND) per m	4,100,000
PROS	Little benefits for short periods
CONS	The coconut piles were rotting within months. The corrosion of binding cables led to undermining and collapse of the structure. Wave reflection due to the steep profile enhances erosion problems by scourging.
Conclusion	Constructions of this design are not recommended for any segments of the Mekong Delta coast. Alternatively, emergency repairs could be carried out with proper sandbag embankments.

Revetment of shore embankment, PVC sheets, concrete piles, and anchoring structures

Fig. 23. PVC sheet-based revetment. Source: Phan Thanh Tinh

Location (*exact values in online CPMD)	Ca Mau province
Costs (VND) per m	About 5,000,000
PROS	Little benefit for short periods, emergency repairs
CONS	Steep vertical "seawall" design leading to high wave reflection and thus negative impact on the seabed elevation. A long-term exacerbation of erosion problems.
Conclusion	Constructions of this design are not recommended for any segments of the Mekong Delta coast. Alternatively, emergency repairs could be carried out with proper sandbag embankments.

Concrete pillar seawall at funnel-shaped port entrance, riprap as toe protection

Fig. 24. Concrete pillar seawall.
Source: Holger Schuettrumpf & Peter Froehle

Position	Close to shoreline
Location (*exact values in online CPMD)	Ca Mau province, West Sea
Costs (VND) per m	30,000,000
PROS	Effective in halting erosion
CONS	High costs
Conclusion	Generally more effective than any solution using gabions. The dimensioning (lower and larger distance between the pillars) and at some sites the positioning (too close to the natural funnel-shaped channel mouth) might work, too.

Gabion revetment of sea-dyke

Fig. 25. Gabion revetment of sea-dyke.
Source: Holger Schuettrumpf & Peter Froehle

Position	At shoreline
Location (*exact values in online CPMD)	At several sites with similar design
Costs (VND) per m	22,000,000
PROS	Short term benefits
CONS	Armouring is not very durable since there is no proper filter layer nor toe protection.
Conclusion	Gabions of this design are not recommended for any segments of the Mekong Delta coast.

Emergency sea-dyke revetment including gabion, concrete tubes and double row of wooden fences, sandbags, slabtiles

Fig. 26. Mixed emergency sea-dyke revetment.
Source: Holger Schuettrumpf & Peter Froehle

Position	At shoreline
Location (*exact values in online CPMD)	East Sea, Soc Trang province
Costs (VND) per m	About 20,000,000
PROS	Effective for short periods
CONS	Use of many different materials, non-coherent ad hoc emergency strategy for dyke repair. Very steep seawards profile which might enhance scouring erosion of the dyke toe leading to collapse.
Conclusion	Not recommended. Generally, there is a lack of a coherent strategy and preparation (materials, emergency funds, manpower) for dyke repair. It is strongly recommended to develop training sessions on the proper use of sandbags for emergency repairs.

Concrete slab armouring of sea-dyke (revetment); overtopping protection, with filter layer – type 1

Fig. 27. Concrete slab armoured sea-dyke. Source: Phan Thanh Tinh

Position	At shoreline
Location (*exact values in online CPMD)	Bac Lieu province
Costs (VND) per m	60-70,000,000
PROS	Gentle slope, solid and rough armouring at exposed sites .
CONS	High costs
Conclusion	Recommended for most exposed sites where high value assets have to be protected (settlements, ports). Special attention should be paid to toe protection and filter layer (see text below). The effectiveness of slabs and in particular their surface features (roughness) and underlying filter layers can be optimised and need more physical modelling studies, specifically on interlocked slab armouring and overtopping performance.

Concrete interlocked slab armouring of sea-dyke with recurved topstone against overtopping by waves – type 2

Fig. 28. Interlocking concrete slab armouring. Source: Holger Schuettrumpf & Peter Froehle

Position	At shoreline
Location (*exact values in online CPMD)	East Sea, Bac Lieu province, Ganh Hao; 2009
Costs (VND) per m	110,000,000
PROS	Gentle slope, solid armouring at exposed sites
CONS	High costs. Critical issue is the filter layer under the armouring which should consist of a gravel layer and strong geotextile. The slope at the dyke toe should be mild (1:6) with proper dyke toe protection.
Conclusion	Recommended for most exposed sites where high value assets have to be protected (settlements, ports). Special attention should be paid to toe protection and filter layer (see text below). The effectiveness of slabs and in particular their surface features (roughness) and underlying filter layers can be optimised and need more physical modelling studies, specifically on interlocked slab armouring and overtopping performance.

Concrete slab armouring of sea-dyke – type 3

Fig. 29. Concrete slab armouring. Source: Stefan Groenewold

Position	At shoreline
Location (*exact values in online CPMD)	East Sea, Bac Lieu province, Ganh Hao; 2009
Costs (VND) per m	90,000,000
PROS	Gentle slope, solid armouring at exposed sites
CONS	High costs. Critical issue is the filter layer under the armouring which should consist of a gravel layer and strong geotextile. The slope at the dyke toe should be mild (1:6) with proper dyke toe protection.
Conclusion	Recommended for most exposed sites where high value assets have to be protected (settlements, ports). Special attention should be paid to toe protection and filter layer (see text below). The effectiveness of slabs and in particular their surface features (roughness) and underlying filter layers can be optimised and need more physical modelling studies, specifically on interlocked slab armouring and overtopping performance.

Earthen dyke with wooden double-fence revetment; Stag-dyke type; originally as repair measure

Fig. 30. Earth dyke with wood fence. Source: Stefan Groenewold

Position	At shoreline
Location (*exact values in online CPMD)	East Sea, Soc Trang province
Costs (VND) per m	15,000,000
PROS	Little benefits for short periods
CONS	Once the earth dyke is exposed, the steep double fence revetment (stag dyke) is ineffective and of short durability. No toe protection.
Conclusion	Earth dykes which are expected to be exposed within a few years due to current erosion trends should be strengthened in time by toe protection and breakwaters in front of the dyke (anticipating management). Proper sandbag deposition is a better alternative for emergency repairs.

Earth dyke

Fig. 31. Earth dyke. ource: Stefan Groenewold

Position	West Sea, currently 2-2,5 m high
Location (*exact values in online CPMD)	West Sea, Ca Mau province; about 100-150 m from shoreline landwards.
Costs (VND) per m	5-6,000,000 if 3-4 m high. An earth dyke with more gentle slope seawards and simple toe protection may cost around 10,000,000 VND
PROS	High benefits and sufficient protection against flooding as long as there is a dyke-foreland of at least 150 m or more.
CONS	Not for exposed or nearly exposed sites. Earth dykes in the Mekong Delta should be constructed with a milder seaward slope (1:3-5) as currently observed, and regularly inspected and maintained.
Conclusion	The strengthening of earth dykes is strongly recommended if there is sufficient space for dyke foreland (especially mangroves). Settlements, agriculture and tree planting onto the dyke crest should be more restricted.

Strengthened earth dyke

Fig. 32. Strengthened earth dyke. Source: Stefan Groenewold

Position	3 m high, 7,5 m crest width at the West Sea coast and 4 m high and 7,5 m crest width at the East Sea coast, with road on the top; about 50-100 m from shoreline landwards.
Location (*exact values in online CPMD)	West Sea, Ca Mau province
Costs (VND) per m	70,000,000
PROS	High benefits and sufficient protection against flooding as long as there is a dyke-foreland of at least 150 m or more.
CONS	Earth dykes in the Mekong Delta should be constructed with a milder seaward slope (1:3-5) as currently observed, and regularly inspected and maintained.
Conclusion	The strengthening of earth dykes is strongly recommended if sufficient dyke foreland (especially mangroves) is available. Settlements, agriculture and tree planting onto the dyke crest should be more restricted. Dykes closer to the current eroding shoreline need proper toe protection. The excavation of materials for the dyke construction directly in front of the dyke (leading to deep channels and eroding currents) should be halted, existing channels should be filled.

6. Guidance for coastal waterworks in the Mekong Delta (“tool box”)

In the following sections (6.1-6.6), selected tools are introduced which can guide the entire process of coastal protection planning. In the first section the design of different waterworks is described with special emphasis on how to determine the best design for the prevailing environmental conditions and purposes. It is important to understand general design principles on the one hand but to realise that simple replications do not work. Every location is specific and the design of coastal waterworks has to be adapted and optimised for that specific location and for its certain purpose.

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- 6.1.1 Typology of coastal waterworks
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- 6.1.4 Emergency repair using sandbags
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6.2 The T-fence story

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6.4 Mangrove forest rehabilitation

6.5 Coastal survey with Unmanned Aerial Vehicles (UAV, light drone)

6.6 Blue planning (Coastal Spatial Planning)

More details and additional tools can be found in the online CPMD library:

- *Strategic Advice for Coastal Protection Planning in the southern of Mekong Delta (Thorenz, F., 2017)*
- *Organizational development and institutionalizing of coastal protection in the Southern Mekong-Delta, Vietnam (Thorenz, F., 2016)*
- *Integrated coastal protection and Mangrove belt rehabilitation in the Mekong Delta - Prefeasibility study for investments in coastal protection along 480 kilometers in the Mekong Delta (Wölcke, J. et al., 2016)*
- *Coastal Protection Mekong Delta, Vietnam (Schuettrumpf, H. & Froehle, P., 2015)*
- *Shoreline Management Guidelines - Coastal Protection in the Lower Mekong Delta (Albers et al., 2013)*

6.1 Principles for designing coastal waterworks

More than 1,9 million people are living on about 700,000 ha of intensively used land within the dyke hinterland - which is here defined by the borders of the official water management units - in the vulnerable immediate area behind the sea-dyke route. In the following pages, guidance is provided for all the different elements of the coastal protection system in the foreshore (breakwater, breakwater-groyne fields, groynes, mangroves) and for revetments and sea-dykes.

Fig. 33. Typical locations of different elements in the coastal protection system: a) breakwaters b) breakwater-groynes (e.g. T-shaped fences) c) fences and groyne-fields d) mangroves e) sea-dyke revetments and toe protection f) sea-dykes. In the CPMD, combined recommendations for all the elements are provided although not all elements are recommended everywhere and at the same time. The image shows an area of high urgency in the district of U Minh in Ca Mau province at the West Sea (still image by lightweight drone, 2017).

Source: Stefan Groenewold

6.1.1 Typology of coastal waterworks

A short typology of coastal works shall precede the assessment. The sequence follows the succession of the typical location from the sea towards the land and sea-dyke (see Fig. 33).

Breakwaters are arranged parallel to the shoreline usually on the foreshore near the breaker zone or in the surf zone. Nearshore breakwaters are mainly built with the purpose to protect the coast from erosion. They provide shelter from waves, causing the littoral transport behind the breakwater to be decreased and the transport pattern adjacent to the breakwater to be modified. Important parameters that characterize breakwaters are their length (LB), their width, the height, the transmission coefficient and the distance to the shoreline (x). Breakwaters are usually semi-permeable and constructed as detached breakwaters or in a series of several breakwaters (segmented breakwaters), where the length of the gap between the breakwaters is defined as L0. Segmented breakwaters are not constructed in a continuous line over long stretches in order to promote natural sediment dynamics (cross-shore and longshore). The width of the crest of a breakwater depends on the shape of the cross-section which can be rectangular, curved or stepped. Construction materials can be concrete, natural stones, synthetic materials or a combination of these. A frequently applied form is the rubble-mound breakwater consisting of a core from quarry run and an armour layer made from rocks or concrete blocks.

Groynes in general are cross-shore (perpendicular to the shoreline) dam-/wall-like constructions for the protection of beaches, floodplains or longshore constructions. They are arranged perpendicular to the shoreline and interrupt the natural longshore sediment transport and lead to accretion at the windward side. The sediment transport to the lee side is reduced at the same rate that sediments are deposited on the windward side. If the impact of the groyne is too strong, downdrift erosion may cause serious damage to longshore structures or severe erosion of the coastline. Impermeable groynes form a complete barrier against longshore transport as long as they do not overflow. Permeable groynes are constructed if a certain transport through the groin is required. Groynes can have various shapes (cross-sections), such as wall-like, curved, case-shaped, and can be emerged, sloping or submerged.

Groyne fields are semi-closed shallow mudflat areas formed by a series of groynes along the shoreline in the foreshore zone (or intertidal zone) in order to stimulate sediment accretion in strongly wave-reduced shallow water zones. This technique was widely used for land reclamation along the European North Sea coast (Wadden Sea) and works best in bays and coasts with medium to low wave impact and a muddy environment.

The **U-shaped fences, the sediment trapping double fences** (Kien Giang bay) and the T-shaped fences in the Mekong Delta have some features of groyne fields but also features of breakwaters and thus are classified as mixed types. What they have in common is the use of mainly natural materials such as bamboo and Melaleuca cajeputi.

Mangrove forest is also included in this section since this green shield is considered as an important integrated part of the protection system. Considering the distinguishing zoning in protection forest and production forest, it should be considered that the protective function of a mangrove shield is only effective if there is still at least 150 m wide closed canopy forest and in the best case up to 500 m. 150 m is the minimum forest width for effective attenuation of wave surge (roughly 50%) also a wider protection forest belt is desired and reaches its optimum (90 % attenuation) at about

500 m for the typical wave spectrum around the Mekong Delta. Experiences from Indonesia after the great Tsunami from 2003 showed that a mangrove belt mitigates the impact of a tsunami nevertheless without hindering the flooding. More detail can be found about mangroves in the respective sections.

Revetments of sea-dykes and embankments are longshore elements (parallel to shoreline like the sea-dyke) constructed to prevent erosion and scouring of sloping embankments and sea-dykes. The revetment can for example consist of riprap, concrete armour units such as tetra-pods or geotextiles placed at the seaward dyke slope.

Gabions are usually wire cages filled with stones to protect embankments. The wire can corrode quickly in seawater and motion of the stones in wave action leads to destruction of the wire and failure of the gabions. Riprap are foundations of natural stones.

Sea-dykes are constructed according to "Technical standards for sea-dyke (sea-dyke) design (Ministry of Rural Development (MARD) dec.no. 1613, July 2012)", including earthen dykes, dyke revetments and other dyke protecting measures. The designs of the dykes are mainly defined by their grade (I-V), depending on exposure and planned lifespan between 20-100 years. Very detailed guidance is provided for the construction of over-topping and dyke-toe protection (see Technical Guidelines for sea-dyke systems).

Fig. 34. Sluice gates. Source: Stefan Groenewold

Sea-sluices and **Pumping-stations** are essential elements of flood management within the coastal protection system and are part of the sea-dyke line. Sluices can be active (with hydraulic gates) or passive (gates that close and open with the tides as found mostly in the MD). In the longer term, the hinterland needs improved drainage with pumping stations because of increasing land subsidence. If sea sluices are an integrated part of the sea-dyke route and thus an element of flood protection, they must be properly connected to the sea-dyke, which is not always the case in the Mekong Delta.

Coastal hinterland. In case of the full inclusion of the Coastal Protection Units (CPUs, the water management units of the adjacent coastal hinterland) into the coastal protection system, respective sluice gates should be active on a long-term perspective. In case of disaster, the risks of flooding might concurrently come from storm surges from the seaward side and heavy rainfall from the landside. In this scenario, water management in the CPUs is crucial for flood and damage control.

6.1.2 Guidance for the development of breakwaters and groynes

Special attention is paid on how to develop the right design for breakwaters and how and where to place them in the foreshore area. The reasoning behind this is that massive retractable concrete constructions could support sediment trapping without essentially disturbing the typical pattern of longshore sediment transport. Any structural coastal protection measure should be planned in regard to optimized design, efficiency and avoidance of negative environmental impacts. In the past, there was generally a lack of impact studies. In the following, shortcut systematic methods (checklists) are presented in order to plan breakwater and groynes for the specific situation in the MD.

Certain types of breakwaters are strongly recommended in order to re-establish shallow mudflats close to the shoreline for mangrove rehabilitation (cf. table 4). Avoiding negative impacts and optimizing their functionality and cost-efficiency are design guiding principles. Among massive breakwater types, a tested pillar-framed riprap breakwater is considered as the most effective erosion protection but there are serious possible down-drift impacts on the coast if not properly planned and monitored. If possible, reusable construction materials for coastal protection structures (clay, sand, natural stones) should be used for waterworks. For a proper planning of effective breakwater that does no harm, close collaborative planning between Kien Giang and Ca Mau Provinces is crucial. If implementing the pre-tested riprap- pillar versions (no. 1 and 2 in PRO & CONS) the regular gaps in the coast parallel elements are important in order not to disrupt longshore sediment transport and ecological services of the existing and afforested mangrove forest. If possible, reusable construction materials for coastal protection structures (clay, sand, natural stones) should be used for waterworks. The following provides technical guidance through the process of design and planning of breakwater and groynes or similar structures in the foreshore area in front of the dyke. Table 1 provides more generalised guidance through the evaluation and planning process, which is in principle valid for all types of coastal waterworks and is mainly for decision makers.

“How to design a breakwater” in the foreshore area in 10 steps

Fig. 35. Discussion on coastal waterworks design after field visits. Coaching at the site by national and international experts was part of the capacity building strategy during the development of the CPMD. Source: Phan Thanh Tinh

1. Clear definition of the problem and analysis of the possible causes

What kind of erosion, how fast, historical development and trends (compare historical coastlines in CPMD), spatial scale of erosion (spot or long stretch), erosion and accretion trends in adjacent areas. If there are only small spots of erosion without a clear trend and the erosion does not directly jeopardize people and assets, the event might be accepted as natural temporal compensation phenomena of the sediment balance. If trends are persistent, the erosion is large-scale, and direct mangrove rehabilitation is not possible, the instalment of breakwaters is considered.

2. Determination of the local wind climate, wave climate and the local tidal and wind generated currents based on measurements, data analysis and / or numerical model results

See respective information on the online CPMD. Currently, numerical models are offering relatively low resolution or are built on a poor data base. In order to develop numerical models as real support for design, the local conditions at the erosion site have to be assessed and studied in the field (see also embedded numerical modelling in Lower Mekong Delta Coastal Zone (LMDCZ) Project. One critical issue is the lack of good hydrological data of extreme weather events and long-term trends which should be improved in the long-term.

3. Site specific bathymetric study of the area aimed for intervention

The local topography (land elevation) and underwater profile (depth, steepness, features, sediment composition) is crucial for the success of larger scale massive investment such as breakwaters, and has to be carried out by skilled institutions.

4. Assessment of the local sediment transport rates and directions based on outcomes under 2 and 3

The processes of the dominant sediment transport processes have to be understood in order to make full use of natural sediment discharges and to avoid negative effects by interrupting natural processes. Although currents are changing with tides and seasons, the dominant sediment transport via longshore currents is from NE to SW in the East Sea and from N to S in the West Sea (except the Bay of Rach Gia). Cross-shore transport of sediment and re-suspension processes by waves at the nearshore are also crucial and this provides the main argument for layouts of breakwaters with gaps in the shoreline parallel elements and certain permeability. There are uncertainties about the behaviour of long waves which can penetrate very far on flat shores with extremely low slopes such as those in the Mekong Delta. There is still much unknown about these processes around the MD and further studies should be encouraged [link to Philipp Jordan].

5. Analysis and assessment of general solutions for the protection of the coast against erosion

There are experiences with certain structures around the world, in Vietnam and in particular in the MD (see PRO & CONS section) which should be considered before implementing completely new untested design options. A deeper discussion with an expert panel of the effects of different alternative (breakwater) layouts is recommended. Provinces should seek wider expertise (Can Tho University, HCMC University, Southern Institute for Water Research, Southern Institute for Water Resource Planning).

6. Aspects of functional and structural design

Does the structure do what it is expected to do? Enhancing sediment trapping without negative impacts on neighbouring coastal stretches? One aim of any breakwater design is to reduce the loading by wave impact due to mild slopes seawards (see recommendations above in PRO & CONS). The final questions for the structural design aspects of importance are: is the structure technically easy to install and cost effective in maintenance? What is the expected load and lifespan and therefore which materials should be used? Another aim is a certain adaptability and flexibility for possible enforcement or reuse. Some of these principals are also valid for dyke revetments and other coastal works (see under respective section). In order to answer these questions properly a physical scale model programme in a wave channel/ flume tank is needed, such as the one of SIWRR in HCMC which provides parameters such as transmission coefficient, wave reflection, bedload etc.) and helps to reduce the development of larger scours in front of the structure and optimise trapping behaviour. A numerical modelling in order to study the behaviour of the selected structure in the respective area completes the preparation on functional design and impact anticipation before deployment of real size structures into the water. The numerical modelling can provide answers on the large-scale layout and the dimensioning and the positioning of the structure(s) if the used parameters are reasonable. Principally, these characteristics can be tested in 3-D physical models using movable bed wave pools. However, this approach is very costly and complex.

7. The monetary estimate of expected costs and benefits should be carried out

8. Deployment of structures in the field

9. Regular field monitoring including adjacent coastal areas in order to assess functionality and impacts of the erected structure

10. Annual evaluation of the solution and dissemination to a wider circle of experts and practitioners in the MD Some conclusions on breakwater design in the Mekong Delta

Small-scale natural sediment transport should be accepted. Short-term small-scale erosion-accretion patterns are part of a natural process for stable coastlines. Poor functionality, adverse effects and structural quality of coastal works are issues in the Mekong Delta and are addressed by suggesting more binding protocols for breakwater assessment, sea-dyke design and cross-sectoral spatial planning.

The background skills and facilities for the described procedures are not fully available at provincial level in the MD and should be coordinated at regional level in order to save development costs and avoid duplication of effort. Budgetary limitations might hinder the full performance of a full test programme including field studies, physical modelling and numerical modelling. However, the high costs of failure of untested structures and the growing financial burden for some provinces underline the need for regional coordination for the development of technical solutions. One strong recommendation for updating the Technical Guidelines is that before any (non-experimental) deployment of massive breakwater construction, the structural and functional feasibility has to be proved by physical and numerical modelling and tested for environmental impacts on the sediment balance and mangrove belt. This is to prevent engineering structures doing more harm than good. It is likely that additional costs for this verifying process will be outweighed by the savings made from avoiding failures and negative impacts.

Fig. 36. Left: Wave basin in the experimental hall with wave generator and riprap absorber. Right: Wave flume tank at the Southern Institute for Water Resource and Research SWIRR. These facilities are very suitable for physical testing of scale models of different waterworks. Source: Holger Schuettrumpf & Peter Froehle

Fig. 37. Physical model of riprap pillar construction (as used in Ca Mau, West sea) in the flume tank of the Technical University of Hamburg-Harburg, Germany (TUHH). The system of Ca Mau's breakwater was reproduced at a reduced scale of 1:10 in the laboratory and the hydrodynamic forces were represented in correct proportions to the actual system. The transmission coefficient and other parameters could be determined and combined with field studies on sediment accretion and resulted in the recommendation to develop some modifications. Source: Philipp Jordan

How to evaluate and plan coastal protection measures?

This step by step approach provides guidance for the evaluation of coastal works in general but should also be carried out beforehand as part of the planning process. It is the outcome of several international workshops in the MD and is aimed in particularly at decision makers.

Table 2. Evaluation and planning of coastal protection measures

	Criterion	Description (evaluation & planning)	In context of the CPMD
Step 1	Relevance	What are the protected values, residents (population density), public and private infrastructure and assets, land-use and annual production, natural, cultural and historical values, future options. How likely is a disaster scenario for this area?	Under the Coastal Protection Units (CPUs) provide detailed information regarding residents and land-use. Under the Coastal Protection Segments (CPSs) information on urgency and erosion trends (coastline changes since 1904) are provided. Background reports on climate change and other impacts are provided. Guidance on strategic coastal protection planning is given.
Step 2	Functional effectiveness	Does the measure achieve what is it supposed to achieve?	Under the Coastal Protection Regions (CPRs) and partially CPUs, information on wave climate, currents, tides, bathymetry and sediment transport are provided. Next to natural design parameters, a comprehensive study on baseline data, field observation, and output of numerical and physical modelling is strongly recommended.
Step 3	Structural effectiveness	Is the structure of optimal design, are the measures durable?	Obligational physical test programs are strongly recommended. Under each Coastal Protection Segment (CPS), specific feasible recommendations on measures / structures and their combinations are given. Despite higher immediate investments, structures with longer lifespan (> 5 years) should be preferred (see below Cost-benefit studies).

Step 4	Impact	What is the impact (positive and negative) of the measure or structure on the environment? And what is the impact on the affected socio-economic situation?	Assessments of possible impacts of coastal structures are provided based on empirical data, acute observations and existing knowledge on coastal sediment transport processes. Are there impacts on natural resources and ecosystem services? One example is the down-drift erosion: despite local positive effects a certain structure leads to increased erosion at neighbouring sites. There is a lack of **impact studies** for most structures erected in the Mekong Delta coastal waters. There might also be positive impacts by synergies e.g. between nearshore wind parks and breakwaters if planned concurrently.
Step 5	Economic efficiency	Are the costs in relation to the effectiveness, durability (lifespan) and protected values reasonable? How is the performance in comparison to other options? What are the maintenance costs (regular inspection, repair)?	**Cost – benefit assessment.** Effectiveness, price and possible impacts are evaluated. This was conducted for selected sites and is documented in the Pre-feasibility study (GIZ 2016). The sea-dyke routing decision support tool offers comprehensive information on the cost-benefits in relation to the location of coastal waterworks.
Step 6	Sustainability	Is the measure / structure beneficial for the long-term vision on natural resources, conservation and socio-economic development?	If the outcome of the evaluation from step 1-5 was positively evaluated there is still the concern if respective measures are **safeguarding larger-scale and strategic long-term aims** for certain regions. Cross-sectoral and regional planning is essential to achieve sustainability. This approach was followed by the CPMD for the Mekong Delta.

6.1.3 Golden Rules for sea-dyke design in the Mekong Delta

A sea-dyke only offers protection for the hinterland if there is an enclosed area, which is the socalled sea-dyke route of the entire Mekong Delta. During development of the CPMD, many observations showed that the sea-dyke urgently needs considerable strengthening. In the following, some general guidance is provided concerning dykes, revetments (armouring of dykes) and maintenance.

The main recommendations are summarised in the following table:

Table 3. Golden Rules for sea-dykes

Dyke Design and Construction	
1	Dykes are built to protect against flooding.
2	The protected values should be higher than the costs for dyke construction. This proves likely for the entire Mekong Delta (safety design level should rise to 100 years at least), therefore adaptable dyke profiles should be implemented.
3	Close a dyke protection line and integrate sluices into the dyke trajectory / sea-dyke route.
4	Land-use in front of the dyke must be strictly regulated in order to prevent harm to the dyke.
5	A dyke should be behind and never in front of a mangrove forest. Vice-versa, a sea-dyke should whenever feasible never be directly exposed to the open sea.
6	Every dyke should be protected against currents, waves, rain, wind and human impacts.
7	A dyke must be designed following the Vietnamese design guidelines for coastal protection systems (TG 1613)
8	A dyke should be constructed according to a clear design.
9	Geotechnical proof is crucial in the design process and filter rules are very important to avoid dyke failures.
10	Every dyke has to be inspected and maintained regularly.

Further comments on the Golden Rules of Sea-dyke design and construction

- Dykes are built to protect against flooding

The purpose of sea-dykes is flood protection and thus the height of the dyke is the primary parameter. There are 5 basic steps to determine the height:

  - Firstly, a characteristic value for a high-water level, e. g. mean tidal high water calculated based on statistical analysis of a time series of the previous 10 years
  - Secondly, the maximum increase of the water level due to seasonal effects or spring tides
  - Thirdly, the largest measured (or modelled) wind wave surge
  - Fourthly, the possible wave run-up
  - Fifthly, a safe margin considering, for example, the sea level rise and subsidence of the subsoil

- The protected values should be higher than the costs for dyke construction. This proves likely for the entire Mekong Delta (safety design level should rise to 100 years at least), therefore an adaptable dyke profile is needed (space for heightening)

The monetary value of the immediate hinterland of the sea-dyke was not determined during the CPMD Project. However, the basic data for land-use and production are available online for the so-called CPU's, the Coastal Protection Units. Considering the high population density and immense importance of the MD for food security and trade on a national and international level, it is reasonable to set a higher safety design level than currently used. A first step might be a zoning based on urgency and value of the hinterland, including the special zones such as ports and urban areas (see urgency of CPS and information on population and land-use of the CPUs. In a second step, more detailed scenarios might be developed in order to draw disaster risk maps for respective areas and to work out preparedness and rescue strategies for the most vulnerable areas.

- Close a dyke protection line and integrate sluices into the dyke trajectory / sea-dyke route

The current sea-dyke route is indicated in the online CPMD. Currently, there are areas which are not dyked in at all (mainly the eastern part of Ca Mau). Estuarine dykes are directly connecting the sea-dykes inland along the larger river and channels. Many sea-sluices are not yet connected to the closed sea-dyke line and thus are weak points in case of an extreme storm event. Another critical issue is that once the sea-dyke line is closed, the importance of active sea-sluices and pumping stations (see above for definitions) increases. This is another reason to think about including the hinterland

– the Coastal Management Units with its embankments and sluices – into coastal protection planning. Compare also remarks under the section (or TOOL) on sea-dyke routing and coastal classification. Critical issues are still the wide openings.

- Land-use in front of the dyke must be strictly regulated in order to prevent harm to the dyke

Next to the conservation of protection forest or special-use forest (including national parks), the regulation of land-use should be extensive and not include permanent settlements. The latter is very difficult to implement and might be seen as a long-term vision.

- A dyke should be behind and never in front of a mangrove forest

This is also stipulated in the TG 1613 but not always observed at district level. Full-size dykes in front of mangroves are not only very vulnerable and extremely costly in maintenance considering current erosion trends but they also sizably reduce the ecological and economic value of the mangrove forest behind the dyke since the natural processes need open water exchange. Water-logged mangroves become impoverished after a short period of time. A sea-dyke is one element in an integrated coastal protection system and the main objective should be that a sea-dyke is never directly exposed to the sea. This might be unavoidable in urbanised areas but is valid for most stretches of the coast.

- Every dyke should be protected against currents, waves, rain, wind and human impacts

More attention should be paid to proper toe protection and possibly against wave overtopping in exposed areas, and in the future, in areas where an exposure can be expected in respect to current erosion rates and trends. Wave overtopping has been responsible for many severe dyke failures in the past. For example, many sea-dykes failed due to wave overtopping during the extreme storm surge disasters in 1953 (Netherlands), 1962 and 1976 (Germany and Denmark), and in 2005 (New Orleans, USA). A possible measure to counter wave overtopping is to increase the crest level. Nevertheless, wave overtopping cannot be avoided completely due to the remaining uncertainties in the design water levels and the design waves. If significant wave overtopping cannot be avoided, dykes have to be designed in such a way that overtopping water has no consequences on the stability of the dyke crest and the landward slope. For the MD, the slope should be at least 1:3 or 1:5 and should be spread out with a very shallow slope of 1:10 near the dyke toe at exposed locations. The riprap toe protection should reach a level below the mudflat of at least 1-2 m.

- A dyke must be designed following the Vietnamese design guidelines for coastal protection systems (TG 1613)

Future dyke strengthening should more closely follow the protocols and guidance provided by the Technical Guidelines 1613. A modification of the TG 1613 for typical Vietnamese conditions at regional level and the inclusion of existing structures is strongly recommended on the basis of experimental model tests in hydraulic laboratories. Despite the current very valuable technical guidelines for sea-dyke systems from 2012, a periodic recalculation of hydrological and hydrodynamic design parameters in a 10-year cycle is needed and a respective modification of the guidelines that takes into account the new insights and special conditions in the Mekong Delta is required (aimed for 2022 for all hydrological regions of Vietnam).

- A dyke should be constructed according to a clear design

It is very important to design a dyke revetment according to technical rules and recommendations. Many dyke failures worldwide occurred due to a violation of the "filter rules" in the past. Therefore, it is highly recommended to consider filter rules and a filter stable cross section for all coastal (and hydraulic) engineering structures in Vietnam. A definition of "filter rules" for the situation in Vietnam must be taken into account for future design and Technical Guidelines.

- Geotechnical proof is crucial in the design process

Heavily armoured dykes on soft soil are sinking. In the MD there is a lack of coarse and gravel resources while there is an excess of silt and clay. For the stability of the entire dyke, the practice of digging excavation channels directly in front of the sea-dyke for gaining construction materials for the dyke is strongly discouraged. This practice undermines the geotechnical stability of the dyke considerably. Instead of this practice (which originates for channel digging in the MD) accessible sites in the hinterland for clay extraction should be identified and assigned. Initially, the overall stability of the subsoil must be proved. The load bearing capacity of the subsoil may limit the dyke height. The hydrostatic and hydrodynamic loads of water levels and waves induce stresses and potential damage to the dyke. Thus, the constructional resistance must be large enough to withstand those stresses. The erosional forces on the seaward side of the dyke can be minimized by a mild slope of 1:3 to 1:5. Steeper slopes cannot be recommended. If the degree of exposure is large and the existing stresses due to water levels and waves exceed the resistance of the dyke, additional constructional elements such as a strengthened toe protection or revetments must be considered.

