Floating Mangrove Garden

EXPLORING FEASIBILITY OF GROWING MANGROVE ON FLOATING ISLANDS IN THE MALDIVES

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Arnhem, August 2012

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by

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Arnhem, August 2012

DECLARATION

I hereby declare that this report contains no materials which have been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this report contains no materials previously published or written by another person, except where due reference is made in the text of the report.

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Jingwen Liu

27-08-2012

PREFACE

The report you are reading is my graduation thesis for the conclusion of my Bachelor program at Land and Water Management, Van Hall Larenstein, University of Applied Sciences. Moreover, it is also a conclusion of my internship at Nautilus Eco-Civiel B.V in the Netherlands.

Furthermore I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I want to thank my supervisor Mr. Jan de Jager and Mr. Sjoerd Endel, who provided me the opportunity to join this interesting project. Jan has offered me lots of useful books and materials about Maldives and mangroves. These materials played a big role in accomplishing the report. I also got an excursion chance to study and have a look at real mangroves.

I am deeply indebted to my adviser Mr. Hans van den Dool, only with his help and advice could this thesis become more regular and well-constructed. Even though we were not able to talk face to face due to long distance, we still did a good job by phone and e-mails. Thanks for your effort Sir, I really appreciate it.

The Maldives Meteorological Service Climate Section has been a great help for the specific data of the Maldives. These data were very helpful when analyzing the project area.

I am extremely grateful to my boyfriend, Jos van de Greef, for his advice and help in checking my grammar and sentences. He gave me good surroundings to write, and encouraged me when I felt uptight about the thesis. I would like to give my special thanks to him whose patient love enabled me to complete this work.

Many thanks to Hans and Wilma van de Greef, who lend me their expertise in the structure of a paper.

Today I finished my report and I will continue to challenge myself with what I have learned. This is not the end but only the start.

Jingwen Liu

27-08-2012, Arnhem

GLOSSARY

Aerial root	root above the ground
Atoll	a coral island (or islands) that encircles a lagoon partially or completely.
Ecosystem	a system formed by the interaction of a community of organisms with their physical environment
Estuary	the wide part of a river where it nears the sea; fresh and salt water mix
Food chain	a community of organisms where each member is eaten in turn by another member
Food web	a community of organisms where there are several interrelated food chains
Habitat	the type of environment in which an organism or group normally lives or occurs
Intertidal zone	area of or relating to the littoral area above the low-tide mark
Littoral	the region of the shore of a lake or sea or ocean
Offshore	at some distance from the shore
Photosynthesis	synthesis of compounds with the aid of radiant energy
Pneumatophores	an air-filled root (submerged or exposed) that can function as a respiratory organ of a marsh or swamp plant
Precipitation	the quantity of water falling to earth at a specific place within a specified period of time
Seedling	a very young plant that grown from a seed
Subtropical	even near the equator vegetation at 5000 ft is subtropical rather than tropical
Tropical	relating to or situated in or characteristic of the tropics (the region on either side of the equator)

SUMMARY

The Maldives is a small island country located in the Indian Ocean region. Due to global warming the sea level keeps rising. By the year 2100 the sea level will be 2-5 meters higher than in the year 2000. However, the average elevation of the Maldives is only 1.6 meters. In this view, if no measures are taken within a 100 years the archipelago will be submerged by water and disappear from the map.

So the Maldives government does its utmost to save the country. Recently the government has come up with the idea to build floating gardens, to increase the land area of the country. The floating mangrove island is a part of this project. Mangroves are typical, tropical specialized trees growing in saline and brackish water systems, and it has specifically adapted itself with aerial and salt-filtering roots and salt-excreting leaves which enable them to occupy the saline wetlands where other plant life cannot survive.

This report analyzes the feasibility of growing trees on artificial floating islands in the Maldives.

There are 13 mangrove species that grow in the Maldives. To find out the most suitable species, the thesis used a Multi-Criteria Decision Making method. It contains three main parts, which are ecological conditions, practical demands and economic factor. The ecological conditions which include air and water temperature, insolation1, wind, nature of soil and drainage, soil salinity, groundwater level and freshwater source. The practical demands describe height of the trees and maintenance requirement. The economic factor refers to the price of young trees. These factors are weighted and valued according to their importance.

The two highest value mangrove species come out after summing up all the value together, they are *Avicennia marina* and *Pemphis Acidula*.
The species may be used in the floating mangrove garden, an impression is given of the basic structure of the floating garden, which is expected to be used in the Maldives floating mangrove gardens project.

[1] Insolation: Incident Solar Radiation, a measure of solar radiation energy received on a given surface area and recorded during a given time.

Table of Contents

1. INTRODUCTION

1.1 Project Background

Figure 1. Location of Maldives (Watts, 2009)

The Republic of the Maldives is an island nation in the Indian Ocean (Figure 1), which is formed by 1190 coral islands. Only 202 of these islands are inhabited. Maldives is an island nation that straddles two hemispheres, the biggest part is in the northern hemisphere. The islands are grouped into 26 natural atolls and 19 atolls for administrative purposes. Most of the atolls have a ring-shaped coral reef island, which is called a lagoon. The sizes of the islands mostly range between 0.5 and 5 square km. These islands are flat and without hills or rivers. Nearly 80% of the land area is less than 1m above average high tidal level (Ministry of Home Affairs, 2001)
The Maldives is famous for the beautiful atolls and natural spots, which are attracting a large number of tourists every year. The country is given the nick name "a tear drop of the God" by the public. However, the Maldives is facing a severe problem now: sea level rise. If the rampant global warming does not stop, the sea level will keep rising, and by

the year 2100 the sea level will be 2-5 meters higher than in the year 2000 (Sea Level Rise Projections to 2100, 2011). The average elevation of the Maldives is 1.6 meters. In this view, if no measures are taken within a 100 years the archipelago will be submerged by water and disappear from the map.

The threat from sea level rise is serious. The Maldives government is trying with might and mean to save their country. The government considered to divert money from tourism into buying new homeland from nearby countries. Recently, another idea has been proposed. The nation has signed an agreement with a Dutch company-Dutch Docklands. The Dutch Docklands will develop several floating gardens inside the island nation, these are meant to increase the land area, and also to make a more aesthetic living environment for the Maldives.

The Dutch Docklands has made a master plan (Appendix I) of building floating gardens in the Maldives, including a floating golf course and several floating villas .

The purpose of this is to find a new place to live. There are about 40 floating villas planned to be installed between the atolls. For greening purpose there will be floating gardens added to connect with these villas(Figure 2). These floating garden can increase the biodiversity of the Maldives. When the floating gardens get included in the food web, then the "artificial nature" can become real nature. In this sense, the floating villas and gardens will be the pioneers of new ways to solve the sea level rising problem. This can be a big success for the world if the project is successful. The Dutch company Nautilus Eco-Civiel b.v. is in charge of the floating garden project.

Figure 2. A floating villa with a floating garden

Nautilus is an all-round enterprise in the young dynamic sector of "bio-civil" engineering. They offer materials including Gabions, and Aqua-Flora products, and use ecological ways to solve environmental problems. Now Nautilus starts to think about putting Nautilus's floating islands to use in the lagoons, which need special aquatic plants and special design of the floating gardens. Nautilus suggests that these "special aquatic plants" can be mangrove trees. This thesis studies the feasibility of growing mangrove trees on the floating garden, and if it is possible, how to make the floating garden a success.

1.2 Problem Definition

Nautilus Eco-Civiel b.v. is in charge of designing and building floating mangrove gardens. The floating garden as a sustainable eco-production has several significant advantages:

- They float, so the sea level rise has no influence to the gloating gardens.
- It could be used as a green part of the villa.
- Mangroves can cool down the temperature of the villa.
- Mangrove gardens can make the air fresher.
- Mangroves can form habitats for flora and fauna, and improve the biodiversity of the Maldives.

The location of the floating gardens is inside the lagoons. Lagoons are shallow bodies of water that are separated from larger bodies by barriers like the coral reef. In this regard, the atoll lagoons are interesting location since they are connected with freshwater at one side and seawater at the other. Most of the vegetation cannot survive in the high density of salt water, because cells of vegetation would be dehydrated by the different concentrations of salt. However, a few specialized plants are able to grow in lagoons or coastal areas, such as banyan, screw pine, mangroves etc. Mangroves grow well with brackish water and even in water with high concentrations of salt (Monks, 1995).

Due to the water conditions in the lagoons the floating islands need specific plants to grow inside. One candidate could be mangroves. The habitat of each mangrove species is different, and so this thesis tries to find out the most suitable mangrove species for floating gardens in the Maldives.

1.3 Research Questions

The main question of this report is: what mangrove species are suitable for planting in the floating gardens inside the project area of the Maldives?

To find the answer to the main question, there are some sub-questions that need to be answered first[2].

- What is the mangrove growth situation in the Maldives and how many species are currently present?
- What are the ecological conditions for mangrove growth?
- What are the practical demands for mangroves of the floating island?
- What is the economic factor of each mangrove species?
- How to value these factors and how to choose the most suitable mangrove species?

