Development of a comprehensive mangrove monitoring system in the Mekong Delta, Viet Nam

Dominic Meinardi

August 2010

LEUPHANA
UNIVERSITÄT LÜNEBURG
Campus Suderburg

As of 1 January 2011:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

gtz Partner for the Future. Worldwide.

COOPERATION
FEDERAL REPUBLIC OF GERMANY
SOCIALIST REPUBLIC OF VIETNAM

Development of a comprehensive mangrove monitoring system in the Mekong Delta, Viet Nam

Master of Science thesis in Water Resources Management in Tropical and Subtropical Regions

Suderburg, August 2010

Hans Dominic Justus Meinardi

Matriculation number: 3009489

Leuphana Universität Lüneburg / Campus Suderburg

Fakultät III Umwelt und Technik

In collaboration with

Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

"Management of Natural Resources In the Coastal Zone of Soc Trang Province"

Examination committee

Prof. Dr. Brigitte Urban

Prof. Dr. Hartmut Wittenberg

Dr. Klaus Schmitt

Acknowledgements

The author would like to express his profound gratitude to Prof. Dr. Brigitte Urban and Prof. Dr. Hartmut Wittenberg for their time as well as for their guidance, kind contribution and momentous support throughout the study.

The author is deeply grateful to Dr. Klaus Schmitt for his time and effort in providing the author with his continual guidance, valuable support throughout the internship and study in Viet Nam and Germany as well as for his rigorous but beneficial and constructive criticism for this thesis.

The author expresses his sincere thanks to the members of the GTZ Team in Soc Trang. Ms. Thuy for her great and hard work, Ms. Kieu for untiring organizing and kind support during all times, Mr. Binh for fast but save transport and his valuable friendship and Mr. Dung for his continuous cooperation, support and precious friendship.

The author greatly acknowledges the kind help and support by Mr. Xe (Director of Kiem Lam), Mr. Khoung, Mr. Hiep, Mr. Hoang (especially for his great field work) and all members of the Forest Protection Sub-department (Kiem Lam) in Soc Trang.

Special and sincere thanks go to Isabelle and Daniel, who became good friends during recreational activities and weekend trips, additional thanks for having a good time in Soc Trang and also supporting this thesis. Furthermore the author wants to thank Mr. Vinh for his precious friendship.

The author expresses his thanks to Dr. Uwe Krumme and the “Leibniz-Zentrum für marine Tropenökologie” for kind support and the free access to the great library of this institute.

Finally the author wants to thank his closest friends for their encouragement. Last but not least the author expresses special thanks to his mother for her valuable support and re-opening “Hotel-Mama” for the time of this thesis.

Summary

Mangroves are highly productive and unique ecosystems adapted to the harsh conditions of coastal areas. They provide a vast amount of ecological and socio-economical benefits; furthermore they play an important role in coastal protection. In past decades mangrove forests worldwide suffered from exploitation, deforestation and land reclamation. Mangrove rehabilitation is one goal in the project of "Management of Natural Resources in the Coastal Zone of Soc Trang Province" conducted by the GTZ and the Forest Protection Sub-Department in Soc Trang, Viet Nam.

The study area is located at the coast of Soc Trang Province in the Mekong Delta, Viet Nam. The interaction of changing sediment flux of the Mekong River, coastal long shore currents driven by prevailing monsoon winds and the tidal regime of the South China Sea creates a very dynamic shoreline. Diverse coastal forests with a natural capability of regeneration must be created to maintain the coastal protection function of mangroves. Risk spreading strategies have been applied to address uncertainties. New approaches for planting and management have been tested to achieve more diverse forests promoting stand resilience to the given threats of climate change.

One approach tested applying dense planting close to established trees bases on the natural pattern of regeneration. Cluster planting mimicking natural regeneration has been carried out as a small scale planting on 24 planting plots of each ca. 30 m^2. Different seedling densities (20, 30 and 40 trees/m^2) and different species compositions of *Rhizophora apiculata*, *Ceriops tagal* and *Avicennia marina* have been implemented.

The other approach tested is the transformation of even-aged monoculture plantations into more diverse forests in terms of species composition and structure. Within an even-aged plantation forest a total of 21 gaps of different sizes (7- 45 m^2) have been created. In 9 plots planting mimicking nature has been carried out with a seedling density of 30 trees/m^2 and species compositions of *Rhizophora apiculata* and *Ceriops tagal*. Another 9 plots have been left for natural regeneration to take place; 3 plots are the control area, no gaps heve been created here. Field-testing will show what the optimal gap size will be and whether natural regeneration is sufficient or if planting mimicking natural regeneration becomes necessary.

A comprehensive monitoring system has been developed, easy in use and covering the needs of the project activities. It consists of the "Location map" to relocate the planting area, the "Site description" and "Planting description" sheet for a comprehensive baseline data documentation and the "Monitoring sheet" to record data during monitoring activities. Three different monitoring strategies have been developed for different planting sites and strategies covered within this study. A first set of monitoring data have been recorded and analyzed.

Table of Contents

Acknowledgements I
Summary II
Table of Contents III
List of Figures V
List of Tables VIII
List of Formulas IX
List of Abbreviations X

1. Introduction ... 1
1.1. Methodology ... 2
1.2. Objectives ... 3
1.3. Background ... 4

2. Literature review ... 5
2.1. Mangroves ... 5
2.2. Attributes of mangroves ... 5
2.3. Mangrove physics ... 7
2.4. Mangrove distribution and zonation ... 9
2.5. Mangrove services ... 9
2.5.1. Socio-economic benefits ... 10
2.5.2. Ecological benefits ... 11
2.5.3. Coastal protection by mangroves ... 11
2.6. Mangrove degradation ... 19

3. Study and project area ... 20
3.1. Geographic location ... 21
3.2. Climate ... 22
3.3. Geology and soil ... 23
3.4. Hydrology ... 25
3.4.1. Tidal regime and currents ... 25
3.4.2. Salt-water intrusion ... 28
3.4.1. Sediment flux ... 28
3.5. Erosion and accretion ... 31

4. Status quo and mangrove regeneration efforts ... 33
4.1. Mangroves in Viet Nam ... 33
4.2. Land use and mangroves in the project area ... 34
4.2.1. Land use ... 34
4.2.2. Mangrove history in Soc Trang Province ... 34
4.2.3. Findings through previous plantings ... 39
4.3. The project ... 41
4.3.1. Integrated Coastal Area Management ... 42
4.3.2. Planting strategies ... 42
4.3.3. Monitoring ... 47
4.3.4. Co-management ... 48

5. Methods and Material ... 50
5.1. Forest planting plan ... 50

5.2. Structure and forms ... 51
5.2.1. Location map ... 51
5.2.2. Planting operation design ... 52
5.2.3. Monitoring settings ... 53
5.2.4. Monitoring sheets ... 55
5.3. Planting projects ... 56
5.3.1. VC001 ... 56
5.3.2. VC002 ... 57
5.3.3. VC003 ... 59
5.3.4. VC004 ... 61
5.4. Monitoring settings ... 67
5.4.1. Monitoring VC001 ... 67
5.4.2. Monitoring VC002 ... 69
5.4.3. Monitoring VC003 ... 70
5.4.4. Monitoring VC004 ... 71

6. Results ... 72

6.1. Data analysis ... 72
6.2. Data analysis within this study ... 73
6.2.1. Data analysis VC001 ... 74
6.2.2. Data analysis VC002 ... 75
6.2.3. Data analysis VC003 ... 77
6.2.4. Data analysis VC004 ... 82
6.2.5. Discussion of results ... 86

7. Discussion ... 88

7.1. Summary ... 88
7.2. Comparisons ... 88
7.3. Recommendations ... 92

References ... 94

Appendices

- Appendix I — The world's 73 mangrove species and hydrides after Spalding et al., 2010
- Appendix II — Location maps for planting sites VC001, VC002, VC003 and VC004
- Appendix III — Site description sheet
- Appendix IV — Planting description sheet
- Appendix V — Site description sheet and planting description sheet for VC003
- Appendix VI — Site description sheet and planting description sheet for VC004
- Appendix VII — Mangrove plot monitoring sheet
- Appendix VIII — Mangrove transect monitoring sheet
- Appendix IX — Mangrove plot monitoring (1 m^2) sheet

List of Figures

Figure 2-1: Distribution of mangroves worldwide (UNEP World Conservation Monitoring Centre:, 2006) 5
Figure 2-2: Stilt roots of *Rhizophora* trees 7
Figure 2-3: Pneumatophores of an *Avicennia* tree 7
Figure 2-4: Classification of mangrove topography (after Cintron and Novelli (1984): (a) Riverine forest type; (b) Fringe forest type; (c) Basin forest type (Mazda et al., 2007) 8
Figure 2-5: Gradient of the water surface (energy slope) within mangroves. 13
Figure 2-6: Sketch of the control volume for ensemble averaging (Mazda, et al., 1997b) 14
Figure 2-7: The relationship between the coefficient of dynamic eddy viscosity *f* and the Reynolds number *Re*. The marks show measured results within different observation sites in Ari-Gawa, Japan 2001 and 2002; Rio-Chone, Equador 2003; Maera-Gawa, Japan 2003. (Mazda et al., 2005) 15
Figure 2-8: A schematic cross-section in an inner portion of a R-type mangrove forest. The drag force and the bottom friction force balancing the pressure gradient due to water surface slope. Θ is the angle of the pressure gradient and v is the mean fluid velocity. (Mazda et al., 2005) 16
Figure 2-9: Differences in the effect of wave reduction with (a) a 1,5 km wide stripe of mangroves and with (b) no mangroves (Mazda et al., 1997) 17
Figure 2-10: Normalized energy Enorm in very dense and low dense forests. (Massel et al., 1999) 18
Figure 2-11: Changes in world mangrove area in 1000 ha, 1980 – 2005 (FAO, 2007b) 19
Figure 3-1: Map of Viet Nam marking the Mekong Delta 20
Figure 3-2: Map of the Mekong Delta 20
Figure 3-3: Map of the project area in Soc Trang Province 21
Figure 3-4: Isohyets of the mean annual rainfall in the Mekong Delta (Yamashita, 2005) 22
Figure 3-5: Average monthly temperature (°C) in Soc Trang City (2001-2004), average monthly rainfall (mm per month) Vinh Chau Town and Mo'O Station (My Thanh River mouth) (2002-2006) (Joffre & Luu, 2007) 23
Figure 3-6: Soil distribution in the Mekong Delta (Yamashita, 2005) 24
Figure 3-7: Topography of the Mekong Delta (Yamashita, 2005) 25
Figure 3-8: Water levels at Vung Tau gauging station in October 2006 26
Figure 3-9: Tidal range at Vung Tau gauging station around neap tide and spring tide in October 2006 26
Figure 3-10: Mean surface circulation in the South China Sea during a) summer b) winter 27
Figure 3-11: Suspended Sediment Concentration at Can Tho station (Lu & Siew, 2006) 29
Figure 3-12: Distribution of sediment texture groups (Nguyen T. T., 2009) 30
Figure 3-13: Mud flats and sand banks in front of Soc Trang Province 31
Figure 3-14: Sedimentation site in front of Vinh Hai Commune 32
Figure 3-15: Erosion site in front of Lai Hoa Commune 32
Figure 4-1: Variations of mangrove areas in Vinh Chau District. The cross marks the same geographic position. (Pham et al., 2009) 35

Figure 4-2: Variations of mangrove areas in Lich Hoi Thuong and Vinh Hai Communes. The cross marks the same geographic position. (Pham et al., 2009) 36
Figure 4-3: Variation of mangrove areas and the coastline in Cu Lau Dung. The cross marks the same geographic location. (Pham et al., 2009) 36
Figure 4-4: Variation of mangrove area in Soc Trang Province 1965-2008 (Pham, 2010) . 39
Figure 4-5: Strong winds in front of Vinh Hai Commune uprooted planted trees. The original planting density was 1 tree per m^2.. 40
Figure 4-6: In places with high erosion, natural regeneration is not possible; mangrove forests are destroyed and waves affect the dyke.. 40
Figure 4-7: A ground net shown on land in Au Tho B Village 41
Figure 4-8: Fishing activities in front of the mangrove forest in Lai Hoa Commune.......... 41
Figure 4-9: Mangrove planting with 1x1 m distance between seedlings in Vinh Chau Commune.. 43
Figure 4-10: Natural regeneration pattern of *Rhizophora* trees. Picture by Dr. Klaus Schmitt 44
Figure 4-11: Cluster planting mimicking nature regeneration of *Rhizophora mucronata* and *Ceriops tagal* trees in Vinh Chau Commune... 44
Figure 4-12: Closed canopy inside the mangroves in Lai Hoa Commune 45
Figure 4-13: Gaps created in the mangroves in Lai Hoa Commune 45
Figure 4-14: The ground inside the mangrove forest without any gaps 45
Figure 4-15: Sunlight reaches the ground through a gaps created inside the forest 45
Figure 4-16: Forest edge conditions create a healthy vertical structure with trees of different age beside the test area in Lai Hoa Commune. 45
Figure 4-17: Natural regeneration appeared supported by forest edge conditions supporting incidence of sunlight... 45
Figure 4-18: The six stages of gap creation and recovery (Duke, 2001b) 46
Figure 4-19: Flow chart of planting and monitoring procedures; the red arrows show the important flow of information based on monitoring results.. 47
Figure 4-20: Overview of the 4 steps of the co-management process and the 4 key principles; ICAM, participation, zonation and monitoring (Schmitt, 2009).......................... 49
Figure 5-1: Location map for planting site VC003; the red lines show path to follow, the dots show waypoints marking the planting plots 52
Figure 5-2: Planting site VC001 in Vinh Chau District... 58
Figure 5-3: Planting site VC002 in Vinh Hai Commune 58
Figure 5-4: Location map for planting site VC003 in Vinh Chau Commune...................... 60
Figure 5-5: Demarcation for VC003 plot No. 7 in Vinh Chau Commune.......................... 61
Figure 5-6: Demarcation for VC003 plot No. 9 in Vinh Chau Commune.......................... 61
Figure 5-7: Planting in rows, VC003 plot No. 10; the bigger propagules are *Rhizophora apiculata* and the smaller propagules are *Ceriops tagal* 61
Figure 5-8: Cluster planting mimicking natural regeneration; VC003 plot No. 12 61
Figure 5-9: Sketch of planting Site VC004 showing information about plots, areas and zones. Horizontal sections are the areas (1, 2, 3, …7); Vertical sections are the zones (a, b, c); Plots are green marked containing a caption of area number and zone identifier. .. 62
Figure 5-10: Location map of planting site VC004 in Lai Hoa Commune 64
Figure 5-11: Measurements inside the mangroves in planting site VC004....................... 65
Figure 5-12: Demarcation of trees to be felled in planting site VC004............................. 65

Figure 5-13: Creating gaps by felling trees in planting site VC004 65
Figure 5-14: Planted plot in planting site VC004, area 3, plot a 66
Figure 5-15: Driftwood and litter after spring tide in planting site VC004 66
Figure 5-16: Demarcation on plots with plastic film and cable ties.................................. 66
Figure 5-17: Planting site VC001 showing the distribution of the coordinates for the sub-areas for monitoring.. 68
Figure 5-18: 40 m^2 monitoring plot for VC001; the plot is marked by the grey rectangle, the red dots show the ranging poles connected with a 20 m rope (red transect line) 68
Figure 5-19: Schematic display of the random location of 40m^2 plots along 3 transects (VC001) 68
Figure 5-20: Local staff gets introduced to the monitoring sheets in the field 70
Figure 5-21: Data recording for monitoring in planting site VC002 70
Figure 5-22: Monitoring activities in planting site VC003 71
Figure 5-23: The subdivided sampling frame facilitates the fieldwork............................... 71
Figure 5-24: Monitoring activities in VC004... 71
Figure 5-25: One square meter marked by wood pegs 71
Figure 6-1: Natural regeneration of *Avicennia marina* (red marked in the figure) between planted *Rhizophora* seedlings after 3 month 79
Figure 6-2: Planted seedlings in planting site VC004 (at the time of monitoring in February 2010) 86
Figure 6-3: Planted *Rhizophora apiculata* in VC001, Vinh Chau Commune 87
Figure 6-4: Planted *Rhizophora apiculata* in VC001, Au Tho B Village 87

List of Tables

Table 4-1: True mangrove species recorded in Soc Trang Province 2008 (Pham, 2010) 38
Table 5-1: Species composition for planting site VC003 in Vinh Chau Commune 59
Table 5-2: Plot size, species composition and amount per plot in planting site VC004 63
Table 5-3: Monitoring pattern for planting site VC002.. 69
Table 6-1: Monitoring results for planting site VC001 74
Table 6-2: Survival rate after 16 months in planting site VC001 74
Table 6-3: Increment in number of knots after 16 months in planting site VC001 75
Table 6-4: Monitoring results for planting site VC002 75
Table 6-5: Survival rate and density of living trees after 12 months in VC002.................. 76
Table 6-6: Increment in number of knots after 12 months in VC002................................ 76
Table 6-7: Monitoring results for planting site VC003 77
Table 6-8: Baseline data in planting site VC003 77
Table 6-9: Density of living trees after 3 months in VC003 78
Table 6-10: Survival rate of Rhizophora apiculata after 3 months in VC003 80
Table 6-11: Survival rate of Ceriops tagal after 3 months in VC003 81
Table 6-12: Increment in number of knots after 3 months in VC003................................ 81
Table 6-13: Monitoring results in planting site VC004... 82
Table 6-14: Baseline data in planting site VC004 82
Table 6-15: Density of living trees after 3 months in VC004 83
Table 6-16: Survival rate of Rhizophora apiculata after 3 months in VC004 84
Table 6-17: Survival rate of Ceriops tagal after 3 months in VC004 85
Table 6-18: Increment in number of knots after 3 months in VC004................................ 85

List of Formulas

Formula (2-1): Manning coefficient *n* 12
Formula (2-2): Energy slope *i* 13
Formula (2-3): Reynolds number R_e 14
Formula (2-4): Effective vegetation length scale l_E 14
Formula (2-5): Rate of wave reduction *r* 16
Formula (2-6): Normalized energy E_{norm} 18
Formula (5-1): Total area to be monitored *I* 54
Formula (5-2): Number of sampling plots *n* 54
Formula (6-1): Average tree height 72
Formula (6-2): Stems per hectare 72
Formula (6-3): Basal area 73
Formula (6-4): Stand basla area 73

List of Abbreviations

cm	Centimeter
g/L	Gramm per Liter
km	Kilometer
m	Meter
m/s	Meter per second
m^2/s	Square meter per second
m^3/s	Qubic meter per second
mm	Milimeter
Mt	Mega tons
ha	Hectare
t	Ton
CO_2	Carbon dioxide
DBH	Diameter at breast height
GPS	Global Positioning System
Kcal	Kilocalories
MKS	Units of the meter, kilogram, and/or seconds
MSL	Mean Sea Level
PVC	Poly vinyl chloride
REM	Riley encased methodology
SSC	Suspended Sediment Concentration
USD	US Dollar
VND	Vietnamese Dong
YBP	Years before present
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung
CWPD	Coastal Wetlands Protection and Development
DARD	Department of Agriculture and Rural Development
FIPI	Southern Sub-Institute of Forest Inventory and Planning
GTZ	Gesellschaft für Technische Zusammenarbeit GmbH
ICAM	Integrated Coastal Area Management
PPC	Province People's Committee
SIWRR	Southern institute of Water Resources Research

1. Introduction

Mangroves grow in intertidal zones along tropical and subtropical coastlines. Over a long evolutionary process, mangrove plants have adapted effective characteristics and strategies for survival. Special features including unique root systems and different reproductive methods make mangrove forests unique ecosystems. These forests provide a wide array of economic and socio-economic benefits wherever they grow. Benefits derived from areas near the mangrove forests have made these highly significant locations throughout past centuries. Today, mangrove forests around the world are suffering from exploitation, deforestation and restrictions to their growing areas. Because of their value, particularly in the context of coastal protection in times of climate change, there are many ongoing efforts to rehabilitate mangroves around the world. (Elster, 2001) (Hensel et al., 2002)

The German Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH) is a federally owned organization active around the world in the field of international cooperation for sustainable development. The GTZ is based in Eschborn, Germany and was founded in 1975. Its chief client is the German Federal Ministry for Economic Cooperation and Development (BMZ), but the GTZ also works for other German ministries, governments of other countries, and the private sector (GTZ, 2010b).

"Management of Natural Resources in the Coastal Zone of Soc Trang Province" is one of the GTZ's current projects in South Viet Nam. Initiated by the Forest Protection Sub-department, the project aims to "*provide pilot solutions to solve the conflict between economic development and sustainable management of natural resources in the coastal zone of Soc Trang Province*" (Joffre & Luu, 2007, p. iii). Moreover, the project includes climate change adaptation activities focusing on livelihood diversification and mangrove management. In this context, one of the project's main targets is the rehabilitation of the mangrove forests, facilitated by forest restoration and protection. The latter objective will be achieved through sustainable exploitation and management. This requires an explicit framework, ecological baseline data and for community involvement to be taken into consideration. To verify whether mangrove rehabilitation has been successful, a monitoring system is needed. The Vietnamese counterpart for this project is the Forest Protection Sub-department (Kiem Lam) of Soc Trang Province and the Soc Trang Provincial People's Committee (PPC). (GTZ, 2010a) (GTZ, 2010b)

Large parts of the Southeast Asian coastline are covered with mangrove forests, but these areas are at high risk due to threatening influences. The coastal areas are densely populated by low-income populations, who harm the mangroves through unsustainable exploitation. Deforestation with the aim of land conversion for salt-farms, shrimp-farms and agricultural usage is also destroying the mangroves. The Mekong Delta in Viet Nam, in particular, suffers from these issues.

Soc Trang Province is located in the Mekong Delta in Southern Viet Nam. The study area of this thesis, which overlaps with the GTZ project area, is the coastal zone of Soc Trang Province. Hydrological and hydraulic conditions in the project area are influenced by the Mekong River, the South China Sea flow regime and prevailing monsoon weather conditions. Currents in the South China Sea and the suspended load of the Mekong River and prevailing monsoon winds create unique conditions for erosion and accretion along the coast of Soc Trang Province.

1.1. Methodology

Within the context of the GTZ project "Management of Natural Resources in the Coastal Zone of Soc Trang Province", mangrove restoration activities have been pursued by planting mangroves and protecting the forests via a co-management pilot project in Au Tho B Village. In order to maintain the coastal protection function of the mangroves, it is necessary to create resilient coastal forests with a natural regenerative capacity. In respect to the failures of previous mangrove rehabilitation programs and given the threats of climate change, risk-spreading strategies might be successful in achieving stand resilience in coastal forests. Two different planting schemes were designed and established in late 2009 and differ from commonly followed practices in this area. These tests, which aim to mimic nature, may provide insight that can be applied to new planting strategies. An integrated mangrove monitoring system has also been designed and put into place to determine factors critical to the success of plantations and how mangrove forests change.

In chapters two and three of this thesis, a literature review will be provided, presenting general attributes of mangrove ecosystems, emphasizing ecological and socio-economic traits of mangroves as well as hydrological conditions. Additionally, in Chapter 4, the study area will be described in respect to land use and mangrove history including project-related efforts.

Chapters 5 and 6 will describe not only planning and development activities, but also the fieldwork conducted for this study. Moreover, Chapter 6 will present data analysis used to evaluate different planting strategies

Chapter 7 gives a final discussion comparing the implemented planting techniques with different planting projects. While the survival rate of planted trees is generally an important parameter for planting success, within this project the testing of new approaches to create a natural mangrove forest structure is crucial.

1.2. Objectives

The objectives of this study are:

- Characterization of mangroves in general with an emphasis on
    - the role of mangroves in coastal protection
    - the hydrology and hydraulics of mangroves

A general and comprehensive description of mangrove ecosystems is presented. Furthermore, hydrological and hydraulic functions will elucidate the role of mangroves in coastal protection as well as in relation to hydrology and natural processes.

- A comprehensive characterization of the study area
    - History of mangroves and status quo

The study area covers a highly dynamic coastal area; therefore planting and rehabilitation activities need to take into consideration a vast number of different parameters affecting mangroves. The lessons learned by prior projects are described in addition to changes in land use. Targets and efforts related to wetland rehabilitation of the GTZ project are also described.

- Description of the implemented rehabilitation strategies

Two new approaches have been tested within this project. Cluster planting that mimics natural regeneration, and creating gaps for natural regeneration or planting. Description are given of the design and implementation of these approaches as well as the design of two prior plantings.

- Description of the comprehensive mangrove monitoring system and the implementation process
    - Data calculation and discussion of the results

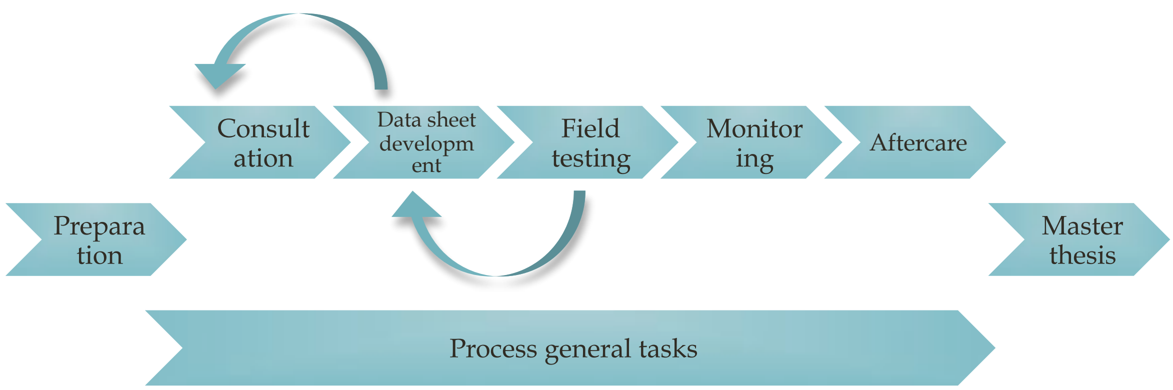
The structure of a planting project includes different forms of baseline data and monitoring systems. Descriptions are given not only of the development and implementation of these forms, but also different monitoring strategies adapted to different planting designs. Moreover, the results are presented and discussed.

1.3. Background

This thesis arose from an internship conducted with the GTZ project "Management of Natural Resources in the Coastal Zone of Soc Trang Province" from September 2009 until April 2010. The tasks during the internship were:

- Assist the project partner with the development and field testing of a systematic monitoring system forsuccessful mangrove planting
- Assist the project partner with the development and field testing of a participatory resource use monitoring system by local communities
- Set up a computerized system for data storage, analysis and reporting
- Support current survey specialists if and when opportunities arise during their respective field work
- Exchange information with project counterparts and assist them in raising awareness among local communities

Some of these tasks became protracted due to local conditions and procedures. For example, all of the documents the project developed needed to be translated into Vietnamese ("resource use monitoring" protocols were translated into Vietnamese and Khmer) and the project partner needed to make staff members available for fieldwork activities. Activities during the internship are briefly presented in the following flow chart.



2. Literature review

2.1. Mangroves

As shown in Figure 2-1, mangroves cover most of the protected coasts, lagoons, deltas and estuaries of tropical and sub-tropical regions around the world. Mangrove growth is related to climatic conditions. As a general rule, the average water temperature should not drop below 24 °C and the average air temperature should not be lower than 20 °C during the coldest month. Changes in air temperature should not exceed 10 °C during the year. This limits mangrove growth to the regions between 30° N and 30° S latitude. Exceptional mangrove growth can be observed in the Bermudas and Japan in the northern hemisphere, and in South Australia, New Zealand and along the East coast of South Africa in the southern hemisphere (See Figure 2-1) (Elster, 2001). The total land area of mangrove forest covers just over 150,000 km², which is less than 1 percent of the entire area of tropical forests (Spalding et al., 2010).

Figure 2-1: Distribution of mangroves worldwide (UNEP World Conservation Monitoring Centre:, 2006)

2.2. Attributes of mangroves

Mangroves are generally trees, but may also grow as shrubs, palms or ground ferns. The habitat is interchangeably referred to as "mangroves", "mangrove forest" and "tidal forest". The less common term "mangal" was proposed for the habitat as well, but was unable to establish itself like the other terms. The exact definition of what a mangrove tree is remains unclear. Some species have been categorized as true mangroves while other taxa are often called mangrove associates (Duke, 1992). Many authors of mangrove literature still disagree about what constitutes a mangrove. Spalding et al. (2010) published a list of 73 true species and hybrids of mangroves, which this thesis accepts as a well researched list. A table of these species is included in Appendix I.

Mangroves form taxonomically diverse groups, the majority of which belong to four genera: *Bruguiera*, *Sonneratia*, and particularly *Avicennia* and *Rhizophora*. Mangroves must be able to demonstrate different morphological and physical adaptations such as mechanisms for coping with high and changing salt concentrations or managing anaerobic soils. (Sands, 2005)

All mangrove species use the water as a dispersal agent for their offspring and therefore five major families of mangroves provide viviparous propagules. The degree of viviparity varies and some mangroves do not share this characteristic. *Rhizophoras* provide highly developed propagules, which can survive for several months in a semi-dormant state and live independently for the first three years of growth. (Duke, 1992) (Spalding et al., 2010)

Duke (2001a) lists four different strategies of *Rhizophora* propagules for natural rejuvenation.

1. Dropper Propagules fall in the right position from the tree

Propagules, which do not successfully "drop" are in a state of propagation and rely on the following characteristics for planting.

2. Bender Propagules lie horizontal on the ground while roots grow into the substrate. After some time, they bend themselves into an upright position.
3. Snagger Propagules get caught in the root systems of mature trees and grow in between them.
4. Holer Propagules are moved by tidal currents and get caught in mud-crab holes and settle there.

Mangroves mostly grow in substrates that are water saturated and in many cases anaerobic. These soils provide no oxygen, and gaseous exchange is impeded because there is no available air space (Duke, 2001a). Mangroves have therefore developed special systems of aerial roots, which have contact with the atmosphere where gaseous exchange is possible through pores - at least during low tide (Sands, 2005). The aerial root can be a stilt root as in *Rhizophora*, originating from the main stem and growing in an arched shape to the ground (see Figure 2-2) or it can be pneumatophores as in *Avicennia* or *Sonneratia* (see Figure 2-3), growing vertically from a radial root below the surface (Elster, 2001) (Sands, 2005).

Figure 2-2: Stilt roots of *Rhizophora* trees

Figure 2-3: Pneumatophores of an *Avicennia* tree

Other types of roots include knee roots, which are knob-like extrusions extending vertically from the sub-surface roots (e.g. *Bruguiera, Ceriops*) and buttress roots, which are flange-like extensions of the trunk extending in sinuous plank-forms above the surface (*Heritiera*). (Spalding, et al., 2010)

Mangroves need to be salt-tolerant and they possess a variety of mechanisms for desalinating the water. Salt can be deposited inside some parts of the tree (e.g. in non functional components of the bark) or excreted through glands on the leaves. Some species accumulate salt in the leaves and then drop them, while other species compensate for high salt concentrations by having higher levels of water retention (salt-succulence). (Duke, 1992) (Elster, 2001) (Sands, 2005)

2.3. Mangrove physics

Over the past decades, interest in mangrove systems has increased due to a better understanding of the benefits of coastal protection and the demand for managing these areas. In less-developed countries, in particular, research funding has been inadequate and field conditions are difficult. Through cooperation with international agencies, the quality of research has improved, but these studies are site-specific, short-term and only address specific questions and environmental conditions. Today, the body of information on mangroves is slightly better and most mangrove systems have been examined. A comprehensive understanding of physical processes is necessary for establishing solid and sustainable management, and also for using mangrove systems for coastal protection. (Wolanski et al., 1992)

Lugo and Snedaker (1974) classified mangrove forests into six types:

1. Fringe forests: This forest type occurs along fringes of protected shorelines and islands with elevations higher than the mean high tide, inundated by most high tides, occasionally affected by strong wind, erosion and accretion.
1. Riverine forest: Forests along river and creek drainage areas, which are inundated by most high tides and flooded during rainy seasons, and therefore subjected to varying levels of salt concentrations.
2. Overwash forest: Small islands and peninsulas, which are completely overwashed during all high tides.
3. Basin forest: This type occurs in inland areas along drainage depressions. Inundated by a few high tides during the dry seasons (also depending on the distance to the coast) and more high tides during rainy seasons.
4. Dwarf forest: This forest type is limited to topographic flats above mean high water levels. The trees are relatively small and may be stunted or dwarf-like; additionally, the environment lacks external nutrient sources.
5. Hammock forest: This type is similar to the basin forest type, but the ground is slightly elevated (5-10 cm) above the surrounding area.

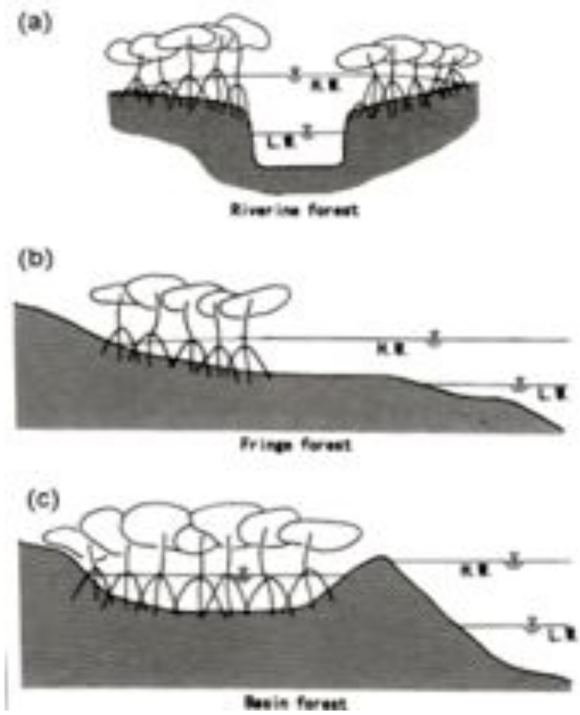


Figure 2-4: Classification of mangrove topography (based on Cintron and Novelli (1984): (a) Riverine forest type; (b) Fringe forest type; (c) Basin forest type (Mazda et al., 2007)

Cintron and Novelli (1984) modified the classification presented above into three forest types (fringe forest, riverine forest and basin forest). Many authors discussing the hydraulics of mangrove forests use this classification. Mazda et al. (2007) presented the classification as follows: (See Figure 2-4 in which H.W. is the water level at high tide and L.W. the water level at low tide)

- Riverine forest (R-type):
- Fringe forest (F-type)
- Basin forest (B-type)

Conditions of inundation are similar to those described by Lugo and Snedaker (1974).

2.4. Mangrove distribution and zonation

The diversity of mangroves worldwide varies from sites with just 1-2 species to areas where up to 47 species are present (Spalding et al., 2010). Limited species diversity can be found in the northernmost and southernmost regions, where the climatic conditions barely allow for mangrove growth, but also along the coasts of eastern and western America, West and Central Africa and East Africa. The most diverse mangrove systems appear in Southeast Asia and along the northern parts of Australia. The local diversity of mangroves is not only influenced by local patterns in the physical and chemical environment, but also by the presence of specific species. (Spalding et al., 2010)

According to Duke (1992), the distribution of mangroves can be divided into three categories; the coastal range, areas within estuaries and areas along the intertidal profile. Hogarth (1999) found that zonation might be a consequence of gradients created by geomorphological changes. "*Finally, zonation might be the product of ecological interactions between species in the community, the species along a transect in space corresponding to a natural succession of species with time*" (Hogarth, 1999, p. 38)

Within the mangrove communities, a pattern of zonation can be observed, as well as a process of succession and changes in species and forest structure over time. Pioneer plant species do not dominate a mangrove forest; subsequent species may shade them out. *Rhizophora* species are known for being very resistant and having a higher degree of shade resistance (Spalding et al., 2010).

2.5. Mangrove services

Mangroves are highly dynamic, critically important ecosystems with a huge biomass production and high levels of productivity. They provide a vast quantity of products and ecosystem services; moreover, they support adjacent ecosystems via exchanges of nutrients. These benefits can be separated into products (socio-economic values) and services (ecological benefits). Indeed, ecological services also hold socio-economic value since humans are a part of the ecosystems, and maintaining functions as well as cost reduction both carry economic implications.

Financial terms carry the most weight in determining policies and decision-making, but they must be carefully considered. To date, there have been a vast number of studies about the economic value of mangroves. UNEP-WCMC (2006) stated that the overall annual value of extensive mangroves can be estimated at USD 200,000 to 900,000 per hectare.

2.5.1. Socio-economic benefits

People have been using mangroves for centuries, with first recorded references dating back over 2000 years. The utilization of mangroves has yielded a wide range of valuable benefits to local communities. In many places, people are dependent on products made or harvested from mangroves. In general, those products can be split into two main categories, timber and non-timber products. (Bandaranayake, 1998) (FAO, 2007a)

Timber products

In general the wood from mangrove trees is of good quality. Trees can reach heights of up to 30 m, but in most areas they are generally smaller. Nevertheless, mangroves are mainly hardwood and have a high resistance not only to pests and fungi, but also to rotting agents and saline water. Timber is used for poles and construction wood. The leaves of *Nypa fruticans* are used as thatch for roofing; hence, complete dwellings can be built from mangrove trees. Additional timber products include fishing gear, wood chips, matchsticks and pulp for the paper industry. (Bandaranayake, 1998) (McLeod & Salm, 2006) (FAO, 2007b) (Spalding et al., 2010)

Mangroves are commonly used as fuelwood, and are burned as firewood or transformed into charcoal on a large scale. As mentioned above, residents of coastal areas are primarily poor, and in the Mekong delta for example, the majority of local communities cannot afford gas stoves or gas. Therefore traditional stoves, which use fuelwood for heating, are used for cooking. Additionally the production of charcoal from mangrove trees is widespread. *Rhizophora* is particularly favored for charcoal production, as its billets have a high caloric power, slow burning characteristics and produce nearly no smoke. (Bandaranayake, 1998) (Elster, 2001)

Non-timber products

The number of non-timber mangrove products is also huge. Fisheries products (mainly fish, shrimps, clams and crabs) are highly valued in mangrove systems; they provide food and a great source of income. (Bandaranayake, 1998) (Elster, 2001) (UNEP-WCMC, 2006)

Additional non-timber products include tannins (used for leather preparation), food (some fruits and leaves are comestible), fodder, vegetable oils, honey, wax, spices, medicine, beverages, food additives (e.g. ash of *Avicennia* has a high mineral content) and substitutes (e.g. tea, betel nut). (Bandaranayake, 1998) (FAO, 2007b)

2.5.2. Ecological benefits

Mangroves also provide a very important habitat for marine and coastal fisheries. The productivity and protection provided by mangrove systems creates ideal nursery conditions, which fish and crustaceans depend on for breeding and rearing of offspring. As a result, mangroves are important in many food chains not only for fish, but also for birds, mammals, amphibians, reptiles and insects. Therefore, over-fishing and mangrove degradation has far reaching consequences (de Graf & Xuan, 1998) (Elster, 2001) (FAO, 2007a). De Graaf and Xuan (1998) estimated in their study about shrimp farming in the southern provinces of Viet Nam, that 1 ha of mangroves supports around 0.449 t/year of marine fish catch. Among other factors, the high biodiversity in mangroves is related to the number of different biospheres within the system (Blaber & Blaber, 2001).

Additional ecological services provided by mangroves include the maintenance of natural ecological processes of the coastal zone, production of biomass, and retention of nutrients. (Pham, 2010)

Moreover, mangroves serve as a carbon sink. The overall area of mangroves is relatively small compared to other tropical forests, but they should not be overlooked in terms of CO_2 sequestration as they have higher rates of productivity. (Spalding et al., 2010)

The impact of mangroves in terms of coastal protection is one of the most valuable functions that these ecosystems serve. This point is discussed separately in the following section.

2.5.3. Coastal protection by mangroves

Biogeochemical and trophodynamic processes as well as forest structure and growth are closely linked to water movement, due to tides and waves within mangrove ecosystems. Thus, hydrodynamic and hydraulic factors play a major role in the structure and function of mangroves. (Massel et al., 1999)

Mangroves provide mechanical protection for the shorelines, flood protection structure (e.g. dykes and water gates) and the hinterland. They create an effective buffer by supporting soil consolidation and sedimentation processes. Mangroves not only decrease the hydrodynamic impacts of waves and erosion processes under normal tide conditions, but also under extreme situations such as hurricanes. This benefit provided by mangroves will translate into a savings on dyke maintenance costs and also protect human lives in extreme situations. In an extensive mangrove forest of sufficient size, these benefits are provided at no cost. After the Indian Ocean Tsunami in 2004, mangroves received increased attention in respect to coastal protection by the international press and scientists. (FAO, 2007b)

The view that mangroves create new land is general discounted these days. In fact sedimentation processes occur first, and then mangroves settle on the land. Afterwards they play an important role in sediment deposition, consolidation and the reduction of erosion rates. (Spalding, et al., 2010)

Hydrodynamics inside mangroves

Wolanski et al. (2001), reported on field experiments of tidal fluxes conducted in Coral Creek, Hinchibrook Island, Australia in 1980. They used linked 1-dimesional and 2-dimensional numerical models to simulate tidal flow distribution within a mangrove area. The field experiments showed that flow velocities of more than 1 m/s are normal in creeks, while the velocity 20 m inside the forest hardly reaches 0.07 m/s. Therefore the mangrove system can be divided into two parts. On the one hand is the creek, and on the other hand is the mangrove swamp, where vegetation decreases the flow velocity through high friction levels. The velocity within the mangrove swamp can be parameterized using the Manning coefficient *n*, which can be determined by approaches in a numerical model or by calculations of representative flow data. The Manning coefficient can be expressed as:

$$n = \frac{1}{v} * i^{1/2} * H^{2/3} \tag{2-1}$$

- v flow velocity in m/s
- i gradient of the water surface (energy slope)
- H water depth in m

While in general R_h (hydraulic radius in m) is used in the Manning formula, in this case it is H (water depth in m). If the water body to be calculated is shallow and broad, the hydraulic radius can be assumed to be equal to the water depths.