- Every dyke has to be inspected and maintained regularly

The high investments planned for the strengthening of the sea-dyke system require a close regular inspection and maintenance scheme. For the future, a re-organisation and capacity building programme for the sea-dyke inspection teams is recommended using modern survey techniques (lightweight drones, training in emergency repair and disaster preparedness. In the MD, inspection teams should include not only members of the irrigation department but also from forestry and aquaculture.

Some further recommendations on sea-dyke design in the Mekong Delta

One principal rule of dyke design is to keep the dyke a safe distance from direct wave surge exposure. The high costs for armouring can be saved and flooding risks are still low. With increasing threat of exposure, the toe protection (which is hardly applied in the MD) mild outer slopes are the next step in safeguarding the system. If exposed, heavy revetments are needed. The designs of breakwater and groynes should involve physical modelling more systematically and be made a requirement of the design planning. The concrete interlocking slab-tile armouring which is very typical for sea-dykes in Vietnam would need a comprehensive assessment programme for stability and functionality. Model tests on wave run-up and wave overtopping for typical sea-dykes in Vietnam must be performed as a basis for a new crest level design. These tests should also include the typical core materials in the MD and the usual geotextile layer, the underlayer (sand, gravel) and the cover layer of the structure, which are crucial for the filter stability. The concrete interlocked slab revetments show gaps between the blocks. Water intrusion due to waves undermines the stability of the structure. Especially in the case of breaking waves, very high pressure can occur, which may lift concrete blocks which are too light or not interconnected. This probably happened during an extreme event at Ganh Hao (Bac Lieu) in 2016. A geotextile layer below concrete blocks and if applicable a gravel layer in order to disseminate wave pressure and prevent wash-out of inner material are essential. The surface of the outer slope or berm should be as rough as possible. This reduces the wave impact and wave run-up considerably. Hence, the use of riprap near the dyke toe may have advantages compared to concrete blocks. Generally, the impermeability of clay layers directly below a massive revetment can cause uplift of the revetment.

As generally for coastal protection planning, a capacity building programme is recommended aimed at practitioners and decision makers at provincial and district level. Additionally, through a capacity building in higher science education in water management and hydro-engineering, might benefit the entire planning for coastal protection. Coastal engineering solutions differ considerably from inland waterworks solutions considering material used and calculation of loads. There is also a history of experiences around the world on coastal engineering solutions which should be made accessible to engineers and local stakeholders in the MD.

Fig. 38. *Typical sea-dyke profile with riprap revetment and foreland in the Mekong Delta in Vietnam (East Sea). The conservation of dyke-foreland is of high importance for the resilience of the dyke. Source: Frank Thorenz*

Fig. 39. *Left: Typical sea-dyke profile of exposed dyke at the North Sea coast in Germany. The seawards slope of the armoured dyke berm is very mild and even milder close to the dyke toe. The reason is to reduce any damaging wave reflection by water waves with long periods. Protruding interlocked concrete slabs are considered to reduce wave run-up. Water reflection leads to scouring in front of the sea-dyke. The salt marshes in the dyke foreland are typical for temperate zones while mangrove ecosystems are confined to tropical and sub-tropical zones. Right: Sea-dyke at the West Sea (Ca Mau) and East Sea (Soc Trang) with typical maintenance roads on the crest or on the landwards berm (right). Source: Frank Thorenz*

Fig. 40. Typical sea-dyke failure along the East Sea coast of the Mekong Delta. Once an earth dyke with very steep profile and a lack of toe protection is exposed to even moderate wave surge, the dyke is undermined and collapsing towards the seafront. Longer periods of storm surge with high water setups and wave overtopping would destroy the sea-dyke in a very short period. Source: Frank Thorenz

Fig. 41. Concrete sea-dyke revetment at Ganh Hao (Bac Lieu) using interlocked slab-tiles as an example. After high storm surge in 2016, the structure failed. The thickness of current concrete revetment in the case in Ganh Hao might not be not sufficient. High waves caused pressure and uplift of the concrete blocks. A milder outer slope is recommended in order to reduce wave run-up and overtopping. Since the blocks seen to be placed directly on clay soil and a geotextile, high uplift pressures can be expected in case of breaking waves. A gravel layer between blocks and geotextile as well as a sandy subsoil in the vicinity of the revetment is recommended. Natural riprap (using large stones) at the dyke toe are rougher than concrete blocks and therefore are expected to reduce wave-run-up as well as overtopping significantly. Source: Frank Thorenz

Fig. 42. Sea-dyke-like embankments in front of the mangrove forest in the East Sea (after dyke breach) and West Sea (under construction in 2017). This practice is strongly discouraged since it will diminish the ecological and economic value of the mangrove forest and requires immense investment and maintenance costs. Alternatives are breakwaters as described in section II. Source: Frank Thorenz

6.1.4 Emergency repair using sandbags

There have been several breaches of sea-dykes observed during the last decades. Responsible agencies had to act fast and were not always prepared for these events. In the following, some guidance on the right deployment of sandbags is provided for the case of emergency repairs. If properly carried out, sandbags are considered a very suitable measure and more attention should be paid on how to prepare provincial and district agencies for acting on local dyke breach events.

Fig. 43. Emergency repair of sea-dykes in Soc Trang and Ben Tre using sandbags. The crucial point for emergency repairs using sandbags is the method of stapling.

Source: Holger Schuettrumpf & Peter Froehle

In the case of locally limited severe erosion of the shoreline, temporary revetments consisting of sandbags should be foreseen as an emergency response. The technically correct execution of a sandbag revetment should be trained, and a sufficient number of sandbags should be kept available for emergency cases. The figures (see sources) below show the correct stapling of a sandbag embankment and the correct filling and placement of sandbags on the top of an existing revetment.

In sandy environments (cf. Ben Tre and Tra Vinh) the temporary sandbag revetments can be manually covered with sand and become part of a medium-term protection element. In that case the sandbags form the core of a dune or sandwall and provide further protection during future storm surges. Emergency erosion protection with sandbags should be designed in an improved way. The sandbags should be filled up to 60 to 70% only and placed overlapping at a certain slope. In addition, UV stabilized plastic bags or natural fabrics like jute must be used. This could then serve as a basis for a new, sloped coastal protection with revetments or even as a basis for a dyke.

Some general guidelines for sandbag packing and structures:

- Possible material: polypropylene or jute bags
- Sand: grain size 0 – 8 mm, can be mixed with split
- Bags are filled two thirds with sand (about 12 kg) and are closed by clenching the endings
- Maximum height of the sandbag slope is 0.5 meters with 35 sandbags per meter
- To reach stability, the sandbags are packed closely in cross bracing and longitudinal bracing
- After use during flood events the sandbags are to be disposed either with the domestic waste, or if the sandbags are contaminated, as hazardous waste.

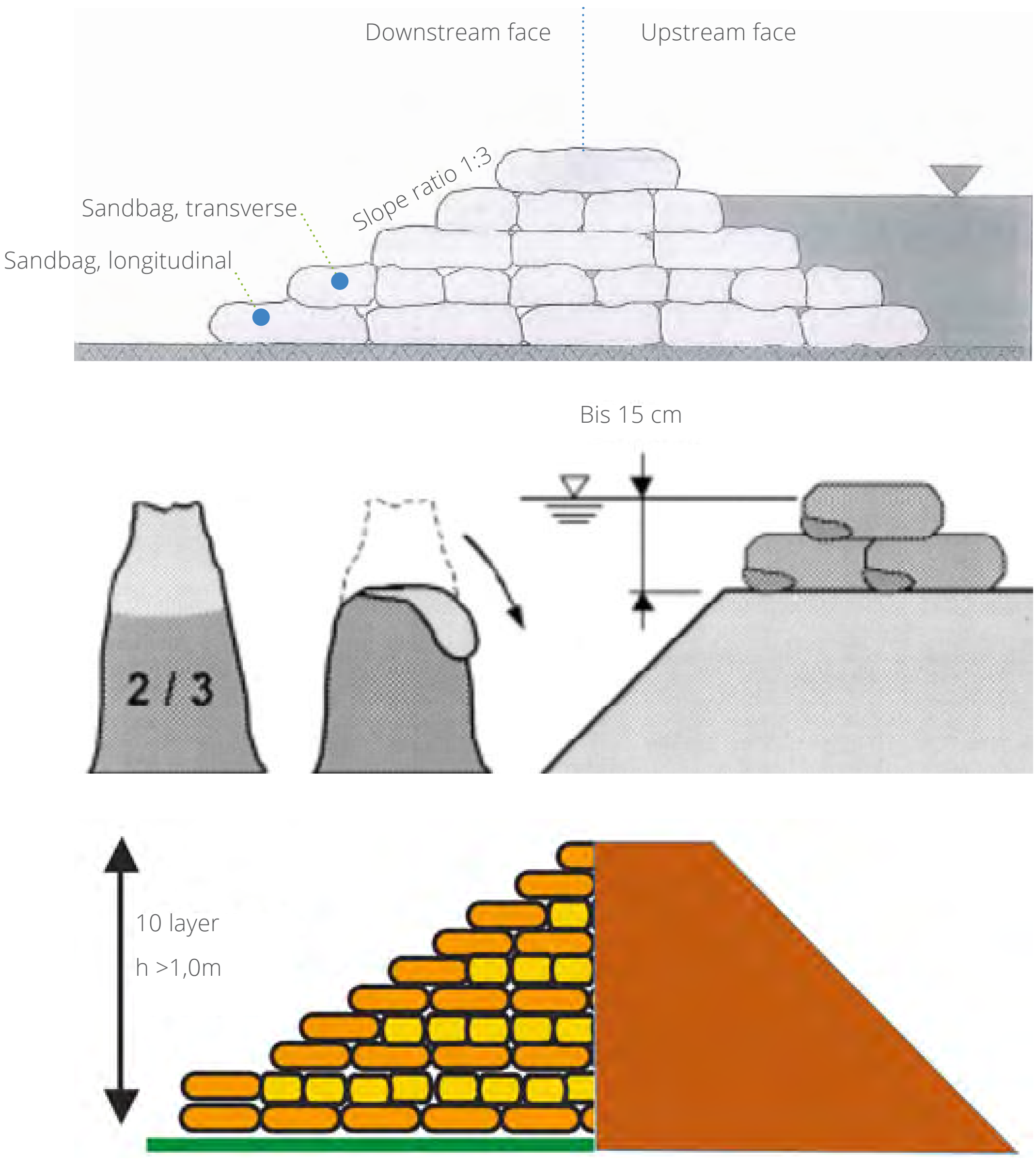

Fig. 44. Principles of sandbag use. Source: Thorsten Albers

6.1.5 Strategic coastal protection planning

One observation during the CPMD development in the four southern coastal Mekong Delta provinces was that coastal protection planning was very technically oriented and disconnected from other relevant planning processes such those for forest, aquaculture, environment, infrastructure and land-use (spatial planning). The importance of coastal protection as a pre-condition for further sustainable development of the entire provinces and region is not reflected in the organisation and institutional structure of coastal protection.

Usually, coastal protection is accommodated under the provincial department for irrigation and water management. One of the consequences in the past was that the planning of sea-dykes, sea-dyke repair and measures against erosion are often responsive to disaster events or considerable damage. Budgets were scarce and there was little special coastal engineering knowledge available at provincial level. Recently, coastal protection planning is considered increasingly as climate change adaptation and mitigation. This opens a different view on budget distribution and also opens a link to international co-funding. Next to the funding question, the objective of strategic coastal protection planning is to prevent disasters and improve the disaster preparedness. Strategic planning also means scaling up the scope of the planning process with the objective of a sustainable, multi-sectoral (next to irrigation and water management also forest, aquaculture, infrastructure, land-use planning and others if found relevant after stakeholder analysis) and the inclusion of science institutions for capacity building and deeper studies. Collating coastal protection planning with land-use and socio-economic planning as given by the provincial SEDPs, sector plans, regional Mekong Delta wide plans or strategy plans such as the Mekong Delta Plan is also an important measure. These multi-sectoral tasks can only be collaboratively planned and implemented by a multi-sectoral board for coastal protection planning. During the development of the "Decision Support Tool for Coastal Protection for the Mekong Delta (CPMD)", this approach was attempted. Models for this approach are the "Masterplan for coastal protection of the federal state of Lower Saxony only available in German]" and the "Louisiana's Comprehensive Master Plan for a Sustainable Coast (2012 and 2017)". Some cross-provincial coastal issues can be best solved by regional approaches and formats. This might also be the level to address national coastal strategies and international issues such as the reduction of the sediment load by dams in the upper Mekong River. Table 2 provides an evaluation framework for any coastal protection structure, while Table 4 guides the entire process of strategic coastal planning.

Guidance for strategic coastal protection planning

The step-by-step approach is based largely on the outcome of a regional workshops in Ca Mau in 2014 and in HCMC at the Southern Institute for Water Resource Planning (SIWRP). Most of the activities are continuous activities and have to be evaluated and modified after certain periods (5-10 years).

Table 4. Strategic coastal protection planning

Step	Activity
1	Assessment of the state of the coastal area, recording of damage, changes and trends
2	Evaluation of existing protection measures
3	Stakeholder analysis (who has which stake in the coastal area)
4	Involvement of science institutions for deeper understanding of the coastal system and processes and development of capacity building curriculum at 3 levels: decision maker, practitioner, science
5	Compilation of any available data sets of the entire system (boundary conditions) with special emphasis on long-term series on extreme weather events (storms, flooding events)
6	Institutional and legal framework analysis
7	Organisation and responsibilities of agencies and ministries
8	Forming of coastal protection planning board with representatives of all relevant stakeholders
9	Link to climate change and adaption strategies and assessment of long-term impacts on the coastal area
10	Coastal flood risk and erosion assessment and management
11	Interaction of spatial planning and coastal risk management, spatial needs for coastal protection
12	Determination of coastal protection system and safety level
13	Numerical modelling of relevant coastal processes
14	Foreland erosion protection and design (mangrove rehabilitation)
15	Mangrove rehabilitation planning and coastal spatial planning
16	Sea-dyke routing (multi-stakeholder process)
17	Sea-dyke construction and design
18	Field study on local bathymetry, sediment transport, wave climate and topography of coastal land

19	Physical modelling of pre-selected coastal structures
20	Impact assessment and cost-benefit analysis of pre-selected protection measures
21	Maintenance and inspection scheme of coastal waterworks
22	Master plan drafting and funding (national and international sources)
23	Collaborative planning sessions with all relevant stake-holding agencies, decision makers and knowledge institution
24	Regional planning format (workgroup, workshops) in order to tackle cross-provincial issues and policy advice (e.g. in respect to address international issues, such as upstream Mekong River dams, national strategies, etc.)
25	Communication strategy raising awareness, understanding and support of local residents.

6.1.6 Main conclusion and recommendations on guidance for coastal protection planning

The general guidance presented might be considered as the direction coastal protection planning should go into the near future. Planning is recommended to move from local event driven and response driven protection planning towards a strategic, regional, cross-sectoral and preventive planning for coastal protection with the aim of sustainable mid- and long-term solutions.

At the current state of knowledge, there are 2 different types of erosion prevention measures which are in particular recommended for wider segments of the MD coast. This is the newest type of the detached pillar-riprap breakwater as a massive breakwater at a distance of about 180-250 m from the shoreline and the T-shaped fences (mixed breakwater-groyne type) for the nearshore (80-180 m). However, the discussion of the best solutions is never-ending with the current state of knowledge. Therefore, the strongest recommendation is to observe fundamental principles for designing and planning coastal protection waterworks from breakwaters to sea-dykes.

6.2 The T-fence story

6.2.1 Introduction

The unsustainable use of natural resources in the coastal zone of the Lower Mekong Delta in Vietnam is threatening the protection function of the local mangrove forests. Thus, the muddy coastlines are subject to erosion and prone to the impacts of climate change, particularly by the increased intensity and frequency of storm surges. In sites where severe erosion has destroyed the mangrove belt, restoration of floodplains and mangrove rehabilitation is only possible after the wave energy has been reduced by physical barriers. Sophisticated and site-specific approaches to coastal protection become increasingly important within this context. Permeable bamboo fences (T-shaped viewed from above) are appropriate to reduce erosion and stimulate sedimentation. This "T-fence story" addresses the design and monitoring of permeable bamboo fences, of which a total of 7,500 m was installed on the East Coast and 2,500 m on the West Coast of the Lower Mekong Delta in Vietnam, but also describes the limitations of the application (Albers & Schmitt, 2015).

First, such a floodplain management approach was developed for Vinh Tan Commune in Soc Trang Province beginning in 2009. Research was conducted to collect and assess available data relevant to the management approach. Missing data on bathymetry, water levels, sediment loads and especially wave climate were acquired through field measurements. This data was also used to verify the results of numerical models and to understand the hydrodynamic and morphodynamic processes in the focus area.

The effectiveness of conventional constructions as well as different designs using local materials was tested in a wave flume. T-shaped bamboo fences yielded the best results and have additional advantages due to bamboo's strength, availability and low cost. Between May 2012 and September 2012, bamboo fences measuring a total of 700 m were installed on the coast of Soc Trang Province. With minor adaptations, the design was transferred to the coast of Bac Lieu Province, where 500 m of bamboo fences were constructed in May 2012. After this pilot phase, further construction followed In October and November 2012 on the coasts of Soc Trang and Bac Lieu, respectively.

In 2013 a comprehensive measurement program was carried out along the East Coast and West Coast of Ca Mau Province to assess the hydraulic and morphodynamic conditions. The results of the analysis were used to transfer the application of the T-fences to the southernmost province of Vietnam and to adapt the design according to the existing boundary conditions.

Immediately after completion of the constructions, a comprehensive monitoring program was initiated. Wave measurements were carried out to quantify the wave damping effect of the bamboo fences during various storm and tidal conditions. Shoreline changes, mud density and the elevation of the mud were also monitored. In addition, tensile tests were carried out to assess the strength of the bamboo construction. Furthermore, a photo documentation was started after completion of the construction at selected sites.

6.2.2 General principle and reasoning for T-shaped bamboo fences

The construction of coastal protection elements such as dykes is expensive and the possibility of increasing the dyke height is limited due to the load bearing capacity of the soft subsoil in the Mekong Delta. Thus, limiting the wave load and wave run-up at the outer slope of the dyke should be a key objective. Wave attenuation due to mangroves is therefore very important if dykes are to protect the hinterland when sea levels rise and storms increase in intensity and frequency. In locations where erosion has destroyed the mangrove forest in front of the dyke and eroded the foreshore, floodplain management is required to restore the eroded floodplain, thereby creating the pre-conditions for rehabilitation of the destroyed mangrove forest.

Fig. 45 shows the steps extending from eroded foreshore to floodplain restoration and mangrove regeneration/ rehabilitation. This also includes the need for effective protection of the mangroves to avoid the reoccurrence of erosion due to the degradation or destruction of mangroves. The photo in Fig. 45 shows an example of an eroded foreshore from Soc Trang Province. The drawing to the right of the photo illustrates the effects of a low (i.e. eroded) floodplain on wave energy dissipation. Little wave energy is lost above the floodplain and most of the wave energy reaches the dyke. This increases the danger of severe erosion or even dyke failure and often leads to costly constructions such as revetments made from gabions.

In order to protect the dyke and reduce the need to increase the height of the dyke, the eroded foreshores must be restored ("restore" refers to a process that aims to return a system to a pre-existing condition). The most effective way to do this along mud coasts is to use permeable T-fences, which do not inhibit sediment input and create calm water conditions for sediment deposition. In addition, such T-fences, or groynes, reduce erosion and therefore lead to the immediate solution to an acute threat in areas where the foreshore erosion has progressed all the way to the dyke. This is illustrated in the second drawing on the right side of Fig. 45. The high (i.e. restored) floodplain dissipates a lot of wave energy and much less energy (eroding force) reaches the dyke.

The principle of the T-fences is based on the transfer of well-known and working structures from the Wadden Sea where floodplain management has become an important active coastal protection measure over recent decades. The principle was transferred to the East Coast of the Mekong Delta, and the actual design of the T-fences has been adapted to local conditions, tested in a wave flume and field-tested in Vinh Tan District at locations where the mangrove forest in front of the dyke had been eroded away and where the earth dyke was threatened by severe erosion (Schmitt & Albers 2014).

Floodplain restoration requires a sound process knowledge and understanding of the overall hydrological and morphodynamic system; for example, based on numerical modelling and data analysis. The results of both field measurements and numerical modelling on the coast of Soc Trang Province were used to define important boundary conditions for the design of countermeasures: soft soil with silty and clayish material; significant wave heights of 0.65 m; wave periods of 5-6 s; tidal range of 3.50 m; water depths at the dyke of up to 2 m at high tide. The modelling is also used to ensure that downdrift erosion can be minimised as much as possible. Design parameters, such as fence height, diameter of poles and embedment depth were based on field measurements, numeric modelling and static calculations. The actual spacing of the poles, selection of the most suitable tying material and composition of brushwood bundles were based on field testing and monitoring results. In addition, physical modelling in a wave flume was used to determine the optimum design of the actual fences. Bamboo was selected based on its strength, availability and low cost, and because it does not face the same problems associated with building heavy concrete structures on soft mud (Albers et al. 2013; Schmitt & Albers 2014). Experience drawn from ten years using bamboo for erosion protection in Khok Kha (Samut Sakhon Province, Thailand) showed that bamboo lasts for five to seven years.

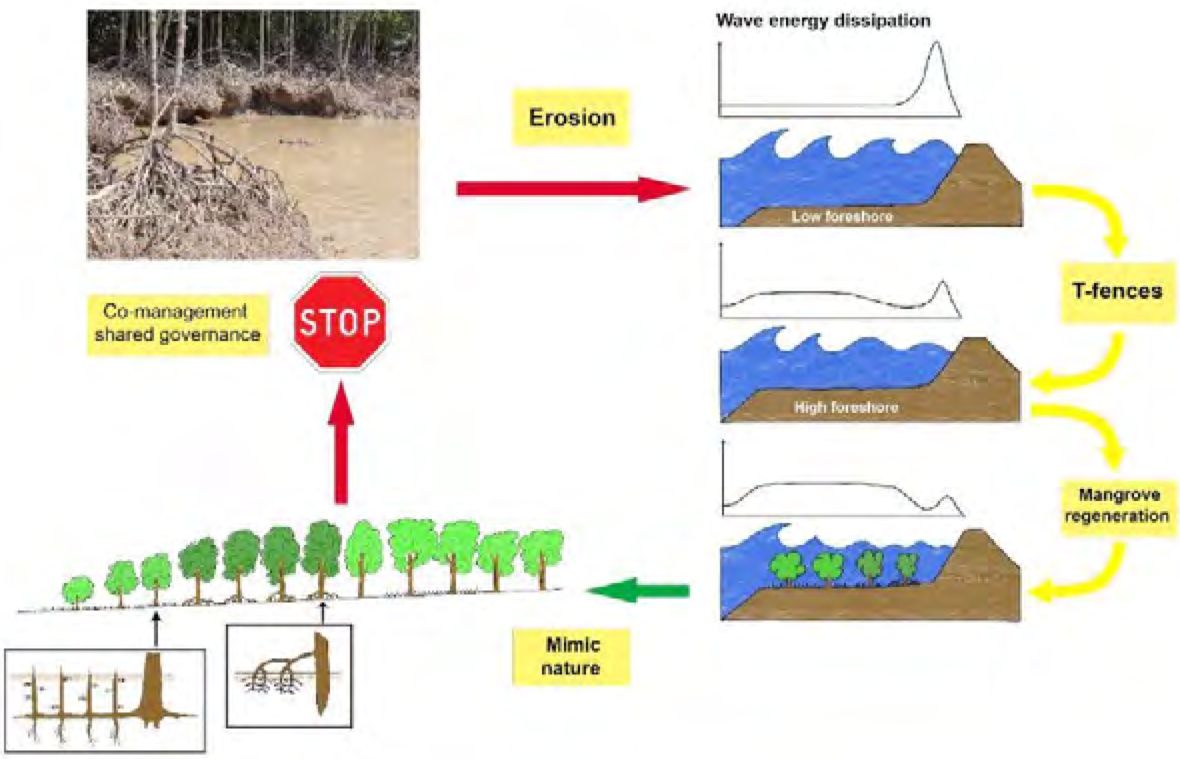

Fig. 45. The steps from eroded foreshore through floodplain restoration to mangrove regeneration / rehabilitation. Effective protection of the mangroves can prevent re-occurrence of erosion due to degradation or destruction of the mangroves. Photo K. Schmitt 2010; wave energy dissipation graphics modified from Albers et al. (2013) and mangrove zonation / root drawing from Schmitt et al. 2013. Source: Thorsten Albers

After successful restoration of the foreshore, natural regeneration of mangroves will occur if the area is protected from human impacts. If natural regeneration rates are not sufficient, supplementary planting of mangroves may be necessary. In such a case, it must be emphasised that the appropriate species have to be planted in the right location at the correct time. This is most easily accomplished by learning from nature – mimicking the way nature plants and the way nature creates a species zonation (see mangrove zonation and root drawing in Fig. 45).

It is important that any ecosystem-based (or area) coastal protection strategy also contain provisions for long-term mangrove protection and management; otherwise all the investments will be wasted if the mangrove forests on the restored floodplains are destroyed (again) by anthropogenic impacts, resulting in the floodplain eroding once again. Co-management, or shared governance, has been shown to be an approach for sustainable and effective mangrove protection and management (Schmitt 2012). Effective mangrove protection and management are essential for the sustainability of investments in floodplain restoration.

6.2.3 General layout of T-fence

To apply the described approach, in a first step, hot spots along the coast, where no mangroves protect the dyke, should be identified. The goal should be to create a closed mangrove belt of approximately 100 m width in a first step. Generally, this can be achieved by the installation of T-fences.

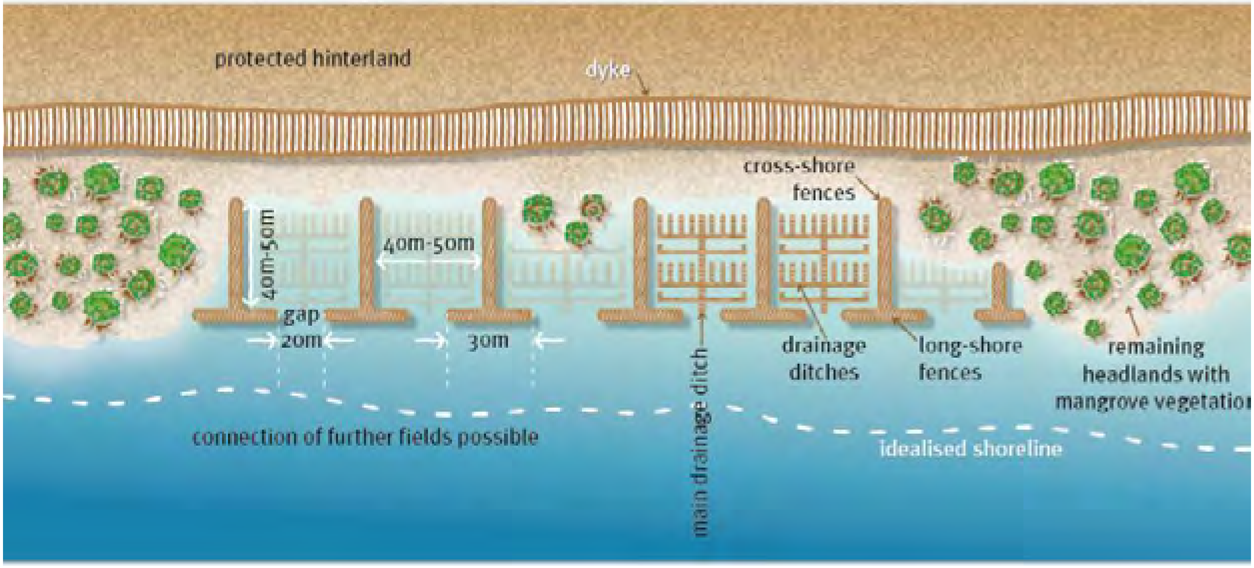

Fig. 46. Land restoration using cross-shore and longshore bamboo fences.
Source: Thorsten Albers

The general arrangement of the permeable bamboo fences consists of a long-shore part, which dampens the incoming wave energy and a cross-shore part, which decreases the long-shore currents. This T-shaped layout is shown in Fig. 46. The long-shore elements close the eroded gap in the mangrove forest by connecting the remaining headlands. The reduction in wave height and thus in orbital velocities under waves leads to accelerated sedimentation rates. The results from benchmarks in Bac Lieu Province showed a deposition of approximately 17 cm of sediments within 7 months. The reduction of wave action on the landward side of the fences also accelerates the consolidation of the mud and thus increases the stability of the sediments against erosion. This was shown through mud density monitoring in Soc Trang Province.

Fig. 47. Restoration of eroded floodplains using bamboo T-fences in Bac Lieu Province (Mekong Delta, Viet Nam). The long-shore elements close the eroded gap in the mangrove forest by connecting the remaining headlands. Photo Cong Ly and G.E. Wind 2013.
Source: Cong Ly và G.E. Wind 2013

The actual placement of the T-fences is done in such a way that they more or less recreate the original coastline by connecting existing headlands with mangrove vegetation (Fig. 47); i.e. they do not interfere with prevailing currents and thus will not cause downdrift erosion. For details about construction and monitoring, see Albers et al. (2013).

During the definition of the general layout, comprehensive knowledge about the overall hydraulic and morphodynamic boundary conditions is essential. For example, the presence of sandbars in the foreshore area significantly influences the design and the effectiveness of the T-fences. The dissipation of incoming wave energy over the sandbanks (cheniers) allows for reduced dimensions of the fences and accelerates the sedimentation rates. In more exposed locations with a steeper beach profile, a combination of the T-fences with concrete breakwaters should be tested. This type of combined solution is now recommended for several segments along the Mekong Delta, especially along the West Sea coast.

6.2.4 T-fence design

The actual placement of the T-fences is done in such a way that they more or less recreate the original coastline by connecting existing headlands with mangrove vegetation (Fig. 47); i.e. they do not interfere with prevailing currents and thus will not cause downdrift erosion. For details about construction and monitoring, see Albers et al. (2013).

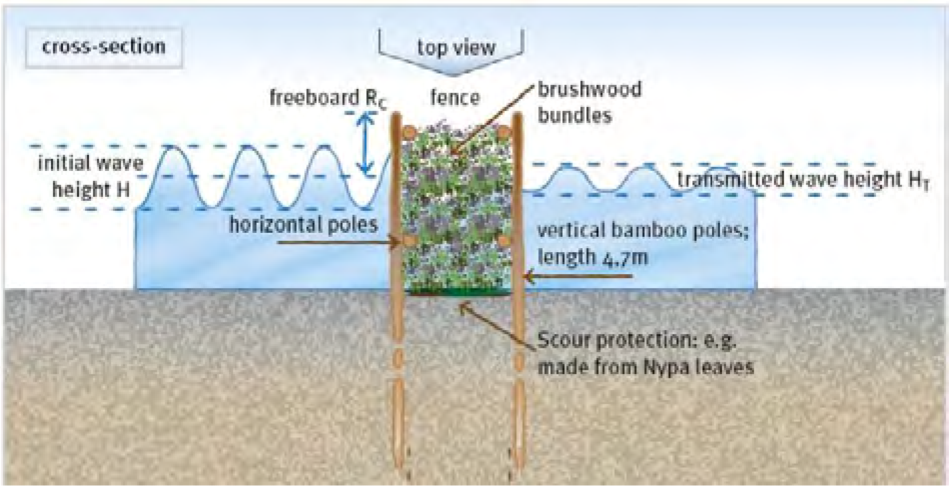

Fig. 48. Design of the permeable bamboo fences and resulting wave transmission.
Source: Thorsten Albers

The following bullet points summarize the technical specifications of the bamboo fences. The given values and dimensions have been calculated for the coast of Soc Trang Province in 2012 based on the aforementioned earlier measurements. Depths of embedment and according lengths of the bamboo poles are site specific and must be adapted to the current site-specific situation of the soil. Further, the depth of the mud layer must be considered. Diameters of the bamboo poles must be adapted to site-specific water levels, bathymetry, wave and current parameters. Fig. 48, Fig. 49, Fig. 50, Fig. 51 and Fig. 52 illustrate further technical specifications of the bamboo T-fences. The dimensions must be adapted according to the local specific conditions. In the described way, groyn fields of roughly 50 m by 50 m are created with seaward openings or gaps between 10-20 m. The dimension of the area depends on local conditions, namely by underwater topography (slope), the tidal range, and the position of the remaining mangrove forest edge. The cross-shore elements have to be well connected to the erosion cliffs landwards.

