The impact of Eucalyptus plantations on the ecology of Maputaland with special reference to wetlands

by

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Declaration of Authorship

I certify that this thesis submitted for the degree of Master of Science is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any university or institute.

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Abstract

**Key words:** interdunal wetlands; peatlands; Eucalyptus; plantation; environmental impact; recharge area; alternative land uses; Maputaland Coastal Plain; South Africa; KwaZulu-Natal

The first trees of the genus Eucalyptus (*Eucalyptus*, blue-gum, gum tree) were introduced to South Africa in 1828, and 125 years later the use of this tree species for timber plantations was documented first time also for the Maputaland Coastal Plain in north-eastern KwaZulu-Natal. Until the 1990s plantation forestry in this region was still classified as a minor land use; however, it started to increase at the end of the last century.

The first concerns about the negative effects of tree plantations on the environment were raised in South Africa already in 1915. As consequence, numerous studies on the environmental and social impacts were realised in South Africa and worldwide until now. Meanwhile, there is a common sense among experts that Eucalyptus plantations may have substantial impact on ecosystem functioning, especially in respect to ecosystem hydrology, biodiversity and soil quality.

On the Maputaland Coastal Plain some of the most extensive wetland and mire areas in South Africa are located. Although these wetland ecosystems provide valuable services to the steadily growing population, they are seriously endangered by direct and indirect land use impacts. It is assumed that the increasing area of Eucalyptus plantations in the ecologically sensitive region of the Maputaland Coastal Plain may have substantial negative effects on the local and regional hydrology and thus, on the ecological and conservational status of the interdunal wetlands and lakes. However, apart from few modelling studies on hydrologic impact, there has not been any direct long-term field research conducted yet.
This study, which is part of an interdisciplinary German – South African research project (AllWet-RES), aims for the better understanding of the possible effects of the plantations on the Maputaland Coastal Plain wetlands, providing information on:

- the ecological impact of the Eucalyptus plantations (literature review)
- the analysis of the development of the area covered by plantations from 1990 to 2012
- the discussion on the recharge area needed to equalize the possible negative water balance of the plantations, as well as proposed buffer zones as management options for wetland protection
- the evaluation of alternative land use options.

The results may be used for the preparation of further on-ground research and as valuable background information in forthcoming decision-making and policy-making processes.
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1 Introduction

1.1 Background

Currently, more than 20 million ha Eucalyptus (Eucalyptus, blue-gum, gum-tree) plantations grow worldwide with the area still expanding (Trabado 2009). In South Africa, about 1 257 000 ha are covered with tree plantations. On approximately 490 000 ha of that area Eucalyptus is grown. They are mainly growing for pulp production which is being used for paper manufacturing. Since the tree species has high water demands and South Africa in general is a water scarce country (mean annual precipitation of 450 mm), the space for growing Eucalyptus is restricted. Therefore, the timber plantation industry tries to use all available high-rainfall areas with mean annual precipitation over 700 mm. This concentration and intensification of the newly introduced land use may cause numerous problems in respect to ecosystem functioning in these regions.

Since 1990, extensive Eucalyptus plantations were established in the north-west of the province KwaZulu-Natal. The region is named the Maputaland Coastal Plain due to the flatness of the area and the proximity to the Indian Ocean. Mean annual precipitation is between 700 mm and 900 mm with a fluctuation of wet and dry periods. The study area is well-known for its high biodiversity as well as for its large amount of wetlands. Most of the wetlands are ground water fed and therefore influenced by a seasonally fluctuant ground water table during the course of one year as well as during wet and dry periods, which tend to last more than 10 years.

A part of the local population is directly or indirectly dependent on wetlands for water provision for their household and livestock, for subsistence farming, to harvest reeds as building material or for making crafts. Furthermore, wetlands provide ecosystem services such as flood attenuation, erosion control, sediment trapping and, in case of peatlands, carbon storage. In respect to peatland occurrence Maputaland Coastal Plain plays a prominent role in South Africa, as about 60% of its peat resources are located in this region (Grundling, Maxus & Baartman 1998). South Africa has lost about 35%–50% of its natural wetlands be-
cause of land use changes and other human impacts (Department of Water Affairs 2005 in Arndt 2014).

Although the wetland system of Maputaland is protected by national legislation (e.g. National Water Act) and is partly located within protected areas (like the iSimangaliso Wetland Park) especially the wetlands on communal land are increasingly threatened by agriculture, forestry and urbanization. Further threats are the still rising pressure through population growth as well as the actual drought period lasting since 2002 (Grundling 2014).

