Quantification of sediment deposition in the Mekong Delta

An assessment of sedimentation in integrated Mangrove-Shrimp farms in the Mekong Delta, Vietnam

Master's Thesis

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Abstract

The Mekong Delta is under threat from natural and anthropogenic disruptions. With no action taken, the coastal parts of the delta could almost disappear by the end of this century due to relative sea level rise (RSLR). This study explores the potential of sedimentation-enhancing-strategies (SES), which could potentially save the Mekong Delta from drowning. By focusing on integrated mangrove shrimp systems, this study aims to quantify sediment accumulation and assess their effectiveness to function as SES and counter RSLR. Fieldwork conducted in Tra Vinh and Ca Mau provinces, Vietnam, involves monitoring eight mangrove shrimp systems over time to analyse sediment accumulation, composition, and deposition. Laboratory tests on accumulated sediments further delve into the sediment composition. The findings of this study contribute to a deeper understanding of sediment accumulation, dynamics, and composition within these systems. Moreover, the study estimates integrated mangrove-shrimp systems' potential as SES for the entire Mekong Delta. Results indicate a high likelihood that these systems can effectively mitigate RSLR, observing pristine uncompacted sedimentation rates of 1.95 cm/30 days in Tra Vinh and 1.16 cm/30 days in Ca Mau. This could imply sedimentation accretion rates of about 24 and 14 cm/year in integrated mangrove shrimp systems in Tra Vinh and Ca Mau, respectively. Potentially, the current integrated mangrove shrimp areas could accumulate up to 30 million m^3 of sediment annually.

Contents

List of abbreviations

USAID	United States Agency for International Development
IUCN	International Union for Conservation of Nature
MARD	Ministry of Agriculture and Rural Development
MONRE	Ministry of Natural Resources and Environment
UBS	Union Bank of Switzerland
WFF-Viet Nam	World Wide Fund for Nature in Viet Nam (WFF-Viet Nam)
SES	Sedimentation-enhancing-strategies
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
RSLR	Relative Sea Level Rise

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1. Introduction

The Mekong Delta is under threat from natural and anthropogenic disruptions such as, but not limited to, climate change, sea level rise, subsidence, sediment deficits, flooding, coastal erosion, loss of mangroves, population growth, and urbanisation (Syvitski, et al., 2009; Anthony, et al., 2015; Szabo, et al., 2016). According to developed likely scenarios for the future of the Mekong Delta, the delta could almost disappear by the end of this century (Schmitt, et al., 2017). Even in the most optimistic Intergovernmental Panel on Climate Change (IPCC) scenario, the future of the low-laying Mekong Delta, with an average elevation of 0.8 m above sea level, is dire (Minderhoud, et al., 2019; MoNRE, 2016; IPCC, 2019).

Adaptation and mitigation efforts must be made to save the Mekong Delta from drowning (Kondolf, et al., 2022). Fluvial sediment flux in deltas is likely to reduce by the end of this century, while fluvial sediment delivery is often mentioned as potentially capable of offsetting relative sea level rise (RSLR) (Dunn, et al., 2019). Sedimentation reduction can be countered by sedimentation-enhancing-strategies (SES), which are using designated areas for sedimentation and are mostly nature-based solutions that can build elevation (Dunn & Minderhoud, 2022). Sedimentation strategies throughout the world are proven to be capable to outpace high rates of SLR (Cox, et al., 2022) and therefore, could potentially save parts of the Mekong Delta from drowning (MoNRE, 2013) (Government of Viet Nam, 2017).

Although sedimentation strategies are proposed as a potential solution for mitigating RSLR in the Mekong Delta, there is limited research supporting the effectiveness of such strategies in the Mekong Delta. Schmitt et al. (2017) developed a set of likely scenarios for the future of the Mekong using a simplified model of the delta's geometry, while Dunn and Minderhoud (2022) examined the quantitative potential of targeted sedimentation strategies to counterbalance RSLR in the Mekong delta. In 2016, International Union for Conservation of Nature (IUCN) Viet Nam conducted an internal preliminary study on sediment accumulation in shrimp farming in Ca Mau, Tra Vinh, and Ben Tre, which lead to a recommendation for a comprehensive study on sediment deposition in mangrove-shrimp systems (Tien, et al., 2016). Phan and Stive (2022) quantitatively documented the evolution of mangrove area in the Mekong delta by analysing satellite imagery and concluded that an integrated mangrove-shrimp farming system is highly recommendable to achieve a beneficial balance between both aquaculture and mangroves in the delta. Lastly, World Wide Fund for Nature in Viet Nam (WFF-Viet

Nam) is currently conducting research on shrimp-rice systems in Ca Mau, Tra Vinh, and Ben Tre (WWF Viet Nam, 2023).

Despite previous research efforts, sedimentation in mangrove-shrimp systems has not been studied, resulting in a limited understanding of this phenomenon. Gaining insight into sedimentation in integrated mangrove-shrimp systems can uncover its potential as a sediment strategy and possibly aid in mitigating RSLR in the Mekong delta.

This objective of this study is to quantify sedimentation in mangrove-shrimp farms and will provide answers to the following research questions:

I. How can sedimentation in integrated mangrove-shrimp farms alleviate the impact of relative sea level rise (RSLR) in the proposed regions?
II. What are the dynamics of sediment deposition in mangrove-shrimp farms?
III. What are the soil properties and composition of the deposited sediments?
IV. To what extend can the implementation of integrated mangrove-shrimp farms be beneficial for the entire Mekong Delta coastline?

This study is supported by International Union for Conservation of Nature (IUCN) and especially the IUCN Ho Chi Minh City office in Vietnam. This study aims to generate knowledge needed for evidence-based policy advocacy on coastal squeeze in Vietnam. This study is part of the IUCN Advocating for Nature-based Solutions to Address the Coastal Squeeze in Mekong Delta project (2021) funded by the Union Bank of Switzerland (UBS) Optimus Foundation (UBS Optimus Foundation, 2023) and the Mekong Delta Coastal Habitat Conservation project (2021) funded by United States Agency for International Development (USAID) (USAID, 2023). These projects aim at increasing mangrove cover along 200 km of the lowest and most vulnerable coastlines of the Mekong delta. The projects encourage working with the government and businesses to allow mangroves, currently trapped between sea level rise on one side and the sea dikes on the other, to retreat inland to offset coastal squeeze.

A literature study on the Mekong Delta is introduced in section 2. Section 3 describes the study areas. In section 4 the methods and data are explained, this chapter is divided into six different subjects; research steps, fieldwork preparation, fieldwork, laboratory tests, schedule, and data processing. Furthermore, section 5 shows the research sites. In section 6 the results of this study are shown, whereas in section 7 the discussion on these results is shown. Lastly, section 8 shows the conclusion of this study.

2. Mekong Delta Literature Study

2.1 General

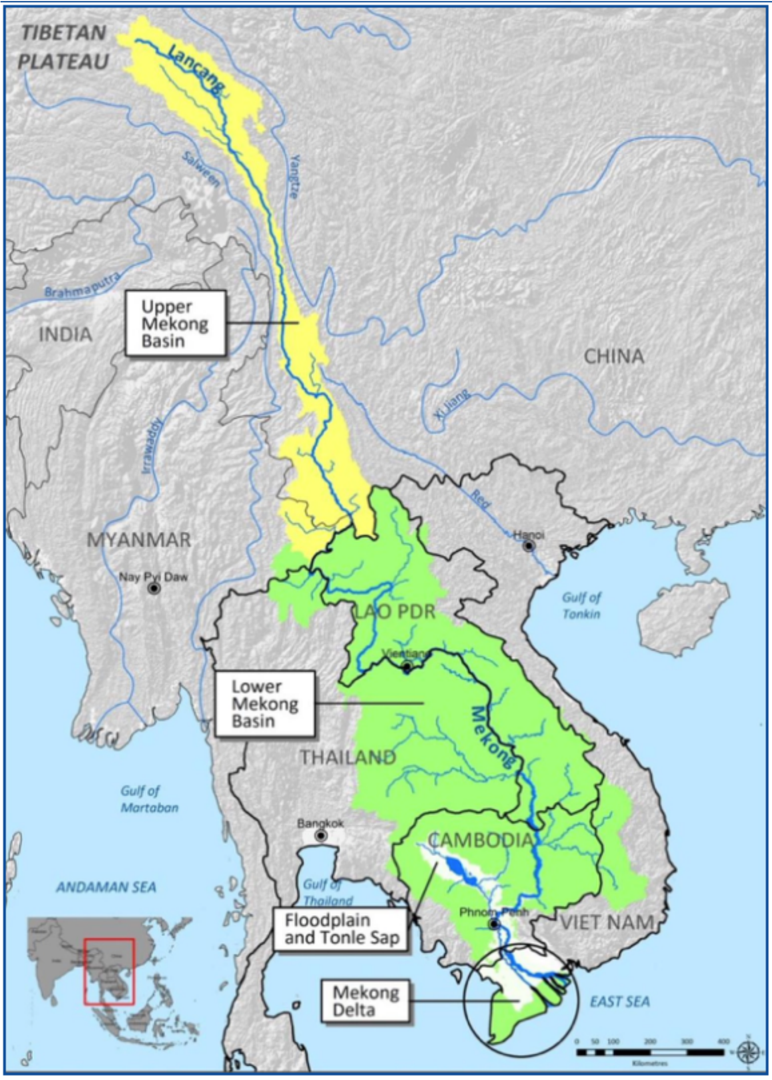

Figure 1: The Mekong River and its basin, the floodplain, and the Mekong Delta. (Mekong River Commission, 2023).

The Mekong Delta is located in the south of Vietnam, Southeast Asia, and is the third-largest delta in the world (Anthony, et al., 2015). The Mekong River is the 12th longest river on Earth and descends from the Tibetan plateau in China. The Mekong River runs through Myanmar, Laos, Thailand, Cambodia, and ends in Vietnam. The Vietnamese Mekong delta is part of the Lower Mekong Basin and with 65,000 km^2 it accounts for only 8% of the total Mekong River catchment area (Mekong River Commission, 2023). The Mekong delta was formed during the second part of the Holocene, which came after the last ice age resulting in high sea levels due to melted ice. The delta could prograde rapidly into the South China Sea due to high sediment supply by the Mekong river, relatively shallow Pleistocene substrate, and its wave-sheltered location (Anthony, 2015; Nguyen, et al., 2000; Ta, et al., 2002). The Mekong Delta is an extremely flat delta, as shown in Figure 1, with an average elevation of around 0.8 m above sea level, it is one of the lowest elevated delta plains in the world (Syvitski, et al., 2009; Minderhoud, et al., 2019). The delta is home to approximately 21 million people, and the most productive agriculture and fishery region in Vietnam (Boretti, 2020). The Mekong delta is also known as the 'rice bowl' because of its major contribution to global rice production (Kuenzer, 2012). With over 50% of

Vietnam's food production and 90% of the rice in Vietnam grown in the delta, it is crucial to Vietnam's economy and food security (General Statistics Office, 2023). The climate in the Vietnamese Mekong Delta is tropical humid, the dry season lasts from December to April while the rainy season lasts from May to November (Kuenzer, 2012). The discharge of the Mekong River ranges from 1,700 m3/s during the dry season up to 40,000 m3/s during the wet season (Le, et al., 2007). The discharge during the rainy season inundates the river, nearby lakes, and floodplains; leaving behind sediments and nutrients which nourish the land and make it highly fertile (Eslami, et al., 2021).

The Mekong Delta in its current state is not sustainable. Natural and anthropogenic disruptions such as, but not limited to, climate change, sea level rise, subsidence, sediment deficits, flooding, coastal erosion, loss of mangroves, population growth, and urbanisation, are threatening the future of the delta (Syvitski, et al., 2009; Anthony, et al., 2015; Szabo, et al., 2016). With no action taken, the delta could almost disappear by the end of this century (Schmitt, et al., 2017).

2.2 Climate Change

Vietnam, thus the Mekong Delta, is often presented as one of the most vulnerable countries to climate change (Agence Française de Développement, 2021); temperatures, annual rainfall, sea level rise, and the seasonal and annual fluvial discharge in the Mekong will rise significantly (MoNRE, 2016; IPCC, 2019). Sea level rise by 2100 varies between

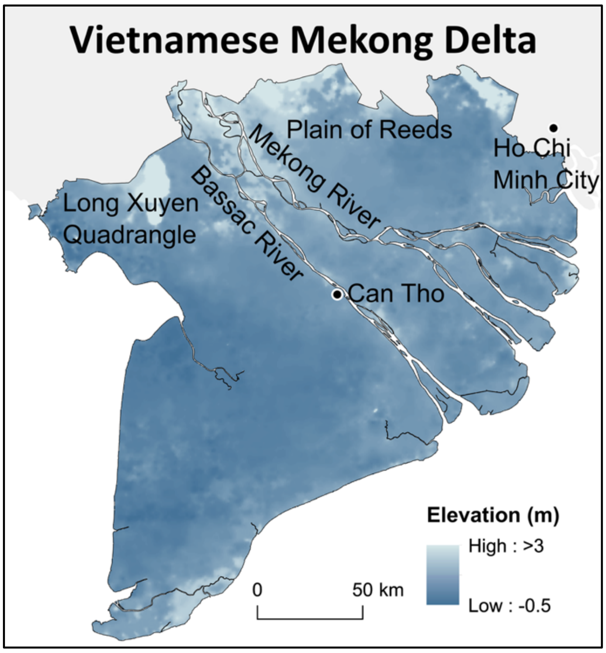

Figure 2: Elevation above sea level of the Mekong Delta. Adapted from Dunn and Minderhoud (2022).

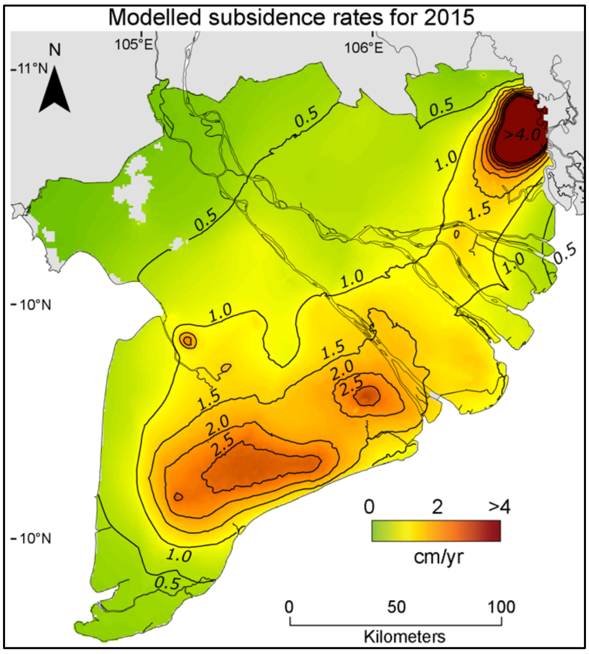

Figure 3: Modelled subsidence rates for 2015. Adapted from (Minderhoud, et al., 2017).

0.27 m to 1.03 m, depending on the Global Greenhouse Gas (GHG) scenarios (MoNRE, 2016). Although these GHG scenarios do not take the polar ice sheet predictions into consideration due to large uncertainties, meaning that higher sea level rise values cannot be ruled out (IPCC, 2019). For the most optimistic scenario the global mean sea level rise could exceed 40 cm in 2100, meaning permanent inundation for the lowest areas of the Mekong delta (MoNRE, 2016; Minderhoud, et al., 2020).

2.3 Subsidence

Delta subsidence is caused by both natural phenomenon and anthropogenic drivers. Tectonic movements, isostatic adjustments, and natural compaction of unconsolidated sediments are examples of natural drivers (Zoccarato, et al., 2018). The Mekong Delta was formed by deposition of mainly unconsolidated, fine-grain (clay-like) sediments, which undergo high rates of natural compaction, up to 2 cm/year (Zoccarato, et al., 2018). Human activities such as, but not limited to, draining surface water, groundwater extraction, additional loading through infrastructure and/or buildings are anthropogenic drivers (Erban, et al., 2014; Minderhoud, et al., 2017). The combination of natural and anthropogenic drivers causes that the Mekong Delta is subsiding with an average rate of 1 cm/year, although local maximum values up to 6 cm/year are reached, as shown in Figure 3 (Minderhoud, et al., 2017; Minderhoud, et al., 2020).The land subsidence is a huge threat to the delta and the main driver of relative sea level rise (RSLR) (Minderhoud, et al., 2020).

A study from Lovelock et al. (2015) looked at shallow compaction in mangrove forests in the Indo-Pacific region. Their study investigated the surface elevation and accretion of multiple locations in the Indo-Pacific, including locations in the Mekong Delta. In these locations in the Mekong Delta they measured surface elevation site means of 1.16 and 3.62 cm/year, and surface accretion site means of 3.68 and 6.79 cm/year (Lovelock, et al., 2015). These values indicate shallow compaction rates of 2.52 and 3.17 cm/year, respectively, showing that mangrove coastal zones in the Mekong Delta have high shallow compaction rates.

Besides the shallow compaction, according to Zoccarato et al. (2018), natural compaction rates of the Holocene sediments at the Mekong Delta coastline equal to 20 mm/year are not unlikely. The subsidence rates due to this natural compaction can rate up to one order of magnitude larger than absolute sea level rise. Indicating that the anticipated subsidence rates seriously threaten the lower delta plain with permanent inundation (Zoccarato, et al., 2018).

2.4 Sediment deficits

There are multiple causes of the sediment deficits in the Mekong delta, such as reduced sediments flow from upstream, riverbed mining, canal building, change of land use, and dyke and levee building (Arias, et al., 2014; Kondolf, et al., 2014; Hackney, et al., 2020; Zoccarato, et al., 2018). Upstream hydropower dams have a big impact on the Mekong River, the dams influence the free flow of sediments into the delta and the discharge in the waterways, which besides a decrease in sediments also increases salt intrusion (Eslami, et al., 2021). Sand mining in the river creates riverbed incision, reduces sediment availability, and alters tidal forcing (Hackney, et al., 2020). To prevent and control natural flooding, many dykes and levees have been constructed in the Mekong Delta. These dykes and levees heavily impede with sedimentation in those areas although they could potentially channel more sediment towards the coastal areas (Thanh, et al., 2020; Tu, et al., 2019). Sediment deficits in the Mekong River are threatening many livelihoods and the future of the delta (Kondolf, et al., 2022). Because of the sediment deficits there is no compensation for the high subsidence and compaction rates (Zoccarato, et al., 2018).

Thereby, the sediment deficits in the Mekong Delta are causing coastal erosion. The Mekong Delta used to progress seaward with a mean rate of over 30 m/year (Anthony, et al., 2015), although nowadays the most of the coastline is eroding, with rates up to 50 m/year (Tamura, et al., 2020). Because of the erosion, caused by sediment deficits, natural systems in the coastal areas are unable to grow and are declining in area rapidly (Besset, et al., 2019; Phan & Stive, 2022).

2.5 Sedimentation strategies

To mitigate the above-mentioned threats to the delta, sedimentation strategies could play an important role. Sedimentation strategies are using designated areas for sedimentation and are mostly nature-based solutions that can build elevation (Dunn & Minderhoud, 2022). Sedimentation strategies are gaining attention internationally and locally in both the scientific and public debate (van Staveren, et al., 2018; MoNRE, 2013; Government of Viet Nam, 2017). Cox et al. (2022) reviewed 21 existing and planned sedimentation-enhancing strategies and found that 79% of these are able to outpace high rates of SLR. One form of sedimentation strategies is controlled flooding, where suspended sediments are allowed to be deposited in floodplains and can locally build elevation (Islam, et al., 2020; Day, et al., 2016). Another sedimentation strategy, which works best with a healthy sediment supply, are mangroves and natural wetlands. These ecosystems are proven solutions to coastal erosion, able to build elevation, and benefiting biodiversity and livelihoods (van Bijsterveldt, et al., 2020; Getzner & Islam, 2020).

2.6 Mangroves

While mangrove vegetation can trap sediments to elevate land, absorb wave energy thus prevents coastal erosion, most of the mangroves in the Mekong delta have been lost in the past decades (Besset, et al., 2019). The mangroves in the Mekong delta have largely been replaced by agriculture and aquaculture, while the remaining mangroves are starved of sediment to trap (Besset, et al., 2019; Hai, et al., 2020). Coastal erosion also plays an important role in the reduction of mangrove forests; this feedback loop will intensify over time since mangroves protect coasts against erosion (Phan & Stive, 2022; Barbier, et al., 2011). The combination of insufficient sediments and erosion is causing the Mekong delta to lose mangrove forests at a rate of 400 ha/year (Phan & Stive, 2022). The total mangrove area in the Mekong delta reduced from 185,800 ha in 1973 to 102,160 ha in 2020, meaning that the delta is losing mangrove areas at a rate of approximately 2,150 ha/year (Phan & Stive, 2022). Besides replanting mangroves directly on the coast, mangrove aquaculture systems such as integrated mangrove-shrimp farms can be implemented to rehabilitate mangroves.

2.7 Integrated mangrove-shrimp farms

There are multiple forms of mangrove aquaculture systems, but this research will only focus on integrated mangrove-shrimp farming. This is a sustainable shrimp farming technique which was originally founded in Malaysia about 70 years ago (Bosma, et al., 2016). In integrated mangrove-shrimp farms, mangroves and shrimp farming are combined; shrimps are cultivated in ponds with mangroves. The mangrove-shrimp farms can differ in mangrove cover, usually the local government has regulations for the mangrove cover percentage. The mangrove cover percentage is the percentage of pond area that must contain mangrove trees. In Vietnam, the Ministry of Natural Resources and Environment (MoNRE) oversees these regulations. Usually, the mangrove cover percentage differs between 30 and 70 percent (Vo, et al., 2013). Research from Nguyen et al. (2022) shows that a mangrove cover percentage of 60% optimises household profitability from shrimp production. Since the 1990s, the Vietnamese government has introduced mangrove-shrimp farming by allocating forestry land to households for mangrove planting and protection (Ha, et al., 2012), while the farmers get permission to cultivate shrimps among the mangroves (Binh, et al., 2008). The integrated mangrove shrimp farms offer coastal protection, sustain livelihoods, work towards sustainable development, conserve ecosystems, increase biodiversity, and carbon storage (Phan & Stive, 2022; Barbier, et al., 2011; Nguyen, et al., 2022). Furthermore, Phan and Stive (2022) recommend integrated mangrove-shrimp farming models as one of the most appropriate approaches to a beneficial balance between aquaculture and mangroves in the Mekong Delta.

3. Study Area

This research will be conducted in the coastal parts of the Mekong delta, specifically in Tra Vinh and Ca Mau province. These provinces are shown in Figure 4. The geomorphological composition of both the provinces consists predominantly of tidal flats, mangrove marsh, marsh, salt marshes, and coastal plains (Nguyen, et al., 2000). Minderhoud (2019) produced a schematic profile including geomorphological units of the typical coastal landscape in the Mekong Delta. Figure 5 shows this schematic profile.