Summary of technical specifications:

- Two rows of vertical bamboo poles
- Distance between the two rows: 0.50 m
- Distance between the single bamboo poles in a row: 0.30 m
- Length of the vertical bamboo poles: 4.7 m
- Depth of embedment of the vertical poles: 3.4 m
- Diameter of the vertical poles: 8 cm for longshore parts; 6 cm for cross-shore parts
- Two horizontal bars at each row; one attached near the bottom, one near the top corresponding to the technical drawings
- Diameter of the horizontal poles: 8 cm for longshore parts; 6 cm for cross-shore parts
- Length of the horizontal poles: 3 - 5 m
- All horizontal poles are attached to every vertical pole with stainless steel wire (diameter 3.0 mm ± 1 mm; ductile behaviour)
- The overlapping distance of two neighbouring horizontal poles must not be less than 30 cm
- 4 - 6 layers of bundles (depending on the degree of compaction) are placed in between the two rows of vertical poles corresponding to the technical drawings so that the top of the bundles is flush with the top of the vertical poles
- The crest of the bamboo breakwater must be 1.30 m above the bottom
- All layers of bundles are attached to the vertical and horizontal poles with stainless steel wire (diameter 3.0 mm ± 1 mm; ductile behaviour)
- The structure of the brushwood that is used for the bundles must be flexible and open; the branches that are used must not be too thick (< 15 mm)

- The brushwood that forms the bundles must be tied properly with stainless steel wire at a minimum of three locations of the bundles (ends, centre)
- The bottom layer of bundles should consist of very fine branches
- As bottom layer a double layer of Nypa palm leaves is to be installed
- At the ends of the fences, one vertical bamboo pole with the same specifications as the vertical bamboo poles described above must be installed in the centre between the two rows of vertical poles for additional stability of the bundles

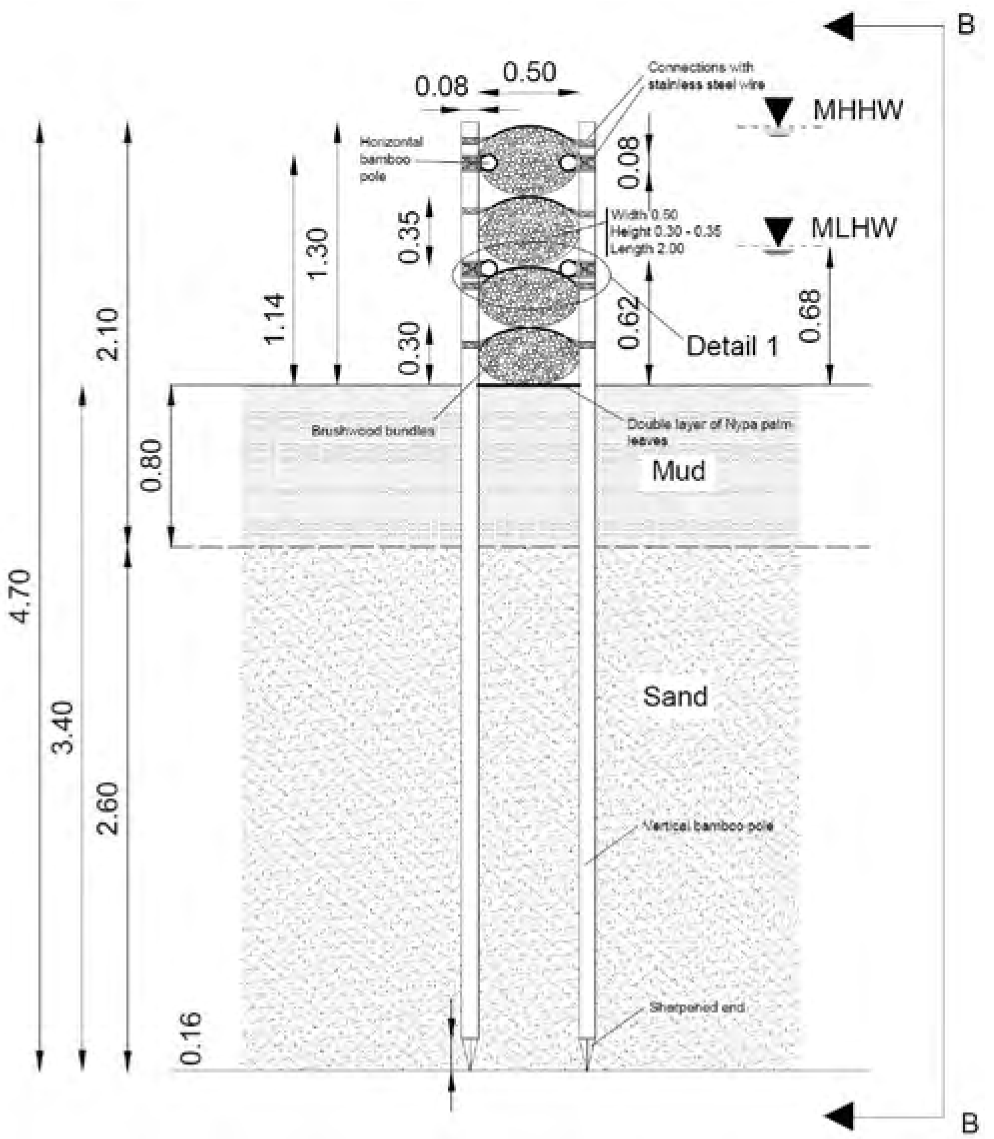

Fig. 49. Longshore bamboo fence; section A-A; dimensions in [m]; MHHW = mean high water; MLHW = mean low high water. Source: Thorsten Albers

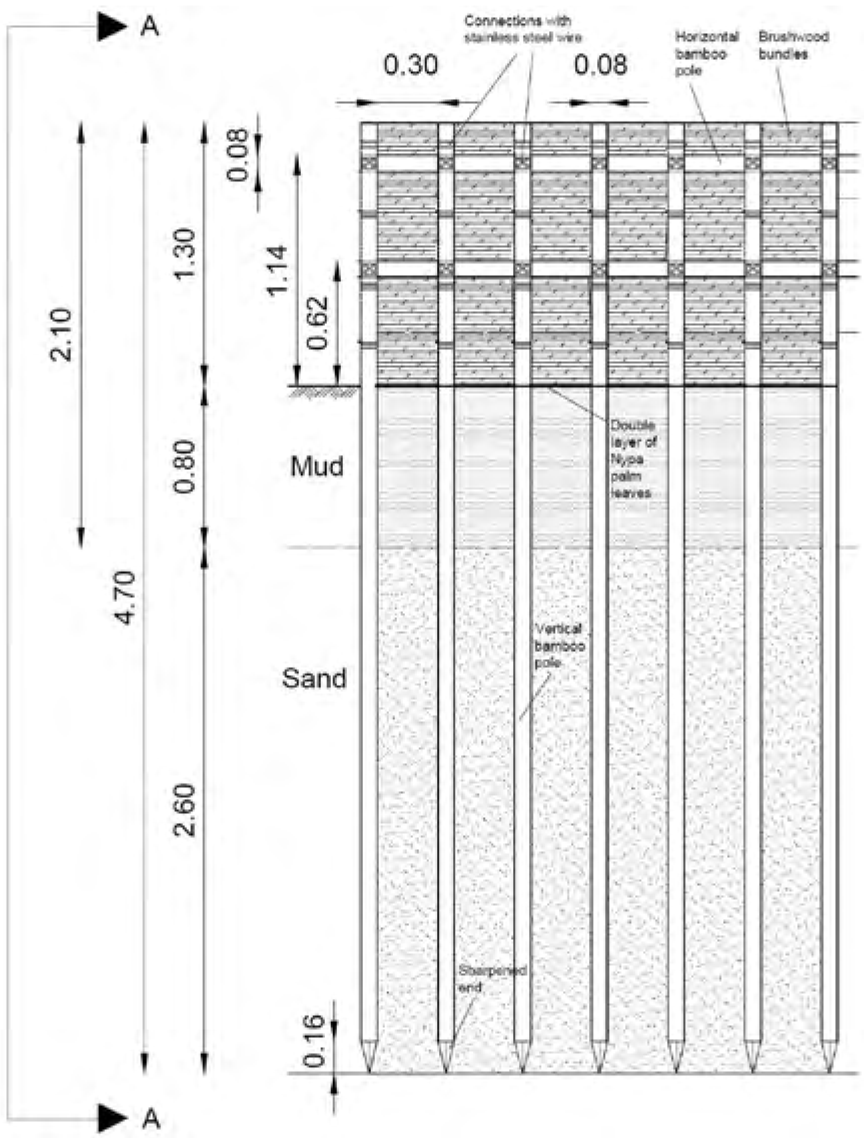

Fig. 50. *Longshore bamboo fence; section B-B ; dimensions in [m]. Source: Thorsten Albers*

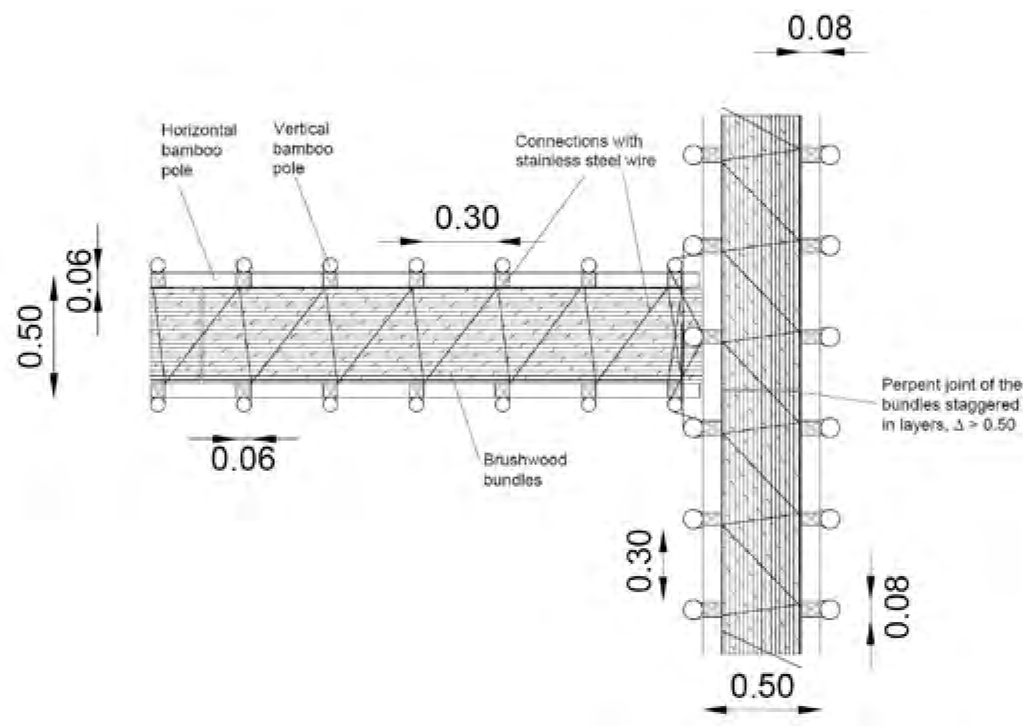

Fig. 51. Connecting section of bamboo longshore and cross-shore fence ; dimensions in [m]
Source: Thorsten Albers

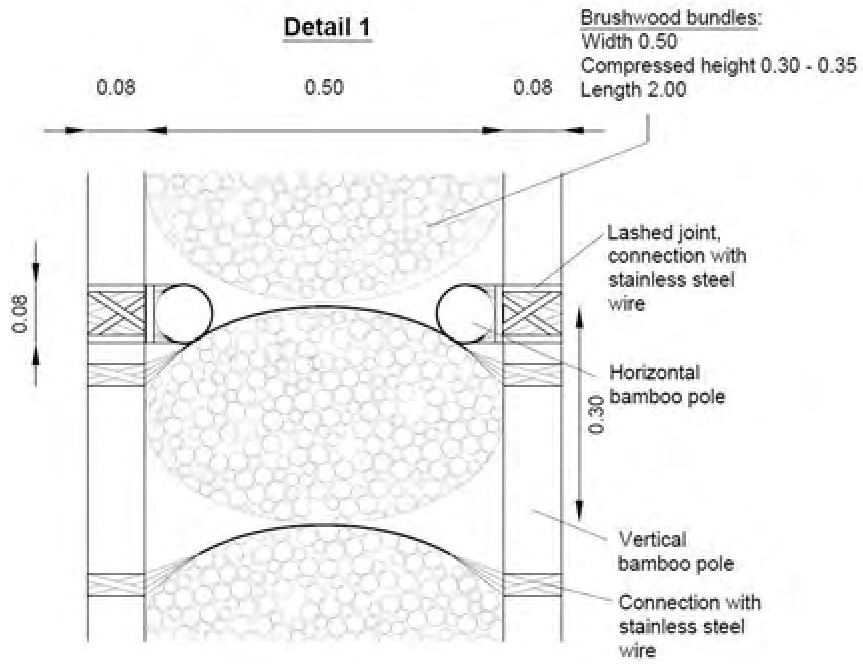

Fig. 52. Bamboo longshore fence; Detail 1 ; dimensions in [m]. Source: Thorsten Albers

It is essential for the stability and durability and thus for the success of the T-Fences to adapt the dimensions according to the site-specific boundary conditions. More exposed locations with higher and longer waves require larger diameters and stronger connections as well as very accurate supervision and quality control on site. Less exposed locations, for example behind sandbars, can be designed with reduced diameters. The depths of embedment must be adapted according to the subsoil, but also the degree of exposure. Thus, a sound knowledge about the hydrodynamic and morphodynamic boundary conditions are essential to ensure an optimized design. Preceding hydrologic measurements and data analysis should be carried out, if no T-Fences have been constructed in those locations before. In any case, regular inspections and maintenance must be carried out for all locations.

For specific locations with a higher degree of exposure, for example in Tran Van Thoi district, Ca Mau province, a combination of bamboo piles, bamboo/melaleuca bundles and concrete piles were applied to consider the larger wave load and increase the stability of the fences.

6.2.5 Monitoring implementation

Immediately after completion of the constructions, a comprehensive monitoring program was initiated.

Within the monitoring program, wave measurements to quantify the wave transmission effect of the bamboo fences during various storm and tidal conditions were analysed. Waves were measured at two locations on the seaward and the landward sides of the bamboo fence, each at a distance of approximately 5m from the fence. Pressure transducers were used for the measurements, which were recorded continuously for approximately six months with a frequency of 10 Hz. The wave data were analysed and summarized in significant wave heights of 15-minute periods.

Fig. 53 shows the results of the field measurements in comparison with the results of physical modelling that was done beforehand. It shows the wave transmission coefficient k_T in relation to a quotient of the freeboard R_C and the initial significant wave height H_S. Flexible bundles lead to smaller wave transmission coefficients (blue dots) than stiff bundles (red dots), and thus have a larger wave dampening effect. They can reach up to an 80% reduction of the initial wave height. The blue, red and black lines represent the best fit through the measured values.

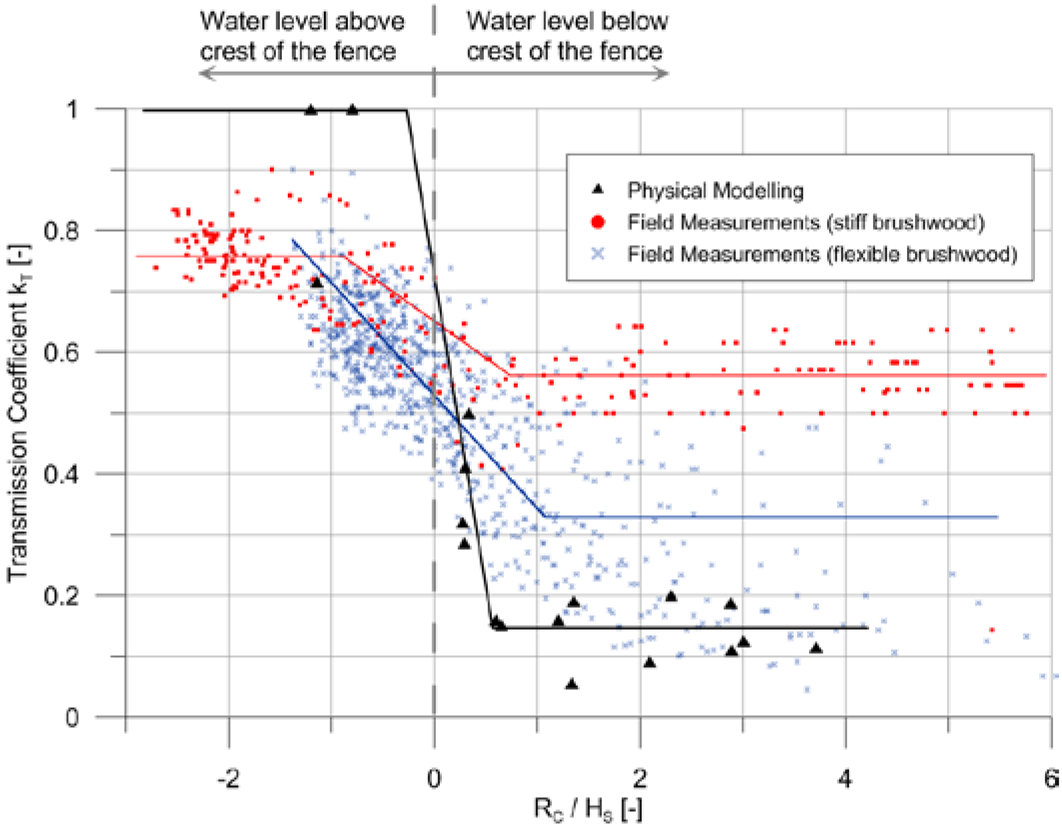

Fig. 53. Wave transmission coefficients of the bamboo fences under various hydrological conditions. Source: Thorsten Albers

The actual mangrove monitoring was carried out by taking fix-point photos at regular intervals. This is shown in Fig. 54 and Fig. 55.

Fig. 54 gives an example of sedimentation and natural regeneration of mangroves from the coast of Soc Trang Province at sluice gate 4. The T-fences were built in October 2012. In the photo top left, from October 2012 the coast parallel elements of the T-fences are still clearly visible. The photo top right (February 2013) shows the beginning of the sedimentation. In November 2013, consolidation of sediments has started from the edge towards the gaps in the T-fences and natural regeneration of Avicennia starts to occur (photo bottom left). The photo bottom right (January 2015) shows the growth of mangroves, which are not disturbed by wave action (due to the high/restored floodplain) or human impacts. Within just 16 months, sedimentation almost completely covered the fields created by the fences. Consolidation of sediments is moving from the edges towards the gap in the fences due to the drainage of fields through the gaps and natural regeneration of Avicennia is following this same pattern. This also shows that mangroves regenerate naturally as long as they are protected from human destruction and as long as propagules are available.

Fig. 54. Natural regeneration of Avicennia on restored floodplains in Soc Trang Province from the construction of the T-fences in October 2012 until January 2015. Source: Roman Sorgenfrei

Fig. 55. Changes in sedimentation and mangrove regeneration/rehabilitation at site 4 on the coast of Bac Lieu Province after installation of the T-shaped bamboo fences. Photos from May 2012 (top left), September 2012 (top right), December 2012 (bottom left) and September 2013 (bottom right). Source: Thorsten Albers

6.2.6 Limitations of T-fences

Based on experiences and monitoring and maintenance data from previous construction sites of bamboo T-Fences, the following boundary conditions must be fulfilled to ensure that the fences as described above can be applied successfully:

- Muddy environment; medium grain size diameter of top layer of the mud d_{50} < 0.03 mm
- Thickness of the top mud layer > 0.50 m
- Small gradient of the tidal flat < 1:1000
- Crest of the construction equivalent to mean high water level during spring tide
- Clearance of the crest of the construction < 1.40 m
- Significant wave height H_S < 0.90 m
- Mean wave period T_m < 8 s

If these limiting criteria are insignificantly exceeded, adaptations, such as strengthening with concrete poles, must be considered. If the limiting criteria are exceeded significantly, the application of T-Fences is not feasible.

Further, it must be considered that bamboo and melaleuca attract shipworms (Teredo sp., Bankia sp., actually wood-burrowing bivalves with wormlike bodies). In several locations, the shipworms seriously affected or even destroyed the T-fence structure after a few months, especially when the sedimentation process occurred slower than this phenomenon. The closer the shoreline and the longer the submergence periods, the higher the risk of shipworm attack. Chemical pre-treatment of the poles in locations where this phenomenon is known, should be considered, whereas the impacts on the environment must be tested beforehand.

Fig. 56. Bamboo pole destroyed by shipworms. Shipworms attach as free-swimming (pelagic) larvae to the wood surface (all kind of wood) and burrow holes and cavities deep into the wood while growing. The visible barnacles are harmless and do not burrow into the wood.
Source: Stefan Groenewold

6.2.7 Conclusions on suitability of T-fences for coastal protection

Along coastal sections without any mangrove belt, bamboo T-fences are an effective coastal erosion and protection measure for restoring floodplains and creating conditions for mangrove regeneration. Their wave transmission effect is sufficient to reduce wave heights significantly and stimulate sedimentation on the landward side. The construction is cost-efficient and often more feasible than massive structures on the soft soil.

However, the application of T-Fences has clear limits. If the location exceeds a certain degree of exposure to waves and a certain duration of submergence, the effort for maintenance significantly increases before the application becomes impractical.

Thus, the general application as well as the design and layout of the T-Fences must be checked and redone for every new site.

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6.3 Foreshore nourishment

An alternative protection measure on eroding coastlines could be foreshore nourishment. Nourishment (also referred to as beach fill) can be regarded as a close-to-nature approach for combating coastal erosion. It artificially replaces a deficit in the sediment budget over a certain stretch with a corresponding volume of fine sand. The benefit of nourishment comes from wave energy dissipation. Waves, which run up the coastal profile, break eventually. The idea behind beach nourishment is to turn an eroding, reflective beach into a wider, dissipative beach, which increases wave attenuation. It is important to note that beach nourishment does not halt erosion, but simply provides sediment from an external source, upon which erosional forces will continue to act. As the cause of the erosion is not eliminated, erosion will continue in the nourished sand. This means that nourishment as a stand-alone measure normally requires long-term maintenance effort. Periodic re-nourishments, or 'top-ups', will be needed to maintain effectiveness. This will require regular re-investment, but can be viewed as a maintenance cost, such as those associated with hard engineered structures. As with any type of shore protection works, reducing the risk of coastal flooding and erosion will result in an increased sense of security. To some extent, this is desirable. Regular nourishment requires a permanent well-functioning organization.

Since material is taken from the coastal system, no erosion of downstream areas and thus no negative impact, such as those resulting from some hard-structural measures which might disrupt the sediment transport by longshore currents, will occur. Ecological impacts are considered as temporary and minor since the fauna on and in the seabed is usually adapted to the highly dynamic nature of their habitat.

The success of a nourishment scheme depends very much on the grain size of the nourished material, the so-called borrow material. Supply of nourishment material by offshore dredging is often favoured because it allows for large quantities of material to be obtained from an area where its removal and onshore transport is reasonably non-disruptive to shoreline communities. During dredging, sediment is removed from the seabed along with significant quantities of water. The mixture is referred to as a 'slurry' and its liquid characteristics allow for it to be transferred ashore by floating or submerged pipelines or by the 'rainbow method'.

One main issue is the source of suitable material. Furthermore, nourishment is a technical method requiring suitable vessels, pumps and technical skills. Thus, the costs for foreshore nourishment are high and need to be considered in a cost-benefit analysis. Nourishment should be applied in an area of 150 m in front of the current shoreline and fill up the sink in the profile. Proper seabed profiling must proceed nourishment measures.

In areas where the application of T-shaped fences cannot be recommended due to a low sediment input, nourishment can be used as additional method to initially feed the fields between the fences with sediments.

An alternative for nourishment of large areas along the coastline could be nourishment at a single location according to the principle of the "sand-engine" in the Netherlands.

An artificial sandbank would be nourished that provides sediments for downstream areas. The coastal longshore currents will transport sediments along the coastline to the southwest and from a buffer zone on the foreshore. This principle is analogue to the natural development of sandbanks. One main advantage would be the locally limited nourishment that also can be realized by fixed pipelines and accordingly reduced costs. Before such a measure is applied, knowledge about the overall morpho-dynamics must be improved based on field bathymetry, studies of currents and waves, and numerical modelling.

A natural "sand engine" system is the distal sediment deposit southwest of Mui Ca Mau. There are also observations of natural sandbanks moving slowly at a few hundred meters distance from the low-water line southwards from the Mekong River mouth reaching from Soc Trang to northern Bac Lieu. The appearance is closely correlated with land accretion behind these banks. A survey and in-depth study of the migrating sandbanks is recommended, applying lightweight drones and bathymetric measurements. These sandbanks induce and increase sedimentation in the nearshore area since approaching waves tend to break on the sandbanks. If structures such as T-shaped fences are constructed at the same time a sandbank migrates in front of a coastal section, T-shaped fences can accelerate the process of sedimentation and regeneration of mudflats. The occurrence of those sandbanks depending of hydrologic conditions of the Mekong River (e.g. increased flow rates) should be studied.

However, at this moment there is only little experience with the very silty sediments around the MD (especially the West Sea coast) and the sediment sources are critical. Any attempt to use this soft engineering coastal protection measure should be held under strictly controlled conditions and be closely monitored by scientific surveys.

Relevant reports can be downloaded at the online CPMD library.

- San (2017): LMDCZ Final report
- Silke Tas (2016), MSc-thesis, TU Delft

Fig. 57. Natural sandbanks in southern Ca Mau Source: Stefan Groenewold

6.4 Mangrove forest rehabilitation

6.4.1 Lessons learned on mangrove plantation

The rehabilitation of the mangrove belt is considered a key element of coastal protection in the Mekong Delta. The following section offers an overview on species suitable for mangrove plantation in the Mekong Delta.

The afforestation of mangroves in areas which were lost due to erosion is a difficult task in the Mekong Delta. This is due to the kind of erosion. At most current erosion locations deep cliffs remain and the original elevation of the mudflats has been lowered by 0,5-1,70 m along the West Sea coast. The main conclusion is that irrigation experts, coastal engineers and forest experts need to collaborate in order to develop concerted rehabilitation plans.

During the past decade, several lessons on mangrove planting in the Mekong Delta were learned. A critical parameter for successful mangrove reforestation is a proper site assessment. In particular, plantations close to the seafront were most successful if the local topography was considered. The lack of proper drainage can be as destructive as high exposure to waves and strong currents. Low elevation is as critical as the absence of the predicted inundation periods and the right drainage is crucial for the survival rate of respective species after they are transplanted from the nurseries. In particular, drainage is needed at sites without sufficient natural slopes. Seedlings can be suffocated by fine mud with a large content of detritus. Lessons learned from test sites show that former shrimp ponds can be rehabilitated if appropriate drainage works are carried out to restore key hydrological functions. Another important lesson learned worldwide is to work with saplings, meaning that seedlings are kept in nurseries until they reach a certain size, which makes them less vulnerable. At smaller scales, planting close-to-nature concepts were also successfully tested but are difficult to upscale. However, due to budgetary decisions and the lack of knowledge and experiences with other mangrove species than Rhizophora apiculata, large afforestation efforts failed in the past since this species is not adapted to the rough conditions at the seafront but characteristic for mid-intertidal and intermediate estuarine locations. The high stilt roots of Rhizophora apiculata elevate the plant and are perfectly adapted to temporary mud layers covering the ground but not against high wave impact. In the following table, the characteristics of 11 different mangrove species are summarized. Some species such as Sonneratia alba and Avicennia marina are perfectly suitable for the pioneer or seafront while others, such as Lumnitzera racemosa and Rhizophora mucronata are best as candidates for reversion of abandoned shrimp ponds.

In respect to coastal protection planning, it is important to select species and nursery sites according to the local conditions and to plan collaborative with hydro-engineers and foresters. The main objective is not just to increase diversity but to make the mangrove forest more resilient and to establish mangroves as a key element of the coastal protection system.

There are several online resources (CPMD) available offering practical help for the planning of mangrove rehabilitation and manuals on the following topics:

- Manual for 11 species of mangroves (in Vietnamese only)
- Site assessment
- Lessons learned
- Nursery
- Technical guidelines of planting mangrove species
- Cost norms for nursing, planting, caring and protecting mangrove

Fig. 58. Deep erosion cliff at the West Sea coast of Ca Mau. The soil layer carrying the mangroves is undermined and collapsing. The fact that there are no remains left seawards of the erosion cliff is an indication for the high speed and power of this process.
Source: Stefan Groenewold

Fig. 59. Terrace-shaped erosion pattern along the West Sea coast of Ca Mau and Kien Giang. These terraces are relicts of former mangrove forests. Even growth with Avicennia, a pioneer species, at the seafront no longer holds erosion if this stage is reached.
Source: Stefan Groenewold

Fig. 60. Former rehabilitated shrimp pond with small embankments which became exposed to the seafront due to the loss of the protection forest in front of the production forest.
Source: Stefan Groenewold

Fig. 61. Erosion pattern along the East Sea coast. There is a clear pattern of different layers visible, which document the evolution and transgression period of the Mekong Delta. The eroded sites are much too deeply excavated by wave action to attempt direct afforestation. Coastal engineering measures are needed to prepare this area. Source: Stefan Groenewold

Fig. 62. Rehabilitation efforts along the West Sea (Ca Mau, with U-shaped fences) and East Sea (Bac Lieu, backshore, and pioneer afforestation; still photos taken by lightweight drones). Source: Sở Nông Nghiệp và Phát Triển Nông Thôn tỉnh Ca Mau

6.4.2 Biodiversity of mangroves and carbon sequestration in the Mekong Delta

The arboretum in Bac Lieu is a collection of mangrove species from the south of Viet Nam. The arboretum is a showcase of species richness and thus contribute to the preservation and research of mangrove forests. Furthermore, it serves eco-tourism and is considered as a learning resource on mangroves in the Mekong area for students and practitioners. Worldwide, about 73 different species are counted as 'true mangroves'. In total, there are 39 true mangroves described for Vietnam and at least 27 can be found in the South of the country. There are few stands of natural old mangroves remaining in the Mekong Delta – most of the forest is reforested. For reforestation efforts in the past, only a few species were selected. This makes it all the more important in future to diversify the planting schemes since every species is the result of a long evolutionary adaptation process and thus much more resilient if planted at the right place with certain environmental conditions. Mangroves store about 78,8 tons of carbon per hectare and provide high ecological services, such as being a nursery and foraging space for numerous coastal shrimp, crab and fish species important to local fisheries and aquaculture.

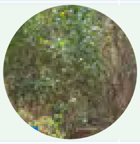
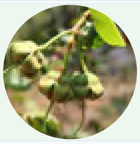
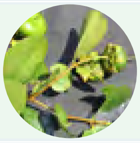
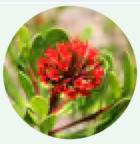
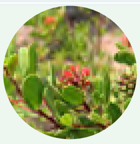
The following illustrates the species present in the arboretum in Bac Lieu.

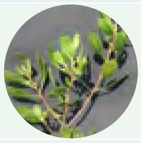
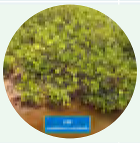
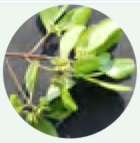
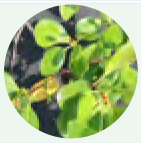
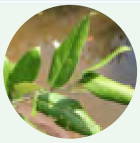
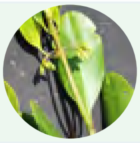
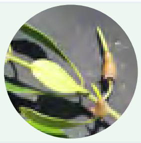
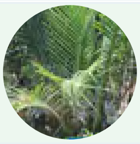
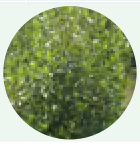
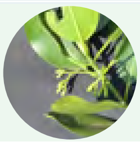
Bac Lieu Mangrove Arboretum

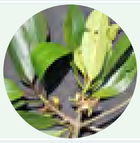
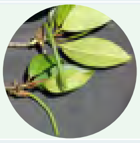
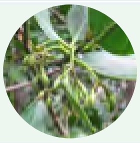
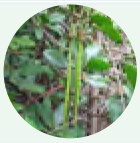
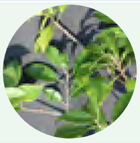
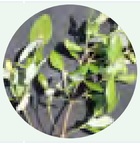
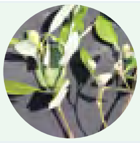
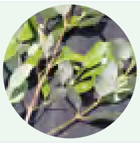
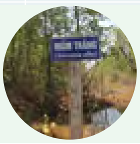
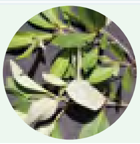
Area 5 ha

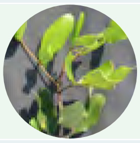
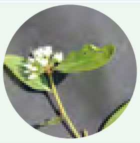
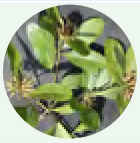
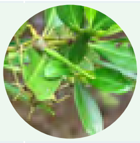
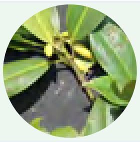
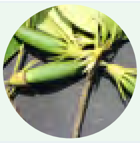
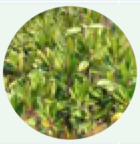
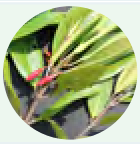
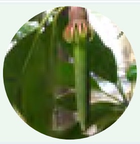
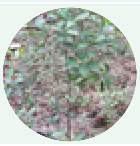
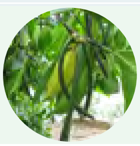
Location Giong Nhan hamlet, Hiep Thanh commune, Bac Lieu town (district), Bac Lieu province

**Click thumbnail to asset full HD image*

No.	Vietnamese nam	Scientific name	Use
1	Bần ổi	*Sonneratia ovate Back*	Wood is not good, lightweight, soft. It plays the role of breaking wind, protecting coastal areas.
		  	