Analysis suggests a Manning coefficient of 0.1-0.2 $sm^{-1/3}$ inside the swamp (Wolanski, et al., 2001). More detailed measurements of the Manning coefficient were collected more recently in the mangrove swamp of Nakama Gawa, Iromote Island, Japan. These more reliable results show a typical coefficient of 0.4 $sm^{-1/3}$ in a range of 0.2-0.7 $sm^{-1/3}$ (Wolanski, et al., 1992)

These Manning coefficients are very high compared to different surfaces (e.g. a riverbed with weedage has a Manning coefficient of 0.05-0.03 $sm^{-1/3}$, a floodplain covered with trees has a Manning coefficient of 0.15 $sm^{-1/3}$). The dimension of the Manning coefficient is believed to depend on the enormous amount of obstacles represented by stems, roots, additional vegetation and drift material caught in between. The Manning coefficient derived from the

Gauckler-Manning-Strickler formula which is used in non Anglo-Saxon areas. The Manning coefficient is the reciprocal of the Strickler coefficient k_{St}. The results expressed as Strickler coefficients are:

- Manning coefficient 0.1 $sm^{-1/3}$ Strickler coefficient 10 $m^{1/3}/s$
- Manning coefficient 0.2 $sm^{-1/3}$ Strickler coefficient 5 $m^{1/3}/s$
- Manning coefficient 0.4 $sm^{-1/3}$ Strickerl coefficient 2.5 $m^{1/3}/s$

To figure out the gradient of the water surface, an example is calculated using an achieved flow velocity of 0.07 m/s and a Manning coefficient of 0.4 $sm^{-1/3}$. This assumes a mangrove forest 5 km in width and with a tidal range of 3 m. The energy slope *i* can be calculated using the reconvert formula (2-1).

$$i = \left(\frac{n * v}{H^{2/3}}\right)^2 \qquad \textbf{(2-2)}$$

- *n* Manning coefficient 0.4 $sm^{-1/3}$
- *H* water depth 3 meters
- *v* flow velocity 0.07 m/s

In this example the energy slope amounts to 0.00018 m/m, which is equal to 0.18 m/km (0.18 ‰). This means that if the maximum tide of 3 m comes to the forest edge, 5 km inside the forest, the water depths would be 2.1 m (3 - (5 x 0.18)) due to the energy slope.

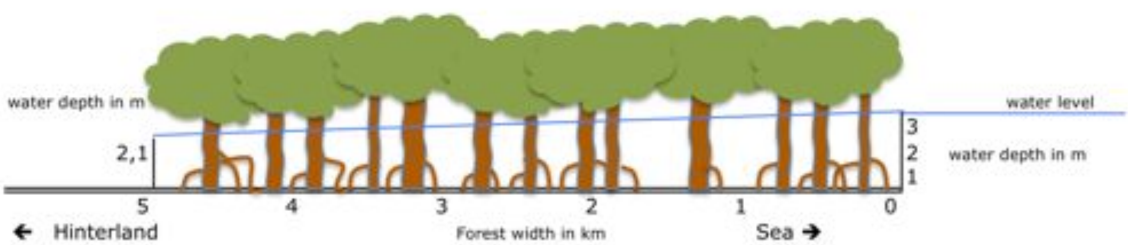


Figure 2-5: Gradient of the water surface (energy slope) within mangroves.

Figure 2-5 shows the calculated slope. Factors like bottom friction, the drag coefficient, and the bottom slope are neglected in this figure.

The water flow through the vegetation inside the mangrove swamp is highly turbulent for water depths of up to 10 cm; therefore the flux shows different characteristics such as small jets, calm zones and whirls. These turbulences influence the flow velocity, which is important in respect to the sedimentation processes. To quantify the flow resistance of the sediments, a dimensionless drag coefficient C_D can be determined. This coefficient depends on the Reynolds number R_e, which is a dimensionless number. The Reynolds number is calculated using the following formula.

$$R_e = v_m * \frac{l}{\nu} \qquad \textbf{(2-3)}$$

- v_m mean fluid velocity in m/s
- l characteristic length scale of the flow in m
- ν kinematic viscosity in m^2/s

The Reynolds number is used to characterize different flow regimes, and laminar or turbulent flows. The smaller the Reynolds number is, the more dominant the viscous forces, and the more constant and smooth the fluid motion are. High inertial forces result in high Reynold numbers and therefore in turbulent flow conditions.

Mazda et al. (1997b) set l as l_E, which describes the effective vegetation length scale.

$$l_E = \frac{(V - V_m)}{A} \qquad \textbf{(2-4)}$$

- V volume based on 1 m^2 substrate surface (1 m^2 × water depth)
- V_m total volume of the obstacles in V (see Figure 2-6)
- A total area of the obstacles in V

The parameters A/V and V_m/V must be calculated using measurements of the number of trunks, prop roots and pneumatophores to ascertain the vegetation's characteristics. The parameters of A and V_m have been simplified by using mathematic shapes like circular cylinders and circular cones.

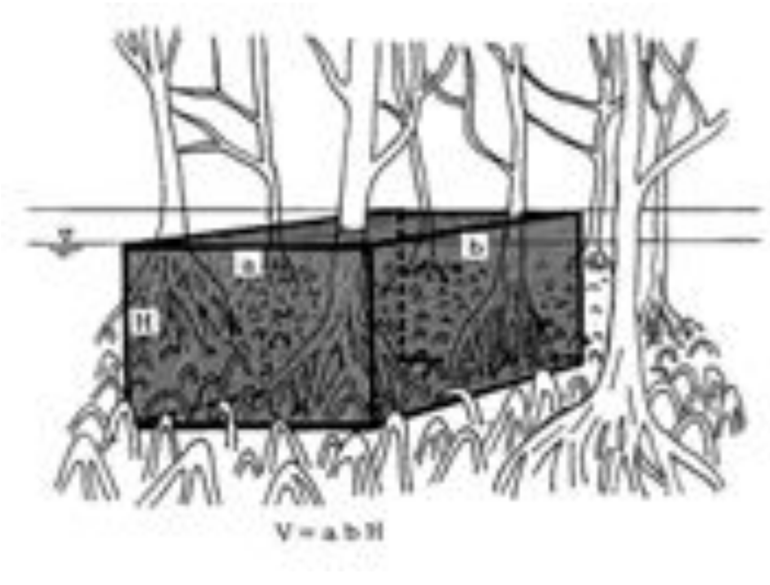


Figure 2-6: Sketch of the control volume for ensemble averaging (Mazda, et al., 1997b)

The results show that the drag coefficient decreases as Reynolds numbers increase. The drag coefficient converges to a value of 0.4 with a Reynolds number $> 5 * 10^4$ and reaches a large value of 10 with a Reynolds number $< 1 * 10^4$. Compared with the results of the Manning coefficient by Wolanski et al. (1980) and Mazda (1991) with results of 0.2-0.4 $sm^{-1/3}$ and 0.2-0.7 $sm^{-1/3}$ in mangrove swamps, it shows that the findings are one order of magnitude larger than the value in estuaries without vegetation. Therefore the hydrodynamics inside mangrove swamps change considerably depending on different types of mangrove species, vegetation densities and tidal conditions. (Mazda, et al., 1997b)

The role of the drag force as an important factor for tidal-scale hydrodynamics has been described above. Mazda et al. (2005) pointed out that both the drag force as well as the eddy viscosity play dominant roles in tidal-scale hydrodynamics within mangrove swamps. As seen above, the drag coefficient C_D can be parameterized as a function of the vegetation density, which depends on the Reynolds number R_e. Analysis of the measurements taken between 2001 and 2003 in Japan and Ecuador reveals that the coefficient of dynamic eddy viscosity f depends on the Reynolds number as well (see Figure 2-8).

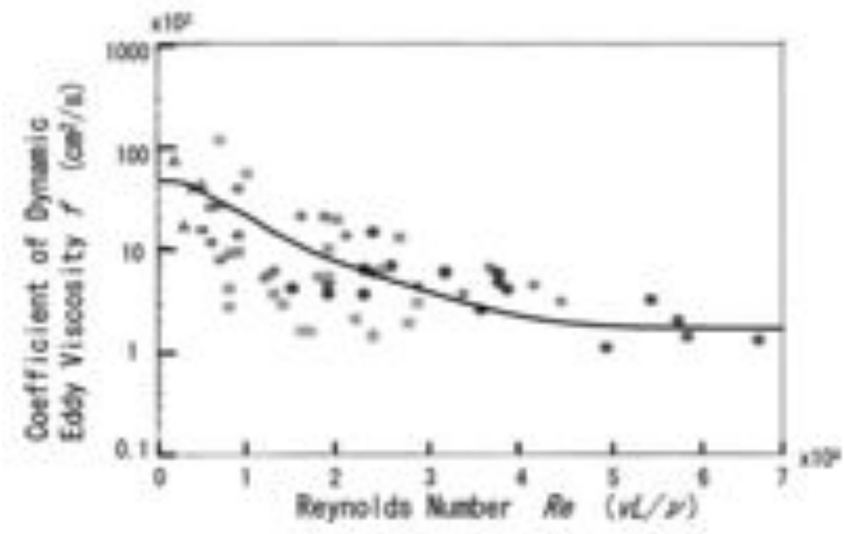


Figure 2-7: The relationship between the coefficient of dynamic eddy viscosity *f* and the Reynolds number R_e. The marks show measured results within different observation sites in Ari-Gawa, Japan 2001 and 2002; Rio-Chone, Equador 2003; Maera-Gawa, Japan 2003. (Mazda et al., 2005)

Mazda et al. (2005) also showed that the sum of the drag force and bottom friction force balance out the pressure gradient due to the water surface slope within R-type forests (see Figure 2-10). R-type mangroves include tidal creeks and mangrove swamps as described in Section 2.3 on Mangrove physics. Wolanski et al. (1992) suggested that the magnitude of the bottom friction force is too small to affect the water balance surface slope. Therefore, the drag force mainly balances out the water surface slope. (Mazda et al., 2005)

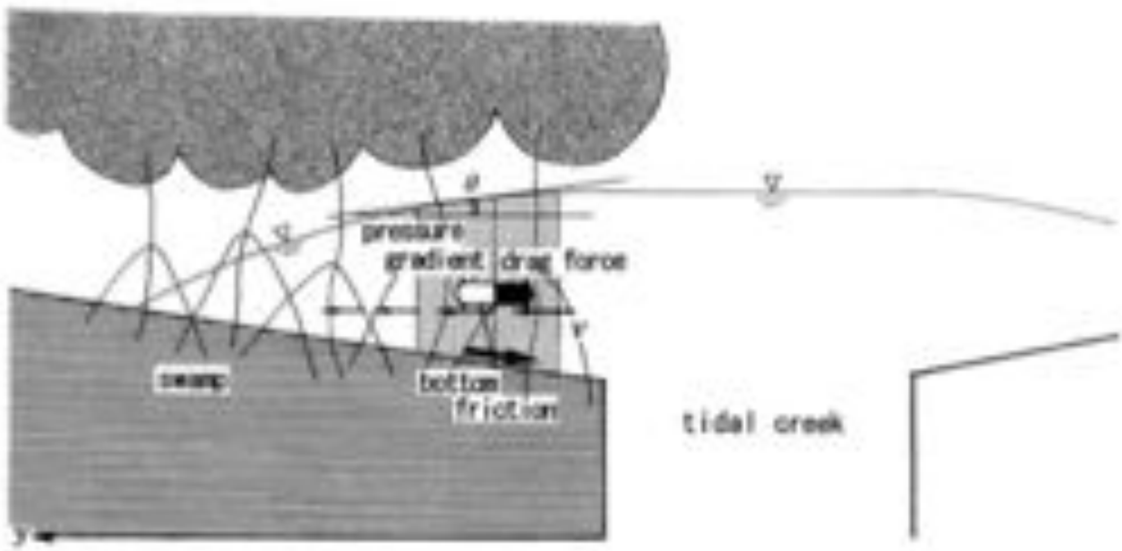


Figure 2-9: A schematic cross-section in an inner portion of a R-type mangrove forest. The drag force and the bottom friction force balance the pressure gradient due to the water surface slope. Θ is the angle of the pressure gradient and v is the mean fluid velocity. **(Mazda et al., 2005)**

Wave reduction

Mangroves growing at the fringes of open shorelines and estuaries have to absorb enormous amounts of wave energy. Two primary mechanisms are responsible for the attenuation of wave power in mangroves: firstly, the multiple interaction of waves with mangrove trees, whereby the efficiency of attenuation varies according to the species, and secondly, bottom friction (Alongi, 2009). This means that F-type forests as mentioned in Section 2.3 on Mangrove physics, are responsible for coastal protection by directly attenuating wave energy. The water flow in R-type mangroves is dominated by tidal periods, because the waves are attenuated in tidal creeks. (Mazda, et al,. 2007)

Mazda et al. (1997a) conducted field experiments in the Tong King Delta in Thai Binh Province in Viet Nam. The study area included a very flat tidal area (slope 0.5:1000) and *Kandelia candel* planted on a strip of land 1.5 km wide and 3 km long composed of three different segments running parallel to the shoreline. Zone 1 faced the open sea and contained 0.5 year old trees (seedlings), Zone 2 lay more landwards and contained 2-3 year old trees and Zone 3 had 5-6 year old trees next to the coastline. The rate of wave reduction *r* due to mangrove vegetation per 100 m from the direction of wave propagation is defined as

$$r = \frac{H_S - H_L}{H_S} \qquad \textbf{(2-5)}$$

- H_S Wave height at sea side station
- H_L Wave height at sea side station 100 m further inshore

Mazda et al. (1997a) calculated that wave reduction of up to 20 % occurred in the mangrove fringe, with the mangroves in Zone 3 providing the most reduction while the young trees (seedlings) in Zone 1 only provided a very small reduction of 0.01-0.03 % with a water depth of more than 1 m. Using the results of the field measurements, they calculated that an incident wave with an average height of 1 m would be reduced to a wave of 0.05 m at the coast as a result of passing through a 1,500 m wide fringe of mangroves 5-6 years in age. Without the mangrove belt, the waves would still have a height of 0.75 m, reduced only by the friction while moving over 1,500 m of mudflats (see also Figure 2-12). They also pointed out that *Rhizophora* and *Bruguiera* trees had a better capacity to reduce wave power because of their concentration levels being higher than for *Kandelia* trees.

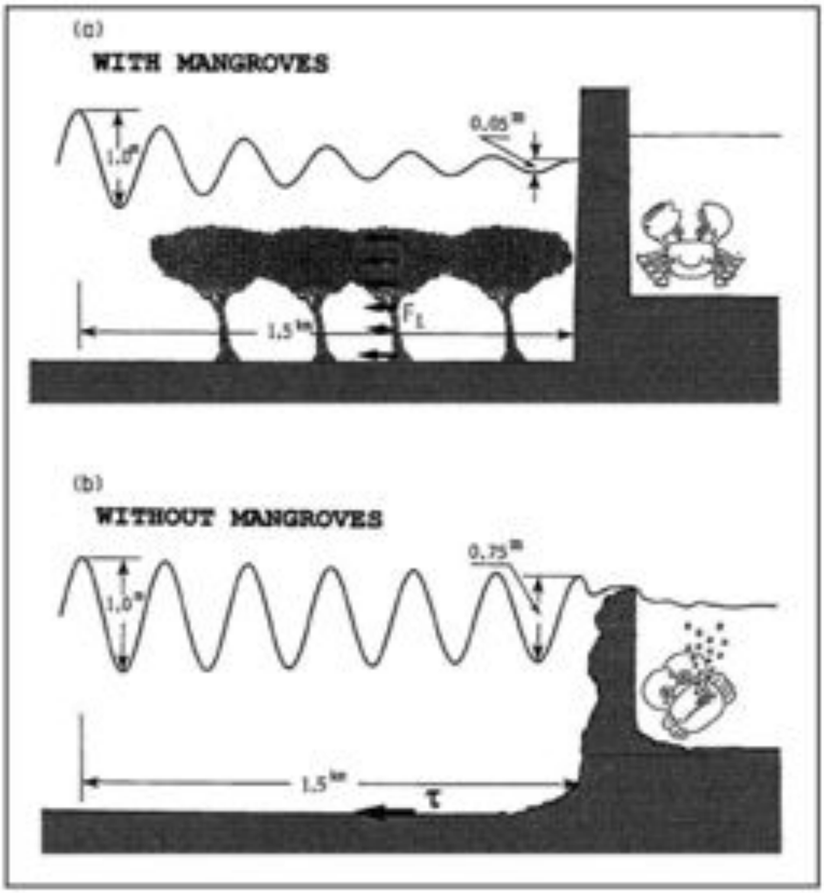
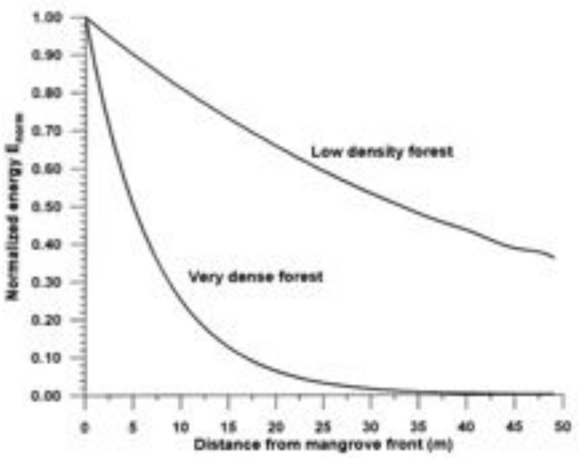


Figure 2-11: Differences in the effect of wave reduction with (a) a 1,5 km wide stripe of mangroves and with (b) no mangroves (Mazda et al., 1997)

Massel et al (1999) presented a theoretical attempt to predict the attenuation of wind-induced random surface waves in mangrove forests. General conclusions from this paper point to the rate of wave energy attenuation depending on the density of mangrove forests. Theoretical analysis and field experiments at Cocoa Creek, Townsville (Australia) and Nadara River, Iromote Island (Japan) showed that combined effects of drag caused by obstacles (mangrove roots and trunks) and bottom friction result in a significant amount of attenuation over a relatively short distance. They also used a normalized energy (function?) $E_{norm}(x)$ to examine wave propagation through a mangrove forest. $E_{norm}(x)$ is expected to be a function of the water depth at any location within the forest. The normalized energy is defined by following formula:

$$E_{norm}(x) = \frac{\sigma_{\xi}^{2}(x)}{\sigma_{\xi_i}^{2}} \tag{2-7}$$

- $\sigma_{\xi}^{2}(x)$ Wave energy at a distance *x* from the mangrove front
- $\sigma_{\xi_i}^{2}$ Incident wave energy



This approach has been modeled by assuming a very dense forest as well as a forest of very low density. Wind-induced waves affect the mangrove forest across a typical spectrum for shallow waters. (See Figure 2-14)

Figure 2-13: Normalized energy E_{norm} in high density and low density forests. (Massel et al., 1999)

Mazda et al. (2006) quantitatively analyzed the characteristics of wave reduction due to drag force on one mangrove species (*Sonneratia* sp). The study area was located along the coast of Vinh Quang in northern Viet Nam, where a 100 m wide mangrove belt of mature planted *Sonneratia* sp protects the coast. There were vertically erected pneumatophores growing very densely there at heights of around 0.25 m with thick leaves spreading out from a height of about 0.6 m above the surface.

Field measurements showed that the rate of wave reduction *r* (see Formula (2-6)) was about 45 % per 100 m with a water depth of 0.2 m. Wave reduction decreased as water depth increased. Therefore with a depth of 0.6 m, wave reduction is just about 26 % per 100 m. Referring to the studies by Mazda et al. (1997a), this confirms that the level of vegetation density causes high reductions in wave energy if water depth increases the effect of resistance due to the vegetation and bottom friction decreases.

Mazda et al. (2006) found that the thick leaves of the trees (starting at heights over 0.6 m) further reduced wave energy. Mazda et al. (2006) suspected that the wave motion is transformed into turbulences or eddies due to interaction with the vegetation. Calculations show that if the significant wave height is 20 cm and water depths are above the height of the thicket of leaves, the wave reduction within a distance of 100 m is estimated at 50 %. This confirmed the initial premise that mechanisms for wave reduction vary among different mangrove species.

2.6. Mangrove degradation

The degradation of mangroves can be attributed to two main forces; human-induced degradation and natural disturbance-related degradation. Mangrove forests around the world have suffered from advanced degradation and overexploitation through human interactions over the last decades. In addition to deforestation for timber products, the largest impact has been from land conversion for agricultural use and aquaculture such as shrimp farming and salt plantations. Even though rates of loss have decreased over the past decade, they are still higher than the overall rates of loss of global forests. Additionally, mangroves are also threatened by rising sea levels due to climate change. While mangroves would usually move further inland if the tidal influenced area moved further up, these areas are no longer available today. (Elster, 2001) (McLeod & Salm, 2006) (FAO, 2007a) (Spalding, 2010)

The FAO (2007b) reported that according to trend analyses, 15.2 million hectares of mangroves existed worldwide in 2005, down from 18.8 million hectares in 1980. FAO (2007b) estimated a worldwide rate of loss of 187,000 ha per year (-1.04 %) in the 1980's and a decreased rate of 102,000 ha per year (-0.66 %) over the period from 2000 to 2005. The largest net loss appeared in Asia, where about 1.9 million ha has been lost since 1980 (see also Figure 2-15). (FAO, 2007b)

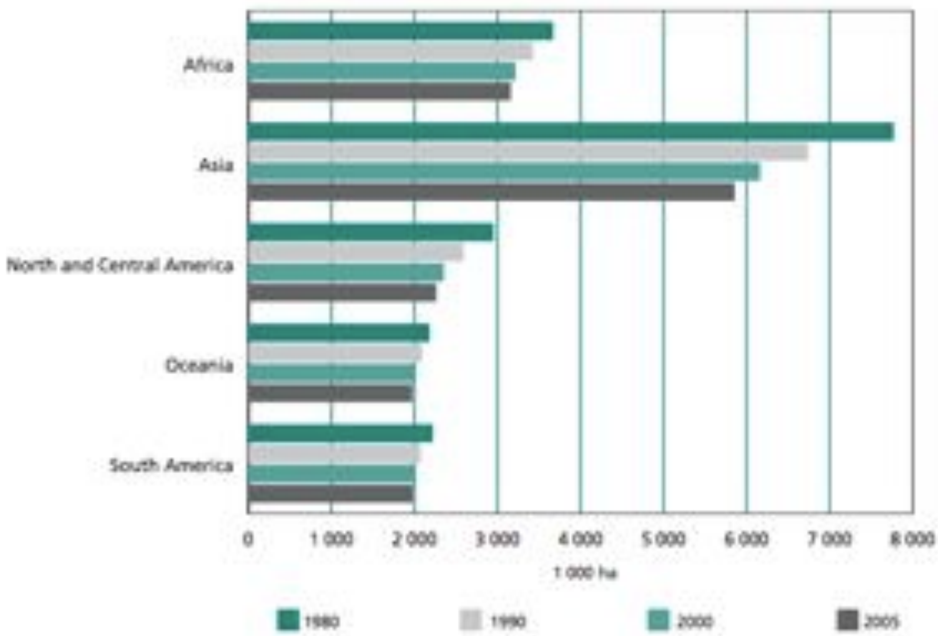


Figure 2-15: Changes in world mangrove area in 1000 ha, 1980 – 2005 (FAO, 2007b)

3. Study and project area

The study area for this thesis is situated in the Mekong Delta of Viet Nam (see Figure 3-1). This area is defined by the Mekong River, which has a length of ca. 4,800 km and a basin that covers an area of 795,000 km^2 - roughly the size of Germany and France put together. The flow rate is 15,000 m^3/s on average (MRC, 2009). The Mekong River originates in Tibet (China) and passes through Myanmar, Lao P.D.R., Thailand and Cambodia before dividing into two branches at Phnom Penh (the Capital of Cambodia), the Mekong (Tien River) and the Bassac (Hau River). Phnom Penh is the point where the Mekong Delta begins, covering an area of approximately 55,000 km^2 (MRC, 2005).

Figure 3-1: Map of Viet Nam, the Mekong Delta is marked

The Mekong divides into six branches, while the Bassac divides into three; these nine branches are the so-called "Nine Dragons River" (*Song Cuu Long* in Vietnamese) (Just 8 branches empty into the South China Sea).

The Mekong Delta covers 13 provinces in southern Viet Nam (Long An, Dong Thap, TienGiang, Ben Tre, Tra Vinh, Vinh Long, An Giang, Can Tho, Hau Giang, Soc Trang, Bac Lieu, Kien Giang and Ca Mau)

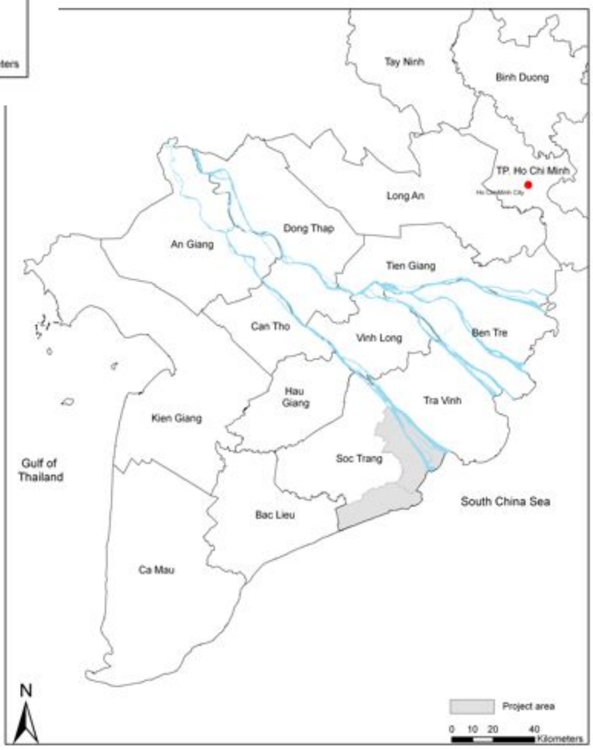


Figure 3-2: Map of the Mekong Delta

(see Figure 3-4) covering an area of approximately 39,000 km^2 (12 % of the country's total area) and home to 17 million people (21 % of Viet Nam's total population) (Nguyen, 1994). The hydrology of the Mekong Delta has been modified by hundreds of years of agricultural use; today it is shaped by a dense net of canals, sluices and water gates. The social and economic development of the Delta has been dominated by paddy rice cultivation, which has resulted in the Mekong Delta also being known as the "rice bowl" of Viet Nam. With fast growing rice varieties, up to three crops can generally be grown each year, while there may only be two crops grown each year in saline risk areas (Nguyen, 1994) (MRC, 2005)

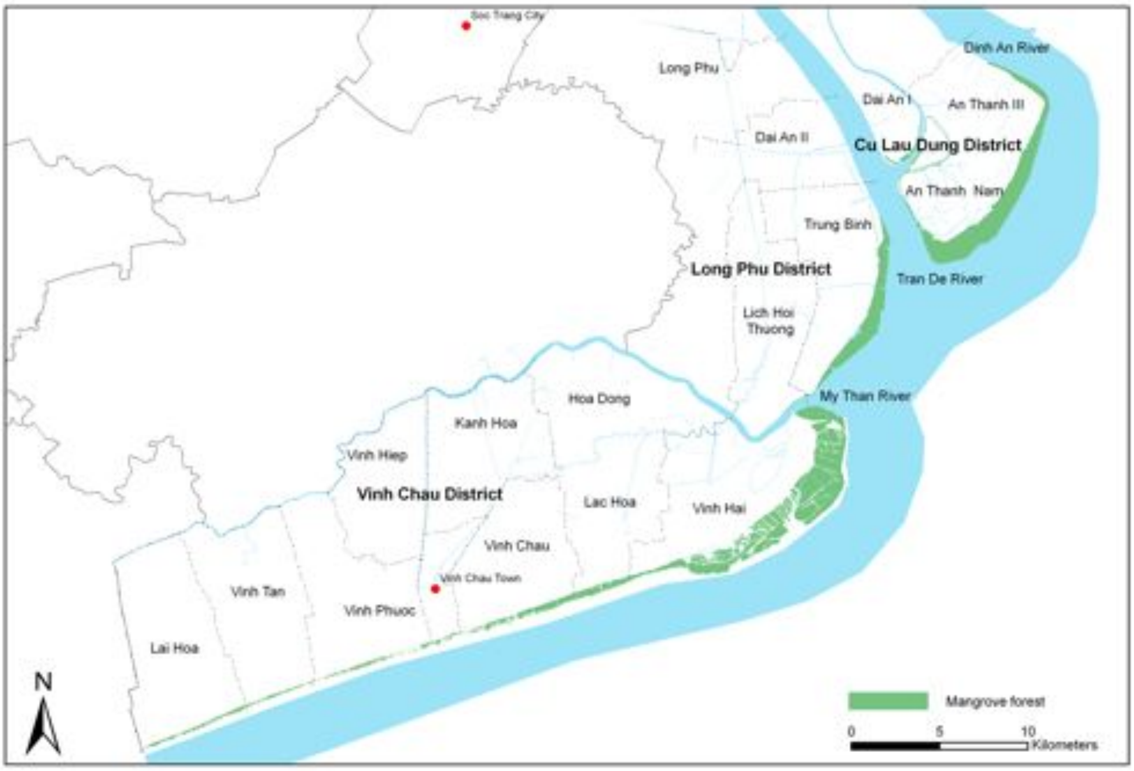


Figure 3-3: Map of the project area in Soc Trang Province

3.1. Geographic location

Soc Trang Province is one of the 13 Provinces in the Mekong Delta lying at 9°14'–9°55' N latitude and 105°32'–106°18' E longitude, covering about 322,330 ha. Soc Trang contains eight districts and one town district (Pham, et al., 2009). The Bassac runs along the northeast border of Soc Trang Province. The project area covers the three coastal districts of Soc Trang (Cu Lau Dung District, Long Phu District[1] and Vinh Chau District) including eleven communes and a total area of 1,153 km^2 (see Figure 3-3) (Soc Trang Province Statistical Book 2006 (2007), as cited in Joffre & Luu, 2007).

1 Parts of Long Phu and My Xyen have recently been changed into Tran De District, which is now part of the project area

The shoreline of Soc Trang Province has a length of 72 km. The local population of the project area is estimated at 188,567 inhabitants living in 38,149 households, of which 32 % are officially considered as poor (< 150,000 VND[1]/person/month) in 2006. (ibid.)

3.2. Climate

The climate conditions of the Mekong Delta are influenced by the tropical monsoon, which divides the year into two seasons. The Southwest Monsoon, so named due to the prevailing wind direction, arises as a result of low pressure regions over China. The Southwest Monsoon occurs from May until November and brings hot and humid air and the majority of the region's annual rainfall into the Mekong Delta during what is known as the "rainy season". The "dry season" occurs from December until April when the wind direction reverses into the Northeast Monsoon bringing relatively cold and dry air. Humidity reaches a maximum level of about 96 % during the rainy season and a minimum level of about 62 % during the dry season. The average humidity is about 83.4 % annually, with a mean average temperature of about 26.8°C. The warmest month is April with average temperatures of 31.1°C and the coldest month is January at 23.8°C (Pham, et al., 2009). The fluctuation between the monthly average temperatures is 3-5°C each year (Phuong, 2008). Total annual solar radiation is about 130 Kcal/cm^2/year with a maximum level between January and April of up to 16 Kcal/cm^2/month and a minimum level between June and September of around 9 Kcal/cm^2/month (Pham, 2010).

As mentioned above, the precipitation across the study area is unevenly distributed over the course of the year. The annual rainfall is between 1,800 and 2,000 mm (see Figure 3-5). Approximately 85 % of the annual rainfall comes during the rainy season, with a maximum level of approximately 300 mm in October and a minimum in February of around 2 mm. (Yamashita, 2005)

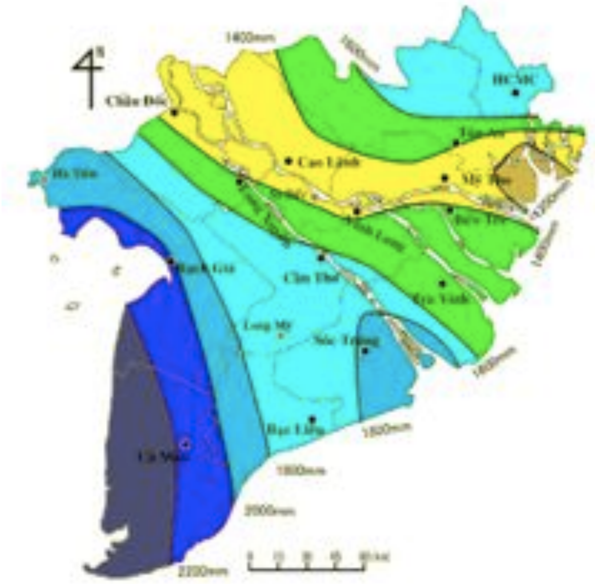


Figure 3-5: Isohyets of the mean annual rainfall in the Mekong Delta (Yamashita, 2005)

1 1 US Dollar (USD) = 19.417,391 Vietnamese Dong (VND) at July 5th 2010: http://www.bankenverband.de/waehrungsrechner/@@currentcurrencies?amount=1&orgin_currency=USD&target_currency=VND&interbank=0&remember_cb=1&date=6.7.2010&currentcurrencyform.calculate=berechnen

Joffre and Luu (2007) compiled rainfall and temperature data from 2002 to 2006 for the project area (See Figure 3-7). They pointed out that 90 % of the overall annual precipitation appears during the rainy season (May to October). Annual rainfall at gauging stations in Vinh Chau Town (Vinh Chau District) and Mo'O (Long Phu District) is 1,558 mm and 1,597 mm, respectively.

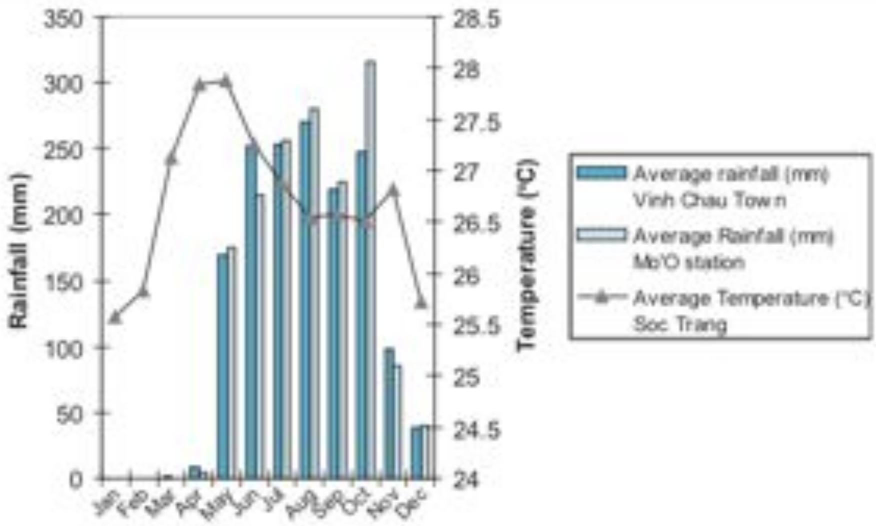


Figure 3-6: Average monthly temperature (°C) in Soc Trang City (2001-2004), average monthly rainfall (mm per month) Vinh Chau Town and Mo'O Station (Mouth of My Thanh River) (2002-2006) (Joffre & Luu, 2007)

3.3. Geology and soil

The geology of the Mekong Delta formed from the Old Tertiary period of the Cenozoic until the Pleistocene, when the Himalaya Mountains appeared. The Mekong Delta was shaped during the Holocene period by transgression and regression, while the Indochina region was affected by global sea level rise (6,000 – 5,000 YBP), which submerged around 80 % of what is today's Mekong Delta area (Yamashita, 2005). Since then, the Mekong Delta has developed through sedimentation and accretion processes (Nguyen, 1993). Therefore, the Mekong Delta is composed of alluvial soils, which have varying depths of up to 260 m. (Yamashita, 2005)

As is common for river mouths in Southeast Asia, the soils are composed of Eutric Gleysols and Thionic Fluvisols, while the coastal area of the Mekong Delta facing the South China Sea is composed of Eutric Fluvisols. The composition of surface soils in the Mekong correlates with site-specific topographic conditions and aquatic influences. Natural flora and the agricultural activities in the Mekong are influenced by the type of surface soil available and its characteristics, such as potential acid sulfate soils, acid sulfate soils and the saline soil group, all of which show particular characteristics of the deltaic area.

Yamashita (2005) divided the soil groups in the Mekong Delta into seven major groups.

1. Alluvium group
2. Saline soil group
3. Acid sulfate soil group
4. Sand group
5. Peat land group
6. The gray soil group on old alluvium
7. Mountain group

The distribution of surface soils is shown in Figure 3-9.

Figure 3-8: Soil distribution in the Mekong Delta (Yamashita, 2005)

Unlike the majority of Viet Nam, which is mountainous, the Mekong Delta is flat and has an average altitude of 2 m above MSL (Yamashita, 2005). This is an important factor considering rising sea levels brought on by climate change. A sea level rise of one meter would inundate 43.7 % of the Mekong Delta in Viet Nam (Carew-Reid, 2008). The topographic conditions are shown in Figure 3-10.

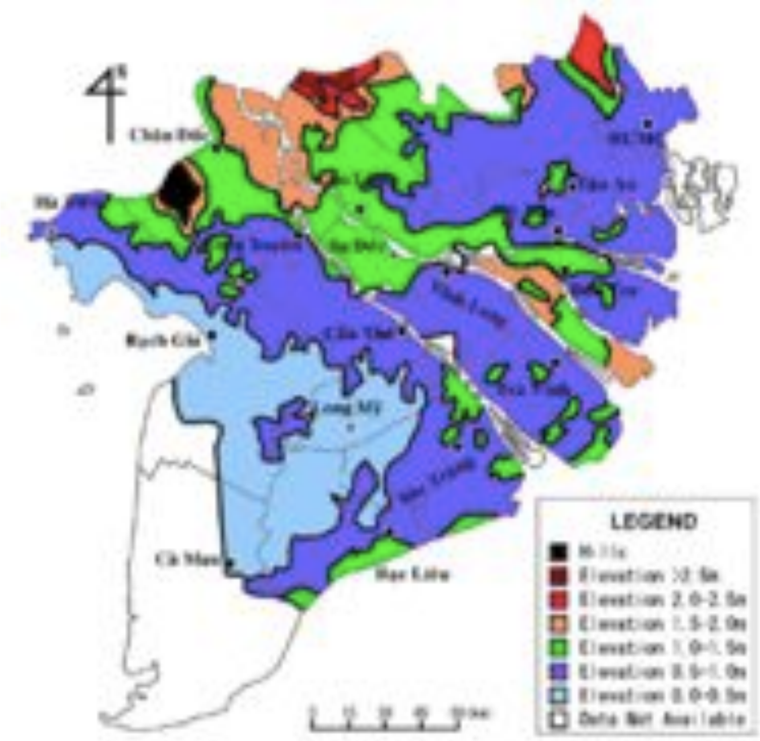


Figure 3-10: Topography of the Mekong Delta (Yamashita, 2005)

3.4. Hydrology

The coastal area of the Mekong Delta is influenced by the flow regime of the Mekong River and the tidal regime of the South China Sea. Interactions between processes like sediment flux, tidal range and currents of different rates and magnitudes over the year create a very dynamic system.

3.4.1. Tidal regime and currents

Mixed, semi-diurnal tides prevail in the South China Sea (also called the “East Sea” in Viet Nam) near the Bassac River mouth. The range in tidal amplitude between the mean lowest sea level (mlsl) and the mean highest sea level (mhsl) varies from 3.6 to 4.2 m in the period from August to January, with the maximum peak occurring in October and November; the lowest level is recorded in April and May (Pham, 2010)

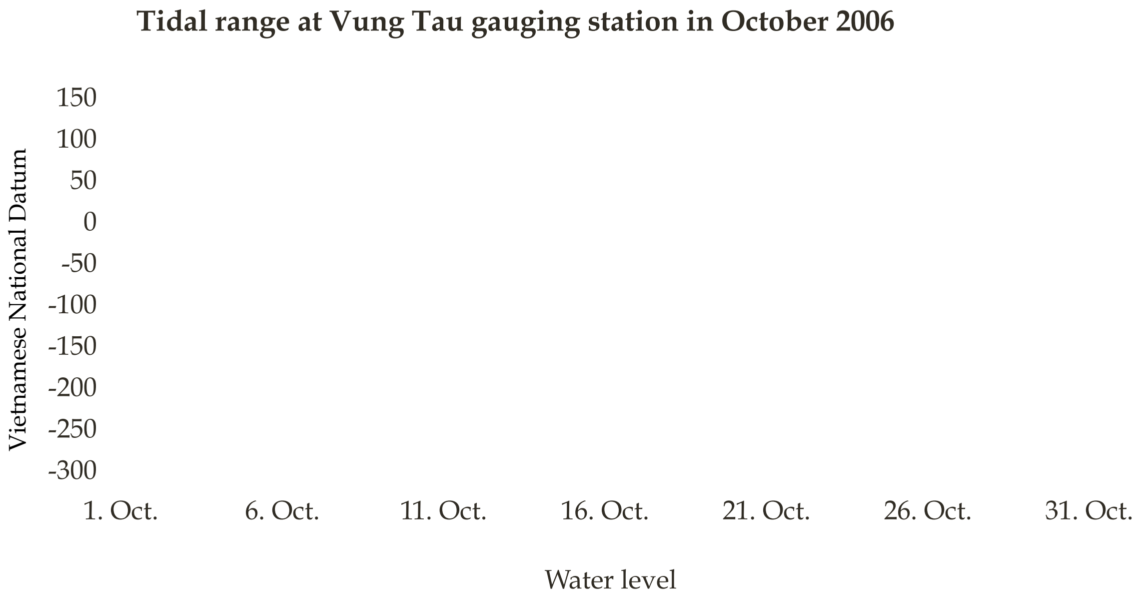


Figure 3-11: Water levels at Vung Tau gauging station in October 2006

The gauging station next to the project is located in Vung Tau, north of Soc Trang Province. Recorded water level data shows that high tides and low tides occur twice a day (see Figure 3-11). While high tides remain nearly the same level, each second low tide is higher than the one before. The minimum difference between the high tide and low tide occurs around neap tide (see Figure 3-12). Thus, there is an iterative pattern over a 15-day period. The data have been provided by the "Southern Institute of Water Resources Research" (SIWRR), Ho Chi Minh City.