1.4 Research Objective

The main objective of this thesis is to present mangrove species that can be planted in the floating mangrove garden inside project area of the Maldives. This will be done with a desk top study, including a Multi-Criteria Decision Making method.

1.5 Content of Chapters

Chapter 2 introduces methods that were applied in this research, and chapter 3 gives an overview of mangrove trees and mangrove species that grow in the Maldives. In chapter 4 you can read the analysis of different data that are related to mangrove growth with using the Multi-Criteria Decision Making method, and the fifth chapter give a result of the research. In chapter 6 you will see the basic structure of floating mangrove gardens. The chapter 7 discussed the accuracy of the research and floating mangrove gardens. In the eighth chapter you will find conclusions, and also recommendations for the designers who are in charge of designing the floating gardens.

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[2] The research questions have been modified and improved due to a better and more accurate result. Also see Appendix II

1.6 Reading Public

This thesis is written for Nautilis Eco-Civiel b.v., and the designers who will devise the structure of floating mangrove gardens. The thesis is also written for the examination committee of Van Hall Larenstein, University of Applied Sciences. And last but not least for the public who is interested in mangrove research

2. RESEARCH METHOD

2.1 Case Study

The location of the project is approximately 20.8 kilometers north-west of Male

(Figure 3). About 40 floating villas will be installed in the lagoon and the floating mangrove gardens will be connected to each floating villa.

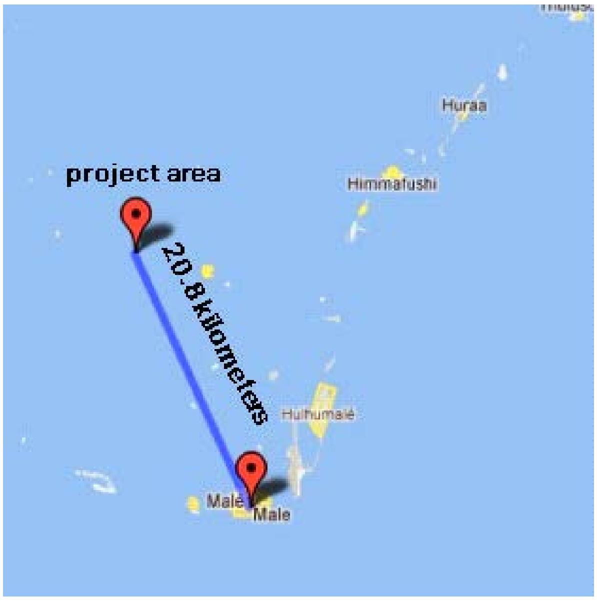


Figure 3. The project area and the capital city Male (Google Maps, 2012)

2.2 Research Methods

2.2.1 Data Collection

Because only limited research has been done in the Maldives, the data that are needed in this report are difficult to find by desk research. Specifically the data of the project area is difficult to get. In order to make sure the research is appropriate, specific data were collected as close to the project area as possible.

The data came from different documents and consults. For example, the data of monthly temperature and monthly rainfall from the year 2008 to 2011 of Hulhule is given by the Maldives Climate Section by email consult. The project spot is located inside the Male atoll. In order to make the result more accurate, the specific data are chosen from islands within the Male atoll.

2.2.2 Multi-Criteria Decision Making

The used decision making method is: Multi-Criteria Decision Making(MCDM), which can integrate multiple determinant factors to make an appropriate decision. Multi-Criteria Decision Making is the most well-known branch of decision making. It is a branch of a general class of operations research models which deal with problems under the presence of a number of decision criteria (E. Triantaphyllou, 1998). For more information on this, see paragraph 4.2.

3. MANGROVE IN THE MALDIVES

The introduction of mangroves will be given in this chapter, and the mangrove growth situation will be stated in the following. The chapter also give a description of lagoon and the project location, South Male Atoll.

3.1 Mangrove

Mangroves consist of various kinds of trees or shrubs that grow in tropical or subtropical saline coastal areas, and can tolerate brackish and even sea water. Mangrove is a common name for two groups: true mangroves and mangrove associates. True mangroves include species that grow in special areas such as intertidal zones, and estuaries; while mangrove associates refer to species that occur in littoral or terrestrial areas. Mangrove species have the common property of tolerating saline water. The trees have special roots that are adapted to saline situations, these are called aerating roots or prop roots. The exact total area of mangrove forests is unknown, but according to different sources, the number of border area of mangrove forests is approximately over 15.7 million hectare (Mastaller, 1997). Most mangrove trees are found between latitude 25°N and 25°S spanning 118 countries (Mark Spalding, 2010).

Most mangroves grow in swamps or estuaries that are under influence off the tidal regime of the ocean. Most kinds of vegetation cannot live in conditions like these. The salt tolerating ability of mangroves differs per species; it ranges from brackish water to sea water, salinity can be up to 90 ppt (parts per thousand). The reason why mangroves can stand such salty water due to their special roots, roots can only absorb water from the surroundings and excludes most of the salt. The respiratory roots are also used for breathing when a mangrove is submerged by water.

There are eight kinds of mangrove roots in total, also see figure 4 for some examples of root shapes. Each of them has its special shape:

- Stilt roots
- Aerial(prop) roots
- Respiratory roots(Pneumatophores)
- Cable (Plank)
- Knee roots
- Buttress roots
- Flute buttresses
- Creeping roots

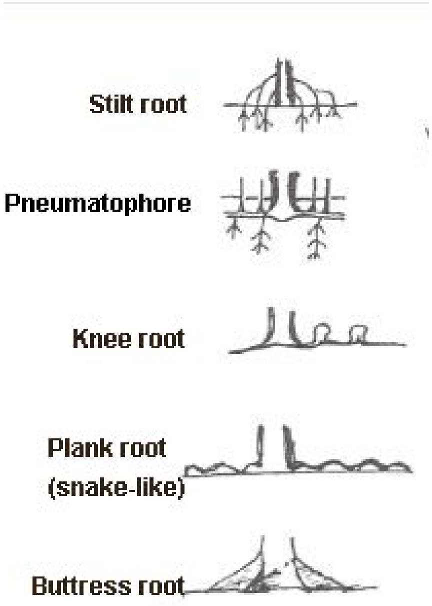


Figure 4 mangrove roots （Rahman, 2005)

With these special roots mangroves can not only survive in highly saline water, but also keep stable in coastal or swamp areas. Mangroves protect coastlines by throttling down waves and storms, and provide nutrients and living shelters for animals that live in mangrove areas. Mangroves have formed a special mangrove eco-system that supports marine life and give rich nutrients from decaying leaves and wood. A mangrove system is a home to birds, worms, crustaceans algae, etc (Dhabi, 2011).

Although the floating mangrove gardens are artificial, these gardens still can be and need to be included in food chains. Being a part of a food chain means the mangrove grow sustainably. Figure 5 shows a food web of a mangrove system. It is not only a cycle of food, but also a cycle of energy. If included in a food web we can be sure that the mangrove gardens can grow naturally and without painstaking maintenance. Because the food web can make sure that mangrove get enough nutrients and maintain, for example, the mangroves can be a home for waterfowls, and waterfowls' excreta can be nutrients for these mangroves.

Mangrove gardens as part of a food web could play a role in improving biodiversity in the Maldives. For example, it can attract microbes and even bats and sea fowls nearby the lagoon, and it can also be a good place for flora. Flora and fauna are important to the mangrove eco-system as they can improve the productivity and recycling ability of the system.

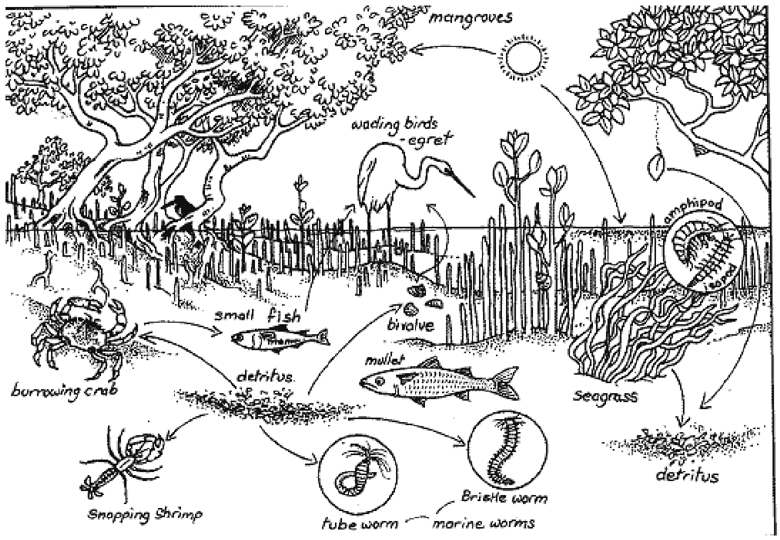


Figure 5. A mangrove ecosystem food web (K & CW, 2012)

3.2 The Species of Mangrove that grow in Maldives

In the Maldives there are 13 species of mangrove. Some of them are relatively common; a few species are quite rare. Male and other similar islands are impacted by tourism activities, which have threatened sea grass and mangrove habitats (Jagtap and Untawale, 1999). In recent years people started to develop shrimp ponds along the seashore, which is very harmful to mangrove eco-systems. Most people really do not care about mangroves and pay little attention to them, and so the size and biodiversity of mangroves in Maldives is decreasing every year. What is more, urbanization also can cause mangroves decreasing, for example, at the Male atoll.