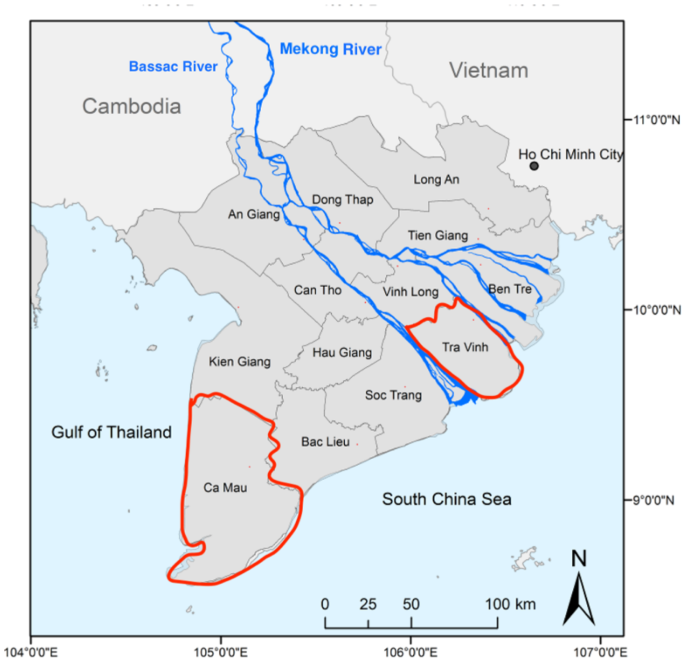

Figure 2: Overview of the Mekong delta with Ca Mau and Tra Vinh highlighted with red encircling. Adapted from (Kuenzer, et al., 2013).

The coast of the Mekong delta has distinct sediment size segregation, as well as our study areas. Tra Vinh is within the river dominated delta landscape with loads of fluvial activity, whereas Ca Mau is in the coastal landscape, thus marine dominated and no fluvial activities (Minderhoud, 2019). Sandier sediments are dominant from the river mouth of the Mekong River to about 30 km westward the Bassac River (major branch of the Mekong river) mouth while further west the coast is composed mainly of silt and clay (Unverricht, et al., 2013; Tamura, et al., 2020). Thus, the coastal sediments near Tra Vinh are coarser, while the Ca Mau sediments have finer grains.

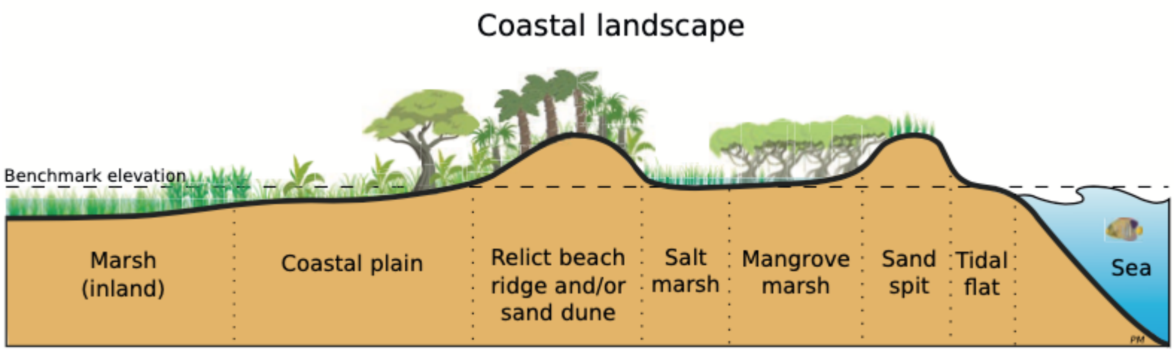

Figure 3: Schematic profile of the coastal provinces in the Mekong Delta. Adapted from (Minderhoud, 2019).

Drill-cores from Ca Mau province consist mainly of finer sediments with thin lenses of coarse silt and very fine sand. The top layers consist of oxidized silt and clay while at depths from around 1-3 m the drill-cores contain mainly silt, clay, and thin lenses of coarse silt and very fine sand (Tamura, et al., 2020). Drill-cores from Tra Vinh province consist mainly of silt, sandy silt, and fine-medium sand. The top layers consist of medium sand, while at depths around 1-3 m the drill-cores contain a layer of silt, followed by more layers of very fine to medium sand (Ta, et al., 2005).

A study on managing mangroves and coastal land cover in the Mekong Delta (Phan & Stive, 2022) quantitively documented the evolution of mangrove area and aquaculture in the Mekong delta between 1973-2020. For this study the 2020 overview of the coastal provinces is used and displayed in Table 1. The table shows the area of aquaculture and mangrove in hectare per coastal province.

Table 1: Coastal provinces in the Mekong and the area of aquaculture and mangroves in hectares in 2020.

Province	Type	ha
Kien Gian	Aquaculture	44,610
	Mangrove	4,920
Ca Mau	Aquaculture	164,030
	Mangrove	68,110
Bac Lieu	Aquaculture	40,140
	Mangrove	3,890
Soc Trang	Aquaculture	18,650
	Mangrove	7,010
Tra Vinh	Aquaculture	28,380
	Mangrove	10,030
Ben Tre	Aquaculture	20,210
	Mangrove	6,820
Tien Giang	Aquaculture	5,540
	Mangrove	1,380
Total	**Aquaculture**	**321,560**
	Mangrove	**102,160**

Ca Mau has the largest share in both aquaculture and mangroves from all the coastal provinces with 51% and 66.7%, respectively. Tra Vinh has the 2nd largest mangrove share with 9.8%, while the aquaculture percentage ranks 4th with 8.8%.

Figure 6: A shallow mangrove-shrimp pond in Ca Mau.

Figure 7: A farmer in a boat in his pond while holding a shrimp.

IUCN internally conducted a preliminary campaign to estimate sediment deposition in mangrove-shrimp systems (Tien, et al., 2016). During this preliminary study, the IUCN team conducted field interviews where they made estimations of sediment deposition. Thus, quantification of the sediment data has not been studied and no actual monitoring was conducted. Nevertheless, these results give an indication of what possibly can be expected during this study. The IUCN preliminary study looked at 145 different sites, including 46 mangrove-shrimp farms, divided over three provinces. 17 of those mangrove-shrimp farms were in Tra Vinh and 20 in Ca Mau. According to the internal study, integrated mangrove shrimp systems occupy an estimated 50,000 hectares of land in the Mekong Delta (The Asean Post, 2018; Tien, et al., 2016). The preliminary study on sediment accumulation by IUCN Viet Nam (2016) estimated that within mangrove-shrimp farms in Ca Mau, Tra Vinh, and Ben Tre, sediment deposition in the farm channels reached an average of 25.13 cm/year. Tra Vinh had an estimated sediment accumulation of 18.11 cm/year while Ca Mau accumulated sediments with an estimated rate of 27.55 cm/year.

4. Methods and Data

The first section of this chapter describes the research steps. Secondly, the fieldwork preparation is described in two steps; equipment, and sourcing research sites. Thirdly, the fieldwork itself, consisting of; placement, retrieval, and interviews, is described. Fourthly, the laboratory tests are explained, fifthly, the schedule is shown, and lastly the data processing is described.

4.1 Research steps

The research steps for this study were: (1) literature review and proposal writing, (2) fieldwork preparation, (3) fieldwork, (4) laboratory tests, and (5) data processing and writing the report. During the fieldwork preparation-stage; the equipment was designed and made, and the research sites were sourced. In the fieldwork stage; the equipment was placed, monitored and retrieved, and interviews were conducted with the landowners. The 4th research step, the laboratory tests, were conducted on the samples that were retrieved during the fieldwork stage.

4.2 Fieldwork preparation

In this section the two stages during the fieldwork preparation; design and making of the equipment, and sourcing the research sites, are described. Many aspects of the fieldwork preparations changed quickly during this process due to different reasons, therefore only the final outcomes of the preparation stage are described below.

4.2.1 Equipment

For measuring the sediment in the mangrove-shrimp ponds over time we used T-shaped trays. A similar designed T-shaped tray was previously successfully tested in three pilot sites in Ben Thre, Tra Vinh, and Ca Mau by World Wide Fund for Nature in Viet Nam (WFF-Viet Nam). WWF-Viet Nam tested the T-shaped trays in mixed rice-shrimp farms to see if there is any elevation gain due to organic and non-organic sedimentation. The

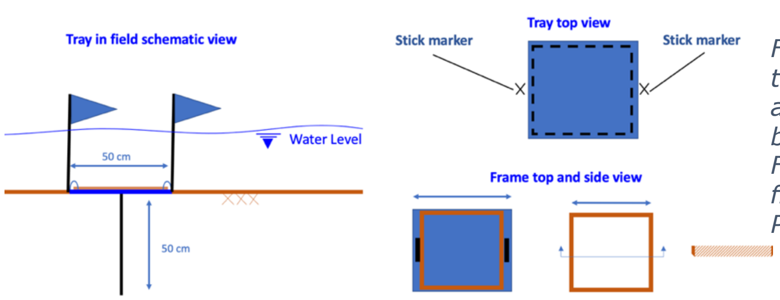

Figure 4: Schematic overviews of a tray. Left: sideways view of a tray in a pond. Top right: top view with bamboo stick marker. Bottom right: Frame top and side view. Adapted from an internal WWF-Viet Nam PowerPoint.

conditions in mixed rice-shrimp systems differ from the mangrove-shrimp systems that are investigated for this research. The main difference is the water level, the mangrove-shrimp ponds are deeper than rice-shrimp systems. Therefore, it is harder to retrieve the sediments on the tray since the trays are placed on the bed of the pond. In Figure 8 the schematic overviews of the tray are shown. Figure 8 also shows a frame, this frame will be used to retrieve the sediments, this process is described elaborately in the 4.3.2 Retrieval paragraph on page 27.

Figure 5: Assembled trays before they were placed in the pond (left) and a retrieved tray with the frame on top, containing little sediments

Furthermore, Figure 9 (left) shows several assembled trays on the bank of one of the ponds before they were placed in the pond. Here the plastic bottles, which were attached as float to find the tray after monitoring for about a month, and the reed stems which were planted next to the handles in the pond bed, are also visible. The image on the right of Figure 9 shows a retrieved tray, with little sediments, and the frame on top. The frame is placed on top of the tray during the retrieval procedure to trap the accumulated sediments, more on this retrieval procedure in paragraph 4.3.2 Retrieval on page 27.

The T-shaped tray was manufactured in a local workplace in Ho Chi Minh City. The tray is forged out of a metal combination that is heavy enough so it will stay put on the bottom of the ponds but also does not become too bulky when transporting. A total of sixty trays were made and distributed over the eight research sites, more information regarding the placement and distribution of the trays in the 4.3.1 Placement paragraph on page 26.

4.2.2 Sourcing research sites

Due to previous projects and good relations of IUCN, the coastal provinces Tra Vinh and Ca Mau were chosen to conduct this research. Together with the Ministry of Agriculture and Rural Development (MARD), People's Committee of Tra Vinh, and People's Committee of Ca Mau different potential research sites were sourced. During a first reconnaissance trip, the proposed potential research sites were visited and, where applicable, choices were made. In Tra Vinh the involved governmental parties proposed 4 research sites, whereas in Ca Mau multiple options were offered. Because there were no choices in Tra Vinh, the 4 proposed research sites had to be accepted. This resulted in the team attempting to find, if applicable, similar ponds (in size and mangrove cover) to Tra Vinh in Ca Mau. When these ponds were offered and sourced, there was no knowledge about the water management practices and other details available. Only the pond size, estimated mangrove cover, and a quick visual inspection were possible during the sourcing of the research sites.

In general, the mangrove cover percentages in ponds in Ca Mau are higher (60%) than in Tra Vinh (30%). This is due to regulations from MoNRE, they compel farmers to keep a certain minimum mangrove cover percentage on their land. The farmers in Ca Mau own more land than the farmers in Tra Vinh due to the lower population density in Ca Mau. This results in larger farms in Ca Mau and therefore it was more difficult to find smaller farms in Ca Mau that were suitable for this research. To enable comparison between the two provinces, the Tra Vinh research sites characteristics have been mimicked in Ca Mau whenever possible. The farms in Ca Mau that were chosen corresponded as much as possible in size, however the mangrove cover is higher than those in Tra Vinh.

4.2.3 Location overviews

Firstly, the overview of the farm locations in Tra Vinh is shown in Figure 10. All the farms in Tra Vinh are in Duyên Hài District, which is the southernmost district of the province. The farms in Tra Vinh are all connected to the same connecting-channel to the Kênh Quan Chánh Bố Canal.

Figure 10: Overview map of Tra Vinh with the red lined zoom-in region and the Kênh Quan Chánh Bố Canal. The zoom in is displayed in Chapter 5. Research Sites.

Secondly, the overview of the farm locations in Ca Mau is shown in Figure 11. The farms in Ca Mau are all located in Ngọc Hiển District, which is the southernmost rural district of Ca Mau province. All the farms are connected to bifurcations of the Cửa Lớn River directly.

Figure 11: Overview map of Ca Mau with the red lined zoom-in region and the Cửa Lớn River Canal. The zoom in is displayed in Chapter 5. Research Sites

4.3 Fieldwork

In this section the different stages of the fieldwork are described. Many aspects of the fieldwork have been altered and modified during the fieldwork itself due to the changing conditions in the research sites. The optimal methods used for this study are described below.

4.3.1 Placement

Before placing the tray in the ponds, the tray had to be assembled on location. The team attached the empty bottles to the tray handles with fishing line and the bottom bar had to be screwed into the tray, Figure 12 shows the team assembling the trays. Once assembled, the bottom bar of the T-shaped tray is pushed firmly into the pond bed during placement. It is of importance that the tray is placed on an even surface and pushed into the sediment in such way that the top of the tray is equal to the pond bed. Awareness of uncertainties on the surrounding pond bed, such as the presence of mangrove stems and roots, crab holes, and other bumps and holes, is important while placing the tray. Locally chopped reed stems were used to mark the locations of the tray as well as empty drinking bottles bought at local teashops. The empty bottles were attached to the handles of the trays with nylon cord and functioned as floating markers in case the reed stems would disappear over time. Besides these visual markers, a Garmin eTrex20 was used to mark the GPS location of the tray and eventually create maps of the research sites with tray locations. The exact protocol for placements of trays can be found in Appendix A.

Figure 6: Assembling the trays before placement in the pond

The sixty manufactured trays were distributed over the eight research sites according to the size of the research sites. In Table 2 below, the number of trays per farm is shown.

Table 2: Number of trays per farm, based on farm size.

Farm	Size (hectare)	Number of trays
1	2.5	6
2	6.5	9
3	2.3	6
4	2.5	6
5	2.5	6
6	3.6	7
7	7.0	9
8	8.3	11

The trays were distributed over the ponds in such way that the entire pond, in length and width, was evenly distributed. With the limited number of trays, optimal placement was achieved by placing two trays close to the sluice gate of every pond and distribute the remaining trays evenly over the pond. The positions of the trays in the research sites can be found in Chapter 5. Research Sites on page 34.

4.3.2 Retrieval

After the placement of the trays, they stayed in the pond for approximately one month before the trays and sediments on top of the trays were retrieved. Ideally the trays would be retrieved after exactly a month. Unfortunately, this was impossible due to several planning issues. The final schedule of the data retrieval trips is shown in the 4.5 Schedule paragraph on page 31.

To retrieve the trays and the accumulated sediments on top of the tray, a frame was used. The frame fits tightly within the handles of the trays and is placed on top of the tray firmly so the sediments will not wash out when the tray is lifted. Once the tray was located by the visual markers (stick markers and floats), the handles of the tray were found, and the frame was pushed in between the handles of the tray firmly in such way that it connects to the topside of the tray without causing any leakage of sediments and water. When this was realised, it was possible to lift the entire tray with the frame and sediments by pulling the tray out of the pond bed with the handles. Once the tray was

Figure 7: Several pictures of retrieved trays with different sediments.

above the water level, five different height measurements of the sediment were taken with a transparent hard plastic ruler. Figure 13 shows several retrieved trays with sedimentations, also note the frame and ruler in the figures. During the first sediment retrieval trip, it became clear that the sediments were not evenly spread onto the trays; therefore the decision was made to take five different measurements per tray for a better overview of the sediment height. Supplementary, pictures of the trays and the ruler in the five different measure points were also taken. This proved to be useful during the processing of the data.

Besides taking the sediment height, for some trays the sediment samples were taken for further laboratory analyses. More information on the laboratory tests can be seen in the 4.4 Laboratory tests paragraph on page 30. To take samples of the sediments, after measuring the height with a ruler and taking pictures, the sediment from the tray was scooped into pre-marked Ziplock bags. Figure 14 shows the team in action, one team member was holding the tray and frame after successfully retrieving it, the others were assisting with ruler measurements, pictures, and storing the sediments in the Ziplock bags. For every tray, one 1 litre Ziplock bag was marked with the research site and tray number beforehand. The sediments were removed from the tray and frame with a putty knife and

Figure 8: The team in action while retrieving the sediments in a tray.

deposited into the Ziplock bag; which was securely closed after and stored in Styrofoam boxes. After a field trip, these Styrofoam boxes with the sediment samples were transported to the laboratory for further testing. For the step-by-step tray retrieval protocol, see Appendix B.

4.3.3 Interviews

The owners of the eight research sites have been interviewed. The interviews were conducted in their houses, next to the ponds. Satellite maps of their ponds were brought, to make sure there was full understanding of the locations. The interviews were conducted in Vietnamese by IUCN employees and MSc students that participated in the fieldtrips.

Figure 9: Interview with one of the owners at the porch of his house.

They would translate the Vietnamese answers to English and answers were written down directly. In case of misunderstanding, doubtful answers, and other uncertainties; the questions were reformulated to make sure that the given answer was correct. The interview questions were on general site information, sedimentation, water management practices, mangroves, neighbouring ponds, and opinion questions on the re-use of accumulated sediments in their ponds. The exact questions and answers from the interviews can be found in Appendix C.

It is important to note that the information provided by the landowners during the interviews were all estimations, consisting of descriptions of depths, dredging dates, mangrove cover, among others.

4.4 Laboratory tests

Several laboratory tests were run on sediment samples, all the tests were run by the University of Science in Ho Chi Minh City and lead by Dr. Nguyễn Văn Đông and his team. To determine the composition of the sediments a laser diffraction particle size (laser granulometry) test was performed. A Loss-On-Ignition (LOI) protocol was used to determine the pore-water percentage, the organic matter percentage, and the CO_2 release percentage, which can be used to calculate the quantity of calcium carbonate ($CaCO_3$). For the LOI protocol a protocol from the University of Cambridge was altered and used (University of Cambridge, 2022). Besides the Cambridge protocol, other literature was also reviewed to alter the protocol and ensure appropriateness (Heiri, et al., 2001; Santisteban, et al., 2004). The main alteration that was made to the existing protocol is that the first drying phase temperature was changed from 105 to 150 °C. This alteration was made because the samples contain a high salinity percentage. With a temperature of 105 °C the salt in the sample will still capture water and therefore the organic matter portion will be overestimated (Mook & Hoskin, 1982). This overestimation is mitigated with the temperature of 150 °C. The complete LOI protocol can be seen in Appendix D.

For the laser granulometry tests a LA-350 Laser Diffraction Particle Size Distribution Analyser from Horiba Scientific England was used. For the Loss-On-Ignition tests a Nabertherm Muffle was used, the calibration certificate can be seen in the data supplement.

Due to financial limitations, it was not possible to run laboratory tests on all the obtained samples throughout this study. Therefore, the decision was made to create a laboratory strategy where an extensive spatial scale was used as laboratory testing baseline. The tests were run on several samples collected after the first month of monitoring in week 42, 2022. The following formula was used to determine the number of samples for laboratory testing: $\frac{number\ of\ trays\ in\ farm}{2} = number\ of\ samples\ for\ testing$. In case of multiple decimals, a round up to a whole number was performed. This resulted in the following number of tests per tray, shown in Table 3.

Table 3: The test quantity of trays, based on the number of trays in the farm, and the selected trays for testing.

Farm:	Number of trays:	Test quantity:	Selected trays #:
1	6	3	1,3,6
2	9	5	3,5,6,7,8
3	6	3	2,3,6
4	6	3	1,2,5
5	6	3	1,3,5
6	7	4	1,2,4,5
7	9	5	1,2,4,5,7
8	11	6	1,3,4,5,6,7

In the last column of Table 3, the selected trays are shown, the location of these trays can be seen in the 5. Research Sites chapter on page 34. The selection process for trays eligible for laboratory testing was conducted with the following criteria:

- Sufficient sediment on the tray
- Well-spread representation of the farm
- Priorities to interesting visual observations
    - Layering in sediment sample
    - High presence of organics
    - Different composition compared to the other trays
    - Presence of different sediments (colour and size)

4.5 Schedule

The schedule for the different fieldtrips is shown in Table 4. Ideally the data would have been collected monthly, unfortunately this was not possible due to logistic issues. Because the intervals between the data collecting were not exactly 30 days, the number of days between collecting data are computed for Tra Vinh and Ca Mau. The number of days between collecting the data is shown in Table 5.

Table 4: Schedule including the dates, week number, and activities of the conducted field trips.

Date	Week	Activity
13 – 15 September 2022	37	Site visits
20 – 23 September 2022	38	Placing equipment
2 – 6 October 2022	40	Interviews and equipment check
18 – 23 October 2022	42	Collecting data after 1st month + laboratory testing
20 – 25 November 2022	46	Collecting data after 2nd month
26 – 31 December 2023	52	Collecting data after 3rd month
29 January – 3 February 2023	5	Collecting data after 4th month

Table 5: Number of days between data collecting trips

DATA COLLECTION TRIP:	NUMBER OF DAYS:	
	Tra Vinh:	Ca Mau:
1ST	27	32
2ND	35	30
3RD	34	38
4TH	37	32

4.6 Data Processing

The aim of this study will be achieved by both quantitative and qualitative research, although it must be mentioned that the quantitative part is leading for this research. The qualitative part is only there to supplement the research. The quantitative research consists of conducting field work at the research sites to quantify the deposited sedimentation in these sites. The deposited sediments were analysed for sediment deposition dynamics, composition, and soil properties. The qualitive research part contains the interviews that were taken with the landowners.

To process the laboratory data, basic statistical analyses were used in Excel. The laboratory processed the raw data from the granulometry tests and the LOI-tests and delivered the processed data. For the laser granulometry tests the raw data is processed into percentages of clay, silt, and sand. For the LOI-tests the raw data contained weight in grams and this has been converted to % loss on ignition at a given temperature. The raw data is also supplied and can be found in the excel data supplement. The processed data from the lab was randomly tested to verify whether the protocols and calculations were executed correctly.

