Identifying pitfalls and key success factors for mangrove replanting in the Gambia

Anne Sandbrink BSc

Stefan van Meijeren BSc

Utrecht University

28 September 2010

Identifying pitfalls and key success factors for mangrove replanting in the Gambia

Written by

Anne Sandbrink BSc
A.M.Sandbrink@students.uu.nl
Master Natural Resources Management,
Graduate School of Life Sciences
Utrecht University, Padualaan 8,
3584 CH, Utrecht, The Netherlands

Stefan van Meijeren BSc
S.vanmeijeren@students.uu.nl
Master Environmental Biology
Graduate School of Life Sciences
Utrecht University, Padualaan 8,
3584 CH, Utrecht, The Netherlands

Internal Supervisor

Dr. G.W. Heil
Landscape Ecology,
Faculty of Bètawetenschappen
Buys Ballotlaboratorium (room 120)
Utrecht University, Princetonplein 5,
3584 CC, Utrecht, The Netherlands
G.W.Heil@uu.nl

External Supervisor

Chris Baker
Wetlands International
Head of Programme and Strategy,
Dep. Wetlands and Water resources
Horapark 9, 6717 LZ, Ede, The Netherlands
Chris.baker@wetlands.org

Abstract

Less than 50 years ago, mangroves covered three million hectares of the West-African coast. Due to human impact, less than one million hectares is left nowadays. In an attempt to restore the mangrove forests, Wetlands International started replanting projects in 2008 in two villages in The Gambia. The aim of this study was to evaluate these projects and to find the key factors that determine mangrove replanting success in The Gambia. With this objective a field study was conducted, in which transects were drawn perpendicular to the river in replanted and reference areas. Soil and groundwater parameters as well as descriptive and vegetative characteristics were recorded. The ecological results could be placed in a social context by means of participant observation and semi-structured qualitative interviews. Results confirm several relations that were known from literature. Ecological key factors that played a role in mangrove seedling survival showed to be the inundation regime and related redox potentials, ammonia concentrations and salinity levels. Ammonia showed to relate positively with height growth, while salinity and redox potential showed to have a negative relation with mortality rates. Other measured parameters showed to contribute little to a total of 51% of data variance that could be explained by the selected parameters. Social key factors for successful project implementation showed to be awareness of the ecological importance of a healthy mangrove ecosystem, a stable and strong community organisation and a transparent bookkeeping.

Table of Contents

Introduction

Mangrove forests occur all along the coast of West-Africa. These often dense forests comprise of woody shrubs and trees that inhabit the intertidal muddy shores. Mangroves are adapted to deal with fluctuating and sometimes very high salt concentrations, high temperatures and waterlogged, anaerobic soils (1). They are characterized by their special root systems which enables them to survive under such conditions. Mangroves have many ecological, environmental and socio-economical functions (2). They are amongst the world's most productive ecosystems (1) and even though these forests mainly contain two or three mangrove tree species which are generally predominant in the vegetation composition, they are home to a great diversity in animal and plant species. They provide habitat and nursery rooms for aquatic species, insects and nesting sites for birds (1, 3-5). They also have an important coastal protection function (1, 3-7) and form a natural resource that the locals use to sustain in their livelihoods (e.g. by extracting wood, fish, shrimps, crabs (1) and oysters (8). Furthermore, mangroves can also supply special chemicals for industry and medical purposes (3, 7).

Less than 50 years ago, mangroves covered three million hectares of the West-African coast. Over the past decades, this amount declined drastically due to combined effects of over exploitation and drought (9). The mangrove forests are exploited for their wood that is used as construction material and for domestic purposes, but also as firewood for fish smoking, shell burning and salt cooking. They are threatened by clearings for aquaculture and agriculture (5, 8, 9). The pressure on the mangrove ecosystem increased with increasing number of people that moved to coastal areas. Nowadays, less than one million from the original three million hectares of mangrove forest remains (9). The heavy degradation and area loss of mangrove forest area leads to biodiversity loss, local shortage of wood, salinisation of coastal agricultural fields and a significant drop in fish stock (9), which directly and indirectly endangers the livelihoods of the local people that depend on these resources. Moreover, at recent climate change talks for Kyoto protocol participating countries in Barcelona (10) it was stated that the degradation of carbon-rich wetland areas like mangrove swamps and peat bogs in Africa lead to alarming levels of greenhouse gas emissions (11), with the emphasis on methane production (1, 12). As global warming leads to raised sea water levels, mangroves are increasingly important to protect the inland from strong waves and flooding (6). To bring the continuing loss and degradation of mangroves to a halt, it is essential to conserve, restore, and manage the mangrove resources sustainably (1). Because secondary succession takes between 15 and 30 years (7), mangrove replanting can be a useful tool to speed up this process.

In Gambia, mangrove rehabilitation projects were set up in 2008 by Wetlands International (WI) and the under the MAVA foundation funded West-African Mangrove Initiative (WAMI). It concerns small-scale projects with a participatory approach that aim to halt the overexploitation of mangrove resources by offering alternative livelihoods to mangrove dependent communities and to promote sustainable mangrove management (9, 13). Although community forestry management is implemented in over 300 Gambian villages (14), community mangrove management is a relatively new concept (13). The project was targeted at three communities Buram, Bali Mandinka and Jasobo, which were selected to

pilot the project (13, 15). During the program, the local people were offered the technical tools to switch from mangrove-degrading activities to beekeeping and solar-energised salt production on tarpaulin. This way, the pressure on the forest is relieved. Additionally, it resulted in a considerable increase of community revenues (9). Monitoring and maintenance activities like replacement planting of dead seedlings were performed by people from the involved communities. Even though mangrove replanting projects are numerous and widespread, many of them end in a failure (7, 16, 17), see paragraph below. The factors that determine the success of replanting projects is hardly understood. High mortality rates can be caused by both ecological and social aspects.

Though, many lessons can be learned from mangrove replanting projects from the past. There were, for example, many projects set up in South-East Asia, after the coastline was severely damaged by a Tsunami on December 26th 2004. A mangrove replanting project in Aceh (Indonesia) showed very low survival rates of the planted seedlings after a rehabilitation period of 1,5 years (16). Mainly mistakes in planting site selection regarding the inundation regime, species selection and community involvement and commitment led in these cases to failure of the replanting projects (7, 17). A study by Ball (2002) showed that salinity can have a great negative impact on survival rates. Even though mangrove species are adapted to handle high salt concentrations, when these concentrations become too high the trees can suffer from severe water stress. This same study also shows that mangrove seedlings generally prefer conditions with high irradiance. Salinity and other soil chemical (redox) processes are influenced mainly by flooding which is divided in inundation time, frequency and height of inundation and soil saturation (7). Inundation time directly affects the amount of time of soil saturation. Frequency has the same effect but on a different scale. Inundation height is less important for soil processes but influences plant growth. As mangrove ecosystems are often nitrogen and phosphorus limited, the presence and availability of these two main components can also affect seedling growth (1, 18, 19). Typically in riverine areas, above mentioned factors change along a gradient perpendicular to the river influenced by the inundation regime (1).

Apart from these ecological aspects, also the social side of the project influences the success of replanting (20). This social side comprises everything that concerns the incorporation of the project within the community. The mangrove rehabilitation projects as they are set up in the Gambia can be seen as Community-Based Natural Resources Management (CBNRM) projects. There is not a single and universal definition of CBNRM, but it can be de described as a way to manage natural resources with the full participation of communities and local (often indigenous) institutions. Its aim is both to sustainable use and protect the environment, and to stimulate socioeconomic development and equity for local people (this definition is an amalgamation of the definitions found in Armitage (2005), Kellert et al. (2000) and Moore & Rockloff (2006) (21-23)). To involve local communities is often seen as most effective, because the people that live close to the resource and have a long tradition of using it are expected to work harder for its conservation. Especially when their livelihoods depend on the resource, as for example on the mangrove forest and forest products, their motivation to preserve it is thought to be big (24). In theory, giving the tools and trainings in both apiculture and salt production in exchange for replanted and sustainable managed forests can sound like an ultimate way to combine the aims of poverty alleviation with the development of a sustainable management system. In reality, however, achieving these

objectives is often complicated (21). Bad communication and coordination can lead to mistakes in for example planting techniques (16). After the trees are planted, the young forest needs sustained tending: dead trees may need to be replaced, pest- and diseases may need to be controlled and monitoring is crucial (16). When the motivation for forest restoration amongst the local inhabitants is low, they may not be willing to make these investments and consider the project finished when the trees are planted. It is therefore important that the importance of all activities (incl. for example monitoring) is clear, and that the community is involved throughout the replanting process. To prevent a 'tragedy of the commons', it is important that the resource benefits are proportional to the persons investments. Without coherence on investment systems, or when community members are separated by status, power and profit distribution, a low overall motivation to preserve the forest can be expected. Therefore, it is very important for a successful community-run replanting project that there is equity of power and profit distribution, and that the link between increased profits and replanted tree species is clear (25). By taking interviews from all strata of the communities, insight can be obtained about which social aspects play key roles in the Wetlands International initiated replanting program.

In our study we used the experiences from the past to select appropriate criteria and to analyze factors determining the success of the mangrove replanting projects set up by Wetlands International in Gambia. An interdisciplinary research is performed regarding the research question:

What are the key factors that determine successful mangrove replanting in the Wetlands International Gambia community projects?

In order to answer this main research question, the following more specific questions were formulated: **(1)** What are the soil and ecological factors that affect seedling mortality in the Wetland International planting sites? **(2)** Were the chosen planting site criteria appropriate? **(3)** Was the project well-embedded in the communities? **(4)** Is the organisation and set-up of these projects applicable in other parts of The Gambia?

It is expected that mangrove replanting fails when soil, ecological and social aspects are not taken into account and the absence of one of these factors will cause higher mortality rates. Within these three aspects there are expected to be certain main factors which are most important. Main factors that influence seedling mortality regarding the soil aspect are thought to be the aeration, pH and structure of the planting site substrate. For the ecological aspect those main factors are thought to be interstitial groundwater salinity and inundation regime. In addition, social aspects which we expect to be important for replanting success include community involvement and equity in power and profit distribution. We expect to find high seedling survival rates (>50%, Primavera stated 20% on the long term as successful (17)) at planting sites where soil, ecological and social conditions are favourable. According to literature on mangrove forests, favourable soil conditions include aerated soil (redox potential -280 < +70 mV, dependent on depth of measurement (26-28), with a pH around 6.7 (26, 28) and soil structure that is appropriate for the replanted species (preferably mudflats (1, 29)). Ecologically, favourable mangrove replanting conditions requires brackish

river water (interstitial water salinity around 40.1 ppt (28)). The intertidal zone should be always periodically (but less than 30% of the time) inundated (7). Success of the mangrove replanting project is promoted when the community is actively involved throughout all project stages and in a broad spectrum of activities (from project initiation till monitoring activities after seedling planting). It is expected that we will observe a positive relation between equity in power and profit distribution amongst community members, and their motivation to cooperate in the project. A higher motivation amongst village inhabitants is no guarantee for low seedling mortality, but it is expected to be an essential ingredient for replanting success.

Even though there are many variables influencing the replanting success, we expect that key success factors can be identified. When we are able to identify which conditions are unfavourable for mangrove replanting, current replanting criteria can be tested for their suitability as replanting criteria. We expect these current criteria to be correct, but incomplete. This incompleteness can be caused e.g. by gaps in knowledge or/and insufficient means. For example, nutrient availability and redox potentials cannot be measured due to a lack of testing materials. Also more distant factors, such as the amount of fresh water supply are expected to be inadequately incorporated due to lack of hydrologic expertise (education) within the communities. It is expected that the set-up of the mangrove replanting project as it was done in Buram, Bali Mandinka and Jasobo has the potential to be used in other parts in The Gambia. However, we expect that this study will give rise to recommendations that will contribute to the improvement of future mangrove replanting projects.