Mangrove communities often exhibit distinct patterns of species distribution (J.Cramer, 1976), and zonation in mangroves is generally obvious. The distribution of mangrove species, in many cases can be explained primarily by salinity gradients (Ball, 1998)

Table 1 describes the 13 mangrove species that are found in the Maldives. The "status" shows the situation and living habitats of each species.

A	**Scientific name**	**Common name**	**Status**
A_1	Avicennia marina	Grey mangrove	Occasional; restricted to northern islands. Only a very few seedlings are found.
A_2	Bruguiera cylinderica	Small-leafed orange mangroves	Common; found either as a dominant or co-dominant species in many of the mangrove eco-systems of Maldives. It is also found in the form of pure stands. A large number of young seedlings are found growing in the areas.
A_3	Bruguiera gymnorrhi za	Large-leafed mangroves	Common; found growing as a dominant or co-dominant species in many of the mangrove ecosystems of Maldives. In some areas it is found in the form of pure stands.
A_4	Bruguiera sexangula	Oriental mangrove	Rare, only 10 to 12 trees are found growing on the landward portion of a brackish water lagoon.
A_5	Ceriops tagal	Yellow mangrove	Rare; found only in Furukolhu Funadhoo island in the northern group of islands. It is present in two to three rows along the border of a large lagoon, which is still connected to the sea by a channel. Only a few seedlings are found, indicating poor natural regeneration.
A_6	Excoecaria agallocha	Blinding tree, river poison tree	Occasional; found on the landward side of the mangroves in some of the northern islands. No seedlings are found in the area where the trees stand found, indicating a poor rate of natural regeneration.
A_7	Heritiera littorslis Aiton	Looking-glass mangrove	Rare, a single tree is observed in Male.
A_8	Lumnitzer a racemosa	Black mangrove	Common; found along the border of closed and open lagoons both in the northern and southern islands. Natural regeneration is very high.

A_9	Pemphis acidula	Iron wood	Abundant; grow along the beaches of almost all islands and forms contiguous stands in many places.
A_{10}	Rizophora apiculata	Red mangrove	Rare; a few individuals are found in the northern islands.
A_{11}	Rhizophor a mucronata	Black mangrove	Occasional; found growing as pure stands or mixed with Bruguiera both in the northern and southern islands. Natural regeneration is found to be moderate.
A_{12}	Sonneratia caseolaris	Crabapple mangrove apple	Occasional; found growing as pure stands as well as a few individuals both in the northern and southern islands.
A_{13}	Xylocarpus rumphii	Cedar mangrove	Rare; a few trees are found in the mangrove environment in some of the northern islands. Natural regeneration is very poor and no seedlings are found.

Table 1. 13 mangrove species information of the Maldives (V.Selvam, 2007)

3.3 Lagoons

A lagoon is a body of shallow water. Salinity may vary from brackish water to hyper salinity depending on rainfall, evaporation and the addition of seawater from storms, temporary flooding by the sea in winter or tidal exchange (Lagoons, 2012). Lagoons are always close to the shoreline. Tidal currents can transport water in and out of the lagoons. In Maldives, the maximum depth of the lagoon is 68m (Kawahata & Atsushi, 1999), but most much less, so they are very easily influenced by precipitation and evaporation. The result is that the salinity of lagoon water is different from open sea water.

Lagoons come in three main types: leaky lagoons, choked lagoons, and restricted lagoons. In leaky lagoons the tidal channels are wide. Choked lagoons always occur along high coastlines and have one or more long narrow channels which prevent water from exchanging with the ocean. Circulation within this type of lagoon is dominated by wind patterns. Restricted lagoons have many channels, well defined exchange with the ocean, and are inclined to show a seaward transport of water. Wind patterns in lagoons can also cause surface currents to develop, and to help transport large volumes of water downwind. The most of Maldives lagoons are restricted type(Figure 6).

The water in many restricted lagoons tends to be well mixed because wind patterns can easily influence them. Wind can enhance vertical mixing in the water column, and also influence surface currents that ensure lateral mixing of estuarine water. This results in a vertical profile of the water column where virtually no change in salinity is observed from the surface to the bottom.

Figure 6. Restricted Atoll from the air. (Air Rarotonga Ltd., 2009)

3.4 The Project Location - South Male Atoll

The project area is located inside the South Male Atoll. South Male Atoll in the Maldives Islands, northern Indian Ocean, is an oval-shaped atoll with maximum dimensions of 12 × 32 km((Figure 7) The lagoon water is connected with the offshore water through many deep channels between shallow reef flats. The channels are 30–70 m deep, i.e. much deeper than typical Pacific atoll channels. Due to its open topography, water exchange between the lagoon and seawater appears to be relatively good. In contrast to scanty reef development in typical Pacific atoll lagoons, flourishing of branching corals on the island slope in the lagoon was reported from Maldivian atolls (Kohn, 1964). This was explained by the unusual large flow of oceanic water through the broad deep channels. (Suzuki & Kawahata, 2003)

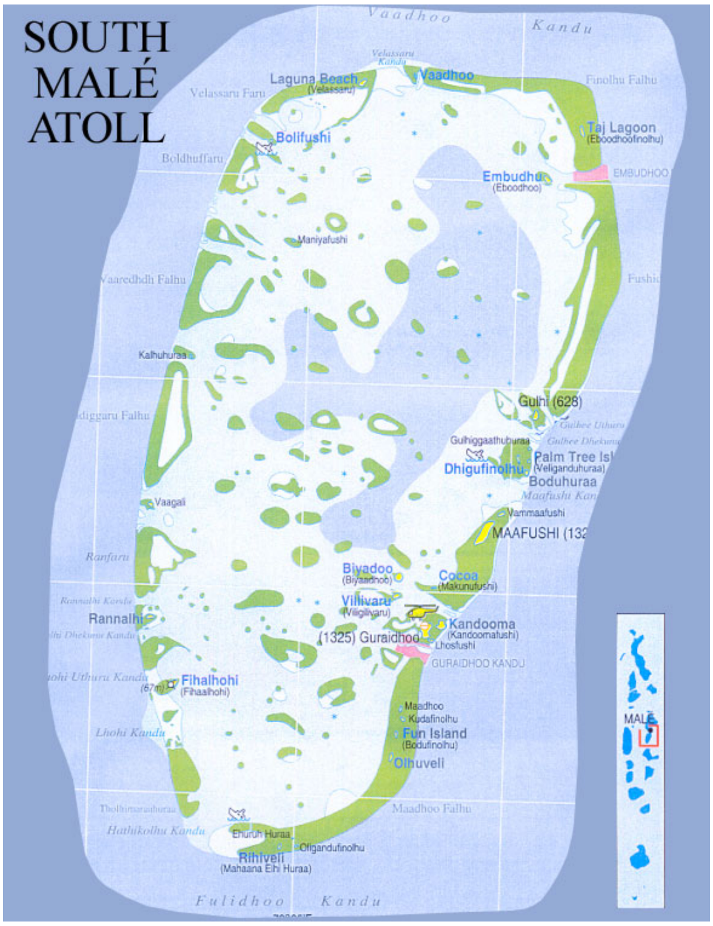


Figure 7. South Male Atoll (Surf Travel, 2009)

4. THE FEASIBILITY OF FLOATING MANGROVE GARDEN

This chapter will use the method MCDM to analyze the three main parts, ecological conditions for mangrove growth, practical demands for floating garden, and economic factor. And gives each of them a weight and value of points.

4.1. The Determinants Analysis

Table2 is from Michael Mastaller who is the author of Mangroves-the Forgotten Forest Between *Land and Sea* (Mastaller, 1997), The table will be used as a model to analyze and find out potentially suitable mangrove species. The seven main physical processes will be analyzed in next part.