Data processing follows these steps: (1) laboratory testing of fieldwork samples; (2) processing laboratory data; (3) basic statistical analysis in Excel.

5. Research Sites

In this section overview maps of both the provinces and the eight individual research sites are shown. Per farm, the basic characteristics, maintenance, and water management practices, which are gathered during the different fieldwork stages of the research, are described. Thereby, the placement of the trays in the farms is shown and explained. This section is divided by the Tra Vinh, and Ca Mau farms.

5.1 Tra Vinh

All the farms in Tra Vinh are in Duyên Hải District, which is the southernmost district of the province. Figure 16 shows the zoom-in of the Tra Vinh overview map from Figure 10. Farms 1 and 2 in Tra Vinh are situated next to each other, whereas farms 3 and 4 are located further away from each other. All the farms in Tra Vinh are owned by different households and therefore have slightly different maintenance and water management practices. The farms are all connected to the same connection to the Kênh Quan Chánh Bố Canal.

Figure 10: Farm locations in Tra Vinh.

5.2.1 Farm 1

Farm 1 is the most southern farm out of the other research sites; meaning that it's the closest to the coast. It has an area of 2.5 hectares and a mangrove cover of 30%. Note that the aerial image in Figure 17 is old, the red line represents the outline of the pond. The larger mangroves on the farm are 10 years old, the others are mostly 4 years

Figure 11: Detailed view of Farm 1, including the sluice gate and tray locations.

old. The farm is dredged almost yearly but they do not dredge the entire farm at once, they dredge it section by section. The last time they pumped sediment was 7 years ago and the farmer is not sure when they will pump sediment again. The sluice gate connects the farm with a bifurcation of the Kênh Quan Chánh Bố, with a manmade channel. The sluice gate is located at 1.1 kilometre (km) from the nearest river downstream, and 2.6 km upstream. The flushing of the farm is done two times per month, for three to four days. During low tide the sluice is opened for 1 to 1.5 hours while during high tide the sluice is opened for 2 hours.

The six trays in farm 1 are distributed over the entire farm; two trays are placed close to the sluice gate while the other four trays are spread out through the farm. The middle part of the farm was very shallow and covered in fish traps, placing a tray there was not feasible. The water depth during the placement of the trays ranged between 54 and 77 cm while the sluice gate depth was 95 cm. The water depth values of farm 1 can be seen in Table 6 below.

Table 6: Sluice gate depth and individual tray depth during placement in Farm 1.

Location:	Sluice gate	1.1	1.2	1.3	1.4	1.5	1.6
Water depth (cm)	95	68	77	54	60	72	76

5.2.2 Farm 2

Farm 2 is the neighbouring (northern side) farm of farm 1 and the largest of the research sites in Tra Vinh. Farm 2 has an area of 6.5 hectares and a mangrove cover percentage of 30%. Most of the mangroves in the middle of the farm are 20 years old, the other ones in the farm are 5 to 6 years old. Sediment is pumped out of the farm every 3 years and is used as foundation for a new house. Dredging of the farm takes place every 1 to 2 years near the riverbanks at the sluice, the other parts of the farm are dredged less

Figure 12: Detailed view of Farm 2, including the sluice gate and tray locations.

often (approximately once per 10 years). The farmers indicate that they do not use the parts of the farm closest to the road and they are not sure what they are going to do with those parts of the pond in the future. The flushing of the farm is done two times per month, for four to five days. The sluice is opened for 2 to 3 hours during high tide and for 2 hours during low tide. Farm 2 is connected to the same manmade channel as farm 1, with 1.3 km to the nearest downstream and 2.4 km to the nearest upstream bifurcation.

In farm 2 there is one tray placed very close to the sluice gate, and another one further away since the pond near the sluice gate is narrow. Tray number 9 is placed in a very shallow position with barely any waterflow since it is so far from the sluice gate and a shallow environment. Tray 7 was placed in a larger pond within the system with a water depth of 90 cm. The other trays were placed with water depths ranging from 31 to 82 cm and the sluice gate water depth was 140 cm. All the water depth values can be seen in Table 7 below.

Table 7: Sluice gate depth and individual tray depth during placement in Farm 2.

Location:	**Sluice gate**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**
Water depth (cm)	140	38	66	70	71	81	82	90	50	31

5.2.3 Farm 3

Farm 3 is connected to the same river as farm 1 and 2, although it's directly connected to the river with the sluice gate. It has an area of 2.3 hectares, the smallest of the research sites, and a mangrove cover of 30%. The mangrove age differs a lot, close

Figure 13: Detailed view of Farm 3, including the sluice gate and tray locations.

to the road the mangroves are over 30 years old, the ones in the pond are 4 to 10 years old and the smallest mangroves are 2 years old.

The farm is dredged every 3 years while sediment pumping is only done every 5 to 7 years. The dredged materials are deposited on the banks while the pumped sediments are used as foundations near the house. The pond is flushed two times per month, for three days and usually for about 2 hours during both low and high tide.

Farm 3 is divided in three larger ponds; a tray was placed in every individual pond and according to the protocol, two trays were placed close to the sluice gate. The pond with tray 3.5, was shallow compared to the other ponds. Tray 3.3 was also located on a shallow bank, while the channel at tray 3.4 was very deep. In Table 8 the water depth values of farm 3 are shown.

Table 8: Sluice gate depth and individual tray depth during placement in Farm 3.

Location:	**Sluice gate**	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**
Water depth (cm)	105	81	99	52	108	54	88

5.2.4 Farm 4

Farm 4 is the most northern farm of the research sites in Tra Vinh. It has an area of 2.5 hectares, and a mangrove cover of 15%. It has a lower mangrove cover percentage compared to the other farms because the landowner only recently (2021) changed from intensive shrimp ponds to mangrove-shrimp, meaning that she had to plant new mangroves. The mangroves in the middle of the farm, on the small island, are 10 years and older while the other mangroves are all 3 months old. The farm is dredged every 3 to 5 years and the sediment pumping is done every 10 years. The farm is connected to the same bifurcation as the other farms with a manmade channel of 0.7 km. Flushing of the farm takes place twice a month for three days, the sluice will be opened for 2.5 hours during both low and high tide.

Figure 14: Detailed view of Farm 4, including the sluice gate and tray locations

In farm 4, one tray (4.6) was placed very close to the sluice while another tray (4.5) is placed further due to an and deeper pond bed. Due to the previous intensive shrimp ponds of the owner, the research site still consists of multiple smaller ponds that are connected to each other. Around tray 4.3 the depth was shallower with 66 cm; the other parts of the farm were all deeper. In Table 9 the water depth values of farm 4 can be seen.

Table 9: Sluice gate depth and individual tray depth during placement in Farm 4.

Location:	**Sluice gate**	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**4.6**
Water depth (cm)	157	107	110	66	116	88	106

5.2 Ca Mau

The farms in Ca Mau are all located in Ngọc Hiển District, which is the southernmost rural district of Ca Mau province. Figure 21 shows the zoom-in of the Ca Mau overview map from Figure 11. The farms lay within 500 meters of each other but do have a larger road or other farms in between them. Farm 6 is connected to a different bifurcation of the Cửa Lớn River than farms 5, 7, and 8; which are all connected to the same bifurcation of the Cửa Lớn River directly. Similar to Tra Vinh, the farms in Ca Mau are all owned by different households and therefore have slightly different maintenance and water management practices.

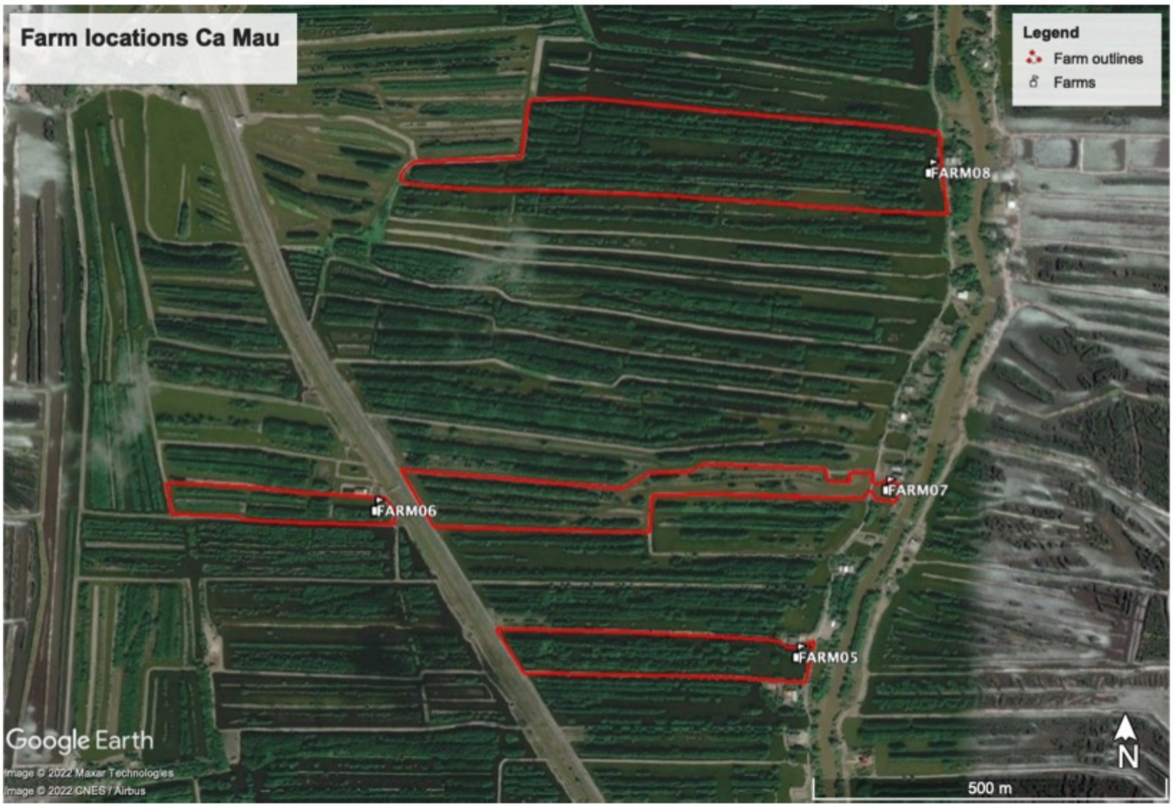

Figure 15: Farm locations in Ca Mau.

5.3.1 Farm 5

Farm 5 has an area of 2.5 hectares and a mangrove cover of 30%. The satellite imagery from Figure 22 is old, the current mangroves are way smaller since they cut the mangroves recently. The bigger mangroves in the farm are 3 years old whereas the others are only about 3 months old. The farm is dredged every one to 3 years, and sediments are pumped out once a year. The dredging works are not consistent, sometimes they dredge one part of the farm in a certain year and the other part(s) in the year(s) after.

The dredged materials from the outer channels are deposited on the outer banks of the farm whereas the dredged material from the inner channels is deposited on the mangrove roots. The deposition of sediment after dredging is done as closely as possible, therefore the sediments from the inner channels are deposited on the mangrove roots. The farm is flushed two times per month to harvest shrimp but can also be flushed when the water quality is bad. Usually during the flushing, they open the sluice for three to four days, 1 hour during high tide and 2 to 3 hours during low tide.

Figure 16: Detailed view of Farm 5, including the sluice gate and tray locations.

The trays at the outsides of the pond and near the sluices were situated at the deepest parts of the pond. Especially the channels in the middle of the pond were shallower, as can be seen with tray 5.2. Tray 5.1 was the deepest with 99 cm, the whole northern bank of the pond was relatively deep due to recent dredging activities. In Table 10 the water depth for the different trays and the sluice gate is noted.

Table 10: Sluice gate depth and individual tray depth during placement in Farm 5.

Location:	**Sluice gate**	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	**5.6**

Water depth (cm)	156	99	57	80	92	80	88

5.3.2 Farm 6

Farm 6 has an area of 3.6 hectares and a mangrove cover of 60%. The mangroves age ranges from 3 to 8 years old and they are placed in sections. The farm is dredged every 3 years with an excavator and they always deposit the dredged material on the closest banks. Mud is pumped out every 2 years and they use those dredged material to heighten the foundation of their house. The farm is flushed two times a month for three to four days, depending on the tidal regime. The owner opens the sluice for 2 hours during low and high tide.

Figure 17: Detailed view of Farm 6, including the sluice gate and tray locations.

In farm 6, besides tray 6.3, all the trays are placed in relatively deep sections. The whole pond was relatively deep except for the inner channels running from north to south and vice versa. Tray 6.3 was the placed in the shallowest part of the pond with a water depth of 60 cm. The other inner north-south channels had similar depths but due to the limitation of the number of trays no other trays were placed in those locations. The deepest part of the pond was close to the sluice, which was similar in the other research sites, were two trays were placed. Tray 6.7 was only placed during the first month of data collection. Table 11 shows the water depth at the sluice gate and for all the trays in farm 6.

Table 11: Sluice gate depth and individual tray depth during placement in Farm 6.

Location:	**Sluice gate**	**6.1**	**6.2**	**6.3**	**6.4**	**6.5**	**6.6**	**6.7**
Water depth (cm)	153	104	101	60	105	109	112	108

5.3.3. Farm 7

Farm 7 is the second largest of the research sites with an area of 7 hectares. The farm has a mangrove cover of 60%, with mangroves from 3 months up to 7 years old. Closer to the road there's many newly planted mangroves that are 3 months old, in the middle of the farm the mangroves are up to 7 years old. The farmer dredges the pond

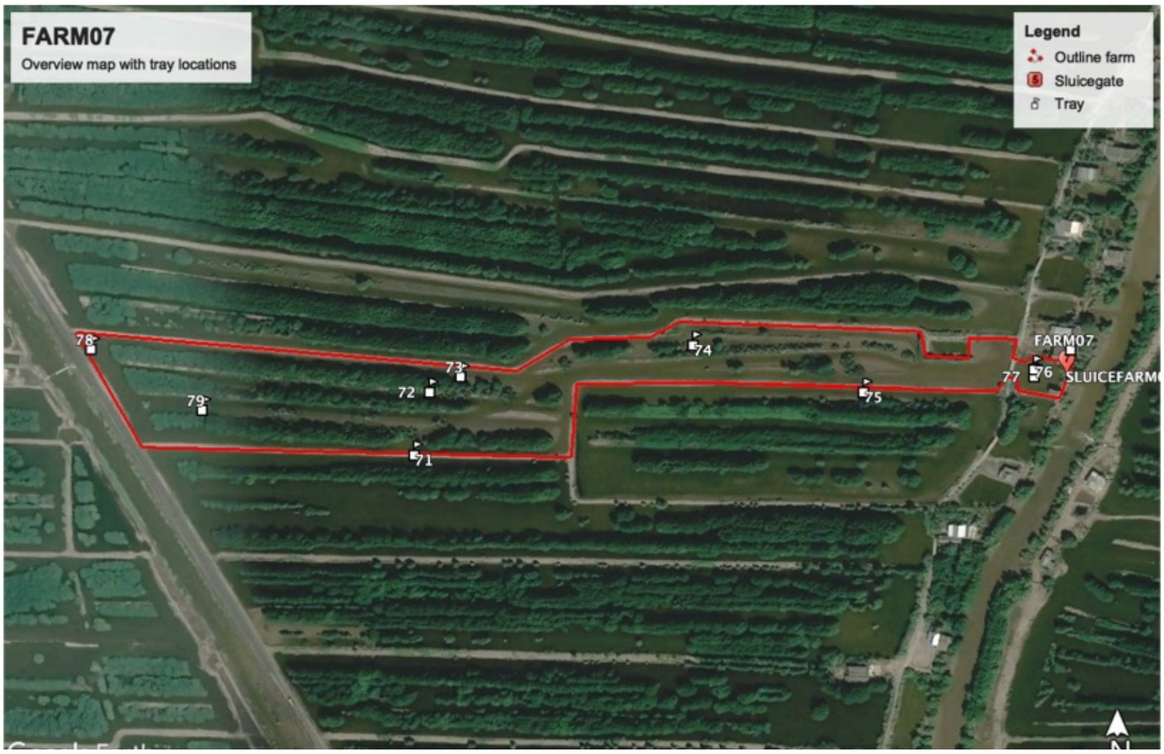

Figure 18: Detailed view of Farm 7, including the sluice gate and tray locations.

every 3 years, together with his neighbours, and pumps the sediment every 2 years. The dredged sediments are deposited on the banks of the pond while the pumped sediments are used to heighten and fertilize his vegetable farm. The farm is flushed two times per month, the gate is opened two to three days for 3 hours during high tide and 4 hours during low tide.

In farm 7 tray 7.7, which is placed directly in front of the sluice is the deepest with 117 cm. When moving to the side, the depth of the pond would get significantly shallower as can be seen by the water depth of 76 cm from tray 7.6. Trays 7.8 and 7.9 were only placed after the first month of monitoring. The inner channel where tray 7.9 was located was shallow along the whole channel. The sluice gate depth of farm 7 was the deepest of all research sites. The sluice gate and different tray depths can be seen in Table 12 below.

Table 12: Sluice gate depth and individual tray depth during placement in Farm 7.

Location:	**Sluice gate**	**7.1**	**7.2**	**7.3**	**7.4**	**7.5**	**7.6**	**7.7**	**7.8**	**7.9**
Water depth (cm)	174	65	80	75	75	86	76	117	80	45

5.3.4. Farm 8

Farm 8 is the largest of the research sites with 8.3 hectares in size. The mangrove cover percentage is above 70% and the mangroves in the farm are mostly 17 years old. The farm is dredged every 2 to 3 years, depending on the sedimentation. The farmer believes the sediment is very rich in nutrients and therefore shovels the deposited dredged material on the riverbank back into the pond after a few years, and when compacted. The sediment is pumped once a year and the sediments are deposited around the house to create a foundation. The last time they dredged was in 2019, and they will only dredge again in 2 to 3 years due to the dense canopy cover of the mangrove. Due to the age and dense canopy of the mangrove currently the focus of this farm is not on catching shrimp or crab, they are waiting until they can fell the mangroves and sell the wood. The water in the pond is flushed twice per month, usually for about four days and 4 hours during both low and high tide.

Figure 19: Detailed view of Farm 8, including the sluice gate and tray locations.

Trays 8.9, 8.10, and 8.11 were only placed after the first month of monitoring. Trays 8.10 and 8.11 have significantly shallower locations in the pond, the middle channels and middle open space were relatively shallower compared to other parts of the pond. No trays were placed in front of the sluice because the farmer had nets there to catch shrimp and fish. Therefore tray 8.7 and 8.8 are further away from the sluice. The water depth near the sluice gate was very deep, over 200 cm. In Table 13 the sluice gate and tray depths can be seen.

Table 13: Sluice gate depth and individual tray depth during placement in Farm 8.

Location:	**Sluice gate**	**8.1**	**8.2**	**8.3**	**8.4**	**8.5**	**8.6**	**8.7**	**8.8**	**8.9**	**8.10**	**8.11**
Water depth (cm)	117	126	106	111	113	100	133	136	100	113	71	87

6. Results

The results are separated in a sedimentation and laboratory test section. Firstly, in the sedimentation section the sedimentation per farm is presented and the individual farms and provinces are compared to each other. Secondly, the laboratory test results are presented.

6.1 Sedimentation

In this section the sedimentation is presented, all the sedimentation values are pristine, uncompacted sediments which are high in water content. The raw data of the measurements made during the data recovery trips is computed to values in cm/30 days, because of the irregular timing of the trips. The averages are computed by combining the 5 individual measurement points, as shown in the raw data file, of every tray. Firstly, each of the eight research sites have their own table with the average sedimentation in cm/30 days per tray (four columns in total), total average cm/30 days per tray of the four research periods combined, and the whole farm average in cm/30 days. When a value in the tables is equal to 0, the text displayed is N/A. Below the eight sedimentation tables, there is an explanation concerning those N/A values. Secondly, a table with the farm and province averages and information is shown in Table 23. Lastly, Table 24 shows the average values per farm per individual data retrieval trip, to see if seasonal trends can be observed. For the best interpretation of the sedimentation results, it is recommended to keep the overview maps and depth-tables of Chapter 5. Research Sites next to the tables below.

6.1.1 Farm 1

Table 14: Sedimentation rates in cm/30 days for Farm 1 (Tra Vinh).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
1.1	0.63	4.05	5.24	2.38	3.08	**2.31**
1.2	2.17	1.83	2.10	0.91	1.75	
1.3	2.28	0.39	1.01	0.06	0.93	
1.4	1.44	3.57	3.30	4.72	3.26	
1.5	0.67	2.90	2.03	2.24	1.96	
1.6	4.00	2.71	3.12	1.69	2.88	

Farm 1 has an average monthly sedimentation rate of 2.31 cm/30 days over the whole farm, the highest of all farms. The trays with most of the sedimentation, >2 cm total average per 30 days, are all situated relatively close to the sluice gate. Trays 2 and 3 are the furthest from the sluice gate and have the lowest sedimentation rate. The water depths of the trays were relatively equal, varying between 54 and 76 cm with an average of 68 cm.

6.1.2 Farm 2

Table 15: Sedimentation rates in cm/30 days for Farm 2 (Tra Vinh).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
2.1	0.39	1.39	1.31	0.19	0.82	**2.14**
2.2	N/A	1.61	1.24	1.54	1.10	
2.3	1.78	3.15	4.04	2.74	2.93	
2.4	3.67	4.30	8.74	3.45	5.04	
2.5	1.00	2.73	3.64	3.26	2.66	
2.6	2.83	2.55	2.65	1.51	2.39	
2.7	0.72	0.84	0.97	0.21	0.69	
2.8	0.50	2.61	3.25	3.66	2.50	
2.9	0.39	2.16	2.14	0.05	1.18	

Farm 2 has the second highest average monthly sedimentation rate over the whole farm, with 2.14 cm/30 days. Trays 3 to 6 all lay close to or in the vicinity of the sluice gate, they all have an average sediment rate of >2.3 cm/30 days. Trays 1, 2, 7, 8, and 9 are further from the sluice gate but do have variated average rates of sediment throughout the months. While trays 8 and 9 are further from the sluice gate, they have averaged monthly sedimentation rates of 2.50 and 1.18 cm/30 days, respectively. Trays 1 and 9 were put in the shallowest areas of the pond in water depths of 38 and 31 cm, respectively. The other trays ranged between 50 and 90 cm depth and the average tray depth of farm 2 is 64 cm.