Our study focuses on the communities of Bali Mandinka and Buram, where the fieldwork is conducted. The project in Jasobo is briefly discussed.

Methodology

Study area and species

This study evaluates the replanting projects that were initiated by Wetlands International in The Gambia. Field work was conducted in the communities Bali Mandinka and Buram in February-April 2010. Mean annual precipitation is 900 mm, with a distinct dry season from November to May (30)(Banjul area, Fig.1). Bali Mandinka (13°34'1.58"N, 16°6'3.71"W) is located in the North Bank District, along the Miniminiyang Bolong, a side branch of the Gambia River. It is a village that comprises about 400 inhabitants belonging to the Mandinka tribe. Buram (13°15'58.93"N, 16°12'49.74"W) is a village with about 150 inhabitants, located along the Bintang Bolong river in Western Division. It has a mixed population of Mandinka and Jola people. At both sites *Rhizophora harrisonii* was hand-planted during the start of the rainy season in August 2008 and 2009. *R. harrisonii* is a viviparous mangrove species (1) that is considered to be a possible hybrid species between *R. mangle* and *R. racemosa* (29, 31). It occurs in West-Africa and the Atlantic coast of tropical America (29). Data collection was conducted in February-April 2010.
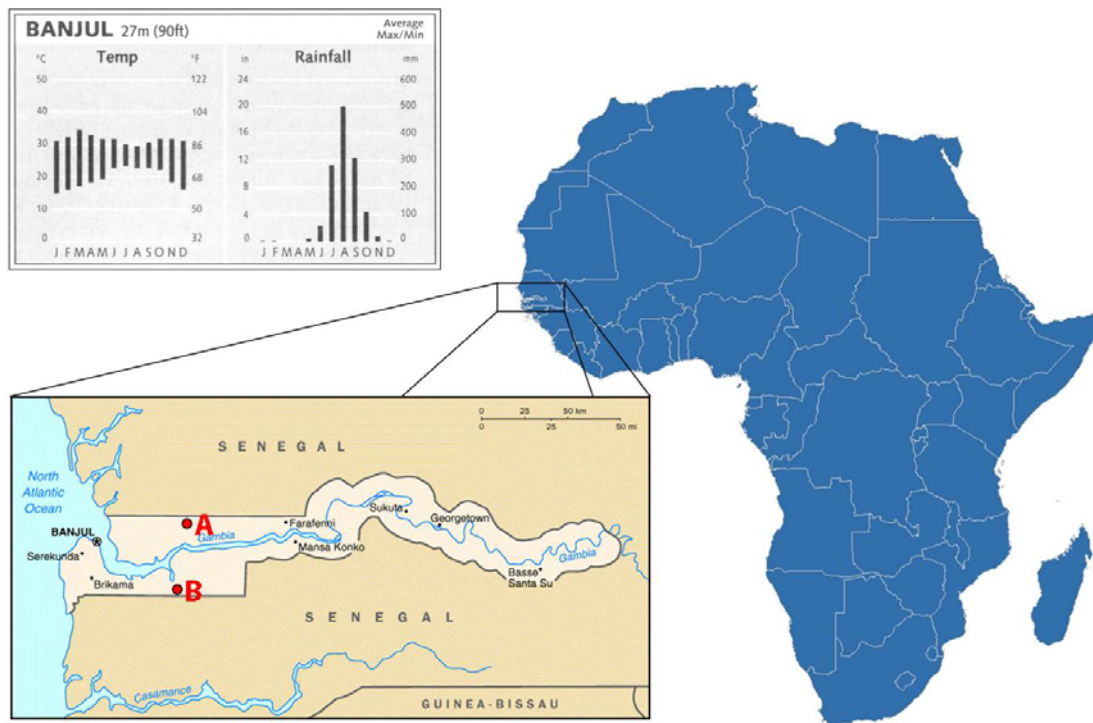
Figure 1. Map of Africa (right) and The Gambia (bottom left). Capital letters indicate the study areas; A: Bali Mandinka, B: Buram. Climate chart (top left, *source:* (32)) is for the Banjul area.

The ecological aspect

Data collection

At each replanted site, transects were drawn perpendicular to the river branch or creek that was responsible for water supply of the area during high tides. The transects were chosen in a way that they included most of the geomorphological features present, and were more or less equally distributed over the replanted areas. Lengths of the transects varied, according to the size of the replanted area. Each transect contained 5 plots of 3 x 3 m. Within each plot, soil characteristics as well as descriptive characteristics were recorded.

For comparison with replanted areas, reference areas of natural and relatively undisturbed mangrove forest were selected in the neighborhood of the replanted areas. Transects were drawn in the same way as in the replanted area, each containing 5 (3 x 3m) plots. Locations of these transects were chosen in such a way that they had the same geomorphological characteristics as those in the replanted areas. In each village, 6 transects (a total of 30 plots) were drawn in the replanted area, and the same amount in the reference area. Treatment categories were thus: Buram Reference, Buram Replanted, Bali Mandinka Reference, and Bali Mandinka Replanted.

A visit was paid to another replanting project in the Sine-Saloum Delta, Senegal. This project was initiated by several organizations (not including Wetlands International) that operated together under the name FOAM. *Rhizophora* seedlings were planted at the start of the rainy season in 2008 by people from the nearby community Sokuta. To validate our findings derived from the fieldwork in The Gambia, two transects (10 plots) were drawn and vegetation recordings and cores taken in the same way as in Bram and Bali Mandinka.

Soil characteristics

The soil parameters which were measured are salinity, nitrogen, ammonia and phosphate content of extracted ground water and pH and redox potential within the soil. Ground water was sampled in every plot using rhizons which extract water from approximately 10 cm depth. The rhizons were placed in the corner closest to the river for a period of three to four hours. The ground water samples were analyzed within 12 hours from sampling. Salinity was determined by using a refractometer. Nitrogen, ammonia and phosphate content was determined by using a chemical aquarium kit (Salifert for phosphate and nitrogen, Tetra Test for ammonia). The PH and redox potential were measured with a WTW pH 330 Set 1 meter, a WTW SenTix ORP redox sensor and a WTW SenTix 41 pH sensor. For these analyses, a core was taken in every plot until a depth of 50 cm. The redox potential and pH were measured at 5 cm from the bottom and the top of the core. Together with pH, temperature was recorded for correction of the measured redox potentials. After the measurements were done, the core was cross-sectioned and a picture of the soil profile was taken. The soil texture was tested with the Van der Zee method (33). According to this method, a soil texture category is assigned by testing the ability to bend without breaking of a rolled soil portion. The categories range from 1 to 10, meaning sand to heavy clay, respectively.

Descriptive characteristics

Descriptive characteristics were separated in vegetation characteristics and environmental characteristics. The vegetation characteristics contained per species the abundance (in %

cover), mortality rates per plot, seedling average and maximum height, the average and maximum number of leaves and presence of diseases. The environmental descriptive characteristics contained the inundation regime, presence of herbivory, damage, slope of the plot, abundance of bio-indicators and irradiance. The Dawkins index was used as a measure for irradiance. This light index describes the light environment of a tree by assigning it a number, according to a scale from one to five (34, 35). The index number indicates the crown position of a tree, one meaning that the tree is completely overshadowed and five meaning the tree is emergent and has full light conditions. The average index number for the seedlings was noted per plot. The bio-indicators noted in this study included crab holes, mudskippers, shells and Seapurslane (fig. 2). The presence of crab holes and the breakability of elongated shells were used by Wetlands International to identify potential replanting sites. The shells were used as indicators for the PH, as they are easily breakable at high acidity. Mud crabs are more often used as bio-indicators for suitable mangrove habitat, as they influence the ecosystem by means of bioturbation and mineralization of nutrients through leaf consumption (36). They diminish sulfide and ammonia concentrations, favoring *Rhizophora* growth (37). Mudskippers occur in muddy substrate along the intertidal gradient, and their presence indicates daily flooding (38). The herbaceous halophyte Seapurslane (*Sesuvium portulacastrum* L.) can be classified as a mangrove-associated 'salt accumulators' (39, 40) and is thus used as an indicator for high saline conditions. The abundance of these bio-indicators was indicated by assigning them one of four simple categories (0: absent, 1: very few, 2: average abundance, 3: very abundant). The only exception to this rule was the Seapurslane, of which a percentage cover was estimated for each plot. Furthermore, general aspects were noted, such as GPS location, time of sampling, distance to previous and next plot and general remarks. At the end of each transect, a situation sketch as well as a transect profile was drawn. Of each plot, a picture was taken.

Figure 2. Bio-indicators. From left to right: shells, Seapurslane, Mudskippers and crab holes.

Ten random seedlings from the replanted areas were marked in both villages to determine average seedling growth rates. The length growth of the seedlings and the number of new leaves that were formed after marking were measured and counted several weeks later. In Bali Mandinka, marking occurred on 4th of March 2010, and measuring on 07th of May 2010. In Buram, marking and measuring occurred on 07th of February 2010 and 18th of March 2010, respectively.

Statistical Analyses
To identify the most important factors that influence replanting success, multivariate analyses were performed on the collected data. This was done with the help of CANOCO 4.5

for Windows (41) and MVSP 3.1 (42). First, a Principal Correspondence Analysis (PCA) was conducted on the response variables to test whether they react differently to the explanatory variables and are therefore discriminating enough to base further analyses on. The three response variables used were the mortality rate, average amount of leaves and average height. These variables were standardized using SPSS 16.0 before they were entered in the PCA. Three very dry transects from Bali Mandinka were excluded from analysis because of their extreme values and abundant missing values. Second, Canonical Correspondence Analyses (CCA) were conducted according to Jongman et al. (1995) (43) with the explanatory variables, that included all measured variables and categorical variables. Standard Monte-Carlo permutation tests of 499 runs were performed on all canonical axes of each plot to identify significant explanatory variables with a 95% confidence interval. Several CCA were conducted, successively leaving our the variables that showed little importance and including only the major explanatory variables.

The social aspect

Interviews

The social aspect was studied by participant observation and conducting semi-structured qualitative interviews among different members of the communities. Participant observation is a qualitative method to study the various perspectives within a community (44). This was done by observing and participating in the daily activities, discussions and conducting informal interviews, during two weeks in both Buram and Bali Mandinka. Participant Observation is an important data collection as well as an analytical tool (45). It enhances the quality of the information obtained during fieldwork by, for example, gaining the trust of the local people. It also enhances the participants' ability to interpret data such as interview questions and encourages the researcher to define hypotheses based on observations (45). In the weeks we spent in Buram and Bali Mandinka we got good background knowledge about the project and the way people think about the project and the mangrove ecosystem. After approximately one week we started conducting semi-structured qualitative interviews, in which each participant was presented a set of open questions within a framework (Appendix B). A colleague from the Forestry Department of Banjul acted as translator. In total, 18 interviews were conducted, of which 9 in each village. The interviewed community members were of various ages, gender, professions and families. In both villages we interviewed the Alkalo[1]. These can be seen as key informant interviews (46), as the Alkalo had a high position on the social ladder and was well-informed about the project developments from the start. More influential figures such as the Imam and the chairman of the Village Development Committee (VDC), but also farmers and fishermen were interviewed. After the interviews were digitalized, the observers' impressions were used to analyze the answers qualitatively. This meant that scores were assigned (from - - to ++) to each of the focal points that were addressed in the interview. Limited time availability did not allow us to spend more than two weeks in the village conducting our participant observations and resulted in a small amount of conducted interviews. Even though, the obtained answers and observations allowed us to place the ecological results in a broader social context.