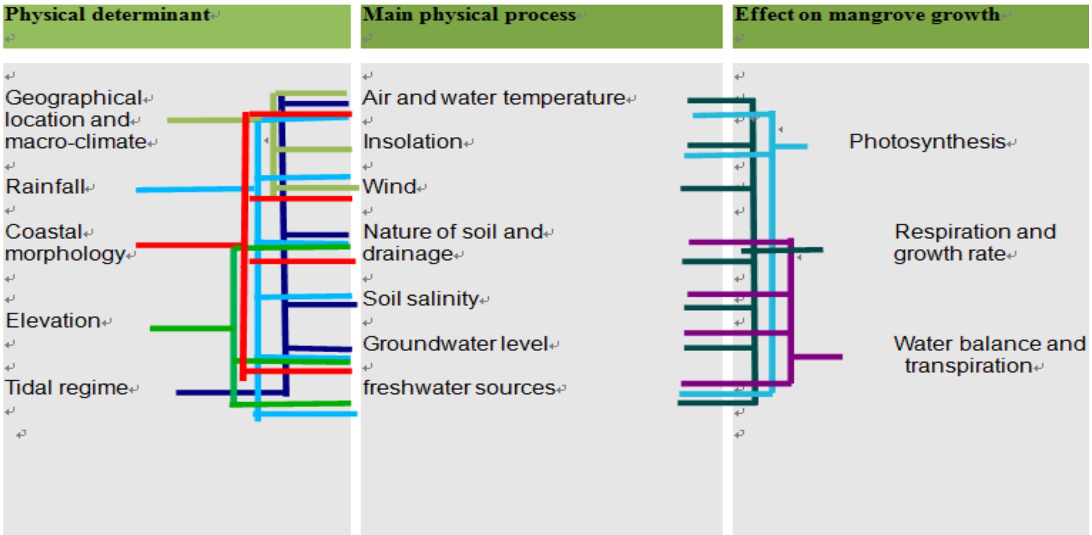


Table 2. Environmental determinants which influence mangrove growth (Mastaller, 1997)

The practical demands of the floating gardens is decided by Nautilus. According to Nautilus the ideal mangrove tree supposed to be 4 m high and do not need to much maintenance. So the determinants of practical demands are: high of trees and maintenance level.

The economic factor refers to the price of young trees. Transport fee also supposed to be a factor. But Nautilus tend to buy young trees from closet nation like Sri Lanka or India. So the transport fee factor can be left out.

4.2 A Detailed Introduction of Multi-Criteria Decision Making

The MCDM is divided in three main parts: ecological conditions, practical demands and economic factors.

The content of ecological conditions is provided by Michael Mastaller, according to table

1, there are seven main physical conditions that influence mangrove growth: Air and Water Temperature, Insolation, Wind, Nature of Soil, Salinity, Ground Water Level and Freshwater Resource.

Practical demands describes the ideal conditions of mangrove trees for the floating garden, which are the height of the trees, and maintenance requirements.

The economic factor refers to the price of the mangrove species.

The MCDM matrix contains four elements: Decision Criteria (C_n), Alternative (A_n), the value of Alternative (a_{nm}) and Weight(W_n). The Decision Criteria can refer to attributes, which represent the different dimensions from which the alternatives can be viewed. Alternative represents the different choices of the floating gardens, in this case, it means the various mangrove species. The value of Alternative means the score A_n under different criteria, and the score of each a_{nm} is from 1 to 10. Weight means the weight of importance of each Alternative, and it adds up to 1 in this thesis(Figure 8).

In terms of weight ($W = W_1+W_2+...+W_n = 1$), the ecological condition is the main determinant to decide which mangrove species should be chosen. Say the weight of the item ecological conditions (W_A) is 0.7. ($W_A = W_1+W_2+...+W_I = 0.7$). The weight of practical demands (W_B) is 0.2. ($W_B = W_{I+1}+W_{I+2}+...+W_M = 0.2$), because the practical demands are still more important than the economic factors. The weight of the economic factor is the lowest, define $W_C = W_{M+1}=0.1$.

$W_{1, ...} W_{I,} W_{I+1, ...} W_{M,} W_{M+1}$ refers to the weight of each determinant that is contained in the three parts, which may be called subweights. The value of each subweight will be analyzed and defined in the following part.

The final calculation starts after setting up the weight of each of the determinants and a_{nm}.

The formula is:

$$A_n = \max \sum_{m=1}^{n} a_{nm} w_n, \text{ for } n=1, 2, 3...i$$

After getting the value of each A_n we can select the most suitable mangrove species for the floating garden. Because the one species that get the highest score supposed to suit the project area best, in case any problem happen to the highest score mangrove that did not predict , so here two that are fitting best are selected.

		Criteria			
	C_1	C_2	C_3	...	C_N
Alt.	W_1	W_2	W_3	...	W_N
A_1	a_{11}	a_{12}	a_{13}	...	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	...	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	...	a_{3N}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_M	a_{M1}	a_{M2}	a_{M3}	...	a_{MN}

Figure 8. A decision matrix

4.3 Ecological Conditions for Mangrove Growth

Mangroves belong to the group of plants that use C3 photosynthetic biochemistry (Marilyn, 1977). The photosynthesis of mangroves depends on the air and water temperature, insolation, and fresh water resource in the Maldives. The next section will analyze the relations and data related to these elements.

4.3.1 Air Temperature

Typically, mangroves are found in areas where average annual temperatures do not drop below 19 ºC (Waisel, 1972), Mangroves are damaged under conditions where temperatures fluctuate more than 10 ºC within short periods of time, or when they are subject to frost conditions for even a few hours (Hill, 2009).

When the water level rises their communities must move upland to survive. Since mangroves have narrow optimal temperature ranges, rising temperatures will cause their distributions to shift north or south to areas where temperature conditions are more suitable, and they will die off in areas that are not suited for them (Duke, 2006)

Therefore the temperature is an important factor and is weighted as such, (W_1) is defined at 0.2.

The Maldives are located on the equator, and has a tropical monsoon climate. Table 3 below shows maximum and minimum temperatures of each month from year 2008 to 2011 of the island Hulhule (20km form the project area). The information is provided by the Maldives Climate Section. Hulhule is an island about 20 kilometers from the project area.

Month	2008		2009		2010		2011		Average Temperature ℃
	Temperature℃		Temperature℃		Temperature℃		Temperature℃		
	Max	Min	Max	Min	Max	Min	Max	Min	
January	30.2	25.7	30.5	25.8	30.8	26.9	30.2	26.0	28.3
February	30.8	26.2	31.0	26.1	31.2	26.8	30.2	25.6	28.5
March	30.8	26.1	31.9	27.1	31.7	27.1	31.3	27.0	29.1
April	31.2	26.6	31.7	26.9	32.1	27.5	31.5	26.8	29.3
May	31.3	26.2	31.7	26.7	31.6	26.8	31.1	26.6	29.0
June	31.2	25.7	31.2	26.6	31.2	26.2	31.3	27.3	28.8
July	30.8	26.1	31.2	26.2	30.7	25.9	31.0	26.4	28.5
August	30.8	26.0	30.3	25.2	30.6	26.5	31.0	26.0	28.3
September	31.3	26.8	30.7	26.1	30.4	25.8	30.9	26.1	28.5
October	30.8	26.1	31.6	26.7	30.4	26.9	30.9	26.5	28.7
November	30.6	26.1	30.6	25.8	30.1	26.0	30.8	26.3	28.3
December	30.6	25.8	30.6	26.0	29.7	25.1	30.5	25.6	28.0
Average	30.9	26.1	31.1	26.3	30.9	26.5	30.9	26.4	28.6

Table 3. Monthly max. and min. temperatures of Hulhule, year 2008-2011 (Maldives Climate Section, 2012)

What can be seen from the table is that the temperature is very stable and the temperature varies little on the island. From the table we can calculate the average minimum temperature and average maximum temperature over the years 2008 to 2011.

Average Min. Temperature = (26.1+26.3+26.5+26.4) / 4 = 26.3°C

Average Max. Temperature = (30.9+31.1+30.9+30.9) / 4 = 31.0°C

The temperature basically ranges from 26.3°C to 31.0°C throughout the year. The average minimum temperature is 26.3°C and the maximum is 31°C. So the criteria(C_1) is set to 26.3°-31.0°.

Value: if the optimal temperature range of a mangrove species is between 26.3-31 (the temperature range in the area), then the species gets full score (a1m=10), which means the species can grow well under these temperature conditions.

If there is any overlap between the C_1 and the optimal plant temperature range, the plant will flourish and so get a relatively perfect score. The difference in degrees will be converted to a percentage (1 degree = 25%), and detracted from the score.

If the temperature range of the plant falls entirely outside the C_1, the difference between the optimal plant temperature and the C_1 will determine the score.

In this case, we take the extreme value from both C_1 and plant that are closest together, and detract them from each other. The difference in degrees will be converted to a percentage (1 degree = 25%), and detracted from the score.

For example, the A_1 Avicennia marina is suitable for living in a temperature between 26-30°C, and the $C_1 =$ 26.3-31, so $a_{1,m}$ = 10 - (26.3-26)*25%=9.9

The table below shows the optimal temperature and the corresponding score for each mangrove species(An).The Weigh factor is W_1=0,2.