Due to the National Water Act, which was established in 1998, every plantation owner has to register and needs to apply for a water use license. Licenses are only granted if the water resource in the catchment area is considered to meet current and new demands. This strict regulation has led to a large number of basically illegal plantations due to the amount of time and money that are needed for the fulfillment of application requirements. Currently, the Licence Assessment Advisory Committee is planning to decide on outstanding license applications for plantations within the study area. If these licenses will be granted, all already existing plantations which were established without a licence between 1998 and now will be principally accepted by the government in a state of legal limbo.

It is assumed that Eucalyptus plantations may have substantial negative effects on ecosystem functioning, especially in respect to ecosystem hydrology, soil quality and biodiversity. As early as 1915, concerns about negative effects of tree plantations were raised in South Africa (Dye 2013). Until today, numerous researches, reviews and studies have been realised worldwide with the first comprehensive one published in 1988 by the Food and Agriculture Organization (Poore & Fries 1988).

In South Africa, the main research focus concerning plantations and water use is concentrated on the change of streamflow after afforestation. Paired-catchments experiments which examined the impact of tree plantations on the hydrology of the catchment have been started as early as 1936 (Chapman 2007). Since then, results of numerous further studies were published (Scott & Lesch 1997; van Lill, Kruger & van Wyk 1980; Smith & Scott 1992; Scott, Le Maitre & Fairbanks 1998). In brief, they show that in general, large afforestation with Eucalyptus causes a significant streamflow reduction.

The impact of Eucalyptus on the hydrology in Maputaland was hardly studied. In 1992, Kienzle & Schulze modelled the effect of afforestation on ground water resources in northern KwaZulu-Natal. They calculated the drawdown of the water table to be 4 m, 6 m or 12 m, dependent on the maximum rooting depth of the trees. A study of Scherzer (2010) investigated the influence of tree plantations on the hydrology of the iSimangaliso Wetland Park. The author concluded that the growing area of plantation forestry in the zone of influence of the park negatively affects the ground water level within the park as well as the lake system of
the park. Three years later, Brites & Vermeulen (2013) published a report about their measurements of the changes of the ground water level under Eucalyptus and Pine plantations on the Maputaland Coastal Plain close to Lake St. Lucia over a period of 13 years. Under Eucalyptus, an average decline of about one meter per year and an overall decline of between 10 m and 16 m were measured.

Recently, the North-West University prepared an internal report for the South African government which investigated the impact of existing and planned tree plantations on wetlands and ground water in the study area (Dennis 2013). The ground water demand and the impact of plantations on the ground water and on the lakes were assessed based on hydrological modelling using various data sources without own field measurements. Regrettably, a clear description of methods and references to used data or sources are often lacking and thus, the background data, outcomes and recommendations of the report cannot be much discussed within the scope of this thesis.

The major change in the land use of Maputaland within the last 25 years is the Eucalyptus plantations that started spreading after 1990. The outgrower schemes established by the two large South African forestry companies MONDI and SAPPI are marketed as socially responsible and claim Eucalyptus plantations as a modern land use without alternative due to the economic benefits and the easy management. This led to a word of mouth promotion between growers and their neighbours which induced the spreading of the woodlots (Cairns 2000). However, the negative impacts may be large and are often not taken into consideration when evaluating this type of land use (Chown 2001).

In the study area, the effect of the Eucalyptus plantations on the hydrology is likely dependent on the rooting depth of the trees and the depth of the ground water table. If it is possible for the trees to reach the ground water table their evapotranspiration is no longer restricted to annual rainfall which, under usual circumstances, limits the evapotranspiration (Dye 2013).

Although a change of dry and wet periods is common for the Maputaland Coastal Plain, the actual dry period has already lasted since 2002 (Grundling 2014) and several wetlands have vanished. The assumption is that the Eucalyptus plantations are one of the main factors responsible for a lowering of the water table and consequently the drying out of wetlands comes along with that.
1.2 Hypothesis

Eucalyptus plantations may harm the wetlands of the Maputaland Coastal Plain by changing the hydrological regime. There are environmentally friendly and economically comparable alternative land use options.