---

[1] Alkalo: Village Head

The interview framework (Appendix B) included the following focal points:

- The intrinsic and practical value of the forest for the local community
- The forest products that were extracted (purposes and quantity)
- The awareness that was present about the function of and threat to the forest
- The perception of and participation in the replanting project
- The importance of the apiculture and improved salt production techniques training
- The power- and profit distribution amongst community members

The ecological aspects: Results

At each replanted site in Bali Mandinka and Buram, transects were drawn through both the replanted area and a reference area. Soil, vegetation and environmental characteristics were measured and described for a total of 120 plots. A full dataset is available on request at Utrecht University, department of Biology. In Appendix C results of all measured parameters are summarized by presenting their ranges, medians, standard errors and sample sizes. We can see that only 26 plots in both replanted and reference area could be tested for phosphate content. This was due to the fact that a phosphate test required 10 mL of ground water. The rhizons we used to collect the water were fragile and some broke or got cut by fiddler crabs (Ocypodidae (47, 48)). Moreover, the clay substrate resulted in very slow water uptake, hence the required 10 mL to test for phosphate was not always collected. However, the phosphate tests that were performed showed very low phosphate contents (M=0 mg L^{-1}, SE=0.08, n=26). Also ammonia (M=2.14 mg L^{-1}, SE=0.27, n=38) and nitrogen (M=0.4 mg L^{-1}, SE=0.16, n=40) contents of the ground water were relatively low. These results show a low nutrient supply from the river, as river water is the main source of nutrients in these environments. The pH and redox potentials shown in Table 1 of Appendix C were measured at 5 cm from the bottom and the top of the core. In some plots (n=19) the soil was too hard to take cores. Here, pH and redox values were measured directly in the ground at a depth of 5 cm. The pH values obtained in this way reached from 4.2 to 7.0 (M=6.28, SE=0.16), redox values were all positive and reached from 202.8 to 468.1 (M=364.20, SE=17.4). When we look at mortality rates, we see that many more seedlings survived at the sites replanted in 2009, compared to the sites replanted in 2008. Appendix C (Table 1) shows the measured parameters, but some vegetation and all environmental characteristics were described rather than quantified. A description of these parameters is given below.

Vegetation and environmental description
Quite logically, the replanted species *Rhizophora harrisonii* was the most abundant species in the replanted areas. Because of low planting density and small seedling sizes, they had an average estimated cover of < 5% of the plot areas. All replanted seedling received direct sunlight. Plots in reference areas were typically surrounded by *R. harrisonii* adjacent to the river and in depressions, followed by *Laguncularia racemosa* further inland. At bigger distances from the river *Avicennia germinans* gradually became dominant. In the replanted areas *R. harrisonii* was almost absent and *L. racemosa* became dominant closer to the river. Typically, land and river branch were separated by a short, steep slope. Further inland a slope gradient could not or hardly be observed. We were not able to perform height measurements, but we can say that the height difference between the first and last plot of the transects were several decimeters maximum. Because of the absence of a steep slope gradient, the inundation regime lacked variance between and within transects. Almost all plots were categorized to be inundated every high tide. Only three transects were drawn in a dryer area that was only inundated a few times per month. In this dryer area Seapurslane was very abundant, covering up to 80% of the plot area. Mudskippers were not present here, while they were present in 70% of the daily inundated plots. In the dryer area, almost no shells were found and crab hole densities were lower than in the daily inundated areas. In general, crab hole density and shell abundance varied strongly. Crabs damaged the seedling stems in some plots and according to tracks of ungulates found along some transects,

grazing of cows was apparent. In the reference areas in Buram we observed many trees that were heavily damaged and half-dead. They seem to be infected by a worm that caused the death of many adult trees. A Mann-Whitney U-test showed that mortality rates at sites where the disease occurred was not higher than at sites where the disease was not observed (U =92, p >0,05 r =0.065). This indicates that the worm only infested itself in older trees, leaving the seedlings until now unaffected.

Comparison of reference and replanted areas

In the replanted area, ammonia and nitrogen concentrations within the interstitial pore water was higher (2.14 and 0.4 mg L^{-1} respectively, Appendix C) than in the reference areas (0.25 and 0.2 mg L^{-1} respectively). PH values did not differ very much, while median redox potentials in the top soil were slightly higher in the replanted area than in the reference area. The soil in the replanted areas was thus a little better aerated. The bio-indicator that was thought to indicate aeration, however, showed a contrasting result, as they were present in larger quantities in the reference areas. As last result in this comparison, the reference areas were more prone to non-lethal diseases but suffered less from grazing of ungulates.

Relations and Correlations

A total number of 60 plots were recorded in areas replanted with *Rhizphora* seedlings, of which 30 in the village of Buram and 30 in Bali Mandinka. The area in Bali Mandinka that was replanted in 2008 was entirely located on an elevated river bench. A fringe of *Laguncularia racemosa* colonized the steep slope that separated the replanted area from the river. Two year after replanting, few seedlings could be found back alive. In the 15 plots located here, a median mortality rate of 1 was found. Tides would only reach the area an estimated few times per month. Consequently, the soil was hard and dry and no groundwater samples could be taken. The plots that were located in this area were excluded from statistical analysis.

As proxies for replanting success, we used the mortality rate, the average number of leaves and average seedling height. A Principal Component Analysis (PCA; Appendix D) placed the average amount of leaves near the average seedling height. However, they were not completely together, which indicates that the selected response variables react differently to the explanatory variables. This was even more the case when mortality rate was included as response variable. Mortality rate was located along the Y-axis, while the median amount of leaves and the median height were located along the X-axis. It emphasizes that the two axes represent different parameters, which supports the assumption that the chosen proxies are suitable for analyses.

A Canonical Correspondence Analysis (CCA) of all explanatory variables can be found in Appendix E. In this CCA, a cumulative percentage of 51.5 of data variance was explained by the two ordination axes. The CCA's shown in this result section were performed with a selection of the major variables. Figure 3 shows a CCA of the measured parameters, represented as arrows that point in the direction of the parameters' maximum change. The highest correlation with the first ordination axis was found with the topsoil redox values

(Redox, correlation coefficient -0.44), while topsoil pH values (pH) correlated most with the second axis (correlation coefficient 0.24). Axis 1 is seen as the most important, since it accounts for 26 out of a total percentage of 30.5 of variability that is explained by the ordination axes. Because the arrow that represents redox values from the topsoil (Redox) pointed in the same direction and were equally long as the redox values in the deeper soil layers (Redox 2), only one redox value is represented in Figure 3 and subsequent graphs. pH and pH2 were strongly correlated in the same way and they will be represented from now on only by pH. A Monte Carlo permutation test (499 runs) that was performed on all canonical axes of each plot resulted in a significant p-value of Redox ($p<0.05$). In figure 3 can be seen that Redox had a significant negative influence on mortality. Salinity also influences mortality rates, and showed to be negatively correlated with average height. Ammonia represents another arrow of considerable length on the X-axis. It showed to have a positive influence on average seedling height. The other explanatory variables did not show to be influential, regarding their relatively short arrow lengths in the CCA.
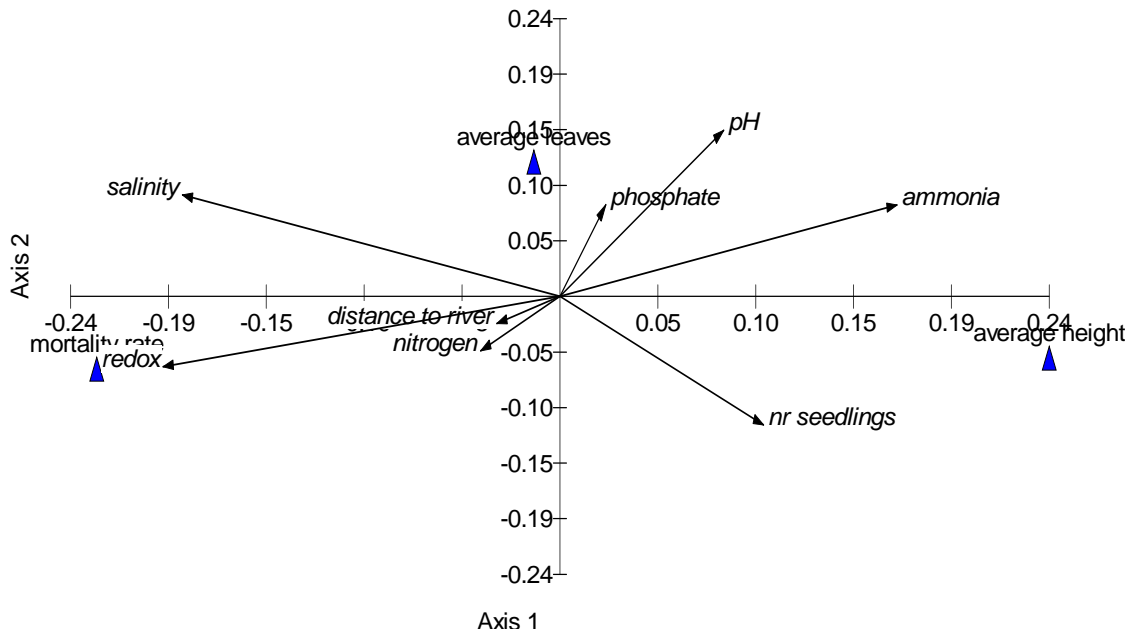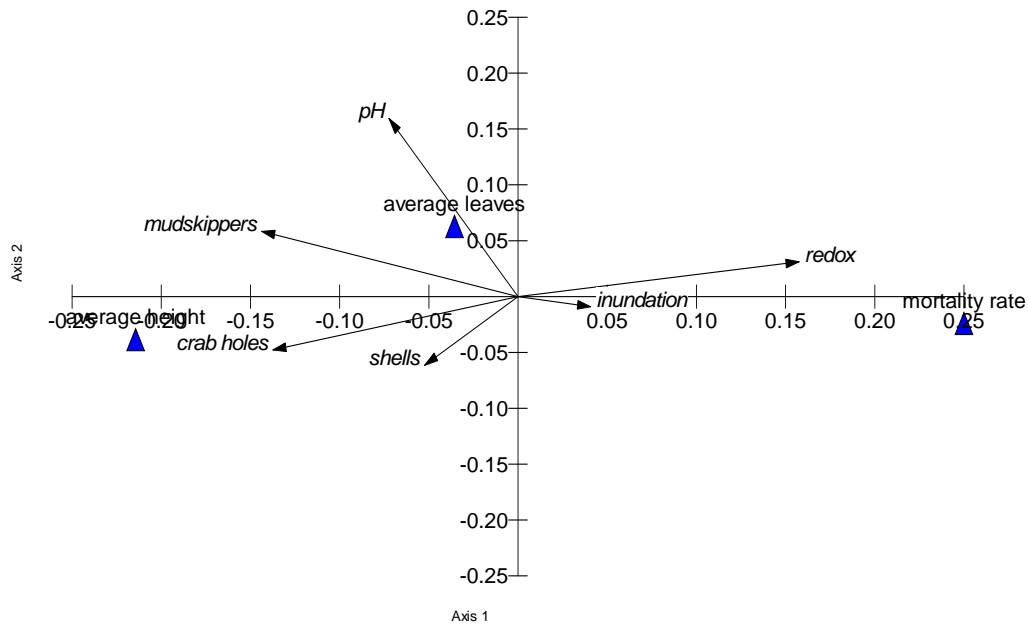