A	Scientific Name	Optimal Temperature(°C)	a_{1m}	a_{1m}* W_1	Reference
A_1	Avicennia marina	26-30	9.9	1.98	(Olesksinska, Merida, Heriberto, Varns, & Muccio, 2012)
A_2	Bruguiera cylinderica	30	10.0	2.00	(Marek, 2012)
A_3	Bruguiera gymnorrhiza	22 to 30	8.9	1.78	(Marek, 2012)
A_4	Bruguiera sexangula	30	10	2.00	(Marek, 2012)
A_5	Ceriops tagal	25-29	9.7	1.94	(Naikwade, Mogle, & Sankpal, 2012)
A_6	Excoecaria agallocha	25	8.7	1.74	(Marek, 2012)
A_7	Heritiera littoralis Aiton	22-24	7.7	1.54	(Kupeli Akkol , Das, Sarker, & Nahar, 2012)
A_8	Lumnitzera racemosa	18-26	9.7	1.94	(Marek, 2012)
A_9	Pemphis acidula	20-24	7.7	1.54	(Siregar, 2000)
A_{10}	Rizophora apiculata	20-30	9.8	1.96	(Duke, 2006)
A_{11}	Rhizophora mucronata	20-30	9.8	1.96	(Duke, 2006)
A_{12}	Sonneratia caseolaris	37	4.0	0.80	(Marek, 2012)
A_{13}	Xylocarpus rumphii	25-29	9.7	1.94	(Marek, 2012)

Table 4.the value table of mangrove species in optimal temperature

4.3.2 Wind

Wind has an influence on waves and currents in coastal areas, which causes soil erosion and changes in mangrove structure. Plants often depend on wind as an agent of pollination and seed dissemination which affects biodiversity (Affect of wind, ocean current, fresh water flow and salinity on Mangrove ecosystem , 2012) So the influence of wind is mainly on the development of seedlings. The mangrove trees that will be planted in the island will be young trees. The wind has not much influence on grown mangrove trees,so the wind item can be left out in this case. That is to say,wind is assigned a weight of 0 ($W_2=0$).

4.3.3 Insolation

Insolation is a measure of solar radiation energy that is received on a given surface area and recorded during a given time. It is also called solar irradiation. The solar radiance is strongly dependent on the location and local climate. In turn, this finding reflects the generally increased structural complexity of mangrove communities under the optimal growing conditions of the tropics (Snedaker, 1993) The insolation data of the Maldives and the optimal insolation of the mangrove species come from different sources, and every author has different ways to measure and calculate the data. Because of this, the reliability may be low, so the determinant insolation is weighted relatively low, at 0.05 (W_3=0.05)

Table 5 shows the insolation per month in the Maldives in kWh/m^2/s. The unit of Maldives insolation is kWh/m^2/day, while most data found on optimal insolation of mangrove species are recorded in μmol /m^2/s. According to the article of Wageningen university (Wageningen UR, 2011),

1μmol /m^2/s=21/11 J /m^2/s,

1 kwh/m^2/s =3.6*10^6 J /m^2/s, that is, 1 kWh/m^2/day=158 μmol /m^2/s.

Month	Insolation, kWh/m²/day	Insolation $\mu mol/m^2/s$
Jan	5.74	906.92
Feb	6.58	1039.64
Mar	6.90	1090.2
Apr	6.27	990.66
May	5.48	845.84
Jun	5.15	813.7
Jul	5.46	862.68
Aug	5.69	899.02
Sep	5.69	899.02
Oct	5.92	935.36
Nov	5.28	834.24
Dec	5.22	824.76

Table 5. The insolation of the Maldives (Tukiainen, 2012)

It can be seen from the table that the lowest insolation occurs in June,

at 814 µmol /m2/s.

The highest insolation of the Maldives is in March: 1090 µmol /m2/s.

The range for the criteria of insolation is 814-1090(C3 = 814 - 1090).

Value: if the optimal insolation ranges of a mangrove species is between 814 – 1090(the insolation ranges in this area), then the species gets full score($a_{1,3}$=10), which means the species can grow well under the insolation condition.

If there is any overlap between the C_3 and the optimal insolation range, the plant will flourish and so get a perfect score.

If the insolation range of the plant falls entirely outside the C_3, the difference between the optimal plant insolation and the C_3 will determine the score.

In this case, we take the extreme value from both C_3 and plant that are closest together, and detract them from each other. The difference in μmol /m^2/s will be converted to a percentage (1 μmol /m^2/s = 1%), and detracted from the score.

The table below shows the optimal insolation and the corresponding score of each mangrove species(A_n). The weight factor is W_3=0.05

A	Scientific name	Optimal Insolation (μmol /m2/s)	a1,3	a1,3* W3	Reference
A1	Avicennia marina	600	7.9	0.40	(Hu, 2009)
A2	Bruguiera cylindeica	1000	10.0	0.50	(Saied, Sohail, Gebauer, & Buerkert, 2010)
A3	Bruguiera gymnorrhiza	1000	10.0	0.50	(Okimoto, Nose, Katsuta, Tateda, Agarie, & Ikeada, 2007)
A4	Bruguiera sexangula	1000	10.0	0.50	(Schmitz, Egerton& Ball, 2012)
A5	Ceriops tagal	1200	8.9	0.45	(Schmitz, Egerton, & Ball, 2012)
A6	Excoecaria agallocha	180 to 215	4.0	0.20	(Fritz, 2012)
A7	Heritiera littoralis Aiton	150	3.4	0.17	(Fritz, 2012)
A8	Lumnitzera racemosa	1200	8.9	0.46	(Chen & Liao, 2006)
A9	Pemphis acidula	1200	8.9	0.46	(Schmitz, Egerton, & Ball, 2012)
A10	Rizophora apiculata	above 600	10.0	0.50	(Kitao, Utsugi, Kuramoto, Tabuchi, Fujimoto, & Lihpai, 2003)
A11	Rhizophora mucronata	800	9.9	0.50	(Kathiresan & Rajendran, 2000)
A12	Sonneratia caseolaris	1000	10.0	0.50	(Chen & Tam, 2008)
A13	Xylocarpus rumphii	lower than 275	4.6	0.23	(Department of Agroenvironmental Science and Technology, 2009)

Table 6. The value of optimal insolation of each mangrove species

4.3.4 Nature of Soil and Salinity

Mangroves are real masters at coping with different soil types. The same species may even occur on different substratum in the same region (Mastaller, 1997).

Soil in Maldives is mostly young, vigorous and shallow, composed mainly of coral debris mixed with sandy loam, containing humus. Soils are rich in Calcium and alkaline in nature with very poor water retaining capacity (Jagtap T., 2008).

The Maldives lacks good soil; the nutrient substances are not very rich, In order to have better and more suitable soil for growing mangroves, the mangrove gardens will not contain native soil. The soil could be transported from nearby nations who do have rich soil resources, for instance Sri Lanka or India.. After deciding which species will be used for mangrove gardens, the most suitable soil will be known.

In terms of the salinity, the salinity of the soil basically depends on the salinity of the lagoon water. Assuming that the soil salinity itself is less than the salinity of lagoon water, the salinity of soil will be definitely influenced by lagoon water because the lagoon water will be the most important water resource for the mangroves.

In this way , the soil is not taken in to account in the decision making, that is, the weight of soil type is 0($W_4=0$).

4.3.5 Ground Water level

Because of the special design of mangrove floating gardens, there is no ground water resource which can be accessed. The mangroves will float on the surface of the lagoon and the mangroves roots are supposed to root directly into the lagoon water. Also, the normal fluctuations in the groundwater level do not occur here, since the floating gardens will rise and fall with the lagoon water. So in this case the item groundwater level can be left out.

That is, the weight of the ground water level is 0 (W_5=0).

4.3.6 Salinity

Mangroves do not depend on a salty environment to survive.. For example, some Rhizophora species make attractive pot-plants when nursed exclusively with freshwater. The main reason mangroves do occur in brackish habitats is that there is less competition for existence The saline environment for some mangroves is even a limiting factor, meaning above a certain level of salinity, growth is not possible for some species (Michael, 1997).

The salinity gradient has long been recognized as a potential stressor and an important factor that regulates physiological processes such as growth, height, survival, and zonation patterns in mangroves (Lin & Sternberg, 1993).

That is to say mangroves do not have to live in a saline environment, and sometimes a high salt content might cause some species to die, even though other mangroves are the only kind of trees that can tolerate hyper-saline water.

The salinity tolerance of each species varies. Hence, the water salinity plays an important role in selecting a suitable mangrove species. So the weight is defined at 0.4(W_6=0.4).

From figure 8 it can be seen that the salinity of the lagoon in South Male Atoll is between 35.41 and 36.07 ppt.