2	Cóc đỏ	*Lumnitzera littorea (Jack) Voigt*	Wood is used in household appliances, for fuel. Trees are planted to protect estuary areas, coastal areas.
		  	

3	Cóc trắng	*Lumnitzera racemosa Willd*	Wood is used in household appliances, for fuel, for tannin. Trees are planted to protect estuary areas, coastal areas.
			  
4	Côi	*Scyphiphora hydrophylla*	Its wood is hard and is used as timber for small objects. Trees are planted to protect estuary areas, coastal areas.
			  
5	Cui	*Heritiera littoralis Dryand*	Wood is hard, used in household appliances. Trees are planted to prevent wind for coastal areas.
			 
6	Dà Vôi	*Ceriops tagal(Perr.) C. B. Roxb.*	Wood is red, heavy, smooth, can be used in construction, household appliances, shipbuilding. Bark is rich in tannin.
			  
7	Dừa nước	*Nypa fruiticans (Wurmb) Thunb.*	The stem of Nypa grows under the ground, only leaves and flowers grow above. Nypa is suitable on mudflats of estuaries, helps accretion, prevents erosion. Leaves are used to cover houses from the rain and sun.
			
8	Đưng	*Rhizophora mucronataLam*	Wood is hard, durable, good in construction. Firewood and charcoal supply high heat. Bark has many tannins for dyeing fishing nets, tanning. It plays the role of breaking wind, protecting coastal areas.
			 

9	Đước	*Rhizophora apiculatta Blume*	Wood is hard, durable, good in construction. Firewood and charcoal supply high heat. Bark has many tannins for dyeing fishing nets, tanning. It plays the role of breaking wind, protecting coastal areas.
		 	 
10	Đước vòi / Đâng	*Rhizophora stylosa Griff*	Wood is often used as firewood, making tools for producing salt; trees are mainly planted for protection of dykes due to the growth of its root system. Tannin can be used to dye nets.
			 
11	Giá	*Excoecaria agallocha L*	Wood is white, lightweight, smooth, less used. Resin is very poisonous, can cause blindness. Bark can cause vomiting. Leaves are also poisonous. Resin is used for killing fish. Roots are sponge, less toxic than parts above the ground and are used for making cork. Trees are planted to protect coastal areas
			 
12	Mấm biển	*Avicennia marina (Forsk.) Vierh*	Leaves are used as green manure, rich in protein. Edible fruits. Timber small-sized and only used for firewood. Flowers are the source of bee honey. Bark and root are used in medicine to cure leprosy.
			  
13	Mấm trắng	*Avicennia alba Blume*	Wood greyish-white, growth rings very clear, susceptible to termites and insects. Usually used as firewood but low heat, especially for burning bricks. Leaves used for good green manure. Fruit edible. Bark is used medicinally to cure scabies.
			 

14	Su ổi	*Xylocarpus granatum Koen*	Wood is pink or brown-grey, heavy, no vein, durable, less termites and can be used for housing, pillars or making handicrafts. Bark has high tannin content, used for dyeing and tanning. Trees are planted for coastal protection against waves and erosion.
			 
15	Sú cong	*Aegiceras corniculatum (L.) Blanco*	Wood is often used as a simple tool in households, in construction. Trees are effective against erosion, landslide by tides and protection of coastal areas and estuaries
			  
16	Trang	*Kandelia candel (L.) Druce*	Small stem, usually used for normal furniture, housing. Bark has tanin (12.3%), used for dyeing nets. Trees are planted to protect the coast.
			   
17	Vẹt đen	*Bruguiera sexangular (Lour.) Poir*	Wood used in construction, household appliances, pillars. Bark has (20-25%) of tannins used for dyeing fishing nets and tanning. Trees are planted to prevent coastal erosion and are home for aquatic animals.
			  
18	Vẹt dù	*Bruguiera gymnorrhiza (L.) Lam*	Wood is brown, bright, heavy, twisted, smooth, with little change due to weather changes. Wood is used in construction, household appliances, making charcoal with high heat. Bark has tannins for tanning, dyeing fabric and fishing nets. Propagule containing starch can be used for food.
			  
19	Vẹt Khang/ Vẹt Trụ	*Bruguiera cylindrica (L.) BL*	Red, smooth wood, used for common furniture, housing, pillars and coal. Young shoots can be eaten raw.
			  

No.	Name (VN, EN)	Scientific name	Botanical family	Characteristics		Opt. Salinity (‰)	Elevation of ground, Tidal range	Wave exposure (low, medium, high)	Soil	Cultivation				Distribution in Viet Nam	Planning location
				Root system	Able Height(m)					Fruits(Seed (propagule)/kg)	Seedlings	Planting Seedling /ha	Planting period		
1	Sú, Sú cong, River mangrove	*Aegiceras corniculatum*	Myrsinaceae	Often not showing above the ground	7	10-25	Mid-low intertidal, estuarine, lagoons	Medium	Stiff clay soil	1200-1500 propagules/kg	With bag	3600-5000	Apr-Sep	North to South	Exposed pioneer zone, back shore
2	Mấm trắng, Grey mangrove	*Avicennia alba*	Aviceniaceae	Pencil-like pneumatophores	25	20-33	Low-high intertidal, downstream, estuarine	High	Hard mud - soft clay	500-600 seeds/ kg	With bag	3300-5000	Jul-Sep	South	Exposed pioneer zone
3	Mấm biển, Grey mangrove	*Avicennia marina*	Aviceniaceae	Pencil-like pneumatophores	25	20-35	High - low intertidal, estuarine, open sea	High	Hard mud - soft clay	300-400 seeds/ kg	With bag	3300-5000	Apr-May	North to South	Exposed pioneer zone
4	Mấm đen, Round-leaved mangrove	*Avicennia marina*	Aviceniaceae	Pencil-like pneumatophores	25	20-30	High-mid intertidal, estuarine	High	Hard mud - soft clay	300-500 seeds/ kg	With bag	2000-3300	Jun-Aug	South	Exposed pioneer zone
5	Vẹt dù, Orange mangrove	*Bruguiera gymnorhiza*	Bruguieracea	Thick knee-like pneumatophores	25	15-25	Medium intertidal, downstream, estuarine	Low	Hard mud - soft clay	40-60 propagules/kg	With bag or propagule	2500-3300 (with bag) 5000-10000 (propagule)	Jun-Nov	North to South	Back shore
6	Trang	*Kandelia obovata*	Rhizophoraceae	Thick knee-like pneumatophores	5	15-25	Low-high intertidal	High	Soft mud-hard mud	40-60 propagules/kg	With bag or propagule	2500-3300 (with bag) 5000-20000 (propagule)	Apr-Nov	North	Exposed pioneer zone
7	Cóc trắng, Black mangrove	*Lumnitzera racemosa*	Combretaceae	Knee-like, above-ground	15	15-30	High-mid intertidal, intermediate estuarine	Low	Soft clay, silt	20000-26000 seeds/kg	With bag or propagule	2500-4400	Jun-Aug	North to South	Back shore, former shrimp pond reversion
8	Đước đôi, Stilt mangrove	*Rhizophora apiculata*	Rhizophoraceae	Aerial roots extend from limbs	25	10-20	Medium intertidallow	Low	Hard mud - soft clay	40propagules/kg	With bag or propagule	3300-5000 (with bag) 6000-10000 (propagule)	Aug-Oct	South	Former shrimp pond reversion, back shore
9	Đưng, Stilt mangrove	*Rhizophora mucronata*	Rhizophoraceae	Aerial roots extend from upper limbs	15	15-30	Low-mid intertidal, upper estuarine	Low	Soft mud-hard mud	10-16 propagules/kg	With bag or propagule	3300-5000 (with bag) 4000-8000 (propagule)	May-Jul	South	Back shore, former shrimp pond reversion
10	Bần trắng, Apple mangrove	*Sonneratia alba*	Sonneratiaceae	Pneumatophores cone-shaped	20	15-30	Low intertidal, downstream, open sea	High	Soft mud or sandy soil	20000-28000 seeds/kg	With bag	2500-4400	May-Aug	South	Exposed pioneer zone
11	Bần chua, Apple mangrove	*Sonneratia caeseolaris*	Sonneratiaceae	Pneumatophores cone-shaped	20	5-30	Low intertidal, estuarine, lagunes, river banks	High	Soft mud-hard mud	20000-28000 seeds/kg	With bag	1330-2500	May-Nov	North to South	Exposed pioneer zone

6.5 Coastal survey with Unmanned Aerial Vehicles (UAV, light drone, "flycam")

6.5.1 Surveying the Mekong Delta coast

The monitoring and surveying of the current state of the coastal area as well as the surveying of the effectiveness of coastal protection measures such as dykes, mangrove plantations and breakwaters is a high priority. Furthermore, the complex dynamics of the shoreline – accretion and erosion – can only be understood if the changes can be recorded. Well established methods for collecting data in the coastal zone typically involve two-dimensional profiling using traditional survey techniques like GPS. Limitations of these in situ survey methods include the fact that they are labour-intensive, physically restrictive (e.g. due to the presence of dense vegetation, fragile ecosystems, quagmire etc. preventing access) and simply unfeasible given the extent of the terrain required to be surveyed within a limited timeframe.

There are several coastal monitoring methods which were used in the Mekong Delta. Water-based video monitoring techniques were used in the provinces of Kien Giang and Ca Mau and resulted in a GIS enabled map of mangrove density, erosion intensity and human impacts (see library). Airborne methods such as LiDAR mounted to an airplane overcome many of the limitations of in situ techniques by remotely sensing topographic data over large spatial areas and at very fine resolutions, but are usually very cost intensive and difficult to use, to process and to interpret. For regular overall observations of changes on large Delta-wide scale, the remote sensing using satellite images is still the preferred option.

What is needed in the coastal area of the Mekong Delta is a survey technique serving multiple purposes and stakeholders. Disaster risk management, science, forest coverage and many more purposes can be monitored by a relatively new instrument, the Unmanned Aerial Vehicle (UAV), commonly known also as lightweight drones and "Flycams" in Vietnam. The UAV is an aircraft without a human pilot. UAVs are a component of an Unmanned Aircraft System (UAS); which include an UAV, a ground-based controller, and a system of communications between the two. There are several model lines in use and in the following these drones are presented as suitable cost-efficient tools for coastal surveys.

Fig. 63. UAV (lightweight drone) in use.
Source: Ca Mau Department of Agriculture and Rural Development

6.5.2 The capacity and potential of UAVs for mapping, surveying, and monitoring in coastal zones

In recent years there has been a rapid increase in the use of Unmanned Aerial Vehicles (UAVs or "drones") for commercial and recreational applications worldwide. One such field in which UAVs have been found to be particularly beneficial is as a tool for environmental surveying, mapping and monitoring.

Erosion monitoring, assessing cliff stability, monitoring coastal vegetation and changes in land volume or coastline states are only a few examples of the applications of UAVs in coastal areas collecting data of high accuracy and with very high spatial resolution. They play an increasingly important role in the systematic monitoring of coastal areas and forest rehabilitation around the world. The technology is evolving very fast and both the navigation as well as the data processing of visual results are becoming more sophisticated and user-friendly. Current UAV applications in the coastal engineering sector in Vietnam include: mapping and surveying coastal waterworks and environment. At the same time, the videos improve communication and broader understanding through data visualization. In future it can be expected that new applications will be developed in parallel with advances in data acquisition and processing technologies, which will broaden the scope of UAVs even more.

The result is not only impressive pictures, but equipped with on-board sensors such as a high-resolution camera in the visible or near infrared light bands and making use of state-of-the-art image processing algorithms, UAVs have the potential to rapidly sample large areas of terrain at very high resolution and accuracy. The availability of different camera sensors allows UAVs to provide even more information than observable with the naked eye. Sensors collecting light beyond the human visible spectrum, like near infrared light, can be used to compute vegetation indices. For example, the Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyse and assess whether the target being observed contains live green vegetation or not. It shows the difference between red light reflected from plants, and near-infrared light. Healthy leaves with an active photosynthesis process absorb red light, and strongly reflect near infrared light. Dead, or unhealthy leaves reflect both wavelengths of light. This property can be used to measure the health of vegetation or also to identify plant species.

The following sensors are currently available:

- RGB (red, green, blue): for plant counting, elevation modelling, and visual inspection
- NIR (near infrared): for water management, erosion analysis, plant counting, soil moisture analysis, and crop health
- RE (red edge): plant counting, water management, and crop health
- Thermal Infrared: irrigation scheduling, plant physiology, and yield forecasting

Within the next few years further small and light sensors, such as LiDAR, for lightweight drones, will be developed, expanding the potential usage of this technology even further.

6.5.3 Technical background and UAV basics

A basic UAV system is composed of an aircraft frame, propulsion system, onboard autopilot, and ground control station. The two most common platforms are multirotors (usually consisting of 4, 6, or 8 fixed-pitch propellers), and fixed-wing aircraft. Multirotors are more manoeuvrable than fixed wing platforms but generally have shorter flight times.

A UAV may be remotely piloted using a radio control device (ground control station) or flown autonomously using an onboard autopilot. The autopilot is able to follow a pre-planned flight path by processing positional and attitude data from a global navigation and satellite system (GNSS) receiver and inertial measurement unit (IMU). The ground control station receives flight data such as aircraft location, elevation, speed, and battery status via a telemetry radio link. The operator monitors the flight data while the UAV is in flight and may assume manual control of the UAV at any time.

Safety measures are built into most multirotor UAVs to reduce the likelihood of crashes resulting from low battery power or loss of communications with the ground control station. Additional safety measures such as object detection and avoidance are improving and will broaden applications for UAVs and presumably encourage greater adoption of this technology.

6.5.4 Aerial mapping and surveying using UAVs

Aerial photographs taken from a UAV platform can be processed using commercial Structure-from-Motion (SfM) photogrammetry software to obtain high-resolution orthomosaic photographs and elevation data that is comparable to land-based surveys. Structure-from-Motion describes the process of 3D surface calculation using 2D image information from different perspectives. In order to be able to calculate 3D points from 2D image data it is first necessary to align the set of images. This is done by a combination of photogrammetric algorithms. In general, the technique involves flying the UAV in a lawn mower pattern to acquire overlapping photographs. Specialized flight planning software is used to develop an optimum flight path based on the flight altitude, camera lens properties, and desired photo overlap (influences the results resolution). These parameters are adjusted to fly most economically (maximum area per battery charge).

The flight path with waypoints is uploaded to the drone which automatically starts the engines, takes off, flights to the correct altitude and the starting point of the monitoring track, then follows the flight path while automatically taking the images (orthophotos). After completing the path, or in case of low battery values, it flies back to the starting point where it descends and lands. If issues occur, the operator can take manual control at any time to ensure safe landing.

The orthophotos are automatically georeferenced using the onboard GNSS and can be used directly or processed to obtain mapping products. GNSS stands for Global Navigation Satellite System and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes, for example, the GPS, GLONASS, Galileo, Beidou and other regional systems. The advantage to having access to multiple satellites is accuracy, redundancy, and availability at all times. Pre-established ground control points (GCP) may also be distributed around the project site to increase positional accuracy. The accuracy of the resulting data products is generally less than 0.1 m, which is adequate for many coastal engineering studies. To conclude, the described procedure is most effective for sites where a traditional land survey would be too labour intensive and where manned aerial flights would be too expensive.

An example for the data processing results can be seen in the figure below. Software for photogrammetry was used to process sets of orthophotos into a 3D point cloud. These points were then used to generate a georeferenced orthomosaic and digital surface model (DSM) (Fig. 64). The processing results can be further analysed using geographical information systems (GIS). In case multispectral sensors were used for data collection (e.g. NIR), remote sensing algorithms like NDVI can also be applied.

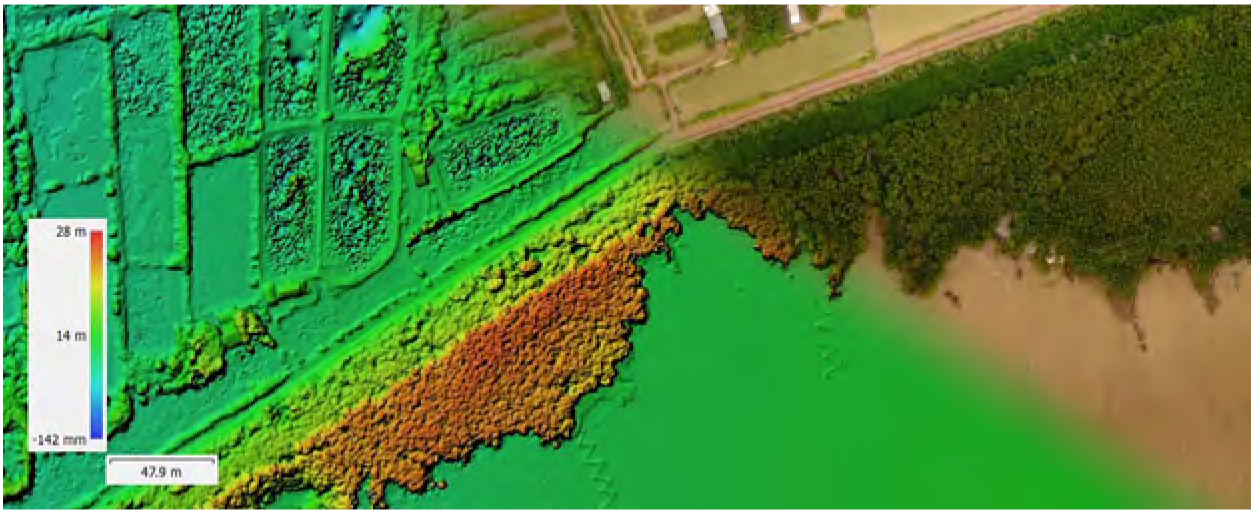


Fig. 64. Scene of processed data from the coast of Soc Trang Province , on the left is the DSM while on the right the orthomosaic can be seen. Source: Roman Sorgenfrei

Examples of application in Mekong Delta provinces

Fig. 65. Ca Mau, T-fences in the West Sea.
Source: Ca Mau Department of Agriculture and Rural Development

Fig. 66. Soc Trang, East Sea.
Source: Soc Trang Department of Agriculture and Rural Development

6.5.5 Comparison with other methods and future applications

In Ca Mau province the Shoreline Video Assessment Method (SVAM) was used to assess the following parameters:

- Shoreline Physical Condition
- Shoreline Mangrove Forest Type,
- Extent and Condition
- Mangrove Resource Use
- Creation of Biomass classes
- Creation of extreme erosion class
- Creation of Human Influence classes

This classification is based on continuous video filming along the coastline followed by an interpretation of the resulting georeferenced images. The biggest limitation of this method is the dimensional limitation of obtaining information only from the seaward side of the coastline. By using UAVs this method could become airborne and provide much needed "in-depth" information about the more landward mangrove forest belt (e.g. width, density, human influence, etc..

Currently several datasets collected by UAV over the coastal area of Soc Trang province are being piloted to calculate forest biomass as well as for mangrove species identification.

6.5.6 Challenges of environmental monitoring using UAV in Vietnam

The current legislation for any usage of UAV, meaning for professional monitoring and mapping and recreational purposes alike, is regulated by the following decrees:

- 36/2008/ND-CP Decree on management of unmanned aircraft and ultralight aircraft
- 79/2011/ND-CP Decree amending and supplementing of a number of articles of the government decree no. 36/2008/ND-CP

Due to security reasons, the application of UAVs in Vietnam is monitored, and flights are often restricted both in time and area. But in emergency situations (e.g. forest fires, comparison of pre- and post-storm damage assessments, acute danger from proceeding river erosion) a flexible deployment of UAV teams is necessary. Therefore, the legal status of UAV usage for environmental monitoring needs to be clarified. This can make the continued application of this innovative technology possible throughout all relevant sectors. At the same time, such legislation should include the necessity to protect individual´s privacy and private information.

6.5.7 Conclusion on applicability of UAVs for coastal monitoring

Drones are the perfect tool for regular coastal surveying, monitoring and mapping. With the application of lightweight drones, the coastal provinces of the Mekong Delta and regional planning institutions are already on the front line of coastal protection techniques. They are used by several authorities which work together on cooperative monitoring and joint planning. The expected added value is strengthened information-based intersectoral planning for coastal management through up-to-date expressive analyses and monitoring results. In future, further fields of application might be explored, such as agriculture and irrigation. The outlook for this technology is excellent as it enables cost-efficient planning and management of coastal zones in the Mekong Delta.

In addition, further lightweight multispectral and hyperspectral sensors for UAVs will be available in the near future. Already, the first appliances of LiDAR (Light Detection and Ranging) and Near Infrared Sensors (NIR for vegetation indices like NDVI) are available. This development increases the array of topics which can be addressed within the next few years and lowers the costs of standard surveys that are only possible using huge, heavy systems on piloted planes or satellite-based systems, enabling coastal provinces to plan and manage coastal zones cost-effectively.

Climate change can cause unpredictable events and it is more important than ever to keep an eye on the development of the coastline. Drones will continue to take an ever-increasing role in the monitoring and assessment of coastal erosion and assist in effective decision making for local planners and environmental bodies.

6.6 Blue Planning

The implementation of measures for coastal protection needs space. Space is sparse along the coast and there are many different stakeholders who claim space for their valid interest. Vietnam is developing a legal framework and guidelines for the use and zoning of coastal areas (Coastal function zoning) and for ICM (Integrated Coastal Management) under the Ministry for Environment MONRE VASI (Vietnamese Administration for Sea and Islands). During the development of the CPMD, several trainings were conducted on “Ecosystem-based coastal spatial planning”, which brings together participants from different stakeholder groups. In April 2018, a training on “Blue Planning in Practice” (manual is downloadable from the online CPMD) took place in the Mekong Delta with representatives from all 7 coastal provinces as well as representatives from the Ministry of Agriculture and Rural Development (MARD), the Ministry of Natural Resources and the Environment (MONRE) and related institutes. Participants strengthened their skills on coastal and marine spatial planning in general and coastal function zoning specifically for practitioners. The training focused on several core elements of Marine and Coastal Spatial Planning, such as the identification of need, process design, the organization of stakeholder participation, the analysis of current and future conditions, as well as drafting and approving a spatial plan which will lead to better coastal function zoning as required by law. Participants appreciated the didactical methodology of the training, which comprised case work, participatory exercises, and presentations and real cases of Marine Spatial Planning. The training builds on "constructed cases" (following the Harvard method) in a first step, which allows participants to evaluate the use of coastal space following objective criteria instead of "getting stuck" into real case conflicts. This approach supports mutual understanding. In a second step, these constructed cases are transferred to a real situation on site.

Fig. 67. Nearshore windpark at the coast of Bac Lieu Province, East Sea. The method of Coastal Spatial Planning (CSP) attempts to map potential risks and opportunities for any use of the coastal area. A common planning of nearshore windparks with coastal protection might result in many benefits for both stakeholders and should not be seen as a threat. Source: Bac Lieu Department of Agriculture and Rural Development

7 Feasibility of protection measures – specific recommendations for coastal protection measures for the MD

7.1 Coastal Protection Classification of the Mekong Delta

There are several classification schemes described in the international coastal science world, but none was sufficient to classify the Mekong Delta coast for the specific purpose of coastal protection. The often-used separation of West Sea and East Sea areas is simply not sufficient to support informed decisions on coastal protection. Therefore, a hierarchical 3-step approach specific to the needs of the relatively uniform coastline of the Mekong Delta (MD) was developed. At first, the Mekong Delta is divided into 7 distinct "Coastal Protection Regions (CPRs)" according to their physical parameters - meaning wave climate, geo-hydrology, bathymetry. In the next step, we wanted to highlight the links between coastal protection and spatial planning or land-use, which resulted in the definition of 29 "Coastal Protection Units (CPUs)". With this step, we included the areas of the existing water management units landwards and the coastal zones seawards into coastal protection planning. What happens in the sea in front of the sea-dyke – e.g. wind-energy parks, sand-mining, touristic developments – is of the same relevance as the land-use and protected values behind the dyke. Thus, the CPMD provides information on resident population, water management, agricultural land-use, and irrigation systems. In addition to a better estimate of protection values and potential damage behind the dyke in case of disaster, the water management units might be considered as a second line of defence in the longer run. In the third step of the classification, we included the actual rate of coastal erosion, the trend of coastline changes within the last century, and the state of the current dyke system. This step resulted in 71 defined "Coastal Protection Segments (CPS)". Based on the feedback given by the provinces, there are special CPSs assigned for port development, tourist spots and national parks. For each coastal segment, specific recommendations for coastal waterworks and mangrove rehabilitation are provided in order to offer the best combination of protection solutions for those localities and coastal stretches. The last classification is also linked to the urgency of investment and provides rough cost estimates for needed measures. In the following, more details on the classifications are described.

Coastal protection regions (CPRs)

The CPRs are defined by physical-hydrological parameters, bathymetry (sea floor elevation) and especially the morphology of the coastline; or in other words CPRs are defined by the natural conditions. We divide the 720 km of coastline into so-called CPRs based on the following seven criteria:

(i) Tidal regime

(ii) Wind regime (including typhoons)

(iii) Wave climate

(iv) Currents

(v) Exposure (angle) to surging waves

(vi) Sediment composition and movements

(vii) Bathymetry
(seafloor topography and angle of nearshore water depth profile)

All these (interrelated) criteria have high relevance for the right choice of a successful coastal protection strategy and sustainable, not regretted measures. Although the biggest differences among the CPRs are between the hydrological regime in the West Sea and East Sea, the inclusion of the other five criteria results in 7 distinct CPRs. In relation to coastal protection planning, these are basic data for design parameters of any water works, such as sea-dykes, breakwaters, groynes, and sluice gates. The physical-hydrological parameter wind strength, wind direction, current speed and direction, tidal regime, tidal and wind waves during the two annual seasons (South West monsoon in May to November, North East monsoon from December to April) are presented in the form of 'roses' are changing gradually from the East Sea to the West Sea. There are not sufficient long-term measurements and model results available around the MD, thus the presented data are based on published records [Open library] and recent measurements.

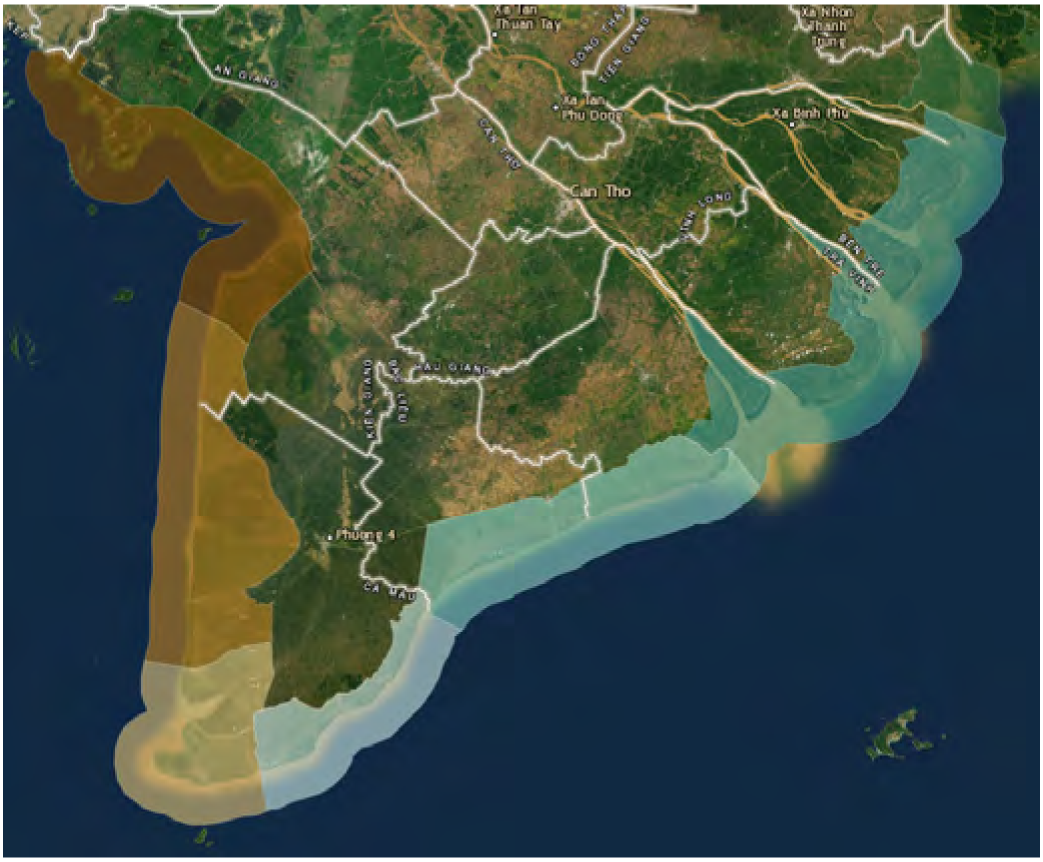


Fig. 68. Overview of CPRs and CPUs. Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Coastal protection units (CPUs)

The CPUs (currently a total of 29 for the entire Mekong Delta) are the core of protection planning by means of the webmap and the CPMD. Here we take the spatial dimension of coastal protection planning into account. The six criteria are:

(i) The landwards border of the CPUs are identical with the inland border of the official water management units behind the sea-dyke line (see reasoning below*), sea-ward borders are identical with the 6 nautical miles (11.11 km) coastal waters as defined by Vietnamese ICM legislation**

(ii) Total number of people in this vulnerable area and population density

(iii) Existing infrastructure and public goods which need to be protected

(iv) Dominant land-use for production (agriculture, forestry, aquaculture) in the hinterland which can be translated into monetary value

(v) Land elevation (although the elevation is quite evenly low in the Mekong Delta, the elevation of the hinterland is one main factor for the vulnerability of the coastal area

(vi) Protection and special-use forest which can be translated into ecological services [see under TOOLS]

* Why relate coastal protection planning with the inland water management units?

Coastal protection is not only about the shoreline management but also about the protection of the hinterland. There is no detailed disaster risk assessment that has been carried out for specific areas along the coast of the Mekong Delta; however, it can be assumed that a sea-dyke breach or very a high-water build-up and flooding due to extreme storm events will especially harm the area close to the shoreline. The existing water management units already have an inland dyke and sluice system in order to manage land-use. For the current version of the decision support system CPMD, we suggest including the existing system in the hinterland of the sea-dyke into the coastal protection planning in order to manage flooding from the seaward side by means of this second line of defence and in order to plan land- and water-use in accordance with the coastal protection requirements. In fact, the areas between the sea-dyke line and the leveed parcels around the water-management units can be considered as reset areas in cases of disaster.

** Why relate coastal protection planning with planning for the seaward areas?

The seaward borders of the CPUs are defined by the Vietnamese ICM legislation on Integrated Coastal Management (6 nautical miles or 11.11 km from the mean low water line). Within these areas, a plan on "coastal function zoning" by the provinces is obligatory. Any planning of coastal protection water works might have positive or negative impacts on natural resources near the shore. Conversely, any infrastructure, such as wind parks or port levees, might have positive or negative impact on the shoreline. In order to assess and optimize synergies of impacts, planning within the seaward borders of the CPUs should be coordinated. In addition, many parameters as requested by the legislation for "Coastal corridors" (meaning high water lines to inland district borders and coastal waters below the mean low water line) are also valuable design parameters for coastal protection (e.g. beach profile, wave regime) and their recording should be coordinated among responsible agencies.