Figure 3. *Biplot of the CCA of all measured variables (vector scaling 0.26), in relation with the response variables average height, average amount of leaves and mortality rate.*

Bio-Indicators
Site selection for the replanted areas was mainly based on the presence of bio-indicators and their associated parameters. The presence of mudskippers, unbreakable shells and crab holes were expected to indicate frequent inundation, higher pH values and higher redox potentials, respectively. The CCA in figure 4 shows that none of the expected relations between the bio-indicators and their associated parameters can be found. However, the bio-indicators showed a weak positive correlation with the measured growth parameters and a negative correlation with mortality rate.
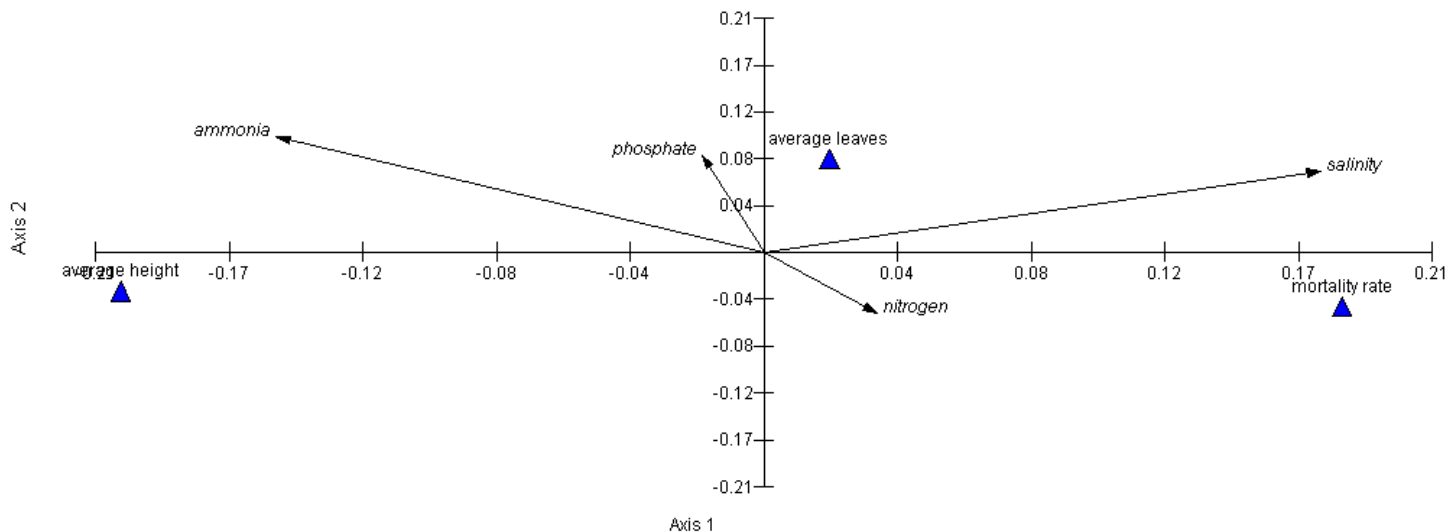
Figure 4. *Biplot of the CCA of the used bio-indicators and their associated parameters (vector scaling 0.21), in relation with the response variables average height, average amount of leaves and mortality rate.*

Nutrients and Salinity

When we focus only on the nutrients and salinity, 19 % of data variance is explained. A Monte Carlo permutation test indicates the significance of salinity (p = 0.004). It has a strong negative influence on growth and is positively related with mortality (Fig. 5). When salinity is excluded (Appendix F), a total of 12.3 % of data variance is explained, and ammonia becomes significantly important with a Monte Carlo value p = 0.014. In figure 5, the arrow of ammonia describes a positive relation with the average seedling height and a negative relation with mortality rates. These results are in line with the findings shown in Figure 3. Both figure 5 and fig. 14 in Appendix F show that phosphate is positioned mainly along the Y-axis. This axis, however, only explains 0.5 % of the data variance. The variables therefore have to be distinguished by their position on the X-axis. Phosphate and nitrogen have short arrows and low X-axis values and their influence on the response variables seems negligible.

Figure 5. *Biplot of the CCA of nutrients and salinity (vector scaling 0.19), in relation with the response variables average height, average amount of leaves and mortality rate.*

The Sine-Saloum Delta

Data was collected from mangrove replanting sites in the Sine-Saloum Delta (Senegal) in the same way as was done in The Gambia. The same parameters were measured and described, as summarized in Table 3 of Appendix G. Even though sample sizes are too small for statistical analysis, the data provides an impression of the replanting conditions at this specific site. We observed that very high survival rates could be reached at very saline replanting sites. In three plots, 100% survival was recorded where salinity values reached between 54 and 60 ppt (Table 3, Appendix G). Another observation was that the seedlings were relatively high (*M*=66, *SE*=5.2, *n*=9) and had many leaves (*M*=43, *SE*=7.9, *n*=9). Seedling densities were very high (*M*=7.7 seedlings m^{-2}, *SE*=1.0, *n*=10) leaving less than 10 cm between each seedling stem (Fig. 6).

Figure 6. *Seedlings in the Sine-Saloum*

The social aspects: Results

The Interviewing techniques

Interviews were conducted by asking open questions according to an interview framework (Appendix B). We have chosen for a qualitative approach with less but more elaborate interviews because this was considered to give us more in-depth information. Most of the time the interview was conducted through a translator of the Forestry Department, Mr. Njai. He sometimes added context, but was very aware of our desire to receive the information as objective as possible. Sometimes it was hard to be completely objective, as especially some women were shy to answer. In that case we tried to make some small talk and give several options for some questions they found hard to answer. In some cases it was hard to know whether the interviewed community member really spoke his mind or gave an answer that he thought was what we wanted to hear. One of the interviewed farmers, for example, was trying to impress us by saying he hunted for tigers in the forest in the past (while clearly tigers did not occur there). However, on the long term people started to trust us and spoke more freely. At the end most people seems to give reliable answers. Our relatively long stay in the communities also allowed us to get some insight in the communities, so that we could place the answers in the right context. At the end we generated enough data to have a good general overview in a qualitative way about the thoughts and usage by the local people of the mangrove forests.

Validation of mangrove forests

The first focal point in the interview framework was about the intrinsic and practical value of the mangrove forest for the local people. Without awareness about the importance of the mangrove ecosystem, we expected that the replanting project would be less useful and less successful. Replanted sites would then be monitored badly and restored forests would be cut again on the long term. According to our interviews, the mangrove forest was seen as very valuable by the local people. They valued the forest mainly for the resources it provided, but it did not seem to have any religious nor traditional value and the mangrove forest was never mentioned for its intrinsic value. The interviews showed some differences between the two villages. In Buram most people mentioned the function of mangroves as a fish breeding place, and therefore essential for maintaining the village fish stock while in Bali Mandinka, this was mentioned by only one person. In Buram more functions of the mangrove forest were described by the interviewed villagers like the protection the forest offers against wind- and water erosion and also the function of mangroves as a wood resource for future generations. Four people stated that they believe forest induces high rainfall, therefore a degraded forest means less rain. In general those answers indicate that the awareness of the ecological and practical value of the mangrove forest was higher in Buram. They realize the importance of a healthy forest which stimulates them to invest time and money in the replanting project. On the long run, this can have a positive effect on the success of restoration. However, we were unable to observe this after a time span of only 2 years.

Mangrove uses

According to the Wetlands International reports (9), the main reason for forest degradation was clear cutting by the local people. This clear cutting is required to make replanting successful in combination with offering alternative resources for their incomes, to reduce the pressure on the forest. In both villages inhabitants said to use mangrove wood for construction, fencing and firewood collection. However, the amount of wood they extracted differed clearly. Bali Mandinka did not have a lot of alternative wood resources, hence almost the whole wood demand was extracted from the mangroves. Because mangrove wood is very durable and the main tree branches are typically straight, it was regarded as very suitable roofing material. Until six years ago (2004), roofing material was harvested also for commercial purposes and transported to Senegal. Intervention of the Forestry Department brought this to a halt. The situation in Buram was quite different from Bali Mandinka. A rich community forest of 42 ha provided the village with sufficient amounts of wood resources for daily use. Because the mangrove forest was less easily accessible and because of the exuberance of alternatives, almost no mangrove wood was used. Dry mangrove wood was sometimes collected, but the trees were seldom cut for firewood purposes. Fences were seldom and less and less made from mangrove wood. They did not use mangrove wood for roofing either, but they did make flights of stairs from main branches.

Non-timber forest products were extracted in both Buram and Bali Mandinka and included honey, fish, and oyster collection. Here, a difference was observed regarding the oyster collection between both communities. In Bali Mandinka the oysters were collected by cutting the *Rhizophora* roots they were attached to. This can lead to die backs of mangrove trees. In Buram oyster collection was performed in a more sustainable way, by scraping the oysters from the roots without cutting. With this scraping technique, the roots remain intact and mangroves were not harmed. However, we do not regard the oyster collection in Bali Mandinka as a big threat and degrading factor to the mangrove ecosystem as it was not harvested on a big nor a commercial scale. Our field observations and above mentioned interview questions regarding mangrove uses point out that the community of Bali Mandinka depends on the mangroves for their livelihoods, while the community of Buram does not (table 1).

Overexploitation and other causes of mangrove degradation

Overexploitation of forest products, of which predominantly wood, was regarded the main reason for degradation of the mangrove forest in Bali Mandinka. Still, the scars of logging activity are obvious and the sound of woodcutting not exceptional. Since the use of mangrove resources seem to be very limited in Buram, the cause for mangrove degradation should be sought elsewhere. The people in Buram spoke about a die-back without any known reason. In the field we observed many trees in the reference areas that were suffering severely from a worm infection (Fig. 7). This seemed to be the main reason for mangrove degradation in Buram.

Figure 7. Reasons for mangrove degradation. Left: overexploitation of mangrove resources (oyster collection (top) and wood cutting (bottom)). Right *(picture: R. DaCosta)*: Die-back of the forest due to a worm plague.

Offering communities alternative livelihoods should allow them to switch from mangrove-degrading activities to more sustainable sources of income. In communities where forest degradation is caused by overexploitation, it is a way to deal with the cause of the problem. However, when the mangrove forest is not overexploited, as we saw in Buram, the alternative livelihoods as beekeeping and improved salt production do not alleviate the pressure on the forest and only work as an economic incentive.

Embedding of the Wetlands International replanting project within the community

Community Participation and Decision-making

As the ecological factors and the causes of degradation play an important role in the replanting projects, also the organization behind the replanting activities can influence the success of the projects. Therefore we assessed the way the project was incorporated and executed by the local people by taking interviews from key persons in those processes but also from randomly selected people within the communities. Answers showed us that the incorporation of the project in both communities was rather structured. Working groups were established that are responsible for the different executive jobs: site selection, propagule collection, mobilizing community members, propagule planting and monitoring, however, the level of community participation differed per village. In Buram, participation was made obligatory by the village head, which resulted in full community participation. Everybody was involved in one or more of the teams. In Bali Mandinka participation was not obligatory for community members and this made that not all community members were aware of the project and its activities (table 1). From the answers to our interviews it became clear that some had heard of the replanting project, but did not know about the hives and improved salt production. People living around the compound of the chairman of the Village Development Committee (VDC) were very well-informed about all Wetlands International activities. However, further away from this organizational epicenter, people were only vaguely informed. The VDC was responsible for information-sharing about the

program, which was partially done during the regular meetings at the village bantaba[2], announced by the mosque. Hence, everybody willing to participate was able to gather information and join in activities. The contrast between the two communities of Buram and Bali Mandinka can be explained by the village size. Bali Mandinka was at least three times as big as Buram, which makes information-sharing and full community participation harder.