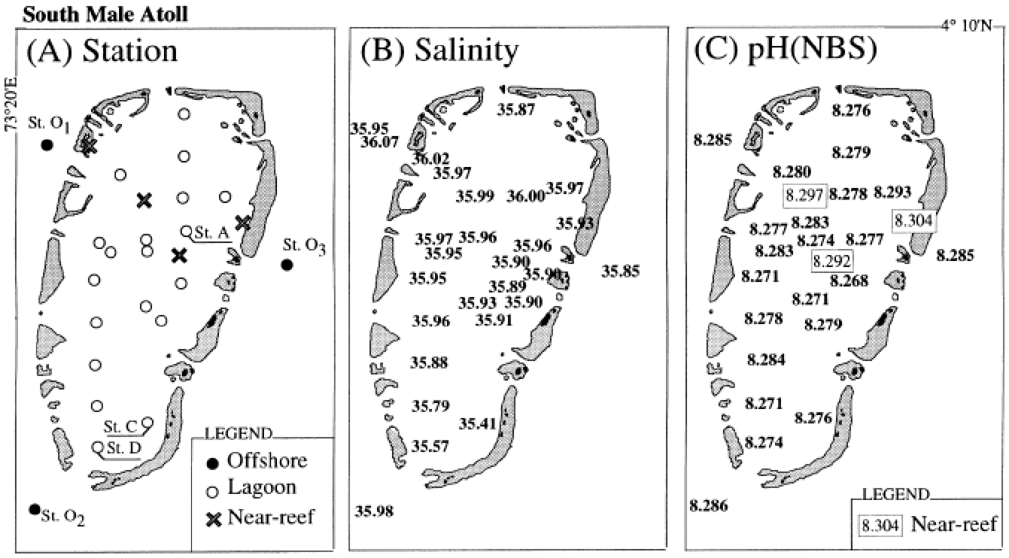


Figure 8. The salinity and PH of Male lagoon (Kawahata & Atsushi, 1999)

Because the mangrove gardens will be located on the surface of a lagoon, the only freshwater resource for them would be precipitation. In other words, the salinity of water completely depends on the lagoon water and precipitation.

A saline environment is required for stable mangrove ecosystems, as many species are less competitive under non-saline conditions.(Lugo & Sbedaker, 1980)

As discussed above, the mangrove species selected to grow in the floating islands have to meet the condition that they can tolerate a salinity of up to 36.07 (≈37) ppt, and a good adaptability is necessary. The criteria for salinity is 37(C_6=37).

Value: if the salt tolerance range of a mangrove species is higher than 37ppt, then the species gets full score($a_{6,m}$=10), which means the species can grow well under the given salinity.

If there is any overlap between C_6 and the salt tolerance, the plant will flourish and so get a perfect score.

If the salt tolerance of a plant is lower than C_6, the difference between the salt tolerance and the C_6 will determine the score. We take the extreme value from both C_6 and plant that are closest together(highest salt tolerance value), and the detract them from each other. The difference in ppt will be converted to a percentage(1ppt = 33%), and detracted from the score. The table below shows the salt tolerance of each mangrove species and the corresponding score of each mangrove species(A_m). The weight factor is W_6=0.4.

A	***Scientific name***	***Salt Tolerance*** **(ppt)**	$a_{6,m}$	$a_{6,m}* W_6$	***Reference***
A_1	Avicennia marina	25-85	10.	4.0	(Binning, Hughes, &Willgoose, 1998)
A_2	Bruguiera cylinderica	15-25	6.0	2.41	(Wetlands International, 2008)
A_3	Bruguiera gymnorrhiza	15-25	6.0	2.41	(Wetlands International, 2008)
A_4	Bruguiera sexangula	<25	6.0	2.41	(Krauss & Allen, 2003)
A_5	Ceriops tagal	15-25	6.0	2.41	(Wetlands International, 2008)
A_6	Excoecaria agallocha	<15	2.7	1.10	(Wetlands International, 2008)
A_7	Heritiera littoralis Aiton	<15	2.7	1.10	(Wetlands International, 2008)
A_8	Lumnitzera racemosa	<25	6.0	2.41	(Ye, Lu, Wong & Tam, 2004)
A_9	Pemphis acidula	20-40	10.0	4.0	(Muhling, Schmitt, & Zorb, 2010)
A_{10}	Rizophora apiculata	15-25	6.0	2.41	(Wetlands International, 2008)
A_{11}	Rhizophora mucronata	8-26	6.4	2.55	(Duke, 2006)
A_{12}	Sonneratia caseolaris	<15	2.7	1.10	(Wetlands International, 2008)
A_{13}	Xylocarpus rumphii	8-26	6.4	2.55	(Allen & Duke, 2006)

Table 7. The value of salt tolerance of each mangrove species

4.3.7 Freshwater Resource

Although mangrove s' living condition is in saline water, they still need to have freshwater access. In this case, the only freshwater that the floating gardens can get is the rainfall, which helps the mangrove to remove salt from there leaves.

The graph below shows the precipitation in the Maldives, The Maldives are strong effected by the monsoon, and the dry season and wet season are very obvious. Because of the monsoon climate, the dry and wet seasons are not the same time every year.

Month	2008 mm	2009 mm	2010 mm	2011 mm	Average rainfall mm
January	69.6	85.2	8.0	101.1	66.0
February	51.3	12.8	92.8	6.0	40.7
March	176.7	36.8	22.4	16.7	16.7
April	136.5	86.6	88.3	98.4	102.5
May	244.7	175.1	276.9	184.5	220.3
June	239.2	213.3	236.1	56.8	186.4
July	157.1	275.9	222.1	163.6	204.7
August	259.9	416.4	177.6	126.2	245.0
September	40.4	193.3	340.9	125.3	175.0
October	247.6	107.5	69.3	224.4	162.2
November	156.3	409.2	128.2	168.3	215.5
December	222.5	189.4	355.3	62.0	207.3
					1842.2

Table 8. Monthly rainfall from year 2008 to 2011 of the island Hulhule (Maldives Climate Section, 2012)

As can be seen from the table above that the average annual precipitation is 1842.2mm(≈1842mm)

Then the criteria of precipitation in the Maldives is 1842(C_7=1842), and the weight of the freshwater resource is W_7=0.1

Value: if C_7=1842 is included in the optimal rainfall range of a mangrove species, then the mangrove species gets full score($a_{7,m}$=10), which means the species can grow well in under the precipitation conditions.

If there is any overlap between the C_7 and the optimal rainfall range, the plant will flourish and so get a perfect score.

If the temperature range of the plant falls entirely outside the C_7, the difference between the optimal plant rainfall and the C_7 will determine the score. We take the extreme value from both C_7 and plant that are closet together, and detract them from each other. The difference in millimeter will be converted to a percentage (1mm=2%), and detracted from the score.

The table below shows the optimal rainfall amount of each mangrove species and the corresponding score of each mangrove species(A_m). The weight factor is W_7=0.1

A	**Scientific name**	**Optimal Rainfall （mm）**	$a_{7,m}$	$a_{7,m}$* W_7	***Reference***
A_1	Avicennia marina	1000–4500	10.0	1.00	(Cruz, 2008)
A_2	Bruguiera cylinderica	1000–8000	10.0	1.00	(Allen & Duke, 2006)
A_3	Bruguiera gymnorrhiza	1000–8000	10.0	1.00	(Allen & Duke, 2006)
A_4	Bruguiera sexangula	1500–2500	10.0	1.00	(Allen & Duke, 2006)
A_5	Ceriops tagal	1000—2000	10.0	1.00	(Obade & Dahdouh-Guebas, 2004)
A_6	Excoecaria agallocha	1800-2500	10.0	1.00	(FAO Corporate Document Repository, 2012)
A_7	Heritiera littoralis Aiton	1800-4000	10.0	1.00	(Bruinsma, 2001)
A_8	Lumnitzera racemosa	1500-2500	10.0	1.00	(Bruinsma, 2001)
A_9	Pemphis acidula	2000	8.4	0.84	(Kiribati Government, 1999)
A_{10}	Rhizophora apiculata	1250-2000	10.0	1.00	(FAO Corporate Document Repository, 2012)
A_{11}	Rhizophora mucronata	1000-2100	10.0	1.00	(Obade & Dahdouh-Guebas, 2004)
A_{12}	Sonneratia caseolaris	>2500	3.4	0.34	(Stedman-Edwards, 2001)
A_{13}	Xylocarpus rumphii	1500-5000	10.0	1.00	(United Nations Environment Programme, 2007)

Table 9. The value of optimal rainfall of each mangrove species

4.4 Practical Demands

4.4.1. Height of Tree

To some extent, the weight of the mangrove tree is determined by its height. It would be a logical decision for the floating garden to be planted with relatively light trees. What's more, the short trees will not block the sunshine from the villas. Nautilus thinks the ideal height of a tree is around 4 meters, which means the tree is a bit bush like. The height of mangrove trees varies greatly among different species. The highest mangrove tree can reach up to 25 m (Institute, 2012).

The criteria of height is set to 4(C_8=4). The weight of this criteria is set to 0.1(W_8=0.1)

Value: use the average height of a mangrove species minus the height criteria C_8, and 25% of the height difference is detracted from the score which starts at 10. The table below shows the height of each mangrove species and its corresponding score (A_n).