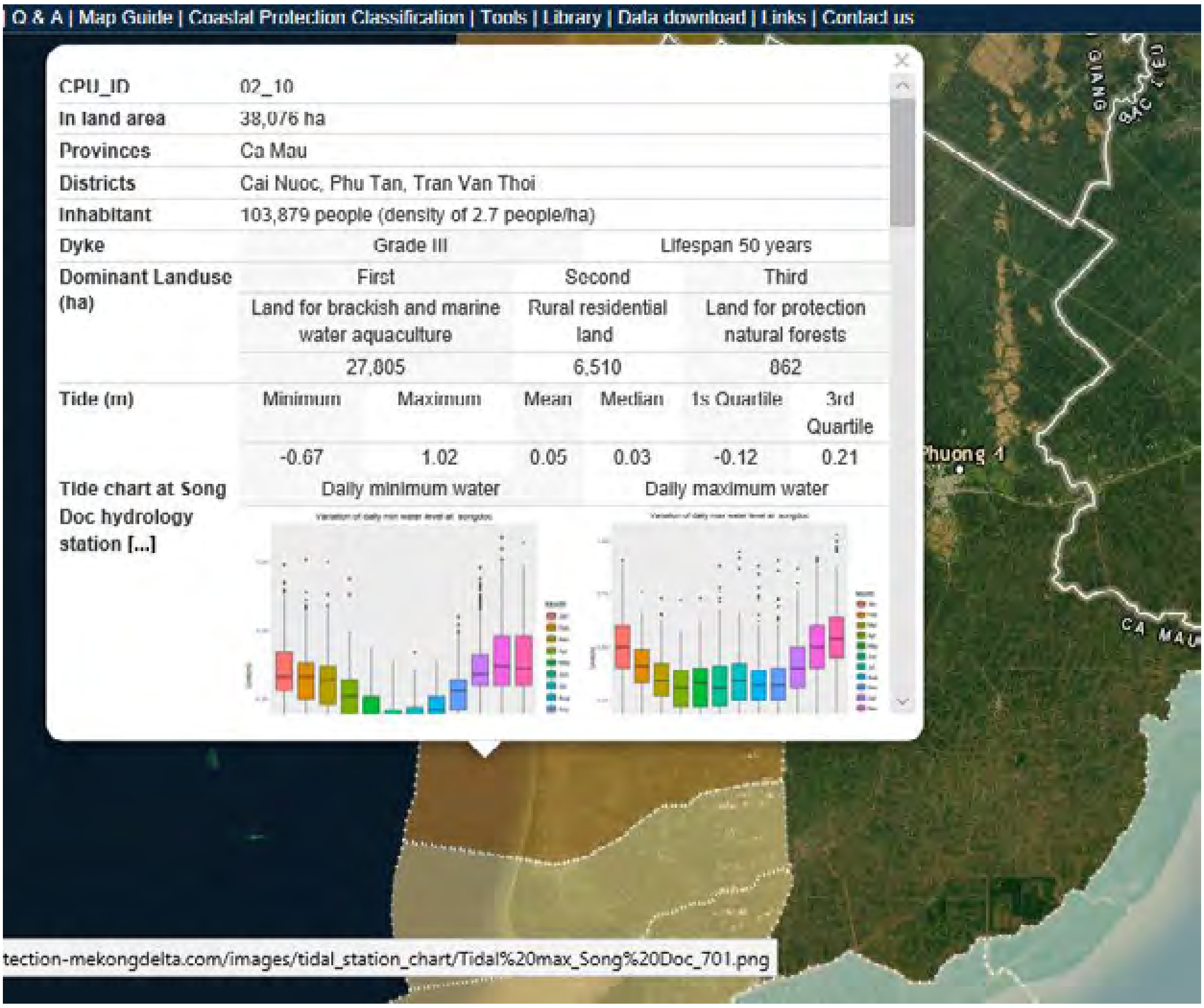


Fig. 69. Example of information accessible via online CPMD interface.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Coastal protection segments (CPSs)

The CPSs indicate a shorter stretch of the coastline within the Coastal protection units (CPUs). Currently there are 71 CPSs along the 720 km of the Mekong Delta coast. The main criterion is urgency! Urgency is defined by the erosion rate and the state of the current protection work. Of course, all other criteria as indicated by CPUs and CPRs are considered when providing concrete recommendations for the respective CPS. We distinguish between 5 categories: Very high urgency (hotspots), high urgency, medium urgency, low urgency, and special segments. These categorizations are also linked to the urgency of investment and cost estimates. Furthermore, we provide very concrete recommendations for the respective segment wherever possible. If uncertainty is high and the knowledge not sufficient to provide no-regret recommendations for technical protection measurements, we also state this clearly. This is also true for the special segments, which are usually reserved for port development or other purposes. The positions of the "very high urgency" hotspots and the special zones were provided during several consultation workshops with the provinces. We deliberately do not recommend even smaller segments for protection planning since this may lead to a habit of repairing hotspots on a very small scale – which may result in even bigger problems – instead of planning ahead preventively.

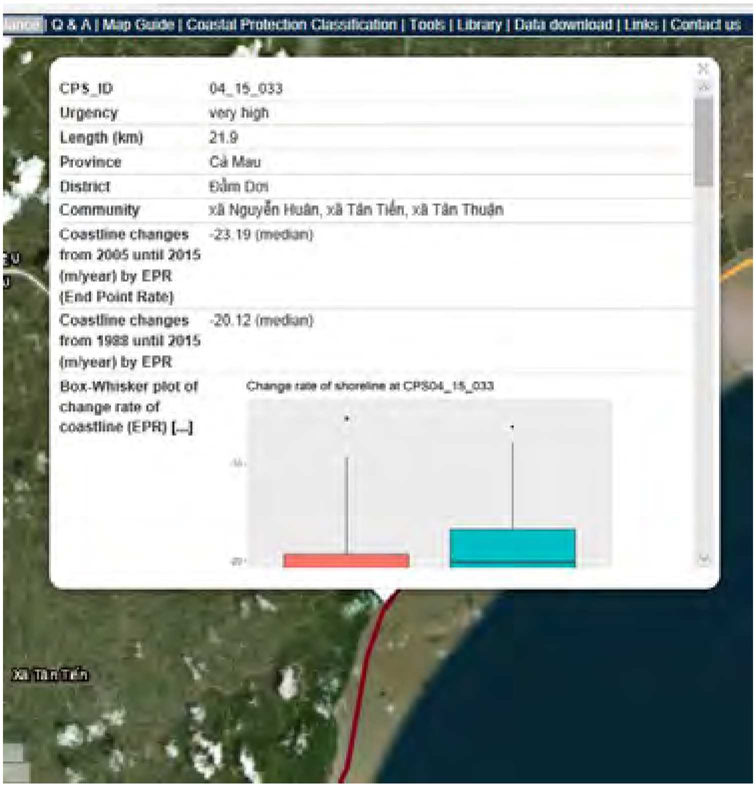


Fig. 70. Long-term statistics for planning (online CPMD)

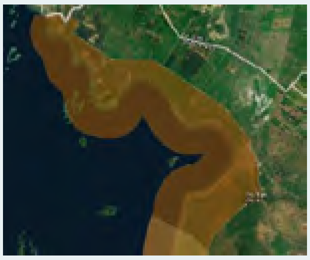
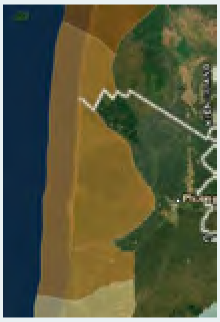
Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

7.2 Specific recommendations on Coastal Protection by region

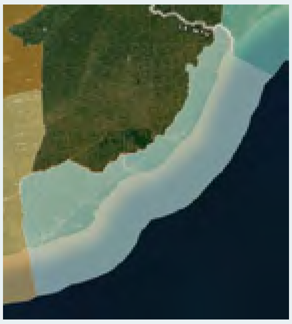
The following chapter provides information on the background data for designing coastal protection waterworks (see proceeding chapters on respective guidance). The Mekong Delta can be divided into 7 distinct regions which show their typical coastal morphology, coastline dynamic and hydrology. Regarding all detailed recommendations per Coastal Protection Segment (CPS) provided in the CPMD, notice should be taken that recommendations for the type of protection measure and guidance for further design development are given but measures have to be adapted for the specific location. Thus, further small-scale geological and hydrological feasibility investigations might to be carried out in order to achieve the best solution for the local situation. Table 5 summarises the information.

There are no recommendations yet given for the larger water management areas of the so-called Coastal Protection Units (CPU), which also consist of the wider nearshore area (including the coastal corridor) and the hinterland (the land area behind the sea-dyke). As explained in the chapter on coastal classification, measures for these CPUs should be planned for better control of floods and droughts, planning of wind energy parks and other nearshore constructions, anticipating a second line of defence, for water reservoirs, for disaster risk reduction and for estimating potential damage from floods and dyke breaches. Since there are no official legal decisions made for the determination of CPUs, the CPUs as suggested in the CPMD shall be considered as recommendations for the near future.

Table 5. Some characteristics of the seven different Coastal Protection Regions. The area of the hinterland is determined by the borders of the official water management units adjacent to the coastline. The table contents record land-use, population and coastal morphology. More details and design parameters (especially wind, tidal range and wave climate) are illustrated in the online CPMD.

CPR 01 	Coastal hinterland of about 102,000 ha inhabited by more than 400,000 people, density 4.0 inhabitants/ha. Dominant land-use is aquaculture (30,000 ha). Province of Kien Giang. Generally low shoreline regression. No clear trends in pattern of erosion. Low risk of high storm surge but risk of flooding from the Mekong overflow. Significant wave height of 30-82 cm. Few stretches of rocky coast in the northwest part close to Cambodia. Clay to silty sediments. Large shallow water bay of Rach Gia.
CPR 02 	Coastal hinterland of about 167,000 ha inhabited by more than 346,000 people, density 2.1 inhabitants/ha. Dominant land-use is paddy crop (38,000 ha). Province of Kien Giang and Ca Mau. Generally medium to very high rates of shoreline regression. Clear trends in pattern of erosion over long coastal sections. Low to medium risk of high storm surge. Significant wave height of 146-175 cm. Clay, silty to very fine sediments. Medium to high slope of seabed with forming erosion terraces.
CPR 03 	Coastal hinterland of about 78,000 ha inhabited by more than 125,000 people, density 1.6 inhabitants/ha. Dominant land-use is production forest (34,000 ha). Including largest national park in the Mekong Delta, showing partly large progressing coastline. Province of Ca Mau. Shoreline generally in dynamic equilibrium. Mixed tidal conditions. Clay to fine and even coarse sediments. In respect to patterns, changing trends of erosion and sedimentation. Medium to high risk of high storm surge. Significant wave height of 110-165 cm. Any interventions should be planned with highest degree of care since the “spits” of Ca Mau and nearshore sediment deposits play an important role in the sediment budgets of the entire Mekong Delta.

CPR 04



Coastal hinterland of about 52,000 ha inhabited by more than 55,000 people, density 1.1 inhabitants/ha. Dominant land-use is production forest (36,000 ha). Province of Ca Mau. Generally large to very large shoreline regression. Very fine to fine sediments. Clear trends in pattern of erosion over the entire coastal section. Medium risk of high storm surge. Significant wave height of 90-200 cm.

CPR 05

Coastal hinterland of about 114,000 ha inhabited by more than 332,000 people, density 2.9 inhabitants/ha. Dominant land-use is aquaculture (80,000 ha). Dominant land-use is paddy crop (38,000 ha). Provinces of Bac Lieu and Soc Trang. Generally medium shoreline regression. Very fine to fine sediments. Clear trends in pattern of erosion with changing local hotspots over the entire coastal section. Medium risk of high storm surge. Significant wave height of 120-220 cm.

CPR 06

Coastal hinterland of about 164,000 ha inhabited by more than 442,000 people, density 2.7 inhabitants/ha. Dominant land-use is aquaculture (58,000 ha). Provinces of Soc Trang, Tra Vinh and Ben Tre. Highly dynamic estuarine environment. Fine to coarse sediments. Shoreline generally in dynamic equilibrium in respect to patterns, changing trends of erosion and sedimentation. Generally, there is a tendency of erosion at the north-eastern edges of the river islands and a slight progression on the south-eastern edges. Most river islands still grow towards the river mouth. Medium to high risk of high storm surge partly combined with river discharge. Significant wave height of 110-259 cm. High to very high sediment transport rates.

CPR 07

Coastal hinterland of about 26,000 ha inhabited by more than 190,000 people, density 7.3 inhabitants/ha (the highest of all CPRs in the Mekong Delta). Dominant land-use is aquaculture (6,600 ha) and paddy crop (5,700 ha). Province of Tien Giang. Highly dynamic estuarine environment influenced by the Mekong River system and the Saigon River. Shoreline generally in dynamic equilibrium in respect to patterns, changing trends of erosion and sedimentation. Silty to fine sediments. Medium to high risk of high storm surge partly combined with river discharge. Significant wave height of 67-141 cm. High to very high sediment transport rates.

7.3 Specific recommended measures at the level of Coastal Protection Segments (CPSs)

The recommended coastal protection measures are divided into 6 different categories (see below) which also form the database for the cost estimates (see next chapter) and are briefly described here. Several solutions tried out in the Mekong Delta and combinations of solutions in order to halt coastal erosion and to reduce the risks of flooding were evaluated. No solution can simply be replicated and transferred directly from one specific location to another but there are fundamental principles for designing waterworks and planning mangrove rehabilitation, which are described in detail in the proceeding chapters of the CPMD or in the tools of the online CPMD. The main conclusion of the evaluation of protection measures is that interventions should not be implemented in response to small-scale erosion hotspots nor should they be implemented as single local measures. Instead, fundamental principles should be observed as well as long-term trends and larger-scale developments along the coast. Coastal protection needs space! The outcome is presented here and more detail can be found in the online CPMD. Usually, a combination of measures out of the 6 categories is recommended for a certain stretch of coast, the so-called Coastal Protection Segments (CPSs). For certain locations such as ports or extremely exposed sites, deeper-going morpho-hydrological studies of the local wave power and underwater profiles are needed in order to plan working measures properly. Although there is room for improved data backing in the future, the recommendations presented here are founded on currently best available data. The sequence of the 6 categories of protection measures follows the direction from the near- and foreshore area towards the sea-dyke line (from the seawards to landwards). The 6 categories of coastal protection measures are:

Measure category I:

Waterworks in the nearshore area (wave surf zone to intertidal zone); nearshore: pillar-type (or similar) massive breakwaters or possibly foreshore nourishment by creating sandbars (sandbanks)

Measure category II:

Construction for foreshore (intertidal zone) stabilisation: groynes/ T-fence/ U-fence/ trapping fence; often combined with mangrove rehabilitation.

Measure category III:

Foreshore and backshore stabilisation: Mangroves rehabilitation, usually by planting in the pioneer zone and “backshore” (formerly used aquaculture ponds, between dyke and intertidal area).

Measure category IV:

Sea-dyke with toe protection or/and revetments (armouring).

Measure category V:

Earthen sea-dyke (newly designed, mild slopes)

Measure category VI:

Sea-sluice gate (different sizes/ types). Passive sea-sluices are not recommended in the first line of defence.

The ***urgency*** of intervention (indicated by different colours in the online CPMD) is divided into 5 categories and provided for every Coastal Protection Segment:

Very high: Coastline regression of more than 40 m per year over longer periods, high exposure and currently weak or no protection.

High: Coastline regression of 20-40 m per year over longer periods, high exposure and weak current protection.

Medium: Coastline regression of 0-20 m per year over longer periods, not directly exposed to the sea but currently insufficient protection.

Low: No coastline regression, stable or progressing coast, low exposure but intervention recommended in order to create a closed sea-dyke system and long-term protection of the hinterland.

Special segment: Special areas, which are ports, highly urbanised areas, resorts, etc. These sites or coastal segments need closer studies and special recommendations.

Out of the 720 km of Mekong Delta coastline, 91 km was classified for interventions of very high urgency, 171 km of high urgency, 260 km of medium urgency and about 140 km of low urgency. Another 58 km was classified as special zones or segments. Segments of very high and high urgency should be prioritised for budgeting and implementation within the coming years, aiming at 2030 for completion of all measures.

Due to the dramatic increase of erosion rates during the last decades, some massive measures are needed along the highly threatened coastal segments. Table 6 provides an overview; further details are given below in Table 6 a through g. Around 77 km of the coastline need quite massive breakwaters as they were tested and optimised by the province of Ca Mau or similar types. In order to stabilise the foreshore and intertidal flats (or to restore them), different types of fences and especially T-shaped groynes are recommended for about 290 km of coast in coastal segments which are not highly exposed or show very high erosion rates. Often this category of measure comes in combination with mangrove rehabilitation. Along more than 580 km of the Mekong Delta coast, an earthen sea-dyke could prevail if other measures such as breakwaters secure the stabilisation of the foreshore area; thus, the fore-dyke land (land between dyke and sea). It is important to consider the arguments for using generally much milder outer berm slopes than those current sea-dykes outlined in the chapter on guidance for designing coastal protection works. The sea-dykes already exposed – if retreat is excluded – need strong dyke toe protection and other revetments. Currently, this kind of measure would be needed along almost 140 km.

The almost 8,000 ha planned mangrove plantation along about 290 km of coast (as suggested in the CPMD) is likely only achievable in combination with other measures for foreshore stabilisation and reflects the significant contribution of the mangroves to secure the coastline. However, further mangrove rehabilitation and stricter measures for mangrove conservation and sustainable management (including co-management approaches) are strongly recommended. It should be noted that not only storm surge and erosion can jeopardize the mangrove forest, but also long-during droughts. The current, relative species-poor Rhizopora - forest is not resistant against the very high salinities in the coastal waters and need, to some extent, a brackish environment. In contrast, the species recommended here for the pioneer zone are better able to deal with high salinity. For the medium term, further reversion of abandoned aquaculture ponds and other backshore areas should be considered for mangrove reforestation, too, especially with typical species of the upper tidal ranges and higher zones (e.g. Ceriops, Lumnitzera, Xylocarpus) since this natural zone of mangrove forest virtually disappeared during the last decades through intensive land-use of those areas. Melaleuca forests are not part of the marine environment but could also contribute to the coastal protection system in the sea-dyke hinterland (behind the dyke) by using them as freshwater reservoirs and buffer areas against saline water intrusion. However, this measure was not included in the CPMD since it would need new clear definitions of water management in the CPUs.

Table 6. Overview on all recommended coastal protection measures in the Mekong Delta per province and category of measure in length (m) or (ha) for mangroves. It should be noted that for wide stretches of the coastline more than one - in fact often a combination of measures - is recommended.

	Nearshore breakwaters, massive or sandbars (I)	Fences & groynes (II) in foreshore	Mangrove plantation (III) in ha	Sea-dyke with revetments (IV)	Earthen sea-dyke (V)	Sea-sluices (VI) in n	Length Coast per province
Kien Giang	12,900	51,500	578	39,900	144,300	23	184 km
Ca Mau	48,600	125,400	5,164	58,000	180,000	51	238 km
Bac Lieu	0	47,800	715	17,400	35,700	20	53 km
Soc Trang	0	19,400	880	12,900	65,700	6	79 km
Tra Vinh	0	6,400	0	8,500	58,300	2	67 km
Ben Tre	0	24,500	367	0	62,700	37	63 km
Tien Giang	15,000	15,500	232	2,000	34,500	8	36 km
Total length per measure (I-VII) in MD	77,000 m	290,500 m	7,936 ha	138,700 m	581,200 m	147 (no.)	720 km
In % of MD	10,7 %	40.3 %		19.3 %	80.7 %		100 %

7.3.1 Recommendations for Kien Giang Province

The coast of Kien Giang has a total length of about 184 km. The CPMD divides the coast into 6 Coastal Protection Units (CPU) and 15 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There is a very high urgency for intervention for more than 11.2 km of coast, and a high urgency for another 34.1 km.

Fig. 71. CPS urgency in Kien Giang Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6a. Specific recommendations per Coastal Protection Segment (CPS). Certain redundancy is intentional. For definitions of technical terms, see section on coastal terminology and guidance on designing coastal protection works. For exact position of the respective CPS, refer to map on the online CPMD.

Recommendations for Kien Giang Province
CPS 01_01_001 (length: 32300 m; low urgency): The western part of this segment is characterised by Ha Tien Bay (which has a separate Management Plan) as well as the port town of Ha Tien. The eastern part is characterised by stretches of limestone headlands. Naturally, mangroves only grow in the numerous bays and less exposed locations. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangrove belt): partially very thin mangrove belt in front of aquaculture ponds; therefore, restoration of mangrove protection zone of at least 150 m is needed for at least 4400 m (mainly Duong Hoa and My Duc) which results in about 66 ha along the segment, including in fillings of sparse forest; planting of Avicennia and Sonneratia; reversion of aquaculture ponds with mangroves (Sonneratia lanceolata, Rhizophora apiculata, Avicennia officinalis). There are some smaller areas with erosion, where mudflats have to be restored by T-fence like structures (ca 4400 m) before pursuing mangrove plantation. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope. The dyke needs toe protection and revetment over at least 2500 m (mainly around Ha Tien).
CPS 01_02_002 (length: 24000 m; low urgency): Mainly Binh An with its limestone headlands, bays and small islands. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangrove belt): partially very thin mangrove belt in front of aquaculture ponds (< 10 m, see drone videos) therefore the restoration of mangrove protection zone of at least 150 m should be aimed for. Breakwaters are recommended (T-fence type, groyne fields, fence made of natural materials) to protect plantation over at least 1300 m. Mangrove restoration here results in about 19.5 ha along the segment, including in fillings of sparse forest and reversion of un-used aquaculture ponds with mangroves (Sonneratia lanceolata, Rhizophora apiculata, Avicennia officinalis). SEA-DYKE: strengthen earth dyke with a mild seawards slope to avoid wave reflection and in some very exposed stretches additional revetment (over 1800 m).
CPS 01_02_003 (length: 23600 m; medium urgency): BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangrove belt): partially very thin mangrove belt in front of the sea-dyke and former aquaculture ponds; therefore, the restoration of mangrove protection zone of at least 150 m should be aimed for (see Drone videos). Breakwaters are recommended (T-fence type, groyne fields, fence made of natural materials) to protect plantations over at least 5100 m,

resulting in potential reforestation of up to 76 ha, including in fillings of sparse forest; planting of Avicennia and Sonneratia; reversion of aquaculture ponds with mangroves (Sonneratia lanceolata, Rhizophora apiculata, Avicennia officinalis).

SEA-DYKE: light dyke revetment and toe protection over a total of 10,000 m (see model at Vam Ray) at locations with no mangrove belt; strengthen earth dyke with a mild seaward slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope. In case of the implementation of a floodway (from An Giang), the coastal protection measures have to be re-assessed.

CPS 01_03_004 (length: 11900 m; medium urgency):

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangrove belt): partially very thin mangrove belt in front of the sea-dyke and former aquaculture ponds therefore the restoration of mangrove protection zone of at least 150 m should be aimed for (see Drone videos). Breakwaters are recommended (T-fence type, groyne fields, fence made of natural materials) to protect plantations over at least 3000 m. Mangrove restoration should focus especially on Tho Son and My Lam, resulting in potential reforestation of up to 76 ha, including in fillings of sparse forest; planting of Avicennia and Sonneratia; reversion of aquaculture ponds with mangroves (Sonneratia lanceolata, Rhizophora apiculata, Avicennia officinalis).

SEA-DYKE: light dyke revetment and toe protection over a total of 4,800 m (see model at Vam Ray) at locations with no mangrove belt; strengthen earth dyke with a mild seaward slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope. In case of the implementation of a floodway (from An Giang), the coastal protection measures have to be re-assessed.

CPS 01_03_005 (length: 16500 m; low urgency):

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangrove belt): partially very thin mangrove belt in front of the sea-dyke and former aquaculture ponds therefore the restoration of mangrove protection zone of at least 150 m should be aimed for (see Drone videos). Breakwaters are recommended (T-fence type, groyne fields, fence made of natural materials) to protect plantations over at least 2400 m. Potential reforestation of up to 36 ha, including in fillings of sparse forest; planting of Avicennia and Sonneratia; reversion of aquaculture ponds with mangroves (Sonneratia lanceolata, Rhizophora apiculata, Avicennia officinalis).

SEA-DYKE: light dyke revetment and toe protection over a total of 1,000 m (see model at Vam Ray) at locations with no mangrove belt; strengthen earth dyke with a mild seaward slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope. In case of the implementation of a floodway (from An Giang), the coastal protection measures have to be re-assessed.

CPS 01_04_006 (length: 13000 m; special segment): Urban area with extensive land reclamation and a seawall.

BREAKWATER in NEARSHORE area: No need for measurements.

FORESHORE (tidal flats and mangroves): Depending on planned developments, certain coastal stretches could be reserved for mangrove planting to protect seawalls and sea-dykes, T-fences could support tidal flat development in the northern part of this segment.

SEA-DYKE: needs upgrading for urban flood control, the seawall alone does not protect against high floods as they may occur (rarely) in the bay area under long-lasting south-western storm surge and backwater conditions. Rach Gia needs a separate coastal protection plan.

CPS 01_05_007 (length: 8900 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): especially during last decade there has been a clear retreat of the mangrove belt including strong species such as Sonneratia. This quite local effect at the most northern tip has already led to the retreat of the earthen dyke. International experts considered this as a temporary counter effect of the land reclamation in the urban area eastwards, and the increasing sediment demand induced since this trend runs against the long-term history of segment 7-9 (see historical coastlines). Partially very steep cliff erosion indicates the fast speed of this process. The recommendation is to allow a certain loss of foreshore and to observe if a new equilibrium is reached within the coming years. Otherwise, a strong local intervention may move this erosion problem spot to other coastal segments. Towards the eastern side, a field (about 50 m seawards) of strong bamboo T-fences could support the restoration of a mangrove protection zone.

SEA-DYKE: the retreated sea-dyke should have a very mild slope and needs toe protection to avoid wave reflection. Close survey of developments by drones is recommended.

CPS 01_05_008 (length: 12400 m; medium urgency): Here, the erosion is a relatively new phenomenon, in principle this segment showed a trend of progression over its long history.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): especially during the last decade there is a clear retreat of the mangrove belt including strong species such as Sonneratia. Reforestation with the support of groyne fields (bamboo T-fence type) is considered possible over 3,000 m.

SEA-DYKE: sea-dyke should have a very mild slope and needs toe protection where exposure can be expected. Close survey of further developments by drones is recommended.

CPS 01_05_009 (length: 5200 m; low urgency):

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): There is a trend of sediment accretion and shoreline progression over a long time. This process could be supported by light sand trapping (melaleuca fences or T-fence groynes) and mangrove planting over 3,000 m. The enhancing of the slightly progressing shoreline could also contribute to a better protection of north-western stretches and Kien Giang city.

SEA-DYKE: Earth dyke with a very mild slope and some simple toe protection.

CPS 01_05_010 (length: 8000 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): There is a trend of sediment accretion and shoreline progression over a long time. This process could be supported by light sand trapping (melaleuca fences or T-fence groynes) and mangrove planting over 3,000 m. The enhancing of the slightly progressing shoreline could also contribute to a better protection of north-western stretches and Kien Giang city.

SEA-DYKE: Earth dyke with a very mild slope and some simple toe protection.

CPS 01_05_011 (length: 4400 m; very high urgency): After a long period of shoreline progression there is a clear trend of regression during the last decades (see historical coastlines).

BREAKWATER in NEARSHORE area: any continuous massive structure might cause harm to the coast in northern and eastern direction (down-stream syndrome). Locally strong cliff erosion.

FORESHORE (tidal flats and mangroves): Although the mangrove forest still exists and is broad, the rapid erosion and open aquaculture ponds (in use or not-used) offers little resistance against wave surge once the denser protection forest disappears. Therefore, forestalling measures are recommended. Strong groynes of bamboo T-fences (or likewise) to re-establish a closed mangrove protection zone of at least 100 m are recommended. Accompanied by active mangrove restoration, including especially the consequent reversion of (abandoned) aquaculture ponds over the entire segment. Since it is not certain that T-fence-like structures made by natural materials are strong enough against storm surge, small-scale concrete breakwater elements should be tested at selected sites.

SEA-DYKE: Earth dyke with a very mild slope and some toe protection is recommended. As for the entire dyke along the West Sea coast it is strongly recommended NOT to deepen the seaward ditch for dyke construction materials but to fill it in. Once exposed (as can be observed at several locations), the deep ditch in front of the dyke reduces the resistance against wave surge considerably. Regular surveys of developments of the West Sea coast by drones is recommended. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 25, especially if nourishment and large breakwater construction are considered in the entire CPR 2 along the West Sea!

CPS 02_06_012 (length: 600 m; very high urgency): Funnel-shaped erosion in the vicinity of a channel and port.

BREAKWATER in NEARSHORE area are not recommended here.

FORESHORE: the embankments need a strongly sloping revetment (see experiences in Ca Mau) possibly with curved jetties that reach not more than 50 m across the shoreline. Reforestation behind the jetties with suitable mangrove species.

CPS 02_06_013 (length: 10500 m; high urgency): After a long period of shoreline progression there is a clear trend of regression during the last few decades (see historical coastlines). Around Dong Hung, the mangrove forest is still quite stable.

BREAKWATER in NEARSHORE area: any continuous massive structure might cause harm to the coast in northern and eastern directions (down-stream syndrome). Locally strong cliff erosion.

FORESHORE (tidal flats and mangroves): Although the mangrove forest still exists and is broad, the fast erosion and open aquaculture ponds (in use or not-used) offers little resistance against wave surge once the denser protection forest disappears. Since some stretches within CPS 13 around Dong Hung still show accretion tendencies, this progression should be supported by active mangrove planting in the pioneer zone. Protection of the young plantations by fences is strongly recommended.

SEA-DYKE: Earth dyke with a very mild slope and some toe protection is recommended. As for the entire dyke along the West Sea coast it is strongly recommended NOT to deepen the seaward ditch for dyke construction materials but to fill it in. Once exposed (as can be observed at several locations), the deep ditch in front of the dyke reduces the resistance against wave surge considerably. Regular surveys of developments of the West Sea coast by drones is recommended. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau in the entire CPR 02, especially if nourishment and large breakwaters are considered!

CPS 02_06_014 (length: 6700 m; high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwaters. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 25, especially if nourishment and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended. For details see*.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-250 m width. On a long-term active mangrove restoration, and especially the reversion of (former) aquaculture ponds to mangroves should be applied.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended. As for the entire dyke along the West Sea coast it is strongly recommended NOT to deepen the seaward ditch for dyke construction materials but to fill it in. Once exposed (as can be observed at several locations), the deep ditch in front of the dyke reduces the resistance against wave surge considerably. Regular survey of developments of the West Sea coast by drones is recommended.

CPS 02_06_015 (length: 6200 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwaters. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 12 to 25, especially if nourishments and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended, for details see*.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover (former ponds) and due to the forming of unstable headlands. The assumption is that there is a need for light T -fences for any mangrove plantation trial in the coming 5 years. Within the protection of the recommended breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-250 m width. On the long-term, active mangrove restoration, and especially the reversion of (former) aquaculture ponds to mangroves should be applied. This includes changes in the zoning of protection forest in order to deal with recent trends of coastal regression.

7.3.2 Recommendations for Ca Mau Province

The coast of Ca Mau has a total length of about 238 km. The CPMD divides the coast into 9 Coastal Protection Units (CPU) and 19 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There is a very high urgency of intervention of 71.3 km, and a high urgency for another 54.9 km.

Fig. 72. CPS urgency in Ca Mau Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6b. Specific recommendations per Coastal Protection Segment (CPS) of Ca Mau Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection works. For exact position of the respective CPS refer to the map on the online CPMD.

Recommendations for Ca Mau Province
CPS 02_07_016 (length: 18800 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades. BREAKWATER in NEARSHORE area: Need for hard structural breakwater. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 12 to 25, especially if nourishment and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended, (for details see respective chapter or online CPMD). At several locations vertical breakwaters have been applied successfully in recent years. There is an alternative option on foreshore beach management (creation of sandbars), which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, see link in online CPMD) for the West Sea coast of Ca Mau. The installation of new structures should be in accordance with the existing ones and consider recent monitoring data. FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover (former ponds) and due to the forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-250 m width. In the long-term, active mangrove restoration, and especially the reversion of (former) aquaculture ponds to mangroves should be applied. This includes changes in the zoning of protection forest in order to deal with recent trends of coastal regression. The dimensions and locations of the groynes or T-fences should be assessed after evaluation of the impacts of the breakwaters. SEA-DYKE: Strengthen sea-dyke with a very mild slope, a proper toe protection where already exposed (some stretches of newly built dyke in Ca Mau are already exposed). As for the entire dyke along the West Sea coast it is strongly recommended NOT to deepen the seaward ditch for dyke construction materials but to fill it in. Once exposed (as can be observed at several locations), the deep ditch in front of the dyke reduces the resistance against wave surge considerably. Close survey of developments in the nearshore area and of the entire sea-dyke system by drones is recommended.
CPS 02_07_017 (length: 2300 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades. BREAKWATER in NEARSHORE area: Need for hard structural breakwater. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 22, especially if nourishment and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwaters is recommended, for details see*. In recent years at several locations vertical breakwaters have been applied successfully. The installation of new structures should be in accordance with the existing ones and consider monitoring data.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, see link in online CPMD; for discussion see text) for the West Sea coast of Ca Mau. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-200 m width. In the long-term, active mangrove restoration, and especially the re-conversion of (former) aquaculture ponds to mangroves should be applied here. The dimensions and locations of the groynes or T-fences should be assessed after evaluation of the impacts of the breakwaters.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended.

CPS 02_08_018 (length: 7700 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwater. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 22, especially if nourishments and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended, (for details see respective chapter or online CPMD). At several locations vertical breakwaters have been applied successfully in recent years. The installation of new structures should be in accordance with the existing ones and consider monitoring data. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, see link in online CPMD) for the West Sea coast of Ca Mau.

FORESHORE (foreshore and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-200 m width. In the long-term, active mangrove restoration, and especially the re-conversion of (former) aquaculture ponds to mangroves should be applied here. The dimensions and locations of the groynes or T-fences should be assessed after evaluation of the impacts of the breakwaters.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended.

CPS 02_08_019 (length: 7400 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwater. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 22, especially if nourishment and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwaters is recommended (for details see respective chapter or online CPMD). At several locations vertical breakwaters have been applied successfully in recent years. The installation of new structures should be in accordance with the existing ones and consider monitoring data. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, see link in online CPMD; for discussion see text) for the West Sea coast of Ca Mau.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwater, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-200 m width. In the long-term, active mangrove restoration, and especially the re-conversion of (former) aquaculture ponds to mangroves should be applied here. The dimensions and locations of the groins or T-fences should be assessed after evaluation of the impacts of the breakwaters.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended.

