Memo: **Report[1] on BUS ticket no. 24**
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SALT WATER FORESTRY: CASE STUDY OF MANGROVES

Definition of the problem
One of the proposed Biomass Transition paths (i.e. Biosaline biomass) suggests to establish tree plantations on salt affected areas: this could be relevant for about 100 million ha.

Questions
1. Which tree species are salt tolerant? (literature review)
2. Which biomass production levels are to be expected in semi-arid zones, with and without irrigation?
3. Are there any experiments with dedicated short rotation coppice on salt affected soils?

Salt tolerance

Halophytes are defined as salt tolerant plant species which can complete their life cycle and reproduce themselves under salt water conditions, characterized by an electrical conductivity of 8 dS/m or higher, which corresponds with a salt concentration of > 6000 ppm (parts per million). Seawater e.g has a salt concentration over 28,000 ppm and an electrical conductivity of > 40dS/m. Under saline conditions most halophytes show reduced growth compared to non-saline conditions. Therefore, salt tolerance often is defined as the salinity level at which a 50% growth reduction occurs. However, approximately 10% of all halophytes have the ability to grow on seawater, which makes them highly salt tolerant. A complicating factor is the variability of salt tolerance during the progressive stages of plant growth. During the germination phase salt tolerance usually is lower than during later stages of plant development.

Salinity problem

The area salt affected land amounts 955 million ha worldwide, which increases annually with 10 million ha. In semi-arid areas, at present about 30% of all irrigated land (i.e 100 million ha) suffers from salinisation, of which 30 million ha is severely affected. Apart from these cultivated lands, other dry land areas in the semi arid and arid Tropics frequently suffer from salinisation too. These include e.g. 2 million ha of the wheat belt in western Australia, which is seriously affected by salt (in combination with water logging); various inland salt deserts, usually with brackish ground water or surface supplies of salt water, or desserts which are being infiltrated with saline affluent water, and coastal deserts presently not used for agriculture or tree planting, but which are located within the reach of seawater for irrigation. A tentative estimation of the total area potentially available for biosaline agriculture and forestry[2] is 125 million ha worldwide[3]. Most of this area could potentially be used for the production of biomass, without competing with the production of food crops.[4]

Various halophitic trees and shrubs (Acacia sp, Atriplex sp., Casuarina sp., Prosopis sp., Eucalyptus sp. Populus sp. Sarcocornia sp., Tamarix sp.[5]) can e.g. be used as fodder and thus may play a role in

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[2] The term “biosaline agriculture and forestry” refers to the dedicated cultivation of salt tolerant plant species with the help of salt or brackish water on saline soils, unsuitable for conventional crops. See e.g. http://www.oceandesertenterprises.com/
[3] University of Arizona 1991. Seaweed and halophytes to remove carbon from the atmosphere, Electric Power Research Institute, Report EPRI ER/EN-7177
[4] NRLO 2000. Bio-productie en ecosysteemontwikkeling in zoute condities. Rapport 2000-11,NRLO,
[5] Trees and shrubs for salt land in western Australia: http://agspsrv34.agric.wa.gov.au/progserv/natural/trees/uses/SALTAPP.HTM#extsal

rangeland improvement, and provide a source of wood as well. These species can either be introduced (as exotics) or selected from natural ecosystems.

Mangroves represent vary valuable ecosystems rich in biodiversity, which are comprised of diverse, salt-tolerant tree and other plant species which thrive in inter-tidal zones of sheltered tropical shores and estuaries. Tens of millions of people around the tropics and sub-tropics depend on mangrove forests as a source of fuelwood, charcoal, timber, and other non-timber products. Mangrove trees have specially adapted aerial and salt-filtering roots and salt-excreting leaves that enable them to occupy the saline wetlands where other plant life cannot survive. Mangroves include approximately 75 different tree and shrub species. The natural environment of mangroves is characterised by the sea level and its fluctuations, air temperature, salinity, ocean currents, storms, shore slope, and soil substrate. Most mangroves live on muddy soils, but they also grow on sand, peat, and coral rock.