6.1.3 Farm 3

Table 16: Sedimentation rates in cm/30 days for Farm 3 (Tra Vinh).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)

3.1	3.67	2.09	1.52	2.71	2.50	**1.83**
3.2	2.28	2.49	2.45	1.51	2.18	
3.3	3.39	2.55	1.73	0.32	2.00	
3.4	1.72	2.73	2.21	0.97	1.91	
3.5	1.44	0.77	0.78	0.06	0.76	
3.6	1.00	3.58	1.27	0.78	1.66	

With an average monthly sediment rate of 1.83 cm/30 days over the whole farm, farm 3 scores the third highest out of the research sites. Trays 1 and 2 were placed very close to the sluice gate and have the highest rates with 2.50 and 2.18 cm total average per 30 days. Tray 3, which is still relatively close to the sluice has a rate of 2.0 cm/30 days, while tray 4, further from the sluice, has a total average per 30 days rate of 1.91 cm. Farm 3 is divided in three smaller ponds and tray 1 to 4 all lay in the pond attached to the sluice. Tray 5 is placed in the furthest pond, which is connected with the sluice-pond through the other pond, which contains tray 6 (see Figure 19 for the locations). Tray 5 has a total average monthly sedimentation height of 0.76, tray 6 has 1.66 cm/30 days. The water depths of the trays ranged from 52 to 108 cm with an average of 80 cm.

6.1.4 Farm 4

Table 17: Sedimentation rates in cm/30 days for Farm 4 (Tra Vinh).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
4.1	1.09	0.71	0.71	N/A	0.84	**1.51**
4.2	2.89	3.98	1.73	0.26	2.21	
4.3	N/A	1.05	0.71	0.05	0.60	
4.4	1.13	1.34	1.92	1.05	1.36	
4.5	0.64	1.29	2.93	1.51	1.59	
4.6	2.76	3.99	1.46	0.24	2.11	

Farm 4 has a farm average sedimentation height of 1.51 cm/30 days, the lowest of the Tra Vinh farms but higher than the Ca Mau rates. Trays 5 and 6 were placed the closest to the sluice and have total average sediment heights of 1.59 and 2.11 cm/30 days, respectively. With a monthly total average rate of 2.21 cm/30 days, tray 2 has the highest values while tray 2 is located the furthest from the sluice gate. Tray 3 was placed on a shallow area in the pond and has the lowest depth, with 66 cm, and the lowest sediment total average with 0.60 cm/30 days. The tray depths in the pond varied from 66 to 116 cm and an average of 98 cm.

6.1.5 Farm 5

Table 18: Sedimentation rates in cm/30 days for Farm 5 (Ca Mau).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
5.1	4.99	N/A	2.38	N/A	3.69	**1.15**
5.2	0.73	1.32	1.88	0.08	1.00	
5.3	0.79	1.84	1.31	0.53	1.12	
5.4	0.32	0.40	0.24	0.51	0.37	
5.5	1.03	2.62	1.44	0.60	1.42	
5.6	0.13	0.90	0.54	0.81	0.59	

With a monthly farm average sedimentation rate of 1.15 cm/30 days, farm 5 has the second highest rate in Ca Mau but the third lowest out of all farms. Tray 1, which is the furthest from the sluice gate, has the highest total average per month value with 3.69 cm/30 days, although it must be mentioned that the tray was displaced twice and therefore the average is calculated with only two input heights. Trays 5 and 6 are placed in front of the sluice and have sediment rates of 1.42 and 0.59 cm/30 days. Tray 6 was placed directly in front of the sluice during the first fieldtrip, afterwards it has been moved slightly to the side of the pond, but still close to the sluice. The water depths ranged from 57 to 99 cm with an average of 83 cm.

6.1.6 Farm 6

Table 19: Sedimentation rates in cm/30 days for Farm 6 (Ca Mau).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
6.1	2.01	1.96	0.51	1.24	1.43	**1.47**
6.2	0.69	0.66	1.25	0.54	0.79	
6.3	0.13	0.56	0.28	0.30	0.32	
6.4	0.19	2.62	1.03	0.84	1.17	
6.5	0.19	7.92	2.16	N/A	3.42	
6.6	0.49	6.20	0.65	0.88	2.05	
6.7	N/A	3.70	0.49	0.79	1.66	

Farm 6 has the highest average sediment rate per month of the Ca Mau farms and has the fifth highest rate of all farms. Trays 5 and 6 have the highest values throughout the survey with total averages of 3.42 and 2.05 cm/30 days respectively. Tray 7 was placed during the first retrieval trip in week 42, 2022. Tray 3 has the lowest total average rate with 0.32 cm/30 days and consistently has low rates throughout the monitoring time. Tray 3 was placed in a water depth of 60 cm, the lowest of this farm. The other water depths ranged between 101 and 112 cm and the average over all water depths was 100 cm.

6.1.7 Farm 7

Table 20: Sedimentation rates in cm/30 days for Farm 7 (Ca Mau).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
7.1	0.94	0.78	1.34	0.43	0.87	
7.2	0.64	0.62	1.07	0.09	0.61	
7.3	0.36	2.00	1.31	0.64	1.08	
7.4	0.53	0.50	1.71	0.58	0.83	
7.5	1.50	3.16	3.09	0.84	2.15	**1.02**
7.6	0.68	0.88	1.75	0.23	0.88	
7.7	0.49	0.48	1.03	1.26	0.81	
7.8	N/A	0.94	2.98	0.28	1.40	
7.9	N/A	N/A	0.43	N/A	0.21	

With a farm average sedimentation rate of 1.02 cm per 30 days, farm 7 has the smallest rate from all the farms and in Ca Mau. Trays 8 and 9 only were placed after the first sediment retrieval trip in week 42, 2022. Tray 9 has the lowest total average sediment rate per month with 0.21 cm/30 days; it must be noted that there was only one occasion that there was sediment on this tray. The other N/A values are mentioned in Table 22 below, where the accompanying text will elaborate on these values. Tray 5 has the highest total average value with 2.15 cm/30 days and is located relatively close to the sluice. Tray 8, which is located the furthest from the sluice gate has the second highest rate with 1.40 cm/30 days. Tray 9 was placed on the shallowest location with 45 cm depth, the other trays ranged between 65 and 118 cm with an average over all depths of 78 cm.

6.1.8 Farm 8

Table 21: Sedimentation rates in cm/30 days for Farm 8 (Ca Mau).

Tray	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)	Total average (cm/30 days)	Farm average 1-4 (cm/30 days)
8.1	1.14	1.50	1.94	1.26	1.46	**1.02**
8.2	2.64	0.54	0.90	0.69	1.19	
8.3	0.60	0.63	1.28	0.68	0.79	
8.4	3.62	0.46	0.99	0.51	1.39	
8.5	1.22	0.20	0.82	0.79	0.76	
8.6	1.97	2.74	1.93	0.49	1.78	
8.7	0.38	1.72	1.83	0.69	1.16	
8.8	0.47	0.20	0.95	1.14	0.69	
8.9	N/A	0.16	1.04	1.65	0.95	
8.10	N/A	N/A	0.28	0.08	0.12	
8.11	N/A	0.22	1.22	0.17	0.53	

Farm 8 has the second lowest sedimentation rate of all farms with a farm average per month of 1.02 cm/30 days. Trays 9, 10, and 11 were placed after the first month of sediment retrieval and therefore have a zero value in the first month. Tray 10 has the lowest value of all trays with a total average per month of 0.12 cm/30 days, it was placed after the first month and in the second month there was no sediment although the tray was placed correctly. Tray 6 has the highest average value with 1.78 and tray 1 is second with 1.46 cm/30 days. The trays with higher and lower values are spread throughout the whole farm, there is no clear trend observed. Tray 8.10, has besides the lowest sediment rate, also the lowest depth with 71 cm. The other trays have depths varying between 87 and 136 cm, with a farm average of 109 cm; the deepest of all farms.

6.1.9 N/A values

Table 22 below shows the N/A values from the tables above. The table presents the location of the farm and tray, the month in which the value was N/A, and the reason why there was no sediment on the tray. In case of 'No particular reason, there was no sediment on the tray while it was placed correctly' the N/A values are processed as 0 in the total averages per month and farm average values in Tables 14 – 21. For N/A values with a different reason, the N/A was not considered for the average calculations. This is done because for those cases either the tray was newly placed in that month, or the tray was dislocated or lost in such way that it was not able to trap sediments. Therefore it would not be representable to count those N/A values in the averages, this could potentially lower the averages without valid reasons.

Table 22: Explanation on the N/A values during the sediment retrieval, including location and field trip month.

Location	Month	Reason no sediment
2.2	1st	No particular reason, there was no sediment on the tray while it was placed correctly
4.2	1st	Tray moved and 'floated' above the bed
6.7	1st	Newly placed tray
7.8	1st	Newly placed tray
7.9	1st	Newly placed tray
8.9	1st	Newly placed tray
8.10	1st	Newly placed tray
8.11	1st	Newly placed tray
5.1	2nd	Tray was displaced, not sure how
7.9	2nd	No particular reason, there was no sediment on the tray while it was placed correctly
8.10	2nd	No particular reason, there was no sediment on the tray while it was placed correctly
4.1	4th	Crabhole displaced the tray
5.1	4th	Tray was displaced, not sure how
6.5	4th	Lost the tray
7.9	4th	Tray was displaced, not sure how

6.1.10 Average sediment rates

Table 23 shows the total average sediment rates per farm per month, as shown in the separate farm tables above, and the total average sediment rate for Tra Vinh and Ca Mau specifically. Besides those, it shows farm details such as the size and the mangrove cover, together with those averaged over both provinces.

Table 23: Farm details, size, mangrove cover, the total average 30 days sediment rates per farm and the details and sediment rates averaged per province.

Farm	1	2	3	4	5	6	7	8
Size (ha)	2.5	6.5	2.3	2.5	2.5	3.6	7	8.3
Mangrove cover (%)	30	30	30	15	30	60	60	70
Total average sediment (cm/30 days)	2.31	2.14	1.83	1.51	1.15	1.47	1.02	1.02
Province	**Tra Vinh**				**Ca Mau**			
Total average sediment (cm/30 days)	1.95				1.16			
Average size (ha)	3.45				4.4			
Average Mangrove cover (%)	26.25				55			

The average total sediment rate of Tra Vinh is 1.95 cm/30 days, while the rate in Ca Mau is 1.16 cm/30 days. Generally, the farms in Tra Vinh are smaller, with an average of 3.45 ha. Most of the farms in Tra Vinh are sized around 2.5 ha, while the largest farm, number 2, is 6.5 ha. The mangrove cover in Tra Vinh is significantly lower, with a cover of 26% it is not even half of the cover percentage of 55% in Ca Mau. The farms in Ca Mau are larger with an average area of 4.40 ha. The smallest farm is 2.5 ha, while the largest has an area of 8.3 ha.

Table 24: The averages per farm per data retrieval trip, the total averages for the individual provinces per data retrieval trip, and the total average over all farms per data retrieval trip, all in cm/30 days.

Farm	Average 1st (cm/30 days)	Average 2nd (cm/30 days)	Average 3rd (cm/30 days)	Average 4th (cm/30 days)
1	1.86	2.57	2.80	2.00
2	1.25	2.37	3.11	1.85
3	2.25	2.37	1.66	1.06
4	1.70	2.06	1.58	0.62
5	1.33	1.42	1.30	0.50
6	0.62	3.37	0.91	0.77

7	0.64	1.04	1.64	0.54
8	1.50	0.76	1.20	0.74
Total average Tra Vinh	**1.77**	**2.34**	**2.29**	**1.38**
Total average Ca Mau	**1.02**	**1.65**	**1.26**	**0.64**
Total average all farms	**1.40**	**2.00**	**1.77**	**1.01**

The table above shows that the 4th data retrieval campaign had the lowest amount of sedimentation for all the farms. The 2nd data retrieval campaign had the highest values. The total averages of all farms are in line with both the Tra Vinh and Ca Mau individual averages.

6.2 Estimated potential sedimentation rates

In this section the sedimentation rates from this research were used to estimate how much sediment these integrated mangrove-shrimp systems could possibly provide to Tra Vinh, Ca Mau, and all the coastal provinces in the Mekong Delta. Moreover, with the estimated potential sedimentation rates it is possible to determine whether mangrove-shrimp systems are capable of mitigating RSLR. The sedimentation rates gathered in this study are used for these estimations, along with, the aquaculture and mangrove areas in 2020 from Phan and Stive (2022), and the mangrove cover factor. The calculations show two scenarios: firstly a scenario with 'infinite' sediment supply, and secondly with limited sediment available.

6.2.1 Background and used literature

The measured sedimentation rates during this study are of pristine, uncompacted sediments which are high in water content. Over time, these sediments would compact, as well as becoming dry when dredged and deposited on land, which causes more compaction eventually. Therefore the sedimentation rates of 1.95 cm/30 days in Tra Vinh and 1.16 cm/30 days in Ca Mau are surface accretion rates. Previous conducted research from Lovelock et al. (2015), and Zoccarato et al. (2018) was used to estimate the surface elevation. To estimate the surface elevation, yearly accretion rates are needed.

To estimate the yearly accretion rates, the assumption was made that this study covers a fair representation of a whole year. This study was conducted from September until February, taking place in both the rainy and dry season, and therefore assumed a fair representation of a year. The yearly sedimentation accretion rates in mangrove-shrimp farms in the research provinces of Tra Vinh and Ca Mau would be 23.73 cm/year and 14.11 cm/year, respectively.

Lovelock et al. (2015) found a shallow compaction rate of 2.52 cm/year in Ca Mau and 3.17 cm/year next to Tra Vinh. Here the assumption was made that these values are representative in the study areas of this research. Thus, these shallow compaction rates are subtracted from the yearly sedimentation rates in this study. Besides shallow compaction, Zoccarato et al. (2018) found natural compaction rates of Holocene sediments at the Mekong Delta Coastline equal to 2 cm/year. Again, the assumption was made that this natural compaction rate is representative in the study areas of this research. Thus, the natural compaction rate of Holocene sediments is subtracted from the yearly sedimentation rates in this study. Resulting in estimated sediment accumulation of 18.56 cm/year for Tra Vinh and 9.59 cm/year for Ca Mau.

An internal study and data from IUCN estimated that integrated mangrove shrimp systems occupy an estimated 50,000 hectares of land in the Mekong Delta (Tien, et al., 2016; The Asean Post, 2018). There is no other data on the area of mangrove shrimp systems in the Mekong delta, therefore the 50,000 hectares is assumed to be correct in this study. It is not clear in which provinces these 50,000 hectares are located and what share of area these provinces have. Therefore, assumptions should be made when using this area of integrated mangrove shrimp. Besides the area of integrated shrimp systems, Phan and Stive (2022) quantitively documented the evolution of aquaculture and mangrove area in the Mekong Delta by processing satellite imagery. Their area data from 2020, shown in Table 1, is used in this section to quantify the estimated sediment potential. The table shows the areas of aquaculture and mangrove in hectare for individual coastal provinces and the entire coastal area of the Mekong Delta in 2020. Please note that these areas of mangrove and aquaculture do not exist out of mangrove shrimp systems only at this moment. It is unclear how many hectares of the Phan and Stive data are actual mangrove-shrimp systems. Therefore the calculations involving these potential hectares of mangrove and aquaculture are assumptions.

According to Phan and Stive (2022), Ca Mau represents 51.0% of all the aquaculture and 66.7% of all the mangroves in the coastal provinces of the Mekong Delta while Tra Vinh represents 8.8% and 9.8% respectively. Thus, these provinces cover 59.8% of all aquaculture areas and 76.5% of all mangrove areas in the coastal provinces of the Mekong delta. This research covered a total of 4 sites in both Tra Vinh and Ca Mau, although these sites were in the same districts in the individual provinces. Therefore, potentially the results from this study could differ from the average rates in both the provinces. Due to limitations of this study, the assumption was made that the sediment rates in this study are representable for the entire province of Tra Vinh and Ca Mau. For the remaining 40.2% (aquaculture area) and 23.5% (mangrove area) that were not covered in this research an assumption of the sedimentation rate was made. The assumption is made that those areas have the averaged sedimentation rate per year over the Tra Vinh and Ca Mau rates, resulting in a surface elevation rate of 0.14 m/year.

The mangrove cover factor is applied to the calculations because the integrated mangrove shrimp ponds have a certain mangrove cover. Thereby, the surrounding pond area is covered by infrastructure such as, but not limited to, roads, buildings, and crops. Meaning that the area does not exist solely out of mangroves nor waterbodies such as rivers, canals, and ponds. These areas, that are not integrated mangrove shrimp systems nor mangroves are assumed to not accumulate sediment in this calculation. Therefore, with above mentioned assumptions, this results in a mangrove cover percentage of 50%, which results in a mangrove cover factor of 0.5.

6.2.2 Calculations scenario 1

With the made assumptions and data obtained above, the potential sediment volume in m^3 can be calculated. For calculating the sediment volume in m^3, the following equation is used:

$$Volume\ in\ m^3 = area\ (ha) * 10.000\ \left(conversion\ rate\ \frac{ha}{m}\ to\ m^3\right) * surface\ elevation\ rate\ \left(\frac{m}{year}\right) * mangrove\ cover\ factor$$

First, the formula is applied to the estimated area of mangrove shrimp systems of 50,000 hectares (Tien, et al., 2016; The Asean Post, 2018), the estimated sedimenta accumulation rates (m/year) of this study, and the estimated mangrove cover factor. Secondly, the same was done for the aquaculture and mangrove areas (ha) by Phan and Stive (2022), to determine the potential if land use is changed into integrated mangrove shrimp systems. For this second part, it must be mentioned that the aquaculture areas, labelled by the study of Phan and Stive (2022), also contain other aquacultural systems such as intensive shrimp farms. Therefore, the yearly sediment volume in m^3 of mangrove and aquaculture could only potentially be reached when aquacultural systems are changing to integrated mangrove-shrimp farming systems, as advised by Phan and Stive (2022). Thirdly, the equation is used to estimate the potential for the entire coastal area of the Mekong Delta. Again, under the assumption that the all the aquacultural and mangrove areas are converted to mangrove-shrimp systems.

In the upscaling calculations for the potential sediment volumes in m^3, if current aquacultural and mangrove areas are converted to mangrove-shrimp systems, the assumption is made that there is an infinite sediment supply. This assumption must be made for the upscaling calculations. This implies that the upscaling values are best estimates and maximum values.

The first calculation results in the following equation:

$$Volume\ in\ m^3 = 50{,}000\ (ha) * 10.000\ \left(conversion\ rate\ \frac{ha}{m}\ to\ m^3\right) * 0.12\ \left(\frac{m}{year}\right) * 0.5 = 30{,}000{,}000\ m^3$$

Thus, the roughly estimated yearly sediment volume in m^3 for the existing mangrove shrimp systems is 30 million m^3.

Secondly, the equation was used to calculate the potential of mangrove shrimp systems in Tra Vinh and Ca Mau if current aquacultural and mangrove areas are converted to integrated mangrove shrimp systems. These results are shown in Table 25, below:

Table 25: Estimated potential yearly sediment volumes in m^3 for Tra Vinh and Ca Mau if aquaculture and mangrove areas are converted to integrated mangrove shrimp systems.

Province:		**Tra Vinh**	**Ca Mau**	**Total**
Estimated potential yearly sediment volume in m^3	***Aquaculture***	*26,329,545*	*78,679,723*	*105,009,268*
	Mangrove	9,305,333	32,670,097	41,975,429
	Total	35,634,878	111,349,820	146,984,698

Thus, when the current aquacultural and mangrove areas in Tra Vinh and Ca Mau are converted to mangrove shrimp systems and the assumption of infinite sediment supply is made, this could potentially create a yearly sediment volume of almost 147 million m^3.

Thirdly, the equation was used to calculate the potential of mangrove shrimp systems in the entire coastal area of the Mekong Delta. Again, if current aquacultural and mangrove areas are converted to integrated mangrove shrimp systems. These results are shown in Table 26, below:

Table 26: Estimated potential yearly sediment volumes in m3 the remaining coastal provinces and all the coastal provinces combined if aquaculture and mangrove areas are converted to integrated mangrove shrimp systems.

Province:	**Total all coastal provinces**

Estimated potential yearly sediment volume in m^3	***Aquaculture***	192,936,000
	Mangrove	61,296,000
	Total	254,232,000

Thus, when the current aquacultural and mangrove areas in the Mekong Delta are converted to mangrove shrimp systems and the assumption of infinite sediment supply is made, this could potentially create a yearly sediment volume of 254 million m^3.

6.2.3 Calculation scenario 2

In the second and third calculations above, the assumption was made that there is an infinite sediment supply in the Mekong Delta. However, this is not the case in the delta where there are actual sediment deficits. In a real situation, there will be competition for available sediments in the delta and the supply would not be infinite. Therefore, unlike the calculations above, another scenario was created where there is actual competition for available sediments. Here the assumption is made that the roughly estimated yearly sediment volume in m^3 for the existing mangrove shrimp systems (50,000 ha) of 30 million m^3, is the total available sediment for the system. Meaning that, if other land uses are converted to integrated mangrove-shrimp systems, the amount of sediment will remain the same but is distributed over a larger area. In this analyse, calculations were made to find out how large this area can be to compensate for RSLR according to Dunn and Minderhoud (2022). This is calculated by the following equation:

$$Potential\ area\ (ha) = \frac{Estimated\ potential\ yearly\ sediment\ volume\ (m^3)}{RSLR\ Scenario\ (\frac{mm}{year})} * 0{,}1\ \left(conversion\ rate\ m^3\ to\ \frac{ha}{mm}\right)$$

Lastly, according to Dunn and Minderhoud (2022) the RSLR rates according to their Middle Scenario for 2050 is 16.5 mm/year in the Mekong Delta. By using the equation from above, the potential area to mitigate RSLR of 16.5mm/year for the Middle Scenario in 2050 is 181,818 hectares. Meaning that with an assumed limited sediment supply of 30 million m^3 and the Middle Scenario for 2050 (RSLR of 16.5 mm/year) from Dunn and Minderhoud (2022), integrated mangrove shrimp systems could mitigate RSLR for an area of almost 182,000 hectares.

6.3 Laboratory tests

Here the results from the laboratory tests are shown, first the laser granulometry tests and after the LOI results. All the laboratory tests are performed on the collected sediments during the first data collection trip in week 42, 2022.

6.3.1 Granulometry

In this section the granulometry data is described. The table with raw data is in Appendix E and shows the composition of all the tested sediment per tray. The table in Appendix E shows the percentages of clay, silt, and sand respectively. In this section, firstly the composition of the tested sediments is visualised in 2-D columns per research province in Figure 26 and 27. The sediment composition in the sites in Tra Vinh is shown first (Figure 26) and the Ca Mau sites second (Figure 27). Secondly, the composites per farm and the farms per province are averaged to compare, Table 27 shows these values.