1.3 Research question and objectives

This work is part of the project “Alliance for Wetlands – Research and Restoration”. This four-year project cooperation (2012–2015) is implemented by two German and two South African Universities and financed by the German Academic Exchange Service (DAAD) together with the German Federal Ministry of Education and Research (BMBF). Research focus lies on the protection, restoration and wise use of the wetlands of the Maputaland Coastal Plain.

The aims of the project are to improve the knowledge on rehabilitation of degraded wetlands and to contribute to a better understanding of their ecosystem function and their role for local communities. Furthermore, recommendations for sustainable land use, restoration and conservation shall be developed.

The first thesis within this project that touched the issue of Eucalyptus plantations in Maputaland was completed in spring 2014 by Jonas Arndt (Technische Universität München) about the distribution and long-term historic impact of the small-scale subsistence farming on wetlands. Arndt performed the first assessments of the spreading of Eucalyptus plantations within his study area (349 km²). The space covered by Eucalyptus grew from 0.3 km² in 1990 to 28.5 km² in 2009. He concluded that likely the plantations may have an enormous negative effect on the landscape hydrology.

The thesis at hand contributes in achieving the aims of the AllWet-RES-project by examining the influence of the Eucalyptus plantations on the wetlands of the study area. This is done by an extensive literature review about the ecological effects of Eucalyptus plantations on the hydrology, biodiversity and soil. Furthermore, the work explores the spreading of the plantation area from 1990 to 2012 by analysing aerial photographs and satellite imagery. Management options such as the implementation of buffer zones around wetlands were visualized and evaluated. In addition, existing laws and regulations concerning the effect of tree plantations on wetlands were considered. At the end possible alternative land use options are introduced and their advantages and challenges discussed.

It is necessary to underline that due to the limited time available no field research (e.g. hydrological measurements) was carried out. However, without doubts the thorough research on already available data and information allow the drafting of conclusions that might be of
importance when negotiating and deciding on the land use practices in Maputaland in the near future.

In brief, the objectives of this work are

- to evaluate the ecological impact of the Eucalyptus plantations by literature research
- to analyse the development of plantations from 1990 to 2012
- to roughly calculate the wetland area that is being influenced by the Eucalyptus plantations
- To discuss buffer zones as management options for protecting the wetlands
- To present and evaluate alternative land use options

1.4 Structure of the thesis

Chapter 2 is an independent part of the thesis with no direct linkage to the study area. The general biology of Eucalyptus is presented as well as specific findings of the literature review about the ecological effect of Eucalyptus plantations on the catchment hydrology, the biodiversity and the soil quality.

Chapter 3 serves as introduction of the study area and of the history of timber plantations in South Africa, especially in Maputaland. In addition, the methods of the GIS-analyses are presented.

Chapter 3.2 presents the results of the GIS-analyses.

Chapter 3.3 discusses the findings of the literature review with reference to the study area. Furthermore, the results obtained from the GIS-analyses are discussed.

Chapter 4 shows and discusses several different alternative land use possibilities. Based on the pre-conditions of the study area, ways to improve the subsistence farming as well as the introduction and evaluation of new methods like horticulture with hydroponics are handled.

Chapter 5 presents the conclusion of this thesis and introduces future research topics.
2 Eucalyptus plantations and their impacts on the environment – a literature review

First, the biology of the genus Eucalyptus as well as its world distribution and commercial use are explained. This is followed by an in-depth literature review of the ecological effects of Eucalyptus plantations which is divided in three parts. The first part presents the effect on catchment hydrology, the second on biodiversity and the third on soil quality.

2.1 Biology and commercial use of Eucalyptus

The genus *Eucalyptus* is indigenous in the Australasian region. Its natural distribution extents from 42 °S to 11 °S in Australia and covers about 28 million hectares from the sea cost to a height of 2 960 m. Eucalyptus plants were discovered by the Western civilization after the voyages of James Cook in the 1770s. The first tree was described by a French botanist in 1788 and 80 years later, already 135 different species were known (Coppen 2002). Today, the genus comprises more than 700 species but only about 20 of them are of international importance due to their use in timber plantations. Four of them and their breeding as well as genetically improved clones dominate plantations globally: *E. camaldulensis*, *E. globulus*, *E. grandis* and *E. tereticornis*.