Distribution of mangroves

The majority of the subtropical and tropical coastline is dominated by mangroves, estimated to cover an area of 22 million hectares[6]. The FAO estimates are somewhat more conservative: a present (2003) some 15 million ha of mangroves exist worldwide[7]. About 55 percent of the world's population inhabits coastal areas and draws heavily on coastal and marine ecosystems for food, housing, industrialization, transportation, recreation, waste disposal and reclamation for other uses. Consequently, mangrove deforestation is continuing, albeit at a slightly lower rate than in the 1980's. This reflects the large-scale conversion of mangroves for aquaculture and tourist infrastructures. The FAO is preparing a second edition of the world atlas of mangroves[8].

Biology of salt tolerance

The roots of mangroves contain many small "breathing" pores, called "lenticels." These allow oxygen to diffuse into the plant, and down to the underground roots by means of air space tissue in the cortex, called "aerenchyma." The lenticels are inactive during high tide. Lenticels in the exposed portions of mangrove roots are highly susceptible to clogging by crude oil and other pollutants, attacks by parasites, and prolonged flooding from artificial dikes or causeways. Over time, environmental stress can kill large numbers of mangrove trees. In addition, the charcoal and timber industries have also severely impacted mangrove forests, as well as tourism and other coastal developments. The rapidly expanding shrimp aquaculture industry poses the most serious threat to the world's remaining mangroves. Literally thousands of hectares of lush mangrove forests have been cleared to make room for the artificial shrimp ponds of this industry. Globally, as much as 50% percent of mangrove destruction in recent years has been due to clear cutting for shrimp farms.

Certain species of mangroves exclude salt from their systems, others actually excrete the salt they take in via their leaves, roots, or branches. In salt excluding mangrove species , the mangrove root system is so effective in filtering out salt that a thirsty traveler could drink fresh water from a cut root, though the tree itself stands in saline soil.[9] Saltwater is not necessary for the survival of any mangrove species, but it does give mangroves a competitive advantage over other plants that do not tolerate salt (Mitsch and Gosselink, 1993). The mangrove vegetation uses three different mechanisms which cope with excess salt.

(1) The roots of salt-excluding species of *Ceriops*, *Excoecaria* and *Rhizophora* can absorb freshwater from the saline water through a process of ultrafiltration (Scholander, 1968).
(2) Species of *Avicennia* and *Sonneratia* can regulate the salt content of their tissues by glands in their leaves.
(3) *Xylocarpus* sp., *Lumnitzera* sp. and *Sonneratia* sp. deposit salt in older leaves, roots and bark (Josh), Jamale and Bhosal, 1975).

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6 http://www.earthisland.org/map/mngec.htm
7 State of the worlds forests 2003 ftp://ftp.fao.org/docrep/fao/005/y7581e/y7581e01.pdf
8 http://www.fao.org/forestry/foris/webview/wmatlas/index.jsp?siteId=5321&sitetreeId=20068&langId=1&geoId=0
9 Lugo, Ariel E., and S. C. Snedaker,1974 "The ecology of mangroves", Annual Review of Ecology and Systematics 5:39-64

Mangroves grow faster in areas with plenty of fresh water such as in riverines and estuaries. Generally, more species can be found in areas with low salinity or in the landward zone, than in areas with high salinity or the seaward zone[10]. Mangroves have been useful in treating effluent, as the plants may absorb excess nitrates and phosphates thereby preventing contamination of nearshore waters.

Certain mangrove species can propagate successfully in a marine environment through "viviparity," which is embryo germination which begins on the tree itself, or through "propagules" which hang from the branches of mature trees. The tree later drops its developed embryos or propagules, which may take root in the soil beneath.

Mangrove nursery

A mangrove nursery is an area where seedlings of different mangrove species are grown until they are ready for planting in the field. The nursery should ideally be on dry land near a river for ease of transport and watering. What are the criteria for a good mangrove nursery?