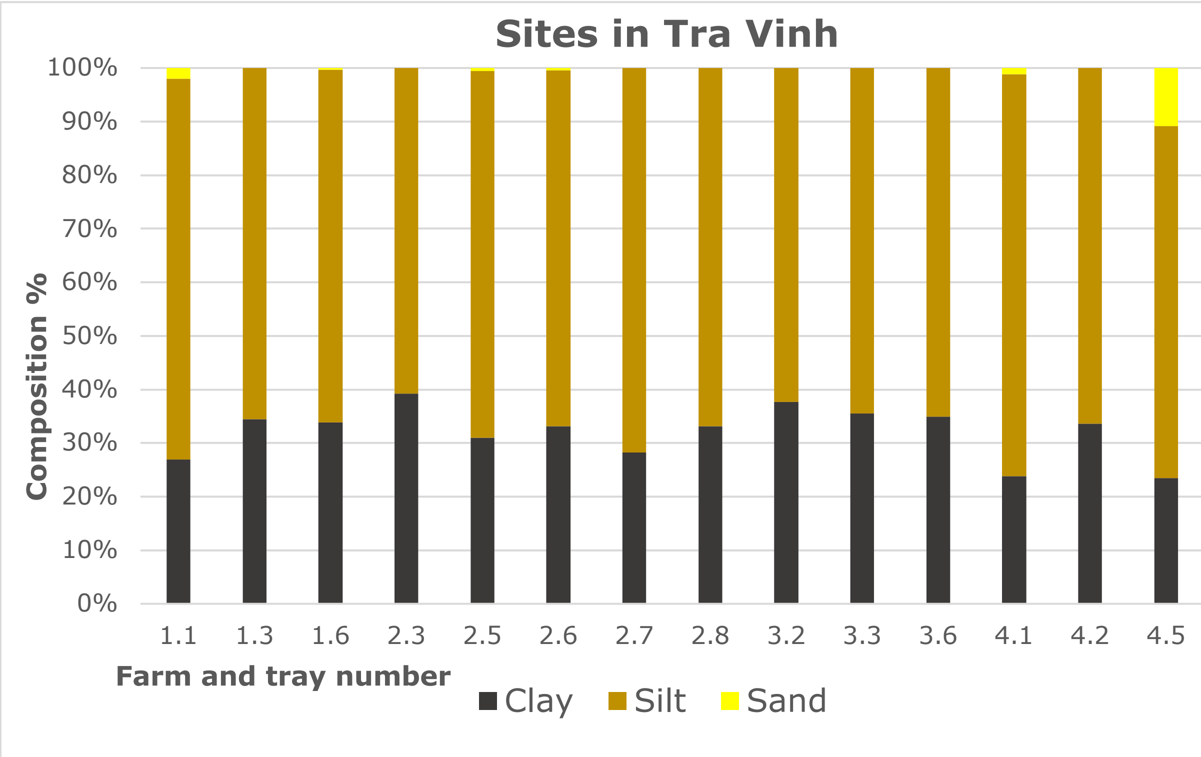

Figure 20: Granulometry results for the sites in Tra Vinh in composition %

Figures 26 and 27 show that there is barely sand within the composition of the accumulated sediments. Tray 4.5 has the highest sand percentage with 10.8%, while tray 1.1 has 2.0%, and tray 4.1 1.1%. The other trays that had a fraction of sand in their sediments are; 2.6, 2.5, and 1.6, their sediments contain <1% of sand. The sediments on tray 7.2 have a silt percentage of 100%. All the other sediments on the tested trays consist of out of a combination of clay and silt only; ranging between 21.1 to 45.6% of clay and between 54.4 and 78.9% silt.

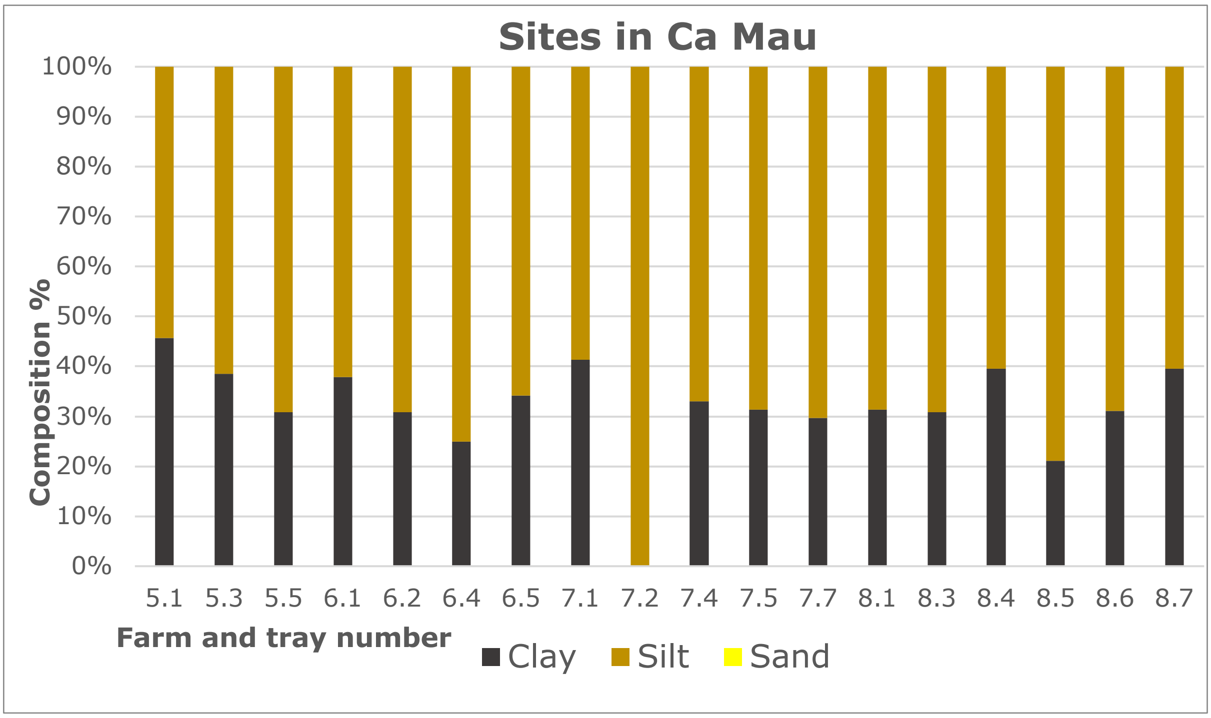

Figure 21: Granulometry results for the sites in Ca Mau in composition %.

Table 27: The average percentages of clay, silt, and sand in the individual farms, total averages over all farms, and divided averages per province.

Farm	1	2	3	4	5	6	7	8	Tot. Av. %
Average clay %	31.7	32.9	36.1	27.0	38.3	32.0	27.1	32.2	31.9
Average silt %	67.5	66.9	63.9	69.0	61.7	68.0	72.9	67.8	67.6
Average sand %	0.8	0.2	0.0	4.0	0.0	0.0	0.0	0.0	0.5
Province	Tra Vinh				Ca Mau				
Total average clay %	32.07				31.77				
Total average silt %	66.84				68.23				
Total average sand %	1.09				0.00				

Table 27 shows that farms 4 and 7 contain the lowest percentages of clay with 27.0 and 27.1% respectively, which is slightly lower than the total average of 32.2%. Furthermore, those farms are also the farms with the highest percentage of silt with 72.9 and 69.0 respectively, while the average is 67.6%. Farms 1, 2, and 4 are the only ones where the sediment contains sand, with 0.8, 0.2, and 4.0% respectively. When Tra Vinh and Ca Mau are compared to each other it can be noticed that the composition differences are not too large. The total average clay percentage in Tra Vinh is 32.07% against 31.77 in Ca Mau, which is only a difference of 0.30%. The total difference in percentage between the silt percentage in Tra Vinh and Ca Mau is 1.40%, with the percentages of 66.84 and 68.23% respectively. Since the farms in Ca Mau do not contain any sand, the difference is 1.09%, the average percentage of sand in the Tra Vinh farms.

6.3.2 Loss on Ignition

In this section the LOI results are presented with tables and graphs. The table with raw data is shown in Appendix F. Containing the farm and tray, pore-water %, organic material %, the calcite ($CaCO_3$) %, and the total LOI % within the sediment samples. Firstly, the information from the table is represented in graphs to give a better visual overview of the LOI results; there are separate graphs for the pore-water %, organic material %, the calcite %, and the total LOI %. Please note that the total LOI percentage has been computed over the wet sample weight and the total weight loss after LOI. The individual LOI percentages for pore-water, organic material, and $CaCO_3$ have been computed according to the LOI protocol as described in the Methods section. Secondly, the individual sample LOI results are averaged per farm and over the research provinces; here the different farms and the two provinces can be compared. Below, in Figures 28, 29, 30 and 31 the data from Appendix F is visualised in 2-D columns per tray.

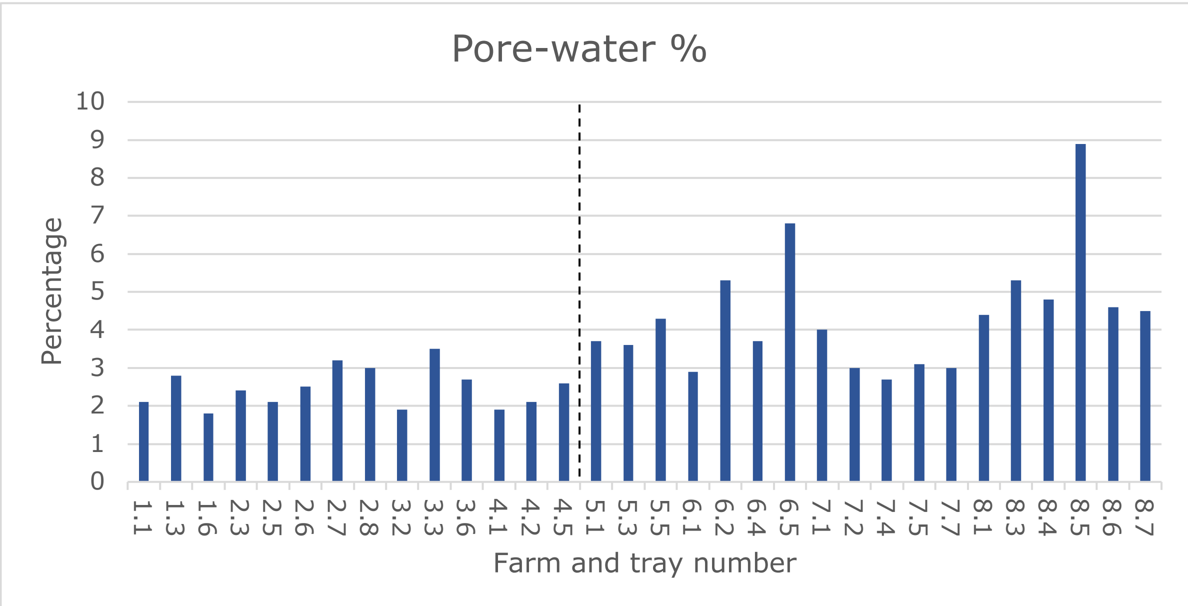

Figure 22: Pore-water percentage in the LOI tested sediments with dashed line split between provinces.

The pore-water percentage in the tested sediments ranges from 1.8 to 8.9%, with an average value of 3.5%. The highest value is pore-water is present in tray 8.5, while the lowest value is in tray 1.6. Generally, the pore-water percentages are higher from tray 5.1 and onwards, which are the farms in Ca Mau.

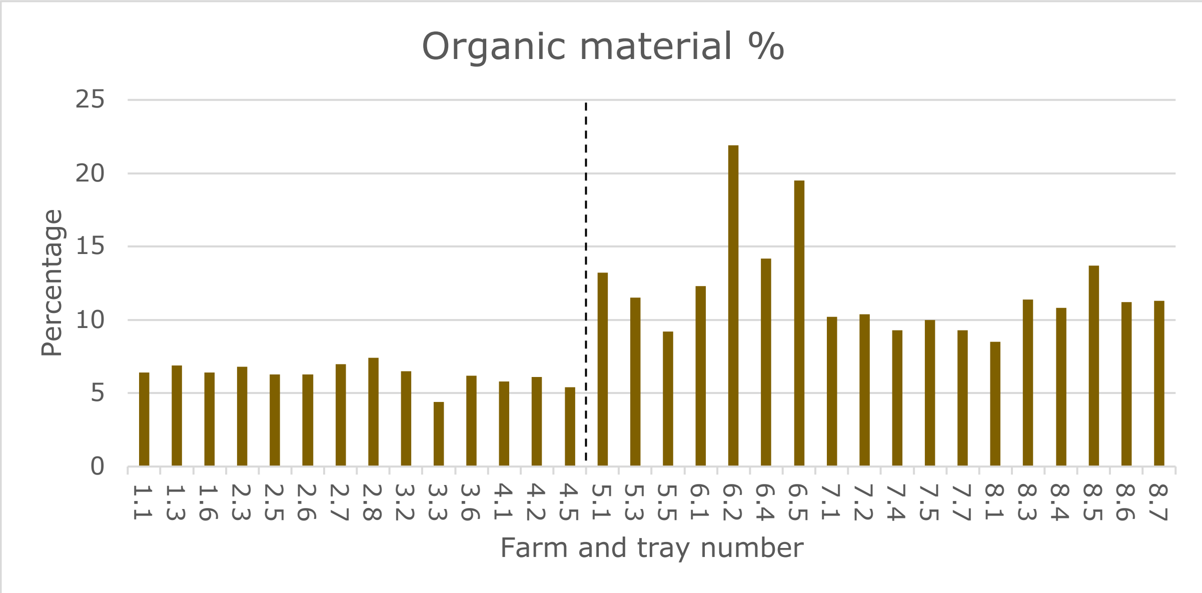

Figure 23: Organic material percentage in the LOI tested sediments with dashed line split between provinces.

In line with the pore-water percentages, the organic material percentage graphs show a trend where the values in Ca Mau are significantly higher than the Tra Vinh percentages. Farm 6 has a significant larger fraction of organic material compared to the other farms. The organic material percentage ranges from 4.4 to 21.9%, with an average value of 9.6%. The 21.9% is found in tray 6.2 and the 4.4% in tray 3.3.

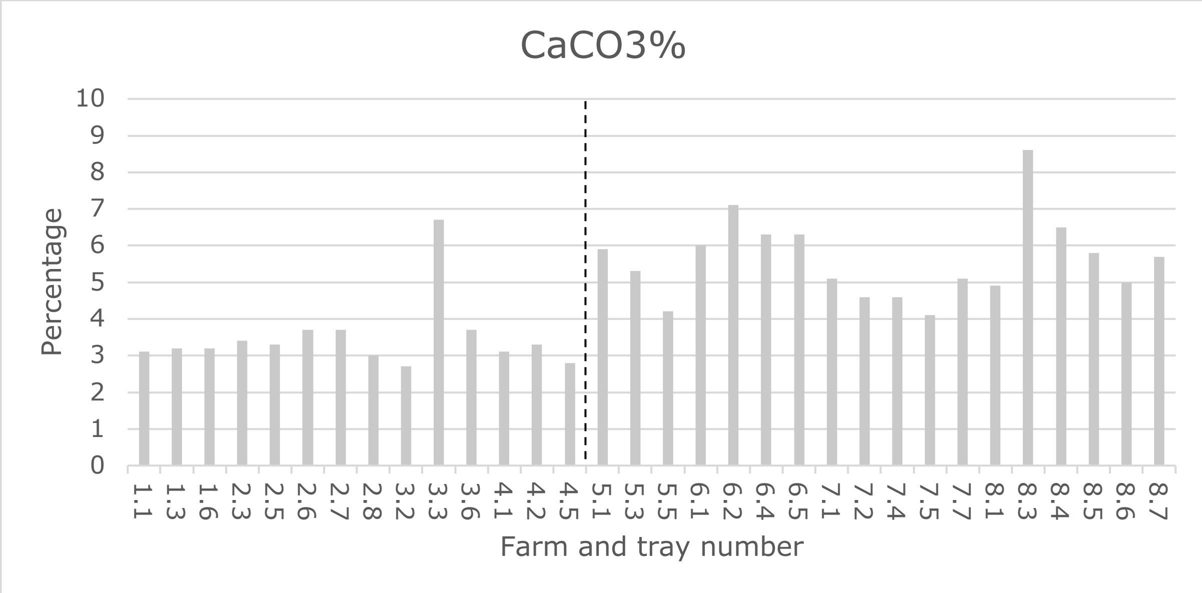

Figure 24: Calcite percentage in the LOI tested sediments with dashed line split between provinces.

The amount of calcite in the tested sediments ranges from 2.7 to 8.6%, with an average value of 4.7%. The highest value is found in tray 8.3 and the lowest in tray 3.2. Besides the calcite percentage in tray 3.3, all the calcite fractions in Ca Mau are higher than those in Tra Vinh.

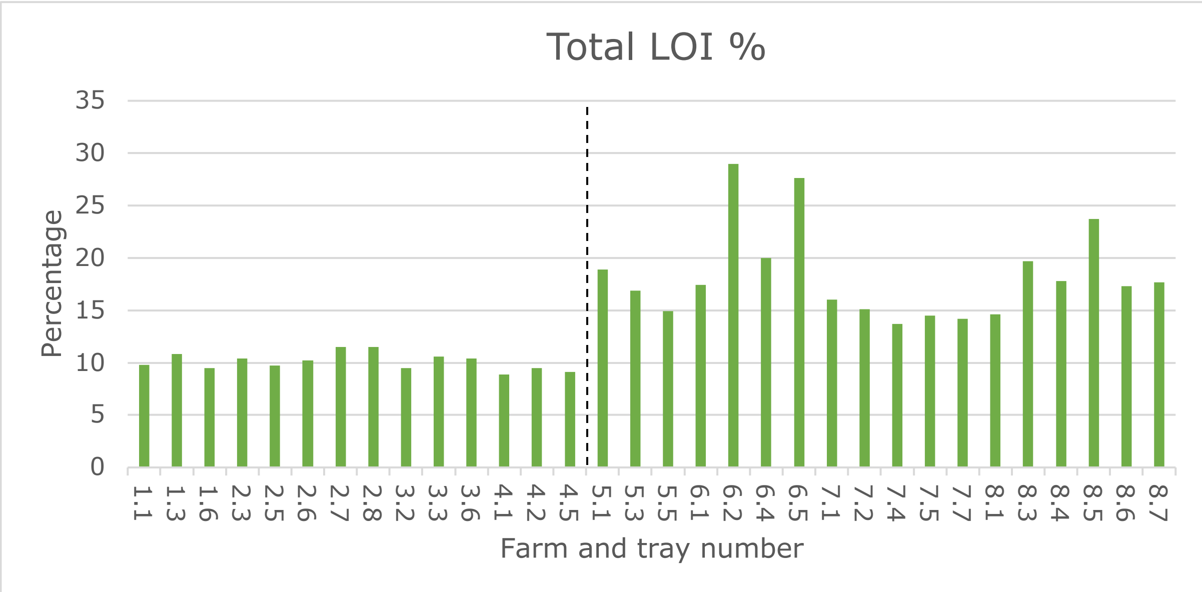

Figure 25: Total LOI percentage with dashed line split between provinces

In Figure 31 the total LOI percentage can be seen. For the total LOI % the values range from 8.9% to 29% with an average of 14.7%. The highest value is found in tray 6.2 and the lowest in tray 4.1. The individual LOI percentages (pore-water, organic material, and CaCO3) in Ca Mau were larger than in Tra Vinh. Logically, the total LOI percentages in Ca Mau are significantly higher than those in Tra Vinh. In Table 28 below the average percentages of the individual LOI tests and total LOI values per farm and per province are displayed.

Table 28: The average percentages of pore-water, organic material, and calcite in the individual farms, total averages over all farms, and divided averages per province.

Farm	1	2	3	4	5	6	7	8	Tot. Av. %
Average pore-water %	2.2	2.6	2.7	2.2	3.9	4.7	3.2	5.4	3.5
Average organic material %	6.6	6.8	5.7	5.8	11.3	17.0	9.8	11.2	9.6
Average CaCO3 %	3.2	3.4	4.4	3.1	5.1	6.4	4.7	6.1	4.7
Average total LOI %	10.0	10.7	10.2	9.2	16.9	23.5	14.7	18.5	14.7
Province	**Tra Vinh**				**Ca Mau**				
Total average pore-water %	2.5				4.4				
Total average organic material %	6.3				12.1				
Total average CaCO3%	3.5				5.6				
Total average total LOI%	10.1				18.3				

Table 28 shows clearly that the pore-water, organic material, calcite percentages, and total LOI are significantly higher in Ca Mau over Tra Vinh. The Ca Mau percentage of pore-water, organic material, calcite, and total LOI are respectively 1.77, 1.93, 1.61, and 1,81 times higher than in Tra Vinh. The farm specific and province specific averages are visualised in a 2-D graph and shown in Figure 32 below.

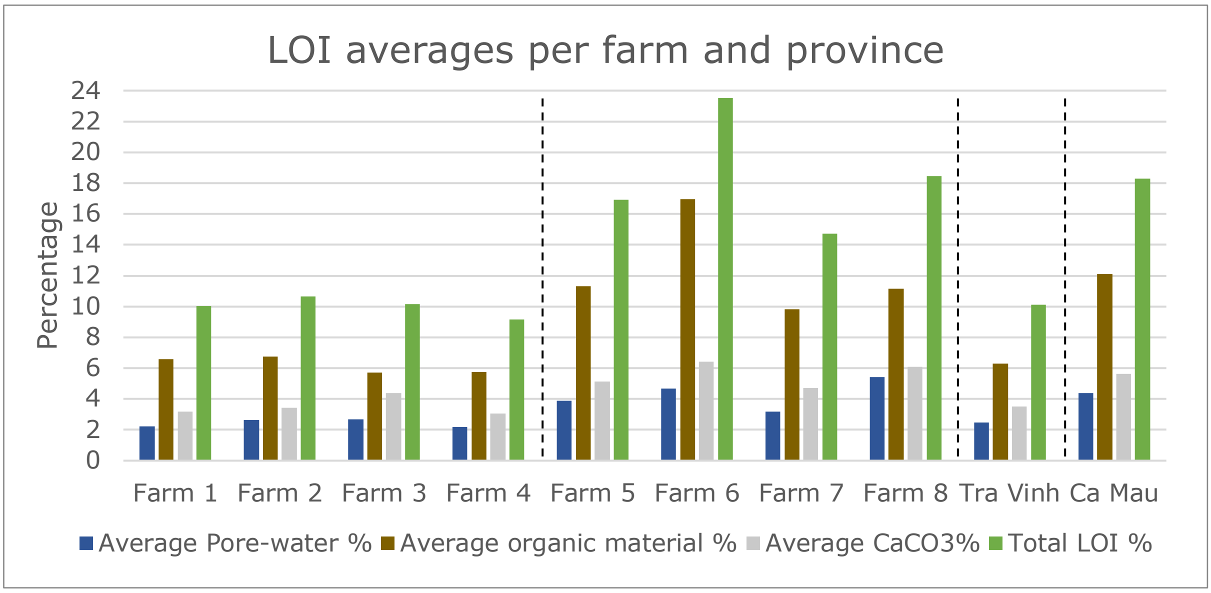

Figure 26: LOI average percentages of pore-water, organic material, calcite, and total LOI per farm and per province with dashed line split between provinces and average per province.