Nowadays, Eucalyptus is probably the most widely cultivated of all plants, over wide geographic and environmental gradients throughout the world (Coppen 2002). Reasons for planting Eucalyptus are the high growth rates, the wide adaptability to soils and climate, the ease of management through coppicing and valuable wood properties. According to Hubbard et al. (2010) Eucalyptus plantations are one of the most productive ecosystems in the world with growth rates of up to 40 m³/year. It is grown for multiple uses including construction timber, fuel, pulp, plywood, poles, firewood, charcoal, essential oils, productions of plant growth regulators, for tannin extracts and industrial chemical additives (Coppen 2002).

The area planted with Eucalyptus is still increasing: In 1995 it was about 13.4 million ha (Coppen 2002), in 2002 about 17.8 million ha (Carle, Vuorinen & Del Lungo 2002) and in 2009 more than 20 million ha with the leading countries in terms of area being India, Brazil, China, Australia, Uruguay, Chile, Portugal, Spain, Vietnam and South Africa (in that order) (Figure 1).
The species of the genus Eucalyptus are heterophyl. Younger leaves are decussately and formed in pairs on opposite sides of the four-sided stem with successive pairs at right angles to each other. Contrary to this older leaves have a different shape, petiole and colour and are alternately, which develops by an unequal elongation of the leaf-bearing axis on opposite sides (Coppen 2002). The bark of most of the Eucalyptus species is a distinguishing feature. Some species shed their outer bark each year, others retain the dead bark. Every Eucalyptus plant puts on an annual increment of bark tissue. Colour, form and thickness of bark types vary considerably with species, age, health and season. Seed morphology is extremely variable between species as well. The germination of Eucalyptus species is epigeal.

The habit of the species that are used for plantations worldwide is characterized by a long bole with a small terminal crown. These species mostly originate in the wetter forest of the eastern seaboard of the Australian continent, for example *E. grandis*, *E. saligna*, *E. globulus*, *E. tertiicornis*, *E. nitens*, *E. dunii* and *E. smithii* (Coppen 2002). Another worldwide grown species, *E. camaldulensis*, has as natural habitat woodland but due to its good adaptability to many differing habitats it probably has the widest natural distribution of all Eucalyptus species.

Almost all commercially used Eucalyptus species develop lignotuber, which grow in the axis of the lower leaf pairs and become lignified over the time. It functions as a store of dormant shoots which tend to develop and produce new stem structures in case the upper part of the plant is lost through e.g. cutting, fire or grazing. Thus, most of the Eucalyptus species are especially appropriate for coppice management.

The huge industrial timber plantations are usually monocultures with a single species. The individuals are genetically selected and it is more and more common to use clones. Re-
cently, over 94% of the genome of *Eucalyptus grandis* was sequenced and assembled (Myburg et al. 2014). The management may be intensive consisting of clean weeding, fertilizing and pest control.

The harvest time of the plantation is dependent on the climate and the desired product of the tree. For pulp production, harvesting happens usually between six and ten years after planting. Due to the coppicing ability, it is common to leave the stumps to sprout. After a thinning of these sprouts, one to three would be left on each stump to grow for the next harvest (Figure 2). Couto & Betters (1995) state that the renewal of the stands after the first harvest has been a common practice but opposite to this, Coppen (2002) writes that the yield from the first coppice crop is higher than the seedling yield. Thereafter, it declines with every cropping.

![Coppiced Eucalyptus in Maputaland](image)

*Figure 2: Coppiced Eucalyptus in Maputaland*
2.2 Ecological effects of Eucalyptus plantations

South Africa was one of the first countries in which environmentalists raised concerns about negative ecological effects of timber plantations. As early as 1915, scientists and foresters discussed mainly the influence of the plantations on water yield and catchment hydrology (Dye 2013). Out of these debates some of the most detailed and definitive studies of water use from forests and commercial timber plantations of any country in the world evolved. Concerns about the ecological effects of Eucalyptus have been raised as well in other countries. A prominent example is India with the scientist Vandana Shiva starting to argue against the establishing of Eucalyptus plantations in her country in 1982 (Coppen 2002). One of her main arguments is that the plantations are likely to deplete water resources. The high water use of Eucalyptus is for example used in parts of Australia where it is grown to lower water tables to fight salination (Heuperman 1999).

Moreover, Eucalyptus advocates and Eucalyptus opponents not only discussed the impact of Eucalyptus plantations on water resources. Two other main concerns are the effect of Eucalyptus plantations on soil quality (inter alia through the allelopathic effects) and on biodiversity.