In both Buram and Bali Mandinka, the decision-making was democratic, and the full community was able to participate. All decisions were made by the VDC, which comprises eight man and women that were democratically chosen by the community. They said to be open to suggestions from community members, and some community members clearly showed they felt involved in the decision-making process. In Buram, they handled the replanting program the same way as their community forest. This meant that before program initiation, the VDC called a meeting in which all community members were asked whether they agree upon embarking in the program. Every time a decision needed to be made, the VDC held a meeting that is open to non-VDC members.

Replanting techniques

Mistakes in replanting techniques are often reason for project failure (16), and can therefore be seen as potential pitfall. On basis of interviews and information from Wetlands International, the delegates that went to the training in Pakalinding got trained on propagule selection and handling (49). In both Buram and Bali Mandinka, propagule collection seem to have gone well, and no problems were encountered with obtaining enough ripe propagules (Fig. 8).

About salt, honey and money

The technical tools were given to the communities to switch from their traditional, wood demanding, way of salt production to an improved salt production technique, and to start beekeeping. The improved salt production technique implies that they first filter the salt water. This filtering is done by using a funnel filled with sand. After

Figure 8. Ripe *Rhizophora* propagules

the filtering, the water is led to a plastic tarpaulin where it dries in the sun. This leads to higher quality of the salt and faster production in comparison with the old method, were large and deep basins were used for the production of salt (9). In Buram, a part of the profits from the honey and salt were reinvested in both the maintenance of the hives and salt production material, and mangrove replanting materials. They explained us that this reinvestment amounts 30% of the total profits from salt and honey production. Another 30% was put aside for emergencies for villagers (e.g. funerals), and 40% was put on a village savings account, reserved for village development. The last year, they produced in Buram a total of 35,5 liters of honey from the communal hives and 32 bags of 30 kg of salt. In Bali Mandinka there was no clear bookkeeping the first year. No one knew the quantities of honey and salt production, nor what happened to the profits (table 1). Rumors about

---

[2] Bantaba: Central meeting place in the village

corruption seemed to have very negative impact on the people's attitude towards the project. The old VDC was suspected of spending the profits, which is something nobody wants to work for: "They just sit and eat, sit and eat". On the 1st September 2009, the 'Reconstitution of Bali Mandinka's VDC' was signed. Since then, a bank account was opened on which all profits are put, and a more transparent bookkeeping started. One thing worth mentioning is that the beekeeping really seems to add motivation for mangrove protection. Mangrove honey is the most valuable honey, and degradation of the mangrove forest may results in less profits.

Summarized, the apiculture and improved salt production techniques made it attractive for communities to get involved in the project. Apart from the long-term mangrove replanting, there is the advantage of making money on the short term. However, one has to be cautious attracting people this way. Communities may embark in the project mainly motivated by the envisioned profit from honey and salt production, and their motivation to replant may reach just as far as the end of the project term. However, for successful forest regeneration it is important that it is used sustainable and planted sites maintained for a longer time period. It is therefore of great importance that awareness is raised about the function of the mangroves and necessity to replant. This was done during the training in Pakalinding (49). However, it may be questioned if it is sufficient to raise awareness amongst delegates of different villages. This way, only four people per village are aware of the importance to replant and use the forest sustainable, and it is up to them to spread the word. Therefore, a community-wide information session can help to tackle this problem.

Table 1. Summary of main focus points and differences between Bali Mandinka and Buram according to the interviews. - - = strongly negative, - = negative, +/- = neutral, + = positive and + + = strongly positive.

	Bali Mandinka	Buram
Awareness about ecological functions mangrove forest	- -	+
Use of mangrove wood	- -	+
Use of non-timber products	+ / -	+ / -
Community participation	+ / -	+ +
Democratic decision making process	+ +	+ +
Replanting techniques	+ +	+ +
Salt production and apiculture	+ / -	+
Bookkeeping	+	+ +

The ecological aspects: Discussion

Redox potential and Salinity
The Canonical Correspondence Analysis (CCA) of all explanatory variables showed that a total 51.5 % of data variance was explained by the two ordination axes. This confirms that the selected variables in this study were relevant for the selected proxies. The CCA presented in figure 3 shows that higher Redox values were related with higher mortality rates. The significance of this relationship was additionally confirmed by the Monte-Carlo permutation test. Also salinity showed to be positively related with mortality rates, and showed to be negatively related with average height. A Monte-Carlo permutation test performed on the CCA of figure 5 performed with nutrients and salinity also confirms this relationship. These findings are consistent with previous studies, which showed that high salinity values results in depressed growth of *Rhizophora* seedlings (50). Other studies also report that Rhizophoraceae have optimal performance at salinity levels below 30 percent sea water (SW; Clough 1984, Krauss & Allen 2003, Parida et al. 2004). The influence of salinity on mortality rate showed to be smaller than the influence of the redox potential. However, these two variables are related. Soils with a high redox potential are well-aerated (1). They have a higher evaporation and therefore higher salinity values. Both redox potentials and salinity are influenced by the inundation regime (1), though this is not clearly confirmed by our analyses results. Inundation showed to be related with mortality rate (Fig. 4), but the length of the inundation arrow shows that this relation is very weak. However, this minor influence of the inundation regime on seedling mortality rate is thought to be an underestimation of its real importance. This study was conducted along transects that lacked a steep slope gradient and consequently also lacked variance in the inundation regime. Also the inundation height and duration were not included in this study. This resulted in a small inundation arrow in the CCA results. The strong influence of redox potential and salinity show that the inundation regime is in fact an important factor. This is further confirmed by the high mortality rates we found at the elevated and seldom inundated replanting site in Bali Mandinka.

Nutrients
Concentrations of ammonia are higher in less aerated soils (1). This is confirmed in the CCA of figure 3, where the opposing arrows show that ammonia concentrations were negatively related with redox. Since low redox potentials showed to be associated with low mortality rates and higher growth, it is not surprising to see that also ammonia concentrations were positively related with height growth (Fig. 3). Soils that are frequently inundated and thus less aerated, showed to have higher ammonia concentrations, and the seedlings showed lower mortality rates and higher growth. Phosphate and nitrogen do not seem to have influence on the response variables (Fig. 5 and Fig. X in Appendix E). The fact that the nitrogen arrow is opposing the ammonia arrow supports the interplay between nitrogen and ammonia in absence or presence of oxygen (1). Therefore, the nitrogen arrow can be seen as an extension of the ammonia arrow in the opposite direction. It is typical for mangrove soils that the inorganic nitrogen (except ammonia) and phosphorus concentrations are extremely low (1, 37, 51), which is exactly what our results show us. These concentrations were even less in the reference areas, probably because more nutrients are present in the form of biomass. There were no other big differences between the measures variables of the

replanted and reference areas. Because there were no previous recordings of the reference areas, no yearly mortality rates could be calculated and compared with mortality rates of the replanted areas. To be able to compare mortality rates between replanted and reference areas, repeated measurements should be performed.

Environmental Factors and comparison with the Sine-Saloum Delta.

Seedling density did not show to be very influential, in the CCA of figure 3 can be seen that the three proxies are distant from the seedling density arrow. This is confirmed by our observations from the Sine-Saloum Delta, where high seedling densities did not result in high mortality rates. On the contrary, these seedlings were taller and had more leaves than the seedlings in the Gambian projects, which started in the same period. This reaction can be explained by a competition for light effect and the related self-thinning rule (52, 53). If seedlings are planted in high densities they will try to outcompete each other by investing in growth and leaf production instead of solidity (54, 55). It is remarkable that these seedlings were capable of such fast growth and leaf production, especially considering the saline conditions in this area. At high salinity, *Rhizophora* seedlings are known to allocate more biomass to the root system at the expense of their leaf mass to increase water and nutrient uptake (50). The excessive growth may have been possible because the high seedling density results in high silt accumulation, which enriches the environment with extra nutrients (56, 57). In this study, seedling density did not show to influence mortality rates and growth parameters. This being said, the evaluated replanting projects were all only two years old and high seedling densities may have an impact on mortality rate and seedling growth on the longer run. This is supported by a study of López-Hofmen *et al.* (2006) in which the establishment of *Rhizophora harrisonii* under saline conditions was studied. In this environment, no juveniles or adult trees of *R. harrisonii* could be found, suggesting that although seedlings are able to survive under this saline conditions, they are unable to transit to another stage of life. Mangrove propagule predation by sesarmid and fiddler crabs is a well recorded phenomenon (58-60), but showed not to be very influential in our study. Other environmental factors like damages and diseases did not show not to have significant influence on seedling mortality rates either. The worm infection that we found in Buram only affected older trees.

Bio-Indicators

Results show that there is a weak positive relation of crabs and mudskippers with the measured growth parameters and a negative relation of these bio-indicators with mortality rate (Fig. 4). However, none of them showed any relation with their associated parameters. The positive relation with the growth parameters can possibly be explained by the biological activity they bring about. Crabs can enhance organic breakdown by modifying particle size distribution (47, 48, 59). Mudskippers may add organic material by excreting feces. Because there is no information available about the abundance of crabs before replanting, it cannot be determined whether crab abundance was high at the time of site selection, or they were attracted by the young seedlings after replanting. Further insights in the functioning of bio-indicators can only be obtained when data is recorded before replanting occurred. In the replanting projects of Bali Mandinka and Buram, bio-indicators formed the best available site-selection tool at the moment. Although these indicators are expressions of environmental conditions, the absence of eminent relations with their environmental parameters suggests that they are not important enough to base management strategies on.

This study shows that the bio-indicators do not form a solid base for mangrove replanting site-selection.

The social aspects: Discussion

Awareness of ecological importance

The villagers validated the forest differently, in Buram they realized the ecological importance, where in Bali Mandinka mainly the economic beneficial reasons were mentioned. This was caused by two main differences between the villages. One difference is the village size, which relates negatively to the extent of information sharing. In smaller communities like Buram, it is easier to reach and involve a majority of the people in information sessions and replanting activities. Bali Mandinka is approximately three times as big as Buram, and here information-sharing was much harder. This resulted in a minority of the community that was actively involved in the replanting project and a lower awareness amongst the villagers about the ecological importance of mangrove forest. Another difference between the two villages is their dependency on the mangrove forest for their daily wood supply. In Bali Mandinka there were not many alternative wood resources available. Therefore it is not surprising that they validate the forest primary a source for firewood and wood for construction purposes. In Buram there was a community forest that provided wood for domestic purposes, and mangrove wood was hardly used. Because the village of Buram was less dependent on the mangrove forest for wood supply than Bali Mandinka, there was more emphasis on the ecological functions of the forest, other than only a wood source.

Causes of degradation

As mentioned above, mangrove usage differed between Bali Mandinka and Buram. In Bali Mandinka, overexploitation was clearly the reason for mangrove degradation. In Buram, this was not the case. A worm infection seems to have caused die-backs in mature mangrove stands. It may be questioned if it is sensible to replant an area that is degraded due to a plague or disease and not by overexploitation. When the disease itself is not dealt with, replanting is not the solution that can halt forest degradation. In a study of Lewis (2005) it is argued that too often the real cause of the problem is overlooked and mangrove replanting is seen as the primary restoration tool (7). With the selection of Buram as a pilot project of the replanting programme its position close to the river and presence of degrading mangrove forests may have been regarded, but the reason for forest degradation is insufficiently addressed.