Figure 33, on the next page, shows all the results for the LOI and granulometry in percentage of the tested trays; sand, silt, clay, $CaCO_3$, Organic material, and pore-water, respectively. Clear correlations on the compositions cannot be assessed quickly with this figure, the tests results appear to be uncorrelated. For example, higher percentages of sand, silt, and/or clay do not appear to have a vast influence on the LOI results. Again, the figure does confirm that there are differences between the compositions of the two provinces and that the values in Ca Mau are significantly higher.

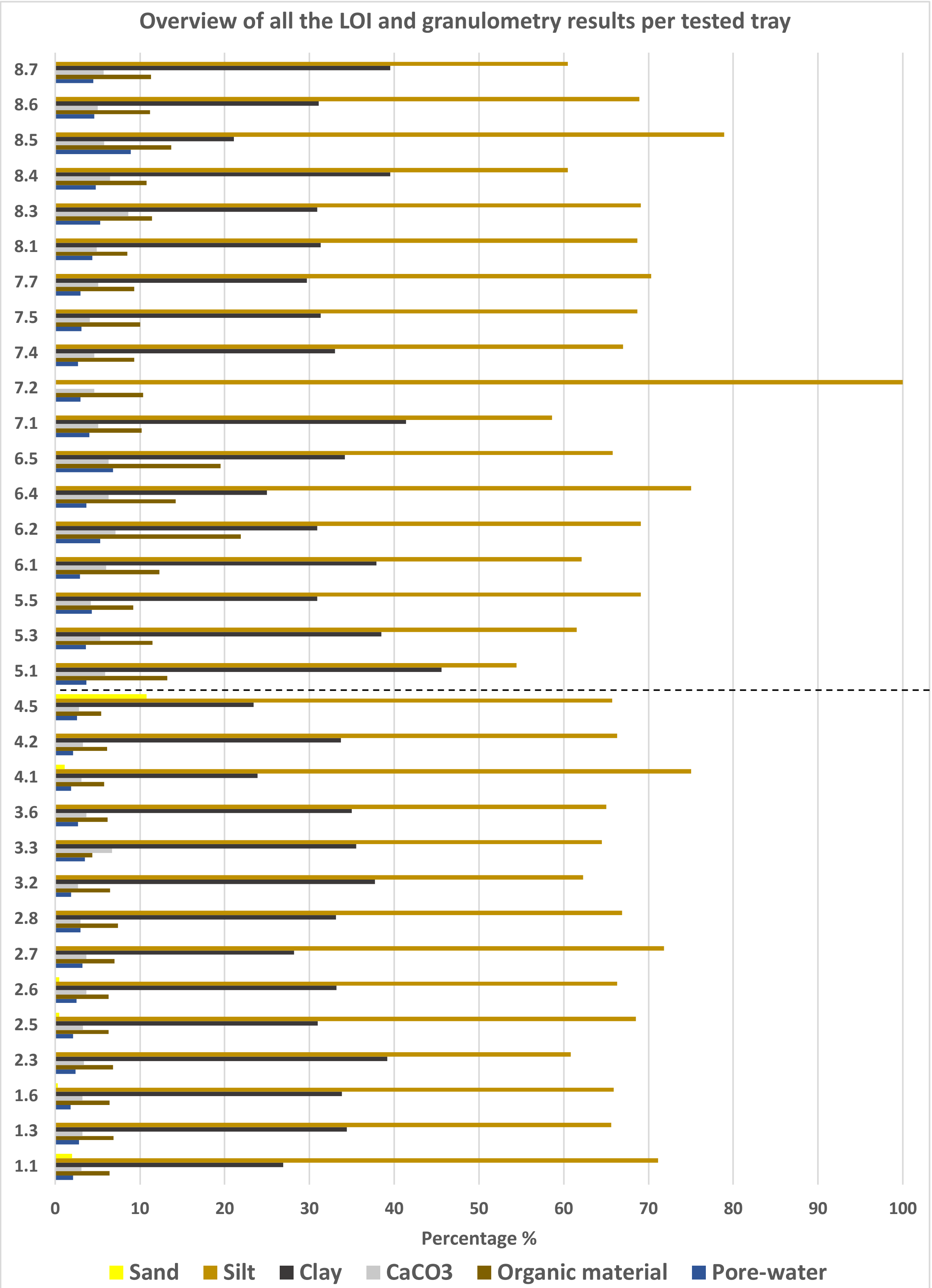

Figure 27: Overview of all the LOI and granulometry results per tested tray with dashed line split between provinces.

7. Discussion

7.1 Accuracy and precision fieldwork

There are several accuracy and precision uncertainties within the different fieldwork stages of this research:

7.1.1 Placement

During placement of the trays in the research ponds, it is hard to determine the ‘perfect’ spot for a tray. The water in the ponds has a very high turbidity, even in the shallowest conditions encountered it is impossible to see the bed of the pond. When wearing scuba goggles it is impossible to look further than 10 cm underwater due to the high turbidity. Therefore, the placement of the trays must be done by carefully touching the surrounding with hands or feet, without disturbing the bed. In this stage it can happen that a tray is placed close to a bump, on a sloped bank, or that the touching disturbed the bed and changed the conditions.

7.1.2 Monitoring period

When the trays are placed in the pond, usually they are left there for around one month before the accumulated sediment on top of the tray is recovered. During this month, the trays are not monitored and different conditions and circumstances can hamper the research results. There is a lot of underwater life within the ponds such as, but not limited to, shrimp, crab, fish, and water snakes that can potentially disturb the samples. During the retrieval of sediments throughout the months, multiple trays were moved by e.g., crabs that dug holes underneath the trays or for unknown reasons. Furthermore, the farmers work in the ponds on regular basis for maintenance practices and to catch shrimp, crabs, and or fish. The farmers navigate with boats in the pond or wade through the water, although the trays are marked with sticks and floats; bumping into trays is not unlikely.

Throughout the month, the farms are usually flushed twice; especially close to the sluice the currents can be very strong, and the sediments can be disturbed or completely flushed off the tray. The farmers open the sluice gate during low-tide to empty the pond, and during high-tide to refill the pond. The farms are being flushed with the river/channel water closest to the farm and therefore the sediment quantities in this water, used for flushing, differs. There is no data available on the water that is being used to flush the ponds. It would be highly recommendable to conduct suspended sediment tests on the water that is being used to flush throughout a year, in both the dry and wet season, to get a solid overview of how much sediments are being carried into the ponds during flushing. Potentially, the differences between the sediment accumulation rates in Ca Mau and Tra Vinh could be explained by different suspended sediment rates in the river or channel systems; further research is required to determine the differences. Additionally, the conducted interviews showed that the flushing regimes of the farmers in the same province would be relatively similar because they are all dependent on the same tidal schedule. Nevertheless, some farmers would open the sluice a bit longer or shorter than others, which can also result in different sedimentation rates. Therefore, it is recommended to conduct exact research on flushing times and water quantities that flow through the sluice gates.

Farmers pump sediments or dredge throughout the year and this can also influence the sediments on the trays when these pumping and dredging works take place close to the trays. Potentially, the flushing and dredging of the farms influence trays in different ways depending on their location. Activities close to trays can clear out the tray and limited sediment. While these activities further away from trays might rework the sediments and increases sedimentation. Therefore, the locations of the trays are important; as many trays as possible have been placed and were evenly distributed to remove spatial variability.

Lastly, the flushing and sediment pumping or dredging of the ponds could potentially cause sediment ‘recycling’ within the ponds. The different maintenance works and/or the flushing does change flow velocities and dynamics within the pond. It is probable that these stir the sediment and bring it into suspension again, after a certain time the sediments will settle again and added to the sediment accumulation rates. Right now, it is uncertain of the accumulated sediments are all ‘new’ sediments instead of ‘recycled’ sediments. Therefore, it is recommendable to further research this matter by e.g., conducting suspended sediment tests on the water that flows through the sluice.

7.1.3 External influences

Besides influence from animals and the farmers, the weather can disturb samples as well. Extreme downpours and storms while samples are retrieved can disturb the samples, these conditions are hard to work in and a mistake is easily made. Measuring the sediment height with the ruler, while the extreme downpour is blurring vision can be inaccurate. Seasonality must also be considered; the conditions during dry and rainy season change significantly. Generally, the dry season in the study area takes place from December to April and the rainy season from May to November. The first measured sediments in this research were collected in October, while the last run was in March; meaning that the research was carried out partially in wet and rainy season. During the wet season there is much more rain, and the rivers carry much more water and sediments, while during the dry season there is less flow rate and less sediment. During the dry season the tidal influences are also larger because the water can be carried further upstream due to the tidal flow. Lastly, within the wet season the heavy downpour can erode sediments from land into the water systems while this effect is not present during dry season.

7.1.4 Retrieval

Lastly, retrieving the trays with the sediment can be challenging and potentially disturb the sediments. When the trays are placed in deeper pond parts, it is difficult to dive down and pull the tray out of the bed. Locating the trays underwater can be challenging, no matter the water depth. It can happen that the sediments on the tray are touched before the handles of the tray are found to pull it out. During the pulling out the tray must be kept straight, and pressure should be applied on the frame to prevent sediments washing away; this can potentially disturb the sediment sample when mistakes are made. Lastly, measuring the sediment height with a ruler can be unprecise if the ruler is not put in exactly 90 degrees and during visually reading the values mistakes can be made.

7.2 Sedimentation

This study found accretion rates of 1.95 cm/30 days in Tra Vinh and 1.16 cm/30 days in Ca Mau. The assumption is made that the four months of monitoring during this study covers a fair representation of a whole year. Resulting in yearly accretion rates in mangrove-shrimp farms in the research provinces of Tra Vinh and Ca Mau of 23.73 cm/year and 14.11 cm/year, respectively.

7.2.1 Preliminary IUCN study

This contradicts the findings of the preliminary IUCN Viet Nam study (Tien, et al., 2016). It must be mentioned that the preliminary IUCN study (2016) used field interviews with sedimentation estimations by farmers; they used 17 mangrove-shrimp farms in Tra Vinh and 20 in Ca Mau. The mangrove-shrimp farms that were used in the IUCN study (2016) were also partially located in Duyen Hai and Ngoc Hien Districts, similar to the districts where this research is conducted. The results from the IUCN study (2016), stated a sediment accumulation rate of 18.11 cm/year in Tra Vinh and 27.55 in Ca Mau. Although the order of the rates is in line, the rates in the provinces are reversed in this study where the results show a higher sedimentation rate in Tra Vinh over Ca Mau.

7.2.2 Interviews

During this study, interviews were conducted with the owners of the research sites. The Interview section in the Methodology shows some general information about how the interviews were conducted, and the Appendix C – Interview section shows the questions and answers. During the interviews with the farmers, all the farmers in Tra Vinh indicated sedimentation rate estimates between 20 and 30 cm per year. Where in Ca Mau the farmers indicated sedimentation rate estimates between 10 to 20 cm (two farmers), 30 to 40 cm (one farmer), and 30 to 50 cm (one farmer). All the farmers in both Tra Vinh and Ca Mau said that there is more sedimentation during rainy season than in dry season, which could not be verified during this study due to its length of four months. The yearly sedimentation rate assumptions of the farmers in Tra Vinh were confirmed during this study, the farmers indicated 20 to 30 cm/year and this study shows a rate of 23.73 cm/year in Tra Vinh. According to this study, half of the farmers in Ca Mau largely overestimated the yearly sedimentation rates with values between 30 to 50 cm/year, while the other two farmers their assumptions were in line with this research with rates between 10 and 20 cm/year; which is in line with the rate of 14.11 cm/year that this study found.

It is important to note that the farmers used estimations during the interviews, e.g. when indicating water depth or sedimentation rates they would show their estimations with their hands first and then guess how many centimetres this would be. This was also the case for other estimations, therefore the outcomes of the interviews cannot be used as exact values.

7.2.3 Estimations

In this study, the sediment accumulation rates were estimated by using the observed accretion rates in the mangrove shrimp farms. To estimate the surface elevation rates, the previous studies of Lovelock et al. (2015), and Zoccarato et al. (2018) were used. These studies take shallow and Holocene compaction in account for the coastal mangrove areas in the Mekong Delta. By using their study results and assuming that those results would be of equal representation in the study sites from this study, sediment accumulation rates were estimated. This resulted in sediment accumulation rates of 18.56 cm/year and 9.59 cm/year in Tra Vinh and Ca Mau, respectively. These rates are still higher than e.g., the sediment accumulation rates from Zoccarato et al. (2018). The study from Zoccarato et al. (2018) was conducted in coastal areas, not specifically in mangrove-shrimp systems as this study did. This could potentially be among the reasons why the rates of this study are of a magnitude higher. Thereby, the shallow and Holocene compaction rates were assumed to be equal to previous research, again not specifically in mangrove-shrimp systems (Lovelock, et al., 2015) (Zoccarato, et al., 2018). Furthermore, accreted sedimentation from this study contained pristine, uncompacted, high in water content sediments. One way to counter these uncertainties is to conduct research on the compaction rates of the sediments from the research sites used in this study.

7.2.4 Assumptions

This study made assumptions for the entire coastal area of the Mekong Delta, based on the eight research sites in Tra Vinh and Ca Mau. For future research it would be beneficial to also conduct research in other provinces, this would decrease the number of estimations and assumptions and increase the confidence of results. Also, in this study the research sites were all located in the same districts in the two provinces. For future research and to obtain a better overview of the delta, it would be beneficial to spread out the research sites evenly.

Furthermore, in this study the assumption is made that the current area of integrated mangrove shrimp systems contains 50,000 hectares of land. This is backed by internal IUCN knowledge (Tien, et al., 2016; The Asean Post, 2018). Unfortunately, there is no data from the General Statistics Office on solely integrated mangrove shrimp systems (General Statistics Office, 2023). They only categorise by mangrove or aquacultural area per province, similar to what Phan and Stive (2022) did. Thereby, the 50,000 hectares is a best estimate but does not give information on shares of this area per province. Therefore, the area only was used to calculate sedimentation over the entire coastal areas of the Mekong Delta.

Additionally, this study made calculations with the assumption that the current areas of aquaculture and mangroves from Phan and Stive (2022) will be converted to integrated mangrove shrimp systems. This would mean immense changes in the current land use practices, and it is unsure whether this is feasible. Thereby, in the calculations for upscaling, the assumption that there is infinite sediment supply was also made. This is in contradiction to the actual situation in the Mekong Delta, where there are sediment scarcities. Therefore the calculations containing the infinite sediment supply can only be used as best estimates and maximum values. Future research could improve these calculations by looking at the available sediments in the Mekong River and using those as the maximum sedimentation instead of infinite.

Moreover, besides assuming infinite sediment supply, another scenario was created where the sediment supply is limited, which is deemed to be a more realistic scenario. Here, the estimated yearly sediment volume in m^3 for the current 50,000 hectares of integrated mangrove shrimp systems was as total available sediment. This resulted in a calculation to determine how much hectares of land could potentially mitigate RSLR from a Middle Scenario in 2050 (Dunn & Minderhoud, 2022) in the Mekong Delta. Again, the available sediments in the Mekong River could improve these calculations in future research.

7.2.5 Sediment dynamics

Concerning the sediment dynamics in the ponds, throughout the four months of research it is very difficult to spot trends in the dynamics. Generally, based on the average data, it seems that the sedimentation rates closer to the sluice are larger. Although, there are some exceptions observed to this trend in some farms and during different field campaigns. Furthermore, different tray depths did not show a concessive trend. In this study shallower laying trays, located further from or close by the sluice, had both higher and lower sedimentation values. Additionally, there was no trend observed in sediment rates in inner or outer channels in the ponds; the average sediment values did differ in both the inner and outer channels. Therefore, it is not possible to yet determine the sediment dynamics inside the mangrove-shrimp farms with certainty. Nevertheless, IUCN Viet Nam will continue this study for a full year; which will give a full overview of the sediments accumulation and increase the chance of spotting a trend in the pond sediment dynamics.

7.2.6 Feasibility

The feasibility of mangrove-shrimp farms as nature-based solution to alleviate the impact of RSLR is probable. This research shows high rates of sediment accumulation within the ponds throughout the wet and dry season. Although, there are still many uncertainties about the processes, and numbers of recommendations have been made for further research. If further research can give clarity on uncertainties and recommendations from this study, the assessments whether these systems can alleviate RSLR can be strengthened.

7.3 Laboratory tests

The laboratory test results from this research do give insights in the composition of the soils in the research sites. Although, all the tests are performed after the first field trip in week 42. It would be beneficial for the research to conduct laboratory tests throughout the year, in both the dry and rainy season. Currently the tests only represent one specific month of sediment accumulation, this makes it hard to make claims and impossible to spot any trends. Therefore, it is highly recommendable to conduct these laboratory tests on accumulated sediments throughout the year. This can give a better overview of the sediment dynamics and composition.

7.3.1 Laser granulometry

The laboratory results of the laser granulometry tests showed that there is barely any sand within the sample compositions. The only sand particles were found in 6 different trays in Tra Vinh where the percentages ranged from 0.3% to 10.8%. The total average percentage of sand in Tra Vinh was only 1.09%. The Ca Mau sediments from this study did not contain any sand particles.

Research from Unverricht et al., (2013), Tamura et al., (2020), and Ta et al., (2005) indicated dominant sandier sediments near the Tra Vinh coast as well as medium sand in the top layer of soil, and a coast mainly composed of mud near Ca Mau. It should be mentioned that their research was not conducted specifically on mangrove-shrimp systems, whereas this study did focus on these systems solely. Their research focused on the coastal areas, subaqueous areas, and shallow offshore coastal sediments. This study indeed shows that there is no sand present in the sediments in Ca Mau, although the supposedly sandier sediments in Tra Vinh were barely represented in this research. Sediment starvation is a common anthropogenic threat in the Mekong Delta, causing sediment deficits. The sediment deficits are caused by disruptions such as, but not limited to, upstream hydropower dams which hamper the free flow of sediments into the delta, and sandmining which reduces sediment availability. These disruptions could be a potential cause of the low sand percentages found in the tested sediments. An informative experiment would be to conduct laser diffraction granulometry tests on sediment samples from the Bassac and Mekong rivers near the research sites to assess their sand components.

7.3.2 LOI-protocol

The laboratory tests of the LOI-protocol showed higher concentrations of pore-water, organic material, and calcite in Ca Mau than Tra Vinh with respectively 1.77, 1.93, and 1.61 times the values in Tra Vinh. According to the study of IUCN (2016), large fractions of the sediments are organic. The LOI results show that organic material percentage is not as high as expected, with farm average values ranging from 5.7 to 17%. The highest percentage of organic material was measured in Ca Mau with 21.9%. During the IUCN study (2016) and the interviews, farmers claimed that the percentage of organics would be very large in ponds with a higher mangrove cover percentage. Therefore, very high organic contents would be expected in farm 8, since that specific farm has a mangrove cover percentage of 70%, the highest of all research sites. This was not the case, farm 5 and 6 exceeded the organic material percentage of farm 8. Farm 5 did this by 0.1% while farm 6 exceeded with 5.8%. This is especially remarkable since Farm 5 only had a 30% mangrove cover at times of the laboratory tests. This indicates that the mangrove cover percentage does not influence the organic contents in the soil as much as previously thought, based on these tests results. To determine which factors influence the organic contents, further research is needed.

8. Conclusion

This study examined the sediment accumulation in integrated mangrove-shrimp farms in Tra Vinh and Ca Mau provinces in the Mekong delta. The quantification of sediment accumulation was conducted during four different field trips over four months. In addition to measuring the accumulated sediment, laboratory testing was carried out on sediment samples to determine their properties and composition. However, to improve the current findings and enhance results, further research is necessary. The main recommendation is to monitor the sediment accumulation for a full year. By analysing a full year's worth of data, trends can be identified more easily and the sediment accumulation, dynamics, properties, and composition of a full year can be analysed, strengthening the research findings. Fortunately, IUCN Viet Nam will continue to conduct monthly field trips for a full year, providing the opportunity to unlock the full potential of this research. However, based on this research, the following conclusions can be drawn:

I. It is highly probable that integrated mangrove-shrimp systems can alleviate local RSLR based on the sedimentation rates observed over four months in Tra Vinh and Ca Mau. The average, pristine, uncompacted sedimentation rate was 1.95 cm/30 days in Tra Vinh and 1.16 cm/30 days in Ca Mau. Potentially, this could imply sedimentation accretion rates of 23.73 cm/year and 14.11 cm/year in integrated mangrove shrimp systems in Tra Vinh and Ca Mau, respectively.

II. The yearly sedimentation accretion rates from I., could potentially result in estimated sediment accumulation rates of 18.56 cm/year and 9.59 cm/year for Tra Vinh and Ca Mau, respectively.

III. Generally, the sediment deposition dynamics in the mangrove-shrimp farms show the highest sedimentation rates near the sluice gates. Although, some exceptions are observed in the data throughout the monitoring duration. Therefore, to describe the sediment dynamics with full certainty, it is recommendable to analyse the full-year dataset when available and subsequently draw a conclusion.

IV. Laboratory testing of accumulated sediments yielded average soil compositions for Tra Vinh and Ca Mau province. The sediments were primarily composed of silt, with an average of 67.6%, followed by 31.09% of clay, and only 0.5% of sand. The granulometry compositions of sediments in Tra Vinh and Ca Mau were nearly identical, except for the sand percentages. However, there were significant differences in the percentages of pore-water, organic material, and calcite. The sediments in Tra Vinh contained 2.5% pore-water, 6.3% organic material, and 3.5% calcite, whereas the Ca Mau sediments contained 4.4% pore-water, 12.1% organic material, and 5.6% calcite.

V. Based on the current area of integrated mangrove shrimp systems in the Mekong Delta, it is estimated that integrated mangrove-shrimp farms have the potential to accumulate up to 30 million m^3 of sediment per year.

This study contributes to the quantification and comprehension of accumulated sediments in integrated mangrove-shrimp systems in the Mekong Delta. It documented monthly sediment accumulation, sediment composition and deposition, and it investigated the potential of integrated mangrove-shrimp systems to serve as sedimentation strategy for mitigating RSLR in the Mekong Delta. The insights obtained from this research can be utilised to promote evidence-based policies on integrated mangrove-shrimp systems in the coastal provinces of the Mekong Delta. Additionally, the study offers recommendations to explore the full potential of integrated mangrove-shrimp systems as sedimentation strategy.