The following three chapters summarize the findings on these topics derived from an in-depth literature review. It was not always possible to assign or to extract the effects caused especially and only by Eucalyptus timber plantations. Therefore the review also includes effects of other timber species plantations.
2.2.1 Effects on catchment hydrology

As early as 1986 the FAO published a report about the ecological effects of Eucalyptus species. The report underlines that “the plantation of extensive forests of Eucalyptus on any deforested catchment will substantially decrease water yield from that catchment” (Poore & Fries 1988). The following results from studies all over the world should be conducive to the understanding of the high water use of Eucalyptus plantations.

In cases where Eucalyptus plantations replace grassland or shrubby natural vegetation, the water use of the plantations is in most conditions higher than the use of the original vegetation (Coppen 2002). In South Africa, this may be assigned to the missing of the dormant season of plantation trees in comparison to grassland (Dye, Olbrich & Everson 1995). The annual transpiration rates of trees are therefore higher than of grasses or shrubs. On a worldwide scale, the difference in water use between short vegetation and trees is often explained by higher interception rates of trees. However, in South African Eucalyptus plantations of the summer-rainfall regions, interception loss was proven to be only 4.1% (Dye, Olbrich & Everson 1995). This rate is similar to grassland canopies, which leaves the higher transpiration rates of trees as the main reason for the difference in water use (Scott & Lesch 1997).

The total amount of water that is being additionally used by Eucalyptus in comparison to grassland is difficult to determine. In the review by the FAO the authors state that on a deep soil with high rainfall regimes, the soil water deficit created by Eucalyptus plantations is approximately 250 mm/year (Poore & Fries 1988). Bosch & Hewlett (1982) reviewed 94 catchment experiments (in a catchment experiment different land uses are compared in respect to their water use) around the world and assessed the difference in water use between Eucalyptus and Pine plantations and short vegetation between 300 mm/year and 400 mm/year. Reasons for this difference are explained by Scott (2005):

In comparison with grassland plantations have
- larger and more complex canopies,
- a wider and more turbulent boundary layer,
- a higher leaf area index (leaf area per square meter),
- deeper roots
- a higher activity in the dry season.

Furthermore, the species of the plantations are mostly exotic and therefore at least in the beginning of their introduction on new sites free of their native pests and diseases. In respect to the species-related water consumption, Dye (2013) found out that there is no definite amount for the water use of particular Eucalyptus species. In his opinion the climate and the soil are more important to determine the water use than the type of Eucalyptus species.
Table 1 shows an overview of some data presented in literature about the water use of Eucalyptus plantations. It ranges from 1.72 mm/day to 6.30 mm/day. The varying data supports the thesis of Dye. For comparison, the range of water use of the pre-afforested vegetation in the forestry regions of South Africa is from about 1.92 mm/day to about 2.47 mm/day (700 mm/year to 900 mm/year) (Bosch & Gadow 1990 in Dye & Versfeld 2007).

Table 1: Water use of Eucalyptus plantations

<table>
<thead>
<tr>
<th>Species</th>
<th>Water use mm/year</th>
<th>Water use mm/day</th>
<th>Rainfall mm/year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different Eucalyptus species</td>
<td>2300</td>
<td>6.30</td>
<td>680</td>
<td>(Greenwood et al. 1985 in Coppen 2002)</td>
</tr>
<tr>
<td>Different Eucalyptus species</td>
<td>1600</td>
<td>4.38</td>
<td>680</td>
<td>(Greenwood et al. 1985 in Coppen 2002)</td>
</tr>
<tr>
<td><em>E. grandis</em></td>
<td>1231</td>
<td>3.37</td>
<td>1459</td>
<td>(Dye 1996)</td>
</tr>
<tr>
<td><em>Eucalyptus spec.</em></td>
<td>1200</td>
<td>3.29</td>
<td></td>
<td>(Bosch &amp; Gadow 1990)</td>
</tr>
<tr>
<td><em>E. camaldulensis</em></td>
<td>1150</td>
<td>3.15</td>
<td>700</td>
<td>(Calder et al. 1997)</td>
</tr>
<tr>
<td><em>E. saligna</em></td>
<td>1084</td>
<td>2.97</td>
<td>1635</td>
<td>(Lima et al. 1996)</td>
</tr>
<tr>
<td><em>Eucalyptus spec.</em> and Pinus spec.*</td>
<td>867</td>
<td>2.4</td>
<td>866</td>
<td>(Brites &amp; Vermeulen 2013)</td>
</tr>
<tr>
<td><em>E. dunnii</em></td>
<td>629</td>
<td>1.72</td>
<td>704</td>
<td>(Dye 2013)</td>
</tr>
</tbody>
</table>

The influence of tree plantations on catchment hydrology depends greatly on the water supply of the trees. If their roots have no access to ground water, their only source of water is the bank of soil moisture which is replenished by precipitation. Otherwise, i.e. if the roots have access to ground water, they do not suffer from droughts and they possibly use as much water as they require which may result in high transpiration rates (Coppen 2002).