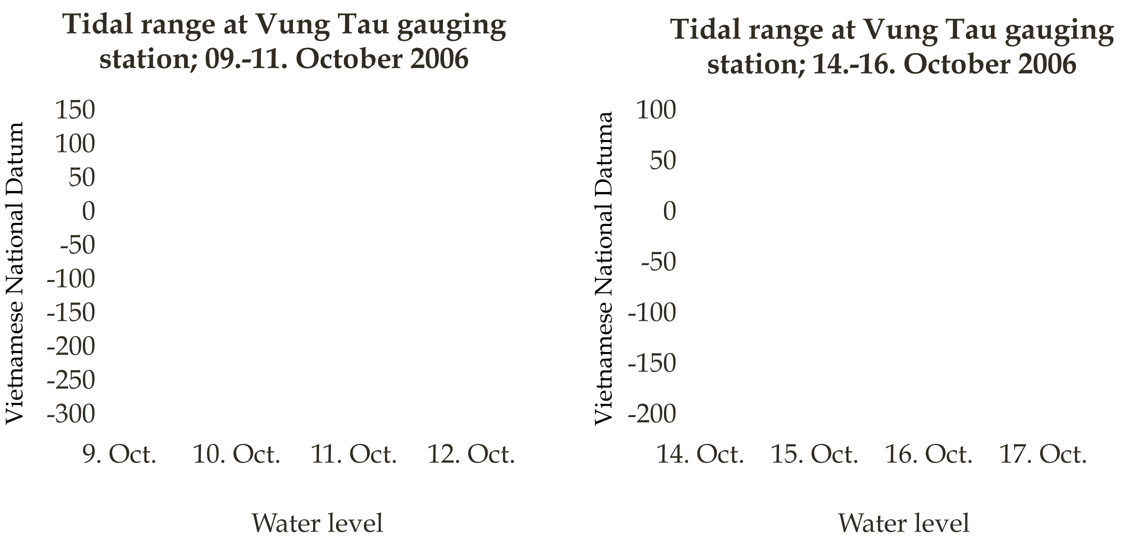


Figure 3-12: Tidal range at Vung Tau gauging station around neap tide and spring tide in October 2006

The tidal range decreases as one proceeds further upstream. Wolanski et al. (1996) reported that at Can Tho (123 km from the Bassac River mouth), it is about 1.9 m during the low-flow season and about 0.7 m during the high-flow season. At Chau Doc (228 km from the Bassac River mouth) the amplitude is only 0.49 m during the low-flow season, while it is not evident at all during the high-flow season.

The currents of the South China Sea are dominated by the monsoon winds. Chu et al. (1999) investigated dynamical mechanisms and seasonal circulations in the South China Sea. They reported that the driving force of the currents is the Viet Nam coastal jet (VCJ), which is caused by the wind stress from monsoon winds. Moreover, the coastal jet during winter (December to February) is a much stronger southward-flowing boundary current than the VCJ in summer (June to August). The mean maximum velocity of the winter VCJ is about 0.95 m/s, with a width of 100 km and a water depth of 500 m. The summer VCJ flows northward with a mean maximum speed of 0.5 m/s, a width of 100 km and a water depth of around 200 m. Figure 3-14 shows the differences in surface circulation between summer and winter.

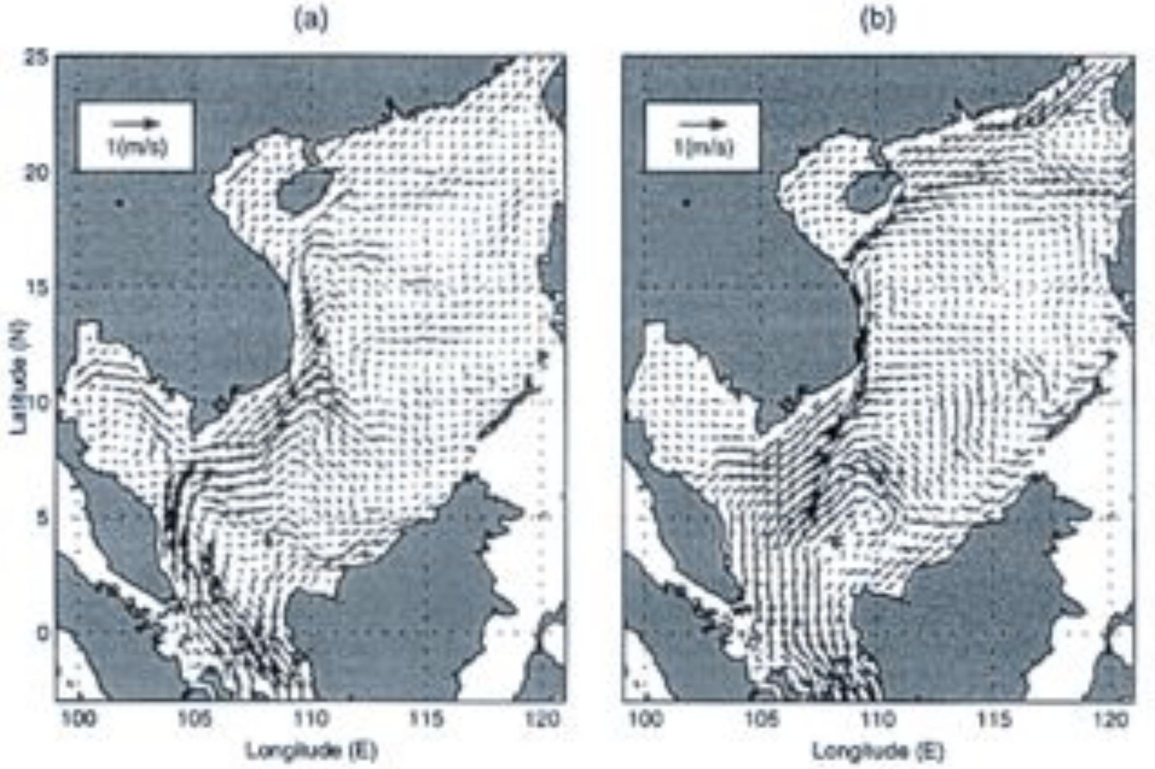


Figure 3-13: Mean surface circulation in the South China Sea during a) summer b) winter (Chu et al., 1999)

3.4.2. Salt-water intrusion

During floods, seawater influx appears in the canal system of the estuarine area if water gates or sluices are not closed or do not exist. Agricultural needs and the management of aquacultures are at odds during this period. Salt-water affects the crops, while aquaculture requires fresh seawater for flushing ponds. Another effect is presented by salt-water intrusion into the aquifers of the Mekong Delta. The higher salinity of irrigation water decreases crop yields. (Wassmann et al., 2004)

Lu and Siew (2006) reported that the discharge of the Mekong River varies significantly across the different seasons. Discharge reaches its lowest level in March and April, after which it begins to rise from May onwards, peaking around September or October. 80 % of the total annual runoff flows between June and October (Lu & Siew, 2006). However, even during the dry season, the discharge of the Mekong River amounts to 2,000 m^3/s. Thus, the tidal influx is strongly dampened through the branches of the Mekong Delta. Prior to 1980, saline intrusion affected 1.7 to 2.1 million ha of agricultural area each year. Salinity control projects reduced this figure and nowadays only 0.8 million ha are influenced every year (Nguyen & Savenije, 2006). Saline intrusion in the Delta correlates strongly with the discharge of the Mekong River, gradually increasing during the dry season (when discharge is the lowest) and decreasing during the rainy season (when discharge is at its highest). The peak annual saline intrusion period lasts from March to April, which is the end of the dry season. The propagation of saline intrusion is also related to the local amount of river water discharge from the many minor riversin the Delta and by pressure and leaching processes. (Le et al., 2005)

3.4.1. Sediment flux

Due to the changing discharge levels of the Mekong River, the amount of sediment entering the South China Sea varies throughout the year. Annual water discharge from the Mekong is generally agreed to be approximately 470 km^3 (Wolanski et al., 1996) (White, 2002) (Lu & Siew, 2006), but there is little data regarding sediment flux. Milliman and Meade (1983) specified the sediment load as 160 Mt. The sediment load of the Bassac branch of the Mekong River, which influences the project area, can be approximated as 45 % of the overall runoff of the Mekong River flow down the Bassac. (Yamashita, 2005).

The influence from Chinese dams on water discharge and sediment flux has been studied by Lu and Siew (2006). They found that the suspended sediment concentration (SSC) declined by approximately 40 % or more at the upstream stations (Chiang Saen to Vientiane) after the dams were built. The SSC at downstream stations only decreased slightly compared with pre-dams periods. The effect of the Chinese dams on SSC levels at Can Tho is shown in Figure 3-15, which shows that SSC levels did drop after 1993 when the dams were built.

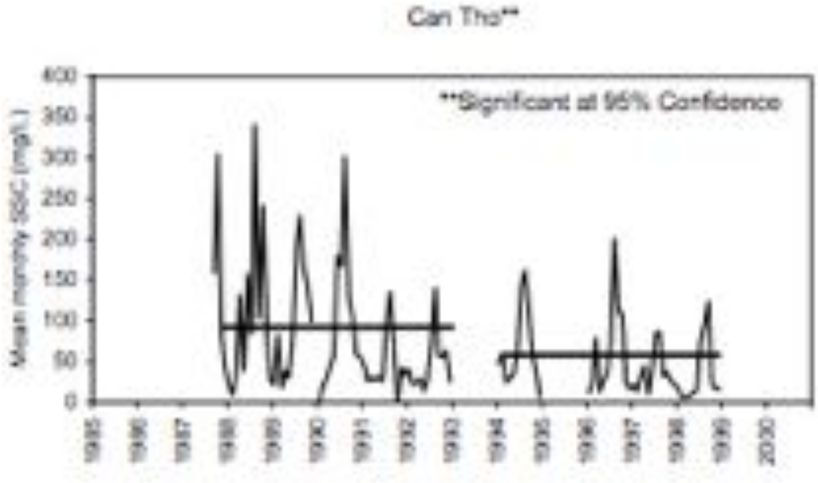


Figure 3-15: Suspended Sediment Concentration at Can Tho station
(Lu & Siew, 2006)

Wolanski et al. (1996) reported that during the high-flow season most of the sediments from the Bassac River are deposited in the shallow waters near the coast (< 20 km). A small fraction (ca. 5 %) returns to the estuary in the salt wedge at flood tide. During low-flood season, sediments will relocate into the estuary system due to oceanographic conditions. Therefore, there is a seasonal reversal of littoral sediments. This process possibly causes the bathymetry of the river mouth. In the freshwater region (between 30 to 140 km from the river mouth), the thalweg is about 10 m deep, but closer to the river mouth, depths decrease to 5 m or less.

The SSC varies according to tidal frequency and is higher near the bottom. A concentration of 0.6 g/L has been recorded in peak ebb currents. Furthermore, Wolanski et al. (1996) indicated that there appeared to be a background concentration of 0.15 g/L. The suspended sediment exhibits the characteristics of fine silt. The median particle size d_{50} varies from 2.5 to 3.9 µm and the clay fraction accounted for 15 to 20 %. (Wolanski et al., 1996)

Nguyen (2009) investigated the characteristics and movement of surface sediment from the Bassac River mouth to the Ca Mau Peninsula. Figure 3-16 shows the distribution of grain size fractions in this area.

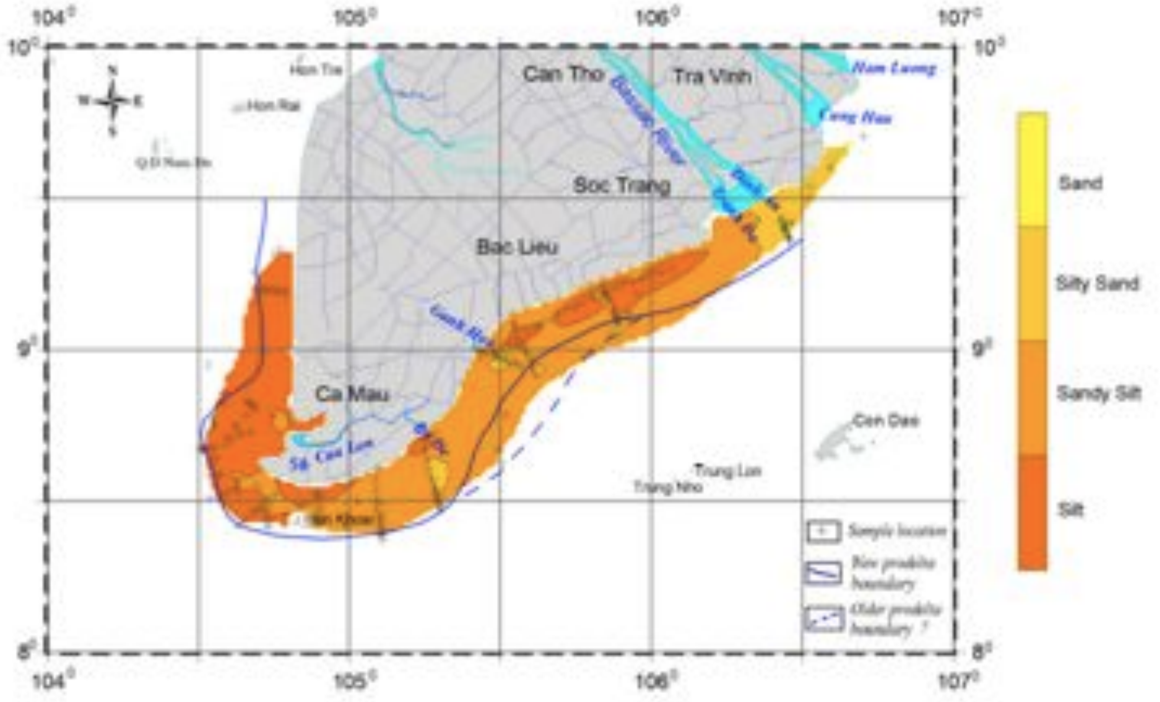


Figure 3-16: Distribution of sediment texture groups (Nguyen T. T., 2009)

Another example of the effect of the sedimentation processes at the mouth of the Bassac River is shown in Figure 3-17. Recently updated data about sand banks, analyzed by the GTZ project in Soc Trang, has been transformed into a map.

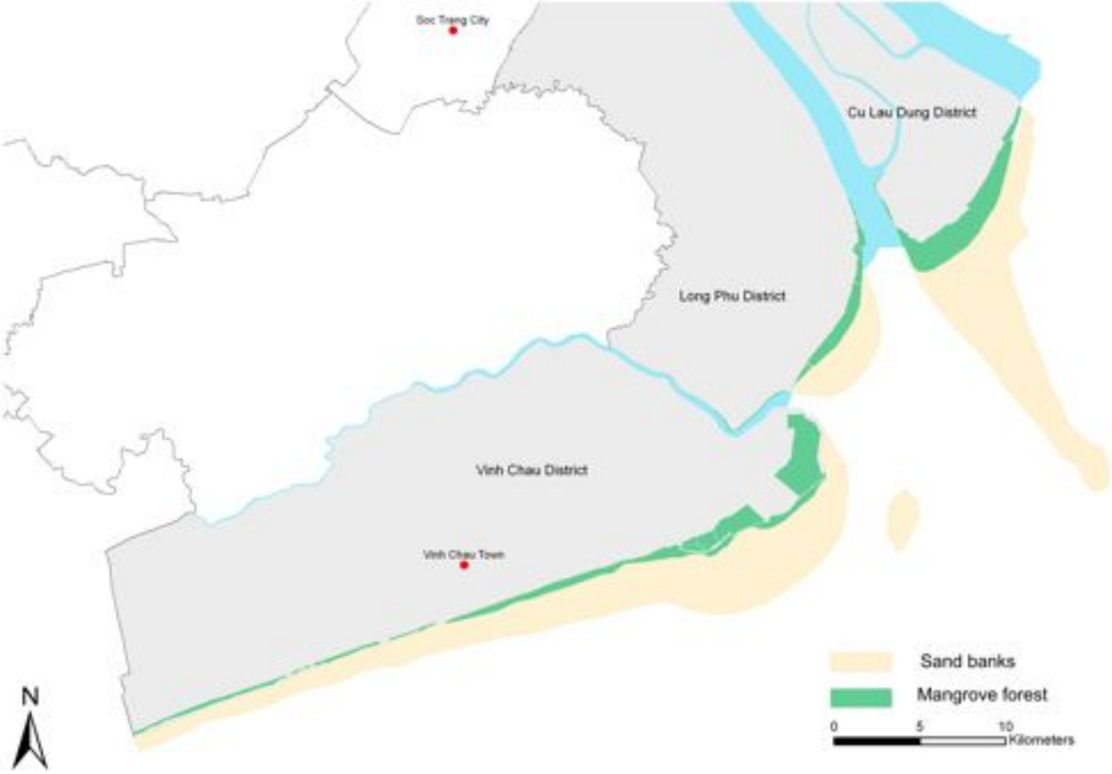


Figure 3-17: Mud flats and sand banks in front of Soc Trang Province

3.5. Erosion and accretion

As mentioned above, the interaction of the changing sediment flux, coastal long shore currents driven by prevailing monsoon winds, and the tidal regime of the South China Sea all combine to create a very dynamic shoreline. Sedimentation and accretion processes are actively occurring along the coast of Soc Trang Province. Sedimentation occurs along An Thanh Nam (Cuu Lau Dung District) and Trung Binh (Long Phu District) as well as in Vinh Hai, Lac Hoa and Vinh Chau (Vinh Chau District) (see Figure 3-18) (Pham, 2010).

The Northeast Monsoon from November to March is stronger than the Southwest Monsoon; therefore coastal erosion intensifies during this period. Erosion processes occur at several locations along Vinh Hai, Vinh Phuoc, Vinh Tan and Lai Hoa (Vinh Chau District) (see Figure 3-19). Erosion has had a serious impact on some locations in Soc Trang and is responsible for the coastline retreating inland by about 300 m over 10 years in some places. (Pham, 2010)

Figure 3-18: Sedimentation site in front of Vinh Hai Commune

Figure 3-19: Erosion site in front of Lai Hoa Commune

4. Status quo and mangrove regeneration efforts

About 3,000 ha of mangroves have been rehabilitated in the coastal areas of Soc Trang Province since 1990 (FIPI, 2004). Sustainable management of mangroves is a mandatory issue for rehabilitation projects, not only in respect to adaption of mangroves to the environment but also in respect to maintenance. Moreover, within the scope of the current project, creating more diverse mangrove forests is another important goal. The terms “natural” and “sustainability” are discussed in the following paragraph.

The word “natural” is used to describe the preferable conditions for an ecosystem. In this case, “natural” means that the ecosystem is in its pristine condition with little or no human impact. Ecology refers to the relationship between all living organisms inside an ecosystem, including mankind. Human impact is therefore a substantial factor that must also be taken into account when considering ecosystems. By looking at the past, it becomes evident that humans have the capacity to degrade ecosystems enormously. However, human interactions with ecosystems need to be considered if management of these areas is to be sustainable. Sustainability is certainly an important concept in terms of utilization, but the term “sustainability” has also become a famous catchword in recent years. Sustainable management should incorporate aspects of economic, environmental and social values. Hence, sustainable management should enable the welfare of both people and their communities in this respect. Above all, an ecosystem must sustain future generations with natural and physical resources, safeguard sufficient quantities of air, water and soil, and also avoid adverse effects on the environment. (Sands, 2005)

The mangroves of Soc Trang as well as other ecosystems must be managed in a sustainable fashion in order to meet present and future economic, environmental and social needs. In the project area, not only are the goods and services provided by mangroves absolutely necessary for the local communities, but also for the surrounding agriculture area. Therefore, mangrove management must be undertaken in a sustainable manner, which takes into consideration human influences and neighboring ecosystems as well as land use management.

4.1. Mangroves in Viet Nam

In its country reports, the FAO (2007a) indicates that for Asian mangroves, biodiversity levels are quite high with 28 true mangrove species. It is pointed out that since the 1980’s overexploitation and land conversion to agricultural fields, salt ponds, urban infrastructure and shrimp aquaculture has had the biggest impact on the size of mangrove areas over the last two decades. In Viet Nam, another impact on the size and distribution of mangroves has been the degradation caused by chemical warfare during the Viet Nam War (1962 to 1972). Southeastern Viet Nam was hit particularly hard, with thousands of hectares of mangroves destroyed along the coasts of the Mekong Delta and the Ca Mau Peninsular through the spraying of herbicides (such as Agent Orange) and the release of napalm. In 1943, about 400,000 ha of mangroves existed in Viet Nam but in 1980, after the war, it was estimated that only 269,150 ha remained. Mangrove forest cover further declined after 1980, dropping to 157,500 ha in 2000, and to an estimated 157,000 ha in 2005. (FAO, 2007a)

4.2. Land use and mangroves in the project area

4.2.1. Land use

Land use in Soc Trang Province is dominated by agriculture, aquaculture and forestry, which cover 84 % of the total province area of 3,310 km^2. Within this area, 79 % is allocated for agricultural use (73 % rice cultivation), 16 % is used for aquaculture, and forestry amounts to 4.4 %. (Soc Trang Province Statistical Book 2006 (2007), as cited in Joffre & Luu, 2007)

De Graaf and Xuan (1998) pointed out that between 1976 and 1992, the rearing of shrimp increased by 3,500 % in the Mekong Delta. From 1988 to 1992, the area for shrimp ponds increased by 60,000 ha. The "pink gold rush", as they call it, started in 1992 when another 60,000 ha of land was converted into shrimp farming area. In 1992/93 the system collapsed due to several reasons (viral infections of post larvae, self pollution due to poor pond management and massive destruction of mangrove forests). Bailey (1988) already pointed out that the expansion of shrimp farming in mangrove habitats caused the transformation of a multi-use/multi-user coastal resource into a privately-owned single purpose resource. He predicted coastal erosion, salt-water intrusion and a reduction of valuable goods and services.

Joffre and Luu (2007) reported on the increase of shrimp farms in Soc Trang Province from 7,802 ha in 1995 to 51,706 ha in 2006.

4.2.2. Mangrove history in Soc Trang Province

As mentioned above, due to the flow regime of the Mekong River, the tidal regime of the South China Sea, sediment flux, coastal long-shore currents and climate conditions, the coastline of Soc Trang Province is subject to very dynamic erosion and accretion processes.

Leuphana Universität Lüneburg / Campus Suderburg
Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

In 1965, mangroves covered just a small portion of the coastline of Vinh Chau District, while in 1995, mangroves covered most areas, with particularly large forests appearing in the Vinh Phouc Commune area. Due to excessive cutting and severe erosion, these forests had disappeared by 2008. Figure 4-1 shows the conditions over these years. (Pham et al., 2009)

Figure 4-2, which shows the eastern side of Vinh Chau District, highlights the accretion that has occurred to the north and to the south of the original mangrove area from 1965 to 2005. During the same period, the coastline on the east side eroded slightly. The total area of mangroves declined over this time period. (Pham et al., 2009)

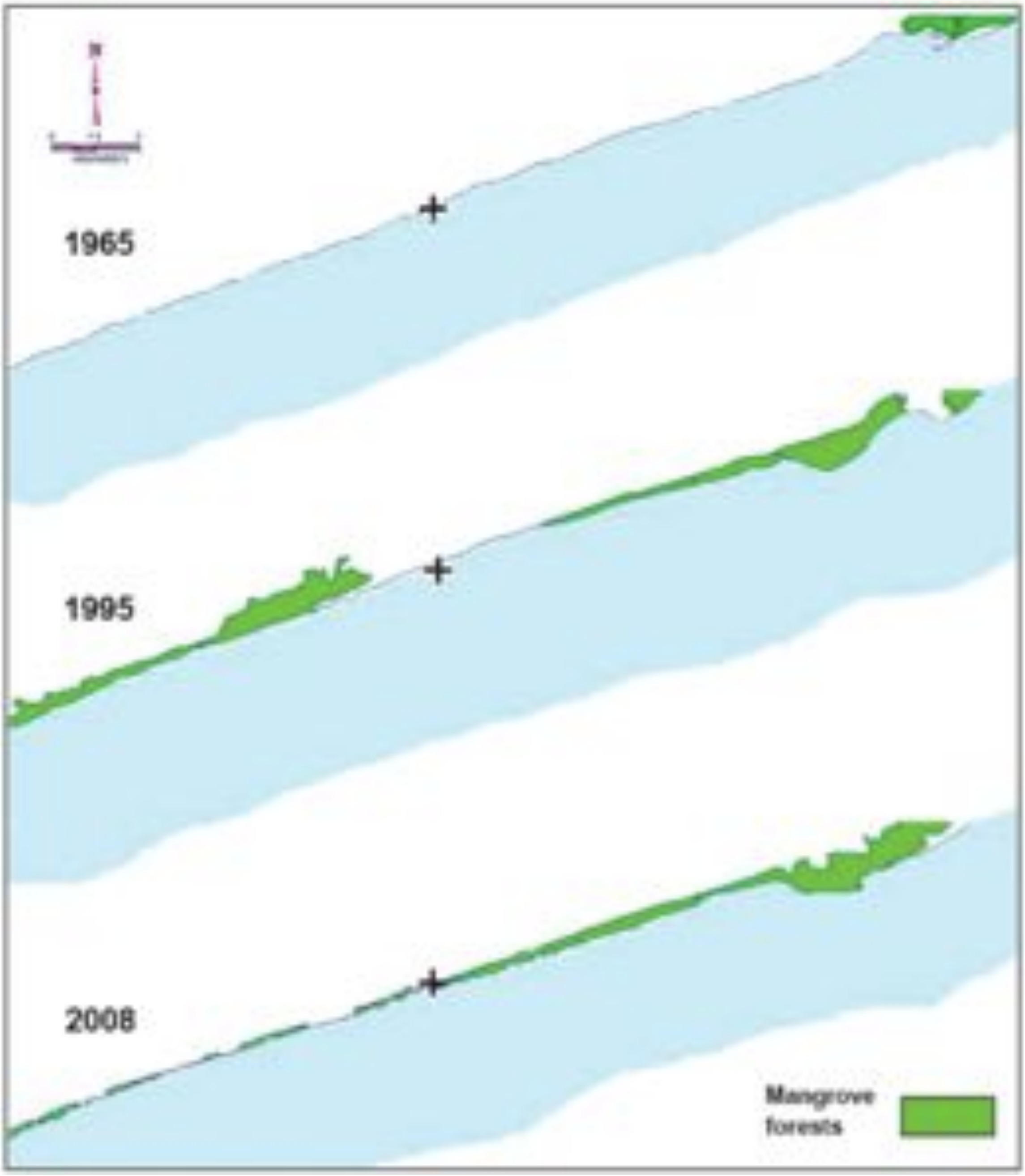


Figure 4-1: Variations of mangrove areas in Vinh Chau District. The cross marks the same geographic position. (Pham et al., 2009)

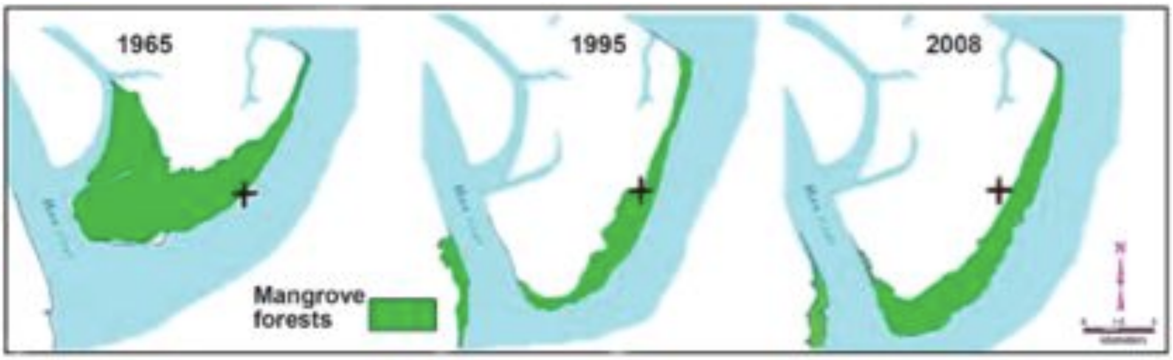


Figure 4-2: Variations of mangrove areas in Lich Hoi Thuong and Vinh Hai Communes. The cross marks the same geographic position. (Pham et al., 2009)

Figure 4-3 shows the variation in distribution of mangroves in the south of Cu Lau Dung District. The area of mangroves decreased rapidly from 1965 to 2005, while the land area increased significantly due to accretion processes. The land area of the two concerned communes (An Thanh Nam and An Thanh Ba Village) increased by 2,061.7 ha - an average of about 48 ha per year. Mangrove forest area in 1965 was 1,791.9 ha, while in 1995 it was 719.3 ha, which is a loss of more than 1000 ha in 30 years. (Pham et al., 2009) Based on statements by local residents, the immense loss of mangroves occurred mainly during the 1980's and was caused by man-made deforestation. Destruction during the Viet Nam War only played a small role as Cu Lau Dung suffered under the defoliation by the U.S. Army.

Figure 4-3: Variation of mangrove areas and the coastline in Cu Lau Dung. The cross marks the same geographic location. (Pham et al., 2009)

Pham et al. (2009) reported that mangrove rehabilitation programs have been implemented in Soc Trang by the Government since 1990. From 1990 to 2000, about 1,900 ha of mangroves were planted in Soc Trang Province, while between 2000 and 2007 the World Bank and Vietnamese Government sponsored rehabilitation and protection activities under the "Coastal Wetlands Protection and Development" (CWPD) project. During this 8 year period, 1,086 ha of mangroves were rehabilitated; the survival rate was around 54 % in 2000, 96 % in 2003 and 78 % in 2005. Moreover, from 2004 to 2007, local farmers received contracts from the CWPD project to nurse plantations less than 3 years old. Contracts were financed by the World Bank project and covered around 482.82 ha of mangrove plantations, while the overall size of mangrove areas protected by this project equalled 1,842 ha annually.

Of the 28 true mangrove species found in Viet Nam, as highlighted by the FAO (2007a), 26 were found in Soc Trang Province by surveys conducted in 2008 Pham (2010) reported (see Table 4-1).

Table 4-1: True mangrove species recorded in Soc Trang Province 2008 (Pham, 2010)

No	Vietnamese name	Scientific name	Life form
	Họ bần	**Sonneratiaceae**	
1.	Bần đắng (bần trắng)	*Sonneratia alba*	Medium wood
2.	Bần chua	*Sonneratia caseolaris*	Medium wood
	Họ mấm	**Avicenniaceae**	
3.	Mấm trắng (mấm lưỡi đồng)	*Avicennia alba* Blume	Medium wood
4.	Mấm đen	*Avicennia officinalis*	Medium wood
5.	Mấm biển	*Avicennia marina*	Medium wood
	Họ Đước	**Rhizophoraceae**	
6.	Đước (Đước đôi)	*Rhizophora apiculata*	Large wood
7.	Đưng	*Rhizophora mucronata*	Large wood
8.	Vẹt dù	*Bruguiera gymnorhiza*	Small wood
9.	Vẹt tách	*Bruguiera parviflora*	Medium wood
10.	Vẹt trụ (Vẹt hôi)	*Bruguiera cylindrical*	Small wood
11.	Vẹt khang	*Bruguiera sexangula*	Medium wood
12.	Dà quánh	*Ceriops decandra* (Griff.)	Medium wood
13.	Dà vôi	*Ceriops tagal* (Perrottet)	Medium wood
14.	Trang	*Kandelia candel*	Medium wood
	Họ Bàng	**Combretaceae**	
15.	Cóc vàng	*Lumnitzera racemosa*	Small wood
	Họ Ba mảnh vỏ	**Europhorbiaceae**	
16.	Giá	*Excoecaria agallocha*	Small wood
	Họ Xoan	**Meliaceae**	
17.	Xu ổi	*Xylocarpus granatum*	Small wood
	Họ Cau dừa	**Palmae**	
18.	Dừa nước	*Nypa fruticans*	
19.	Chà Là nước	*Phoenix paludosa*	
	Họ Ô rô	**Acanthaceae**	
20.	Ô rô biển	*Acanthus ilifolius*	Herbaceous
21.	Ô rô trắng	*Acanthus ebrateatus*	Herbaceous
	Họ Trôm	**Sterculiaceae**	
22.	Cui biển	*Heritiera littoralis*	
	Họ Ráng	**Pterridaceae**	
23.	Ráng đại	*Acrostichum aureum*	Fern
24.	Ráng đại	*Acrostichum speciosium*	Fern
	Họ Bông	**Malvaceae**	
25.	Tra	*Threspecia populnea* .	Small wood
26.	Bụp	*Hibiscus tiliaceus*	Small wood

Pham (2010) presented published data from the Institute of Forest Inventory and Planning, Ministry of Forestry. According to these data, the overall mangrove area in Soc Trang Province was 4,003 ha in 1965 and 3,000 ha in 1983. In 1995, about 4,585 ha of mangroves had been recorded using SPOT satellite images. 98 ha of mangroves have been planted in Vinh Chau and Long Phu District by the MILIEV project (funding by the Dutch Government). In 2001, using Landsat ETM satellite images, 4,336 ha of mangroves were recorded in Soc Trang Province. According to data from the Southern Sub-Institute for Forestry Inventory and Planning, in 2003 the mangrove area was 2,990.79 ha, of which 884.7 ha were natural forest made up of 721.91 ha of *Sonneratia* and 162.16 ha of *Avicennia*. The remaining 2,106.72 ha were planted mangroves composed of 1,354.87 ha *Sonneratia*, 199.6 ha *Rhizophora* and 440.16 ha of mixed *Rhizophora* and *Avicennia*. The variation in mangrove areas in Soc Trang Province is presented in Figure 4-4. (Pham, 2010)

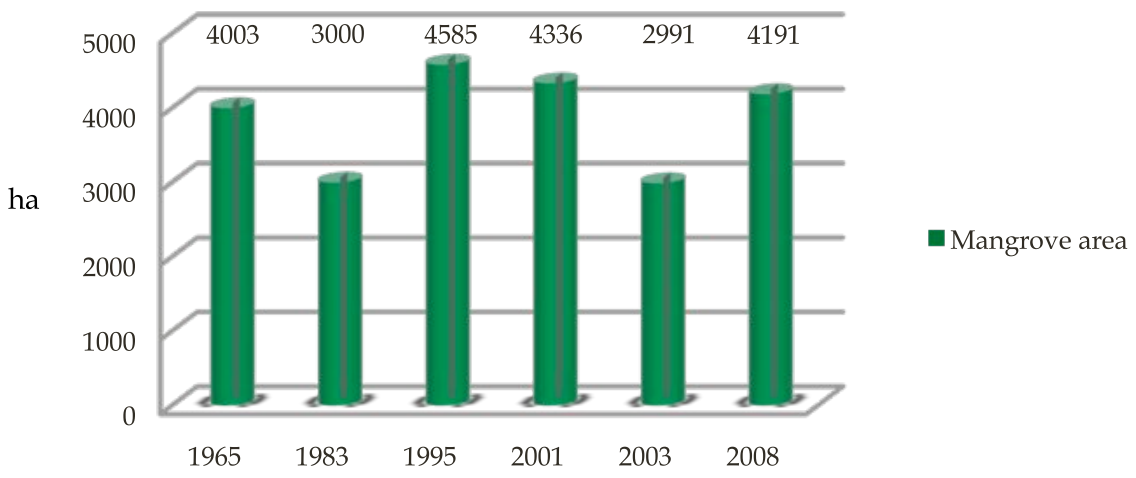


Figure 4-4: Variation of mangrove area in Soc Trang Province 1965-2008 (Pham, 2010)

4.2.3. Findings through previous plantings

The above-mentioned planting programs have been impacted by several factors caused by natural processes and human activities. The three main reasons for successful or failed plantings were strong winds, which uprooted young trees (see Figure 4-5) and eroded substrate (see Figure 4-6), sediments, which covered newly planted areas, and barnacle infestation (Pham et al., 2009).

Figure 4-5: Strong winds in front of Vinh Hai Commune uprooted planted trees. The original planting density was 1 tree per m^2

Figure 4-6: In places with high erosion, natural regeneration is not possible; mangrove forests are destroyed and waves affect the dyke

Pham et al., 2009, summarized the main factors affecting the success of planting programs in Soc Trang.

- Selection of species adapted to the planting site
- Quality of seedlings
- Planting seasons, which avoid sediment accumulation (June to October) and the threat of strong winds and erosion (from November to March)
- Prohibition, or adequate management of fishing activities in planting and regeneration areas
- Maintaining of tidal current flows in plantations
- Adequate investment for planting and post-planting activities
- Participation of local communities in the management and protection of plantations
- Cooperation among various sectors at all social levels

Another factor impacting the low survival rate of mangroves is fishery activities. Fishermen dig up the substrate inside of mangrove forests in order to catch crabs and valuable resources like larvae and worms. Many young mangrove trees are uprooted during the digging process. Another fisheries activity, which impacts natural regeneration and rehabilitation, is the use of ground nets. Nearly every small tree gets uprooted or broken by contact with a ground net. Figure 4-7 and Figure 4-8 show the ground net fishing gear on land, how it works, and its use within the field. The net's edge uproots and breaks young trees just above the ground surface. This fishing technique is common in the project area and is carried out up to two times per day. The areas in front of mangrove forests are highly suitable for natural regeneration and rehabilitation, however these areas are also very lucrative fishing grounds.

Figure 4-7: A ground net shown on land in Au Tho B Village

Figure 4-8: Fishing activities in front of the mangrove forest in Lai Hoa Commune

Maintenance of planting sites is essential for planting success. Maintenance should not be restricted to the protection of the planting site and infrastructure by local government officers, but should also encompass involvement by local communities in order to stop activities that restrict regeneration. For example, it turned out that contracts made by the local authorities and citizens can protect planted seedlings. In return for payment, individual residents take care of planted areas and protect them from trampling or destruction by local inhabitants.

Biswas et al. (2009) presented a step-by-step guideline for mangrove restoration wherein the participation of local communities plays a major role. The first step is the development of a systematic restoration plan; the preparation of this plan should include participatory steps. The next steps include site selection, site preparation and propagule and seedling sourcing. Planting multiple species and thus creating a mixture of species can force diversity in plantations. To avoid the collapse of planting efforts after external support has been withdrawn, it is essential to involve local communities. Local ecological knowledge has a high potential for facilitating mangrove planting efforts, while involvement in planting efforts would enable an economic return for the community and help to sustain the planting project. Biswas et al. (2009) also identified a lack of documentation. Even where planting projects have failed, they have generated just as much knowledge as successful projects. Hence, monitoring and documentation during the pre-planting and the post-planting periods is important for solving problems arising during future restoration projects.

4.3. The project

The overall objective of the GTZ project "Management of Natural Resources in the Coastal Zone of Soc Trang Province" is to protect and sustainably manage the coastal wetlands of Soc Trang Province for the benefit of the local population. Effective and sustainable mangrove rehabilitation, protection and management are all key tasks undertaken by the project and will support efforts to accomplish the project's objectives. The major issues currently threatening the frail, narrow mangrove belt in the project area include unsustainable utilization, the consequences of shrimp farming, and the impacts of climate change. (Pham et al., 2009)

New approaches to the planting and management of mangroves have been proposed and emphasize stand resilience against the threats posed by climate change. When dealing with the uncertainties of climate change, there is a need to apply risk-spreading strategies, namely: "Don't put all your eggs in one basket". Undertaking such things without full scientific proof is a reflection of the precautionary principle. The management of scientific risk has been defined in Principle 15 of the Rio Declaration, which states "*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*." (United Nations, 1992)

4.3.1. Integrated Coastal Area Management

Coastal areas are diverse in terms of form and function and cannot be defined according to strict spatial boundaries. The long-term process of coastal area management is dynamic and iterative, and all stakeholders should be enabled to participate. It is necessary to think outside the box and comprise a holistic approach when managing coastal areas. The term used for combining all issues of a management project is "Integrated Coastal Area Management" (ICAM). (FAO, 1998)

Mangroves as they appear in Soc Trang, namely as a narrow belt bordered by mud flats, aquacultures, agricultural area and village infrastructure, cannot be effectively managed in isolation. It is important to understand what happens in adjacent areas and what interactions exist. Therefore, mangrove management has to be part of ICAM. In the project, risk management across space and time as well as with an emphasis on resilience to climate change, constitutes part of the project's ICAM. (Schmitt, 2009)

4.3.2. Planting strategies

In addition to site and species selection and planting time, another important factor impacting successful plantiations is the planting technique applied. Previous plantings have been carried out in rectangular shaped monocultures with tree densities of up to 10,000 trees per hectare (1x1 m distance between seedlings) depending on the species (see Figure 4-9). This pattern might be suitable for timber production, and is also able to achieve high survival rates on sites without high wave energy. In respect to coastal protection from strong winds and waves, the efficiency of these even-aged monocultures is limited. Additionally, global warming will increase the frequency and intensity of storms, therefore promoting stand resilience to strong wind and waves takes on added importance.