CPS 02_09_020 (length: 3300 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwater. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 22, especially if nourishment and a large breakwater are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended (for details see respective chapter or online CPMD). At several locations vertical breakwaters have been applied successfully in recent years. The installation of new structures should be in accordance with the existing ones and consider monitoring data. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, see link in online CPMD) for the West Sea coast of Ca Mau.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-200 m width. In the long-term, active mangrove restoration, and especially the re-conversion of former aquaculture ponds to mangroves should be applied here. The dimensions and locations of the groynes or T-fences should be assessed after evaluation of the impacts of the breakwaters.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended.

CPS 02_09_021 (length: 8300 m; very high urgency): After a long period of shoreline progression there is a significant trend of regression during the last few decades.

BREAKWATER in NEARSHORE area: Need for hard structural breakwater. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, for link*, for discussion see text) for the West Sea coast of Ca Mau. An integrated protection concept should be closely coordinated for the entire West Sea coast of Kien Giang and Ca Mau between CPS 11 to 22, especially if nourishment and large breakwaters are considered. Principally, a chain (with gaps) of modified, detached pile breakwater is recommended, for details see*. At several locations vertical breakwaters have been applied successfully in recent years. The installation of new structures should be in accordance with the existing ones and consider monitoring data. Here is an alternative option on foreshore beach management (creation of sandbars) which was proposed by SIWRR (LMDCZ Project supported by AFD and EU, for link*, for discussion see text) for the West Sea coast of Ca Mau.

FORESHORE (tidal flats and mangroves): Locally high cliffs caused by erosion. Although the mangrove forest still exists, this mangrove forest offers no resistance against erosion due to partially low cover and due to forming of unstable headlands. Within the protection of the breakwaters, simple groynes of bamboo T-fences (or similar) should be constructed to enhance sediment accretion and to re-establish a dense mangrove protection zone of at least 150-200 m width. In the long-term, active mangrove restoration, and especially the re-conversion of (former) aquaculture ponds to mangroves should be applied. The dimensions and locations of the groynes or T-fences should be assessed after evaluation of the impacts of the breakwaters.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, toe protection and revetment where already exposed. Close survey of developments by drones is recommended.

CPS 02_09_022 (length: 6200 m; high urgency): Significant retreat of the mangrove forest has occurred in recent years. Although the width of the mangrove belt is still sufficient to protect the dyke, this section is still subject to major erosion.

BREAKWATER in NEARSHORE area: Soft and close-to-nature measures such as T-Fences are recommended in the nearshore area supported with low density plantings after initially high sedimentation has occurred.

SEA-DYKE: Strengthen sea-dyke with a very mild slope, basic toe protection and revetment where already exposed. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 02_09_023 (length: 1600 m; special segment): Port development planned. In the detailed planning it is of high importance to investigate the impact of jetties or other cross-shore structures in order to minimise disturbance or interruption of the longshore sediment transport. For the prevention of funnelling effects see respective text.

CPS 02_09_024 (length: 1600 m; special segment): Port development planned. In the detailed planning it is of high importance to investigate the impact of jetties or other cross-shore structures in order to minimise disturbance or interruption of the longshore sediment transport. For the prevention of funnelling effects see respective text.

CPS 02_10_025 (length: 17500 m; medium urgency): Still sufficient width of the mangrove forest. No significant trend analysed.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): foresight mangrove planting (150 m width) should be promoted and supported with light fences over about half the segment (8.750 m). Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 03_11_026 (length: 3900 m; medium urgency): Still sufficient width of the mangrove forest. No significant trend analysed. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 03_11_027 (length: 18800 m; low urgency): Still sufficient width of the mangrove forest. Slight progression of mangrove belt. national park buffer or core zone. No significant trend analysed.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation of the shoreline induces decreased wave load. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 03_12_028 (length: 15200 m; low urgency): Still sufficient width of the mangrove forest. Slight progression of mangrove belt. national park buffer or core zone. No significant trend analysed.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation of the shoreline induces decreased wave load. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 03_13_029 (length: 21800 m; medium urgency): Still sufficient width of the mangrove forest. Slight progression of mangrove belt. national park buffer or core zone. No significant trend analysed.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation of the shoreline induces decreased wave load. The condition of the dyke, the bridges and the floodplains should be inspected regularly to recognize negative trends in time. Close survey of developments by drones is recommended.

CPS 03_13_030 (length: 31400 m; special segment): Development of a large-scale tourism complex under construction. Groynes / jetties have been constructed and sand nourished. In the detailed planning it is very important to investigate the impact of jetties or other cross-shore structures in order to minimise disturbance or interruption of the longshore sediment transport. The processes of shoreline development around the Ca Mau spits are considered as a sensitive indicator for changes in the entire sediment budget (sediment supply by MR). Developments and impacts should be regularly monitored by drones.

CPS 03_14_031 (length: 33500 m; high urgency): Clear trend of regression since 1905.

BREAKWATER in NEARSHORE area: No measures recommended since any massive structures are most likely to cause harm to the coast in south-western directions. Locally, very strong cliff erosion. Although the mangrove forest still exists and is relative broad, this mangrove forest offers no resistance against erosion due to low cover and former shrimp ponds.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences (possibly re-enhanced by pillars) to stop further regression and to re-establish a mangrove protection zone of 500 m dense forest without any ponds. It is recommended to test the construction of entire groyne fields (not only a row of T fences) in less exposed sites, using natural materials. Strengthening of the backshore mangroves and reversion of any ponds are strongly recommended to save the mangrove belt in this area. Since there are no experiences yet, close monitoring and research accompanying the reforestation efforts are recommended. Evaluated final evaluation should be done after 5 years. For further reasoning see text on strategic protection of the entire CPR 4.

SEA-DYKE: Earth dyke with a very mild slope (to avoid reflection of long waves) and a basic toe protection. Close survey of developments by drones is recommended.

CPS 04_15_032 (length: 15200 m; high urgency): Clear trend of regression since 1905.

BREAKWATER in NEARSHORE area: No measures recommended since any massive structures are most likely to cause harm to the coast in a south-western direction. Locally very strong cliff erosion. Although the mangrove forest still exists and is relative broad, this mangrove forest offers no resistance against erosion due to low cover and former shrimp ponds.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences (possibly re-enhanced by pillars) to stop further regression and to re-establish a mangrove protection zone of 500 m dense forest without any land-use. It is recommended to test the construction of entire groyne fields (not only a row of T fences) in less exposed sites, using natural materials. Strengthening of the backshore mangroves and reversion of any ponds are strongly recommended to save the mangrove belt in this area. Since there are no experiences yet, close monitoring and research accompanying the reforestation efforts are recommended. Evaluated final evaluation should be done after 5 years. For further reasoning see text on strategic protection of the entire CPR 4.

SEA-DYKE: Earth dyke with very a mild slope (to avoid reflection of long waves) and a basic toe protection. Close survey of developments by drones is recommended.

CPS 04_15_033 (length: 21900 m; very high urgency): Clear trend of regression since 1905.

BREAKWATER in NEARSHORE area: No measures recommended since any massive structures are most likely to cause harm to the coast in south-western directions. Locally very strong cliff erosion. Although the mangrove forest still exists and is relative broad, this mangrove forest offers no resistance against erosion due to low cover and former shrimp ponds.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences (possibly re-enhanced by pillars) to stop further regression and to re-establish a mangrove protection zone of 500 m dense forest without any land-use. It is recommended to test the construction of entire groyne fields (not only a row of T fences) in less exposed sites, using natural materials. Strengthening of the backshore mangroves and reversion of any ponds are strongly recommended to save the mangrove belt in this area. Since there are no experiences yet, close monitoring and research accompanying the reforestation efforts are recommended. Evaluated final evaluation should be done after 5 years. For further reasoning see text on strategic protection of the entire CPR 4.

SEA-DYKE: Earth dyke with very a mild slope (to avoid reflection of long waves) and a basic toe protection. Close survey of developments by drones is recommended.

CPS 04_15_034 (length: 1600 m; very high urgency): Section near the port of Dong Hau is subject to significant erosion including severe cliff erosion. Location in a highly dynamic and exposed area. Heavy structures are required to protect the shoreline. Vertical front breakwaters are recommended including sufficient depth of embedment.

Mangrove rehabilitation is important in this area. Yet due to high erosion it is not possible without complementary structures such as strong T-Fences. After installation of such structures it is recommended to wait until initial sedimentation has occurred and start planting 1 year after construction. Alternatively, at very exposed locations additional nourishment is recommended. Low density cluster planting is considered sufficient as this area would be naturally reclaimed by mangroves over time.

SEA-DYKE: Strengthen the earth dyke with a mild seaward slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope. Near the port embankment is needed. This needs closer assessment for detailed recommendations.

7.3.3 Recommendations for Bac Lieu Province

Bac Lieu has around 53 km of coast. The CPMD divides the coast into 2 Coastal Protection Units (CPU) and 8 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There is a very high urgency of intervention for 3.1 km of coast, and a high urgency for another 7.7 km.

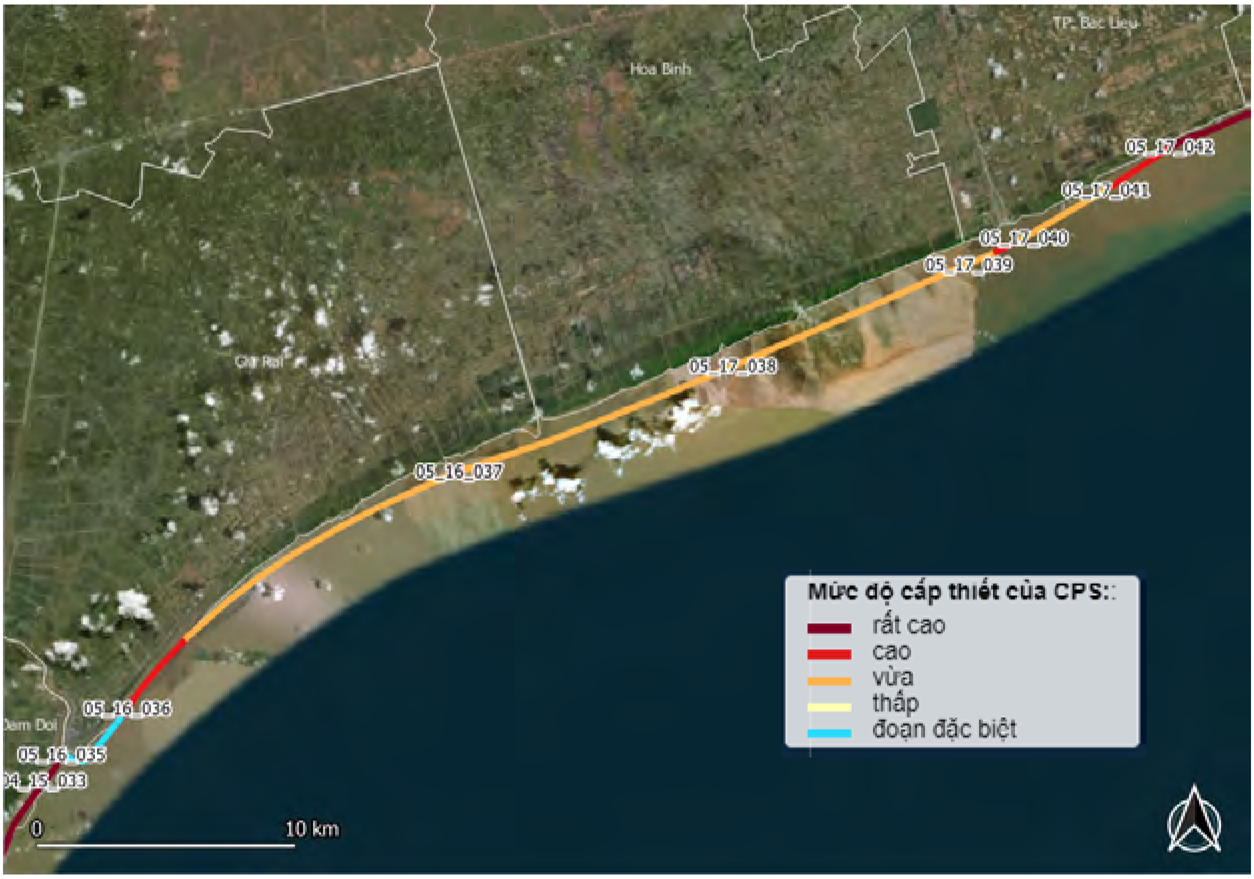


Fig. 73. CPS urgency in Bac Lieu Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6c. Specific recommendations per Coastal Protection Segment (CPS) of Bac Lieu Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection work. For exact position of the respective CPS refer to map of the online CPMD.

Recommendations for Bac Lieu Province
CPS 05_16_035 (length: 3300 m; special segment): Section near the port of Ganh Hao. Needs strong protection measures after the failure of a fully armoured sea-dyke. For details see text. Possibly breakwater (details only after further investigations) while jetties are strongly discouraged since they would probably enhance erosion towards the south.
CPS 05_16_036 (length: 3800 m; high urgency): BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): partially decreasing mangrove belt and erosion spots. Bamboo T fences to re-establish mangrove protection zone of at least 150 m; planting of Avicennia and Sonneratia at the sea front; re-conversion of aquaculture ponds within the zone. SEA-DYKE: light dyke revetment at locations with no mangrove belt; strengthen earth dyke with a mild seawards slope to avoid wave reflection and reduce hydrodynamic load on the seaward slope.
CPS 05_16_037 (length: 16000 m; medium urgency): BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion. FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.
CPS 05_17_038 (length: 18900 m; medium urgency): BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion. FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.

CPS 05_17_039 (length: 1000 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.

CPS 05_17_040 (length: 4100 m; medium urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.

CPS 05_17_041 (length: 2900 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.

CPS 05_17_042 (length: 3100 m; very high urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended. It is strongly recommended to apply heavy temporary erosion protection at the dam and the bridge foundation in order to avoid the collapse of the construction. This can be done by building up a mild sloped revetment of heavy armour stones founded on a filter-stable thick geotextile. The stones can be re-used in a later phase in order to construct a new permanent revetment. Interactions with the nearshore windfarm need to be considered and monitored.

7.3.4 Recommendations for Soc Trang Province

The coast of Soc Trang is about 79 km in length. The CPMD is divides the coast into 3 Coastal Protection Units (CPU) and 11 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There is a very high urgency of intervention for more than 5.5 km of coast, and a high urgency for another 23.3 km.

Fig. 74. CPS urgency in Soc Trang Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6d. Specific recommendations per Coastal Protection Segment (CPS) of Soc Trang Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection work. For exact position of the respective CPS refer to map of the online CPMD.

Recommendations for Soc Trang Province
CPS 05_18_043 (length: 5500 m; very high urgency): BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion and complete erosion of the mangrove forest. Existing mangrove forest offers no resistance against erosion. FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.
CPS 05_18_044 (length: 12600 m; high urgency): BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion and complete erosion of the mangrove forest. Existing mangrove forest offers no resistance against erosion. FORESHORE (tidal flats and mangroves): Strong groynes of bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. SEA-DYKE: Earth dyke with a very mild slope and a strong toe protection; especially at exposed locations at sluice gates including strong revetment and strong toe protection. Close survey of developments by drones is recommended.
CPS 05_18_045 (length: 15300 m; medium urgency): BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion. FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 05_18_046 (length: 3800 m; medium urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 05_18_047 (length: 6700 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 05_18_048 (length: 4000 m; high urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 05_19_049 (length: 2200 m; medium urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western directions. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves.

SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 05_19_050 (length: 8700 m; medium urgency):

BREAKWATER in NEARSHORE area: No need for measures, any massive structures might cause harm to the coast in south-western direction. Locally strong cliff erosion. Although the mangrove forest still exists and is relatively broad, this mangrove forest offers no resistance against erosion.

FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone of at least 150 m are recommended accompanied by active mangrove restoration, and especially the re-conversion of aquaculture ponds to mangroves. At locations further in the estuary, the length of the groins/T-fences must be reduced.

SEA-DYKE: Earth dyke with a mild slope and a toe protection. Survey of developments by drones is recommended.

CPS 06_20_051 (length: 14800 m; medium urgency): Still sufficient width of mangrove forest.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.

CPS 06_20_052 (length: 2800 m; medium urgency): Still sufficient width of mangrove forest.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.

CPS 06_20_053 (length: 2200 m; medium urgency): Location parallel to the estuary.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended. Local and temporary erosion protection in form of revetments required.

7.3.5 Recommendations for Tra Vinh Province

Tra Vinh has a coast of about 67 km in length. The CPMD is divides the coast into 4 Coastal Protection Units (CPU) and 9 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There are no coastal stretches with a very high urgency of intervention, but high urgency is stated for 6.4 km.

Fig. 75. CPS urgency in Tra Vinh Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6e. Specific recommendations per Coastal Protection Segment (CPS) of Tra Vinh Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection work. For exact position of the respective CPS refer to map of the online CPMD.

Recommendations for Tra Vinh Province
CPS 06_21_054 (length: 10600 m; medium urgency): Location parallel to the estuary. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Bamboo T-fences to re-establish mangrove protection zone are recommended accompanied by active mangrove restoration. At location further in the estuary, the length of the groins/T-fences must be reduced. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended. Local and temporary erosion protection in form of revetments required.
CPS 06_21_055 (length: 14500 m; medium urgency): Reduced width of mangrove forest. Sandy environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.
CPS 06_21_056 (length: 2000 m; special segment): insufficient information available for proper specific recommendations.
CPS 06_22_057 (length: 4700 m; special segment): Insufficient information available for proper specific recommendations.
CPS 06_22_058 (length: 12800 m; medium urgency): Reduced width of mangrove forest. Sandy environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.

CPS 06_22_059 (length: 6400 m; high urgency): Decreasing width of mangrove forest. Strong longshore currents resulting in a highly dynamic environment.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.

CPS 06_22_060 (length: 1800 m; low urgency): Location parallel to the estuary.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended. Local and temporary erosion protection in the form of revetments required.

CPS 06_23_061 (length: 9500 m; low urgency): Location parallel to the estuary.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended. Local and temporary erosion protection in the form of revetments required.

CPS 06_24_062 (length: 4500 m; low urgency): Still sufficient width of mangrove forest.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.

7.3.6 Recommendations for Ben Tre Province

The coast of Tra Vinh has a total length of about 63 km. The CPMD is divides the coast into 3 Coastal Protection Units (CPU) and 6 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There are no coastal stretches with very high urgency of intervention but high urgency is stated for 24.5 km.

Fig. 76. *CPS urgency in Ben Tre Province.*

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6f. Specific recommendations per Coastal Protection Segment (CPS) of Ben Tre Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection work. For exact position of the respective CPS refer to map of the online CPMD.

Recommendations for Ben Tre Province
CPS 06_25_063 (length: 11700 m; medium urgency): Reduced width of mangrove forest. Sandy environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.
CPS 06_25_064 (length: 17300 m; high urgency): Decreasing width of mangrove forest. Partly sandy environment. Strong longshore currents resulting in a highly dynamic environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.
CPS 06_26_065 (length: 5100 m; medium urgency): Reduced width of mangrove forest. Sandy environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.
CPS 06_26_066 (length: 5100 m; medium urgency): Reduced width of mangrove forest. Sandy environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.

CPS 06_27_067 (length: 16300 m; medium urgency): Reduced width of mangrove forest. Sandy environment.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Survey of developments by drones is recommended.

CPS 06_27_068 (length: 7200 m; high urgency): Decreasing width of mangrove forest. In certain sections strong cliff erosion. Partly sandy environment. Strong longshore currents resulting in a highly dynamic environment.

BREAKWATER in NEARSHORE area: No need for measures.

FORESHORE (tidal flats and mangroves): Regular monitoring.

SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to west-east orientation and obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.

7.3.7 Recommendations for Tien Giang Province

The coast of Tien Giang is approximately 37 km in length. The CPMD is divides the coast into 2 Coastal Protection Units (CPU) and 3 Coastal Protection Segments (CPS) with specific recommendations for measures (see Table below). There are no coastal stretches with very high urgency of intervention but high urgency is stated for 20.5 km. Since the immediate hinterland is very densely populated, those CPSs should be prioritised.

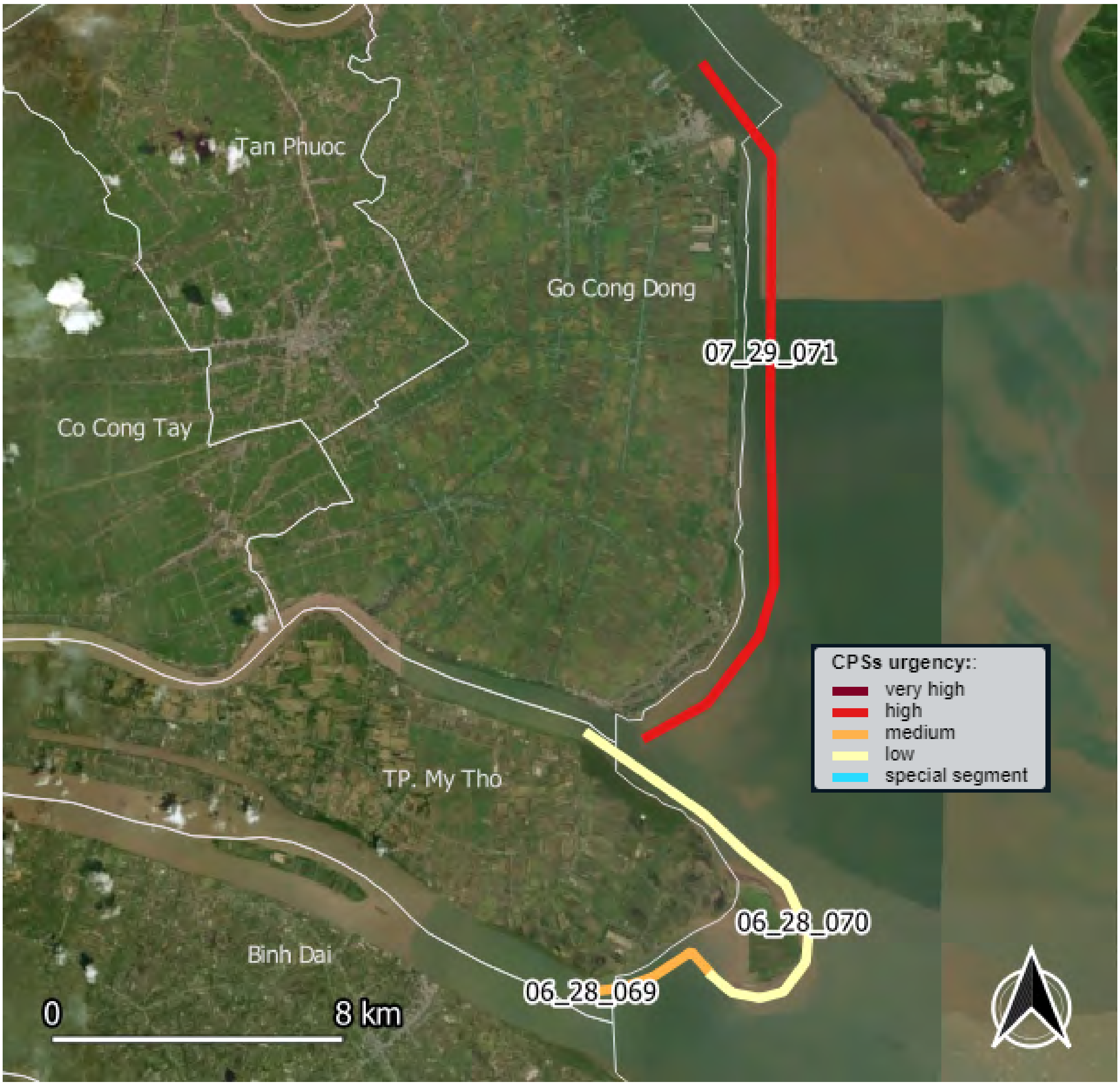


Fig. 77. CPS urgency in Tien Giang Province.

Source: Satellite map is provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and GIS community users

Table 6g. Specific recommendations per Coastal Protection Segment (CPS) of Tien Giang Province. Certain redundancy is intended. For definitions of technical terms see section on coastal terminology and guidance on designing coastal protection work. For exact position of the respective CPS refer to map of the online CPMD.

Recommendations for Tien Giang Province
CPS 06_28_069 (length: 3800 m; medium urgency): Decreasing width of mangrove forest. Strong longshore currents resulting in a highly dynamic environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.
CPS 06_28_070 (length: 12200 m; low urgency): Decreasing width of mangrove forest. Strong longshore currents resulting in a highly dynamic environment. BREAKWATER in NEARSHORE area: No need for measures. FORESHORE (tidal flats and mangroves): Regular monitoring. SEA-DYKE: strengthen earth dyke with a mild seaward slope to avoid wave reflection. Reduced wave run-up due to obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended.
CPS 07_29_071 (length: 20500 m; high urgency): Decreasing width of mangrove forest. Highly dynamic environment under the influence of several tidal rivers. Very strong tidal character. NEARSHORE Breakwater: hard structures or sandbar nourishment are recommended over a stretch of 15500 m (as an outcome of the LMDCZ Project) in order to hold riverine sediments and stop erosion in the more marine parts. At this moment no further, detailed recommendations can be provided. FORESHORE (tidal flats and mangroves): reforestation with suitable mangrove species along the entire area from more riverine brackish habitats to marine locations at least 150 m along the eroding stretches of up to 15500 m (using Avicennia officinalis, Avicennia marina, Rhizophora apiculata, see mangrove chapter). Regular monitoring. SEA-DYKE: strengthen earth dyke with mild seaward slope to avoid wave reflection. Reduced wave run-up due to obliquely approaching waves induces decreased wave load. Survey of developments by drones is recommended (for other details see links to AFD & EU Project in online CPMD).

7.4 Cost estimates for the recommended coastal protection measures

The CPMD tool provides detailed and specific recommendations on coastal protection measures for each coastal protection segment (CPS), (see map). The indicated cost estimates for the coastal protection provided in the CPMD should be considered as a first reference only. The recommendations are specified according to their location in the coastal area (nearshore = sea area between wave surf zone and swash zone at the beach, foreshore = intertidal area, periodically dry-falling sea area, sea-dyke route on land). Furthermore, there is a distinction between soft measures (predominantly mangrove plantation and mangrove protection or foreshore nourishment with sand) and hard structural measures using natural materials (wood, stones) and/or concrete. For each segment there are recommendations and cost estimates provided, including six different kinds of coastal protection measures (see below) and their combination, based on price per meter of coastline. In addition, costs for closer feasibility studies, construction and supervision are estimated. Hence, presented cost estimates are indicate the sum of all costs per segment.

How the costs were estimated

There are six kinds of measures:

(1) Nearshore: pillar (or similar) massive breakwater in m OR beach / foreshore nourishment by creating sandbars (sand banks or sand bars) (unit in m length)

(2) Foreshore stabilisation: groynes/ T-fence/ U-fence/ sediment trapping fence (unit in m length)

(3) Foreshore and backshore stabilisation: predominantly mangrove rehabilitation in ha (unit in 10,000 sqm)

(4) Sea-dyke with toe protection or/and revetments (unit in m length)

(5) Earthen sea-dyke (newly designed with mild outer slope of 1:5-6), (unit in m length)

(6) Sea sluice gate (different sizes and properties, unit in m length)

The costs for construction are based on the specific recommendation for measures under the Coastal Protection Segments (CPS), the scale of the recommended constructions and the actual cost for similar constructions that have previously been built in the Mekong Delta. Table 7 gives an overview of the costs reported from recent real cases. The construction cost is calculated by the proposed scale (m or ha) multiplied with cost per unit (see table 2). For example, for mangrove planting, it is the planting area (ha) * 172 mil. VND/ha.

Decision No. 79/QD-BXD, dated 15/02/2017, promulgates the cost norms for project management and consultancy investment for constructions in general. It includes 24 tables with different expenses to calculate the cost of any kind of construction. In the cost estimation for coastal protection measures, Tables 3 and 22 of the respective decision (No. 79) were used to calculate the costs for feasibility studies and expert supervision. All recommended coastal protection measures fall into the category of Agriculture and Rural Development. The costs for feasibility studies and expert supervision are equal to the construction cost multiplied by the respective percentage stated in the cost norm. Table 9 and Table 10 are the respective tables extracted from Decision No. 79//QD-BXD [Click].

The formula of the total cost is therefore:

- COSTS (VND) = (Dimension of the measure in m or ha * Unit cost for construction per m or ha) + (feasibility construction cost * percentage cost norm) + (supervision construction cost * percentage cost norm)

For the plantation of mangroves, a relatively high average price of 172,000 VND per ha was assumed based on 13 different case studies of successful plantations from the entire Mekong Delta. The costs for mangrove reforestation vary considerably depending on the species, the location and the preparation of the planting site. Planting in the pioneer zone using a selection of suitable species is usually much more expensive than planting Rhizophora sp in the backshore.

An exemplary calculation for each kind of coastal protection measure is presented in Table 8.

The results of these cost estimations for all recommended measures per Coastal Protection Segment (CPS) of the CPMD can be accessed via the respective layer in the online CPMD. An overview of the results is reported below.

Reliability and limitations of presented cost estimates

The cost estimates were made as reliable and transparent as possible at the current state of information and insights but the presented estimates should be considered as the minimum costs and as a rough indication. There is no doubt that costs for materials, labour and transport will increase within the horizon of the CPMD (until 2030). Deliberately, there are no correction factors for price development and inflation included since more sophisticated cost calculations will have to be carried out once the decision for certain measures has been made. There will be further costs on feasibility investigations at the respective sites by name on the local bathymetry and geology in order to find the most appropriate and exact location, and size of a certain type of construction which is recommended for this CPS by the CPMP tool. Detailed guidance on how to find the best design is provided in the latter chapters (and online tools). There will be other category of costs which could not be included, such as the need for capacity building, Research and Development (R & D), disaster preparedness and risk reduction, and finally regional coordination (symposia, workshops, inter-provincial and / or cross-sectoral roundtables). Unforeseen costs are possible costs for relocation – if needed – and additional measures to counteract land subsidence. A transformation of land- and water-use behind the sea-dyke as recommended by the CPMD will also be linked to related investments. However, in the longer term, these investments are expected to pay for themselves the coastal area will be safer and more resilient than before.

Overview of results

The current cost estimates for direct investments in structural measures are in the order of about 1.4 billion USD for the coming 10-15 years (2018-2030). The largest investments have to be made in Ca Mau and Kien Giang, almost 63 % of the total (Fig. 78). The construction of the sea-dyke and sea-sluices accounts for roughly 88% of the total costs while the reforestation of the mangroves, including the restoring and protection of tidal mudflats, accounts for only 12% (Fig. 79). This is a strong argument to invest in the restoration of coastal habitats. Keeping in mind the sustainability of these structural investments, although mangrove rehabilitation counts as a minor part of the expense, it is of the highest importance for the durability of the entire coastal protection system. Proper prioritizing of implementation following the degree of urgency is crucial and the classification system used for the CPMD might help in this regard. There is a very high urgency for interventions along more than 91 km of the 720 km coastline.