The depth of the rooting system is controversial discussed and has been a research topic since 50 years. Haigh (1966) and Scott (1993) (in Le Maitre, Scott & Colvin 1999) did root excavation studies on the Zululand sand plain. They showed that both Pine and Eucalyptus trees develop strong sinker roots to a shallow water table between three meters and
six meters below ground level. Another study from South Africa conducted in 1996 by Dye found out that three-year old *Eucalyptus grandis* trees soak their water out of the soil from depths up to eight meters, whereas nine-year old *Eucalyptus grandis* trees obtained most of their water from even deeper layers: drilling revealed living roots up to 28 m deep. The author poses the question whether the soil water may be recharged during continuous Eucalyptus cropping.

Studies from Australia and India show similar results. In Australia, Nulsen et al. (1976) did research on the rooting habit of a *Mallee* community with *E. pileata* and *E. eremophila*. He found roots up to 28 m deep. Greenwood (1979 in Coppen 2002) showed that roots of two year old Eucalyptus trees growing in Australia possibly reach the water table at a depth of between three meters and five meters. Carbon (1980) studied the root distribution in an Australian forest mainly consisting of *E. marginata*. He found out that the density of fine roots is not significantly decreasing between 4 m and 15 m and that the trees root to a depth of about 20 m. Contrary to this, another study from Australia found no large roots penetrate deeper than 1.2 m (Greenwood 1982 in Coppen 2002).

In India, Mathur et. al (1986 in Schütt et al. 2006) examined five root systems of *Eucalyptus globulus*. They found out that the roots do not grow deeper than three meters after ten years. Recently, Kallarackal (2010) revealed roots of plantations of *E. grandis* reaching more than ten meters deep.

Dye, Olbrich & Everson (1995) summarized the findings about the rooting system of Eucalyptus and stated that if the soil is deep, Eucalyptus tends to root deep. However, even if root depths are not particularly great and the roots are not reaching the ground water table, the trees may have a large effect on water balance. The root system may affect ground water by decreasing recharge through extracting water from the unsaturated zone and creating additional storage capacity in the unsaturated zone, without there being direct abstraction from ground water (Le Maitre, Scott & Colvin 1999).

The above facts lead to the conclusion that in areas where the ground water table is around eight meters below the surface and the soil is deep and easy to penetrate, it is likely that roots of a three-year old eucalypt may already reach the ground water table. In that case, total evaporation may exceed annual precipitation. Examples for total evaporation exceeding annual precipitation are known from Australia: Greenwood et al. (1985 in Coppen 2002) examined the annual evapotranspiration rates of different Eucalyptus species and of pasture. The rates of Eucalyptus exceeded the annual rainfall rate of 680 mm more than three times. For pasture 390 mm were measured whereas for Eucalyptus it varied between 1 600 mm and 2 300 mm depending on the position on slope and on Eucalyptus species. Soil coring studies revealed tree roots at a depth of six meters, one meter below the average water table. In a study by Kallarackal (2010), the evaporation of *E. grandis* exceeded annual rainfall
(1500 mm). The author concludes that water must be drawn from deeper layers of the soil or from a phreatic aquifer. Another study from India by Calder et al. (1997) showed that *Eucalyptus camaldulensis* extracts and evaporates an extra 400–450 mm of ground water in addition to the annual input of rainfall (of approx. 700 mm). Roots of these trees penetrated the soil in depths of more than eight meters with a rate exceeding 2.5 m per year. Calder et al. call that phenomenon “water mining” by deep rooting.

In cases where the water use is greater than the replenishment rate, the ground water reservoir will deplete (Scott 2005). Accordingly, studies already have shown a lowering of the water table under Eucalyptus plantations.