Figure 4-9: Mangrove planting with 1x1 m distance between seedlings in Vinh Chau Commune

Within the GTZ project, Pham et al. (2009) proposed new approaches to the planting and management of mangroves by:

- Applying risk spreading strategies to address uncertainties
- Protection of mangroves that have shown persistence over time
- Restoration of degraded coastal areas
- Establishment of upland buffer zones to allow migration of mangroves in response to rising sea levels
- Effective management/protection strategies to reduce human threats
- Development of alternative livelihoods for mangrove-dependent communities
- Monitoring the response of mangroves to climate change

The most effective mangrove planting strategies have been developed by nature through the evolutionary process. Over time, mangroves have developed very successful characteristics and strategies to ensure their survival, reproduction and distribution throughout coastal areas. Supporting natural processes may be the key to increasing planting success. Two new approaches have been tested to implement risk spreading strategies by copying natural regeneration techniques that mimic nature. (Pham et al., 2009)

To imitate nature as accurately as possible, natural patterns must be understood. Even if most propagules of mangrove trees can survive a long time without rooting and may be distributed by water movements, in natural forests young plants often take root close to parent trees, are unevenly distributed, and grow at high densities (see Figure 4-10). Natural regeneration also adds new seedlings every year (Duke, 2001a) as opposed to monoculture plantations, where trees are planted just once. Therefore, to achieve planting techniques that mimic nature, dense planting next to established trees is required and planting activities must be repeated as needed.

Figure 4-10: Natural regeneration pattern of *Rhizophora* trees. **Picture by Dr. Klaus Schmitt**

Figure 4-11: Cluster planting mimicking nature regeneration of *Rhizophora mucronata* and *Ceriops tagal* trees in Vinh Chau Commune

For the first approach, during the planning stage small areas (around 30 m^2) are chosen, located next to existing established trees in the mud flats facing the open sea (see Figure 4-11). This pattern may also be resistant to high wind and wave energy occurring in the area. Different tree combinations are planted to impede monocultures developing. (Pham et al., 2009)

The second approach entails the transformation of even-aged, monoculture plantation forests into more diverse forests in terms of species and structure. The natural occurrence of canopy gaps is copied to investigate the natural regeneration and success of plantings that mimic nature with mixed species. (Pham et al., 2009)

Figure 4-12 and Figure 4-13 show the difference between the original mangrove forest canopy and conditions after the canopy gap has been created. Figure 4-14 and Figure 4-15 show the differences between a closed canopy and created gaps on the ground in respect to the incidence of light. A huge natural glade of approximately 150 to 200 m^2 is situated right next to the test area. It is obvious that trees (identical in species and age) on the gap fringe are in a better condition due these forest edge conditions. Moreover, natural rejuvenation takes place in this gap; therefore the trees are not just in a better condition and providing more biomass, but the vertical structure is also improved due to the addition of trees of different heights (see Figure 4-16 and Figure 4-17).

Figure 4-12: Closed canopy inside the mangroves in Lai Hoa Commune

Figure 4-13: Gaps created in the mangroves in Lai Hoa Commune

Figure 4-14: The ground inside the mangrove forest without any gaps

Figure 4-15: Sunlight reaches the ground through a gaps created inside the forest

Figure 4-16: Forest edge conditions create a healthy vertical structure with trees of different age beside the test area in Lai Hoa Commune

Figure 4-17: Natural regeneration seems to be supported by forest edge conditions supporting incidence of sunlight.

Duke (2001a) says that the first burst of growth among *Rhizophora* seedlings is endogenously controlled. Even in shady places, the growth during the first year shows no irregularities, but after consuming all endogenous nutrients the growth rate decreases until eventually the young trees die. It seems that mangrove forests are well-prepared for tree loss. If wood glades happen to appear, a large number of young trees and seedlings are in stock to grow and fill in these gaps.

Duke (2001b) recognized that unlike terrestrial forests, natural gaps in mangroves rarely involve individual older trees falling over. The most common gaps are caused by lightning strikes and affect 10 to 20 trees. Other causes of gaps include hail, wind, insects, pathogens and pollution. Duke (2001b) developed a schematic showing the six steps of gap creation and recovery based on observations of common mangrove gaps (see Figure 4-18). Without gaps, the canopy in mangrove forests is dense and little sunlight reaches the surface, which is needed for the growth of young trees.

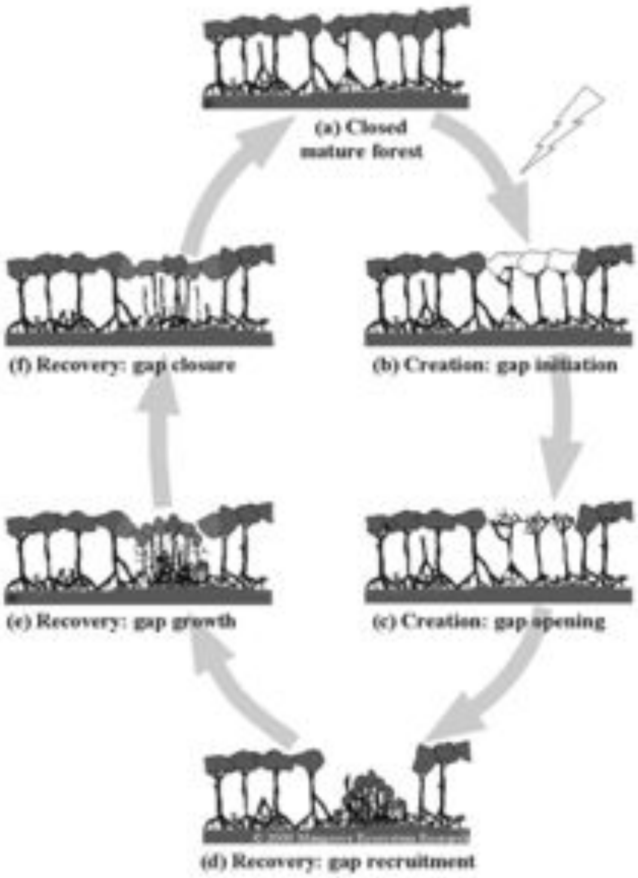


Figure 4-18: The six stages of gap creation and recovery (Duke, 2001b)

Both approaches (i.e. dense planting and gap creation) should not be one-off activities; they should be followed by comprehensive maintenance activities until plantations are three years old. Pham et al. (2009) recommend filling in sparse areas of the planting site in the first year and continuing to replace dead trees in the second and third years. Moreover, it is important to carry out monitoring activities to obtain results describing failures and successes in order to carry out timely management interventions. (Pham et al., 2009)

4.3.3. Monitoring

During mangrove restoration processes, whether they are forced via planting activities or occur through natural regeneration, monitoring is a mandatory task. Mangrove monitoring aims to detect changes, determine their directionality, and assess their intensity or extent. Data should be collected systematically and then analyzed to better understand the conditions of the planting site. The important information gained from monitoring means that the effectiveness of management efforts can be assessed, changes can be detected, and management actions directed.

As shown in Figure 4-19, monitoring is essential to carrying out effective maintenance and to supporting additional planting activities. The red arrows demonstrate information flows, which are crucial for sustainable and successful management.

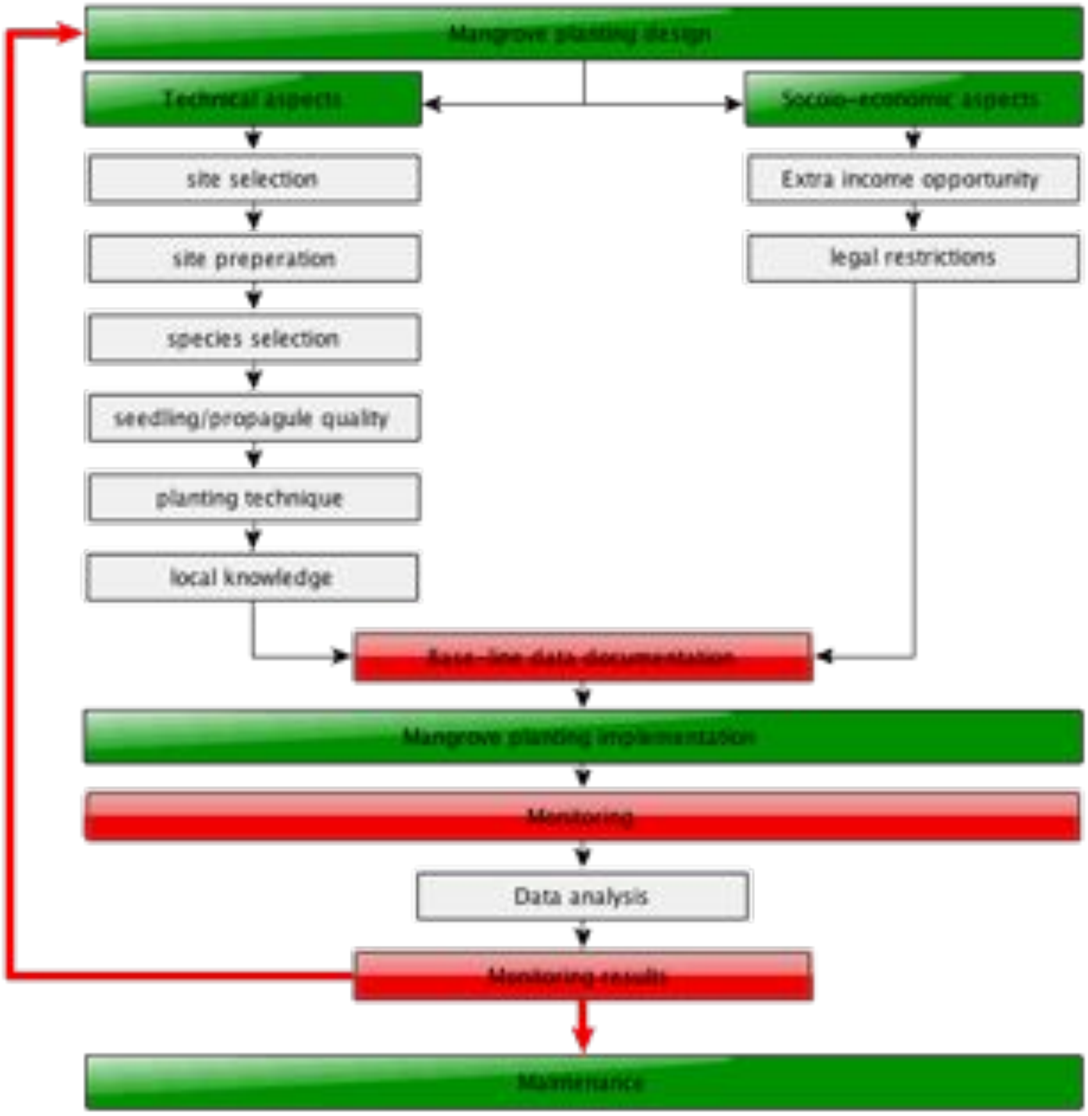


Figure 4-19: Flow chart of planting and monitoring procedures; the red arrows show the important flow of information based on monitoring results

Prior to designing monitoring strategies, it must be clear what the objectives are, as parameters to be monitored need to be designed accordingly. While carrying out monitoring activities, an understanding of biological processes and a common sense approach is essential to distinguishing between natural short-term changes and unacceptable long-term changes within the ecosystem.

To achieve this objective, baseline data for the planting site as well as baseline data related to the planting itself are necessary for evaluating change. For data collection during the pre-planting and the post-planting periods, distinct and comprehensive forms are required, which have to be simple and easy to use.

Monitoring to determine the **success of mangrove planting** is usually done three months after the time of planting. The application of technical measures and the specified workload of planting activities are verified. Parameters that need to be evaluated include survival rate, tree distribution, planting techniques, soil reclamation measures, seedling quality, site conditions, soil conditions, tidal level and volume of work done according to different tree species and site conditions.

Monitoring to determine the **quality of plantations** is usually conducted every five years to provide baseline data and information to formulate the silviculture treatment in forest protection, use and maintenance. The tree density, increments in tree height and diameter, average diameter, height and volume of stems, site conditions, pests and diseases, efficiency of forest management as well as protection and impacts of external factors should all be evaluated.

Monitoring of **mangrove structures** reveals the composition of a mangrove forest in terms of canopy height, stem density, age, tree diameter, and species. Composition is influenced by several factors including climate, tidal inundation, soil pH, salinity, grain size distribution and the freshwater levels. Mangrove structures vary among different forest types as well as among identical forest types in different locations. Mangrove structure monitoring should be conducted regularly at intervals dependent on forest age; short intervals in young forests and longer intervals in old forests.

4.3.4. Co-management

An important element of natural resource management, and indirectly related to this thesis, is the co-management pilot project. Co-management directly relates to the management and maintenance of mangrove areas in Au Tho B Village and therefore will be briefly described in this passage to explain its effects on mangrove restoration.

Co-management in the context of natural resource management is a partnership arrangement in which a resource user group receives the right to use natural resources inside a defined area of state owned land. In return, they bear the responsibility for sustainably managing and protecting the resources. Resource users and local authorities jointly negotiate a formal agreement determining who can do what, where, when, how and how much in particular resource areas (rehabilitation zone inside/outside the forest, protection zone, sustainable use zone). The resource users themselves primarily carry out the implementation and monitoring of the agreement. (Pham et al., 2009)

Under this agreement, effective protection of mangroves is undertaken by the resource user group, not only through sustainable use and diminished exploitation, but also through zonation protecting planted seedlings as well as natural mangrove rehabilitation within the protection zone. (Schmitt, 2009)

Schmitt (2009) also presented four steps of the co-management process and four key principles, which must be applied during the process (see Figure 4-20). The project's implementation of co-management comes under the umbrella of an integrated coastal area management (ICAM); furthermore, all activities must be executed in a participatory way.

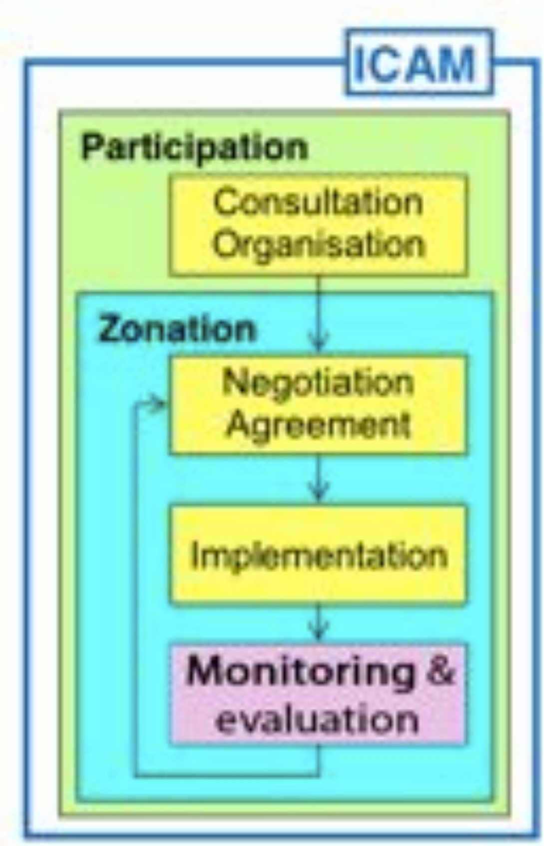


Figure 4-20: Overview of the 4 steps of the co-management process and the 4 key principles; ICAM, participation, zonation and monitoring (Schmitt, 2009)

1. Consultation and organization: Consultation includes surveys, information about the process, procuring acceptance for co-management, capacity building and awareness raising
2. Negotiations will result in a formal agreement between local authorities and resource users. The agreement must apply the key principles of zonation and monitoring.
3. Implementation of the formal agreement
4. Monitoring and evaluation must be applied throughout the co-management process. Information gathered during this process will aid future re-negotiations.

5. Methods and Material

As a component of the GTZ project activities, a mangrove monitoring manual has been developed based on field testing of monitoring techniques on three different planting sites. Development and implementation activities are described in this chapter.

5.1. Forest planting plan

The first step in a mangrove planting or rehabilitation project is the preparation of a forest-planting plan. The plan should ensure the suitability of the planting or rehabilitation site and strategy, and should include the following points:

- Information about land demarcation, boundaries of planting or rehabilitation sites
- Status quo in terms of flora, land use, accretion and erosion
- Physical and hydrological features of the planting or rehabilitation sites (mean tidal inundation, soil maturity)
- Site suitability, species selection and quality of seedlings
- Technical specifications as presented in the annual planting operations plans[1]
- Technical and economic norms applicable to the annual planting operations design

Comments and recommendations related to the collected geographical, physical, and hydrological data as well as the suitability of planting subjects (seedling composition, site suitability, etc) need to be considered within the forest planting plan. An assessment of the personnel and budget plans is also required.

The forest planting or rehabilitation plan should consist of three parts, which are designed to provide all required information. First, a desk study should be undertaken to collect and review existing documents and information from annual reports on planting operation plans, site maps, technical and economic norms, and forest development policies by local authorities. Moreover, monitoring results from completed planting projects should be considered.

Secondly, a field survey using satellite images, maps, GPS data, tape measures, data sheets and questionnaires should be undertaken. A comprehensive record of the geographic location, existing vegetation, tidal levels (inundation), land use, soil types, soil maturity,

1 The annual planting operations plan is an instrument of all Vietnamese Forest Protection Sub-departments for carrying out planting projects

alluvial deposition and coastal erosion taking place should be compiled at this stage. Important outcomes of the field survey include the location map and a comprehensive site description.

The final step is an evaluation of the forest planting plan by an independent evaluation team.

5.2. Structure and forms

All planting projects require a project number for clear assignment, and project information should be available in both hard copy (i.e. folder containing all necessary information) and soft copy (i.e. digital data). The structure of the stored information must be identical for all projects. In this case:

1. Location map
2. Site description sheet
3. Planting description sheet
4. Monitoring sheets
5. Monitoring results

The storage of collected data must follow uniform archiving rules so that anyone can access the data easily. This includes forms, photos and GPS data. The structure of all forms and sheets must be simple and easy to understand. If written text is required to complete the sheets, it must be kept short and precise. Forms should be designed as protected templates to ensure uniformity.

Sketches must be simple and clear to understand with links to GPS coordinates, photo references and distances.

5.2.1. Location map

The location map must be clear and easy to understand so that anybody can visit the planting site by using the location map and a GPS device. The map should be based on a satellite image containing GPS coordinates for key places, distances and landscape features, if available. Google Earth is an easily accessible and suitable tool for creating such a location map. An example for the planting site VC003 is shown in Figure 5-1. The red lines show the walking directions for within the area. Comments about distances and features as well as GPS coordinates related to significant positions have been added. The dots show waypoints marking the planted plots; relevant data (GPS coordinates) is stored according to uniform rules. Location maps for all planting sites VC001, VC002, VC003 and VC004 are provided in Appendix II.

5.2.2. Planting operation design

To enable the evaluation of monitoring data, each mangrove planting project requires baseline data, which can be obtained using a planting operation design. A planting operation design includes data on the site selection and planting technique, as well as all planting baseline data. All data should be recorded in the "site description sheet" and the "planting description sheet" to create the baseline.

Baseline data are mandatory to enable future analysis of the planting project. Any data not recorded at the beginning of a planting project are irretrievable and cannot be considered in future analysis. The more exact the data collection process, the more exact the outcomes.

Figure 5-1: Location map for planting site VC003; the red lines show paths to follow, the dots show waypoints marking the planting plots

Site description sheet

All site conditions should be recorded on the site description sheet form, which is shown in Appendix III. The site description sheet should collect data including:

- Soil structure
- Inundation
- Additional description (water flow, barnacle conditions, coastal erosion/accretion)

- Site description
- Additional remarks

In order to be able to find the planting site again, adequate photo documentation as well as GPS coordinates and sketches are necessary. Satellite images (such as those from Google Earth) are also a useful tool for describing the planting site and location.

Planting description sheet

This form includes all data about the planting as well as a description of the seedlings. The seedlings will be described twice, once prior to planting and once afterwards. The first description records how many seedlings of each species have been ordered (number and weight), from where, and in what condition (height, number of knots and diameter). The height in this case means either the length of the propagule, or the height of the seedling from the ground up to the topmost knot.

After planting, the seedlings will be described again in terms of species, number of planted trees, and plant heights. The planting description sheet, provided in Appendix IV, includes the following data:

- Seedling information prior to planting
- Planting description (Date of planting, tree density)
    - Tree combination
    - Planting technique
- Seedling description after planting (height)
- Additional remarks

Here, extensive photo references, a collection of GPS coordinates, and sketch maps are all essential.

5.2.3. Monitoring settings

As mentioned above (4.3.3 Monitoring), the intervals for monitoring the planting success and the quality of the plantation have already been defined. This thesis recommends monitoring the mangrove structure at one-year intervals. Monitoring activities have to take into consideration human and financial resources. Areas where new approaches are being tested should be considered for scientific monitoring three times a year, in an ideal situation, so as to obtain convincing results. If this is impossible, a minimum of two monitoring sets per year should be conducted; one set before the Northeast Monsoon and one set afterwards.

Number of sampling plots

The number of sampling plots or the total area to be monitored (sampling area), can be calculated based on the total area planted. In order to obtain reliable results, the sampling area should be no less than 1% of the total planting site. Typically, the sampling area should be between 1 – 5% of the total planting site, depending on the budget, human resources and site conditions (e.g. softness of soil).

An easy and simple way to calculate the number of sampling plots as a percentage of the total area follows. S is the total area of the planting site in m^2 and R is the intended sampling area as a percentage. The variable I then refers to the total area to be monitored in m^2.

$$I = \frac{S * R}{100} \tag{5-1}$$

The number of sampling plots n can be calculated based on the total area to be monitored I and the intended sampling plot size a in m^2

$$n = {}^{I}\!/_{a} \tag{5-2}$$

Distribution of sampling plots

Ideally, sampling plots should be randomly distributed in order to gain a representative sampling of the total area to be monitored. However, depending on soil conditions, this can sometimes only be achieved in mangrove forests through unreasonably intense efforts in terms of time and manpower. Therefore, placing the sampling plots at random along transects is a simple and time-effective solution.

The transects are placed parallel to the coastline and cover the environmental gradients in terms of soil types and species composition, for example. Placing each transect in a different gradient ensures a stratified sampling. A subsequent calculation of the results is possible for each separate stratum.

5.2.4. Monitoring sheets

For each monitoring strategy, brief field instructions have been designed to enable the local staff to work with the monitoring sheets and fill them in correctly. Precise data collection is necessary in order to obtain reliable results. Data that needs to be recorded includes:

- Site conditions (wind, wave, erosion, accretion, etc.)
- Pests and diseases
- Photo references (if photos are taken in the field)
- Number of trees
- Tree species
- Height
- Knots
- Diameter
- Additional remarks

Additional remarks should be recorded on the health and quality of trees in three different groups (dominant trees; healthy trees; suppressed, collapsing, or damaged trees). Furthermore, factors that affect the growth of trees (wave, wind, erosion, accretion, sedimentation, barnacles, human activities, etc.), as well as the site conditions (tidal circulation, inundation, etc.) and pests and diseases must also be recorded.

The stem diameter of each tree must be measured at breast height (1.3 m above the surface). Only trees with a stem diameter at breast height of 2.5 cm or more have to be measured, while saplings and seedlings do not. Seedlings are plants < 1 m tall, and saplings are plants higher than 1 meter, but with a diameter at breast height of less than 2.5 cm.

For irregularly shaped trees, different procedures may be used to measure the diameter at breast height.

- For multiple stems with forks below breast height, measure the diameter of each stem at breast height and record the results in one box on the data sheet.
- For multiple stems with forks at breast height, the diameter can be measured slightly below the swelling caused by the fork.
- For stilt or buttress roots, the diameter will be measured 30 cm above the stilt root, topmost prop root, or buttress.

- For trunk swellings, take the measurement slightly above or below the swelling. Some smaller mangrove forests may be naturally stunted or dwarf-like (see 2.3 Mangrove physics); these trees are not suitable for determining the growth status.

An individual monitoring sheet must be developed for each monitoring strategy to support the workflow and facilitate participation in monitoring. The design of the monitoring protocol differs mainly in respect to the different monitoring plots to be examined in the field. The monitoring plots depend on the planting site and planting technique. If possible, a stratification of the monitoring area should be undertaken in order to obtain additional information (see Distribution of sampling plots). In the coastal zone of Soc Trang, three different monitoring strategies have been implemented based on the planting technique (the monitoring sheets were re-designed following use in early 2010).

5.3. Planting projects

Each planting operation gets a unique identifier consisting of a 2 or 3 letter code for the district and a 3-digit numerical value. For monitoring events, another running number is added after an underscore (e.g. VC003_1, VC003_2, etc.)

5.3.1. VC001

Design

Within the "Coastal protection forest planting of Soc Trang province, period 2008 – 2015" project, *Rhizophora apiculata* was planted on a mud-flat area of 150 ha (1x1 m distance between trees (10,000 trees per hectare)) in the communes of Vinh Hai, Lac Hoa, Vinh Chau and Vinh Tan. The planting site is shown in Figure 5-2 (the area marked green). The planting followed the requirements of the Department of Agriculture and Rural Development (DARD). There were no site and planting description sheets at the time; therefore there is only a limited amount of baseline data. The planting took place in September 2008.

5.3.2. VC002

Design

Site VC002 was planted between September 10, 2008 and February 15, 2009 by the GTZ project in Au Tho B Village, Vinh Hai Commune, Vinh Chau District. The planting site has an area of 20.37 ha. The site length parallel to the coastline is about 1,000 m, with a width varying between 180 and 220 m.

The planting site is contained by the two, red-bordered rectangles shown in Figure 5-3; the transects are not shown on the satellite image. The existing forest is composed of *Avicennia marina, Rhizophora apiculata* and *Nypa fruticans*, between 2 and 4 meters in height. Along the northern boundary of the west end of the planting site, there is an area of ca. 1 ha that is characterized by a very low tree density. In the east of the planting area, there is a stand of *Rhizophora apiculata* (dark green color on the satellite image), which was planted at the end of 1997.

500 transects were cut into the forest area, perpendicular to the shoreline, with a width of 80 cm and a distance of 2 m between the transects. The length of each transect depends on the width of the forest and varies from 180 to 220 m. Along these transects, propagules were planted at 1 meter intervals. The species composition consists of *Rhizophora mucronata* (7.71 ha) planted near the coast and *Rhizophora apiculata* (12.66 ha) planted near the sea.

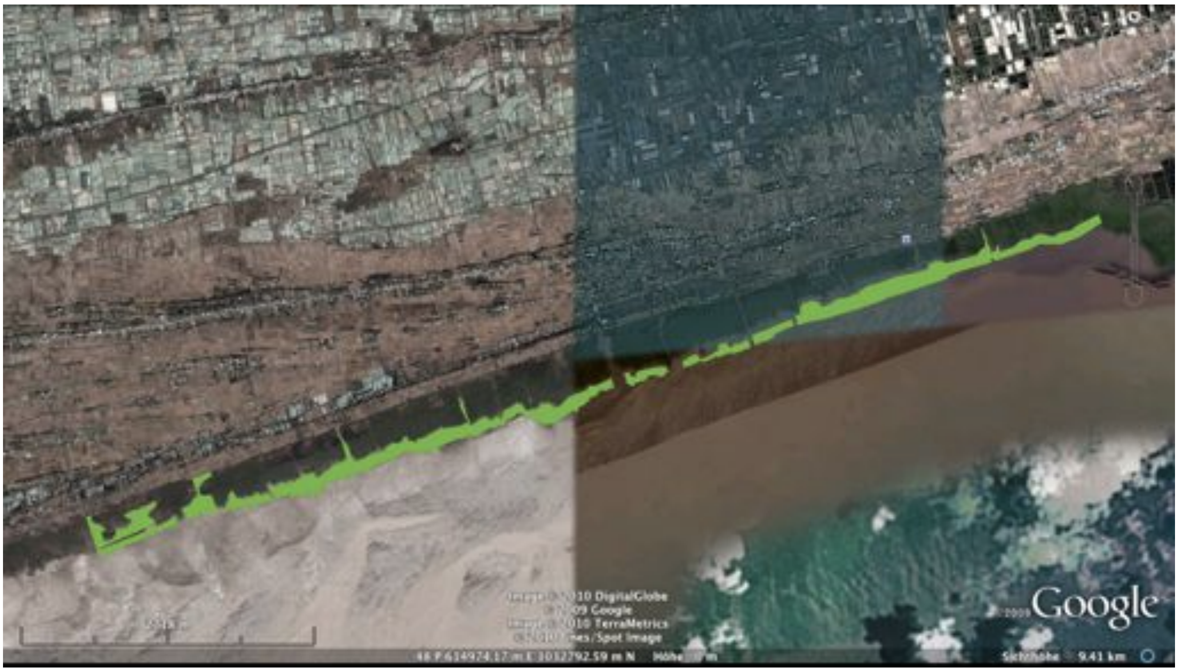


Figure 5-2: Planting site VC001 in Vinh Chau District; the planting area is marked in green

Figure 5-3: Planting site VC002 in Vinh Hai Commune; the planting site is located within the red lines

5.3.3. VC003

Design

The VC003 area represents one approach tested by the GTZ project and is characterised by dense planting close to mature trees in the mud flats of Vinh Chau Commune, which was carried out in October 2009.

The planting site is comprised of 24 plots of around 30 m^2 over 8 different sites next to existing *Avicennia*, and *Rhizophora* stands on the coastline; in some places *Sonneratia* trees also appear. Established mangroves within the planting site vary in height, but have an average height of about 2-3 m (For detailed information about surrounding vegetation, see Appendix V). Each site contains three plots, which were planted with tree densities of 20, 30 and 40 seedlings/m^2, respectively. Furthermore, the following species compositions, shown in Table 5-1, were used for planting.

Table 5-1: Species composition for planting site VC003 in Vinh Chau Commune

Plot No.	Waypoint No.	Plot size in m^2	Tree/m^2	*Rhizophora apiculata*	*Ceriops tagal*	*Avicennia marina*
1	359	30	20	-	100%	-
2	360	30	30	-	100%	-
3	361	30	40	-	100%	-
4	364	26	23	100%	-	-
5	362	30	30	100%	-	-
6	363	30	40	100%	-	-
7	365	30	20	60%	20%	20%
8	366	30	30	60%	20%	20%
9	367	30	40	60%	20%	20%
10	368	32	19	60%	20%	20%
11	369	30	30	60%	20%	20%
12	370	30	40	60%	20%	20%
13	409	31,5	19	20%	60%	20%
14	408	28	32	20%	60%	20%
15	407	30	40	20%	60%	20%
16	406	35	17	20%	60%	20%
17	405	30	30	20%	60%	20%
18	404	28,5	42	20%	60%	20%
19	397	32	19	20%	20%	60%
20	400	32,5	28	20%	20%	60%
21	398	36	33	20%	20%	60%
22	403	30	20	20%	20%	60%
23	402	32	28	20%	20%	60%
24	401	36	33	20%	20%	60%

The planting site is shown in Figure 5-4; detailed information related to the planting site and the planting itself has been added in Appendix V (Site description sheet VC003, Planting description sheet VC003). All of the listed pictures as well as .gdb files (GPS coordinates) are provided in the attached CD.

Location map planting site VC003

- 48 P 608263 1028547 → parking
- walk along the dyke direction east, till you reach point 48 P 608889 1028741
- behind the sluice gate turn right, walk down the path till you reach the first planting site area (waypoint 359,360,361)
- Now the planting sites (waypoints 359 -409) are located to the east along the forest edge (about 1,350 m)
    - o Waypoint file: VC003_2009-10-19.gdb

Figure 5-4: Location map for planting site VC003 in Vinh Chau Commune

Implementation

The first step taken was site selection, which was completed by the staff of the Forest Protection Sub-department. Sites were selected based on their suitability for planting *Rhizophora* and *Ceriops* and the presence of already established forests close to the sea. After choosing the site within a field survey, the exact locations for the planting plots were chosen and marked with poles (see Figure 5-5 and Figure 5-6). The propagules were planted by the straightforward method of pushing the propagule into the sediment until firmly wedged.

The planting of *Rhizophora* and *Ceriops* propagules took place within three days (October 23-25, 2009) of demarcation; at this point of time the planting of *Avicennia* seedlings has been scheduled for April 2010. Cluster planting mimicking natural regeneration was planned for all 24 plots. The planting was done by local laborers. Within the first plots, seedlings were planted in rows. Planting techniques mimicking nature were followed after field supervision was given. Therefore, in plots 1-7, trees were planted in rows and in plots 8-24, trees were planted in such a way as to mimic nature. (See Figure 5-7 and Figure 5-8)

Figure 5-5: Demarcation for VC003 plot No. 7 in Vinh Chau Commune

Figure 5-6: Demarcation for VC003 plot No. 9 in Vinh Chau Commune

Figure 5-7: Planting in rows, VC003 plot No. 10; the bigger propagules are *Rhizophora apiculata* and the smaller propagules are *Ceriops tagal*

Figure 5-8: Cluster planting mimicking natural regeneration; VC003 plot No. 12

Inspections of the planting sites between implementation and the first monitoring event in February 2010 revealed that minimal damage had occurred due to human activities. A few seedlings had died due to trampling, and about 70 % of the demarcation poles had been removed.

5.3.4. VC004

Design

The other approach tested by the GTZ project was the creation of gaps for natural regeneration and planting. The planting took place inside the mangrove forest covering the coastline of Lai Hoa Commune from November 28-30, 2009. The forest consists of even-aged, 13 year old *Rhizophora* trees with an average height of 6-8 meters. Among these trees, a few seedlings have been found, but no trees of intermediate heights. Hence, even if propagules roots within the forest, natural regeneration does not succeed.

The aim of the approach is to determine the optimal gap size and planting density to transform even-aged monoculture plantations into more diverse forests, or if natural regeneration in gaps is sufficient. To achieve these objectives, two different treatments were carried out. Gaps of different sizes were created for:

- planting in gaps
- natural regeneration

The planting site has been divided into 7 areas comprising a total of 21 plots (3 plots per area) (See Figure 5-9). Felling 2, 3 and 4 trees, respectively, created gaps of different size. No preparations were carried out for control plots. Two trees were felled in areas 1 and 5; three trees were felled in areas 2 and 6; four trees were felled in areas 3 and 7. Area 4 is the control area.

Areas 1, 3 and 6 have been planted with mixed tree species (*Rhizophora apiculata*, *Ceriops tagal*) at a density of 30 seedlings/m^2. Areas 2, 5 and 7 have been left for natural regeneration. Within each area, the position of plots is related to zone a, b or c, based on the field position. "A" means next to the seaside, "b" lies in the middle and "c" is next to the hinterland. Table 5-2 shows an overview of all plots.

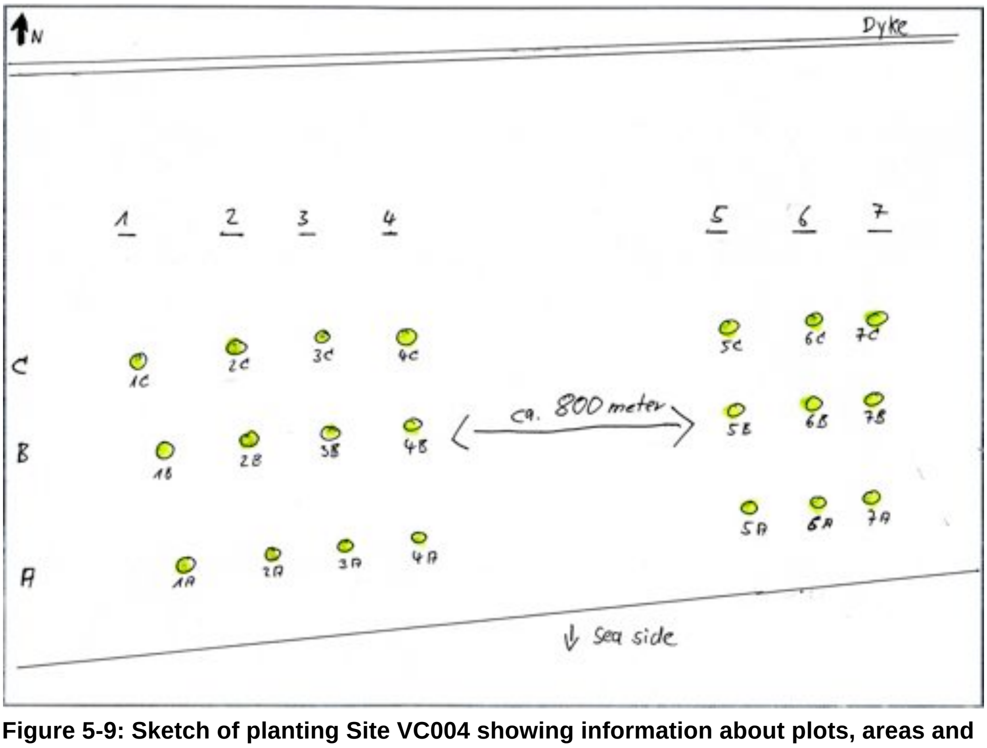


Figure 5-9: Sketch of planting Site VC004 showing information about plots, areas and zones. Horizontal sections are the areas (1, 2, 3, …7); Vertical sections are the zones (a, b, c); Plots marked green contain a caption with area number and zone identifier.

The planting mimics nature and has been carried out according to the following scheme.

- Position a *Ceriops tagal* 66 %, *Rhizophora apiculata* 34 %
- Position b *Ceriops tagal* 34 % *Rhizophora apiculata* 66 %
- Position c *Rhizophora apiculata* 100 %

Table 5-2: Plot size, species composition and amount per plot in planting site VC004

Plot No.	Area	Position	Plot size in m^2	Tree/m^2	*Rhizophora apiculata*	*Ceriops tagal*
1	1	a	13	42	184	356
2	1	b	22	44	634	326
3	1	c	20	30	600	0
4	2	a	26	-	-	-
5	2	b	7	-	-	-
6	2	c	9	-	-	-
7	3	a	30	34	347	673
8	3	b	38	24	594	306
9	3	c	32	35	1110	0
10	4	a	18	-	-	-
11	4	b	38	-	-	-
12	4	c	24	-	-	-
13	5	a	16	-	-	-
14	5	b	39	-	-	-
15	5	c	20	-	-	-
16	6	a	24	38	306	594
17	6	b	20	41	535	275
18	6	c	24	38	900	0
19	7	a	28	-	-	-
20	7	b	45	-	-	-
21	7	c	28	-	-	-

The propagules have also been planted using a straightforward pushing method. The planting site is shown in Figure 5-10; detailed information about the planting site and about the actual planting has been added in Appendix VI (Site description sheet VC004, Planting description sheet VC004). All of the listed pictures as well as the .gdb files (GPS coordinates) are provided in the attached CD.

VC004 directions

- 48 P 590838 1022099 → parking
- walk along the dyke direction east, till you reach point 48 P 591275 1022308
- turn right, walk down the path till you reach point 48 P 591332 1022184
- turn left, walk down the shoreline
    - o site 1 is about 200 m distand from point 48 P 591332 1022184
    - o site 2 is about 1,200 m distand from point 48 P 591332 1022184

Figure 5-10: Location map of planting site VC004 in Lai Hoa Commune

Implementation

After choosing a suitable site containing even-aged single-species mangrove stands with a minimum height of 6 meters, 21 plots were demarcated in the field (see Figure 5-11 and Figure 5-12). Felling 2,3 and 4 trees, respectively, created 18 gaps of different size (7 to 45 m^2) (see also Table 5-2). As described above, the number of trees felled per plot (3 plots per area) is as follows:

- Area 1 2 trees
- Area 2 3 trees
- Area 3 4 trees
- Area 4 no trees (control area)
- Area 5 2 trees
- Area 6 3 trees
- Area 7 4 trees

The gap size is affected only by the number of felled trees (see Figure 5-13). The plot is bound by a string that connects all trees around their stumps. For purposes of simplification, the received polygons were calculated with formulas for circles or ellipses depending on the shape of the plot. The plots in the control area were demarcated in the same way, assuming an average gap size.

Figure 5-11: Measurements inside the mangroves in planting site VC004

Figure 5-12: Demarcation of trees to be felled in planting site VC004

Figure 5-13: Creating gaps by felling trees in planting site VC004

The planting took place from October 28-30, 2009 (see Figure 5-14). Around November 6th, about one week after planting, spring tides carried a huge amount of driftwood into the planting site. Thus, some planted plots suffered from broken and wrapped seedlings (see Figure 5-15).

It turned out that a very suitable opportunity for more permanent demarcation inside the forest was possible using plastic film with signal color, fixed with cable ties to the trees. These colors are clearly visible in the dense forest and only one mark disappeared during the initial 4 months (see Figure 5-16).

Figure 5-14: Planted plot in planting site VC004, Area 3, Plot A

Figure 5-16: Demarcation of plots with plastic film and cable ties

Figure 5-15: Driftwood and litter after spring tide in planting site VC004

5.4. Monitoring settings

These following terms should be defined:

- **Sub-areas** are applied in VC001 to resize the area to be monitored
- A **sampling plot** is a defined area in which data collection occurs
- A **sampling frame** is the area that is monitored using a 1 m^2 frame
- A **sampling area** is the area to be monitored
- **Transects** are lines in which the monitoring can occur (Monitoring transects) or on which monitoring plots can be allocated (Monitoring plots)

5.4.1. Monitoring VC001

As mentioned in Section 5.3.1, the VC001 planting site covers around 150 ha in the communes of Vinh Hai, Lac Hoa, Vinh Chau and Vinh Tan. Depending on the soil structure, work in the mud flats can be very difficult and exhausting. Therefore, monitoring activities should be designed in the easiest way possible while also capturing all necessary data.