Managing and profits of the project

The decision-making process occurred in both communities in a democratic way. Everyone who wanted to take part and influence the project had the possibility to do so. In both communities there were working groups lead by active community members that voluntarily took on the function of group leader. We also observed in both villages a structured and transparent bookkeeping. In Buram they profited from their managing experiences with their community forest. In Bali Mandinka, however, this was a recent development, as part of the reformation of the VDC. Because there was not a structured bookkeeping in the first

1.5 years, we still noticed a rather reserved attitude toward the project in parts of the village that were less involved. When it is not clear where profits go, the villagers get very discouraged and loose the sense of working for a communal good. This underlines the importance of a transparent bookkeeping and profit distribution, even in villages where trade by barter is common practice. Rules like demanding a yearly financial report and bookkeeping trainings is thought to attribute to a positive attitude towards the project.

The Jasobo case

Initially, three villages were incorporated in the project: Buram, Bali Mandinka and Jasobo. The replanted areas in Buram and Bali Mandinka were incorporated in this evaluation but the one in Jasobo (13°27'46.99"N, 15°40'31.54"W) was not. In August 2008 the project was initiated here just as in Buram and Bali Mandinka, and replanting activities were executed by the villagers. However, after two years, everything had died. The most probable reason after observing the sites together with Wetlands International staff seemed to be low inundation frequency and the resulting high salinity. The seedlings were planted at elevated sites that were too high for the river to reach. A high abundance of Seapurslane indicated high salt concentrations.

Jasobo had to cope with an internal power conflict. The community was divided into two, one part that supported the Alkalo, and one part that opposed the Alkalo. Since it was the Alkalo that agreed upon embarking in the Wetlands International mangrove replanting project, the conflict led to disagreements about the project. After the failure of the first year, the villagers could not agree upon a planting site for the second year. They decided to plant a small trial patch (Fig. 9) with around 100 seedlings to test if the site was suitable for replanting. This time they used the bio-indicators shells and crab holes as selection criteria. Many of the seedlings were still alive when we visited but no hard data are available. We visited this village one day so we were not able to fully evaluate the consequences of this internal power conflict. Conducting field work in Jasobo in the same way as we did in Bali Mandinka and Buram was not possible, as the community was not supportive and the replanted areas were too small to draw transects.

Another observed problem was the location of the site. The replanting sites were located quite far from the village. The walking distance to reach the planting site was over an hour. This long distance between village and replanting site was clearly not motivating for site monitoring. People just monitored a few times a year, which is low in contrast with Buram and Bali Mandinka, where monitoring takes place every month.

Concluding, the selection of Jasobo for the replanting project was unfortunate. The internal power conflict that arose resulted in marginal community support. Motivation was further lowered by the big walking distance of the replanted sites from the village. The Jasobo case supports the idea that the social embedding of the project in the community is no guarantee, but definitely a prerequisite for successful replanting projects.

Figure 9. The trial patch of about 100 seedlings in Jasobo.

Integration of social and ecological aspects

After discussing the ecological and social aspects of The Gambian mangrove replanting projects, we can conclude that both aspects play an important role in the project success. Although the two aspects were discussed separately, they are in fact inevitably connected. A good replanting site selection is meaningless when the villagers are not motivated to replant or maintain the replanted area. Even when the best propagules are selected for replanting, overexploitation may continue if the people are not aware of the importance of the forest.

One of the first steps in the program implementation is the project site selection. This study shows the importance of some selection criteria. Only communities in the right ecological setting should be selected for participation in a mangrove replanting project. To avoid complicated manuals about finding appropriate ecological settings, we propose that this setting can be assumed when two ingredients are present. First, the reason for mangrove forest degradation is overexploitation. This means that the soil- and ecological conditions are suitable for mangroves, and that they therefore can regenerate when pressure is taken off and seedlings are replanted. Second, the hydrological conditions did not change dramatically (e.g. due to the construction of a dam) since degradation started. Besides a suitable ecological setting, it showed to be important to select villages that have a stable organization. Smaller villages are preferred over bigger villages for program implementation. In the selected villages, awareness has to be raised and information sessions about replanting techniques have to be given. The training that was given in Pakalinding for a delegation of Buram and Bali Mandinka showed to be a strong point in the program implementation in the Gambia. It resulted for example in good propagule selection and the establishment of effective working groups. It showed to be essential that good site selection criteria are developed to avoid trial and error scenarios. In our study we saw that the first replanting year was less successful than the second, mainly because the inundation regime was overlooked. Except for avoiding trial and error scenarios by paying attention to ecological site selection criteria, several things can be done to enhance motivation amongst the community members. Amongst others, these include a transparent bookkeeping and a reasonable walking distance to the replanted site.

Answer to the Research question

Our study showed that most important soil- and ecological factors that determine seedling mortality in the Wetlands International replanting projects in The Gambia are formed by the inundation regime, and related salinity values and redox potentials. Planting sites were merely selected with the use of bio-indicators. Our study showed that the relation that these indicators show with their related parameters is not discriminating enough to base management decisions on and thus do not form a solid base for selection of the replanting site. Further research is needed to further investigate the functionality of these bio-indicators. The project was well-embedded in the community. Focus points of this study included information-sharing, equity in power- and profit distribution and decision-making. However the awareness about the ecological functions of the forest could have been higher,

the villagers seemed conscious, motivated and organized about the replanting work. Information-sharing was less in bigger villages, there was equality in profit- and power distribution and the decision-making process was democratic. It is too early to tell whether the set-up of the replanting projects in The Gambia is applicable in other Gambian communities. The second year after replanting was more successful than the first, however, the success on the long run (all the way to full forest regeneration) cannot be predicted after only two years. To conclude, the main research question can be answered.

What are the key factors that determine successful mangrove replanting in the Wetlands International Gambia community projects?

There are both ecological and social key factors that determine the success of the Gambian replanting projects. Social key factors for successful project implementation showed to be awareness of the ecological importance of a healthy mangrove ecosystem, a stable and strong community organisation and a transparent bookkeeping. The most important ecological key factors that played a role in mangrove seedling survival showed to be the inundation regime and related redox potentials, ammonia concentrations and salinity levels.

Conclusions

The aim of this study was to find the key factors that determine mangrove replanting success in The Gambia. With this objective, a field study was conducted to evaluate two mangrove replanting projects in Buram and Bali Mandinka. Results confirm several relations that were known from literature. Key factors that played a role in mangrove seedling survival showed to be the inundation regime and related redox potentials, ammonia concentrations and salinity levels. Ammonia showed to relate positively with height growth, while salinity and redox potential showed to have a negative relation with mortality rates. Other measured parameters showed to contribute little to a total of 51% of data variance that could be explained by the selected parameters. Social key factors for successful project implementation showed to be awareness of the ecological importance of a healthy mangrove ecosystem, a stable and strong community organisation and a transparent bookkeeping.

Practical implications

The obstacles we encountered and observed in the pilot projects in Buram, Bali Mandinka and Jasobo, provide us with valuable information that allows us to formulate some recommendations for future projects.

Project site selection
Coupling alternative livelihoods with replanting alleviate both poverty and the pressure on the forest. However, it is only effective when the reason of forest degradation is overexploitation. As seen in Buram, the forest was degraded by a worm infection and not by overexploitation. In fact, their main wood resource was a community forest and not the mangrove forests. Here, replanting in combination with offering alternative livelihoods has little effect. Replanting makes less sense since the disease is expected to kill the seedlings in a later stage in succession. First, the disease should be challenged before replanting starts. It is therefore recommended that during project site selection, the reason for forest degradation is elaborately assessed. When we add the experiences from Jasobo where there was an internal power conflict, we will recommend only to include communities into the Wetlands International mangrove rehabilitation project that have a stable and strong organization. Because the project requires a lot of organization, it is additionally recommended to include only smaller communities, up to 400 inhabitants, to make information sharing, decision making and community participation easier.

Planting site selection
Our results showed that the interstitial pore water salt concentration and the redox potential in the top soil are playing an important role in the success of mangrove replanting. During the Wetlands International training in Pakalinding, emphasis within the site selection criteria was mainly on the inundation regime and salinity. However, in these criteria it was not specified when exactly the site selection should be conducted. Before planting, site selection should occur in dry season before replanting, but is often done at the start of the raining season. During the raining season, both river water level and precipitation are higher than during dry season. This leads to sites which are regular inundated during raining season but not during dry season. Though, the seedlings need to survive the dryer periods of the year as well. Therefore, we advise to perform the site selection at the end of the dry season to safeguard full year water supply for the seedlings. Hereby, the salinity values in the interstitial pore water en the redox are expected to be correct if the inundation conditions are right and replanting is done at sites were mangrove forest occurred in the past. Detailed topographic maps can be helpful in this case to search more effectively for such areas and are directly accessible on the internet. To prevent scenarios of trial and error, it is recommended to actively join in the site selection process in the first year, and to monitor the site selection process closely for the next two years.

More study is needed to determine the ecological key factors for more detailed site selection criteria. Also the functionality of the bio-indicators should be investigated. A research to the functionality of the bio-indicators should start before new replanting sites are chosen. The ideal situation for this research would be to set up permanent sample plots before the replanting starts, that are maintained for several years, preferably until the forest

is fully regenerated. Measurements of soil characteristics, inundation regime (including height, frequency and duration) and counting of the bio-indicators should be performed on regular basis. Except for the abundance of bio-indicators, as much parameters as possible should be kept identical. The bio-indicators can then be related to changes in soil composition, vegetation development and seedling mortality rates. Our study results do not allow us to scientifically recommend the use of these indicators.

Enhancing long-term motivation and awareness raising
Complete mangrove forest regeneration takes much longer than the Wetlands International project term of two years. It is therefore desired that after the project term, people continue to use the forest resources sustainable and continue to maintain the replanted areas. It is recommended that awareness is raised, not only during the delegates training, but amongst all villagers. This can be achieved e.g. by giving an open information session at the local school, or hand out posters and leaflets. This awareness is important to keep people motivated on the longer term. If they see the importance of healthy mangroves for e.g. a healthy fish stock, protections against erosion and flooding, replanting will make more sense and there is a smaller chance people will cut it again. In Bali Mandinka, where mangrove wood is used for daily needs, the project can be more successful on the long term if the villagers learned to cut in a sustainable way. Cutting cannot be stopped totally in this village and generally cutting is done by clearing greater patches. Mostly people cut the wood which is easiest accessible, without selecting specific trees or species (61). By cutting selectively, the negative inpact on the mangrove forest will be reduced.

Since we observed that some control from Wetlands International increased the commitment and motivation, we propose to extend the monitoring period with some years (proposed to add three more). We consider it advisable to ask the Treasurer for an annual report on production quantities and destination of products. This will both enhance motivation and transparency of profit distribution. In case of insufficient knowledge about bookkeeping, we advise to add a section bookkeeping to the training.

Acknowledgements

Reference list

1. Hogarth PJ. The biology of mangroves and seagrasses. New York, US: Oxford University Press; 2007.

2. Kirui B, Huxham M, Kairo J, Skov M. Influence of species richness and environmental context on early survival of replanted mangroves at gazi bay, kenya. Hydrobiologia. 2008 05/01/;603(1):171-81.

3. Kairo JG, Lang'at JKS, Dahdouh-Guebas F, Bosire J, Karachi M. Structural development and productivity of replanted mangrove plantations in kenya. For Ecol Manage. 2008 4/20;255(7):2670-7.

4. Walters BB, Rönnbäck P, Kovacs JM, Crona B, Hussain SA, Badola R, et al. Ethnobiology, socio-economics and management of mangrove forests: A review. Aquat Bot. 2008 8;89(2):220-36.

5. Dahdouh-Guebas F, Koedam N. Long-term retrospection on mangrove development using transdisciplinary approaches: A review. Aquat Bot. 2008;89(2):80-92.