- Brackish water supply
- Accessibility
- Central location
- Open area with adequate sunlight
- Drainage
- Low risk of flooding by tide
- Slightly sloping terrain

Practical experiences with mangrove plantation management

In a recent World Bank experiment in Bangladesh[11], so far about 130,000 ha of mangrove plantations have been planted, which included commercially important mangrove species, *Sonneratia apetala, Avicennia officinalis, A. marina, A. alba, Amoora cucullata, Bruguiera sexangula, Excoecaria agallocha, Xylocarpus mekongensis, Heritiera fomes, Ceriops decandra* and *Nypa fruticans. Sonneratia apetala* proved itself to be the most successful one. Both *Sonneratia apetala* and *Avicennia officinalis* are pioneer species in the ecological succession in the natural mangroves of Bangladesh. They are strongly light demanding. Soil texture ranged from silty loam to silty clay loam. pH varied between 7.5 and 8.2. In most instances very limited (if any) site preparation is necessary, and propagules or pre-germinated seed and seedlings can be easily collected from nature and planted to achieve good results. In Bangladesh mature fruits collected directly from the trees are dumped in 0.6 to 1.3 m deep pits and are covered with thick brushwood and watered with saline water regularly for four to seven days. The fruits are then taken out, bruised lightly by hand and washed in river water to obtain white-coloured pre-germinated seeds which are immediately broadcasted in seed beds or sown in plastic bags. Most mangrove species have an elaborate root system and root development is much faster than the shoot development; as a result, roots in plastic containers may develop into balls and, when the plant is transplanted, its growth may be hampered. Seedlings raised in soft nursery beds can be easily pulled out without any damage to the roots. The Bangladesh Forest Research Institute (BFRI) has contributed significantly on the artificial regeneration of mangrove species and the establishment of man-made mangrove plantations.

Weeding usually is not required as the initial growth of seedlings is quite fast. However, depending on the abundance of weeds, one to three weedings are generally carried out every year during the first two to three years. In the earlier experiments, trees were spaced 2.4 m x 2.4 m. A greater proportion of plantations was raised at a spacing of 1.2 m x 1.2 m. Presently, a spacing of 1.5 m x 1.5 m is recommended for *Sonneratia apetala* and 1 m x 1 m for *Avicennia officinalis*. The growth of *Sonneratia apetala* varies greatly from place to place. Productivity tends to increase from east to west of the coastal belt. On a good site a stand may attain an average height of about 20 m with a diameter of 20 cm at breast height in 20 years. Productivity may be up to 10 m3/ha/year. A rotation age of 12-15 years has been found suitable.

[10] http://www.pemsea.org/young%20environ/ye101/mangrove5.htm#12Can
[11] http://banglapedia.search.com.bd/HT/C_0298.htm

It should be noted, however, that these growth rates found under more or less natural conditions, may be enhanced by a factor 3 to 4 by means of modern cultivation methods and the proper selection of fast growing cultivars. The traditional Dutch willow coppices ('grienden') e.g. used to produce about 3 oven dry tons/ha of biomass on average. By the use of modern cultivation techniques (including fertilisation) and the selection of fast growing willow varieties, dedicated energy coppices of willow now produce 10-12 odt/ha annually, which is a 4 fold increase in 20 years time. Similar improvements may be expected in biosaline forestry management.