A	*Scientific name*	*Height* (m)	$a_{8,m}$	$a_{8,m}$* W_8	Reference
A_1	Avicennia marina	10	8.5	0.85	(Simpson, 2010)
A_2	Bruguiera cylinderica	20	6.0	0.60	(Simpson, 2010)
A_3	Bruguiera gymnorrhiza	36	2.0	0.20	(Marek, 2012)
A_4	Bruguiera sexangula	5-10	9.1	0.91	(Marek, 2012)
A_5	Ceriops tagal	40	1.0	0.10	(Global Information Hub On Integrated Medicine, 2011)
A_6	Excoecaria agallocha	15-20	6.6	0.66	(Global Information Hub On Integrated Medicine, 2011)
A_7	Heritiera littoralis Aiton	25	5.8	0.58	(Global Information Hub On Integrated Medicine, 2011)
A_8	Lumnitzera racemosa	10	8.5	0.85	(ARKIVE, 2012)

A_9	Pemphis acidula	11	8.3	0.83	(ARKIVE, 2012)
A_{10}	Rizophora apiculata	15-25	6	0.6	(Tan, 2011)
A_{11}	Rhizophora mucronata	20-25	5.4	0.54	(Gillikin & Verheyden, 2002)
A_{12}	Sonneratia caseolaris	20	6	0.6	(Sivasothi, 2001)
A_{13}	Xylocarpus rumphii	8-10	8.8	0.88	(WildSingapore.com, 2008)

Table 10. The value of height of each mangrove species.

4.4.2. Maintenance

It is important to know how much maintenance a mangrove species needs. The intensity of maintenance also differs from each mangrove species. A low maintenance tree is much more convenient for the floating gardens than a tree which needs high maintenance. So the weight of maintenance is set to 0.1(W_9=0.1). In the project, the selected mangrove species would preferably be a low maintenance one, since less labor makes the project more cost-effective.

So the criteria of the maintenance is low(C_9=low).

Value: define the lowest maintenance to full score 10, moderate maintenance to 7.5, And the highest maintenance level is 5. The table below shows the maintenance level of each mangrove species and its corresponding score (A_n). The weight factor is W_9=0.1.

A	*Scientific name*	*Maintenance*	$a_{9,m}$	$a_{9,m}$* W_9
A_1	Avicennia marina	Low	10.0	1.00
A_2	Bruguiera cylinderica	Low	10.0	1.00
A_3	Bruguiera gymnorrhiza	Low	10.0	1.00
A_4	Bruguiera sexangula	Moderate	7.5	0.75
A_5	Ceriops tagal	Moderate	7.5	0.75
A_6	Excoecaria agallocha	Low	10	1.00
A_7	Heritiera littoralis Aiton	High	5.0	0.50
A_8	Lumnitzera racemosa	Moderate	7.5	0.75
A_9	Pemphis acidula	High	5.0	0.50
A_{10}	Rizophora apiculata	Moderate	7.5	0.75
A_{11}	Rhizophora mucronata	Low	10	1.00
A_{12}	Sonneratia caseolaris	Moderate	7.5	0.75
A_{13}	Xylocarpus rumphii	High	5.0	0.50

Table 11. The value of maintenance of each mangrove species. (Selvam, 2007)

4.5 Economic Factors

4.5.1 Price of the Trees

The price of the trees has little effect on the choice of a species. If two species have very comparable properties, however, the price will to be take into account. The price per species in the table below is from the Austria website *Mangroves.at* . The price has a big difference between seedlings and young trees, the price shown in the table is young trees.

Set the weight of sapling price to 0.05 (W_{10}=0.05), the exchange rate is 1 AUD=0.831 EUR. The ideal price is infinitely near 0, so set the criteria to 0(C_{10}=0)

Value: 20% of the species price is the subtracted score. The table below shows the price of each mangrove species and the corresponding score of each mangrove species(A_n). The weight factor is W_{10}=0.05.

A	***Scientific name***	***Price (Euro)***	$a_{10,m}$	$a_{10,m} * W_{10}$
A_1	Avicennia marina	34	3.2	0.16
A_2	Bruguiera cylinderica	15	7.0	0.35
A_3	Bruguiera gymnorrhiza	20	6.0	0.30
A_4	Bruguiera sexangula	20	6.0	0.30
A_5	Ceriops tagal	14	7.2	0.36
A_6	Excoecaria agallocha	16	6.8	0.34
A_7	Heritiera littoralis Aiton	18	6.4	0.32
A_8	Lumnitzera racemosa	16	6.8	0.34
A_9	Pemphis acidula	20	6.0	0.30
A_{10}	Rizophora apiculata	18	6.40	0.32
A_{11}	Rhizophora mucronata	15	7.0	0.35
A_{12}	Sonneratia caseolaris	15	7.0	0.35
A_{13}	Xylocarpus rumphii	25	5.0	0.25

Table 12. The value of price of each mangrove species. (Marek P. , 2012)**,**

5. MULTI-CRITERIA DECISION ANALYSIS

The previous chapter has determined the weights of each factor and analyzed the values of each alternative. This chapter will put all the alternatives and factors together to give an comprehensive analysis, and then come to a conclusion.

In the table below you can see the weight of each factor:

Item	Weight	*Wn*	Condition	Subweight
Ecological condition	W_A=0.75	*W1*	Air Temperature	0.2
		W2	Wind	0
		W3	Insolation	0.05
		W4	Nature of Soil	0
		W5	Ground Water Level	0
		W6	Salinity	0.4
		W7	Freshwater Resource	0.1
Practical Demand	W_B=0.2	*W8*	Height of Trees	0.1
		W9	Maintenance Requirement	0.1
Economic Factor	W_C =0.05	*W10*	Price	0.05
Total Weight	*W =1*			1

Table 13. Weight of each item

In the MCDM table below, all the elements and values are put together, and all the numerical values are summed up:

C	Criteria	C1= 26.3-31	C_3 = 814 - 1090	C_6=37	C_7=1842	C_8=4	C_9=low	C_{10}=0	
W	Weight	W1=0.2	W3=0.05	W_6=0.4	W_7=0.1	W_8=0.1	W_9=0.1	W_{10}=0.05	
A	*Scientific name*								Summation
A_1	Avicennia marina	1.98	0.40	4.00	1.00	0.85	1.00	0.16	9.39
A_2	Bruguiera cylinderica	2.0	0.50	2.41	1.00	0.60	1.00	0.35	7.86
A_3	Bruguiera gymnorrhiza	1.78	0.50	2.41	1.00	0.20	1.00	0.30	7.19
A_4	Bruguiera sexangula	2.0	0.50	2.41	1.00	0.91	0.75	0.30	7.87
A_5	Ceriops tagal	1.94	0.45	2.41	1.00	0.10	0.75	0.36	7.01
A_6	Excoecaria agallocha	1.74	0.20	1.10	1.00	0.66	1.00	0.34	6.04
A_7	Heritiera littoralis Aiton	1.54	0.17	1.10	1.00	0.58	0.50	0.32	5.21
A_8	Lumnitzera racemosa	1.94	0.46	2.41	1.00	0.85	0.75	0.34	7.75
A_9	Pemphis acidula	1.54	0.46	4.00	0.84	0.83	0.50	0.30	8.47
A_{10}	Rizophora apiculata	1.96	0.50	2.41	1.00	0.60	0.75	0.32	7.54
A_{11}	Rhizophora mucronata	1.96	0.50	2.55	1.00	0.54	1.00	0.35	7.9
A_{12}	Sonneratia caseolaris	0.80	0.50	1.10	0.34	0.60	0.75	0.35	4.44
A_{13}	Xylocarpus rumphii	1.94	0.23	2.55	1.00	0.88	0.50	0.25	7.35

Table 14. MCDM table

It is can be seen from the table that the highest two scores (highlighted) are 9.45 and 8.51, and that those go with *Avicennia Marina* and *Pemphis Acidula* respectively.

6. MANGROVE SPECIES FOR THE FLOATING GARDENS

As analysed above, the most suitable mangrove species are *Avicennia Marina* and *Pemphis Acidula*. The introduction of the two species is given the follow:

6.1 Avicennia marina

Avicennia marina is a shrub or tree that can grow 2 -10 meters tall, and it has pencil-sized peg type above-ground roots (Figure 10). It could grow on any position in the intertidal regions of estuaries, lagoons and backwater, etc. It prefers fine clay soil and alluvial soil. It is highly saline tolerant and tolerates the widest range of soil salinity. It can also tolerate high aridity.

Figure 10. Avicennia marina (Yeo, 2011)

6.2 Pemphis Acidula

Pemphis Acidula is an ever green, much branched, and slow growing shrub or tree, which can get less than 10 meters tall (Figure 11). It can grow in different kinds of soil, even including limestone rock and coral conglomerate. Specially perform good in well fertilized and waterlogged soil (Shazra, Rasheed, & Ansari, 2008).

Figure 11. Pemphis Acidula (Australasia, 2011)

The suitable soil for the floating garden depends on the mangrove species.

Fine clay soil could be used to plant *Avicennia marina,* whereas *Pemphis Acidula* grows better in muddy soil.

7. FlOATING GARDEN

The idea of floating garden structure is presented by Nautilus.