6. Thailand steps up efforts to reclaim lost mangroves [homepage on the Internet]. Bangkok; 2009 [updated 20/10/2009. Available from: http://www.voanews.com/engilsh.

7. Lewis III RR. Ecological engineering for successful management and restoration of mangrove forests. Ecol Eng. 2005 4/5;24(4):403-18.

8. National Environment Agency. Inventory of coastal resources vulnerable to climate and shoreline changes. cape verde, the gambia, guinea bissau, mauritania and senegal. National Environment Agency, Ministry of Environment and Protection of Nature Department of Environment and Classified Establishments; 2006.

9. Da Costa, Mamadou. Improving the traditional salt exploitation system by sun-dried salt production technique on tarpaulin in bali mandinka, republic of gambia. Wetlands International; 2009.

10. [homepage on the Internet].; 07 september 2010. Available from: http://unfccc.int/meetings/intersessional/barcelona_09/items/5024.php.

11. Africa's disappearing wetlands produce 'alarming' levels of greenhouse gas [homepage on the Internet]. Dakar; 2009 [updated 11/10. Available from: http://www.voanews.com/engilsh.

12. Strangmann A, Bashan Y, Giani L. Methane in pristine and impaired mangrove soils and its possible effect on establishment of mangrove seedlings. Biol Fertility Soils. 2008 02/01/;44(3):511-9.

13. Wetlands International. Activities implemented in the gambia. 2008.

14. Bojang F, Reeb D. Community forest ownership: Key to sustainable forest resources management. the gambian experience. Forestry Department, Banjul, The Gambia; 1998.

15. Wetlands International. Hive distribution and installation in WAMI project sites in the gambia. 1998.

16. Wibisono ITC, Suryadiputra INN. Study of lessons learned from Mangrove/Coastal ecosystem restoration efforts in aceh since the tsunami. Bogor: Wetlands International - Indonesia Programme; 2006.

17. Primavera JH, Esteban JMA. A review of mangrove rehabilitation in the philippines: Successes, failures and future prospects. Wetlands Ecol Manage. 2008;16(5):345-58.

18. Koch MS, Snedaker SC. Factors influencing rhizophora mangle L. seedling development in everglades carbonate soils. Aquat Bot. 1997 11;59(1-2):87-98.

19. Feller IC. Effects of nutrient enrichment on growth and herbivory of dwarf red mangrove (rhizophora mangle). Ecol Monogr. 1995 Nov.;65(4):477-505.

20. Field CD. Mangrove rehabilitation: Choice and necessity. Hydrobiologia. 1999 10/01/;413(0):47-52.

21. Kellert SR, Mehta JN, Ebbin SA, Lichtenfeld LL. Community natural resource management: Promise, rhetoric and reality. Society and Natural Resources. 2000;13(8):705-15.

22. Moore SA, Rockloff SF. Organizing regionally for natural resource management in australia: Reflections on agency and government. Journal of Environmental Policy and Planning. 2006;8(3):259-77.

23. Armitage D. Adaptive capacity and community-based natural resource management. Environ Manage. 2005;35(6):703-15.

24. Knapp S. The community forests of mexico - managing for sustainable landscapes. In: Bray DB, Merino-Pérez L, Barry D, editors. Biological Conservation. University of Texas Press; 2006. p. 406-7.

25. Dahdouh-Guebas F, Collin S, Lo Seen D, Rönnbäck P, Depommier D, Ravishankar T, et al. Analysing ethnobotanical and fishery-related importance of mangroves of the east-godavari delta (andhra pradesh, india) for conservation and management purposes. Journal of Ethnobiology and Ethnomedicine. 2006;2.

26. Ferreira TO, Otero XL, Vidal-Torrado P, Macias F. Redox processes in mangrove soils under rhizophora mangle in relation to different environmental conditions. Soil Sci Soc Am J. 2007 March 12;71(2):484-91.

27. Matthijs S, Tack J, van Speybroeck D, Koedam N. Mangrove species zonation and soil redox state, sulphide concentration and salinity in gazi bay (kenya), a preliminary study. Mangroves Salt Marshes. 1999 12/01/;3(4):243-9.

28. McKee KL, Mendelssohn IA, Hester MW. Reexamination of pore water sulfide concentrations and redox potentials near the aerial roots of rhizophora mangle and avicennia germinans. Am J Bot. 1988 Sep.;75(9):1352-9.

29. Tomlinson PB. The botany of mangroves. Ashton PS, Hubbell SP, Janzen DH, Raven PH, Tomlinson PB, editors. United States of America: Cambridge University Press; 1986.

30. Camara K. Socio-economic survey on gambian mangroves -country paper. West-African Mangrove Initiative (WAMI); 2007.

31. Dodd RS, Fromard F, Rafii ZA, Blasco F. Biodiversity among west african rhizophora: Foliar wax chemistry. Biochem Syst Ecol. 1995 12;23(7-8):859-68.

32. Kane KL. Directory. In: The Gambia and Senegal. 4th ed. Lonely Planet; 2009. p. 256-320.

33. Zee FFvd. Botanische samenstelling, oecologie en erosiebestendigheid van rivierdijkvegetaties. Enschede: Febodruk; 1992.

34. Keeling HC, Phillips OL. A calibration method for the crown illumination index for assessing forest light environments. For Ecol Manage. 2007;242(2-3):431-7.

35. Dawkins HC, Field DRB. A long term surveillance system for british woodland vegetation. . 1978.

36. Walton ME, Le Vay L, Lebata JH, Binas J, Primavera JH. Assessment of the effectiveness of mangrove rehabilitation using exploited and non-exploited indicator species. Biol Conserv. 2007 8;138(1-2):180-8.

37. Holguin G, Vazquez P, Bashan Y. The role of sediment microorganisms in the productivity, conservation, and rehabilitation of mangrove ecosystems: An overview. Biol Fertility Soils. 2001 04/09;33(4):265-78.

38. Polgar G. Species-area relationship and potential role as a biomonitor of mangrove communities of malayan mudskippers. Wetlands Ecol Manage. 2009 04/01;17(2):157-64.

39. Lokhande VH, Nikam TD, Penna S. Biochemical, physiological and growth changes in response to salinity in callus cultures of sesuvium portulacastrum L. Plant Cell, Tissue and Organ Culture. 2010:1-9.

40. Lokhande VH, Nikam TD, Suprasanna P. Sesuvium portulacastrum (L.) L. a promising halophyte: Cultivation, utilization and distribution in india. Genet Resour Crop Evol. 2009;56(5):741-7.

41. ter Braak CJFt, Smilauer P. CANOCO reference manual and CanoDraw for windows user's guide: Software for canonical community ordination (version 4.5). Ithaca, NY, USA: Microcomputer Power; 2002.

42. Kovach WL. MVSP - A MultiVariate statistical package for windows. 2005;3.1.

43. Jongman RHG, ter Braak CJF, van Tongeren OFR. Data analysis in community and landscape ecology. Cambridge, UK: Cambridge University Press; 1995.

44. Qualitative research methods: A data Collector's field guide. module 2: Participant observation. In: Denzin NK, Lincoln YS, editors. The Sage Handbook of Qualitative Research. 3rd ed. Thousand Oaks, CA: Sage Publications.

45. Dewalt KM, Dewalt BR. Participant observation. Oxford, UK: AltaMira Press; 2002.

46. Berkwits M, Inui TS. Making use of qualitative research techniques. Journal of General Internal Medicine. 1998;13(3):195-9.

47. Kristensen E, Alongi DM. Control by fiddler crabs (uca vocans) and plant roots (avicennia marina) on carbon, iron, and sulfur biogeochemistry in mangrove sediment. Limnol Oceanogr. 2006;51(4):1557-71.

48. Kristensen E. Mangrove crabs as ecosystem engineers; with emphasis on sediment processes. J Sea Res. 2008 2;59(1-2):30-43.

49. Pakalinding Travellers Lodge. Capacity-building of mangrove management comittees. 2008.

50. López-Hoffman L, DeNoyer JL, Monroe IE, Shaftel R, Anten NPR, Martínez-Ramos M, et al. Mangrove seedling net photosynthesis, growth, and survivorship are interactively affected by salinity and Light1. Biotropica. 2006;38(5):606-16.

51. Krauss KW, Lovelock CE, McKee KL, López-Hoffman L, Ewe SML, Sousa WP. Environmental drivers in mangrove establishment and early development: A review. Aquat Bot. 2008 8;89(2):105-27.

52. Li B, Wu H, Zou G. Self-thinning rule: A causal interpretation from ecological field theory. Ecol Model. 2000;132(1-2):167.

53. Lonsdale WM. The self-thinning rule: Dead or alive? Ecology. 1990 Aug.;71(4):1373-88.

54. Arenas F, Viejo RM, Fernández C. Density-dependent regulation in an invasive seaweed: Responses at plant and modular levels. J Ecol. 2002;90(5):820.

55. Weiner J, Berntson GM, Thomas SC. Competition and growth form in a woodland annual. J Ecol. 1990;78(2):459.

56. Furukawa K, Wolanski E. Sedimentation in mangrove forests. Mangroves Salt Marshes. 1996 03/01;1(1):3-10.

57. Ishikawa Y, Sakamoto T, Mizuhara K. Effect of density of riparian vegetation on effective tractive force. Journal of Forest Research. 2003 11/01;8(4):235-46.

58. Ellison AM. Mangrove restoration: Do we know enough? Restor Ecol. 2000;8(3):219-29.

59. Cannicci S, Burrows D, Fratini S, Smith III TJ, Offenberg J, Dahdouh-Guebas F. Faunal impact on vegetation structure and ecosystem function in mangrove forests: A review. Aquat Bot. 2008 8;89(2):186-200.

60. Smith III TJ, Chan HT, McIvor CC, Robblee MB. Comparisons of seed predation in tropical, tidal forests from three continents. Ecology. 1989;70(1):146-51.

61. Walters B. Local management of mangrove forests in the philippines: Successful conservation or efficient resource exploitation? Hum Ecol. 2004;32(2):177-95.

Appendix A

Figure 10. Locations of the transects in Bali Mandinka. REF are the reference areas and RP are the replanted areas. The numbers are similar to the transect numbers.

Figure 11. Locations of the transects in Buram. REF are the reference areas and RP are the replanted areas. The numbers are similar to the transect numbers.

Appendix B

Interview Questions

Note: Date, interviewee, village, gender

1. What is your age/ profession / marital state

2. What is your family situation?

3. What are your activities (sources of income)?

4. Do you use mangrove wood and for which purposes? Only daily needs or also commercial?

5. How do you value the mangrove forest? Is the health of the forest important?

6. What do you think about the replanting project that started here two years ago?

7. Did you cooperate in the replanting?

   ➢ If yes, in what function/activities?

   ➢ If yes, do you still invest time in the project? How many hours a week?

8. Why do/don't you participate in the project?

9. Can everybody (equally) participate in the project?

10. How is the decision-making process? / Who makes the decisions about the project? Is this person or official body chosen democratically?