Different monitoring strategies were field tested to ascertain their suitability. For example, since large-scale areas no longer contain planted trees, a track-log was recorded (using a GPS device) by walking around the area still containing planted trees, which in turn reduced the area that needed to be monitored. It turned out that the workload for the track-log was too high in terms of time and human resources. Furthermore, a uniform retake of track-log data for the next monitoring set could not be guaranteed, and this would result in a distortion of the collected data.

To monitor the whole planting site of 150 ha, the area was divided into seven subsections of around 1,500 m in length, lying parallel to the coast. Each subsection of 1,500 m contains one sub-area that is 500 m long (See Appendix II). The width of the planting area varies, but averages around 120 m. Now there are seven sub-areas of 60,000 m^2 (500x120 m) located in the field. The intended monitoring area is 1 % of one sub-area.

Using Formula (5-3), $I = (S * R) / 100$ $\quad$ $I = (60.000 * 1) / 100$ $\quad$ $I = 600\ m^2$

Therefore a monitoring plot area of 40 m^2 is suggested to be suitable.

Using Formula (5-2) $n = I / a$ $\quad$ $n = 600 / 40$ $\quad$ $n = 15$

Thus 15 plots of 40 m^2 are to be monitored in one area oriented based on three transects lying parallel to the shoreline. The distribution of the sub-areas is shown in Figure 5-17, with each sub-area located to the right of the given coordinate.

Figure 5-17: Planting site VC001 showing the distribution of the coordinates for the sub-areas for monitoring

The three transects were placed parallel to the coastline covering the environmental gradients in the sampling area. The gradients in this case are the distance between the trees and the coast. Along each of the transects, five rectangular monitoring plots have been sampled at random intervals. Monitoring plots will be tagged in the field by putting two ranging poles in the ground, connected by a 20 m rope. The advantage of this kind of plot compared to standard 10x10 meter plots is the minimized effort. By walking on either side of the stretch, holding a 1-meter long stick perpendicular to the rope, all trees under the stick are recorded (see Figure 5-18). This monitoring strategy is less time-consuming in the case of difficult soil conditions. The "Mangrove plot monitoring" sheet is provided in Appendix VII and includes brief field instructions. Monitoring was carried out in February 2010. A plan for walking along the transects inside the monitoring plot is shown in Figure 5-19, and included as a component of the brief field instructions.

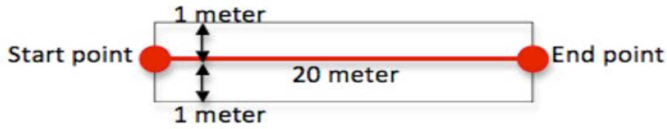


Figure 5-18: 40 m^2 monitoring plot for VC001; the plot is marked by the grey rectangle, the red dots show the ranging poles connected with a 20 m rope (red transect line)

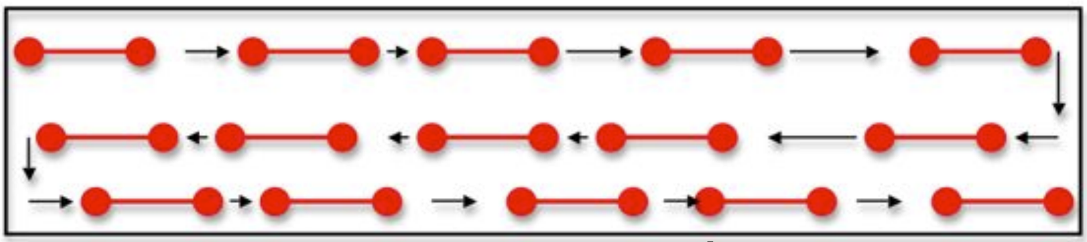


Figure 5-19: Schematic display of the random location of 40m^2 plots along 3 transects (VC001)

5.4.2. Monitoring VC002

The monitoring of planting site VC002 is designed specifically for this special type of planting pattern. The planting took place inside the created transects within the mangrove forest. Therefore, the length of the transect varies depending on the width of the forest in Au Tho B Village.

Monitoring inside the transect follows a special design. Due to the forest structure, the first 10 meters of a transect are not recorded. Thereafter, plants are recorded at 10 meter intervals along the transect, with 30 meter spacing intervals where no plants are recorded (see Table 5-3). This pattern is repeated along the entire length of the transect.

Table 5-3: Monitoring pattern for planting site VC002

Mangrove Forest edge		**Sector 1**		**Sector 2**		**Sector 3**		**Sector 4**		**Sector 5**		**Sector 6**		**Sector 7**
	10 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m

Using this pattern, one quarter of each monitored transect is recorded. To obtain a monitoring area of 1 % of the complete planting area, a minimum of 20 transects must be recorded.

Using Formula (5-3), $I = (S * R) / 100$ $\qquad I = (500 * 1) / 100$ $\qquad I = 5$ transects

In this case, S is the number of transects; just ¼ per transect will be recorded.

5 * 4 = 20 transects

However, 30 transect should be monitored in case any unexpected problems arise. The effort implied by monitoring 30 transects is reasonable.

Monitoring of the VC002 planting was scheduled for November 2009. Different designs of the monitoring sheet were pre-tested in the field (see Figure 5-20 and Figure 5-21). After completion of the finalized sheet, staff of the Forest Protection Sub-department started the monitoring but then had to abandon the work in November/December 2009. An infestation of caterpillars, which can cause eye diseases, appeared at this point in time. The renewed monitoring activities lasted until February 2010. Therefore, the data recorded in late 2009 were rendered useless.

The monitored transects were chosen in the field to ensure random distribution. Indeed, the distribution needs to cover the entire length of the planting site. The "Mangrove transect monitoring" sheet is provided in Appendix VIII and includes brief field instructions.

Figure 5-20: Local staff gets introduced to the monitoring sheets in the field

Figure 5-21: Data recording for monitoring in planting site VC002

5.4.3. Monitoring VC003

This monitoring was designed to cover the planted areas plots where planting techniques mimic natural regeneration. The tree density varies between 20 and 40 trees/m^2 and the species composition also varies. The planted plots are relatively small and cover an area of about 30 m^2. Therefore, to cover 1 % of the planted plot, an area of 0.3 m^2 should be monitored. The sampling frame must be big enough to contain a sufficient amount of plants to make density estimates. The sampling frame must also be small enough to keep counts within reasonable parameters. Due to the heterogeneous distribution of planted mangroves and the size of the plant to be recorded, the size of the sampling frame was set to 1 m^2. This size is considered adequate to obtain representative data; moreover, a minimum of two sampling frames per planted plot will be recorded.

To minimize effort and time needed, a sampling frame (1x1 m) was constructed (see Figure 5-22). This frame was subdivided into 4 areas of 50 x 50 cm to facilitate the work (see Figure 5-23). The position of the sampling frame within the planted plot takes place at random. All trees of all species inside the square meter plot will be recorded. Monitoring took place in February 2010 across all plots.

The application of this monitoring strategy in the field is relatively easy and less time consuming compared with other monitoring strategies. Indeed, the VC003 planting site is easy to enter. The "Mangrove plot monitoring (1m^2)" sheet is provided in Appendix IX and includes brief field instructions.

Figure 5-22: Monitoring activities in planting site VC003

Figure 5-23: The subdivided sampling frame facilitates the fieldwork

5.4.4. Monitoring VC004

Monitoring for the VC004 planting site matched monitoring activities in VC003. Due to the similar planting techniques, each plot will be monitored and a minimum of two sampling frames will be recorded (see Figure 5-24).

The VC004 planting site has an uneven ground surface due to the stilt roots. Therefore, the use of a sampling frame was not feasible. To facilitate the work, a system of 4 wood pegs connected with 4 strings, 1 m each, mark off a quadratic area of one square meter (see Figure 5-25). Each tree of each species within the sampling frame is then recorded.

The monitoring was carried out in February 2010 across all plots.

Figure 5-24: Monitoring activities in VC004

Figure 5-25: One square meter marked by wood pegs

6. Results

Collected data must be transformed into information in order to evaluate project activities. Within plantations under 3 years old, maintenance activities have to be undertaken like the replacement of lost or dead seedlings and thinning. Regular monitoring is important for detecting and preventing destructive human activities and for assessing natural damage and infestations. The tending strategies that end up being applied will be chosen based on monitoring information. In addition, comprehensive information provides a greater knowledge base for supporting future planting/rehabilitation projects.

6.1. Data analysis

Comprehensive data records provide a vast quantity of information. Information about a mangrove forest's structure or level of development can be expressed using the following parameters.

- tree height
- stems per hectare
- basal area

Average **tree height** provides an indicator of canopy height. It can be calculated using Formula (6-1). Average tree diameter can also be calculated with this formula by using *d* (diameter in cm) instead of *h* (height).

$$h_a = \sum h_i / n \qquad \text{(6-1)}$$

h_a= average height

h_i= height of each tree

n= number of trees

The parameter **stems per hectare** gives an overview of tree densities.

$$Stems/ha = \frac{Number\ \ of\ \ living\ \ stems\ \ in\ \ plot * 10{,}000}{Area\ \ of\ \ plot\ \ (m^2)} \qquad \text{(6-2)}$$

The number of dead stems per hectare as well as the overall ratio of dead to living stems can also be calculated using this formula.

The **basal area** refers to the cross section area of plant stems (measured at breast height) calculated by Formula (6-3). The sum of all stem basal areas within the sampling plot is the **stand basal area**, expressed in square meters per hectare. Tree basal area indicates the stocking percent and size or level of a mangrove forest's ecological development.

The cross section number for an individual tree is:

$$Basal\ \ area\ (cm^2) = \pi * r^2 \tag{6-3}$$

- r = radius of stem (cm) = Diameter at breast height (DBH) / 2
- π = 3,1416

The basal area factor or stand basal area is calculated as

$$Stand\ \ basal\ \ area\ (m^2/ha) = \frac{\sum Basal\ \ area\ \ for\ \ the\ \ plot\ (cm^2)}{Area\ \ of\ \ the\ \ plot\ (m^2)} \tag{6-4}$$

Using the calculations described above, the following analyses can be carried out.

- Density of dead or live trees
- Survival rate of planted trees (density of surviving trees compared to the original planting density)
- Increment in total height and diameter
- Increase or decrease in basal area (This analysis can only be carried out with more than one monitoring set)

6.2. Data analysis within this study

To ensure sustainability, all collected data are stored in a simple to use and easily accessible database.

The data collected for the planting sites VC001, VC002, VC003 and VC004 during monitoring activities in February 2010 were entered into a Microsoft EXCEL spreadsheet to facilitate calculations.

Monitoring results mentioned in this thesis are based on the baseline data and the monitoring carried out in February 2010. All data collected are provided in the attached CD.

The following parameters have been analyzed:

- Density of live trees
- Survival rate
- Increment in height and knots[1]

6.2.1. Data analysis VC001

A total of 15 sampling plots of 40 m^2 were recorded in each of the 7 sub-sections after planting in September 2009. The overall number of recorded trees was 806; the average height was 82 cm with a minimum of 40 cm and a maximum of 120 cm. Within the range from 0 to 14, the average number of knots per tree was 6. (See Table 6-1)

Table 6-1: Monitoring results for planting site VC001

Monitoring Feb. 2010	Number of trees	806	Average height in cm	82	Average number of knots	6
			min.	40	min.	0
			max.	120	max.	14

Density of live trees

As mentioned above, the total number of living trees was 807, which corresponds to a tree density of 1,919 trees per hectare after 16 months.

Survival rate

The total sampling area covered was 600 m^2 per sub area (15 sample plots per sub area, 40 m^2 in each sample plot). The planting density in VC001 was 10,000 trees per hectare. With 806 recorded trees, the overall survival rate after 16 months amounted to 19.21 %. The maximum survival rate of 34.50 % per sector was recorded in Au Tho B Village, and the minimum rate of 6.67 % was found in Vinh An Village (see Table 6-2).

Table 6-2: Survival rate after 16 months in planting site VC001

Survival rate VC001 after 16 months			
Overall	VC001	19.19	%
Sector 1	Dai Bai A	18.33	%
Sector 2	San Chim	16.33	%
Sector 3	Vinh Binh	20.17	%
Sector 4	Vinh An	6.67	%
Sector 5	Ca Lang B	22.17	%
Sector 6	Au Tho B	34.50	%
Sector 7	Au Tho A	16.17	%

1 The height of propagules have not been measured after planting, therefore just data of absolute height can be reported

Increment in number of knots

The average height in cm as well as the average number of knots is presented in Table 6-1. The increment depends on the condition of the propagules at the time of planting. In this case, the height of the planted *Rhizophora apiculata* propagules was not recorded during planting. Therefore, information about increments in height can only be obtained after the next monitoring set. The number of knots was zero.

As an average result for the total planting site, the increment in the number of knots was 6. The results are shown in Table 6-3.

Table 6-3: Increment in number of knots after 16 months in planting site VC001

Increment in number of knots after 16 months		Knots (16 months)
Overall	VC001	6
Sector 1	Dai Bai A	8
Sector 2	San Chim	8
Sector 3	Vinh Binh	6
Sector 4	Vinh An	7
Sector 5	Ca Lang B	7
Sector 6	Au Tho B	5
Sector 7	Au Tho A	3

6.2.2. Data analysis VC002

A total of 26 transects were analyzed across the planting site 12 months after planting. The total number of recorded trees was 373; the average height was 65 cm, with a minimum of 31 cm and a maximum of 120 cm. Across the 2 to 8 range, the average number of knots per tree was 6. Table 6-4 shows information about species planted between September 10, 2008 and February 15, 2009.

Table 6-4: Monitoring results for planting site VC002

Monitoring Feb. 2010	Number of trees	373	Average height in cm	65	Average number of knots	6
			min.	31	min.	2
			max.	120	max.	8

Density of living trees

The overall planting density was 5,000 trees per hectare within the planting site of 20.37 ha. Of the total 101,850 trees planted, there were two species: 63,300 *Rhizophora apiculata* trees and 38,550 *Rhizophora mucronata* trees. The planted trees were distributed across 500 transects, 80 cm wide and between 180 to 220 m long, depending on the width of the forest. Due to the monitoring strategy, data collection appeared across one quarter of each transect. A total of 373 recorded trees within 26 transects were monitored. The results show a density of 352.14 trees per hectare; 106.68 *Rhizophora apiculata* trees/ha and 245.54 *Rhizophora mucronata* trees/ha. (See Table 6-5)

Survival rate

The 101,850 trees planted in total, distributed over 500 transects, resulted in a figure of 203.7 trees per transect (126.6 *Rhizophora apiculata* trees and 77.1 *Rhizophora mucronata* trees). In this case, the overall survival rate after 12 months was 7.04 %; the rate for *Rhizophora apiculata* was 2.13 %, and the rate for *Rhizophora mucronata* was 4.91 %. (See Table 6-5).

Table 6-5: Survival rate and density of living trees after 12 months in VC002

Survival rate and density of living trees after 12 months in VC002	Density in trees/ha (12 months)	Survival rate (12 months)
Overall VC002	352,14	7,04 %
Rhizophora apiculata	106,68	2,13 %
Rhizophora mucronata	245,46	4,91 %

The survival rate of *Rhizophora mucronata* planted next to the hinterland was higher than the survival rate of *Rhizophora apiculata* in the area next to the sea.

Increment in number of knots

Baseline data about height was not recorded at the time of planting. The number of knots was zero at the time of planting. A list of the average height and the number of knots is shown in Table 6-4. More detailed results are presented in Table 6-6.

Table 6-6: Increment in number of knots after 12 months in VC002

Increment in number of knots after 12 months	Knots (12 months)
Overall VC002	6
Rhizophora apiculata	6
Rhizophora mucronata	6

Both species have the same increment in number of knots. Therefore, the lower survival rate of *Rhizophora apiculata* is not due to diminished growth but perhaps related to site-specific conditions.

Rhizophora apiculata seedlings were planted next to the sea where parameters might be influenced by increased fishing activities unlike areas inside the dense forest. Presumably, the greatest factors causing the lower survival rate were the wind and waves. Close to the sea, forest density levels decreased; thus, in this area waves are only attenuated by bottom friction but not by interaction with mangroves. Unimpeded winds can also affect the mangrove seedlings. Therefore, seedlings in this area are either less protected or not protected at all from wave energy and winds.

6.2.3. Data analysis VC003

The monitoring for VC003 was carried out in 24 monitoring plots in 8 different areas. Within each plot, 2 sampling frames were monitored. A total of 1,012 trees of all species were recorded 3 months after planting (see Table 6-7).

Table 6-7: Monitoring results for planting site VC003

Monitoring Feb. 2010	Number of trees	1012	Average height in cm	19	Average number of knots	2
			min.	2	min.	0
			max.	45	max.	4

Table 6-8 shows detailed baseline data from the planting on October 23-25, 2009.

Table 6-8: Baseline data in planting site VC003

Plot No.	Area	Plot	Plotsize in m^2	Trees per plot	Tree per m^2	*Rhizophora apiculata*	*Ceriops tagal*	*Avicennia marina*
1	1	1	30	600	20	0	600	0
2	1	2	30	900	30	0	900	0
3	1	3	30	1200	40	0	1200	0
4	2	1	26	600	23	600	0	0
5	2	2	30	900	30	900	0	0
6	2	3	30	1200	40	1200	0	0
7	3	1	30	600	20	360	120	120
8	3	2	30	900	30	540	180	180
9	3	3	30	1200	40	720	240	240
10	4	1	32	600	19	360	120	120
11	4	2	30	900	30	540	180	180
12	4	3	30	1200	40	720	240	240
13	5	1	31,5	600	19	120	360	120
14	5	2	28	900	32	180	540	180
15	5	3	30	1200	40	240	720	240
16	6	1	35	600	17	120	360	120
17	6	2	30	900	30	180	540	180
18	6	3	28,5	1200	42	240	720	240
19	7	1	32	600	19	120	120	360
20	7	2	32,5	900	28	180	180	540
21	7	3	36	1200	33	240	240	720
22	8	1	30	600	20	120	120	360
23	8	2	32	900	28	180	180	540
24	8	3	36	1200	33	240	240	720

Density of living trees

For plantings in VC003, different tree densities were used (20, 30 and 40 trees/m^2). The density inside the planting plots varied slightly due to a fixed number of seedlings per plot and different plot sizes (see Table 6-8). Natural regeneration also impacted the density results, survival rate and species composition. The results shown in Table 6-9 are for all tree species.

Table 6-9: Density of living trees after 3 months in VC003

Tree density in VC003 after 3 months	Plot size in m^2	Planting density in trees/m^2	Recorded trees within 2 sampling frames	Density in trees/m^2 (3 months)
Plot 1	30	20	29	14.5
Plot 2	30	30	55	27.5
Plot 3	30	40	31	15.5
Plot 4	26	23	28	14
Plot 5	30	30	29	14.5
Plot 6	30	40	55	27.5
Plot 7	30	20	35	17.5
Plot 8	30	30	84	42
Plot 9	30	40	59	29.5
Plot 10	32	19	25	12.5
Plot 11	30	30	43	21.5
Plot 12	30	40	32	16
Plot 13	31,5	19	21	10.5
Plot 14	28	32	63	31.5
Plot 15	30	40	50	25
Plot 16	35	17	25	12.5
Plot 17	30	30	57	28.5
Plot 18	28,5	42	43	21.5
Plot 19	32	19	26	13
Plot 20	32,5	28	50	25
Plot 21	36	33	30	15
Plot 22	30	20	41	20.5
Plot 23	32	28	38	19
Plot 24	36	33	63	31.5

The tree density can exceed the original planting density as a result of the planting technique in combination with a random positioning of the sampling frame inside the plot (e.g. Plot No. 8). The planting technique causes an uneven distribution (as in a natural setting) of seedlings inside the planted plot. The position of the sampling frame is random; thus a place inside the sampling plot can be monitored where no trees have actually been planted. The sampling frame can also be placed in an area with high tree density. The tree density used (20, 30 and 40 trees per square meter) is calculated for the whole plot, but mimicking nature does not mean planting an exact number of trees within each square meter. Furthermore, natural regeneration takes place on the planting site. In this case, natural regeneration of *Avicennia marina* took place between the time of planting and the first monitoring event (see Figure 6-2). The planting of *Avicennia* trees was scheduled for April 2010.

Figure 6-1: Natural regeneration of *Avicennia marina* (marked red in the figure) between plantings of *Rhizophora* seedlings after 3 months

Survival rate

The survival rates after 3 months only take into consideration planted trees; therefore results are shown for *Rhizophora apiculata* and *Ceriops tagal*.

Table 6-10: Survival rate of *Rhizophora apiculata* after 3 months in VC003

Survival rate of *Rhizophora apiculata* after 3 months	Planted trees	Plot size in m^2	Recorded trees within 2 sampling frames	Survival rate in % (3 months)
Overall survival rate	8100	740	487	105,86
Plot 1	0	30	29	-
Plot 2	0	30	55	-
Plot 3	0	30	31	-
Plot 4	600	26	28	60,67
Plot 5	900	30	29	48,33
Plot 6	1200	30	55	68,75
Plot 7	360	30	32	133,33
Plot 8	540	30	40	111,11
Plot 9	720	30	52	108,33
Plot 10	360	32	13	57,78
Plot 11	540	30	27	75,00
Plot 12	720	30	22	45,83
Plot 13	120	32	8	105,00
Plot 14	180	28	13	101,11
Plot 15	240	30	26	162,50
Plot 16	120	35	14	204,17
Plot 17	180	30	20	166,67
Plot 18	240	29	16	95,00
Plot 19	120	32	12	160,00
Plot 20	180	33	30	270,83
Plot 21	240	36	4	30,00
Plot 22	120	30	14	175,00
Plot 23	180	32	12	106,67
Plot 24	240	36	24	180,00

Table 6-11: Survival rate of Ceriops tagal after 3 months in VC003

Survival rate of *Ceriops tagal* after 3 months	Planted trees	Plot size in m^2	Recorded trees within 2 sampling frames	Survival rate in % (3 months)
Overall survival rate	8100	740	472	102,60
Plot 1	600	30	29	72,50
Plot 2	900	30	55	91,67
Plot 3	1200	30	31	38,75
Plot 4	0	26	-	-
Plot 5	0	30	-	-
Plot 6	0	30	-	-
Plot 7	120	30	3	37,50
Plot 8	180	30	44	366,67
Plot 9	240	30	7	43,75
Plot 10	120	32	12	160,00
Plot 11	180	30	14	116,67
Plot 14	540	28	50	129,63
Plot 15	720	30	23	47,92
Plot 16	360	35	16	77,78
Plot 17	540	30	17	47,22
Plot 18	720	29	25	49,48
Plot 19	120	32	13	173,33
Plot 20	180	33	17	153,47
Plot 21	240	36	23	172,50
Plot 22	120	30	19	237,50
Plot 23	180	32	23	204,44
Plot 24	240	36	30	225,00

Due to the same reasons mentioned above, results may show a survival rate of more than 100 %.

Increment in number of knots

Absolute information about the average height and number of knots is shown in Table 6-7. The average height was 23 cm for of *Rhizophora* seedlings and 12 cm for *Ceriops* seedlings at the time of planting. The number of knots was zero for both species. The increment after 4 months is presented in Table 6-12.

Table 6-12: Increment in number of knots after 3 months in VC003

Increment in height and knots after 3 months	Knots (3 months)
Rhizophora apiculata	2
Ceriops tagal	1

Depending on soil conditions, up to 1/3 of the length of a propagule is pushed into the substrate. The height of seedlings was only measured prior to planting. Therefore the increment in height cannot be calculated. This is a lesson learned due to the process of designing the planting description sheet and using these baseline data for calculations with monitoring data. It will be possible to calculate information about increments in height after the next monitoring set.

6.2.4. Data analysis VC004

Monitoring of planting site VC004 includes a total of 21 plots in 7 different locations. The monitoring strategy is to the same as for VC003; hence, 2 sampling frames were monitored inside each plot. A total of 356 trees of all species were recorded 3 months after planting (see Table 6-13). Table 6-14 shows detailed information about the baseline data from planting on October 28-30, 2009.

Table 6-13: Monitoring results in planting site VC004

Monitoring Feb. 2010	Number of trees	356	Average height in cm	19	Average number of knots	2
			min.	2	min.	0
			max.	45	max.	4

Table 6-14: Baseline data in planting site VC004

Plot No.	Area	Purpose	Zone	Plotsize in m^2	Trees per plot
1	1	Planting	a	13	540
2	1	Planting	b	22	960
3	1	Planting	c	20	600
7	3	Planting	a	30	900
8	3	Planting	b	38	810
9	3	Planting	c	32	900
16	6	Planting	a	24	1020
17	6	Planting	b	20	900
18	6	Planting	c	24	1110
4	2	Natural regeneration	a	26	0
5	2	Natural regeneration	b	7	0
6	2	Natural regeneration	c	9	0
13	5	Natural regeneration	a	16	0
14	5	Natural regeneration	b	39	0
15	5	Natural regeneration	c	20	0
19	7	Natural regeneration	a	28	0
20	7	Natural regeneration	b	45	0
21	7	Natural regeneration	c	28	0
10	4	Control area	a	18	0
11	4	Control area	b	38	0
12	4	Control area	c	24	0

Density of living trees

The tree density for all plots within VC004 was planned to be 30 trees/m^2. Due to a fixed number of seedlings per plot and varying plot sizes, the actual planting density varies (see Table 6-14). The number of seedlings ordered depended on a rough assessment of gap size. Following exact demarcation of the created gaps, the sizes varied slightly. Therefore the planting density inside the plots varies as well.

Trees were planted within areas 1,3 and 6, while areas 2, 5 and 7 were left for natural regeneration; area 4 is the control area and no gaps were created here. The following calculations take both species into consideration (see Table 6-15); additional species have not yet been found within planting site VC004. A drawing of the planting site including plot numbers, areas and zones is shown in (Figure 5-9).

Table 6-15: Density of living trees after 3 months in VC004

Tree density in VC004 after 3 months	Purpose	Plot size in m^2	Planting density in trees/m^2	Recorded trees within 2 sampling frames	Density in trees/m^2 (3 months)
Plot 1	Planting	13	42	74	37
Plot 2	Planting	22	44	38	19
Plot 3	Planting	20	30	43	21.5
Plot 7	Planting	30	30	32	16
Plot 8	Planting	38	21	29	14.5
Plot 9	Planting	32	28	14	7
Plot 16	Planting	24	43	34	17
Plot 17	Planting	20	45	21	10.5
Plot 18	Planting	24	46	45	22.5
Plot 4	Natural regenration	26	0	-	-
Plot 5	Natural regenration	7	0	1	0.5
Plot 6	Natural regenration	9	0	-	-
Plot 13	Natural regenration	16	0	4	2
Plot 14	Natural regenration	39	0	1	0.5
Plot 15	Natural regenration	20	0	7	3.5
Plot 19	Natural regenration	28	0	1	0.5
Plot 20	Natural regenration	45	0	9	4.5
Plot 21	Natural regenration	28	0	2	1
Plot 10	Control area	18	0	-	-
Plot 11	Control area	38	0	1	0.5
Plot 12	Control area	24	0	-	-

The results associated with the density of living trees show that little or no natural regeneration took place between the time of planting and the first monitoring event. As with VC003, information about the density of living trees within planted plots was less significant due to the planting technique, which mimics nature, and the random distribution of the sampling frame.

The greatest increase in natural regeneration appeared in plot No. 20, which, compared to other created gaps, had a relatively large gap size of 45 m^2. As mentioned above, *Rhizophora* seedlings are able to survive in a semi-dormant state for several months. Moreover, due to their highly-developed viviparous propagules, they are believed to be able to survive a long time without nutrients or sunlight. On the planting site, several human activities including digging for worms and cutting of wood took place. This may have been a factor for the small number of naturally regenerated seedlings. Monitoring human activities on the planting site yielded information that could be used for a convincing evaluation of natural regeneration. Certainly, assumptions about planting success or natural regeneration would be premature at this point in time.

Survival rate

The survival rates for *Rhizophora apiculata* and *Ceriops tagal* are shown in Table 6-16 and Table 6-17 for planted plots. As with the survival rates in VC003, results of more than 100 % are caused by the uneven distribution of seedlings due to the planting technique (see 6.2.3 Data analysis VC003).

Table 6-16: Survival rate of *Rhizophora apiculata* after 3 months in VC004

Survival rate of *Rhizophora apiculata* after 3 months	Purpose	Planted trees	Plot size in m^2	Recorded trees within 2 sampling frames	Survival rate in % (3 months)
Plot 1	Planting	184	13	14	49.46
Plot 2	Planting	634	22	18	31.23
Plot 3	Planting	600	20	43	71.67
Plot 7	Planting	306	30	2	9.80
Plot 8	Planting	535	38	13	46.17
Plot 9	Planting	900	32	13	23.11
Plot 16	Planting	347	24	9	31.12
Plot 17	Planting	594	20	19	31.99
Plot 18	Planting	1110	24	44	47.57

Table 6-17: Survival rate of Ceriops tagal after 3 months in VC004

Survival rate of *Ceriops tagal* after 3 months	Purpose	Planted trees	Plot size in m^2	Recorded trees within 2 sampling frames	Survival rate in % (3 months)
Plot 1	Planting	356	13	60	109.55
Plot 2	Planting	326	22	20	67.48
Plot 7	Planting	594	30	30	75.76
Plot 8	Planting	275	38	16	110.55
Plot 16	Planting	673	24	16	28.53
Plot 17	Planting	306	20	2	6.54

Increment in number of knots

Absolute information about height and number of knots of both species is presented in Table 6-13. The average height was 23 cm for *Rhizophora* seedlings and 12 cm for *Ceriops* seedlings at the time of planting; the number of knots was zero for both species. As with VC003, the height of the planted seedlings was not measured after planting. Information about increments in height can not be obtained until after the next monitoring set. The increment in number of knots is presented in Table 6-18.

Table 6-18: Increment in number of knots after 3 months in VC004

Increment in number of knots after 3 months	Knots (3 months)
Rhizophora apiculata	1
Ceriops tagal	1

Figure 6-3 shows a planted plot at planting site VC0 nbv04. The level of development here is lower in comparison with planted seedlings from planting site VC003.

Figure 6-3: Planted seedlings in planting site VC004 (at the time of monitoring in February 2010)

6.2.5. Discussion of results

Data analysis of the planting project shows that the comprehensive and exact recording of baseline data is essential for obtaining results.

To gather additional information about the relatively low survival rate in VC001, Sector 4, a follow-up should be carried out in order to collect more detailed parameter information for this particular part of the planting site (e.g. different soil conditions, human impact, wind, waves, etc.). Furthermore, these parameters need to be compared with other locations within the planting site.

Figure 1-2 and Figure 6-1 show *Rhizophora* trees planted in different locations within Vinh Chau District. Comparison of the density of living trees as well as the survival rate within these planting areas, shows variation in level of structure and development. Different levels of progress in these even-aged planting areas depend on natural impacts (winds, waves, sedimentation, etc.) and different soil conditions. Therefore, information about suitability of site conditions in respect to planting success is very important.

Figure 6-5: *Rhizophora apiculata* planted in VC001, Vinh Chau Commune

Figure 6-4: *Rhizophora apiculata* planted in VC001, Au Tho B Village

The same applies to *Rhizophora apiculata* planted in VC002, which also have a small survival rate compared to planted *Rhizophora mucronata* trees within the same planting site.

At this point in time, plants within VC003 and VC004 are still too young to provide any relevant information in respect to location, planting pattern (e.g. mixed species), gap sizes, etc.

In regard to VC001 and VC002, the survival rate is the most important parameter for the assessment of the planting's success. There is less significance to the survival rate for plantings in VC003 and VC004. Natural regeneration provides a vast number of seedlings on a small area and creates a natural community structure. After a certain period of time, the number of seedlings decreases while a few trees become established. Hence, natural regeneration does not depend on a high survival rate either. Small-scale plantings next to established or mature trees might lead to a greater resilience in the ecosystem of planting site VC003.

The approach tested in VC004 should provide information about the optimal size of gaps transforming an even-aged single-species mangrove forest into a more diverse forest that provides higher stand resilience. Equally important is the question of whether natural regeneration will take place or if planting inside created gaps will be necessary for success. If planting is necessary, questions arise as to what tree density and what species composition will lead to the best results. The planting inside created gaps also follows cluster planting that mimics natural regeneration.

The aim of creating a more diverse forest in respect to species composition as well as horizontal and vertical structures could be achieved by using cluster planting, which mimics natural regeneration. This could in turn establish a natural mangrove forest structure more resilient to the negative impacts of climate change.

7. Discussion

7.1. Summary

When considering coastal protection, there is a necessity to rehabilitate mangroves on the coastal zone of Soc Trang Province. Creating a more diverse forest structure with a natural regenerative capacity might facilitate higher stand resilience to the threats of climate change. Risk-spreading strategies have therefore been implemented to address uncertainties. The challenges posed by a highly dynamic shoreline and the exploitation of mangroves demand effective rehabilitation strategies. Moreover, land conversion for shrimp farms and agriculture limits the area for mangrove reforestation and afforestation.

Cluster planting mimicking natural regeneration aims at small scale planting next to established trees. This approach might also be suitable for plantings in areas with high wave energy. Experience gathered in several afforestation projects has shown that on such sites only seedlings planted close to mature trees survive. Creating gaps in forests might be a suitable mechanism for transforming even-aged plantations into more diverse forests, both in terms of structure and species composition. A small-scale approach making use of field-testing and monitoring will provide relevant data related to the optimal gap size as well as proof as to whether natural regeneration is sufficient or if planting mimicking natural regeneration is necessary.

Neither approach is a one-off activity, so they must be carried out periodically within the same area. Constant monitoring will provide information for future management decisions.

7.2. Comparisons

While mangrove rehabilitation within this study has concentrated on creating more diverse forests and promoting stand resilience using small-scale approaches, most mangrove-related programs emphasize large-scale plantings. In the following paragraphs, some issues and activities are discussed in respect to the objectives of the GTZ project.

Field (1999) pointed out that conservation, land use management, sustainable production and coastal protection are the four main reasons for mangrove rehabilitation. While restoration turns degraded mangrove areas into something resembling the presumed original state, rehabilitation returns degraded mangrove areas into fully functional mangrove ecosystems regardless of the original state of the degraded area. Furthermore, Field (1999) reports that research has concentrated on understanding the structure and function of pristine mangroves. The future of mangrove rehabilitation will focus on six issues/activities.

- Biodiversity
- Biotechnology
- Modeling of ecological processes in mangroves
- Geographical Information Systems (GIS) and mapping
- Human factors and mangrove rehabilitation
- Databanks

He stresses that the already substantial body of knowledge must be extended.

Based on the suggestions mentioned above, the current project in Soc Trang attempts to achieve a greater knowledge and understanding of mangrove reforestation and afforestation techniques. Ongoing monitoring activities about the success or failure of mangrove rehabilitation are mandatory to achieving suitable strategies.

Riley and Kent (1999) presented principles and processes of mangrove habitat creation and restoration based on the Riley encased methodology (REM). For the purpose of establishing mangroves along high-energy shorelines, the principles of REM consist of individual seedling isolation and the adaption of the juvenile plant to the environment after becoming self-supportive. Encasements were made from thin wall poly-vinyl-chloride (PVC) pipes with a diameter of 3.8 cm for *Rhizophora mangle*. Encasements also have a longitudinal cut across their entire lengths. Seedlings have been protected from environmental damage (i.e. washing away, impacts from materials and strangling sea grasses) as long as they are fully encased. In 1995, Hurricane Erin (Category 1) badly damaged those mangroves that were not fully encased at Sebastian Inlet, Florida. Plants had been particularly damaged where sea grasses had wrapped around exposed foliage. REM demonstrated that mangroves can be established along high-energy shorelines.

Kent and Lin (1999) compared REM and traditional techniques for planting red mangroves. For testing the effectiveness of the encasements, three different types have been used (half-length PVC, full-length PVC and bamboo pipes). Wild red mangroves (*Rhizophora mangle*) propagules were planted during two seasons in 1997 (August and November) at Sebastian Inlet and Rocky Point, Florida. The study showed that use of the full-length PVC encasement (as described above) has been the only effective mangrove planting strategy.

Mangrove planting according to REM might be suitable in some cases, but this method will not meet the objectives required in the coastal zone of Soc Trang, including the creation and promotion of mangrove forests that are resilient and have a natural regenerative capacity. Plantings following REM can establish trees on high-energy shorelines, but cannot create natural forests providing a natural regenerative capacity.

Toledo et al. (2001) reported on cluster planting of nursery-reared *Avicennia germinans* seedlings at Laguna de Balandra, Baja California Sur, Mexico. The planting area consisted of 53 ha and arid conditions (less than 150 mm of rain per year). 5 propagules were planted in bags, 1-2 cm apart. After 90 days, propagules had reached heights of approximately 10 cm and had 4-6 leaves each. 555 plants in 111 bagged clusters were planted in their plastic bags at a distance of 1±0.20 m from one cluster to another. Planting was done at some distance from existing forests and has not received treatment since planting. The survival rate after 2 years was 74 %. The number of plants in each cluster declined over the time, but most clusters still consist of 5 trees each. This approach showed the feasibility of reforestation of mangroves in arid areas where natural regeneration is low.

The use of clusters was suitable for this approach. As mutual support between plants in each cluster can be assumed, cluster planting indeed has certain advantages compared with the planting of individual trees. Furthermore, interaction between trees causes an uneven distribution of trees differing in height, number of leaves and number of trees per cluster (Toledo et al., 2001). This removes the issue of forests where all trees are the same height.

As mentioned in 4.3.2 Planting strategies, Duke (2001b) figured out that the turnover in mangrove forests is influenced by stand development and factors influencing tree death. Due to the six stages of gap creation and recovery (see Figure 4-18), initial growth of seedlings begins with exposure to sunlight.

The effect of sunlight penetrating beneath the canopy has led to the approach of creating gaps for planting or natural regeneration. A greater knowledge and understanding is necessary to ensure effective maintenance and transformation of even-aged single-species mangrove forests into more diverse forests.

Since 1978, a major reforestation program has been underway in the Can Gio District located southeast of Ho Chi Minh City, Viet Nam. Phan (2004) reported that during Operation Ranch Hand from 1966 to 1970 in the second Viet Nam War, heavy defoliation killed vegetation as well as the local fauna and destroyed the entire ecosystem. Due to the destruction of the mangroves, coastal erosion increased. From 1978 to 1997, 20,638 ha of *Rhizophora apiculata* have been reforested. In the 1980's, replanted mangroves were degraded due to exploitation for timber and the conversion of mangroves into shrimp farms. Since 1991, the Government of Viet Nam has declared Can Gio mangrove forests as environmental protection forests. At present, the mangroves of Can Gio are divided into 24 forestry units with clearly marked boundaries. Furthermore, changes within the mangroves are monitored by using maps and exploitation log-books. The mangroves of Can Gio District are more diverse in community structure now than before the Viet Nam War; valuable species mixed with naturally regenerated ones have been rehabilitated. Not only mangroves, but also plankton, benthos, fishes, amphibians and reptiles, birds and mammals have been considered in evaluations of the ecosystem. In early November 1997, an unusually severe storm hit the coastal zone of Southern Viet Nam. Many coastal provinces suffered serious damage, but the mangrove belt at Can Gio mitigated storm damage. Mangrove restoration also reduced erosion and increased accretion, ensured the conservation of soil and water, an increase of biodiversity and also the development of eco-tourism, which all improved local living standards. (Phan, 2004)

Monitoring of changes over time has supported the comprehensive and vast achievements in Can Gio District. Moreover, huge areas with lower populations than Soc Trang and intelligent land use management have supported the reforestation activities in Can Gio. Results show that more diverse mangrove forests not only provide more effective protection during severe storms, but also bring benefits for local people’s living standards.

A consideration of different mangrove rehabilitation or reforestation/afforestation projects shows that each project has its own unique physical and ecological site conditions; moreover, the target objectives are also variable. Therefore a uniform standard for measuring the success or failure of different projects produces no valuable information. Information about successful strategies as well as lessons learned from failure are the most valuable pieces of information. There continues to be a lack of information here. The key to achieving an appropriate quantity of knowledge is comprehensive monitoring being carried out on a periodic basis. To support future strategies, this information should be accessible for interested persons, organizations and authorities.

McLeod and Salm (2006) found that due to the limited amount of pristine mangroves and the increasing threats, establishing baseline data on mangrove forests is urgent and essential. Ellison (2000) listed several parameters which baseline data should cover in order to establish objectives for restoration projects. These parameters are tree stand structure: tree abundance, species richness and diversity; invertebrate abundance: species richness and diversity; primary production (biomass and litter); nutrient export; and hydrologic patterns. Furthermore, rates of sedimentation, relative sea level rise, human threats and existing management should be considered (McLeod & Salm, 2006).

7.3. Recommendations

The following recommendations are based on site conditions and the objectives of the project "Management of Natural Resources in the Coastal Zone of Soc Trang Province". The responsibility for the implementation of these recommendations rests with local authorities cooperating with Vietnamese institutes or universities. Recommendations for the project area:

- Expand field testing of both of the approaches being tested
    - Try different species compositions
    - Try lower planting densities
    - Create forest edge conditions

Field-testing is essential for collecting information. Therefore, a wider range of field-tests might address uncertainties and provide more information in terms of quality and quantity. New planting plots can be established to extend field-testing. To gather more information, different site conditions can be used as well as different planting patterns in respect to species composition, planting density, etc. Additionally, encouraging planting patterns can be repeated .

Creating forest edge conditions by cutting larger gaps could provide the characteristics of forest edge trees. These trees provide a valuable protective function in respect to deflecting strong winds and waves. (Duke 2001b)

- Protect planting areas from human activities

In the past, planting areas have repeatedly suffered from human activities such as fishing, cutting of timber and fuel wood as well as exploitation and trampling. These effects have to be avoided, which can be achieved by introducing co-management, restrictions, observation of planted areas and the raising the environmental awareness among local communities.