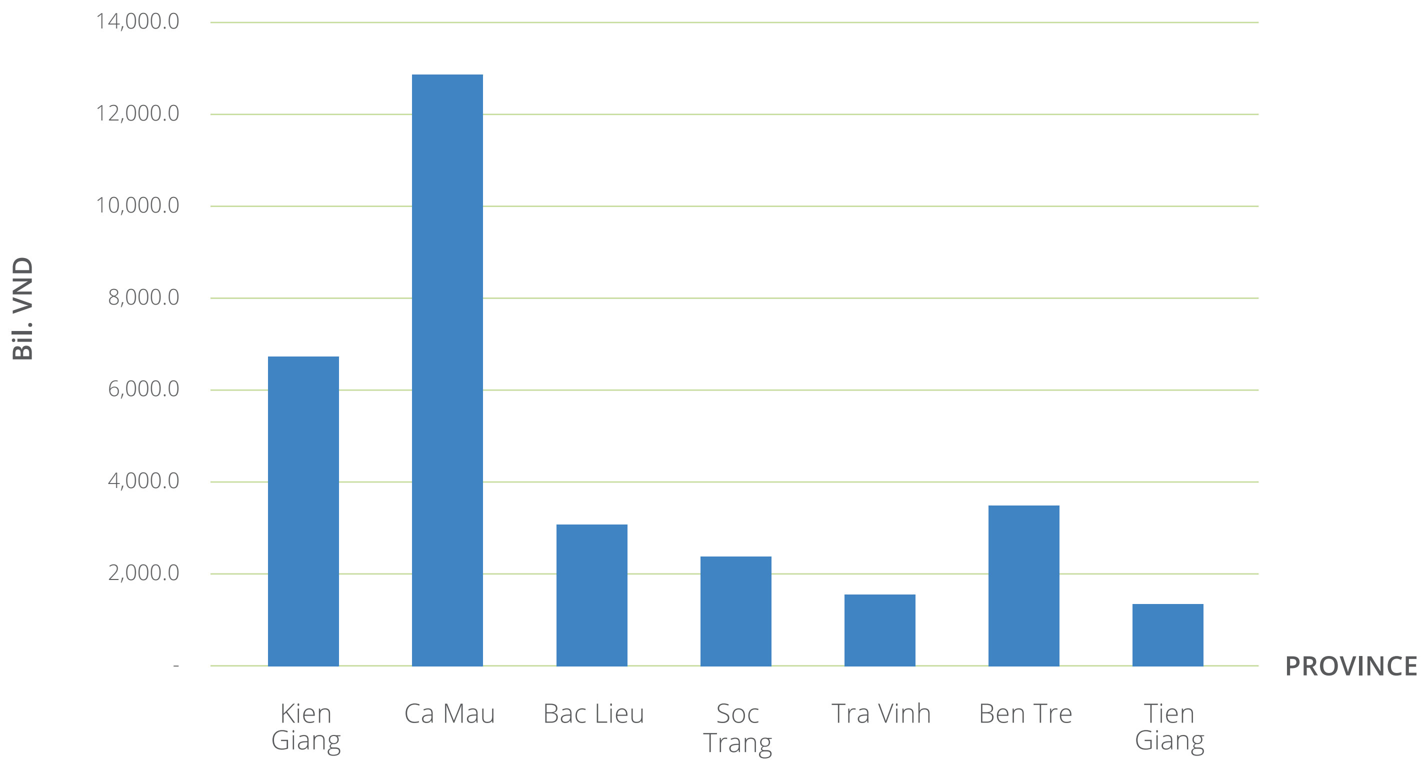


Fig. 78. Estimated costs for coastal protection measures according to the CPMD for 2018-2030 per province. Source: Southern Institute for Water Resources Planning (SIWRP)

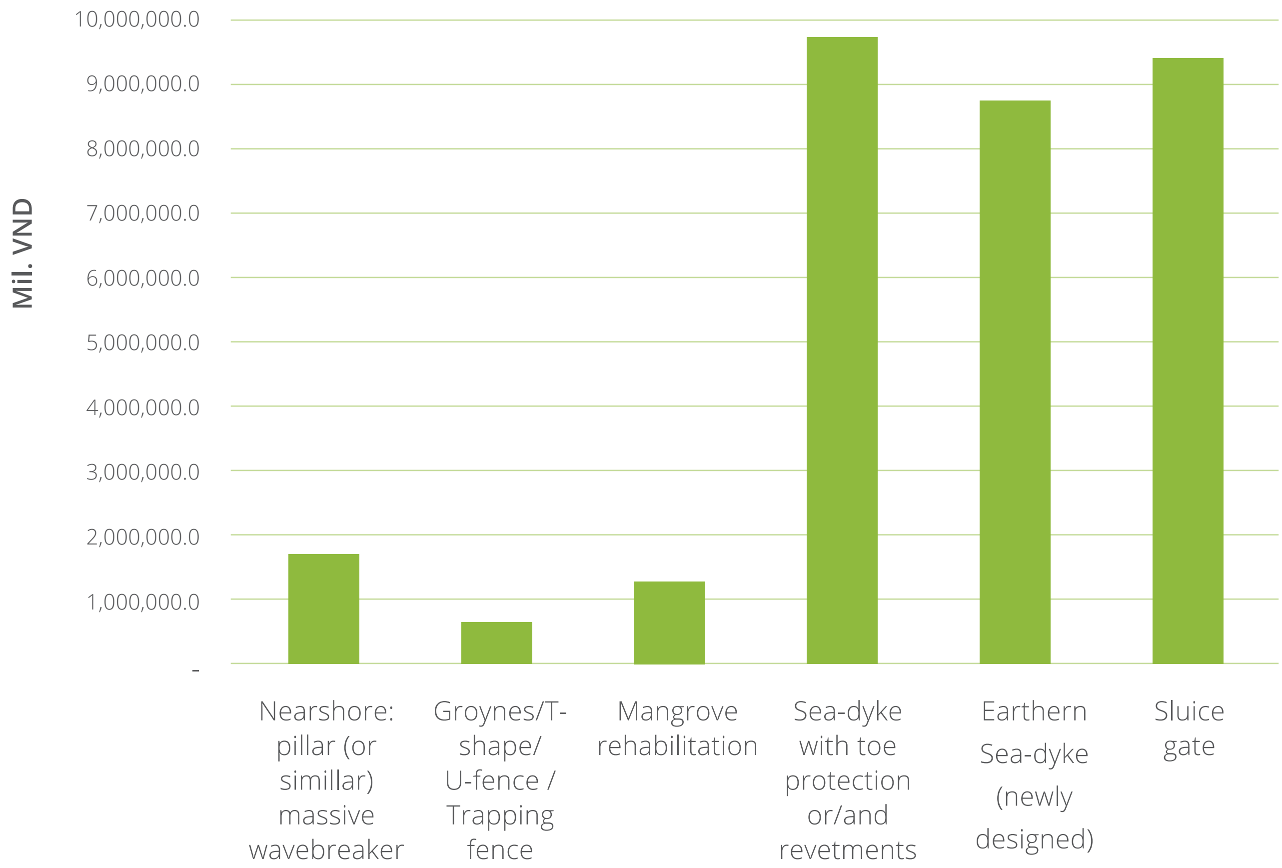


Fig. 79. Estimated costs for 6 different categories of coastal protection measures according to the CPMD for 2018-2030. Source: Southern Institute for Water Resources Planning (SIWRP)

Table 7. Cost overview of various coastal protection measures which were built previously in the Mekong Delta (see also CPMD tool Guidance for Coastal Works). Marked in bold are the costs which were used for the cost estimations per CPS.

Categories	Price range (mil. VND per m)		Average price (mil. VND per m)	Source of unit cost
	Low	Hign		
Earthen dyke	4	6	**5**	Surveyed by SIWRP
Earthen dyke with hard layer cover	12	18	15	Surveyed by SIWRP
Earthen dyke with revetment	40	100	70	Surveyed by SIWRP
Earthen dyke with revetment and overtopping wall on crest	90	130	**110**	Surveyed by SIWRP

Nearshore bamboo T-fence			1.2	GIZ
Bamboo T-fence strengthened with concrete piles			**2.4**	GIZ
Bamboo U-fences			1.2	Ca Mau Sub-department of Irrigation
Sediment trapping fences			3.4	GIZ
Breakwater (concrete)			40	Bac Lieu Sub-department of Irrigation
Breakwater (rocks) / reinforced concrete pile, natural stones			**22**	Ca Mau Sub-department of Irrigation
Mangrove plantation (per ha)			**172**	GIZ (weighted average of 13 case studies from 4 coastal provinces in the Mekong Delta between 2014-16)
Sluice gate			**4,400**	Estimated based on the existing construction in MD

Table 8. Calculation of construction costs for water works.

No.	Water works	Cost estimation	Price from Table 7 in mil. VND
1	Nearshore: pillar (or similar) massive wave breaker in m OR beach / foreshore nourishment by creating sandbars (sandbanks)	= Length of structure * Cost unit/m	22
2	Foreshore stabilisation: groynes/ T-fence/ U-fence/ trapping fence in m	= Length of structure * Cost unit/m	2.4
3	Foreshore and backshore stabilisation: Mangroves in ha (10,000 sqm)	= Area (ha) * Cost unit/ha	172
4	Sea-dyke with toe protection or/and revetments in m	= Length of structure * Cost unit/m	110
5	Earthen Sea-dyke (newly designed) in m	= Length of structure * Cost unit/m	5
6	Sluice gate*	= Length of structure * Cost unit/m	4,400

* Sluice gate costs are referring to the earlier report "Reviewing sea-dyke planning from Quang Ngai to Kien Giang" by the Southern Institute for Water Resources Planning (SIWRP) (Click)

Table 9. Extract of the cost norms for the formulation of feasibility study reports which follows table 3 of Decision No. 79//QĐ-BXD [Click]. Units are given in percentages.

No.	Group of Works	Cost of construction excluding VAT (bil. VND)											
		≤ 15	20	50	100	200	500	1.000	2.000	5.000	10.000	20.000	30.000
1	Civil works	1,114	0,914	0,751	0,534	0,402	0,287	0,246	0,209	0,167	0,134	0,102	0,086
2	Industrial Buildings	1,261	1,112	0,882	0,654	0,515	0,466	0,404	0,315	0,248	0,189	0,135	0,107
3	Transport works	0,689	0,628	0,501	0,393	0,271	0,203	0,177	0,151	0,120	0,097	0,075	0,063
4	Agriculture and Rural Development	0,943	0,858	0,685	0,48	0,361	0,273	0,234	0,201	0,161	0,129	0,100	0,084
5	Urban Infrastructures	0,719	0,654	0,524	0,407	0,280	0,211	0,185	0,158	0,127	0,101	0,078	0,065

Table 10. Extract of the cost norms for expert supervision , which is referring to table 22 of Decision No. 79//QĐ-BXD [Click]. Units are given in percentages.

No.	Group of Works	Construction costs (exclusive of VAT) of the approved construction bidding package price (bil. VND)										
		≤ 10	20	50	100	200	500	1.000	2.000	5.000	8.000	10.000
1	Civil works	3,285	2,853	2,435	1,845	1,546	1,188	0,797	0,694	0,620	0,530	0,478
2	Industrial Buildings	3,508	3,137	2,559	2,074	1,604	1,301	0,823	0,716	0,640	0,550	0,493
3	Transport works	3,203	2,700	2,356	1,714	1,272	1,003	0,731	0,636	0,550	0,480	0,438
4	Agriculture and Rural Development	2,598	2,292	2,075	1,545	1,189	0,950	0,631	0,550	0,490	0,420	0,378
5	Urban Infrastructures	2,566	2,256	1,984	1,461	1,142	0,912	0,584	0,509	0,452	0,390	0,350

Table 11. Example cost estimation for each type of recommended coastal protection measure. The cost estimation for each CPS.

No.	Construction type	Dimension	Unit cost (mil. VND) per m	Constructed cost (mil. VND)	Feasibility study (mil. VND) - Table 3 of No. 79/QD-BXD	Expert supervision cost (mil. VND) - Table 22 of No. 79/QD-BXD	Total cost (Bil. VND)
1	Nearshore: pillar (or similar) massive breakwater in m OR beach / foreshore nourishment by creating sandbars (sandbanks)	10 m	22	220	7.32	19.24	246.56
2	Foreshore stabilisation: groynes/ T-fence/ U-fence/ trapping fence in m	10 m	2.4	24	1.58	4.02	29.60
3	Foreshore and backshore stabilisation: Mangroves in ha (10,000 sqm)	10 ha	172	1720	30.31	82.34	1,832.65
4	Sea-dyke with toe protection or/and revetments in m	10 m	70	700	16.29	43.61	759.90
5	Earthen Sea-dyke (newly designed) in m	10 m	5	50	2.63	6.75	59.38
6	Sluice gate in m	10 m	4,400	44,000	284.78	814.75	45,099.52

8. Conclusions and general recommendations

In this chapter, key conclusions and recommendations are provided in relation to technical, capacity building, institutional, organisational and policy aspects. While some detailed technical advice is given in preceding chapters 2-7, the main messages are compiled and summarized here.

8.1 Key conclusions

Concerning mangrove rehabilitation

Mangroves provide an essential element of the coastal protection system for the Mekong Delta by shielding the coastline. In addition, mangroves considerably enhance the production of natural resources, such as fish and shrimps. One important recommendation is to stimulate the nursing and plantation of more resilient species in the right areas. For instance, Sonneratia alba and Avicennia marina at the seaward front, and Avicennia officinalis and Rhizophora mucronata for the reversion of abandoned shrimp-ponds and areas near sluice gates. A protective function of a mangrove shield is only achieved if there is still at least 150 m wide of closed canopy forest while 500 m would be the ideal width. The conservation and extension of the existing 50,000 ha of non-production mangrove forest (declared as special-use forest and protection forest, including parts of biosphere reserves and national parks) should have high priority. At least 7,900 ha of mangrove protection forest along about 290 km of coast can be rehabilitated in the MD even under difficult current conditions if combined with the right structural measures. A critical parameter for successful mangrove reforestation is a proper site assessment. In particular, plantations close to the seafront were most successful if the local topography was considered. The lack of proper drainage can be as destructive as high exposure to waves and strong currents. The main conclusion is that irrigation experts, coastal engineers and forest experts need to collaborate in order to develop concerted rehabilitation plans. Concerning management, the involvement of local stakeholders (forest management boards) and communes is essential. A co-management approach for mangrove forest was successfully piloted and might help to conserve and use mangrove forests in a sustainable way. A clear national legal framework for co-management is still lacking.

Concerning interlinking of planning forest and waterworks

In detail, there are specific recommendations on feasible waterworks and mangrove rehabilitation for the entire 720 km of coastline per coastal segment; a total of 71. The most effective coastal protection systems consist of different elements one after the other, from breakwaters to mangroves to a sound dyke arranged according to integrated planning. For about 290 km of the coastline breakwaters and fences made of natural materials (bamboo, Melaleuca, others) erected close to the shoreline are recommended in order to stabilize the coast and enhance mangrove rehabilitation. Along 77 km, the erosion can only be stopped by the construction of massive breakwaters or comparable measures.

Concerning the planning and design of coastal protection work such as sea-dykes and breakwaters

Poor functionality, adverse effects and structural quality of coastal works are issues in the Mekong Delta and are addressed in the CPMD by suggesting protocols for breakwater assessment, sea-dyke design, and cross-sectoral spatial planning. Existing structures should be evaluated annually. The systematic evaluation of structures is only partially documented since successes are recorded but reports of failures are omitted. However, limitations and failures are both part of a complete learning experience. Selected types of breakwaters with adapted designs are strongly recommended in order to re-establish shallow mudflats close to the shoreline for mangrove rehabilitation. Avoiding negative impacts and optimizing their functionality and cost-efficiency are design guiding principles. Among massive breakwater types, a vertical-front breakwater made from concrete pillars and filled with riprap was applied and adapted and is considered as the most effective erosion protection measure under certain boundary conditions. However, there are serious down-drift impacts on the coast that are possible if not properly planned and monitored. If possible, reusable construction materials for coastal protection structures (clay, sand, natural stones) should be used for waterworks. The so-called T-fences (permeable groynes, T-shaped from viewed form above) turned out to be highly effective if applied along respective stretches and if the limitations are considered. For critical coastal segments, a combination of massive breakwater and T-fence like structures is recommended. It is desirable that there is a periodic recalculation of hydrological and hydrodynamic design parameters in a 10-year cycle, more obligatory protocols (as directives) and some respective updating of the guidelines that consider new insights and special conditions in the Mekong Delta.

An alternative protection measure on eroding coastlines could be foreshore nourishment. Nourishment (also referred to as beach fill) can be regarded as a soft, close-to-nature approach for combating coastal erosion. Critical aspects are the source of the borrow material – locations that are lacking in sand and suffering from erosion themselves must be avoided – and the grain size distribution of the borrow material (if the grain sizes are significantly coarser or finer than the natural material, the half-life of the nourishment will decrease). An open issue is still the source of suitable sand. At this moment there is only little experience with the prevailing silty sediments around the MD (especially the West Sea coast) and any attempt should be run under strictly controlled conditions and closely monitored by scientific surveyors.

Concerning strengthening of sea-dykes and spatial needs for upgrading

The primary function of sea-dykes is flood protection, not erosion protection. Therefore sea-dykes should not be constructed in front of the mangrove belt. It is desirable that sea-dykes are constructed in a way that allows adaptable profiles for additional heightening if needed. Therefore, roads for maintenance should not be placed on the top but on the landwards berm if the berm is broad enough. The strict implementation of the legal space reservation of at least 50 m at both sides of the sea-dyke is urgently recommended as well as the reservation of clay extraction sites nearby in the hinterland at a distance that is not affected by the geohydrology of the dyke. A ditch for clay extraction in front of the dyke seawards should be avoided. About 539 km of earthen dyke have to be strengthened which means they have to be constructed up to the respective design water level with a much milder slope (1:3.5-5, depending on degree of exposure) than currently, and to a lifespan of at least 50-100 years. A total of 139 km of sea-dyke has urgently to be protected by massive revetments and toe protection, especially along the coast of western Ca Mau, south-western Kien Giang, and sites in Tien Giang. A total of 147 (another 30 are under construction) sea-sluices are proposed which would permit much better control of saline intrusion and freshwater conservation. Surveying and maintenance of sea-dykes receive greater attention and regular funding.

Concerning synchronising of coastal protection, spatial planning, and land-use

The strategic aim until 2030 should be to close all gaps of the sea-dyke system and to create a synchronized spatial water- and land-use plan for coastal protection, mangrove forests, aquaculture and irrigation at provincial and regional levels. Water-management behind the dyke is the key of any land-use and depends on coastal protection measures. Moreover, these hinterland (in fact the water management units adjacent to the sea) are especially prone to dyke breaches but also to saline intrusion and droughts. Therefore, the spatial dimensions of coastal protection planning should exceed the planning of the sea-dyke system. This includes the water-management units in the hinterland and should include resilient livelihood development and disaster reduction measures. The land area adjacent to the sea-dyke and marked out by the existing water management units consisting of about 700.000 ha of land and inhabited by at least 1,900,000 people is recommended as a focal area for measures that link to coastal protection. In the long term, the outline of this area (coastal protection regions in the CPMD) might serve as a second line of defence and irrigation measures (inland-dykes, sluice gates, setback areas, water reservoirs) might be planned accordingly. Although as for now the provincial governments in the Mekong Delta have clearly committed not to retreat from the current sea-dyke trajectory, there might be situations at some critical stretches of coast where there will be hardly any other options in the long term to plan for setback options. A "Digital decision support tool for sea-dyke routing" was developed (only included in the online CPMD) in order to carry out mathematical cost-benefit calculations, but was received with some scepticism.

Concerning capacity building

Besides the recommendations concerning technical matters, there are concrete measures suggested to enhance the capacity for coastal protection planning at three different levels in the Mekong Delta. Namely for decision makers, for practitioners and for academic and knowledge institutions. Since the factual construction of coastal waterworks is usually carried out via bidding processes by the provinces, capacity building is particularly important at provincial level. Additionally, capacity building is needed in the fields of emergency response, dyke construction, breakwater design, maintenance of coastal waterworks, risk prediction and disaster preparedness. Basic knowledge of coastal spatial planning techniques (e.g. Blue Planning, see section in chapter 6) are desirable for all stakeholders in order to enhance cross-sectoral planning.

Concerning institutional setup of coastal inspection and monitoring

While clearly improved during the period of the CPMD development, the quality and standards of sea-dyke inspection and maintenance could still be improved at the local level. The closer involvement of resident stakeholders (including Forest Management/ Protection Boards and co-management communes) might be helpful for raising awareness and for acceptance and support of measures as observed in Soc Trang and Ca Mau. The use of light-weight drones finds another field of application here since it is relatively easy to use and produces impressive results. It might be possible to delegate more responsibility to local districts concerning inspection and monitoring, to raise awareness and acceptance of solutions.

Concerning Research & Development

Concerning the scientific basis for the planning, investment in equipment (tidal gauges, field measurement campaigns) and capacity building is recommended enabling periodic recalculation of hydrological and hydrodynamic design parameters every 10 years and regular monitoring of the coastal area at least every 5 years. The re-designing of all coastal waterworks in the future will greatly benefit from a stronger database than available at present. Especially, small-scale bathymetric data at certain sites as well as long-term monitoring data of the wave climate and storm events are still lacking. A central database with a respective service concept is currently missing. Capable existing knowledge institutions such as SIWRP, SIWRR, Sub-FIPI, and the Universities of Can Tho and HCMC are all involved in coastal planning and research. A consequent use of light-weight drones, the extension of contemporary, automatized gauge stations, and use of (multi-beam) echo-sounders as well as ADCPs (Acoustic Doppler Current Profiler) for mapping bathymetry and flow conditions of river channels and nearshore areas is technically possible but not coordinated in use. This package is considered a public national, and partly regional or provincial task, and requires close linkages to responsible ministries.

Concerning budgeting and prioritization of measures

There are investments on hard structural and soft measures proposed in the order of about 1.4 billion USD. These cost estimates are based on the existing level of baseline data, information, knowledge, and guidelines and thus serve for the purpose of a first reference only. The total costs for the reforestation of the mangroves, including the restoration and protection of tidal mudflats, accounts for 12% which is only a fraction of the total cost estimates. The largest investments with the highest priority have to be made in Ca Mau and Kien Giang (63% of the total). The construction the sea-dykes and sea-sluices accounts for 88%. By proper prioritizing of certain areas, especially at the West Sea coast, the recommended measures could be widely implemented within 10-12 years (2018-2030). Proper prioritizing the implementation is crucial and the classification system used for the CPMD might help in this regard. However, next to these direct infrastructure costs, there more resources will be needed for capacity development, Research & Development, disaster preparedness and risk reduction, and regional coordination. Unforeseen are possible costs for relocation – if needed – and measures to counteract land subsidence and increasing sea level rise might have to be added.

Concerning cross-sectoral roundtables and institutional setup

During the development of the CPMD, numerous experiences and lessons learned on coastal protection could be exchanged regularly during informal coastal protection roundtables. It is strongly recommended to institutionalize roundtables or similar formats including all coastal Mekong Delta provinces in order to harmonize strategies, raise capacity and increase the efficiency of technical measures. Currently at provincial level, coastal protection is a mandate of the sub-department of irrigation under DARD. Regarding the character of cross-sectoral planning (especially irrigation, forest, aquaculture, land-use planning and environment), it might be a consideration to create coastal protection boards with members of each sector organizing cross-visits and combined workshops. In the longer term, an institutional upgrading (or up-valuation) of coastal protection might be considered, which would reflect the high investments, capacity, facilities and greater responsibility.

Concerning coordination and strategic coastal protection planning

Harmonized coastal planning in the Mekong Delta can greatly enhance the process of sea-dyke strengthening as stated during several workshops involving decision makers from the entire Mekong Delta and central government. Despite local differences, the problems and solutions in the Mekong Delta are similar and a fast exchange of experiences will raise the capacity of everyone involved at provincial level. In particular, the expensive and sophisticated collection of physical parameters, numerical modelling, and for instance the testing of scale models in the flume tank, is in good hands with capable regional state institutions and universities. This can also save costs for development and research, and for technical solutions in general. Neither the sediment loads of the Mekong, nor typhoons nor sea level rise stop at provincial borders, and a close cooperation among provinces in case of disaster is needed. A regional approach that started as an informal roundtable might become a permanent institution at regional level in the long term.

8.2 Main recommendations

Mangrove forest:

• The consequent conservation and rehabilitation of a mangrove shield of at least 150 m and ideally 500 m is recommended, including the reversion of abandoned shrimp-ponds.

• High priority should be given for conservation of existing mangrove forest and a re-consideration of zoning.

• Rehabilitation of at least 7,900 ha of mangrove protection forest along about 290 km of coast combined with the right structural measures.

• Proper systematic site assessment before any attempt to plant mangroves using the right species for the right location (multi-species approach).

• More involvement of local stakeholders in management and planning of mangrove forest by considering co-management approaches and new livelihood options (for instance, supporting value chains for local products, eco-tourism, organic aquaculture).

Breakwaters:

• Any deployment of structural coastal protection measures should be carefully planned by preceding field investigation and numerical and physical modelling, following an obligatory protocol or updated technical guideline.

• Avoiding negative impacts (down-drift erosion) and optimizing the functionality and cost-efficiency of breakwaters are recommended as guiding principles for design. Monitoring and evaluation for breakwaters should include far-field impacts that mean down-drift erosion at the leeside and blockade of sediment supply with longshore currents.

• Vertical-front breakwaters made from concrete pillars and filled with riprap considered as the most effective erosion protection, but positioning and functionality could still be improved.

• If possible, reusable construction materials for coastal protection structures (clay, sand, natural stones) should be used for waterworks.

• The so-called T-fences (permeable groynes, T-shaped viewed from above) should be applied along recommended coastal segments if the limitations are fully considered.

• For critical coastal segments, a combination of massive breakwaters and T-fence-like structures is recommended.

• Nourishment of beaches and foreshores should be explored as an alternative protection measure in the nearshore area but needs close monitoring due to the lack of experiences.

Sea-dyke design:

• Design parameters for breakwaters and sea-dykes and mangrove reforestation (site assessment) should be regularly re-estimated (e.g. in a 10-year cycle) using obligatory protocols, and technical guidelines should be amended.

• Sea-dykes should not be constructed in front of the mangrove belt and sea-dyke design should allow the adaptation of the profiles for further strengthening if necessary.

• A wide spatial reservation for sea-dyke systems should be considered in order to safeguard further strengthening.

• The reservation of clay extraction sites for sea-dykes nearby in the hinterland at a certain distance should be considered in order to avoid ditches seawards in front of the dyke.

• Milder slopes for earthen sea-dykes are recommended (1:3.5-5, depending on degree of exposure and design level) with a planned lifespan of at least 50-100 years.

• Selected massive revetments (avoiding gabions!) are recommended for exposed dykes, considering suitable filter layers and proper toe protection.

• Sea-sluices are proposed to allow active control of saline intrusion and freshwater conservation.

• Further capacity building for surveying and maintenance of sea-dykes is needed, using light-weight drones and supporting the involvement of local communities.

Cross-sectoral and spatial planning:

• The Mekong Delta needs a stronger interlinking of planning for mangrove protection forest, breakwaters, and sea-dykes.

• The strengthening of coastal protection needs synchronized spatial planning of water- and land-use in front and behind the sea-dykes (foreshore and hinterland).

• It might be a strategic aim to close all gaps of the sea-dyke system by 2030 and to create a synchronized spatial water- and land-use plan for coastal protection, mangrove forests, aquaculture and irrigation at provincial and regional level.

• The water management of the land area adjacent to the sea-dyke within the currently existing water management units (about 700.000 ha of land and inhabited by at least 1,900,000 people) is proposed to be included into coastal protection planning (defined as coastal protection units in the CPMD) since this area might serve as a second line of defence and focal area for disaster risk reduction, potential buffer reservoirs, and possibly setback areas, if needed.

• A bundle of further capacity building is recommended for different levels of intervention, in particular at provincial level. The inclusion of basic knowledge of coastal spatial planning techniques is desirable for all stakeholders.

Database and service concept for coastal protection:

• The periodic recalculation of hydrological and hydrodynamic design parameters every 10 years and regular monitoring of the coastal area at least every 5 years is recommended.

• A central database with a respective service concept is also desirable, involving the strong existing knowledge institutions such as SIWRP, SIWRR, Sub-FIPI, and the Universities of Can Tho and HCMC.

• A coastal database should include a service concept for extension as for instance modelled with the current CPMD (free download, clear metadata).

• The use of upgraded technical equipment and methods for hydrological studies is needed, consequent use of light-weight drones, the extension of contemporary, automatized gauge stations, and use of (multi-beam) echo-sounders as well as ADCPs (Acoustic Doppler Current Profiler) for mapping bathymetry and flow conditions of river channels and nearshore areas is desirable.

• This package is considered a public national and partly regional or provincial task and requires close linkages to responsible ministries.

Budgeting:

• Proper prioritizing of implementation and respective budgeting is crucial and the main recommendation is to coordinate budgeting and prioritization at all three governmental levels – provincial, regional and national – and to tap international climate change funds through the concerted actions of neighboring provinces.

Roundtables and institutional organisation:

• Regarding the character of cross-sectoral planning (especially irrigation, forest, aquaculture, land-use planning and environment), it might be a consideration to create coastal protection boards with members of each sector organizing cross-visits and combined workshops, and to consider on a longer term an institutional upgrading of coastal protection which would reflect the high investments, capacity, facilities and greater responsibility. Regular roundtables are recommended and may result in institutional working groups focussing on solutions for overarching coastal issues.

• Because of the importance of coordinating measures, strategic coastal protection planning should be carried out at regional level.

8.3 Final conclusion & Outlook

Coastal Protection needs space and the close collaboration of national and local governments, agencies and knowledge institutions, residents and international donors. Despite highly sophisticated models for prediction and design development, coastal protection is still a continuous learning experience from best-practices worldwide. The planning of the coastal protection of the Mekong Delta does not end with this current work. For the purpose of implementation in detail, the construction of protection works and the rehabilitation of a fully functional mangrove protection belt, detailed feasibility studies at respective sites have to be conducted considering the recommendations on policy and further development or amendments of Technical Guidelines. Newly collected data, knowledge and evidence needs to be continuously incorporated into the CPMD for its perfection – which is a non-ending process. The best-fitting collaboration mechanism for cross-provincial and especially cross-sectoral coastal planning in Vietnam, specifically in the Mekong Delta, has still to be defined and guided by the government. The CPMD might provide some inspiration from other countries and shows clearly that Vietnam is not alone in facing the challenges described in this report.

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  Luật phòng chống thiên tai

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- No. 10/2014/TT-BNNPTNT (2014): Regulation on the criteria for determining buffer zones of special-use forests and protective belt of conservation zones

  Quy định về tiêu chí xác định vùng đệm của khu rừng đặc dụng và vành đai bảo vệ của khu bảo tồn biển

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- No. 82/2015/QH13 (2015): Law on Resources, sea environment and island

  Luật tài nguyên môi trường, và hải đảo

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- No. 29/2016/TT-BTNMT (2016): Technical guideline of coastal protection corridor

  Quy định kỹ thuật thiết lập hành lang bảo vệ bờ
- No. 119/2016/ND-CP (2016): Decree on a number of policies for management, protection and sustainable development of coastal forests in response to climate change

  Nghị định Về một số chính sách quản lý, bảo vệ và phát triển bền vững rừng ven biển ứng phó với BĐKH
- No. 40/2016/ND-CP (2016): Detailed regulations on the implementation of a number of articles of the Law on Resources, Sea environment, and island

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- MONRE (2016): Climate Change and Sea Level Rise Scenarios for Vietnam

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- No. 36/2017/ND-CP (2017): MONRE function, task and its structure

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  Chức năng nhiệm vụ của Bộ Nông nghiệp và Phát triển nông thôn
- No. 2295/QD-TTg (2014): Integrated coastal management strategy in Vietnam to 2020, vision to 2030

  Chiến lược quản lý tổng hợp đới bờ Việt Nam đến năm 2020, tầm nhìn đến năm 2030
- No. 1205/QD-BNN-TCLN (2016): Technical guideline of planting mangrove species: Kandelia obovata, Aegiceras

  Ban hành hướng dẫn kỹ thuật trồng rừng các loài cây: Trang, Sú, Mắm đen, Vẹt dù và Bần chua
- No. 5365/QD-BNN-TCLN (2016): Technical guideline for planting mangrove species: Avicennia alba, Avicennia marine, Rhizophora apiculata, Rhizophora mucronata, Sonneratia alba, Lumnitzera racemose

Hướng dẫn kỹ thuật trồng rừng 6 loài cây ngập mặn: Mấm trắng, Mấm biển, Đước đôi, Đưng, Bần Trắng và Cóc Trắng

- No. 1206/QD-BNN-TCLN (2016): Cost norm for nursing, planting, caring and protecting mangrove

  Định mức kinh tế - kỹ thuật gieo ươm, trồng, chăm sóc và bảo vệ rừng ngập mặn.

Appendix I: Q & A about coastal protection planning in the Mekong Delta

During many workshops and events there were questions asked about the CPMD and coastal protection in the Mekong Delta (MD) in general. In the following section, 14 of these questions, which were raised repeatedly (although in different wording) and their answers, are compiled.

Q1: Do we need a concrete sea-dyke around the MD?

A1: What is needed for the MD is a strong interlinked system of mangrove protection forest, breakwaters, sea-dykes and proper land-use and water management in the hinterland. This, on the other hand, needs a cross-sectoral and spatial planning approach. Instead of "concrete" the term "armoured sea-dykes" is preferred since the armouring for a very exposed sea-dyke not only consists of concrete slabs but of proper toe protection, and recurved overtopping elements and proper filters. In the CPMD, this type of sea-dyke is recommended for up to 139 km out of the 720 km of coastline of the MD. A dyke design should be site-specific. This includes the design dyke height as well as the structural design. A design adapted to local boundary conditions is most effective. In many locations, a properly built earth dyke with a sound toe protection and shielding foreland – in the best case a mangrove belt of 150 m or more – is the best solution. In other locations, a reinforced dyke with a strong toe protection and heavy concrete revetments on the seaward slope are required.

Q2: The CPMD is introducing a new coastal classification system. What is the reasoning behind this?