11. Do you have any influence on the decisions made?

12. Would you like to change anything in the project?

13. Do you think the project as it is now is going to be a success (will it evolve in a mature forest?)

14. Did something change in your normal way of life since the project started? Did it increase your income?

15. How is the profit distributed amongst community members?

16. What do you think is the biggest threat to the forest?

   ➢ If the person fulfilled a significant role in the replanting activities:

17. Can you explain step by step what your activities were?

Appendix C

Table 2. The range, median (M), standard error (SE) and sample size (n) of all measured parameters of replanted and reference areas.

|	Replanted Area				Reference Area			
	Range	*M*	*SE*	*n*	*Range*	*M*	*SE*	*n*
Soil characteristics								
Salinity (ppt)	14 to 55	32	1.67	42	14 to 51	30.0	1.16	58
Ammonia (mg/L)	0.1 to 5	2.14	0.27	38	0 to 3	0.25	0.09	47
Nitrogen (mg/L)	0 to 5	0.4	0.16	40	0 to 3.5	0.2	0.08	57
Phosphate (mg/L)	0 to 2	0	0.08	26	0 to 2	0	0.08	26
PH	6.18 to 7.6	6.76	0.05	35	4.65 to 7.15	6.22	0.08	47
Redox (mV)	-145 to 391	172	26.5	35	-190 to 355	160	22.0	47
Vegetation characteristics								
Seedling density (#/m^2)	0 to 5	1.51	0.14	60	0 to 11.8	1.84	0.37	60
Pneumatophores (#/plot)	0 to 200	0	5.1	60	0 to 1000	475	48.6	60
Mortality Rates (2008)	0 to 1	0.69	0.06	32	n.v.t.	n.v.t.	n.v.t.	
Mortality Rates (2009)	0 to .83	0.26	0.04	28	n.v.t.	n.v.t.	n.v.t.	
Average seedling height	25 to 60	45	1.35	47	13 to 45	25	1.14	39
Average amount of leaves	4 to 93	10	2.95	47	2 to 40	4	0.95	39

Appendix D
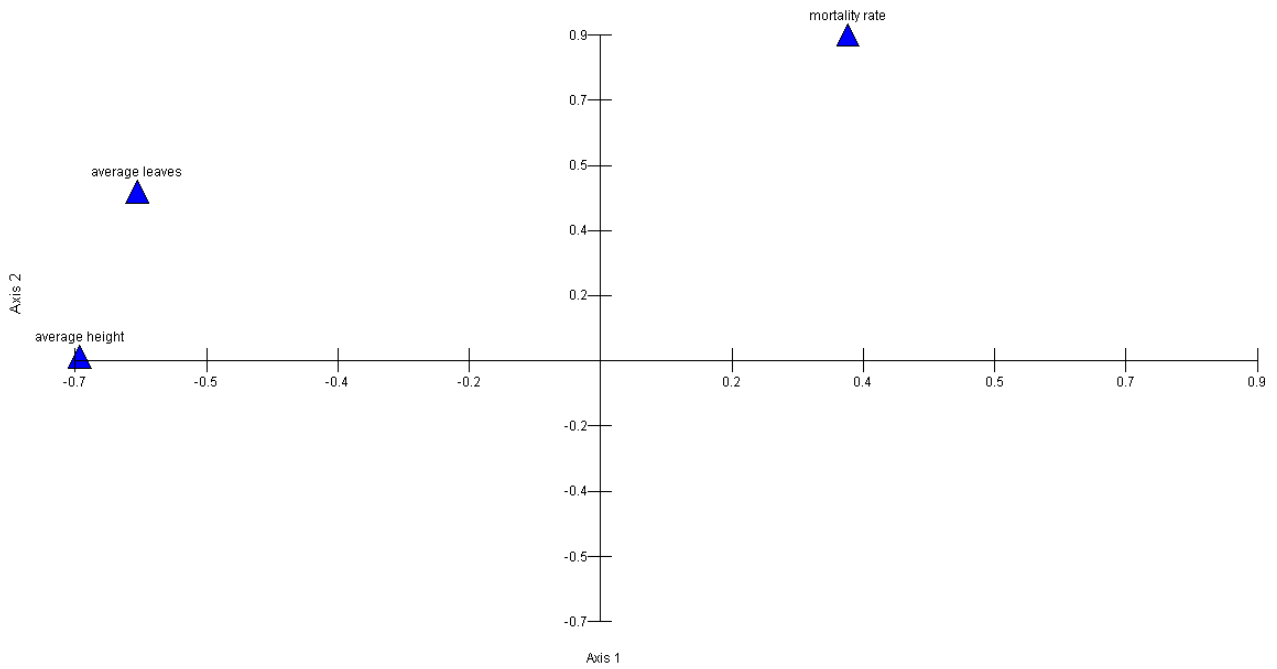
Figure 12. *Biplot of a Principal Components Analysis (PCA) shows the three response variables mortality rate, average amount of leaves and average height.*

Appendix E
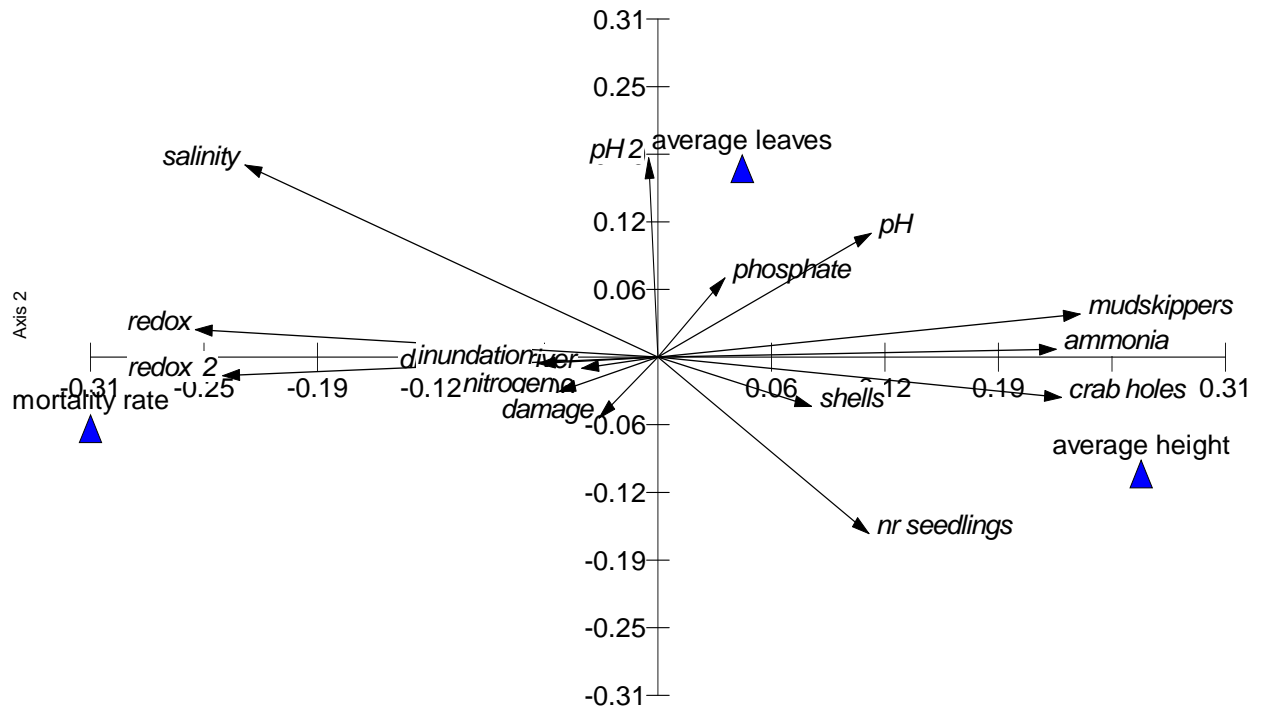
Figure 13. *Biplot of a Canonical Correspondence Analysis (CCA, vector scaling 0.41) with all explanatory variables included, in respect to the response variables mortality rate, average amount of leaves and average height.*

Appendix F
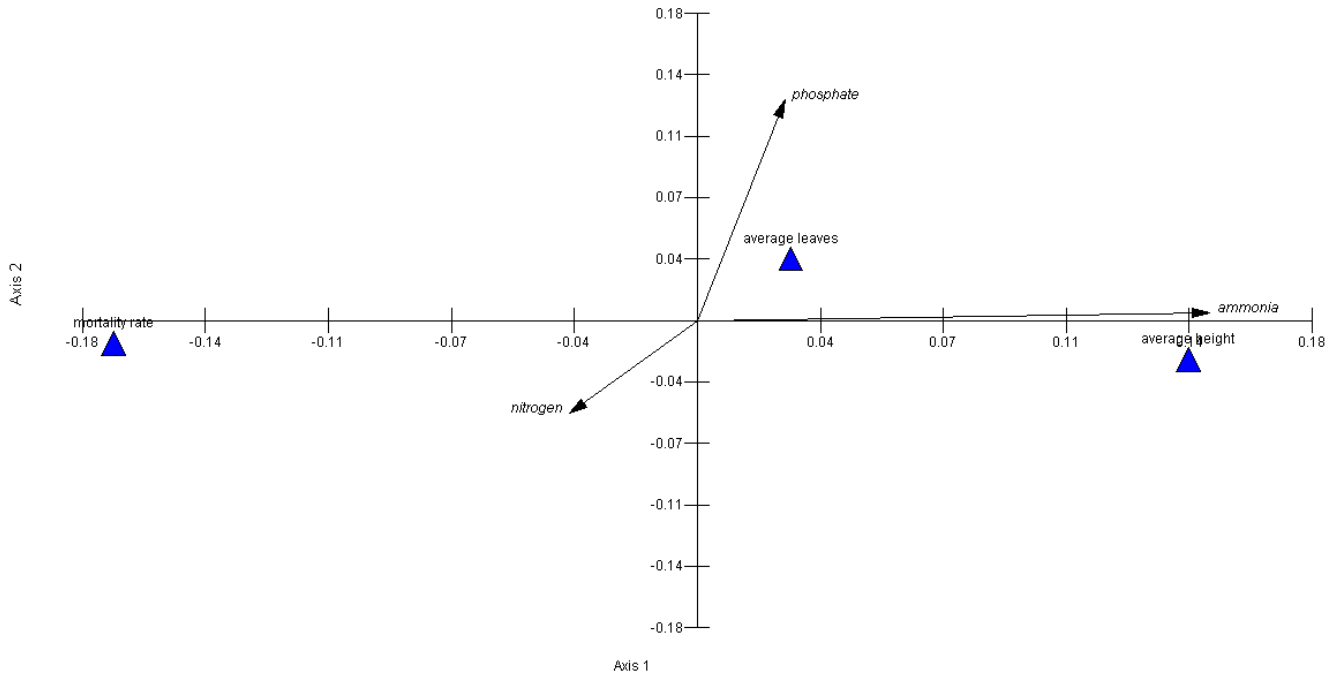
Figure 14. *Biplot of a Canonical Correspondence Analysis (CCA, vector scaling 0.16) with the nutrients Phosphate, ammonia and nitrogen in respect to the response variables mortality rate, average amount of leaves and average height.*

Appendix G

Table 3. All measured values from the Sine-Saloum Delta. Redox was not measured due to a broken redox sensor.

transect	distance to river (m)	Salinity (ppt)	Nitrogen (mg/L)	Phosphate (mg/L)	Ammonia (mg/L)	PH	average height (cm)	average leaves (#)	Mortality rate (%)
Saloum1	16.9	74	0.3	0.1	x	6.81	65	31	0.44
Saloum2	22.8	53	0	0.25	1.5	6.69	52	65	1.00
Saloum3	29.8	58	x	0.03	x	6.61	45	21	0.64
Saloum4	36.9	64	0.1	0	2	6.71	x	x	1.00
Saloum5	42.5	64	0	0.25	1	6.37	30	12	0.82
Saloum6	47	59	0	0	0.1	6.64	75	49	0.00
Saloum7	18.7	60	0	0	x	6.73	66	63	0.00
Saloum8	14.1	58	0.3	0.2	x	6.62	70	88	0.99
Saloum9	0	54	0.8	x	x	6.85	77	38	0.00
Saloum10	0	x	x	x	x	7.06	71	43	0.00