- Continue scientific monitoring

Monitoring the success of mangrove planting, quality of plantations and mangrove structures is mandatory for obtaining information about the mangrove ecosystem and for facilitating maintenance and management decisions. Scientific monitoring considers the approaches being tested. As mentioned above, the ideal case would consist of 3 monitoring sets per year. A minimum of two monitoring sets per year (before and after the Northeast Monsoon) is necessary to obtain important information.

- Consider a wider range of parameters

A wider range of considered parameters would enhance the results of field-testing. Data dealing in particular with soil conditions, the richness of fauna species, and human threats could contain valuable information for evaluating the mangrove ecosystem.

- Establish a database into which to enter all collected data

Recorded data should be entered into a database that also automatically transfers data into the required information.

- Model mangrove conditions on the coast of Soc Trang in respect to their capability to attenuate wave energy

To protect the dyke, information about hydrological and hydraulic capabilities of mangroves would reveal not only sufficient forest widths and tree density, but also suitable species compositions.

References

Alongi, D. M. (2009). *The Energetics of Mangrove Forests.* Townsville, Queensland, Australia: Springer Science and Business Media B. V.

Bailey, C. (1988). The social consequences of tropical shrimp mariculture development. *Ocean Shoreline Mnagement* (11), 31-44.

Bandaranayake, W. M. (1998). Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes* (2), p. 15.

Biswas, S. R., Mallik, A. U., Choudhury, J. K., & Nishat, A. (2009). A unified framework for the restoration of Southeast Asian mangroves—bridging ecology, society and economics. *Wetlands Ecological Management* (17), 365-383.

Blaber, S. J., & Blaber, T. G. (2001). Die Artenvielfalt der Fische in den Mangroven. In E. Wolanski, *Mangroven: Lebensräume zwischen Land und Meer* (pp. 119-153). Wolanski, E.

Carew-Reid, J. (2008). *Rapid Assessment of the Extent and Impact of Sea Level Rise in Viet Nam.* ICEM – International Centre for Environmental Management, Brisbane, Australia.

Chu, P. C., Edmonds, N. L., & Fan, C. (1999). Dynamical Mechanisms for the South China Sea Seasonal Circulation and Thermohaline Variabilities. *Journal of Physical Oceanography* (29), 2971-2989.

Cintron, G., & Novelli, Y. Methods for studying mangrove structure. In S. Snedaker, & J. Snedaker, *The Mangrove Ecosystem: Research Methods* (pp. 91-113). UNESCO.

de Graf, G. J., & Xuan, T. T. (1998). Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. *Mangroves and Salt Marshes* (2), 159-166.

Duke, N. C. (1992). Mangrove Floristics and Biogeography. In A. I. Robertson, & D. M. Alongi, Tropical Mangrove Systems (pp. 63-100). Washington D. C., United States of America: American Geophysical Union.

Duke, N. C. (2001a). Regenerative Prozesse formen Diversität und Struktur von Mangrovensystemen. In E. Wolanski, Mangroven: Lebensräume zwischen Land und Meer (pp. 59-97). Fürth, Deutschland: Wolanski, E.

Duke, N. C. (2001b). Gap creation and regenerative processes driving diversity and structure of mangrove ecosystems. *Wetlands Ecology and Management* (9), 257-269.

Ellison, A. (2000). Mangrove restoration: Do we know enough? *Restoration Ecology* (8), 219.

Elster, C. (2001). *Mangroven, Ihr Stellenwert, Ursachen ihrer Schädigungen, Möglichkeiten ihrer Rehabilitierung.* Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

FAO. (1998). *Integrated coastal area management and agriculture, forestry and fisheries.* Rome: Food and Agriculture Organization of the United Nations.

FAO. (2007a). *Mangroves of Asia 1980 - 2005 Country Reports.* Working Paper, Foood and Agriculture Organization of the Inited Nations, Forestry Department, Rome.

FAO. (2007b). *The world's mangroves 1980-2005.* Food and Agriculture Organization of the United Nations, Rome.

Field, C. (1999). Mangrove rehabilitation: choice and necessity. *Hydrobiologia* (413), 47-52.

FIPI. (2004). *Report on status of land-use in Full Protected Zones in Soc Trang Province.* Southern Sub-Institute of Forest Inventory and Planning, Ho Chi Minh City.

GTZ. (2010a, 16-June). (GTZ) Retrieved 2010, 16-June from Management of Natural Resources in the Coastal Zone of Soc Trang Province: http://czm-soctrang.org.vn/en/home.aspx

GTZ. (2010b, 12-June). *About us*. Retrieved 2010, 16-June from Deutsche Gesellschaft für Technische Zusammenarbeit, Corporate profile: http://www.gtz.de/en/689.htm

Hogarth, P. J. (1999). *The Biology of Mangroves.* Oxford University Press.

Joffre, O., & Luu, H. T. (2007). *A Baseline Survey in the Coastal Zone of Soc Trang Province, Livelihood Assessment and Stakeholder Analysis.* Management of Natural Resources in the Coastal Zone of Soc Trang Province. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Kent, C. P., & Lin, J. (1999). A comparison of Riley encased methodology and traditional techniques for planting red mangroves (Rhizophora mangle). *Mangroves and Salt Marshes* (3), 215-225.

Le, A. T., Chu, T. H., Miller, F., & Bach, T. S. (2005). Flood and Salinity Management in the Mekong Delta, Vietnam. In T. Than Be, B. Tan Sinh, & M. Fiona, *Challenges to sustainable Development in the Mekong Delta: Regional and National Policy Issues and Research Needs.* Stockholm Environment Institute.

Lu, X. X., & Siew, R. Y. (2006). Water discharge and sediment flux changes over the past decades in the Lower Mekong River: possible impacts of the Chinese dams. *Hydrology and Earth System Sciences* (10), pp. 181-195.

Lugo, A. E., & Snedaker, S. C. (1974). The Ecology of Mangroves. In *Annual Review of Ecology and Systematics* (Vol. 5, pp. 39-64). Annual Reviews.

MacFarlane, G. R. (2001). Mangroven und Umweltverschmutzung. In E. Wolanski, *Mangroven: Lebensräume zwischen Land und Meer* (pp. 153-171). Wolanski, E.

Massel, S., Furukawa, K., & Brinkman, R. (1999). Surface wave propagation in mangrove forests. *Fluid Dynamics Research* , 219-249.

Mazda, Y., Magi, M., Kogo, M., & Phan, N. H. (1997a). Mangroves as a coastal protection from wavers in the Tong King delta, Vietnam. *Mangroves and Salt Marshes* (1), pp. 127-165.

Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuke, D., & Magi, M. (1997b, March 10). Drag force due to vegetation in mangrove swamps. *Mangroves and Salt Marshes* (1), pp. 193-199.

Mazda, Y., Kobashi, D., & Okada, S. (2005). Tidal-scale hydrodynamics within mangrove swamps. *Wetlands Ecology and Management* (13), 647-655.

Mazda, Y., Magi, M., Ikeda, Y., Kurokawa, T., & Asano, T. (2006). Wave reduction in a mangrove forest dominated by Sonneratia sp. *Wetlands Ecology and Management* (14), 365-378.

Mazda, Y., Wolanski, E., & Ridd, P. V. (2007). *The Role of Physical Processes in Mangrove Ecosystems.* Japan: TERRAPUB.

McLeod, E., & Salm, R. V. (2006). *Managing Mangroves for Resilience to Climate Change.* The International Union for the Conservation of Nature and Natural Resources. Gland, Switzerland: IUCN.

Milliman, J. D., & Meade, R. H. (1983). World-wide delivery of river sediment to the oceans. *The Journal of Geology , 1* (91).

MRC. (2005). *Overview of the Hydrology of the Mekong Basin.* Mekong River Comission. Vientiane: Mekong River Comission.

MRC. (2009, 3-August). *About Mekong*. Retrieved 2010, 15-June from Mekong River Comission: http://www.mrcmekong.org/about_mekong/about_mekong.htm

Ngo, N. C., Pham, H. T., Do, D. S., & Nguyen, N. B. (2006). *Food and Agriculure Organization of the United Nations.* Retrieved July 11, 2010, from STATUS OF COASTAL EROSION OF VIETNAM AND PROPOSED MEASURES FOR PROTECTION: http://www.fao.org/forestry/11286-1-0.pdf

Nguyen, A. D., & Savenije, H. H. (2006). National Workshop on Co-management Concept and Practice in Vietnam. *Hydrology and Earth System Sciences* (10), pp. 743-754.

Nguyen, H. C. (1993, September). Geo-Pedological Study of the Mekong Delta. Southeast Asian Studies , 2 (31).

Nguyen, H. C. (1994, March). Former and Present Cropping Patterns in the Mekong Delta. *Southeast Asian Studies , 4* (31), pp. 345-384.

Nguyen, T. T. (2009). *Surface sediment characteristics and sediment transport from Bassac River mouths to Ca Mau Peninsula (Mekong Delta).* Master thesis, Christian Albrechts Universität, Coastal Research Laboratory, Kiel.

Pham, T. T., Hoang, T., Tran, H. M., Le, T. H., & Schmitt, K. (2009). *Tool Box for Mangrove Rehabilitation and Management.* Management of Natural Resources in the Coastal Zone of Soc Trang Province. Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Pham, T. T. (2010). *Mangroves of Soc Trang 1965 - 2008.* Management of Natural Resources in the Coastal Zone of Soc Trang Province. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Phan, N. H. (2004). Effects of mangrove restoration and conservation on the biodiversity and environment in Can Gio District. In M. Vanucci, *Mangrove Management & Conservation: Present & Future* (pp. 111-137). United Nations University.

Polsenberg, J. F. (2001). Der Anstieg der Meeresspiegel und die Mangroven. In E. Wolanski, *Mangroven: Lebensräume zwischen Land und Meer* (pp. 41-59). Wolanski, E.

Quarto, A. (2001). Auf dem Weg zur Beteiligung der lokalen Bevölkerung am Schutz und nachhaltigen Management der Mangroven. In E. Wolanski, *Mangroven: Lebensräume zwischen Land und Meer* (pp. 171-199). Wolanski, E.

Riley, R. W., & Kent, C. P. (1999). Riley encased methodology: principles and processes of mangrove habitat creation and restoration. *Mangroves and Salt Marshes* (3), 207-213.

Saenger, P., & Siddiqi, N. (1993). Land from the sea: The mangrove afforestation program of Bangladesh.

Sands, R. (2005). *Forestry in a Global Context.* Christchurch, New Zealand: CABI Publishing.

Schmitt, K. (2009). *Protection and sustainable use of coastal wetlands through co-management and mangrove rehabilitation with emphasis on resilience to climate change.* Mangement of Natural Resources in the Coastal Zone of Soc Trang. Soc Trang: Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Soc Trang Province Statistical Book. 2006. (2007). as cited in: A Baseline Survey in the Coastal Zone of Soc Trang Province, Livelihood Assessment and Stakeholder Analysis. In J. Olivier, & H. T. Luu, *Management of Natural Resources in the Coastal Zone of Soc Trang Province.*

Spalding, M., Kainuma, M., & Collins, L. (2010). *World Atlas of Mangroves.* Okinawa, Japan: International Society for Mangrove Ecosystems (ISME).

Toledo, G., Rojas, A., & Bashan, Y. (2001). Monitoring of black mangrove restoration with nursery-reared seedlings on an arid coastal lagoon. *Hydrobiologica* (444).

UNEP. (2006, 22-August). *bure.unep-wcmc.org.* Retrieved 2009, 17-Juli from http://bure.unep-wcmc.org/imaps/marine/mangroves/Authorize.htm

UNEP-WCMC. (2006). *In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs.* Cambridge: UNEP-WCMC.

UNESCO. (2000). *Valuation of the Mangrove Ecosystem in Can Gio Mangrove Biosphere Reserve, Vietnam.* Vietnam MAB National Committee, Hanoi.

United Nations. (1992). Rio Declaration on Environment and Development. *Report of the United Nations Conference on Envrionment and Development.* Rio de Janeiro: United Nations.

Wassmann, R., Nguyen, X. H., Chu, T. H., & To, P. T. (2004). Sea Level Rise Affecting the Vietnamese Mekong Delta: Water Elevation in the Flood Seson and Implications for Rice Productio. *Climatic Change* (66), 89-107.

White, I. (2002). *Water Management in the Mekong Delta: Changes, Conflicts and Opportunities.* Technical Documents in Hydrology No. 61, UNESCO, International Hydrological Programme, Paris.

Wolanski, E., Mazda, Y., & Rid, P. (1992). Mangrove Hydrodynamics. In A. I. Robertson, & D. M. Alongi, Tropical Mangrove Ecosystems (pp. 43-62). Washington D. C., United States of America: American Geophysical Union.

Wolanski, E., Nguyen, N. H., Le, T. D., Nguyen, H. N., & Nguyen, N. T. (1996). Fine-sediment Dynamics in the Mekong River Estuary, Vietnam. Estuarine, Coastal and *Shelf Science* (43), 565-582.

Wolanski, E., Stieglitz, T., Mazda, Y., Furukawa, K., Ridd, P., Kitheka, J., et al. (2001). Wasserkreisläufe in den Mangroven und deren Bedeutung für Biodiversität. In E. Wolanski, *Mangroven: Lebensräume zwischen Land und Meer* (pp. 3-41). Wolanski, E.

Wolanski, E., & Nguyen, H. N. (2005). Oceanography of the Mekong River Estuary. *International Conference on DELTAS (Mekong venue): Geological Modeling and Management.* Ho Chi Minh City: Sub-Institute of Geography, Vietnam Academy of Science and Technology.

Yamashita, A. (2005). *Zoning for risk assessment of water-related natural disasters in the Mekong Delta.* Master thesis, Can Tho University, Can Tho.

Appendices

Appendix I (A-3)

The world's 73 mangrove species and hydrides after Spalding et al., 2010

Appendix II (A-7)

Location maps for planting sites VC001, VC002, VC003 and VC004

Appendix III (A-21)

Site description sheet

Appendix IV (A-27)

Planting description sheet

Appendix V (A-35)

Site description sheet and planting description sheet for VC003

Appendix VI (A-57)

Site description sheet and planting description sheet for VC004

Appendix VII (A-77)

Mangrove plot monitoring sheet

Appendix VIII (A-83)

Mangrove transect monitoring sheet

Appendix IX (A-89)

Mangrove plot monitoring (1 m^2) sheet

Appendix I

The world’s 73 mangrove species and hybrids after Spalding et al., 2010

The world's 73 mangrove species and hybrids, seperated into Indio-West Pacific and Atlantic East Pacific floras (Spalding et al., 2010 p.2)

Indio-West Pacific Species

Familiy	Species
Acanthaceae	*Acanthus ebracteatus*
	Acanthus ilicifolius
Arecaceae	*Nypa fruticans*
Avicenniaceae	***Avicennia alba***
	Avicennia integra
	Avicennia marina
	Avicennia officinalis
	Avicennia rumphiana
Bignoniaceae	*Dolichandrone sapthacea*
Bombacaceae	*Camptostemon philipinese*
	Camptostemon schultzii
Caesalpiniaceae	*Cynometra iripa*
Combretaceae	***Lumnitzera littorea***
	Lumnitzera recemosa
	Lumnitzera x rosea
Ebenaceae	*Diospyros littorea*
Euphoriaceae	*Excoecaria agallocha*
	Exoecaria indica
Lythraceae	*Pemphis acidula*
Meliaceae	*Aglaia cucullata*
	Xylocarpus granatum
	Xylocarpus moluccensis
Myrsinaceae	*Aegiceras corniculatum*
	Aegiceras floridum
Myrtaceae	*Osbornia octodonta*
Plumbaginaceae	*Aegialitis annulata*
	Aegialitis rotundifolia
Pteridaceae	*Acrostichum aureum*
	Acrostichum danaeifolum
	Acrostchum speciosum

Familiy	Species
Rhizophoraceae	***Bruguieria cylindrica***
	Bruguiera exarisata
	Bruguiera gymnorhiza
	Bruguiera hainesii
	Bruguiera parviflora
	Bruguiera sexangula
	Bruguiera x rhynchopetala
	Ceriops australis
	Ceriops decandra
	Ceriops tagal
	Kandelia candel
	Kandelia obovata
	Rhizophora apiculata
	Rhizophora mucronata
	Rhizophora samoensis*
	Rhizophora stylosa
	Rhizophora x lamarckii
	Rhizophora x neocaledonica
	Rhizophora x selala
Rubiaxeae	*Scyphiphora hydrophylacea*
Sonneratiaceae	***Sonneratia alba***
	Sonneratia apetala
	Sonneratia caseolaris
	Sonneratia griffithii
	Sonneratia lanceolata
	Sonneratia ovata
	Sonneratia x gulngai
	Sonneratia x hainanensis
	Sonneratia x urama
Sterculiaceae	*Heritiera fomes*
	Heritiera globosa
	Heritiera littoralis

Atlantic East Pacific Species

Familiy	Species
Avicenniaceae	***Avicennia bicolor***
	Avicennia germinans
	Avicennia schaueriana
Bignoniaceae	*Tabebuia palustris*
Caesalpiniaceae	*Mora oleifera*
Combretaceae	***Conocarpus erectus***
	Laguncularia racemosa

Familiy	Species
Pellicieraceae	***Pelliciera rhozophorae***
Preridaceae	*Acrostichum aureum*
Rhizophoraceae	***Rhizophora mangle****
	Rhizophora racemosa
	*Rizhophora x harrisonii***

Notes: Those considered core mangrove species are highlighted in bold.
This list updates that used in Spalding et al (1997), based on Duke (1992), and largely follows the revisions to that list made by the same author (Duke, 2006; Duke et al, 1998a) with direct input and guidance from the same author.

* Rhizophora mangle/samoensis - see notes in Annex 1 on the different approaches to dealing with these species.

** Rhizophora x harrisonii is regarded as a hybrid by Duke and others (Beentje and Bandeira, 2007; but many authors working locally treat it as a distinct species and elsewhere in the book we simply refer to it as R. harrisonii (no'x').

Appendix II

Location maps for planting sites VC001, VC002, VC003 and VC004

Location map planting site VC003

- 48 P 619319 1032216 Point of orientation (Mr. Tach Soal house)
- The planting site is 9,8 km along the forest edge in the mud flats
- **The sampling area marks, mark the LEFT boarder of the sampling area.** The sampling areas will be located to the right of the marks

Sampling area 1

7,9 km in western direction from the point of orientation (In front of Vinh Binh Village)

Sampling area 2

6,3 km in western direction from the point of orientation (In front of Vinh An Village)

Sampling area 3

4,75 km in western direction from the point of orientation (In front of Ca Lang B Village)

Sampling area 4

3,4 km in western direction from the point of orientation (In front of San Chim Village)

Sampling area 5

1,7 km in western direction from the point of orientation (In front of Dai Bai A Village)

Sampling area 1

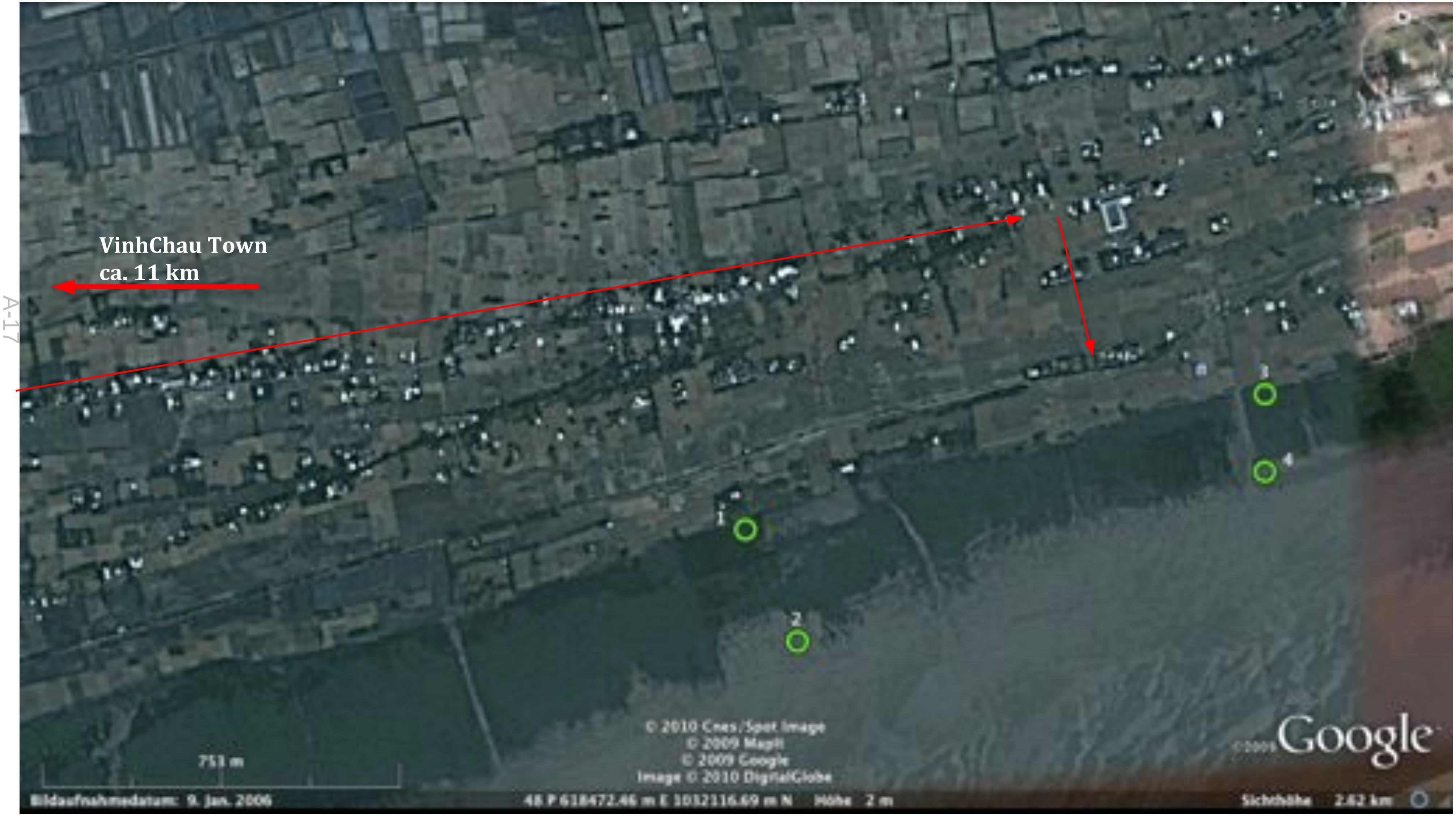
0,3 km in western direction from the point of orientation (In front of Au Tho B Village)

Sampling area 7

1,4 km in eastern direction from the point of orientation (In front of Au Tho B Village)

Location map planting site VC002

- 48 P 608263 1028547 → parking
- walk along the dyke direction east, till you reach point 48 P 608889 1028741
- behind the sluice gate turn right, walk down the path till you reach the first planting site area (waypoint 359,360,361)
- Now the planting sites (waypoints 359 -409) are located to the east along the forest edge (about 1,350 m)
    - Waypoint file: VC003_2009-10-19.gdb



Location map planting site VC003

- 48 P 608263 1028547 → parking
- walk along the dyke direction east, till you reach point 48 P 608889 1028741
- behind the sluice gate turn right, walk down the path till you reach the first planting site area (waypoint 359,360,361)
- Now the planting sites (waypoints 359 -409) are located to the east along the forest edge (about 1,350 m)
    - o Waypoint file: VC003_2009-10-19.gdb

Location map planting site VC004

- 48 P 590838 1022099 → parking
- walk along the dyke direction east, till you reach point 48 P 591275 1022308
- turn right, walk down the path till you reach point 48 P 591332 1022184
- turn left, walk down the shoreline
    - site 1 is about 200 m distand from point 48 P 591332 1022184
    - site 2 is about 1,200 m distand from point 48 P 591332 1022184

Appendix III

Site description sheet

Site description sheet

Code

General information

Recorder(s) ______________________ Date ____________

Forest owner/management ______________________

District ______________________

Commune ______________________

Village

Area remarks

Soil structure

Dilute mud ☐ Soft clay ☐ Very hard clay ☐

Hard mud ☐ Hard clay ☐ ☐

Inundation

hours/day ____________ days/year ____________

Additional descriptions

Water flow, Fishing industry, Barnacle. Coastal erosion/accretion

Site description

Remarks	

Photo documentary [a]		
No.	**Date**	**File**

[a] File names and location following naming convention and archiving rules

GPS coordinates [b]			
No. in map	**Coordinates**		**Waypoint No.**
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		

[b] Submit all waypoints and tracklogs in a .gdb file named: code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd]

Sketch map Notes	

Appendix IV

Planting description sheet

Planting description sheet

Code

General information

Recorder(s) | Date

Forest owner/management

Document description

District

Commune

Village

Remarks

Seedling description before planting			
Species			
Origin			
Number			
Quantity in kg			
Heights in cm			
Knots			
Diameter in cm			

Remarks

General descriptions

Planting description

Date of planting ______________________ Density (trees/m^2) __________

Tree combination

Planting technique

Seedling description after planting

Species			
Number			
Heights			

Remarks

Photo reference [a]

No.	Date	File

[a] File names and location following naming convention and archiving rules

GPS coordinates [b]

No. in map	Coordinates		Waypoint No.
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		
	48 P		

[b] Submit all waypoints and tracklogs in a .gdb file named: code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd]

Sketch map Notes	

Appendix V

Site description sheet and planting description sheet for VC003

Site description sheet

Code **VC003**

General information

Recorder(s)	Nguyễn Đức Hoàng	Date	05/11/2009
Forest owner/management	Soc Trang Forest Protection Sub-department		
District	Vinh Chau	Area remarks	24 plots of ca. 30 m^2 spread along the forest edge (ca. 1,350 m). For detailled information see VC003 location map. Sketch map is divided into 8 maps with each 3 Plots.
Commune	Vinh Chau		
Village	Ca Lang A Bien		

Soil structure

Dilute mud	☐	Soft clay	☒	Very hard clay	☐
Hard mud	☐	Hard clay	☒		☐

Indutation

hours/day 6-8

days/year 50-60

Additional descriptions

Water flow, Fishing industry, Barnacle. Coastal erosion/accretion

Good water circulation, no water logging, regular collections of fisheries resources, few barnacles. Settled accretion soil, no erosion

Site description

Settled soil, declining towards seaside, annual accretion 5-10 cm/year

Remarks	Site with many *Avicennia* trees mixed with few *Sonneretia* trees

Photo documentary [1]		
No.	**Date**	**File**
1	2009-10-19	VC003_2009-10-19_Plot-1-1.jpg
2	2009-10-19	VC003_2009-10-19_Plot-1-2.jpg
3	2009-10-19	VC003_2009-10-19_Plot-2-1.jpg
4	2009-10-26	VC003_2009-10-26_Plot-2-2.jpg
5	2009-10-19	VC003_2009-10-19_Plot-3-1.jpg
6	2009-10-26	VC003_2009-10-26_Plot-3-2.jpg
7	2009-10-26	VC003_2009-10-26_Plot-4-1.jpg
8	2009-10-26	VC003_2009-10-26_Plot-4-2.jpg
9	2009-10-26	VC003_2009-10-26_Plot-5-1.jpg
10	2009-10-26	VC003_2009-10-26_Plot-5-2.jpg
11	2009-10-26	VC003_2009-10-26_Plot-6-1.jpg
12	2009-10-26	VC003_2009-10-26_Plot-6-2.jpg
13	2009-10-26	VC003_2009-10-26_Plot-7-1.jpg
14	2009-10-26	VC003_2009-10-26_Plot-7-2.jpg
15	2009-10-26	VC003_2009-10-26_Plot-8-1.jpg
16	2009-10-26	VC003_2009-10-26_Plot-8-2.jpg
17	2009-10-26	VC003_2009-10-26_Plot-9-1.jpg
18	2009-10-26	VC003_2009-10-26_Plot-9-2.jpg
19	2009-10-26	VC003_2009-10-26_Plot-10-1.jpg
20	2009-10-26	VC003_2009-10-26_Plot-10-2.jpg
21	2009-10-26	VC003_2009-10-26_Plot-11-1.jpg
22	2009-10-26	VC003_2009-10-26_Plot-11-2.jpg
23	2009-10-26	VC003_2009-10-26_Plot-12-1.jpg
24	2009-10-26	VC003_2009-10-26_Plot-12-2.jpg
25	2009-10-26	VC003_2009-10-26_Plot-13-1.jpg
26	2009-10-26	VC003_2009-10-26_Plot-13-2.jpg
27	2009-10-21	VC003_2009-10-21_Plot-14-1.jpg

[1] File names and location following naming convention and archiving rules

28	2009-10-21	VC003_2009-10-21_Plot-14-2.jpg
29	2009-10-21	VC003_2009-10-21_Plot-15-1.jpg
30	2009-10-21	VC003_2009-10-21_Plot-15-2.jpg
31	2009-10-21	VC003_2009-10-21_Plot-16-1.jpg
32	2009-10-21	VC003_2009-10-21_Plot-16-2.jpg
33	2009-10-21	VC003_2009-10-21_Plot-17-1.jpg
34	2009-10-21	VC003_2009-10-21_Plot-17-2.jpg
35	2009-10-21	VC003_2009-10-21_Plot-18-1.jpg
36	2009-10-21	VC003_2009-10-21_Plot-18-2.jpg
37	2009-10-21	VC003_2009-10-21_Plot-19-1.jpg
38	2009-10-21	VC003_2009-10-21_Plot-19-2.jpg
39	2009-10-21	VC003_2009-10-21_Plot-20-1.jpg
40	2009-10-21	VC003_2009-10-21_Plot-20-2.jpg
41	2009-10-21	VC003_2009-10-21_Plot-21-1.jpg
42	2009-10-21	VC003_2009-10-21_Plot-21-2.jpg
43	2009-10-21	VC003_2009-10-21_Plot-22-1.jpg
44	2009-10-21	VC003_2009-10-21_Plot-22-2.jpg
45	2009-10-21	VC003_2009-10-21_Plot-23-1.jpg
46	2009-10-21	VC003_2009-10-21_Plot-23-2.jpg
47	2009-10-21	VC003_2009-10-21_Plot-24-1.jpg
48	2009-10-21	VC003_2009-10-21_Plot-24-2.jpg

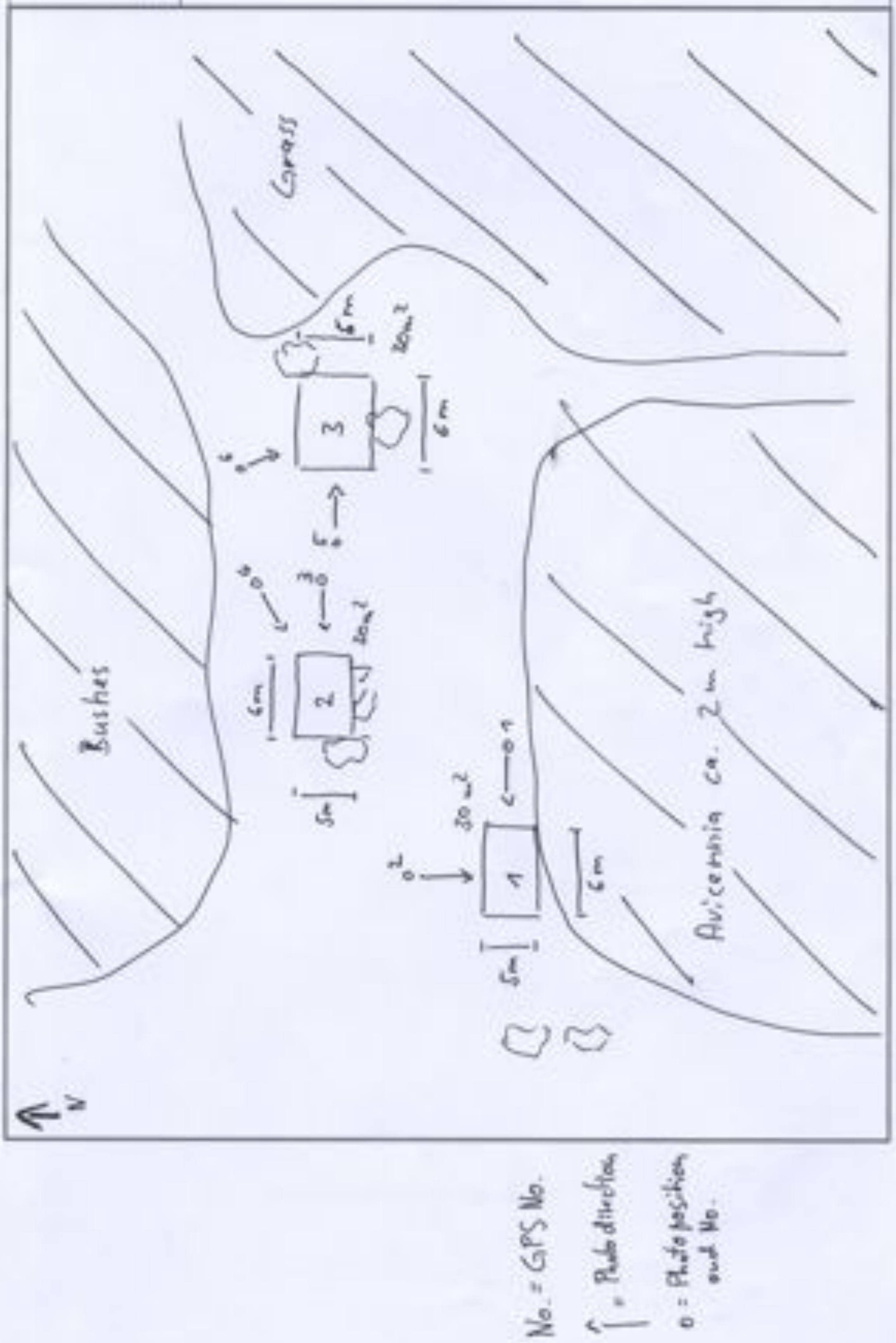
GPS coordinates [2]			
No. in map	**Coordinates**		**Waypoint No.**
1	48 P	48 P 608997 1028409	359
2	48 P	48 P 609020 1028431	360
3	48 P	48 P 609057 1028426	361
4	48 P	48 P 609149 1028395	364
5	48 P	48 P 609167 1028411	362
6	48 P	48 P 609207 1028400	363
7	48 P	48 P 609261 1028531	365
8	48 P	48 P 609293 1028545	366
9	48 P	48 P 609323 1028532	367
10	48 P	48 P 609465 1028544	368
11	48 P	48 P 609496 1028548	369
12	48 P	48 P 609530 1028549	370
13	48 P	48 P 609669 1028635	409
14	48 P	48 P 609702 1028645	408
15	48 P	48 P 609728 1028665	407
16	48 P	48 P 609746 1028714	406
17	48 P	48 P 609782 1028715	405
18	48 P	48 P 609837 1028737	404
19	48 P	48 P 610148 1028763	397
20	48 P	48 P 610203 1028787	400
21	48 P	48 P 610208 1028738	398
22	48 P	48 P 610255 1028706	403
23	48 P	48 P 610247 1028670	402
24	48 P	48 P 610292 1028680	401

Sketch map notes: Planting area overview (8 areas with 3 plots each)

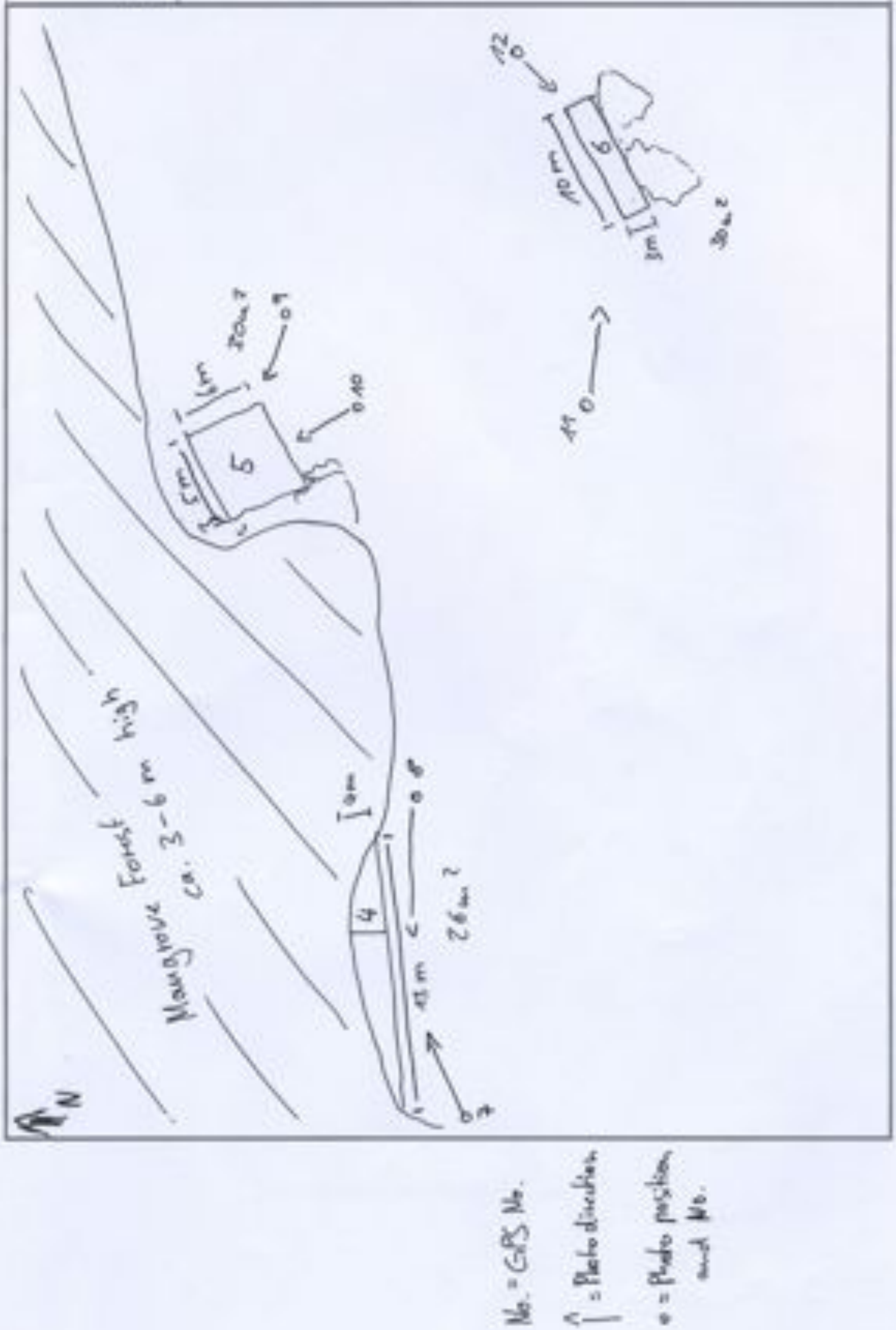
[2] Submit all waypoints and tracklogs in a .gdb file named: code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd]


map 8
map 7
map 6
map 5
map 4
map 3
map 2
map 1
Google

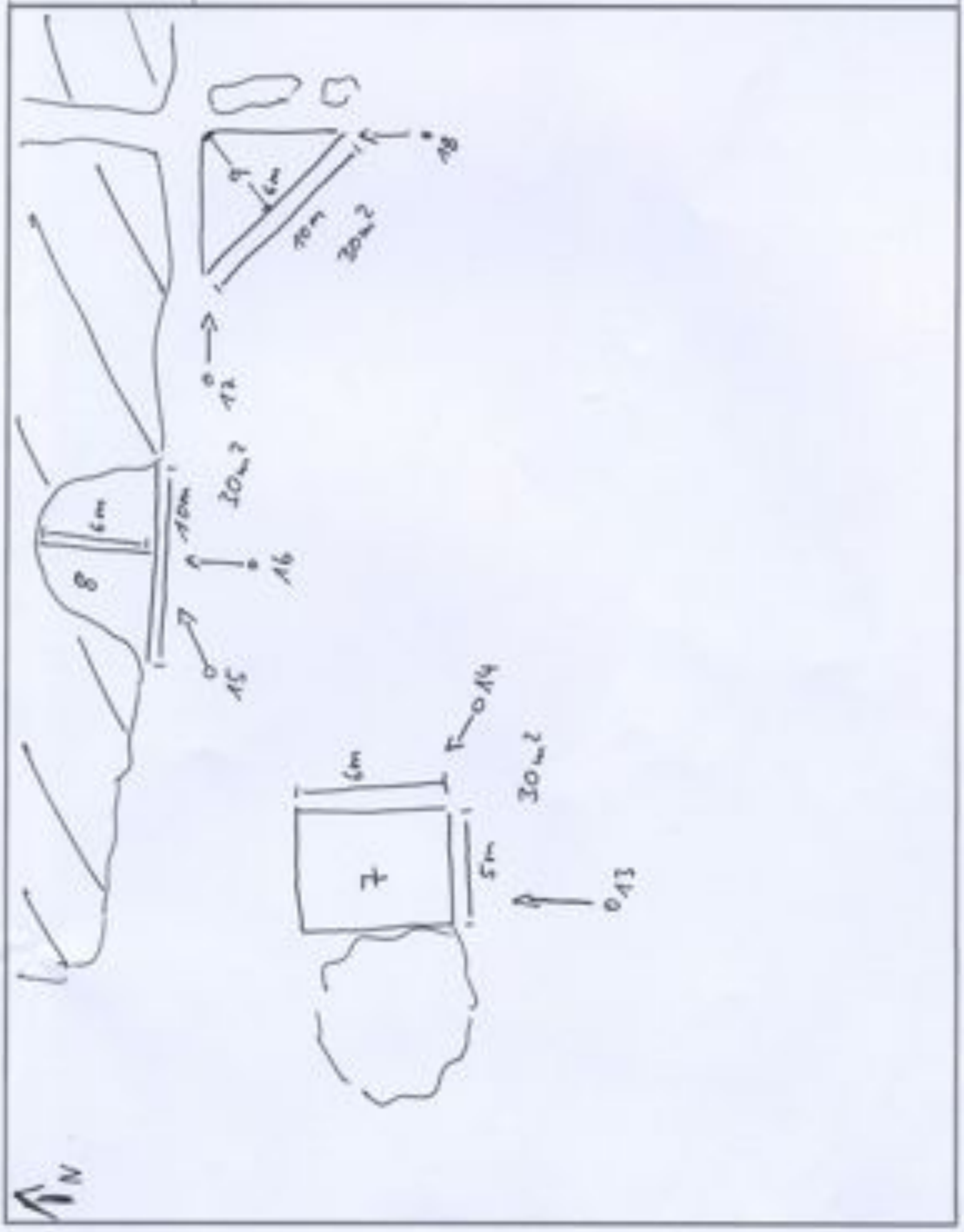
Sketch map Notes	map 1



Sketch map Notes	map 2



Sketch map Notes	map 3

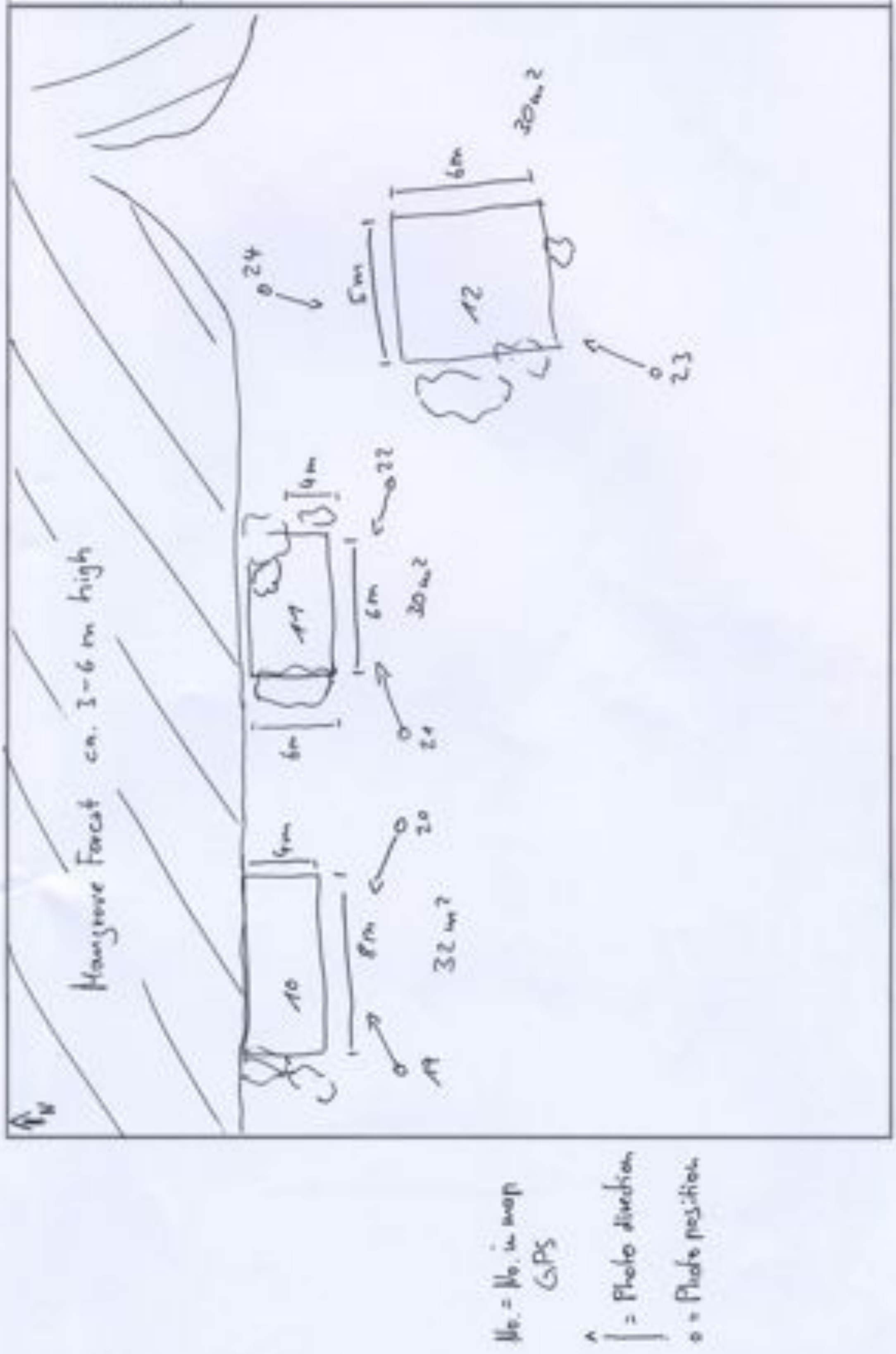


No. = GPS No.