The size of a floating garden is 4 to 6 m long and wide. Both sides of the gardens are connected with a round pontoon, which makes sure the gardens can float on water. The thickness of the pontoon wall is 0.05 m and air fill inside. The height of the pontoon is

1.2 m. The bottom of the gardens uses two layers of woven geotextiles[3]. Because of the geotextiles, lagoon water can come into the floating garden, without soil going out. The size of the woven geotextile is preferably the SG 40/40-S version, which is made of very thin permeable fabrics and woven very fine, so the space between the fabrics is quite small. It is supposed to stop sand; only water can go through it. Sand is put between the coconut fiber mat and the geotextile layer, which provides nutrients for the growing trees (Figure 12).

Lagoon water comes in through the bottom of the floating garden, and rainfall comes from the above. Rainwater and lagoon water mix inside the floating gardens and some of it is absorbed by the trees.

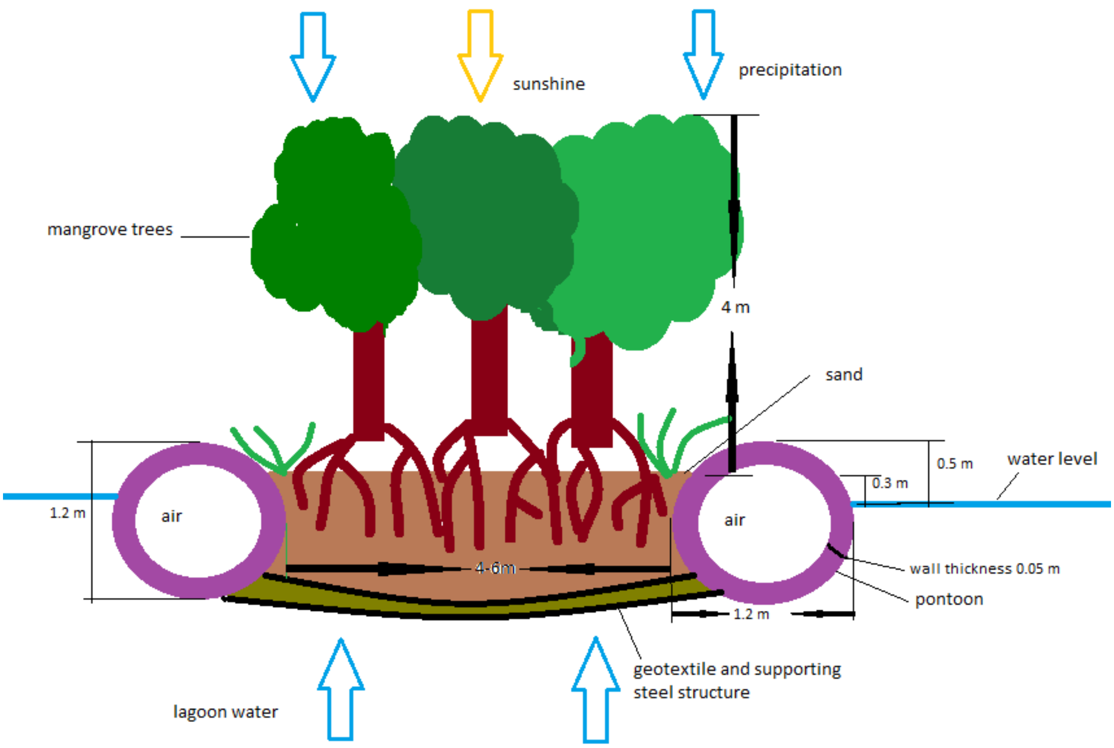


Figure 12. Basic structure of floating garden

[3] Geotextile is permeable fabric which, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain.

8. DISCUSSION

In the thesis, the criteria salinity really creating a "no go" in case that the tree species cannot grow in high salinity environment. Then the species cannot be chosen, even if the rest of scores would be really high. In general, the data obtained showed very few patterns, and there could be more possibilities and information that have not been considered. Some of the data is quite reliable, such as the annual temperature and precipitation of the Maldives, which provided by the Maldives Climate Section. Data like the height of grown mangrove tree are various of each resource, for example, in website *ARKIVE*(ARKIVE, 2012)it says the height of Pemphis Acidula can reach 11m , while in the *book Trees and Shrubs of the Maldives* (Selvam, 2007), it say the tree only can grow to 4-6m. So data from different resources may lead to different results. The best way of doing the research is to text on site.

9. CONCLUSIONS AND RECOMMENDATIONS

The thesis has stated the growth situation of 13 mangrove species in the Maldives. The ecological conditions for mangrove growth are Air and Water Temperature, Insolation, Wind, Nature of Soil, Salinity, Ground Water Level and Freshwater Resource.

Practical demands describes the ideal conditions of mangrove trees for the floating garden, which are the height of the trees, and maintenance requirements.

The economic factor refers to how much is paid for the mangrove species

The thesis use MCDM to put ecological conditions of mangroves, practical demand of floating garden and economic factor in to account. . Each of these three main parts has been given a weight and all 10 sub parts a score. These two are multiplied which gives all a total score that can be listed to find the mangrove that are best suited for growing on floating islands . The mangrove *Avicennia marina* and *Pemphis Acidula* got the highest score. So they are the most suitable mangrove species for growing in the floating garden in the Maldives.

To sum up, the species *Avicennia marina* and *Pemphis Acidula* are the best choice for mangrove floating gardens.

There are several recommendations for the designers who will be in charge of designing the shape of the floating mangrove garden:

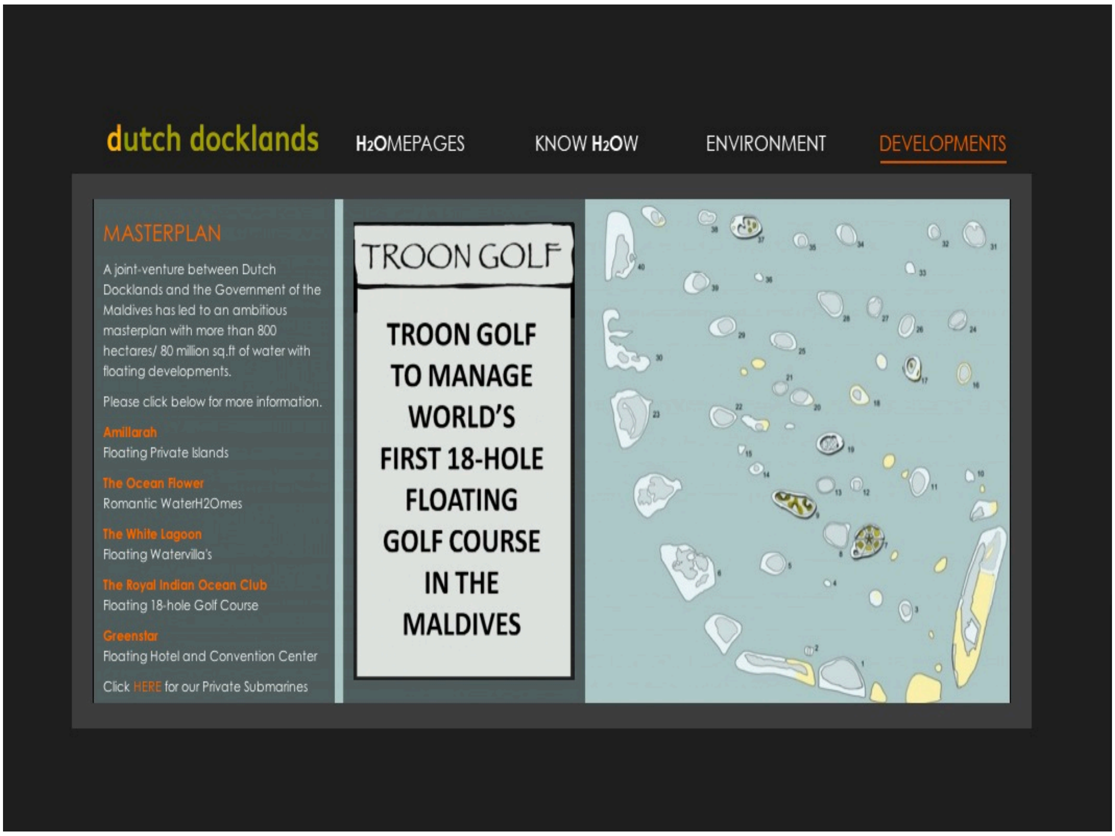
- Both of the selected grown mangrove species may reach about 10 m, so they might need to be cut regularly.
- Mangrove roots can be extremely strong and long. The roots might stress or damage the floating garden, so it would be better to use very substantial materials.
- The size of the islands will determine how alluring these islands are for birds and other animals.

Overall, The idea floating mangrove garden is new, and it would be good Nautilus has it tested before put into use. Hopefully the project can be completed successfully, and be an example and a pioneer of the solution of sea level rise.

APPENDIXES

Appendix I

the master plan of the Maldives from the Dutch Docklands



(Dutch Docklands)

Appendix II

The plan of approach of the thesis I have handed in April this year, and according to it I have completed the first version of the thesis. After handing in it to my adviser he had some doubt the way to do the research. So I have changed the thesis structure and the sub-questions to make a more sufficient thesis.

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