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Appendices

Appendix A - Protocol tray placement

Appendix B - Protocol tray retrieval

Appendix C - Interviews

Appendix D - Loss-on-Ignition Protocol

Appendix E - Table with granulometry results for all research sites in composition %

Appendix F - **Table with the LOI results shown per tray, pore-water %, organic material %, Calcite ($CaCO_3$) %, and total LOI % in the sediments.**

Appendix A

Protocol tray placement:

- See the overview map of the farm where to put the tray. The cross in the map is not exact, if you think that it should be a bit more to left/right feel free to place the tray there.
- Feel the bed of the location where you want to place a tray with your foot / hand. Be careful, do not push too hard or disturb the sediment too much.
- Make sure that there's no mangrove trees (roots) there and that the bed is relatively flat.
- Take the tray and put it in the soil. You might have to use some force to push it down. Make sure that the tray is really pushed into the bed and not "floating" over the soil. It should be the same height or pushed even a little bit lower than the soil and bed around it.
- Place the two markers next to the handles of the tray, firmly into the soil. It is very important that you place the markers exactly next to the tray's handles. Otherwise, we are not able to locate the handles and pull the tray up next month.
- Now measure the water height from the top of the tray until the water level and write the water height down! Make sure that the measurement stick is straight up (90 degrees from the bed) and take account of any waves / movement of the water.

When all the steps above are covered:

- take a video of the location, make sure that the surroundings and the markers/floats are visible in the video. Please speak and say which pond, which tray (number …) and describe where in the pond you are. This is important for documentation and to back-up the GPS coordinates.
- Add the newly placed tray to the GPS machine: !make sure the GPS doesn't get too wet, keep it above the water and be careful with rain!
- Turn on
- "Mark Waypoint"
- Change name (next to the blue flag) into: Number farm + Number tray. For example: Farm 2 + Tray 5 = 25
- Press "Done"
- Waypoint is saved now. You can put the GPS away.

Appendix B

Protocol tray retrieval:

Procedure to retrieve the tray with samples:

- Use the farm overview map to know whereabout the trays are located.
- Navigate to the point where the tray should be located according to the overview map
- Visually locate the bamboo markers and floats to find the tray
- Now, carefully, try to reach to the handles of the tray with your hand or foot to locate them. Be careful that you do not touch the sediments in the tray!
- Once the handles are located: place the frame exactly in between the handles of the tray. This should fit exactly but you have to do this with care! There's not much space left so it can be difficult to put the frame in between the handles.
- It is very important that the frame is actually on top of the tray and in the middle! If the frame is not exactly on the tray, all the sediments will flush out once you pull up the whole tray + frame.
- If you are 100% sure that the frame is in the middle and that it covers the entire tray proceed to next step
- Push the frame firmly into the tray with two hands -> now grab under the tray with your fingers while constantly applying pressure to the frame! Make sure that all the sediment stays in the frame.
- Now slowly pull the tray out of the soil while maintaining pressure on the frame (very important)
- Slowly pull out the tray + frame + sediment out of the water
- Keep pressure on the frame all the time! Constantly push it into the tray!
- Once it is out of the water, allow the water to flush out of the tray slowly: this can take a while.
- Now take 6 pictures of the sediment in the tray. It is very important that the marking in the ruler is visible in the photographs!
- 1 picture of the whole tray
- 4 pictures in total: 1 picture with the ruler in every corner of the tray
- 1 picture with the ruler in the middle of the tray (be aware, don't put the ruler on top of the screw in the middle of the tray, place it just next to it)
- Write down the heights of the sediment in the tray that you just read off the ruler. Also write down general, visual, observations of the sediment, such as: lots of sediment/barely sediment/organic material e.g. shells, mangrove leaves/lots of fish and shrimp etc.
- Now use the putty knife and the zip lock bags to put all the sediments in the bag. Make sure that you put the sediments in the right bag! Farm number and tray number are written on the bags! It is very important that you take the sediment from top to bottom; not just the top layer! We want as much sediments as possible in the ziplock bag.
- Properly close the ziplock bag and put it away.
- Clean the tray from any excessive sediments, make sure there's no more sediment on it.
- Place the tray back between the markers -> see steps of "procedure to place a new tray" for instructions. (No need to measure water height/add video/add GPS)

Appendix C

Interviews

Tra Vinh:

Farm 1:

General:
- Size in ha – 2.5 ha
- Location of the channels - bring aerial pictures of the farm

Dredged around the whole farm and also the middle riverbank, see drawing.
4-5 m width dredged
70-80 cm depth dredged
- Water depth in m
- Location

o Connection to what kind of waterway (channel/river)?
River
o River/channel size
+ 30 m high tide width
5-6 m low tide
- Maintenance practices (if applicable)

Dredging
Pumping sedimentation, last time 7 years ago, not often. He did about 1m of sedimentation pumping depth but mainly close to the sluice. See detailed drawing on phone picture
He doesn't do anything with the mangroves at this moment. Local people asked him for the leaves of the mangrove for the animals, he said it's okay. So people use the mangrove leaves but that's it.
He sometimes cuts down whole trees to use the wood. Last time cut down three years ago for the wood but nowadays he can buy it at the marketplace so doesn't cut trees anymore.
- Subsidence in cm

No subsidence because I can't put his dredged material on the riverbank, it doesn't subsidence.
- Land use rights: green or red book?

No green or red book. Land belongs to the government though. He already asked them for the book but they didnt provide.

Sedimentation:
- How much cm per month / year

50 cm per year sedimentation. Most of the sedimentation close to the sluice, where he also dredged the most. Furthest from the sluice it's still 20-30 cm sedimentation.
- Seasonal differences

30-40 cm sedimentation in wet season (September - February) - in dry season (February - August) 10-20 cm
- Where does the sediment quantity depend on according to the farmer?

Sediment from the river and the sea (most of it)
Rain (not that much influence)
Mangrove leaves
- Dredging

o How often
2-3 years
o Dredging quantities

o Dredging where?
See map and drawing
o When did they dredge for the last time?
October 2020 and 2021. In 2020 around the whole riverbank - in 2021 the new channel (new location of riverbank, see the line I draw in GE)
This year (recently) be dredged close to the sluice (see pictures from previous fieldwork)
o Where do they deposit the dredged materials

He uses the dredged material to raise the riverbank. He deposits the dredged materials as close as possible.

o What kind of material do they dredge?

Mostly clay and silt, no sand. He says that his neighbour, about 100 m in the north-east, there's sand in the dredged material. He says that this is due to the fact that the specific area contains a lot of sand. If you want sand you have to dredge deeper - around 5-6m.

Water management practices:

- Flushing of the farm

o How often

6 times per month (day 14,15,16,17 high tide levels, day 30,1,2 again high tide)

o Duration

Around 1 - 1.5 hours for low tide and getting water out and 2 hours high tide getting water in

o Sluice details

§ Size of the inlet

1 m in width - depth depends on water level

- Determination of water quality

He had death shrimps a few days ago so he refreshed the water. He looks at the water colour, doesn't have measurements equipment. If the colour becomes red it's bad. He thinks the red colour is related to aluminium.

- Use of fertilizers and/or food

No. Just releasing shrimp, natural shrimp release.

- Groundwater use

No. In the past he used groundwater, about 5-10 years ago. He did this to reduce salinity. He found out that this isn't effective so now he doesn't do it any longer

Mangrove:

- Mangrove cover percentage (%)

30%

- Mangrove age

Some 10 year old (near to his house and basically all the larger ones.) at the dividing riverbank it's about 4 yr old mangroves

- Natural occurring or planted mangroves?

Some natural, some planted. Mostly planted ones.

- Other canopies

Mam, gia, duc, ghong, cha la Mấm- Avicennia, Giá- Excoecaria agallocha, Chà Là - Phoenix paludosa, Đước- Rhizophora apiculata, Đưng - Rhizophora mucronate

He allows other species to grow in the farm too. He has around 5 species. Some species are natural and some are planted.

There is one specie with a lot of thorns, he cuts that one (Chùm Lé) --- ??no in mangrove list

Neighbouring ponds:

- Same amounts of sedimentation?

He doesn't know, it depends on the farmer getting in the water etc.

- Same water management practices?

They have different water management practices, other days of flushing etc. The neighbour farm does more flooding.

- Connected to same waterway?

Yes

Opinion:

- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).

He never contributed sediments to a road or heightening some other places. Other farmers do sell their soils in this area. So yes, it is possible but he didn't do it so far. At this moment he doesn't have any place to put the sediments from the middle pond in his system because it's very loose sedimentation and a lot of water content. He says that if he puts it on the riverbank it will flow back into the pond.

- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?

He never thought about it because no one needs the sedimentation now. Maybe for free, if they give money yes. But no one needs it so they wouldn't pay money and he doesn't have to think about it

Farm 2:

General:
- Size in ha

6.5
- Location of the channels - bring aerial pictures of the farm

In the inner bends of all the river banks. See map. They dredge 2-3 m from the riverbank in width. Around 1 m of depth dredging
- Water depth in m

- Location
  - o Connection to what kind of waterway (channel/river)?

Small bit of man made channel very close to natural river
- o River/channel size

15 m average. 20 m high tide
- Maintenance practices (if applicable)

Dredging. Every 1-2 year.
Sediment pumping about every 3 years. 2021 for the last time to build a new house. See yellow area in picture for pumping area.
They are planting new mangroves - if there's available land without mangroves they plant new
Cutting mangrove branches with leaves for the animals
Cutting branches to put traps in the pond
- Subsidence in cm

No subsidence
- Land use rights: green or red book?

Land belongs to forestry department but farmers can manage. but no red or green book

Sedimentation:
- How much cm per month / year

See previous survey
- Seasonal differences

Rainy season much more sedimentation than dry - she has no clue how much
- Where does the sediment quantity depend on according to the farmer?

River
Rain brings the sediment in the pond

Dredging
- o How often

Every 1 - 2 year
- o Dredging quantities

- o Dredging where?

They did the river bank at the side of the sluice (see edited picture phone, red lines)
The other parts of the system they dredge less frequently (about 10 yr ago). The other parts of the system are not really used by them. They didn't decide on the purpose of that part of the system, they will do that later.
- o When did they dredge for the last time?

2021 August to September (red lines)
- o Where do they deposit the dredged materials

They used pipes and pumps to deposit the dredged material next to their house (red lines). See Google Earth for their house. It's opposite of the Lucky Farm bird nests house. They also used the sedimentation close to the road, deposited there although that's still land of the farmer (but not a pond)
- o What kind of material do they dredge?

Mostly mud, silt

Water management practices:
- Flushing of the farm
o How often
10 times per month
o Duration
Days 14-18 the month and 30-4 of the month.
Water inlet during flood for about 2-3 hours. On the same days they drain around 2 hours with low tide.
o Sluice details
§ Size of the inlet
80 cm
- Determination of water quality
They visually determine the water quality. When it's red (aluminium from the soil) they change the water. Development of seaweed / algeas turns water green, also flush.
- Use of fertilizers and/or food
No
- Groundwater use
No

Mangrove:
- Mangrove cover percentage (%)
30%
- Mangrove age
Oldest ones 20 years of age, in the middle of the pond mainly. Newer ones are 5-6 years old.
- Natural occurring or planted mangroves?
Some natural and some planted. Mostly natural.
- Other canopies
They accept other species, trees, plants, canopy's. They keep new species

Neighbouring ponds:
- Same amounts of sedimentation?
No idea
- Same water management practices?
No idea. They flush on different days, mangrove maintenance about the same.
- Connected to same waterway?
Depends on the neighbour, most are connected to same natural river directly or by small channel

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).
Yes it is possible to do this, because they already use their sediment to heighten the area of their land close to the road.
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?
They do use it themselves, on their own land. She wouldn't give it to other people nor sell it to other people because they need the sediment themselves

Farm 3:

General:
- Size in ha
2.3 ha
- Location of the channels - bring aerial pictures of the farm
Channel is literally around the whole farm, see the drawing. Close to every riverbank. Around 5 m of width dredging. They dredge around 1.2 m of sediment depth

- Water depth in m

- Location
  - o Connection to what kind of waterway (channel/river)?

River
  - o River size

40 m average, depends on low and high tide. Low tide 30 m - high tide 60-70 m
- Maintenance practices (if applicable)

They do the dredging with a machine every 3 years - they only dredge the drawn channel in the overview
They also pump sedimentation every 5-7 years - then they do the whole pond
Mangrove forest maintenance he cuts some of the branches to make traps
- Subsidence in cm

He doesn't notice any subsidence, he mentions because he's far from the sea
No flooding either in this area
No subsidence near his house but at the sluice gate there is subsidence because (according to him) it's near the river. So he claims it's not subsidence but the river flow that attacks the sluice gate
- Land use rights: green or red book?

Green book - belongs to authority

Sedimentation:
- How much cm per month / year

1-3 cm per month -> 24 cm per year approx
- Seasonal differences

Juli to February, wet: loads of sedimentation - cannot make estimation
February - July - much less sedimentation can't make estimation
- Where does the sediment quantity depend on according to the farmer?

Water resource: in flooding season loads of sedimentation
Rain is also an influencing factor. The rain brings sediment in the pond from riverbank etc.
- Dredging
  - o How often

Every 3 years
  - o Dredging quantities

  - o Dredging where?

See map
  - o When did they dredge for the last time?

August 2021
  - o Where do they deposit the dredged materials

Directly on the Riverbank where they dredge. See map. Around the whole farm and middle boundary (see picture as well)
  - o What kind of material do they dredge?

Mostly muddy and silt. No sands
They just deposit the dredged material on the riverbank, don't do things to increase compaction. There's not much compaction of the sediment. One month less than 1 cm afterwards no more compaction

Water management practices:
- Flushing of the farm
  - o How often

6 days per month, depending on the tides. Low tide he drains the pond, high tide he flushes.
  - o Duration

3 days for draining and flooding in total
Days 15,16,17 - drain and flood
Days 28,29,30 - drain and flood
  - o Sluice details
    - § Size of the inlet

80 cm width - height depends on the water level
- Determination of water quality

The water quality is being tested with his equipment. PH, salinity, temperature -> he does this when the water changes colour, so visually. When the values are bad he changes the water - around 10% of the total water. He estimates based on water level.
- Use of fertilizers and/or food

No
- Groundwater use

No

Mangrove:
- Mangrove cover percentage (%)

30% mangrove cover - but mainly everything in one part of the pond.
- Mangrove age

For the high cover pond:
30 years for the ones close to the road
10 years the one in the middle (large)
4 years the small ones in the middle
The ones in the middle of the less covered pond about 2 years
- Natural occurring or planted mangroves?

He has 5 or 6 species of different mangrove in the pond.
The high canopy cover area is all natural.
The low canopy part (4 yr old) is planted
On the river banks they are planted
If there’s natural trees he will keep them. Sometimes he cuts branches, not the whole tree.
- Other canopies

If there’s other species growing in the pond he will keep them.
Species: Mấm- Avicennia, Đước - Rhizophora apiculata, Đưng - Rhizophora mucronata, Cóc - Lumnitzera racemosa, Giá- Excoecaria agallocha, Chà Là- Phoenix paludosa

Neighbouring ponds:
- Same amounts of sedimentation?

He estimates it’s not much different because it’s connected to the same river
- Same water management practices?

Water management practices might be different but not much different. He guesses it’s around the same days of the month. If water quality from one pond is worse it can occur that they refresh while others don’t

They don’t rent machines for maintenance with other farmers because it’s connected to a big road. Easily accessible
- Connected to same waterway?

Yes, same river

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).

Authorities own the dredged material because the land ownership. They just use the sediments for his riverbanks, they didn’t use it on other places yet. If the authorities want to use the dredged material elsewhere he wants money for it. So deposition on this land is okay but if they take it to other locations they should pay
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?

Yes when they pay for it they can bring it anywhere

Farm 4:

General:
- Size in ha:

2.5 ha

- Location of the channels - bring aerial pictures of the farm

See the drawing for the channel that is dredged. There's plans to dredge more but that will happen in 2-3 years. Dredged around 4m of width maximum. Dredged around 70-80 cm of sediments (depth)

- Water depth in m

- Location

o Connection to what kind of waterway (channel/river)?

Channel - channel is about 1 km from the river.

o River/channel size

8-10 m of width

- Maintenance practices (if applicable)

They use a pump to pump out sedimentation - big pipe to suck out the sediment - they rent the machine see picture for example - they only did this once in 10 years - 2012 last time - she will do again in 2-3 years

- Subsidence in cm

She notices subsidence - estimation 1-2 cm per 2-3 year

- Land use rights: green or red book?

Red book so she is landowner

Sedimentation:

- How much cm per month / year

20-30 cm in about 1 year

- Seasonal differences

Rainy season more sedimentation than dry season because of the rain and floods. Dry season about 1 cm sedimentation/month - wet season around 2-3 cm sedimentation/month - she can't make an accurate estimation

- Where does the sediment quantity depend on according to the farmer?

River and rain

- Dredging

o How often

3-5 years they create the channel

o Dredging quantities

o Dredging where?

See channel

o When did they dredge for the last time?

October 2021

o Where do they deposit the dredged materials

They put all the materials on river banks.

o What kind of material do they dredge?

Mostly muddy and silty - no sand

They rent a machine to compact the sediment after depositing it on the banks of the pond

Water management practices:

- Flushing of the farm

o How often

When the water level of the pond gets less they will get in new water. Approximately 2 times per month

o Duration

3 days with high tide

o Sluice details

§ Size of the inlet - not sure

- Determination of water quality

Water quality is quite good. She doesn't test PH at this moment because she notices the quality is good. She used to do it in the past when she had intensive shrimp, for mangrove she doesn't

- Use of fertilizers and/or food

No

- Groundwater use

No

Mangrove:

- Mangrove cover percentage (%)

10-20 %
- Mangrove age
In the middle island it’s around 10+ years
- Natural occurring or planted mangroves?
Planted the middle island rhizophora. Riverbank is all planted as well. Sometimes natural (avicennian) occurring mangroves are there but they cut it off. There is a difference between the natural species and the one that she plants, that’s why she takes out the natural ones. The mangroves she uses (rhizophora) the leaves for feeding animal.
- Other canopies
If other plants are growing in the pond she will take them out. Some species attract worms and she doesn’t want it

Neighbouring ponds:
- Same amounts of sedimentation?
Yes same sedimentation
- Same water management practices?
Same water management practices too. Every time they rent machines they do it with the neighbours too.
Flushing is mostly the same too but sometimes differs when other farmers want to catch shrimp
- Connected to same waterway?
Yes

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).
Yes. This is possible. Local authorities sometimes ask her for sediment from the pond to raise roads and she allows.
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?
Yes she is willing to do this. Neighbours and other farmers also allow when authorities ask. It’s for free, they don’t take anything, constructing company by authority takes machine to dredge. This doesn’t happen often, last time was around 2019 and this happened only once.

Ca Mau

Farm 5:

General:
- Size in ha
2.5
- Location of the channels - bring aerial pictures of the farm
See picture of the farm
4 m of width dredging
70 cm depth of dredging
- Water depth in m

- Location
o Connection to what kind of waterway (channel/river)?
Channel man made
o River/channel size
High tide 10 m
Low tide 4-5 m
- Maintenance practices (if applicable)
Dredging 1-3 years. See dredging bulletpoint for more information

Every year they sediment pump one time. But if there's not enough mud they won't do it anyways. They pump the sediment towards the end of the pond close to the road (where one marker and two bottles went missing on our tray). Marker 5.1.

They don't maintain the mangroves now because the trees are too young. They can't cut it, maybe in 2-3 years. They sometimes thin out the canopy if it covers the water surface too much but not often.

- Subsidence in cm

He doesn't see any land subsidence from visual observation but he does mention that the road did subside a lot (but that can be compaction). He says about 20 cm per year for the big road that we drive on too. Not the road at his.

- Land use rights: green or red book?

Green book

Sedimentation:

- How much cm per month / year

30 - 40 cm per year.

- Seasonal differences

Rainy season more sediment than dry. Within 3 months of rainy season there's already 50% of the yearly sediment.

- Where does the sediment quantity depend on according to the farmer?

Two main sources:
Soil from the banks, the soils follow the flood water.
Rainy season the river caries more sediment and follows the flow and get in the farm.

Dredging

o How often

Depends on the amount of sediment, can be 1-3 years. Sometimes they only dredge certain parts of the canals and more next year. Sometimes everything at once

o Dredging quantities

o Dredging where?

Depends on the situation. See answer above, can be everything at once but also smaller parts.

o When did they dredge for the last time?

2 years ago - august 2020

o Where do they deposit the dredged materials

They deposit it on the outside river banks. For the outside channels. Inside channels they deposit close to the mangrove roots. Along the mangroves there some space to deposit, they deposit there.

o What kind of material do they dredge?

Top layer (5 cm) very soft sediment and mud/silt. Last layer is more clay very compacted already. No sand. Because his farm doesn't have much big trees there's not much organic sediment (mangrove leaves)

Water management practices:

- Flushing of the farm

o How often

2 times per month to harvest the shrimps

o Duration

3-4 days for each time they open. High tide is 1 hour and low tide about 2-3 hours.

o Sluice details

§ Size of the inlet

85 cm (not too sure)

- Determination of water quality

Visually observation. If colour becomes dark he knows it's not good and he flushes. He thinks Maybe rain water dilutes the water. Generally in rainy season the water quality is really bad so they open the sluice gate more often, they try to change about 30% of the water in the pond and get new water from the canal.

There is a monitoring station of the government close to the farm, in the river and he can check the water quality in the river on his phone on a daily base. It's more north to the bridge. Everyone can assess this app and obtain this data (PH, salinity) (Ca Mau Aquam App).
- Use of fertilizers and/or food

Bio based enzymes to create food for shrimps.
In rainy Season they use lime acid ? to increase PH levels (PH goes down due to rain)
Fertiliser to get some kind of algal blooms.
- Groundwater use

No

Mangrove:
- Mangrove cover percentage (%)

30 to 40%
- Mangrove age

The satellite imagery is old! They already cut down the mangroves and replanted. They have 3 years old mangroves (the bigger ones) and new ones about 3 months old. See drawing. 2018 cut one time and replanted. 2020 they also cut and only replanted 3 months ago.
- Natural occurring or planted mangroves?

Everything is planted mangroves (replanted after the cutting). If there's natural plants they keep them. Some are natural mangroves but the majority is planted.
- Other canopies

Other naturally species he will keep! But there's not many species that grow there. Just 5 or 6 common species that grow there.

Neighbouring ponds:
- Same amounts of sedimentation?

About the same sedimentation.
- Same water management practices?