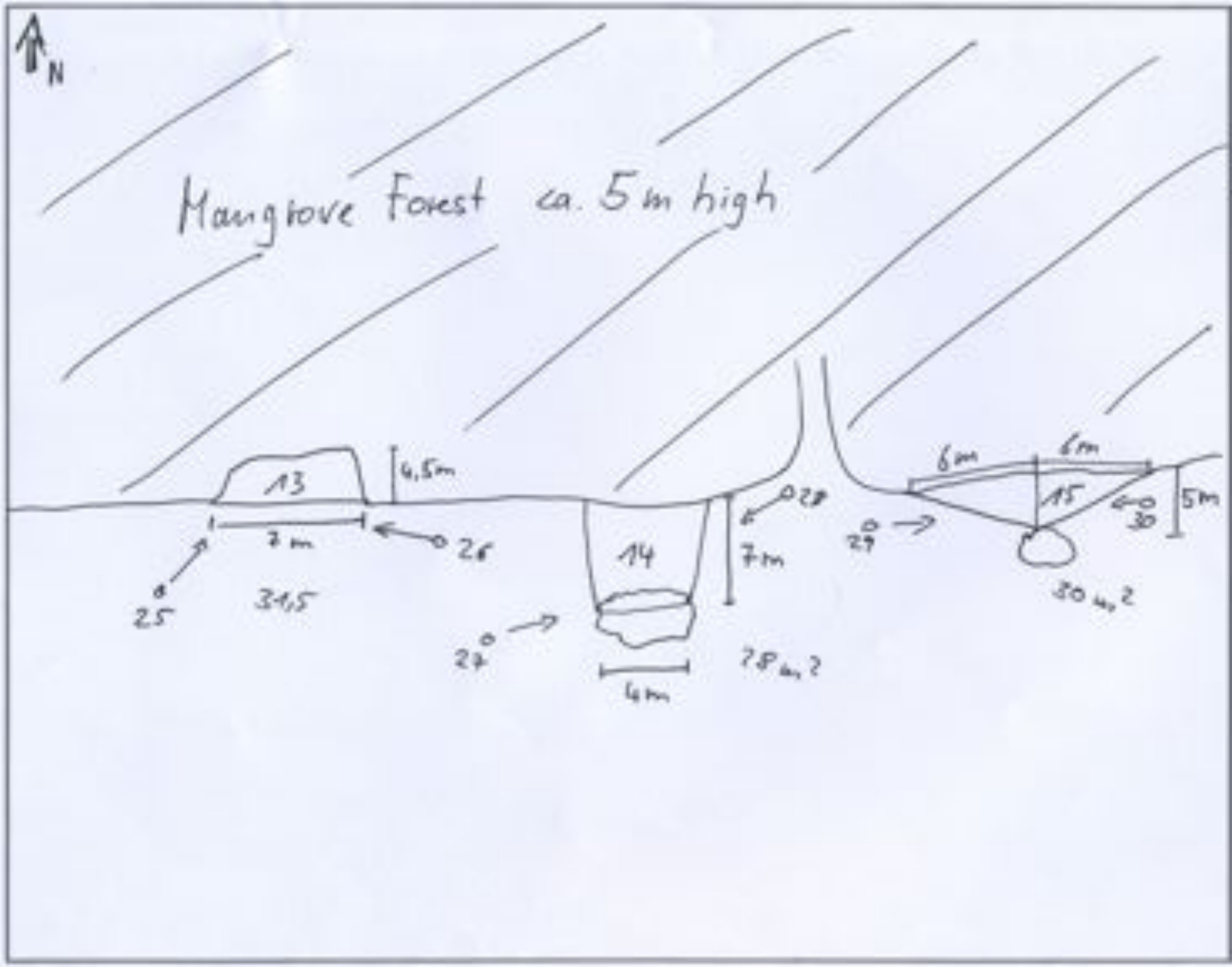
↑ = Photo direction

o = Photo position and No.

Sketch map Notes	map 4



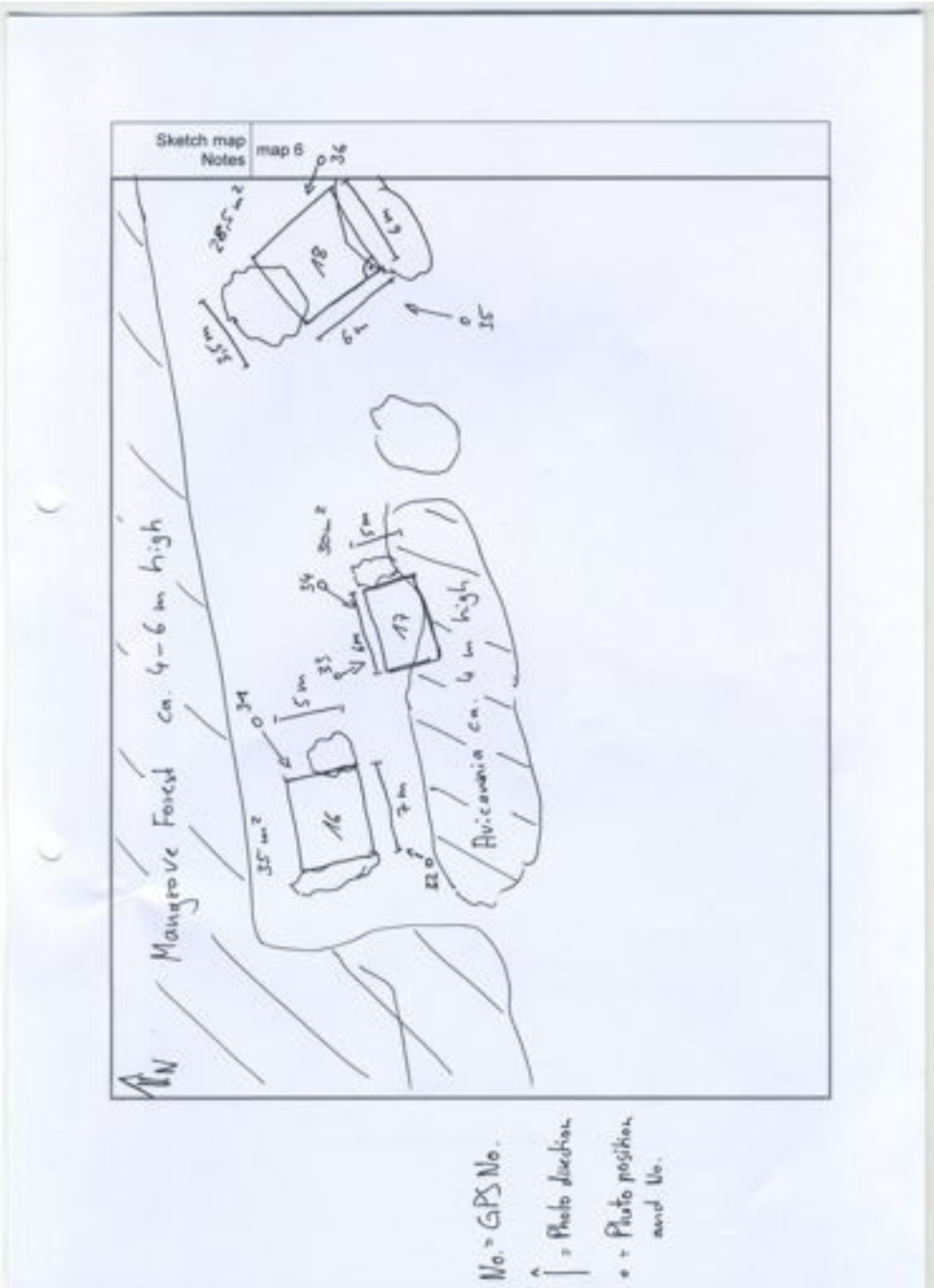
Sketch map Notes | map 5



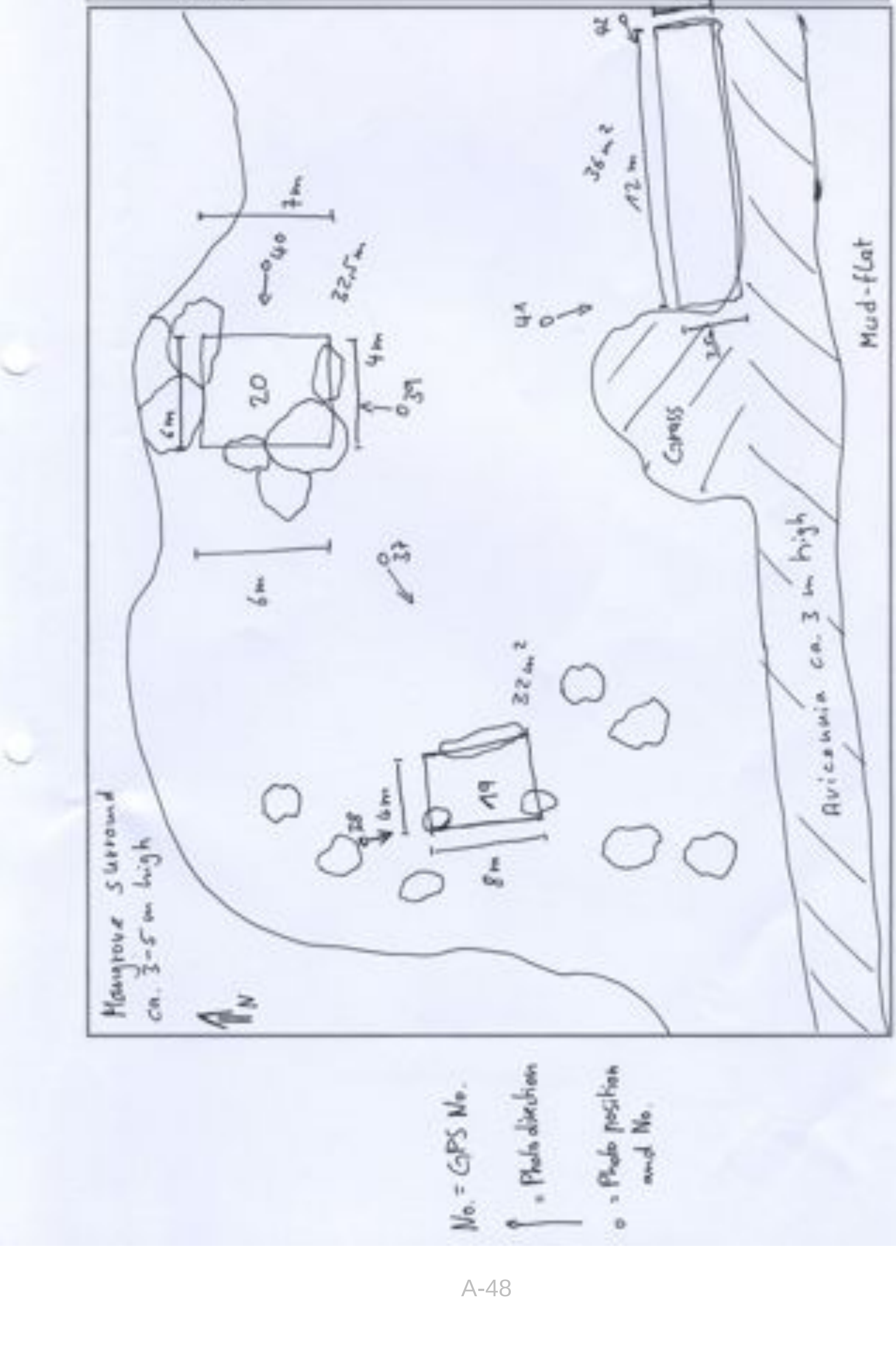
No. = GPS No.

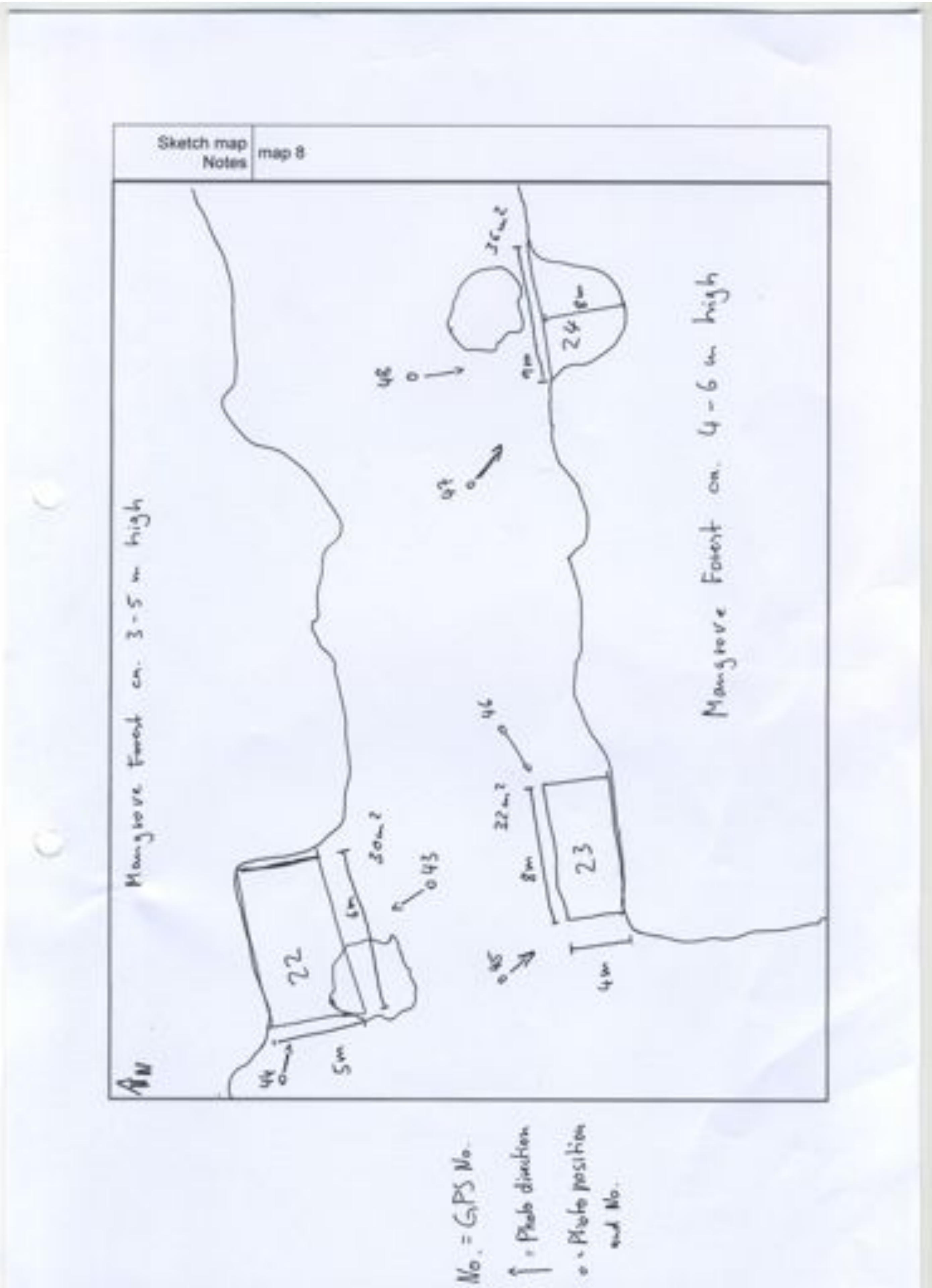
↑ = Photo direction

o = Photo position and No.


Sketch map
Notes
map 6
N
Mangrove Forest ca. 4–6 m high
Avicennia ca. 4 m high
16
17
18
35 m²
30 m²
28,5 m²
5 m
7 m
6 m
3,5 m
No. = GPS No.
= Photo direction
= Photo position and No.

Sketch map Notes	map 7




Sketch map Notes
map 8
N
Mangrove forest ca. 3-5 m high
44
22
5m
6m
30m2
043
045
8m
32m2
46
4m
23
47
48
9m
36m2
24
8m
Mangrove Forest ca. 4-6 m high
No. = GPS No.
= Photo direction
= Photo position and No.

Planting description sheet

Code **VC003**

General information

Recorder(s)	Nguyễn Đức Hoàng	Date	05/11/2009
Forest owner/management	Soc Trang Forest Protection Sub-department		
District	Vinh Chau	Document description	For details see VC003 location map
Commune	Vinh Chau		
Village	Ca Lang A Bien		

Remarks 24 Plots of ca. 30 m^2 along forest edge over ca. 1,350 meter

Seedling description before planting

Species	*Rhizophora apiculata*	*Ceriops tagal*	Remarks
Origin	Vinh Hai commune, Vinh Chau District	Vinh Hai commune, Vinh Chau District	
Number	8,900	8,900	
Quantity in kg	232,65	89,1	
Heights in cm	23	12	Estimated
Knots			Not recorded before planting
Diameter in cm			Not recorded before planting

Remarks *Avicennia* trees will be planted in Spring 2010

General descriptions

VC003 is subdivided into eight areas which are distributed along the forest edge (ca. 1,350 m). Each area contains three plots which are planted. For more details, see the Site-description-sheet_VC003.

The areas varies in tree combination and tree density. See the attached table for detailed information.

Planting description

Date of planting 23.10. - 25.10. 2009 Density (trees/m^2) 20 - 40

Tree combination

Plot No.	Waypoint No.	Plot size in m^2	Tree/m^2	Rhizophora	Ceriops	Avicennia
1	359	30	20	-	100%	-
2	360	30	30	-	100%	-
3	361	30	40	-	100%	-
4	364	26	23	100%	-	-
5	362	30	30	100%	-	-
6	363	30	40	100%	-	-
7	365	30	20	60%	20%	20%
8	366	30	30	60%	20%	20%
9	367	30	40	60%	20%	20%
10	368	32	19	60%	20%	20%
11	369	30	30	60%	20%	20%
12	370	30	40	60%	20%	20%
13	409	31,5	19	20%	60%	20%
14	408	28	32	20%	60%	20%
15	407	30	40	20%	60%	20%
16	406	35	17	20%	60%	20%
17	405	30	30	20%	60%	20%
18	404	28,5	42	20%	60%	20%
19	397	32	19	20%	20%	60%
20	400	32,5	28	20%	20%	60%
21	398	36	33	20%	20%	60%
22	403	30	20	20%	20%	60%
23	402	32	28	20%	20%	60%
24	401	36	33	20%	20%	60%

Planting technique

Plot 1 – 7: Mainly planted in rows

Plot 8 – 24: Cluster planting mimicking nature rejuvenation

Seedling description after planting

Species	*Rhizophora apiculata*	*Ceriops ssp.*	
Number	8,100	8,100	
Heights	-	-	Not recorded after planting

Remarks

Photo reference [a]

No.	Date	File
1	2009.10.26	VC003_2009-10-26_Plot-1-3.jpg
2	2009.10.26	VC003_2009-10-26_Plot-2-3.jpg
3	2009.10.26	VC003_2009-10-26_Plot-3-3.jpg
4	2009.10.26	VC003_2009-10-26_Plot-4-3.jpg
5	2009.10.26	VC003_2009-10-26_Plot-5-1.jpg
6	2009.10.26	VC003_2009-10-26_Plot-6-3.jpg
7	2009.10.26	VC003_2009-10-26_Plot-7-2.jpg
8	2009.10.26	VC003_2009-10-26_Plot-8-3.jpg
9	2009.10.26	VC003_2009-10-26_Plot-9-3.jpg
10	2009.10.26	VC003_2009-10-26_Plot-10-2.jpg
11	2009.10.26	VC003_2009-10-26_Plot-11-2.jpg
12	2009.10.26	VC003_2009-10-26_Plot-12-3.jpg
13	2009.10.26	VC003_2009-10-26_Plot-13-2.jpg
14	2009.10.26	VC003_2009-10-26_Plot-14-3.jpg
15	2009.10.26	VC003_2009-10-26_Plot-15-3.jpg
16	2009.10.26	VC003_2009-10-26_Plot-16-3.jpg
17	2009.10.26	VC003_2009-10-26_Plot-17-3.jpg
18	2009.10.26	VC003_2009-10-26_Plot-18-3.jpg
19	2009.10.26	VC003_2009-10-26_Plot-19-3.jpg
20	2009.10.26	VC003_2009-10-26_Plot-20-3.jpg
21	2009.10.26	VC003_2009-10-26_Plot-21-3.jpg
22	2009.10.26	VC003_2009-10-26_Plot-22-3.jpg
23	2009.10.26	VC003_2009-10-26_Plot-23-3.jpg
24	2009.10.26	VC003_2009-10-26_Plot-24-3.jpg

[a] File names and location following naming convention and archiving rules

GPS coordinates [b]			
No. in map	**Coordinates**		**Waypoint No.**
1	48 P	48 P 608997 1028409	359
2	48 P	48 P 609020 1028431	360
3	48 P	48 P 609057 1028426	361
4	48 P	48 P 609149 1028395	364
5	48 P	48 P 609167 1028411	362
6	48 P	48 P 609207 1028400	363
7	48 P	48 P 609261 1028531	365
8	48 P	48 P 609293 1028545	366
9	48 P	48 P 609323 1028532	367
10	48 P	48 P 609465 1028544	368
11	48 P	48 P 609496 1028548	369
12	48 P	48 P 609530 1028549	370
13	48 P	48 P 609669 1028635	409
14	48 P	48 P 609702 1028645	408
15	48 P	48 P 609728 1028665	407
16	48 P	48 P 609746 1028714	406
17	48 P	48 P 609782 1028715	405
18	48 P	48 P 609837 1028737	404
19	48 P	48 P 610148 1028763	397
20	48 P	48 P 610203 1028787	400
21	48 P	48 P 610208 1028738	398
22	48 P	48 P 610255 1028706	403
23	48 P	48 P 610247 1028670	402
24	48 P	48 P 610292 1028680	401

[b] Submit all waypoints and tracklogs in a .gdb file named: code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd]

Sketch map Notes	GPS and Photo position

(16) = Photo number

= Photo direction

Sketch map Notes	GPS and Photo position

(No) = Photo number

→ = Photo direction

Appendix VI

Site description sheet and planting description sheet for VC004

Site description sheet

Code **VC004**

General information

Recorder(s)	Nguyễn Đức Hoàng	Date	05/11/2009
Forest owner/management	Soc Trang Forest Protection Sub-department		
District	Vinh Chau	Characteristics	For detailed information about location, watch VC004 directions
Commune	Lai Hoa		
Village	Preychop		

Soil structure

- Dilute mud ☐
- Soft clay ☒
- Very hard clay ☐
- Hard mud ☐
- Hard clay ☒
- ☐

Indutation

hours/day 6-8

days/year 35-40

Additional descriptions

Water flow, Fishing industry, Barnacle. Coastal erosion/accretion

Water level goes up and down within the day, no water logging, few collections of fisheries resources due to high land with tidal inundation, from time to time seeing people collecting snail, sesarmid crab. No barnacle, coastal erosion ≥ 10 m per year. However, presently people are digging the soil to collect sneakily sipunculus nudus

Site description

High land area, tidal inundation only from September to January. No inundation during the remaining time, soil base kept humid by rainfall, high soil surface resulting in annual accretion of about 5 cm.

12 year old Rhizophora Mucronate plantation forest with closed canopy. Trees heights ca. 6 - 8 m.

On the coastline occasional occurring trees of Ceriop and Avicennia Marina originated by washed up seeds and seedlings

Remarks	Soil suitable for mangrove planting

Photo Reference [a]		
No.	**Date**	**File**
1	2009-10-27	VC004_2009-10-27_Area-1_plot-a.jpg
2	2009-10-27	VC004_2009-10-27_Area-1_plot-b.jpg
3	2009-10-27	VC004_2009-10-27_Area-1_plot-c.jpg
4	2009-10-27	VC004_2009-10-27_Area-2_plot-a.jpg
5	2009-10-27	VC004_2009-10-27_Area-2_plot-b.jpg
6	2009-10-27	VC004_2009-10-27_Area-2_plot-c.jpg
7	2009-10-27	VC004_2009-10-27_Area-3_plot-a.jpg
8	2009-10-27	VC004_2009-10-27_Area-3_plot-b.jpg
9	2009-11-06	VC004_2009-10-27_Area-3_plot-c.jpg
10	2009-11-06	VC004_2009-10-27_Area-4_plot-a.jpg
11	2009-11-06	VC004_2009-10-27_Area-4_plot-b.jpg
12	2009-11-06	VC004_2009-10-27_Area-4_plot-c.jpg
13	2009-10-27	VC004_2009-10-27_Area-5_plot-a.jpg
14	2009-10-27	VC004_2009-10-27_Area-5_plot-b.jpg
15	2009-10-27	VC004_2009-10-27_Area-5_plot-c.jpg
16	2009-11-06	VC004_2009-11-06_Area-6_plot-a.jpg
17	2009-11-06	VC004_2009-11-06_Area-6_plot-b.jpg
18	2009-11-06	VC004_2009-11-06_Area-6_plot-c.jpg
19	2009-11-06	VC004_2009-11-06_Area-7_plot-a.jpg
20	2009-11-06	VC004_2009-11-06_Area-7_plot-b.jpg
21	2009-11-06	VC004_2009-11-06_Area-7_plot-c.jpg

a File names and location following naming convention und archiving rules]

b Submit all way points and track logs in a gdb file named code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd

GPS coordinates [b]			
No. in map	**Coordinates**		**Waypoint No.**
1	48 P	48 P 590838 1022099	426
2	48 P	48 P 591275 1022308	427
3	48 P	48 P 591327 1022194	428
4	48 P	48 P 591556 1022221	430
5	48 P	48 P 591551 1022236	431
6	48 P	48 P 591535 1022248	433
7	48 P	48 P 591513 1022260	434
8	48 P	48 P 591565 1022277	435
9	48 P	48 P 591571 1022261	436
10	48 P	48 P 591579 1022243	437
11	48 P	48 P 591585 1022236	438
12	48 P	48 P 591611 1022258	439
13	48 P	48 P 591600 1022264	440
14	48 P	48 P 591597 1022277	441
15	48 P	48 P 591583 1022294	442
16	48 P	48 P 591633 1022278	443
17	48 P	48 P 591622 1022287	445
18	48 P	48 P 591613 1022296	446
19	48 P	48 P 591614 1022314	448
20	48 P	48 P 592431 1022568	449
21	48 P	48 P 592422 1022581	450
22	48 P	48 P 592396 1022604	451
23	48 P	48 P 592379 1022610	452
24	48 P	48 P 592421 1022607	453
25	48 P	48 P 592434 1022592	454
26	48 P	48 P 592449 1022582	455
27	48 P	48 P 592461 1022573	456
28	48 P	48 P 592486 1022590	457
29	48 P	48 P 592479 1022602	458
30	48 P	48 P 592471 1022616	459
31	48 P	48 P 592467 1022640	460

a File names and location following naming convention und archiving rules]

b Submit all way points and track logs in a gdb file named code_date [code = VCxxx, LPxxx, CLDxxx; date = yyyy-mm-dd

The planting site includes 7 (1 to 7) Areas, subdivided into 3 (a, b, c) plots.

The plots in Area 1 and 5 have a gap size of 2 felled trees
The plots in Area 2 and 6 have a gap size of 3 felled trees
The plots in Area 3 and 7 have a gap size of 4 felled trees
The plots in Area 4 have no gap, therefore they are the control area

The zoning (a, b, c) tells about the position of the plot. Zone “a” is close to the shoreline, while “c” is more close to the dyke. Zone “b” is in between them.

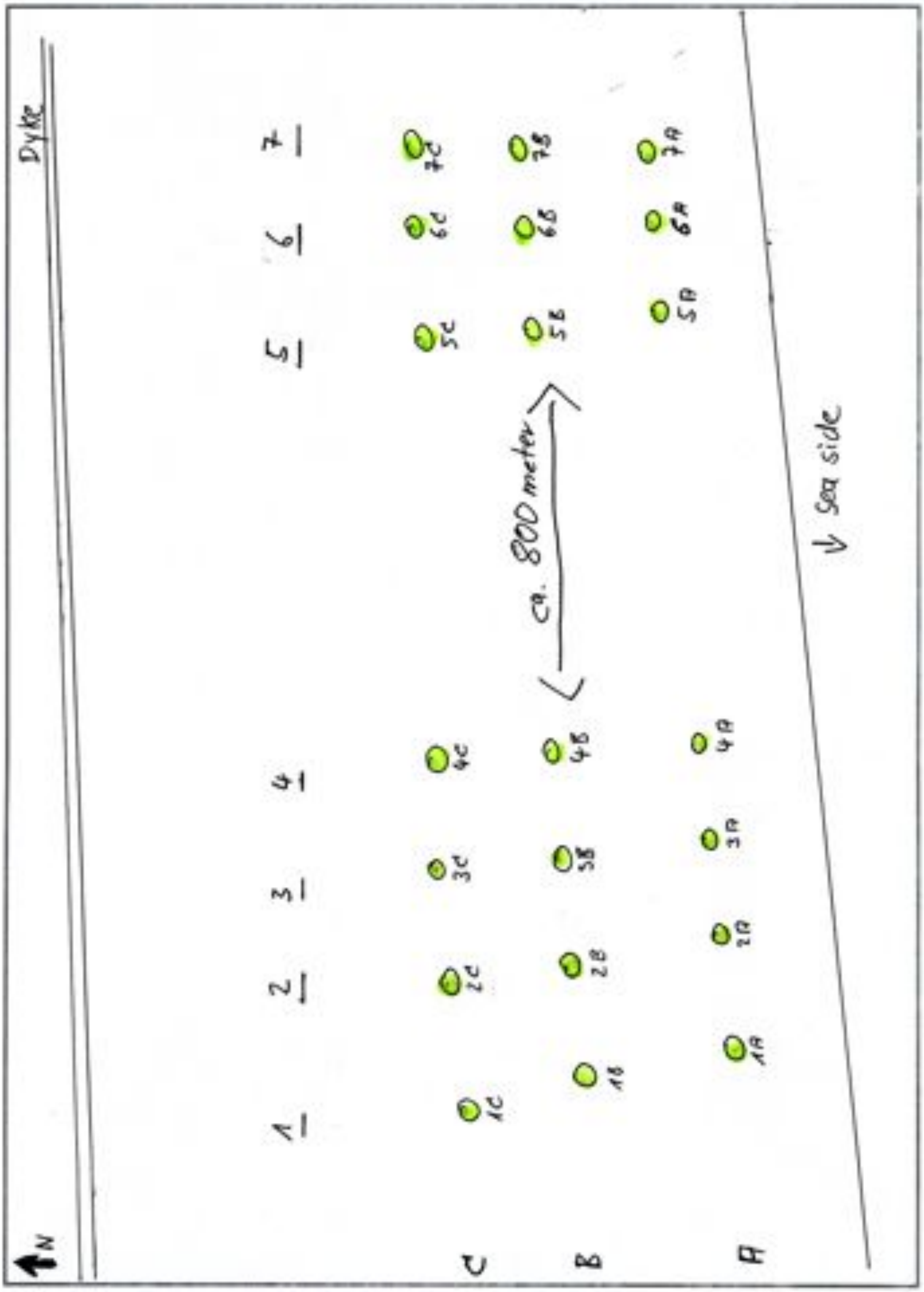
The gap size will be calculated by the assumption the plot is a circle or an ellipsis.