Traditionally, mangroves produced fuelwood, charcoal and bark (for tannins). Mangrove wood was the main fuel in the Philippines until World War II (NAS, 1980a). A great advantage is the ease with which the wood is split. It makes an excellent charcoal, rather high in sulphur. In Bangkok, mangrove charcoal, which burns steadily, giving off intense heat without sparking, sells for twice the price of other charcoal (NAS, 1980a). With a calorific value higher than oak, it burns with even heat. [12]

Only in Asia, mangroves forests have been under management for a long time, sometimes over 100 years. Silvicultural systems have been developed based either on selection or clear-felling. Mangrove plantations were also established, either enrichment planting in areas under clear-felling management or as reforestation or afforestation[13], [14]. [15] In the Philipines, planted mangrove forests 40 years old are projected to yield 400 m^3/ha, an average of only 10 m/ha/yr. In Tamil Nadu, *Rhizophora mucronata* plantations for fuel are managed on 30-year rotations. The wood, which is quite durable except when exposed to ground, and difficult to saw, is used for construction, fish traps, house frames, piling, and poles. Thousands of tons of mangrove woodchips are exported annually from Indonesia, Sabah, and Sarawak for pulp manufacture.[16]

By sustainable forest management and community forestry people are encouraged to harvest the by products of that forest, rather than cut the trees themselves. No cutting of mangrove trees is allowed beyond a certain limit-- just enough to meet one's needs. Mangrove forest by products could include limited fuel-wood gathered from fallen or dead branches, fruits or leafy plants from the forest, medicinal herbs, sturdy poles for building, and other useful materials that the mangrove forest produces.[17]

The Manzanar Project in Eritreia
Desert and saltwater are two things Eritreia has plenty of: they are spread out along a coastline of some 1,200 km. The basic assumption of the Manzanar project is that the vast deserts, readily available seawater, and abundant sunshine can be utilized to grow plants that can be irrigated with seawater. About 15 percent of Eritrea's coastline is covered with mangroves with the trees found in areas where flash floods occasionally flow across the sand and into the sea. To make them grow in new locations, each tree needs to be provided with fertiliser in the form of a half kilo plastic bag containing nitrogen and phosphorus and buried at the tree's roots, which eliminates run-off of nutrients into the sea.[18], [19]

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[12] http://www.hort.purdue.edu/newcrop/duke_energy/Rhizophora_mucronata.html#Energy
[13] http://www.tropenbos.nl/DRG/dry.htm
[14] http://www.fao.org/docrep/v5200e/v5200e09.htm#silviculture%20of%20mangroves: Unasylva no. 181
[15] http://www.specola.unifi.it/mangroves/human/restoration1.htm
[16] James A. Duke. 1983. Handbook of Energy Crops. Unpublished
[17] http://wwwscience.murdoch.edu.au/centres/others/mangrove/
[18] http://forests.org/articles/reader.asp?linkid=26137
[19] http://www.rolexawards.com/laureates/pdf/laureate0069.pdf

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Follow-up?
A number of biological and technical problems still needs to be addressed:

1. Species selection for different geo-climatical zones; ranked by salt tolerance
2. Inventory of lands suitable for biosaline plantation forestry
3. Feasibility study for pilot areas: what yields are possible, what are the production costs? What will be the environmental impacts?[20]
4. Bridging the gap between scientific research and forestry practise by means of demonstration projects on integrated salinity management and dissemination of research findings
5. Relevance for The Netherlands: how can we be (and do we want to be) involved in the development of biosaline agriculture and forestry; who are the main stakeholders?

Furthermore, the development of biosaline forestry will face various social and economic problems (e.g. related to sustainability and market development) which need to be approached in a multiple disciplinary way.

6. A integrated vision on the role biosaline forestry may play in the provision of biomass in very near future will be very helpful[21], which should include (but not limit itself to) the status and trends in the extent of mangrove forests worldwide;
7. The development of appropriate silvicultural systems for (irrigated) biosaline plantation forest management adapted to inland and coastal deserts, which could provide a variety of products and services (multiple-use forestry; agro-forestry).

[20] Mangrove ecosystems of Australia: http://www.deh.gov.au/coasts/publications/somer/annex1/mangrove.html
[21] At the moment, Ocean Desert Entreprises is investigating the possibilities and the main barriers to the deployment of biosaline biomass, for which a grant has been given by the Ministry of Economic Affairs within the framework of the Biomass Transition.