A2: There are several classification schemes described in the international coastal science world, but none was sufficient to classify the Mekong Delta coast for the specific purpose of coastal protection. The often-used separation of West Sea and East Sea areas is simply not sufficient to support informed decisions on coastal protection. Therefore, a hierarchical 3-step approach specifically for the needs of the relative uniform coastline of the Mekong Delta (MD) was developed. At first, the Mekong Delta was divided into 7 distinguished "Coastal Protection Regions (CPRs)" according to their physical parameters - meaning wave climate, geo-hydrology, bathymetry. In the next step we wanted to highlight the links between coastal protection and spatial planning or land-use, which resulted in the definition of 29 "Coastal Protection Units (CPUs)". With this step, we included the area of the existing water management units landwards and the coastal zones seawards into the coastal protection planning. What happens in the sea in front of the sea-dyke, e.g. wind-energy parks, sand-mining, tourist developments, is of the same relevance as the land-use and protected values behind the dyke. Thus, the CPMD provides information on resident population, water management, agricultural land-use and irrigation systems. In addition to a better estimate of protection values and potential damage behind the dyke in case of disaster, the water management units might be considered as a second line of defence in the long run. In the third step of the classification, we included the actual rate of coastal erosion, the trend of coastline changes within the last century, and the state of the current dyke system. This step resulted in 71 defined "Coastal Protection Segments (CPS)". Based on the feedback given by the provinces there are special CPSs assigned for port development, touristic spots or national parks. For each coastal segment specific recommendations for coastal waterworks and mangrove rehabilitation are provided in order to offer the best combination of protection solutions for those localities and coastal stretches. The last classification is also linked to the urgency of investment and provides rough cost estimates for the required measures.

Q3: One of the strategic approaches of coastal protection is the retreat option, which appeared to be not very popular in the MD?

A3: This concerns in particular but not only the East Sea coast of Ca Mau with very high erosion rates and the southern area of the huge Ngoc Hien District. There is low acceptance among local residents and provincial governments for the retreat option. The main argument is that the safety of the densely populated area is at stake, resulting in migration and consecutive problems. Flooding and regular inundations also hampers the development options for coastal areas. The CPMD follows the sea-dyke route as provided by MARD. However, the CPMD recommends firstly small-scale retreats at notoriously eroding spots, and where there are still healthy mangroves and where there is no strengthened sea-dyke. Small-scale natural sediment transport should be accepted. Short-term and small-scale erosion-accretion patterns are natural processes of a stable coastline. A stable coast needs space. Moreover, the CPMD recommends preventive planning for setbacks in the future's long-term perspective. Especially, the situation in Ngoc Hien district at the southern tip of Ca Mau, which can be considered as an island, should get closer attention and needs further assessments. The CPMD recommends a careful re-planning of the sea-dyke route and the study of options such as ring-shaped dykes around settlements and adaptation of road constructions on broad but still permeable dams (on stilts, sluice gate systems). The national park, where there is the largest accretion area (and still accreting area) in the MD, should be included in this strategy. Because of the importance of the distal sediment deposit southwest of the CM tip, this deposit might be of great importance for the stability of the entire West Sea coast in the long term. Although the complex system of sediment transport is not understood in detail, a recent study carried out by the Southern Institute for Water Resource Research and supported by the European Union and the French Development Agency shed light on the complex processes. The balance is apparently very sensitive and any disruption of the longshore sediment transport from East to West will likely have a large effect on the accretion and stability of the entire West Sea coast.

Q4: Do we need a sea-dyke at all? Might it hamper natural processes and a natural adaptation of the shoreline?

A4: The primary function of sea-dykes is flood protection by forming a vertical barrier. The MD is densely populated; on average 425 people per square kilometre. A 50-year or 100-year flood would be devasting for the residents, public and private assets and the productivity of the MD. One of the main goals is to close the sea-dyke line in order to achieve sufficient protection for the people in the MD. Wide coastal stretches, especially in Ca Mau, are not protected at all and the sea-dyke system in the other coastal provinces is not sufficient to withstand the continuously growing erosion not to mention a 'century flood'. Generally, an effective sea-dyke line is essential if the coastal areas are inhabited and used for agriculture, aquaculture etc. In remote locations, the integration into a closed dyke line could be too complex and costly. Here, adapted approaches such as dwelling mounds or living-with-floods can be applied. The construction of dykes binds sediments that were once part of natural coastal processes, meaning these sediments are not available any more for a natural dynamic coast. However, the protection function of dykes should be considered of a higher priority than the promotion of natural processes and adaptation. The MD is not a pristine landscape anymore but a highly developed and cultivated system although the main natural forces – the sediment load of the Mekong River, the tides, the waves and the currents are still the main active players. The general design approach should follow the rule of minimizing interference of the natural system and favour close-to-nature approaches. At the same time, the CPMD acknowledges the central role that mangrove forests play for stabilizing the shoreline and protecting the dykes. In order to be effective in the dissipation and attenuation of waves, the green shield of a mangrove protection forest needs space – at least 150 m – in the best case, 500 m. Therefore, the CPMD recommends as the highest priority the restoration of eroded mudflats and the reforestation in the dyke foreland, the seaward area in front of the dyke. Not only are the dyke and forelands needed to be involved but also the stakeholders of the hinterland, the area behind the dyke landwards. For a common goal of sustainable coastal protection, responsible agencies, experts and stakeholders from different sectors such as forestry, aquaculture, irrigation, and environment have to plan together. The water-management behind the dyke is the key of any land-use that is dependent on coastal protection measures. Moreover, these areas are especially prone to dyke breaches but also to saline intrusion. Therefore, the planning space in the CPMD is defined quite widely and includes the water-management units in the hinterland. Disaster preparedness and the long-term planning of a second line of defence may focus on these areas.

Q5: What is the best design for a sea-dyke? A

A5: The most important design parameters for sea-dykes is the dyke height since the primary function of a dyke is to form a vertical barrier against water levels of a certain height. According to international convention, the design dyke height should consider:

- Firstly, a characteristic value for a high-water level, e.g. mean tidal high water calculated based on the statistical analysis of a time series of the previous 10 years.
- Secondly, the maximum increase of the water level due to seasonal effects or spring tides.
- Thirdly, the largest measured wind surge.
- Fourthly, the possible wave run-up.
- Fifthly, a safety margin considering e.g. the sea level rise and subsidence of the subsoil.

This calculation defines the height of the dyke and the life-cycle of the construction. Initially, the overall stability of the subsoil must be proved. The load bearing capacity of the subsoil may limit the dyke height. The hydrostatic and hydrodynamic loads of water levels and waves induce stresses and potential damage at the dyke. Thus, the constructional resistance must be large enough to withstand those stresses. The erosional forces on the seaward side of the dyke can be minimized by a mild slope of 1:3 to 1:5. Steeper slopes cannot be recommended. If the degree of exposure is large and the existing stresses due to water levels and waves exceed the resistance of the dyke, additional constructional elements such as a strengthened toe protection or revetments must be considered. Finally, a sea-dyke should be one element in an integrated coastal protection system. If feasible, a sea-dyke should never be directly exposed to the sea. If exposed, heavy revetments are needed, while foreshore areas and foreshore mudflats in front of the sea-dyke will form a natural protection. Consequently, costly elements such as revetments are not required. Proof of stability of the subsoil is also required for earth dykes without further armouring. These geotechnical calculations will also show the risks of the usual practice of digging excavation channels in front of the dyke in order to gain material for the dyke body itself. Instead of this practice, sites for the extraction of sand and clay should be identified at a safe distance from the construction site. A road located on the landward berm or on the top of the dyke will facilitate inspection and maintenance. Additional loads induced by cars or small trucks must be considered in the design process.

Q6: Does a sea dyke need armouring?

A6: This depends on the degree of exposure to be expected. There are several recommendations concerning the armouring or revetments and toe protection, too. Next to these structural issues, the regular schemes and protocols for inspection and maintenance are gaining increasing importance because of the currently critical situation and the large investments that have to be protected. Finally, despite the current very good technical guidelines for sea-dyke systems from 2012, there is a periodic recalculation of hydrological and hydrodynamic design parameters in a 10-year cycle that is required and a respective modification of the guidelines that takes into account new insights and special conditions in the MD.

Q7: Do T-fences really work?

A7: Bamboo T-fences are an effective coastal erosion and protection measure for restoring floodplains and creating conditions for mangrove regeneration. Their wave transmission effect is sufficient to reduce wave heights significantly and stimulate sedimentation on the landward side. The construction is cost-efficient and often more feasible than massive structures on the soft soil. Simply planting mangroves is of little use without protection - conserving mangrove ecosystems through co-management (or shared governance) is important for sustainability. However, the application of T-Fences has clear limits. If the location exceeds a certain degree of exposure to waves and a certain duration of submergence, maintenance significantly increases before the application becomes impractical. Thus, the general application as well as the design and layout of the T-Fences must be checked and redone according to the specific site. Coastal protection and climate change adaptation measures must be site-specific and appropriate, based on a sound understanding of natural and coastal processes (spatial and temporal), comprehensive data analysis and numeric modelling. Governance of mangroves should be incorporated as an element of an ecosystem-based adaption approach, into integrated coastal land-use planning and management.

Q8: Can we save the mangroves in the MD at all?

A8: Mangroves are quite adaptable since they evolved and thrived for millions of years in a continuously changing environment at the edge of what is possible for trees to survive. However, in the period two hundred years ago mangroves in the MD could evade landwards with increasing sea levels and propagate seawards with retreating sea level. Nowadays the mangrove belt is squeezed in between human activities landwards and sea level rise. Meanwhile, the elevation of coastal mudflats is so low and the erosion cliffs so steep that there is hardly a chance for mangroves to resettle naturally at these sites. The entire efforts to find coastal engineering solutions which restore intertidal flats and positively influence the sediment balance is the attempt to save the mangroves. The observations at many sites is that this is possible if the right pioneer species are planted in the seaward front and if there is a broad zone of pure, dense protection forest without any use for aquaculture. Afforestation must use resilient species. There are at least 11 species which are very suitable for planting at well assessed and prepared sites. In wide stretches there are additional engineering measures needed to create good conditions for mangroves by means of T-fences or well-planned concrete breakwaters. Natural accretion processes should be enhanced by favouring carefully designed breakwaters and protection fences. Dykes do not belong in front of the mangroves. The dominant natural process for sediment transport in the MD is longshore-currents which must not be disrupted by poorly planned structures in the coastal foreshore area. With the proposed concerted efforts, it might be possible to reforest at least 8,000 ha of protection forest within the coming 10 years to make a start. Mangrove habitats are delivering so many ecological services, regarding their function as a nursery for fish and shrimp, fish production in coastal waters and coastal protection by attenuating waves and their ability of stacking up 11 mm of soil per year by sediment trapping. Waterlogged, isolated inland mangroves - cut off from the sea - are not able to deliver these services. Speaking about the coming decades, mangroves can likely be saved by implementing a combination of measures. Speaking about challenges in the very long term which is difficult to foresee, strategies might have to be adapted concerning the MD.

Q9: How does the Coastal Protection Tool for the Mekong Delta (CPMD) fit into the current planning framework?

A9: Not being an official plan, the CPMD is supposed to feed into both provincial sector plans and provincial Masterplans as well as into regional plans. Traditionally, coastal protection planning is done by the provincial DARDs, by name the irrigation sub-departments in certain coordination with the DARD forest sub-departments, DoNRE and other ministries at provincial level. Many concrete demands and proposals for strengthening of the local coastal protection work comes also from the districts, since here stakeholders are directly affected by erosion, saline water intrusion and flooding. The legal foundation of the CPMD is the Vietnamese national plan to upgrade the coastal protection system and to review existing plans (P.M. decision 667 in 2009). Another milestone was the Vietnamese-Dutch initiative to develop a Mekong Delta Plan (MDP) as a long-term vision for developing infrastructure and land-use (2014) although no detailed recommendations on coastal protection were included. The CPMD intends to fill this gap and links cross-sectoral and inter-provincial planning. The high efforts of the Vietnamese Government to tackle those challenges in the Mekong Delta is lately reflected in the "Resolution on Sustainable and Climate-Resilient Development of the Mekong Delta of Viet Nam (no. 120, Nov 2017)".

Q10: What are the advantages of a unified coastal protection for the entire MD?

A10: Harmonized coastal planning in the MD can greatly enhance the process of sea-dyke strengthening. Despite local differences, the problems and solutions in the MD are similar and a fast exchange of experiences will raise the capacity of everyone involved at provincial level. In particular, the expensive and sophisticated collection of physical parameters, numerical modelling, and for instance the testing of scale models in the flume tank, is in good hands with capable regional states institutions and universities. Not the sediment loads of the Mekong, nor typhoons nor sea level rise stops at provincial borders and close cooperation among provinces in case of disaster is needed. A regional approach can also save costs for development and research, and for technical solutions in general. Next to the benefits of a collective shared expertise for the entire MD, a coordination or advisory board for coastal management could possibly help to raise disaster preparedness and trigger sustainable development regarding, for example, natural resources, tourism or wind energy.

Q11: How much does it cost to save the MD concerning coastal protection?

A11: The current cost estimates (based on the existing level of baseline data, information, knowledge and guidelines) for direct investments in structural measures are in the order of about 1.4 billion USD for the coming 10-15 years. The largest investments have to be made in Ca Mau and Kien Giang, almost 63% of the total. The construction of the sea-dyke and sea-sluices accounts for roughly 88% of the total costs while the reforestation of the mangroves, including the restoring and protection of tidal mudflats, accounts for only 12%,. This is a strong argument to invest in the restoration of coastal habitats. Keeping in mind the sustainability of these structural investments, mangrove rehabilitation counts for the minor part of expenses while being of the highest importance for the durability of the entire coastal protection system. Proper prioritizing the implementation is crucial and the classification system used for the CPMD might help in this regard. However, next to these costs, there will be others concerning the need for capacity building, Research and Development, disaster preparedness and risk reduction, and regional coordination. Unforeseen costs are possible costs for relocation – if needed - and measures to counteract land subsidence. A transformation of land- and water-use behind the sea-dyke as recommended by the CPMD will also be linked to investments. However, in the longer term, these investments are expected to pay for themselves since the coastal area will be safer and more resilient than before.

Q12: How were these cost estimates achieved?

A12: We tried to make the cost estimates as reliable and transparent as possible at the current state of information and insights but the presented estimates should be considered as a minimum and rough indication. In order to calculate the total costs for each type of protection measure the costs for construction, feasibility study and construction supervision were combined. The cost for the constructions is based on the CPS recommendation regarding the scale of the construction and the actual costs for similar constructions that have been built previously in the Mekong Delta. There is no doubt that costs for materials, labour and transport are increasing. Deliberately, we did not include correction factors for price developments and inflation since more sophisticated cost calculations will have to be carried out once the decision for a certain measure has been made.

Q13: What is the source of the data presented in the CPMD and is the quantity and quality of the data sufficient for the purpose of the CPMD?

A13: The current data layer was mainly collected and compiled by three institutions; namely the Southern Institute for Water Resource Planning (SIWRP), the Southern Institute for Water Resource Research (SIWRR) and the Sub- Institute for Forest Inventory, Planning and Investment (Sub-FIPI), which are all based in HCMC and associated with MARD. These are the main sources of data information from the government counterpart side to formulate the technical recommendations and cost estimations of the CPMD. There is a detailed documentation of metadata included which specifies the origin and also the quality of data. For information on human population and predominant land-use, we decided to process data based on "Planning for agriculture and rural development under the context of climate change and sea level rise in the Mekong Delta up to 2020 and vision to 2030". One reason was that these data sets were legitimized by an official approval (Decision No. 639/QĐ-BNN-KH in 2014), and another reason was that data sets are fitting harmoniously into the other data sets of the geographical information system (GIS) focusing on irrigation, water management, wave climate, forest and coastal protection works. We limited the visual presentation of data to the coastal areas in the neighbourhood of the sea-dyke system. In principle, the CPMD is open for new data layers and the recommendation for the near future is to include updated data on bathymetry, sediments, biodiversity, fishing and aquaculture activities, and more detailed socio-economic information on population distribution and infrastructure. However, it is important to state that generally all this background knowledge relevant for coastal protection decisions is already included in the current version of the CPMD.

Q14: What are the final recommendations by the team of authors for the future towards decision makers and practitioners of coastal protection in the Mekong Delta?

A14: The cross-sectoral and inter-provincial platforms on coastal protection should be maintained in order to trigger the intensive exchange on this topic among the provinces in the Mekong Delta and informed stakeholders. The knowledge in this field is accelerating very fast and the CPMD could be an effective instrument to document and distribute new insights gained by competent national and international institutions but also local experiences. This is one prominent success factor in order to overcome technical challenges. In addition, land subsidence and the impact of downscaled climate change scenarios linked with climate proofing of any coastal protection works should be systematically included in future coastal protection planning. Two essays on these topics are included in the CPMD. With a view on policy, the spatial needs of coastal protection and effective regional cooperation mechanisms are preconditions for the proper development of the entire Mekong Delta and might need even more attention in the future. The CPMD is not an official plan for coastal protection but it models the possible ways how create an expert system that includes a service concept for cross-sectoral data provision which is relevant to make informed decisions. The data and documents of the CPMD are generally transparent and available online to download. Hence, another recommendation for the future is to extend this kind of service to other kinds of relevant data for the entire Mekong Delta. The sustainable strengthening of the sea-dyke system as presented in the CPMD is closely linked to land-use planning at all levels. With a view on the CPMD itself, additional layers of information and in the longer run the completion and regular maintenance of solid data base services provided to the different stakeholders by assigned focal points is desirable.

Appendix II: Coastal terminology concerning functional aspects of coastal protection

The different stakeholders in the coastal areas are using slightly different terminology, which is not a surprise if taking into account the different backgrounds and interests of foresters, shrimp-farmers, hydro-engineers and environmentalists. The following provides an overview of common terms which are often confused. This may contribute to the harmonization of coastal terminology in Vietnam and is therefore in English and Vietnamese.

Nearshore BREAKWATERS are arranged parallel to the shoreline usually on the foreshore near the breaker zone or in the surf zone. Nearshore BREAKWATERS are mainly built with the purpose to protect the coast from erosion. They provide shelter from waves, causing the littoral transport behind the breakwater to be decreased and the transport pattern adjacent to the breakwater to be modified. Important parameters that characterise breakwaters are their length (LB) and the distance to the shoreline (x). BREAKWATERS are usually semi-permeable and constructed as detached breakwaters or in a series of several breakwaters (segmented breakwaters), where the length of the gap between the breakwaters is defined as L0. Segmented breakwaters are not constructed in a continuous line over long stretches in order to promote natural sediment dynamics (cross-shore and longshore). The width of the crest of a breakwater depends on the shape of the cross-section which can be rectangular, curved or stepped. Construction materials can be concrete, natural stones, synthetic materials or a combination of these. A frequently applied form is the rubble-mound breakwater consisting of a core from quarry run and an armour layer made from rocks.

GROYNES in general are cross-shore dam / wall-like constructions for the protection of beaches, floodplains or longshore constructions. They are arranged perpendicular to the shoreline and interrupt the natural longshore sediment transport and lead to accretion at the windward side. The sediment transport to the leeside is reduced at the same rate that sediments are deposited on the windward side. If the impact of the groyne is too strong, downdrift erosion occurs. Impermeable groynes form a complete barrier against longshore transport. Permeable groynes are constructed if a certain transport through the groyne is desired. Groynes can have various shapes (cross-sections), such as wall-like, curved, case-shaped, and can be emerged, sloping or submerged.

A JETTY is an elongated groyne that is constructed in order to protect port basins and navigation channels from wave action and to change sediment transport e.g. to prevent the sedimentation of port access.

GROYNE-FIELDS are semi-closed shallow mudflat areas formed by a series of groynes along the shoreline in the foreshore zone (or intertidal zone) in order to stimulate sediment accretion in strongly wave-reduced shallow water zones. This technique was widely used for land reclamation along the European North Sea (Wadden Sea) and works best in bays and coasts with medium to low wave impact and a muddy environment.

SEA-WALLS are more or less vertical, massive hard-structures exposed directly to the open sea. Usually sea-walls are constructed in urban areas (e.g. Rach Gia) and ports to prevent coastal erosion and other damage due to wave action and storm surge, such as flooding.

REVETMENTS are longshore elements constructed to prevent erosion and scouring of sloping embankments. The revetment can for example consist of RIPRAP (stones), concrete armour units such as Tetrapods or geotextiles placed at the seaward dyke slope.

GABIONS are usually wire cages filled with stones to protect embankments. The wire can corrode quickly in seawater and motion of the stones in wave action leads to destruction of the wire and failure of the gabions.

SEA-DYKES are constructed according to "Technical standards for sea-dyke (seadike) design (Ministry of Rural Development (MARD) dec.no. 1613, July 2012)", including earthen dykes, dyke revetments and other dyke protecting measures. The designs of the dykes are mainly defined by their grade (I-V), depending on exposure and planned lifespan between 20-100 years. Very detailed guidance is provided for the construction of over-topping and dyke-toe protection (see also Sea-dyke reports, and the Golden Rules for Sea-dyke construction, and Sea-dykes in Germany).

SEA-SLUICES and PUMPING-STATIONS are essential elements of flood management within the coastal protection system and are part of the sea-dyke line. Sluices can be active (with hydraulic gates) or passive (gates that close and open with the tides). In the longer term, the hinterland needs improved drainage with pumping stations because of increasing land-subsidence.

STORM SURGE BARRIERS are very large scale and costly waterworks which are proposed to shut-off entire river systems in case of extreme storm events.

SEA-DYKE SYSTEM according to the Vietnamese law are all elements that contribute to the protection of the coastal areas and hinterland such as sea-dykes, dunes, mangrove belts, and mudflats that range up to 500 m offshore.

HARD STRUCTURAL COASTAL ENGINEERING PROTECTION MEASURES are sea-dykes, sluice system, revetments, groynes, embankments and breakwaters, also if made of natural or other materials than concrete or stones.

SOFT COASTAL ENGINEERING MEASURES are e.g. sand nourishment of beaches or foreshore areas by pumping sediment onto the beach or by creating sandbars (sandbanks) in the foreshore area. Usually this technique is used in sandy environments but less at muddy coasts. In principle, the active restoration of a mangrove belt (or saltmarsh) is considered also a soft-engineering measure. Mangrove plantation might be combined with hard structural measures.

SOFT NON-ENGINEERING MEASURES FOR COASTAL PROTECTION are measures such as mangrove protection, coastal function zoning, organisation of coastal inspection, regular surveys and waterworks maintenance, capacity building and disaster risk management. All the mentioned measures have important contributions to the CPMD for the MD.

OFFSHORE is the zone of deeper water seawards beyond the low tide breaker line

NEARSHORE is the zone between the low tide breaker line (where the waves start to break, also surf zone) and the high tide breaker line (where waves run up the beach, also called swash zone). Therefore, this zone is moving closer to the land with high tide and is moving seawards with low water tide. Most important sediment transport and beach forming processes are taking place within this shallow water zone. The recognition of this zone is important for the right placement of breakwaters.

FORESHORE is defined by the mean high tide line seawards and the mean low tide line landwards. There is overlap with the NEARSHORE (see above) that moves with the tides. In ecological terms the foreshore equals the intertidal zone or eulittoral zone. This area falls dry during low tide and exposes the mudflats. The lower and mid foreshore (or intertidal zone) are the pioneer zone for mangroves. Avicennia alba, Avicennia marina, and Sonneratia alba are the typical pioneer species growing in this area.

BACKSHORE is defined by the mean high tide line seawards and the foam line (salt spray) of the beach landwards. This area is flooded at exceptional high floods and storm events. In undisturbed coastal areas in the MD, this is the typical zone for mangrove such as Bruguiera cylindrica, Rhizophora apiculata, and Lumnitzera racemosa. This zone is often used for aquaculture ponds.

SHORELINE is internationally mostly defined as Mean High Water Line although in the general use the shoreline is often moving up and down with the tides.

The COASTLINE is usually (depending on the context) defined as the boundary of terrestrial vegetation and sea, or the Normal High Spring Tide Line on beaches or the cliff foot at rocky coasts. The definitions are not handled consistently among policy makers and legal frameworks in Vietnam.

COASTAL HINTERLAND is usually defining the land beyond the sea-dyke (or planned sea-dyke route). There is no agreed official definition for the landwards border. In the coastal function zoning, the landwards administrative borderline of the coastal district limits the coastal zone. For practical reasons of coastal protection (see information on Coastal Protection Classification), in the CPMD the hinterland is defined as inland border of the water management units. It is the area that is highest prone to dyke breaches.

SEA-DYKE ROUTE is the first line of coastal flood protection and consists of the continuous line of sea-dykes and sea sluices.

MANGROVES and DUNES (including dune forest) are an integrated part of the SEA-DYKE SYSTEM in Vietnam.

NATURAL COASTAL PROTECTION ELEMENTS are the mangrove belt, sand dunes, tidal flats, and sand bank systems which can be considered as eco-system services. There are intensive ongoing discussions in the scientific community about the effectiveness of mangroves for coastal protection and their potential for wave attenuation. The latter depends very much on the local wave climate and type, density and age of the mangroves. It is generally agreed that more than 80% of the waves typical for the East Sea conditions in Vietnam are absorbed by roughly 250 m, and 50% respectively by 100 m of a characteristic mangrove belt.

Appendix III: List of abbreviations

English	Full meaning	Thuật ngữ đầy đủ	Tiếng Việt
ADCP	Acoustic Doppler Current Profiler	Thiết bị đo lưu lượng dòng chảy bằng nguyên lý Doppler	ADCP
AFD	Agence Francaise de Développement	Cơ quan Phát triển Pháp	AFD
BMZ	German Federal Ministry for Economic Cooperation and Development	Bộ Hợp tác kinh tế và Phát triển Đức	-
CC	Climate Change	Biến đổi khí hậu	BĐKH
CPMU	Central Project / Programme Management Unit	Ban quản lý chương trình / dự án Trung ương	BQLDA TW
CPO	Central Project Office	Bản quản lý Trung ương các dự án	CPO
CPR	Coastal Protection Region	Vùng bảo vệ	-
CPS	Coastal Protection Segment	Phân đoạn bảo vệ	-
CPU	Coastal Protection Unit	Đơn vị bảo vệ	-
CS	Climate Services	Dịch vụ khí hậu	-
CSP	Coastal Spatial Planning	Quy hoạch không gian vùng bờ	QHKGVB
CTU	Can Tho University	Trường Đại học Cần Thơ	ĐHCT
DARD	Department of Agriculture and Rural Development	Sở Nông nghiệp và Phát triển nông thôn	Sở NN&PTNT
DCM	Department of Construction Management	Phòng quản lý Xây Dựng	-
DFAT	Australian Department of Foreign Affairs and Trade	Bộ Ngoại giao và Thương mại Úc	-
DONRE	Department of Natural Resources and Environment	Sở Tài nguyên và Môi trường	Sở TN&MT

DPC	District People's Committees	Ủy ban nhân dân Huyện	UBND Huyện
DPI	Department of Planning and Investment	Sở Kế hoạch và Đầu tư	Sở KHĐT
DSAS	Digital Shoreline Analysis System	Hệ thống phân tích số hóa vùng bờ	-
DSM	Digital Surface Model	Mô hình số bề mặt	-
DST	Decision Support Tool	Công cụ hỗ trợ ra quyết định	-
DWR	Directorate of Water Resources	Tổng cục Thủy lợi	TCTL
ECMWF	European Centre for Medium-Range Weather Forecasts	Trung tâm Châu Âu về Dự báo Thời tiết tầm trung	-
EPR	End Point Rate	Tỷ lệ điểm cuối	-
ERA	ECMWF Re-Analysis	-	-
EU	European Union	Liên minh châu Âu	EU
GCP	Ground Control Point	Điểm kiểm soát mặt đất	-
GIS	Geographic Information System	Hệ thống thông tin địa lý	GIS
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit	Cơ quan Hợp tác Phát triển Đức	GIZ
GLONASS	Global Navigation Satellite System	Hệ thống định hướng vệ tinh toàn cầu	-
GNSS	Global Navigation and Satellite System	Hệ thống định hướng và vệ tinh toàn cầu	-
GPS	Global Positioning System	Hệ thống định vị toàn cầu	GPS
HCMC	Ho Chi Minh City	Thành phố Hồ Chí Minh	TP. HCM
ICM	Integrated Coastal Management	Quản lý tổng hợp vùng ven biển	ICM
ICMP	Integrated Coastal Management Programme	Chương trình Quản lý tổng hợp vùng ven biển	ICMP
ICZM	Integrated Coastal Zone Management	Quản lý tổng hợp đới bờ	QLTHĐB

IMHEN	Vietnam Institute of Meteorology, Hydrology and Climate Change	Viện Khoa học Khí tượng thủy văn và Biến đối khí hậu	IMHEN
IUCN	International Union for Conservation of Nature	Tổ chức bảo tồn thiên nhiên quốc tế	IUCN
IMU	Inertial Measurement Unit	Đơn vị đo lường quán tính	-
IWEC	Irrigation Works Exploitation One-Member Limited Liability Company	Công ty Trách Nhiệm Hữu Hạn Một thành viên Khai Thác Thủy Lợi	-
LMDCZ	Lower Mekong Delta Coastal Zone	Dự án vùng ven biển Đồng bằng sông Cửu Long	LMDCZ
LRR	Linear Regression	Hồi quy tuyến tính	-
MARD	Ministry of Agriculture and Rural Development	Bộ Nông nghiệp và Phát triển nông thôn	Bộ NN&PTNT
MD	Mekong Delta	Đồng bằng sông Cửu Long	ĐBSCL
MDP	Mekong Delta Plan	Kế hoạch Đồng Bằng Sông Cửu Long	MDP
MONRE	Ministry of Natural Resources and Environment	Bộ Tài nguyên và Môi trường	Bộ TN&MT
MOF	Ministry of Finance	Bộ Tài Chính	Bộ TC
MPI	Ministry of Planning and Investment	Bộ Kế hoạch và Đầu tư	Bộ KHĐT
NLWKN	Coastal Protection Agency in the state of Lower Saxony	Cơ quan bảo vệ vùng ven biển vùng Hạ Saxon	-
NAP	National Action Plan	Kế hoạch Hành động Quốc gia	KHHĐQG
NE	Northeast	Đông Bắc	NE
NDVI	Normalized Difference Vegetation Index	Chỉ số thực vật	-
NIR	Near Infrared	Cận hồng ngoại	-
NOAA	National Oceanic and Atmospheric Administration	Cục quản lý đại dương và khí quyển quốc gia Mỹ	-

ODA	Official Development Assistance	Hỗ trợ phát triển chính thức	ODA
PES	Payment for Ecosystem Service	Chi trả dịch vụ hệ sinh thái	PES
PM	Prime Minister	Thủ tướng	TTg
PPC	Provincial People's Committee	Ủy ban nhân dân Tỉnh	UBND Tỉnh
PPMU	Provincial Project / Programme Management Unit	Ban quản lý chương trình / dự án Tỉnh	BQLDA Tỉnh
PVC	Polyvinyl Chloride	-	-
SEDP	Socio-Economic Development Plans	Kế hoạch Phát triển Kinh tế - Xã Hội	KHPT KT-XH
RGB	True Colour Composite (Red, Green, Blue)	Hệ màu RGB	RGB
SIWRP	Southern Institute for Water Resources Planning	Viện Quy hoạch Thủy lợi miền Nam	VQHTLMN
SIWRR	Southern Institute for Water Resources Research	Viện Khoa học Thủy lợi miền Nam	VKHTLMN
SLR	Sea Level Rise	Nước biển dâng	NBD
Sub-FIPI	Southern Sub-Institute for Forest Inventory and Planning	Phân viện Điều tra, Quy hoạch rừng Nam Bộ	-
SVAM	Shoreline Video Assessment Method	Phương pháp đánh giá đường bờ bằng ghi hình	-
SW	Southwest	Tây Nam	-
TG	Technical Guideline	Hướng dẫn kỹ thuật	-
TUHH	Technical University Hamburg-Harburg	Đại học kỹ thuật Hamburg-Harburg	-
UAV	Unmanned Aerial Vehicle	Thiết bị bay không người lái	-
UNEP	United Nations Environment Programme	Chương trình Môi trường Liên hiệp quốc	UNEP

USA	United States of America	Hợp Chủng Quốc Hoa Kỳ	-
USD	United States Dollar	Đô La Mỹ	USD
UV	Ultraviolet	Cực tím	-
VASI	Vietnam Administration of Seas and Islands	Tổng cục Biển và Hải đảo	VASI
VAT	Value-Added Tax	Thuế Giá Trị Gia Tăng	Thuế GTGT
VND	Vietnamese đồng	Việt nam đồng	VNĐ
VNDMA	Vietnam Disaster Management Authority	Tổng cục Phòng Chống Thiên Tai	TCPCTT
VNFOREST	Vietnam Administration of Forestry	Tổng cục Lâm nghiệp	TCLN
WB	World Bank	Ngân hàng Thế Giới	WB
WLR	Weighted Linear Regression	Hồi quy tuyến tính có trọng số	-
	Decree-Government	Nghị Định-Chính Phủ	ND-CP
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	Decision-Ministry of Natural Resources and Environment	Quyết định-Bộ Tài Nguyên và Môi Trường	QĐ-BTNMT
	Decision-Ministry of Construction	Quyết định-Bộ Xây Dựng	QĐ-BXD
	Decision-People's Committe	Quyết định-Ủy Ban Nhân Dân	QĐ-UBND
	National Assembly	Quốc hội	QH
	Branch standard	Tiêu chuẩn ngành	TCN
	Vietnam's National standard	Tiêu chuẩn Việt Nam	TCVN

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