Similar water management practices with flushing. Not every also uses the fertilisers etc, really depends on the farms.
- Connected to same waterway?

Yes same channel

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).

He has no idea of using the sedimentation for other things than road or construction. He didn't supply his sediments to others. So he only used it in the one corner to make foundation for a new house and deposits around his currents house.
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?

If the government would ask him for sediments to e.g., heighten the road he has no idea if he would. When the government makes the new road they already use mud to make dikes around the road and pump sand in there as foundation.
When someone offers money for his sediment: he doesn't want to sell sediments because he needs it himself but he does know that some neighbours do sell sediment. The other that sell sediment already have very high riverbanks and dikes so they don't need it themselves. The buyer normally use it for foundation for house

Farm 6:

General:
- Size in ha

3.6
- Location of the channels - bring aerial pictures of the farm

See drawing. Channels are basically in every visible channel too.
4 m channel width

80 cm depth is being dredged
- Water depth in m

- Location
  - o Connection to what kind of waterway (channel/river)?

Channel, man-made. Channel connects to the main river after 6 km
  - o River/channel size

22 m high tide
2 m low tide
- Maintenance practices (if applicable)

They dredge about every 3 years with the excavator and then they dredge deeper (up to 80 cm)

They pump the mud every 2 years with a pump. They pump the depth of the mud only, usually about 40 cm maximum

So they decide to dredge or pump when there's too much sediment and when the sediments start to smell like rotten eggs (sulphur)

Every 12 to 13 years they exploit the mangroves and cut them all. When they plan to cut them they ask permission of the forestry manager and they assess all the mangroves. Then they point out the ones that you can cut down, usually it's not everything because some are too small.

Every time they maintain the canal they also thin out the canopy of the mangroves, make sure the channel is still accessible

- Subsidence in cm

Yes he notices subsidence. He doesn't have any clear information about this but he does visually notice subsidence. He mentions that the road next to his house is really lowering. His estimation is 2-3 cm over 2020-2022. Before 2020 he didn't put much attention on subsidence, but he noticed that the road in the past 10 year became 1 m lower. It's probably mainly compaction and some subsidence

- Land use rights: green or red book?

Green book, right to use 20 year.

Sedimentation:
- How much cm per month / year

40-50 cm per year in some places. 10-20 cm sediment accumulation per year is the average. Depends on location in the farm.
- Seasonal differences

Rainy season more sediment than dry season. He estimates in Rain season 12 cm and dry season 8 cm sedimentation
- Where does the sediment quantity depend on according to the farmer?

The river - erosion on the riverbank brings sediment and the river transports sediments to the farm
Mangrove leave, organic material
Rain also drives erosion into the pond from the bank

- Dredging
  - o How often

Every 3 years
  - o Dredging quantities

  - o Dredging where?

See drawing, they did the whole pond in one time as drawn in drawing. All the channels included.
  - o When did they dredge for the last time?

2020 September / October

There is not much sediments in this farm so he's not planning to dredge again until next or maybe even in 2 years.

  - o Where do they deposit the dredged materials

As close as possible to the dredged location, so on the riverbanks around the farm.
Also on the inside channels but only on the southern side (see aerial image and drawing in there)

When they pump the sediments they also use it for construction, they use it for the foundation of their own house, so always close. Some other households here pump it into the river which is illegal, he doesn't do this.

o What kind of material do they dredge?
Mostly muddy, no sand or clay. If they dredge deeper (over 1 m) they hit a clay layer though.

Water management practices:
- Flushing of the farm
o How often
2 times per month
o Duration
3-4 days (depends on the tidal) for both 2 times
Inflow 2 hours
Outflow 2 hours
o Sluice details
§ Size of the inlet
80 cm width
- Determination of water quality
No equipment to measure. He tastes the water for salinity estimation. They test the quality (PH, salinity) in the nursery pond where they buy the shrimps with equipment though but in this pond he just tastes.
- Use of fertilizers and/or food
Nothing. Neighbours use some stuff to reduce salinity (CaCo3)
- Groundwater use
No

Mangrove:
- Mangrove cover percentage (%)
60% - regulation says 70% mandatory but he only has 60%.
- Mangrove age
See drawing. 3 year close to farm.
- Natural occurring or planted mangroves?
Natural occurring mangroves everywhere where canopy cover is high. He only plants in the river banks himself
- Other canopies
Usually doesn't grow other species but when occurs he will keep them

Neighbouring ponds:
- Same amounts of sedimentation?
It's different for each pond he says. Because the neighbours inflow a lot so different water management and they have much more mangroves as well.
- Same water management practices?
Neighbours flush about the same but it they harvest shrimps more often they would also flush more. Depends on harvest frequency.
- Connected to same waterway?
More
To the north east it's the same channel. But everything south west is different channel

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).
Nobody needs the sediments to raise land. It's not legal to sell the soils.
Authority do not allow sale. The regulation is clear but in practice it's not too clear how this works. We can't dig in land and sell the sediment because you change the land. But you can use sediment close by.

- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?
See answers above.

Farm 7:

General:
- Size in ha
7 ha
- Location of the channels - bring aerial pictures of the farm
See the drawing of farm 07. Main outliners of the farm are dredged, back side has 2 channels in middle (4 in total) and front side one in middle (3 total).
- Water depth in m
- Location
o Connection to what kind of waterway (channel/river)?
Natural river - same as farm 6
o River/channel size
High tide 10 m width
Low tide 5m width
- Maintenance practices (if applicable)
Dredging, see dredging bullet (3 year outside channels only with excavator)
3 m of width dredging
50-60 cm of depth while dredging
They dredge with the machine every 3 years with the whole neighbourhood (from the outside riverbanks), they rent machine and do all ponds.

And the inner channels are being pumped every 2 years by pumping
Pumping 30 cm deep

- Subsidence in cm
In the last 25 years the land subsided around 1 m. He needs to heightening his land for a while now. Before 25 years ago there was also subsidence. Example: usually they put the house 70 cm above the land, after 10 years the water already reached the foundation of the house.

- Land use rights: green or red book?
Green book - 20 years ownership. Now it's still green book, in the near future they will get red book due to the road nearby.

Sedimentation:
- How much cm per month / year
Farmer male says 10 cm per year
Lady says 20 cm per year
In general around 20 cm of deposition per year (they discussed and believed 20 cm)
- Seasonal differences
Sediment in rain season is more than dry season. In general: If sediment is about 25 cm - 15 cm will be rainy season and 10 cm dry season
- Where does the sediment quantity depend on according to the farmer?
Rain: When the rain comes soil will follow water from the riverbank to the river, channel, and into the pond
Sediment from the canal -> More water turbidity in wet season
- Dredging
o How often
Every 3 years for the outside channels (close to riverbank)
Inside channels (2 in back 1 in front) they pump with pumps every 2 years.
o Dredging quantities

o Dredging where?
Outside close to riverbanks and inside channels. Not close to the sluice (from after the bridge)

o When did they dredge for the last time?
Excavator dredging outer pond banks: south side of the main river channel they did in 2021 July - august. They didn't have enough money to do the other side of the channel too (north side)
2020 around July they did the north side of the outer channel

June 2021 they pumped the inner channels

o Where do they deposit the dredged materials
Dredging directly to the closest riverbank to heighten riverbank.

In the last 2 years when pumping they placed it all around the house (the porch / veranda)

o What kind of material do they dredge?

Mainly mud in the dredged material and some organic such as mangrove leaves. No sand no clay.

When pumping it's very soft, not compact, very small grains

Water management practices:
- Flushing of the farm
o How often
Every month they open 2 times
o Duration
Every time they open it's 2 to 3 days
Outlet 2.5 to 3 hours per day
Inlet 3-4 hours per day

Tidal scheme: 2 times high tide per day on this location
o Sluice details
§ Size of the inlet
105 cm width
- Determination of water quality
No determination of water quality, he doesn't use any equipment. He is experienced but also sometimes got lucky. He's basing it on luck, water good is lucky and water not good is unlucky. Sometimes he got unlucky and he had to do water treatment -> used some bio fertiliser back then, like for PH
- Use of fertilizers and/or food
Using lime for PH ->
Water treatment multi bio (see pictures): enzymes, some sugar like enzymes. He uses this 2 times per month. Every 2 weeks.
They use fertiliser to increase shrimp food (very small worms) - see the picture as well.
- Groundwater use
No. No need to use this in mangrove shrimp. Only intensive shrimp farmers use this mentioned the farmer.

Mangrove:
- Mangrove cover percentage (%)
60% but there's very young mangroves now because he recently replanted. (So canopy cover is lower)
- Mangrove age
They planted 2 months ago (July - August) at the locations where they cut down mature trees. He's planting new ones whenever there's place for them. So when they cut down they replant. this can be at several locations, depending on the age.
- Natural occurring or planted mangroves?
Planted mangroves.
- Other canopies
There's not many species in the farm, only 3 or 4 species. He does keep them when they occur.
Mangrove species: Mấm- Avicennia, Đước- Rhizophora apiculata, Dà- Ceriop, Bần- Sonneratia, Cóc- Lumnitzera racemosa, Vẹt - Bruguiera

Neighbouring ponds:
- Same amounts of sedimentation?

Same sedimentation is about the same
- Same water management practices?
Water management is about the same
- Connected to same waterway?
Yes

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).
Not enough sediment to use it somewhere else. He didn't think about this because there is not enough sediment. He also has a vegetable farm and he uses his sediments there. In the past his land (porch) was very low, year by year he pumped sediment to this place and that's why it's so high now. They put a lot of sediment in the porch but it's still getting lower and lower (subsidence and/or compaction)
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?
No they wouldn't. He needs the sediments himself, he was very clear about this. He won't even sell it because he still hasn't enough for himself

Farm 8:

General:
- Size in ha
8.3 ha
- Location of the channels - bring aerial pictures of the farm
See the drawing - there are 4 main channels, 2 outside and 2 inner.
Width of dredging: 4 m
Depth dredging: 60-70 cm

There is also 6 smaller channels: they don't dredge those but they pump them by machine.
They pump around 30-40 cm
They pump every year for 3 channels; They do half of it in one year and the other half next year. 3 per year. They do side by side, southern half first and then northern (or other way around).

- Water depth in m
- Location
o Connection to what kind of waterway (channel/river)?
Natural river! See Google Earth. Same as 5,7 and 8
o River/channel size
15-20 m high tide
4 m with low tide
- Maintenance practices (if applicable)
Dredging every 3 year (but not now due to various reasons)
Pumping every year

Mangrove exploiting will take place next year, he will harvest the mangroves then.
Because of this there's also room again for dredging machine so he can dredge after, when the neighbours want too.

When you cut the mangroves you have to replant them the next year, requirement from from forest management (forestry company from the government). This company manages land and forest operations here.

Forest mangroves here are production mangrove area.

- Subsidence in cm

Yes there's land subsidence. Last 20 year his house became much lower, about 1m. New house is still high on foundation now, about 1 m and he mentioned that the old house used to be like that too.

- Land use rights: green or red book?

Green note

Extra note:
They barely catch any shrimp or crabs now because its hard to catch them due to the mangrove canopy cover (so dense). So they currently don't really focus on shrimp catching, just waiting until they can sell the wood. They barely harvest crab or shrimp. They follow government regulations though, so no cultivation now because green book.

50.000 USD for the wood of the whole farm

The practices of this farmer are different: when he dredges the canal he puts the sediments to the bank, then waits for a few years, then all the before dredged sediments are compacted but he also thinks there's still a lot of organic content in there. So after a few years (usually at least 3 years, he thinks it needs at least 3 to let the organic material decay) they put the riverbank back in the pond again, he thinks this improves food for shrimps in the pond.

Sedimentation:

- How much cm per month / year

30 - 50 cm per year.

- Seasonal differences

More sedimentation in rain season, rainwater flows in the farm containing sediments. Water in river is more turbid and gets into the farm as well.
Sedimenten deposition in rainy season is about 60% and dry season 40%

- Where does the sediment quantity depend on according to the farmer?

Rain, turbidity river as explained above. In the rainy season everyone dredging their farms and this gets into the river and that ends up in his farm. So due to "dredging" season there's is also more sediment. -> There's many people in this area that pump the soft sediments directly into the river because they have no place for it. Special thing for this area: local authority allows farmers to pump sediment directly into the river for two months a year (August - September).

- Dredging
  - o How often

Sometimes 2 years sometimes 3 years

o Dredging quantities

o Dredging where?

See map

o When did they dredge for the last time?

Three years ago, in 2019 in October/November for dredging the main channels. They will dredge again in the next 2 to 3 year. The canopy of the mangrove is so dense that they can't dredge anytime soon. Also, usually they share the dredging hiring (ferry to the farm etc) and they won't do that next year. They have to break up the road to do this and repair after.

Pumping they have to do every year.

o Where do they deposit the dredged materials

They deposit the sediments from the outer two canals on the riverbank. And for the inner two they deposit it on inner riverbanks which are very close too. Always deposit as close as possible to the dredged soil.

They pump all the sediments to the house, next to it north and south they create foundation.

o What kind of material do they dredge?

No sand. They can get clay if they really dig deep but they don't want this because it's bad for the shrimp if they touch the clay. Mainly Silt, muddy, and organic material such as mangrove leaves.

Pumping is very soft and fine sediments and some mangrove leaves.

Water management practices:
- Flushing of the farm
o How often
2 times every month
o Duration
Every time around 4 days
Flushing 4 hours
Get out 4 hours
o Sluice details
§ Size of the inlet
90 cm per sluice gate (he has two gates) so in total 1.80 m
- Determination of water quality
No equipment to check water quality. He follows the tide scheme only, so if other farmers flush he also does so.
Based on his experience he checks the water quality. Too green is not good, too much blooming. He wants the water to be turbid and brownish like the rivers, not too clean.

Based on his experience: when the water is too clean (not turbid) the shrimps will get a shock and die.

When the water is not good he will renew the water, let out first and nee water in from the sluice. About 50 % of the whole farm renew.
- Use of fertilizers and/or food
Currently he doesn't use anything. In the past he used residue of soya bean in the farm as shrimp food. He has an idea for the future of his farm: use chicken feces and spread around the farm so it will increase blooming and food for shrimp.

100 years ago a big tree species grew in this area and this big trees are all gone now. But still under the ground. Many farmers here sell those trees because it's very good wood. He doesn't want to and keeps it under the mangrove.

- Groundwater use
No.
He knows that some areas do use it to dilute the water but in extensive shrimp models.

Mangrove:
- Mangrove cover percentage (%)
Forest officer said 50% during the previous survey but the farmer (and I) are pretty sure it's much more. More like 70% or more.
- Mangrove age
17 years old, almost all the trees! Some trees close to the house (at the back are) over 30 years old! The previous time the government allowed to cut them but now they don't allow anymore. He will cut the old ones (30 years old) next year) because there's permission now
- Natural occurring or planted mangroves?
Planted mangroves
- Other canopies
If other species grow it depends on the species if he keeps them. Some have fruit, he will keep those, some don't have use and will be cut down

Neighbouring ponds:
- Same amounts of sedimentation?
Basically the same but depends on the management practices.
- Same water management practices?
If people flush more there's more sedimentation so it depends on the farmers. But he says that they do same same. When the farmers put in baby shrimp they don't flush the water for a month, to keep stable. Otherwise shrimp shock
- Connected to same waterway?
Yes

Opinion:
- Do you think it will be possible to use the dredged sediments to raise land elsewhere? For example, creating elevation to help against Sea Level Rise (raise a local road, raise the pond in totality, raise levees and riverbanks).

He just keeps the sediment for himself. No one asked for his sediments so he didn’t think about this. It should be possible to heighten land though.
- Do you have any thoughts on the question above, would you be willing to participate in such activities or contribute towards it?

No sell of sediments! Pretty clear about it. He needs sediments for vegetable cultivation. His sediment is very good, very nutritious sediment due to the logs below and his practices.

Appendix D

Loss-on-Ignition Protocol (V. 1.2)

University of Cambridge Department of Geography

Physical Geography Laboratories

Equipment

- Balance - 2 or 3 decimal place, eg. in 1g, 10% accuracy = 0.1g, 1% accuracy = 0.01g, 0.1% accuracy = 0.001g
- Crucibles of an appropriate size for the samples - differently numbered
- Desiccator - with purple silica gel, if white put in 150°C oven for 6 hours to dry out.
- Drying oven - Must be booked in advance!
- Heat proof gloves.
- Muffle Furnace - capable of up to 1000°C - Must be booked in advance!
- Tongs.
- Trays & stack - capable of withstanding 1000°C.
- Volumetric Sampler.

If you have large batches of samples, using a Sartorius balance connected to a pc is a useful way to speed up collection of data.

Protocol (%water, bulk density, %organic, %calcium carbonate, %silicate residue)

- Clean dry, numbered porcelain crucibles are weighed empty.
- Approximately 1g of wet sediment is placed in the crucible, and the wet weight recorded. If bulk density of the sample is required a calibrated 1 cm^3 brass volumetric sampler should be used and the sample should be weighed, allowing mass per unit volume to be calculated.
- Crucibles should then be placed on trays, the tray rack may be required if large numbers of samples are being processed.
- The samples are dried for 6 hours (until constant weight is achieved) usually overnight at 150°C (for high saline samples) in either the Drying Oven or Muffle Furnace. Remove trays carefully using the heat proof gloves. Use tongs to place crucibles in desiccator until they reach a temperature at which they can be handled safely. The desiccator prevents the absorption of water from the atmosphere and therefore weight gain. Then weigh samples again.

- The samples are transferred to a muffle furnace then heated to 550°C for at least six hours (overnight), the furnace should then be reduced to ~100°C, when this temperature has been reached samples should be allowed to cool in a desiccator to a temperature at which they can be safely handled, then weighed.
- The samples are then returned to the furnace and heated to 950°C for at least six hours (overnight) the furnace should then be reduced to ~100°C, when this temperature has been reached samples should be allowed to cool in a desiccator to a temperature at which they can be safely handled, then weighed.

Results

- The weight loss when the samples are dried at 150 °C (wet weight - dry weight) represents of the amount of pore-water held within the sample. The percentage of water should be expressed as a proportion of the wet weight. If the volume of the sample taken is known then the "Bulk Density" can be calculated from this, expressed as weight of sample per unit volume, e.g. g/cm^3 ($g\ cm^{-3}$).
- The weight loss between 150 and 550°C as a percentage of the total original dry sample weight is the % volatile matters, which is an approximation of organic material. This probably also includes water loss from clay minerals, this is likely to be an insignificant addition.
- The weight loss between 550 and 950°C is representative of the amount of CO_2 released from the sample. This can be used to calculate the amount of $CaCO_3$ present in the sample by using the ratio between the molecular weights, expressed as a percentage of the total original dry sample weight this is the % carbon.

Calculation (molecular weights in brackets)

- Ca (40.08) + C (12.01) + O_3 (3 x 16.00) = $CaCO_3$ (100.09)
- C (12.01) + O_2 (2 x 16.00) = CO_2 (44.01) Removed between 550 - 950 °C
- Ca (40.08) + O (16.00) = CaO (56.08) Remains in sample
- So to calculate the quantity of $CaCO_3$ the weight of CO_2 lost must be multiplied by a factor to account for the CaO remaining in the sample.
- $CaCO_3$ (100.09) / CO_2 (44.01) = 2.274
- So the part of the sample that is represented by the CaO is 2.274 times that of the known CO_2.
- So to calculate the quantity of $CaCO_3$ in a sample the weight lost between 550 - 950 °C must be multiplied by 2.274.

Appendix E

Table with granulometry results for all research sites in composition %

Farm & Tray	%		
	Clay	Silt	Sand
1.1	26.9	71.1	2.0
1.3	34.4	65.6	0.0
1.6	33.8	65.9	0.3
2.3	39.2	60.8	0.0
2.5	31.0	68.5	0.5
2.6	33.2	66.3	0.5
2.7	28.2	71.8	0.0
2.8	33.1	66.9	0.0
3.2	37.7	62.3	0.0
3.3	35.5	64.5	0.0
3.6	35.0	65.0	0.0
4.1	23.9	75.0	1.1
4.2	33.7	66.3	0.0
4.5	23.4	65.7	10.8
5.1	45.6	54.4	0.0
5.3	38.5	61.5	0.0
5.5	30.9	69.1	0.0
6.1	37.9	62.1	0.0
6.2	30.9	69.1	0.0
6.4	25.0	75.0	0.0
6.5	34.2	65.8	0.0
7.1	41.4	58.6	0.0
7.2	0.0	100.0	0.0

Farm & Tray	%		
	Clay	**Silt**	**Sand**
7.4	33.0	67.0	0.0
7.5	31.3	68.7	0.0
7.7	29.7	70.3	0.0
8.1	31.3	68.7	0.0
8.3	30.9	69.1	0.0
8.4	39.5	60.5	0.0
8.5	21.1	78.9	0.0
8.6	31.1	68.9	0.0
8.7	39.5	60.5	0.0

Appendix F

Table with the LOI results shown per tray, pore-water %, organic material %, Calcite (CaCO3) %, and total LOI % in the sediments.

Farm & Tray	Pore-water %	Organic material %	CaCO3%	Total LOI %
1.1	2.1	6.4	3.1	9.8
1.3	2.8	6.9	3.2	10.8
1.6	1.8	6.4	3.2	9.5
2.3	2.4	6.8	3.4	10.4
2.5	2.1	6.3	3.3	9.7
2.6	2.5	6.3	3.7	10.2
2.7	3.2	7.0	3.7	11.5
2.8	3.0	7.4	3.0	11.5
3.2	1.9	6.5	2.7	9.5
3.3	3.5	4.4	6.7	10.6
3.6	2.7	6.2	3.7	10.4
4.1	1.9	5.8	3.1	8.9
4.2	2.1	6.1	3.3	9.5
4.5	2.6	5.4	2.8	9.1
5.1	3.7	13.2	5.9	18.9
5.3	3.6	11.5	5.3	16.9
5.5	4.3	9.2	4.2	14.9
6.1	2.9	12.3	6.0	17.4
6.2	5.3	21.9	7.1	29.0
6.4	3.7	14.2	6.3	20.0
6.5	6.8	19.5	6.3	27.6
7.1	4.0	10.2	5.1	16.0
7.2	3.0	10.4	4.6	15.1

Farm & Tray	Pore-water %	Organic material %	CaCO3%	Total LOI %
7.4	2.7	9.3	4.6	13.7
7.5	3.1	10.0	4.1	14.5
7.7	3.0	9.3	5.1	14.2
8.1	4.4	8.5	4.9	14.6
8.3	5.3	11.4	8.6	19.7
8.4	4.8	10.8	6.5	17.8
8.5	8.9	13.7	5.8	23.7
8.6	4.6	11.2	5.0	17.3
8.7	4.5	11.3	5.7	17.7