Gap	Gap size in m^2	Plot lies between waypoint
Area-1_plot-a	13	430 – 431
Area-1_plot-b	22	431 – 433
Area-1_plot-c	20	433 – 434
Area-2_plot-a	26	437 – 438
Area-2_plot-b	7	436 – 437
Area-2_plot-c	9	435 – 436
Area-3_plot-a	30	439 – 440
Area-3_plot-b	38	440 – 441
Area-3_plot-c	32	441 – 442

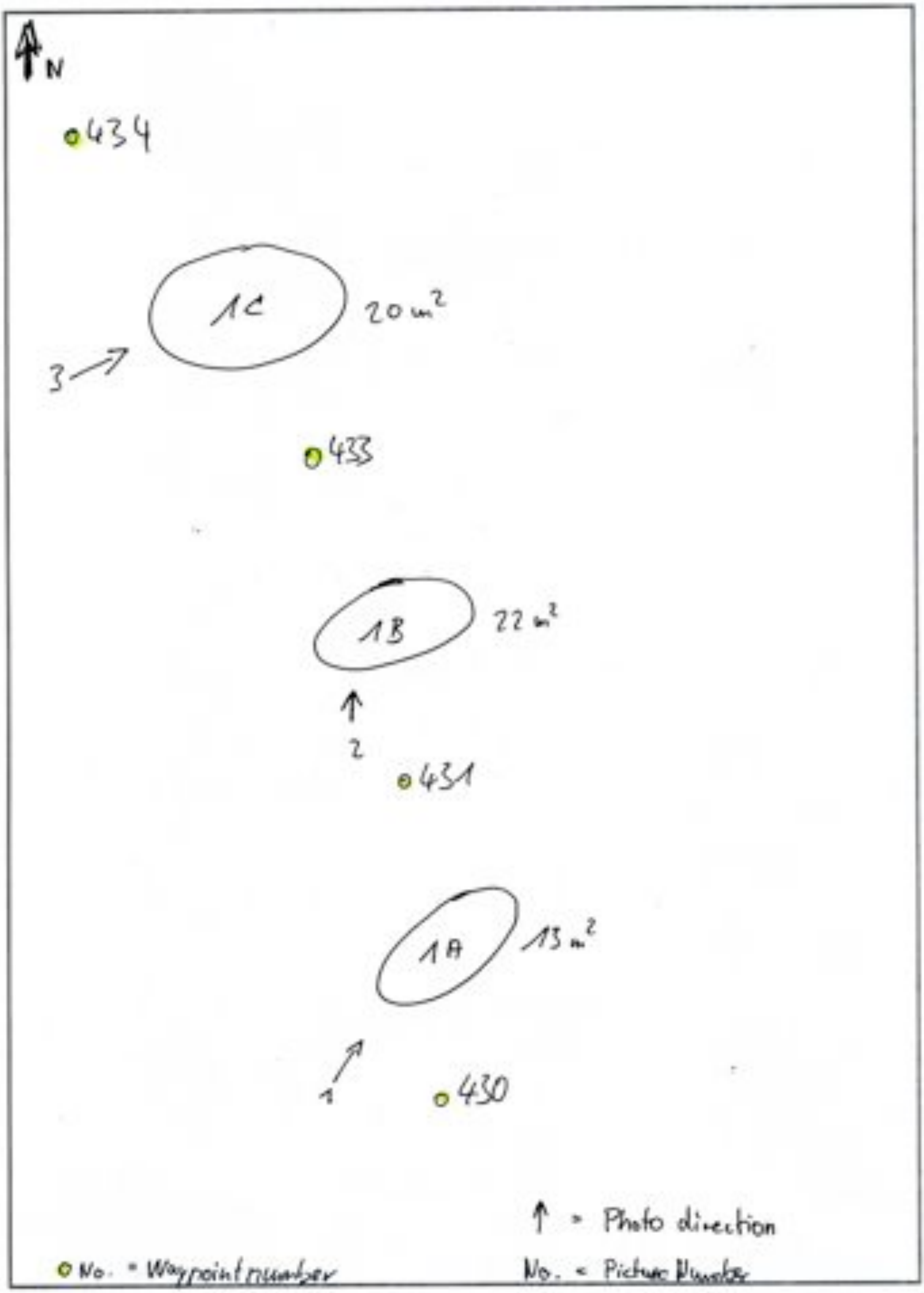
Area-5_plot-a	16	449 – 450
Area-5_plot-b	39	450 – 451
Area-5_plot-c	20	451 – 452
Area-6_plot-a	24	455 – 456
Area-6_plot-b	20	454 – 455
Area-6_plot-c	24	453 – 454
Area-7_plot-a	28	457 – 458
Area-7_plot-b	45	458 – 459
Area-7_plot-c	28	459 – 460

Area-4_plot-a	18	443 – 445
Area-4_plot-b	38	445 – 446
Area-4_plot-c	24	446 - 448

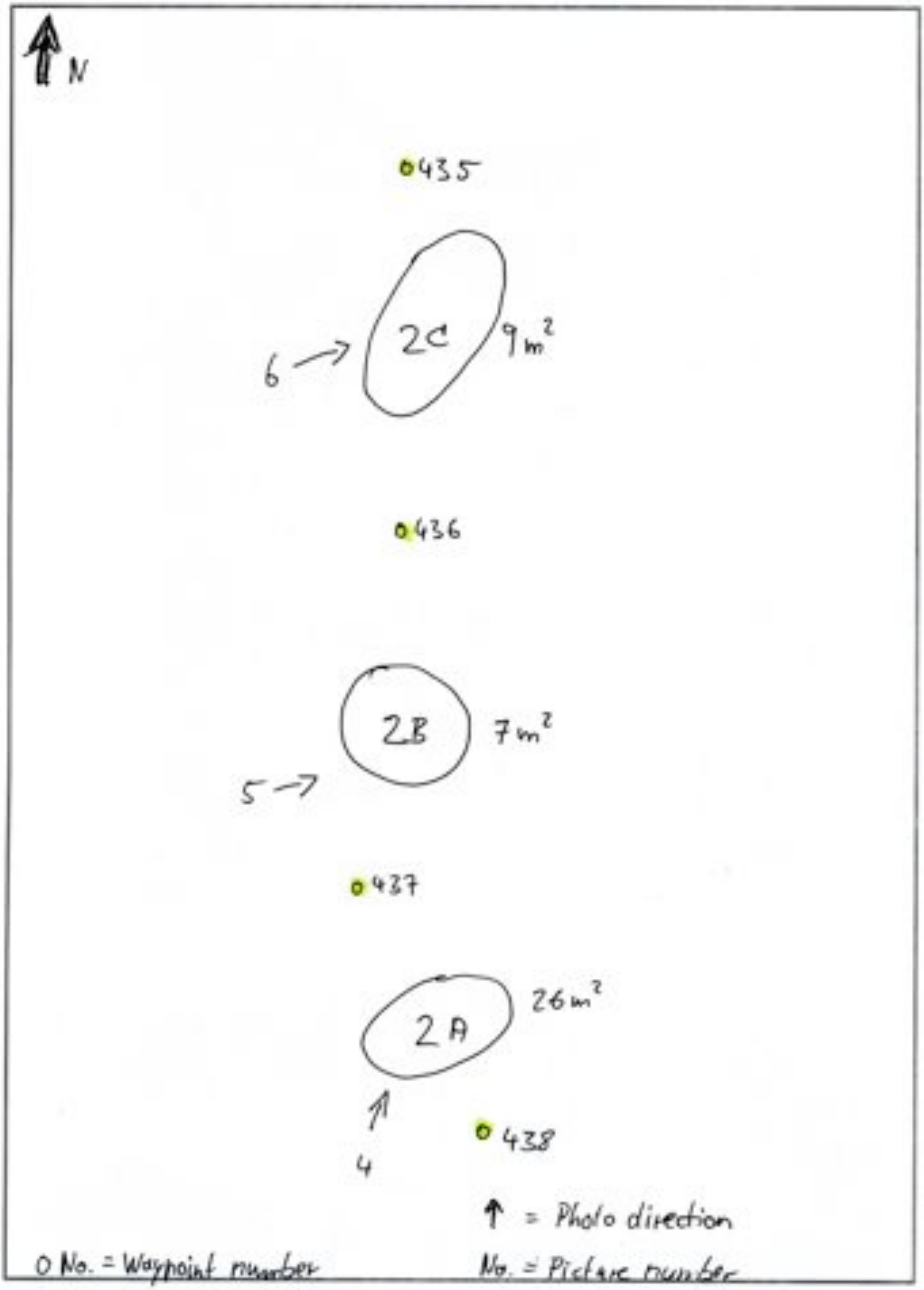
Sketch map Notes	Overview



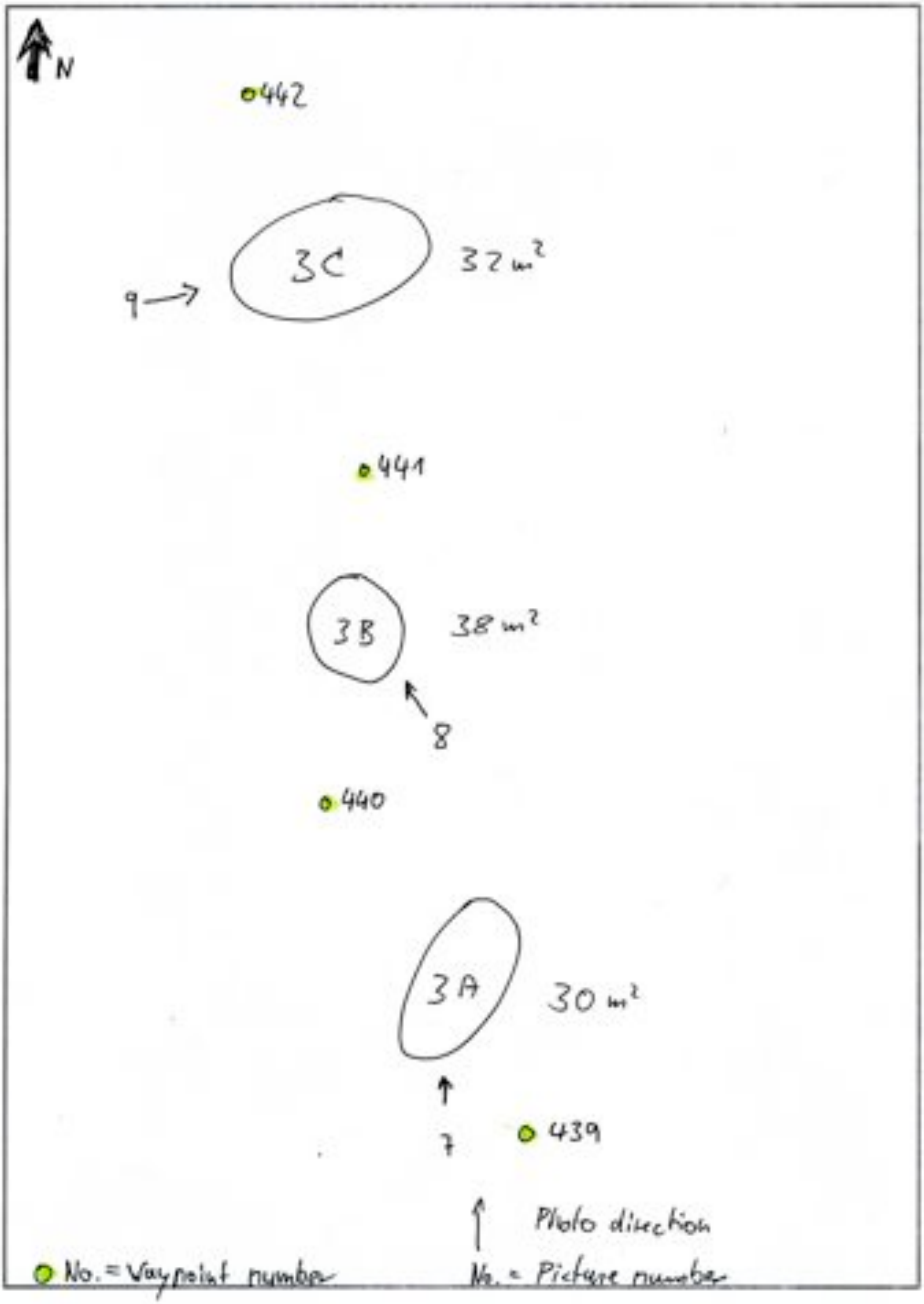
Sketch map Notes	Area 1, gap size of 2 felled trees



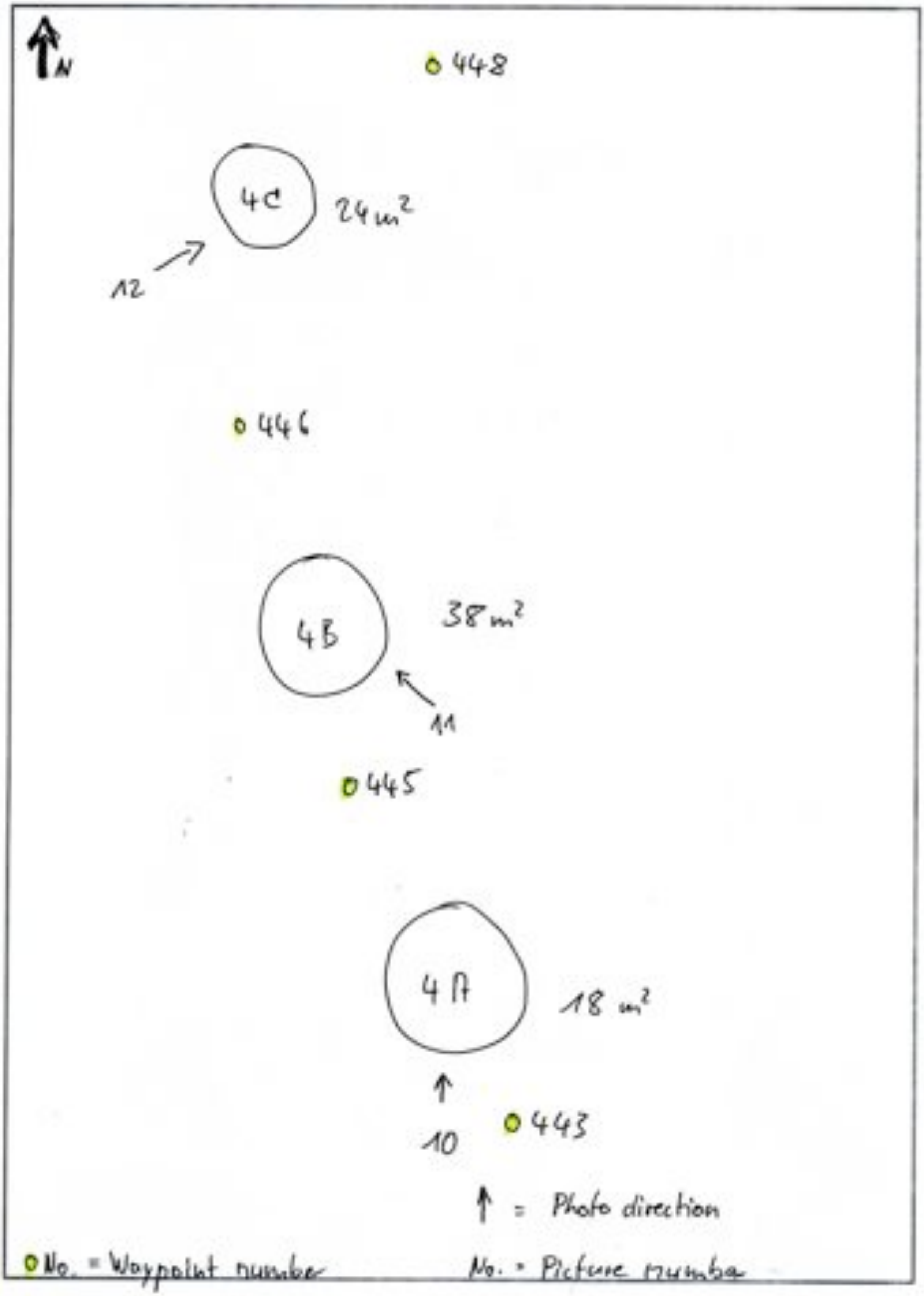
Sketch map Notes	Area 2, gap size of 3 felled trees



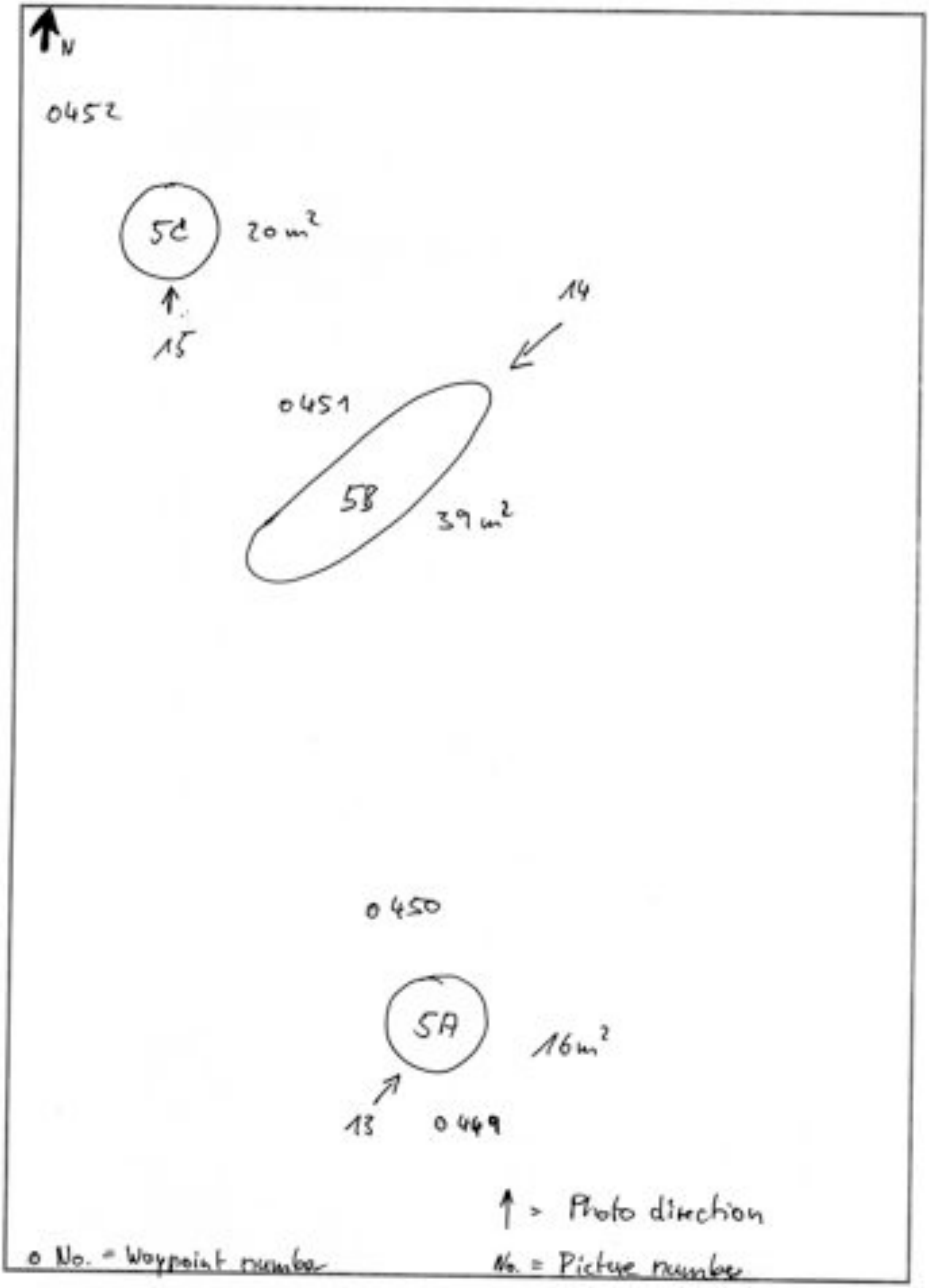
Sketch map Notes	Area 3, gap size of 4 felled trees



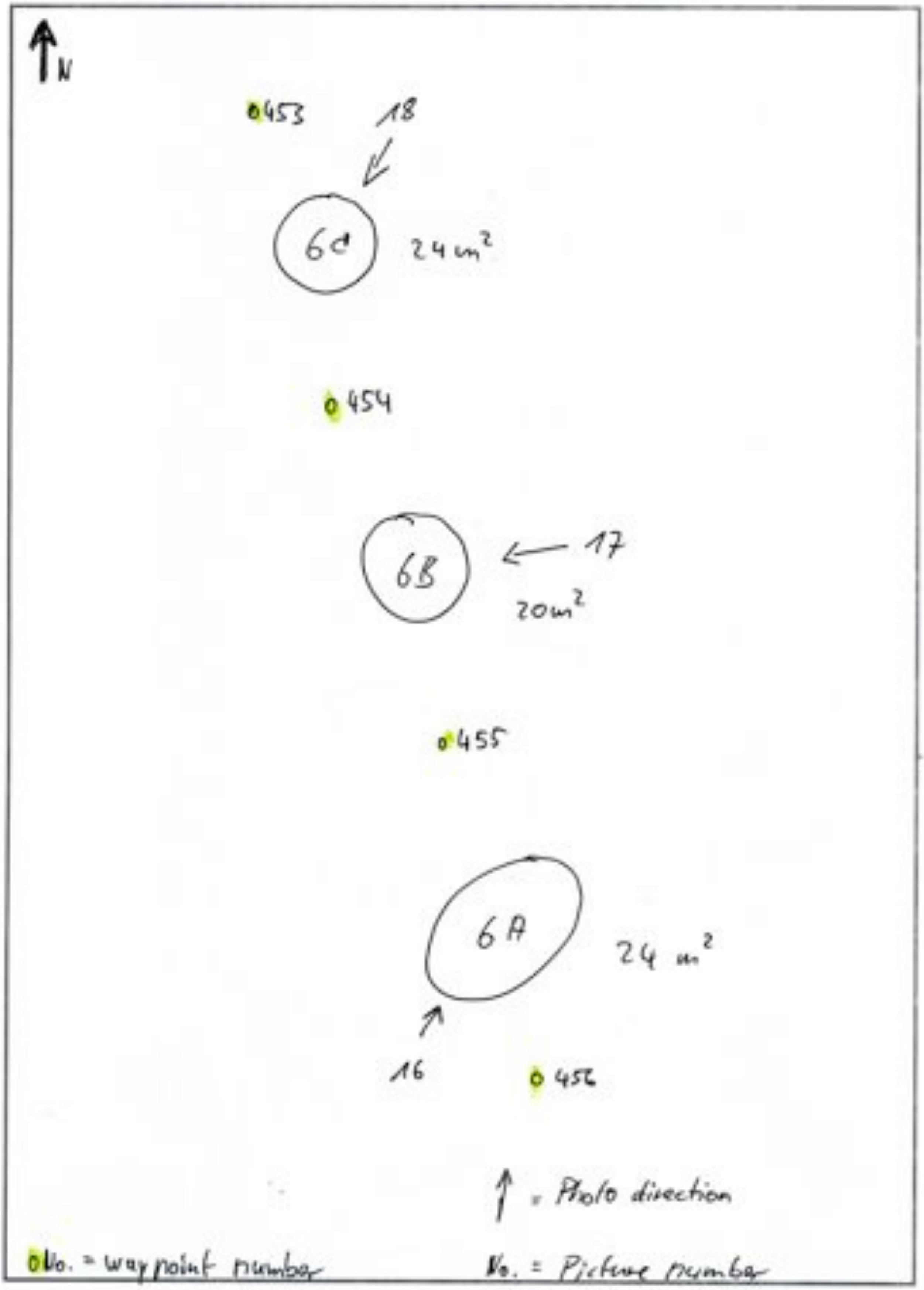
Sketch map Notes	Area 4, control area, no gaps cutted



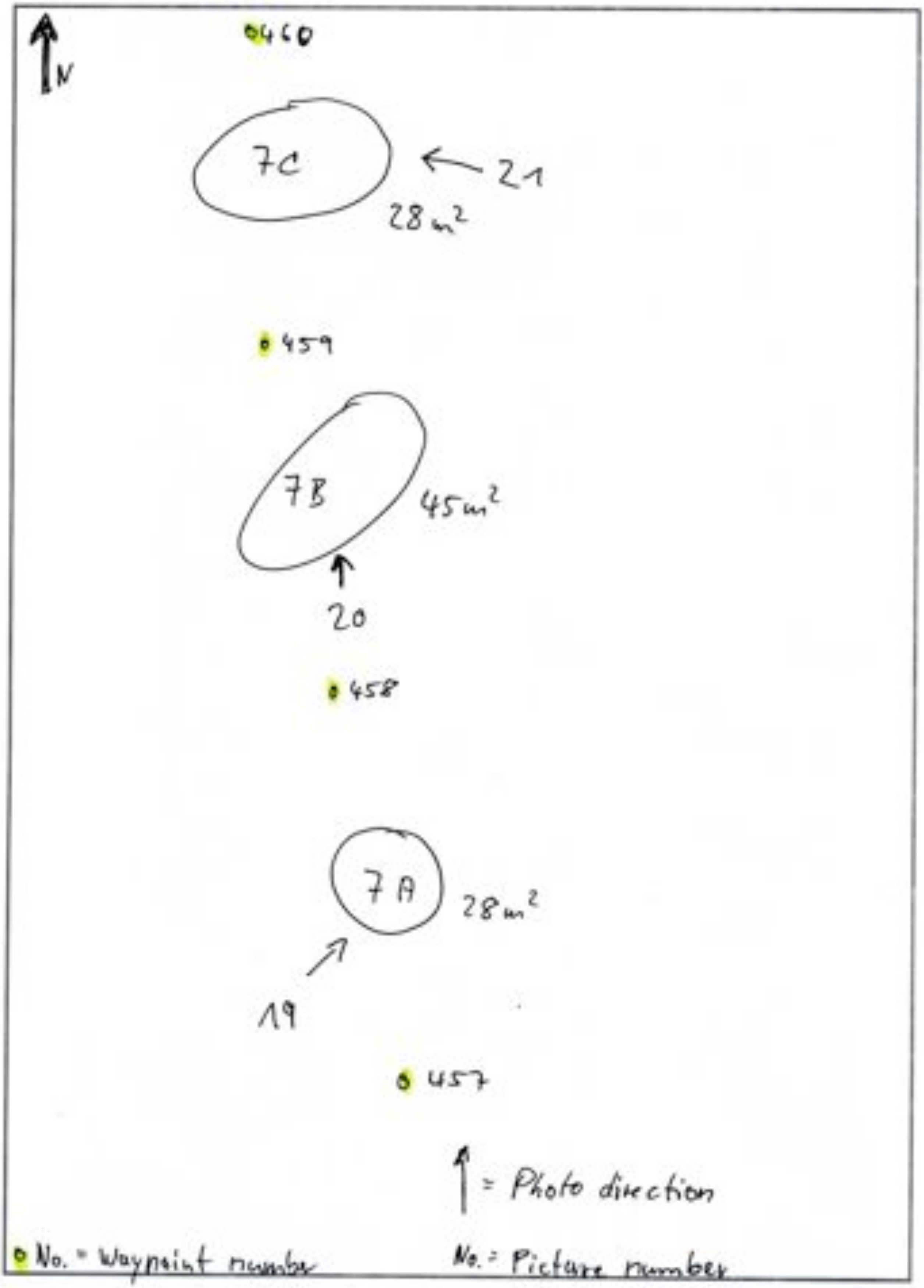
Sketch map Notes	Area 5, gap size of 2 felled trees



Sketch map Notes	Area 6 gap size of 3 felled trees



Sketch map Notes	Area 7, gap size of 4 felled trees



Planting description sheet

Code **VC004**

General information

Recorder(s)	Nguyễn Đức Hoàng	Date	
Forest owner/management	Soc Trang Forest Protection Sub-department		
District	Vinh Chau	Document description	For details see VC004 location map
Commune	Lai Hoa		
Village	Preychopt		

Remarks 7 Areas with each 3 Plots along the forest belt in Preychop

Seedling description before planting

Species	*Rhizophora apiculata*	*Ceriops tagal*	Remarks
Origin	Vinh Hai commune, Vinh Chau District	Vinh Hai commune, Vinh Chau District	
Number	5940	3060	
Quantity in kg	164	34	
Heights in cm	-	-	Not recorded before planting
Knots	0	0	
Diameter in cm	-	-	Not recorded before planting

Remarks

General descriptions

Planting in Area 1, 3, and 6

Plot “A” Rhizophora 34 %, Ceriops 66 %
Plot “B” Rhizophora 66 %, Ceriops 34 %
Plot “C” Rhizophora 100 %, Ceriops 0 %

Natural rejuvenation in Area 2, 5, and 7

Control area in Area 4

Planting description

Date of planting ______________________ Density (trees/m^2) 30

Tree combination

Plot No.	Area	Position	Plot size in m^2	Tree/m^2	*Rhizophora apiculata* No.	*Ceriops tagal* No.
1	1	a	13	42	184	356
2	1	b	22	44	634	326
3	1	c	20	30	600	0
4	2	a	26	-	-	-
5	2	b	7	-	-	-
6	2	c	9	-	-	-
7	3	a	30	34	347	673
8	3	b	38	24	594	306
9	3	c	32	35	1110	0
10	4	a	18	-	-	-
11	4	b	38	-	-	-
12	4	c	24	-	-	-
13	5	a	16	-	-	-
14	5	b	39	-	-	-
15	5	c	20	-	-	-
16	6	a	24	38	306	594
17	6	b	20	41	535	275
18	6	c	24	38	900	0
19	7	a	28	-	-	-
20	7	b	45	-	-	-
21	7	c	28	-	-	-

Planting technique

Cluster planting mimicking nature
Area 1, 3, 6

Nature rejuvenation
Area, 2, 5, 7

Control Area
Area 4

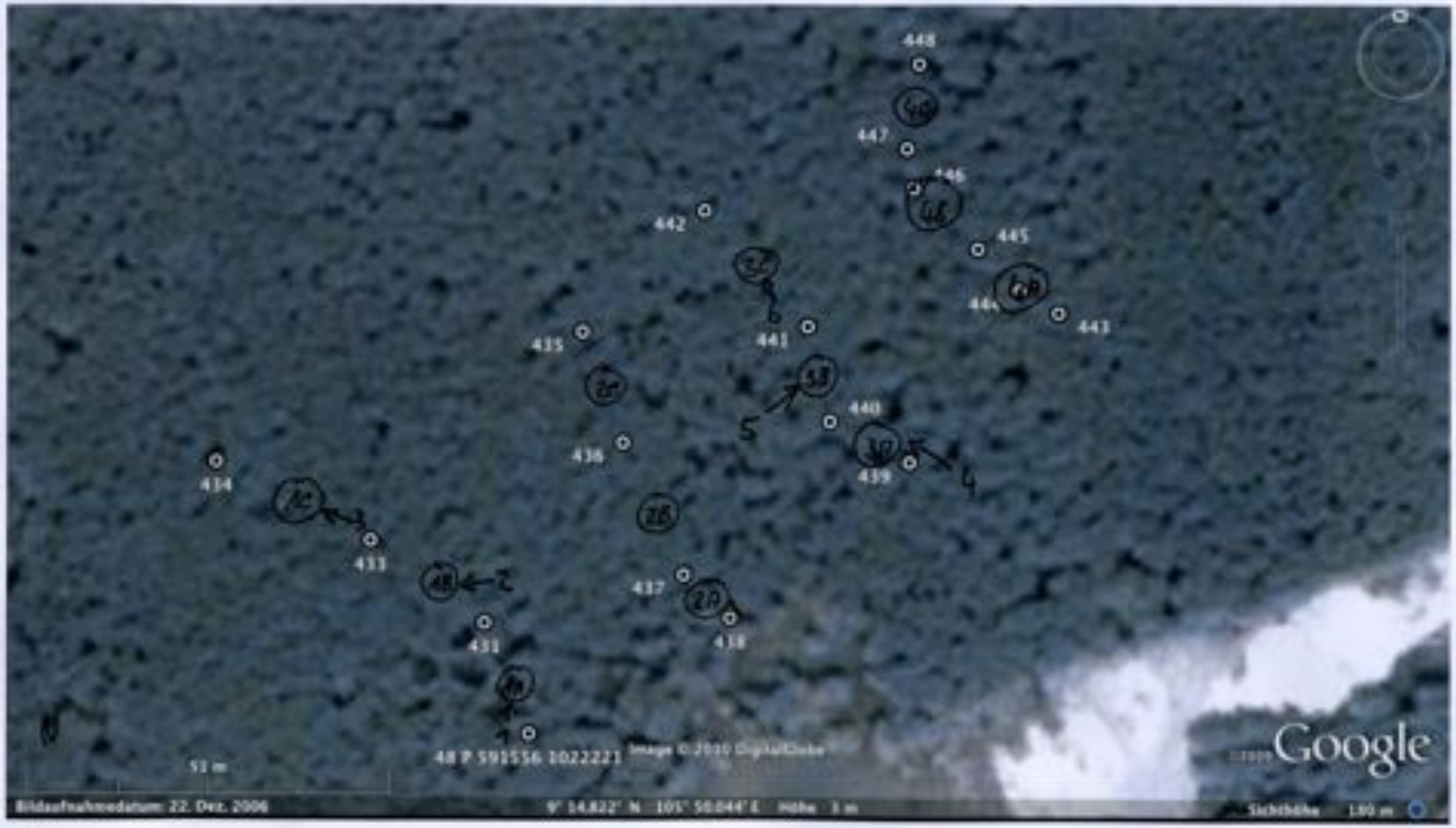
Seedling description after planting

Species	*Rhizophora apiculata*	*Ceriops tagla*	Remarks
Number	5681	2784	
Heights	-	-	Not recorded after planting

Photo reference [a]

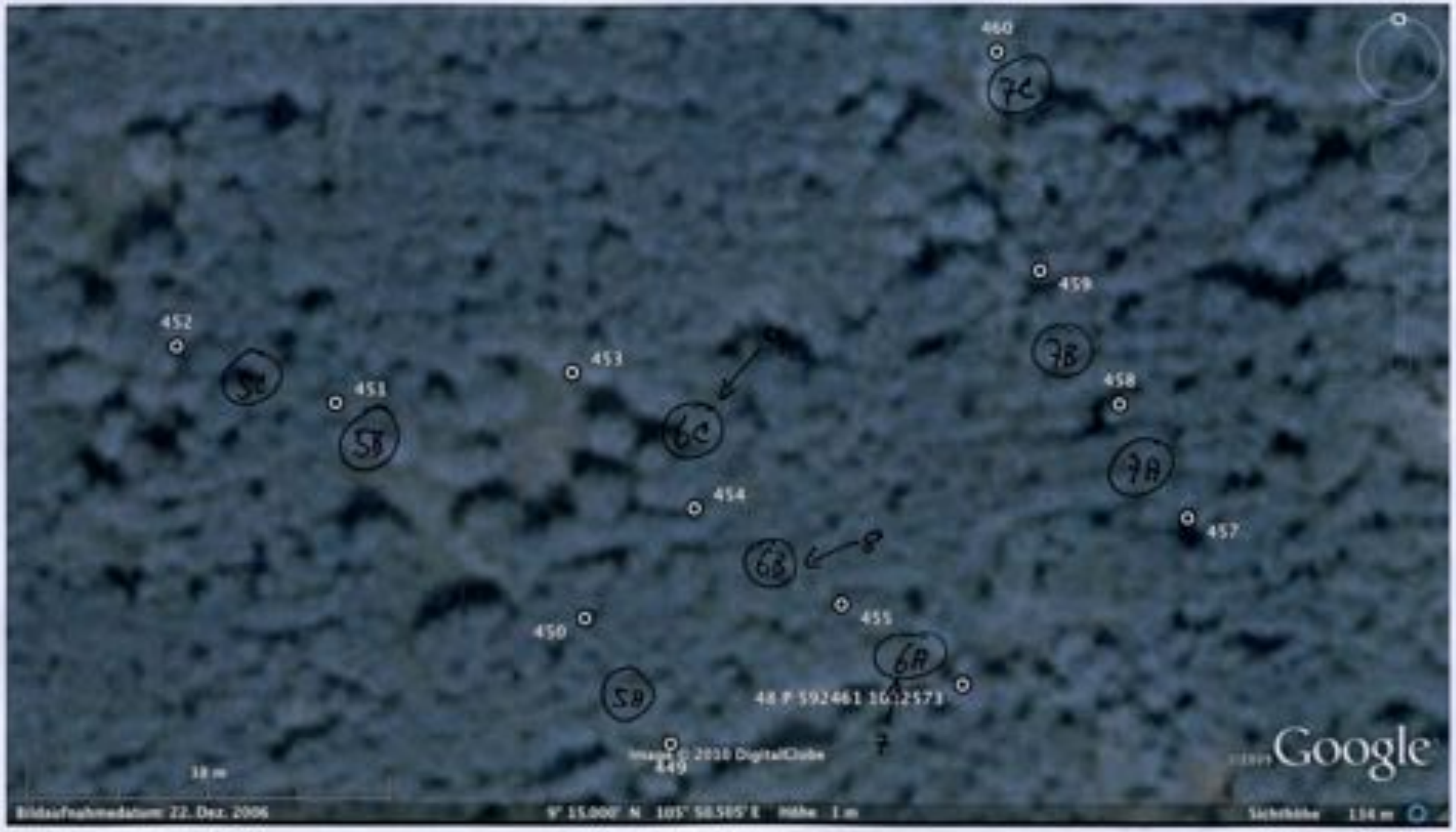
1	2009-11-06	VC004_2009-11-06_Area-1_plot-a.jpg
2	2009-11-06	VC004_2009-11-06_Area-1_plot-b.jpg
3	2009-11-06	VC004_2009-11-06_Area-1_plot-c.jpg
4	2009-11-06	VC004_2009-11-06_Area-3_plot-a.jpg
5	2009-11-06	VC004_2009-11-06_Area-3_plot-b.jpg
6	2009-11-06	VC004_2009-11-06_Area-3_plot-c.jpg
7	2009-11-06	VC004_2009-11-06_Area-6_plot-a.jpg
8	2009-11-06	VC004_2009-11-06_Area-6_plot-b.jpg
9	2009-11-06	VC004_2009-11-06_Area-6_plot-c.jpg

[a] File names and location following naming convention and archiving rules



↑ = Photo direction

No. = Picture number



↑ = Photo direction

No. = Picture number

Appendix VII

Mangrove plot monitoring sheet

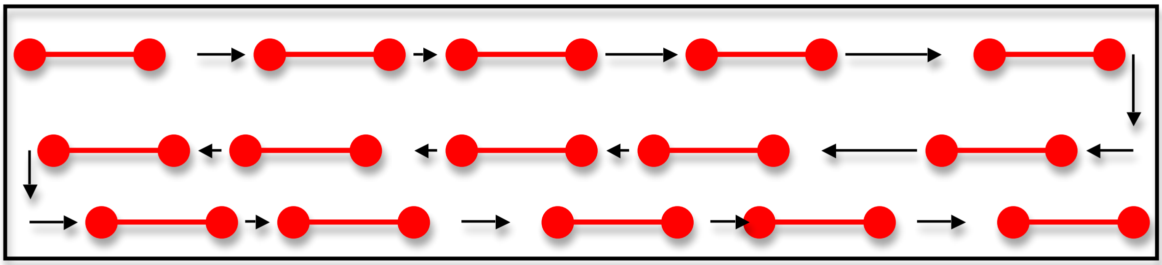
Brief field instructions for mangrove plot monitoring

Make sure that you have the necessary equipment and that it is working

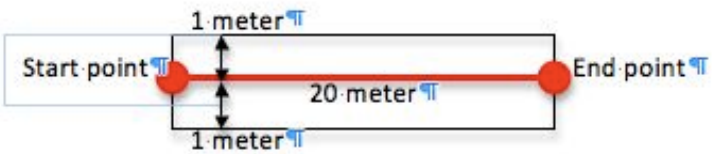
Sampling plot placement

1. Mangroves planted during the same season are monitored at one planting area with **unique identifier** (e.g. VC001)
2. Within each planting area, 500 meter long **sampling areas** are placed to cover the planting area representative. Each **sampling area** contains 15 sampling **plots** of 40 m^2 (2*20 m) to achieve 1 % density. Those **plots** are placed randomly along 500 m long **transects**.
3. Three transects should be placed more or less parallel to the tree line
4. The distance between the sample plots in one transect must vary every time
5. The number of plots per transect and the size of each plot must be calculated before data collection starts in such a way that the total plot area represents about 1% of the size of the sampling area.
6. The picture below shows how the transects and plots should be located with a sampling area. The arrows indicate the path to follow when placing the sampling plots.

Picture of a sampling area



Picture of a plot



Plot data collection

- Put a ranging pole at the start point, walk 20 m in a straight line place the second pole there and tie the rope to this pole.
- Take the GPS coordinates and waypoint numbers at each ranging pole.
- Two people walk with a one metre distance stick along each side of the rope. All plants within in the area covered by the stick must be recorded.
- Measure height, knots, species (and if necessary remarks and diameter) for each plant located within the sampling plot area.
- **All plants of all species must be recorded**

Please note

- All empty columns of the table must be crossed out
- If a plot contains no trees, this is a result (then cross out all columns)

Mangrove plot monitoring sheet

Code	

Name(s) of Recorder(s) ______________________ Date ____________

Photo reference (field note) ______________________

Factors affecting the growth of trees

Waves ☐ Erosion ☐ Human activities ☐ Sedimentation ☐

Wind ☐ Accretion ☐ Barnacles ☐ _______ ☐

Remarks ______________________

Site conditions

Innundation

hours/day _______

Tidal circulation _______

Pests and diseases ______________________

(For particular infestation fill in the column "Remarks") ______________________

____

Remarks

____

____

Plot size: 2x_____meter

Plot No.	

Start point of sampling plot	48P	UTM	**Waypioint number**	
End point of sampling plot	48P	UTM	**Waypioint number**	

Height in cm	Diameter in cm	Knots	Species	Remarks

Height in cm	Diameter in cm	Knots	Species	Remarks

Appendix VIII

Mangrove transect monitoring sheet

Brief field instruction for mangrove transect monitoring

Be sure you have all the necessary equipment and that it is working

1. Start every transect at the first tree of the transect at the coastline
2. Mark the first tree with the ranging pole, fill in the top part of the monitoring sheet including GPS coordinates and the waypoint number (Start coordinates)
3. Walk 10 meters along the transect, take the coordinates and note the waypoint number
4. Record heights, knots, species (and if necessary remarks) for all planted mangroves along the sector
    a. The height of each single tree must be **measured**, not estimated
    b. All **empty columns** of the table must be crossed out
    c. **If a sector contains no trees, this is a result**
5. After 10 meters you reach the end of the sector, take GPS coordinates and the waypoint
6. Walk 30 meters to the next sector, **stay always in the same transect, do not change the transect!**
7. Monitor the next sector as described in steps 4 and 5 above
8. After the last sector (=end of transect) note the GPS coordinates and the waypoint (End coordinates)
    a. All **empty sector tables** must be crossed out
9. Start next transect from the coastline

Mangrove transect monitoring sheet

Code

Name(s) of Recorder(s) ______________________ Date ____________

Photo reference (field note)

Factors affecting the growth of trees

Waves ☐ Erosion ☐ Human activities ☐ Sedimentation ☐

Wind ☐ Accretion ☐ Barnacles ☐ ________ ☐

Remarks ____

Site conditions

Innundation

hours/day ________

Tidal circulation ________

Pests and diseases ______________________

(For particular infestation fill in the column "Remarks") ______________________

Transect No.			**Start Coordinates** ☆	48P	UTM	**Waypoint number**	

Mangrove Forest edge ☆		**Sector 1**		**Sector 2**		**Sector 3**		**Sector 4**		**Sector 5**		**Sector 6**		**Sector 7**
	10 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m	10 m

Sector 1 Start Waypoint ____________ End Waypoint ____________

Height in cm	Knots	Diameter in cm	Species	Remarks

Sector 2 Start Waypoint ____________ End Waypoint ____________

Height in cm	Knots	Diameter in cm	Species	Remarks

Sector 3 Start Waypoint ______________ End Waypoint _______________

Height in cm	Knots	Diameter in cm	Species	Remarks

Sector 4 Start Waypoint ______________ End Waypoint _______________

Height in cm	Knots	Diameter in cm	Species	Remarks

Sector 5 Start Waypoint ______________ End Waypoint _______________

Height in cm	Knots	Diameter in cm	Species	Remarks

Sector 6 Start Waypoint ______________ End Waypoint _______________

Height in cm	Knots	Diameter in cm	Species	Remarks

End	48P	UTM	**Waypioint**	

Appendix IX

Mangrove plot monitoring (1 m^2) sheet

Brief field instructions for mangrove plot monitoring ($1 m^2$)

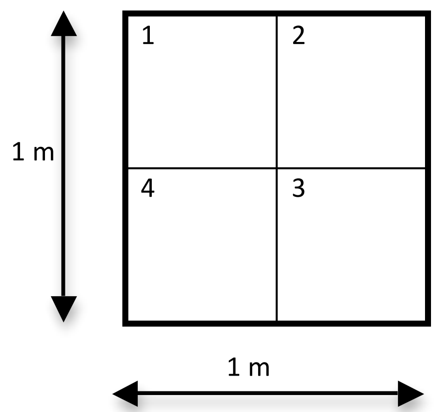
Make sure that you have the necessary equipment and that it is working

General information

- Mangroves planted with a **unique identifier** (e.g. VC001) must be monitored using the same unique identifier
- **Plots** are distinct and contiguous areas which have been planted at the same time
- A **sampling frame** is the area that is monitored by using a 1 m^2 frame
- Within each plot a sampling density of at least 1 % must be achieved. The minimum number of sampling frames placed per plot must be 2.

Picture of a sampling frame

- The area of a sampling frame is 1 m^2
- The frame is subdivided into four areas of 50 x 50 cm to facilitate recording in the field
- Record all plants in each 50 x 50 cm quadrate starting at the top left and proceed in clock-wise order



Plot data collection

- Put the sampling frame inside the border of the plot
- The distribution must be random (do not exclude parts with few or without any trees)
- Take the GPS coordinates and waypoint number at the sampling plot (top left hand corner)
- Record species, measure height and count number of knots for each plant located within the sampling frame; add remarks if possible (and measure diameter if required)
- **All plants of all species must be recorded**

Please note

- All empty columns of the table must be crossed out
- If a plot contains no trees, this is a result (then cross out all columns)

Code

Mangrove plot monitoring sheet (1m^2)

Name(s) of Recorder(s) ____________________ Date __________

Photo reference (field note) ____________________

Plot description and location ____________________

Factors affecting the growth of trees

Waves ☐ Erosion ☐ Human activities ☐ Sedimentation ☐

Wind ☐ Accretion ☐ Barnacles ☐ ________ ☐

Remarks ____________________

Site conditions

Innundation

hours/day ________

Tidal circulation ________

Pests and diseases ____________________

(For particular infestation fill in the column "Remarks") ____________________

____

Remarks

____

____

Sampling frame No.	

Sampling frame location	48P	UTM	**Waypioint number**	

Height in cm	Diameter in cm	Knots	Species	Remarks

Height in cm	Diameter in cm	Knots	Species	Remarks