Kienzle & Schulze (1992) simulated the impact of Eucalyptus plantations on the Zululand coastal plain with different values for the maximum rooting depth (10 m, 15 m and 20 m). The model simulated the water table from 1952 to 1988 for different sized Eucalyptus plantations and for natural vegetation on deep sandy soil. Depending on the different maximum rooting depths, the drawdown was calculated to be about 4 m, 6 m or 12 m after the simulation period. A fast drawdown occurs within the first years after establishing the plantations, leading to a slow levelling off to a certain depth. In 1988, the water table under natural vegetation was calculated to be at 8 m depth whereas the water table under the plantations was calculated to be at 12 m, 14 m or 20 m, depending on the maximum rooting depth. According to the study, the drawdown leads to a depression area affecting wetlands and streams in the surrounding of the plantations.

Another study in that region conducted by Brites & Vermeulen (2013) examined the impact of different plantations on ground water. The outcome was that the water table under Eucalyptus plantations was lowered between 10 m and 16 m over a period of 13 years – an average decline of about one meter per year.

Heuperman (1999) confirmed that the decline of the ground water table affects the ground water outside of the plantation area. The results of this study conducted in Australia showed that a drawdown of two meters to four meters extends 20 m to 40 m into adjacent pastures, respectively, even on loamy soil with low water conductivity (Ks=0,01 m/day). On soils with higher water conductivity the extent of the drawdown could be much more. This may result in the drying up of wetlands and streams close to plantations.

The extent of the effect of plantations on the streamflow of the catchment strongly depends on the vegetation that was replaced. South Africa has a long research history regarding the comparison of streamflow before and after planting timber plantations. The calibration of the first of such paired catchment experiments started in 1936 (Chapman 2007).

In the Mokubulaan catchment in the Mpumalanga Province the streamflow of catchments afforested with Eucalyptus, catchments afforested with Pine and catchments with nat-
ural vegetation was compared in a long-term study. The results show that the afforestation with Eucalyptus caused a quicker reduction in streamflow than afforestation with Pine (Scott & Lesch 1997). This is explained by the quicker canopy growth and the faster growth in general of Eucalyptus (Dye 2013). This result even appears in an information paper about Eucalyptus trees of the forest industry, which declares that Eucalyptus uses 15% to 30% more water than Pine (Sappi 2012). Another paired-catchment experiment which was analysed by Scott (2005) showed that dry season flows are reduced earlier and to a greater extent than total flows because the trees are depleting soil reserves which nourish dry season flows. Additionally, catchments planted with Eucalyptus showed a significant reduction three years after planting whereas catchments planted with Pine showed this reduction not before five years after planting (Smith & Scott 1992).

After the clear cut of one of the afforested Eucalyptus catchments it took five years to restore the streamflow to pre-afforestation levels (Scott & Lesch 1997). It is assumed that the depletion of ground water reserves may be the reason for this gap and that it took five years of rainfall to replenish the ground water (Le Maitre & Versfeld 1997).

Also other paired-catchment experiments conducted in South Africa confirmed a substantial effect of the afforestation on the catchment streamflow: In the KwaZulu-Natal Drakensberg region an 82% reduction in streamflow 20 years after planting grassland with Pine was observed (Bosch 1979 in Chamier et al. 2012), and in the Western Cape Province researchers measured a 55% reduction in streamflow 23 years after converting fynbos to Pine plantation (van Wyk 1987 in Chamier et al. 2012).

As overall result of these experiments, a formula was developed for calculating the reduction in streamflow out of the percentage of the afforested area of a catchment. The estimation is that Eucalyptus plantations cause 30 mm to 40 mm change in water yield per 10% of the catchment area subjected to change in cover (Bosch & Hewlett 1982; Scott & Smith 1997). The experiments were conducted only in regions with rainfall of more than 1100 mm/year therefore it is not possible to transfer the formula to catchments with a mean annual precipitation below this amount.

Another important aspect to consider when referring to the water use of Eucalyptus plantations is the coppicing ability. After a harvest which leaves the stems to sprout for a second rotation cycle, the root system is already established and therefore the water use especially in the first years is higher than during the first rotation cycle. This may have a significant short-term effect on local hydrology due to high water use as the above-ground biomass develops rapidly (Coppen 2002; Sharda et al. 1998).

When considering the effects of the high water use of Eucalyptus trees, one must not forget that in terms of water use efficiency (ratio of amount of water consumed per amount of
biomass produced) the species is more efficient than most other plantation trees. Binkley, Stape & Ryan (2004) found out that for young Eucalyptus plantations, more productive sites tend to have higher efficiency of resource use than less productive sites.

Referring to the water use of plantations, Scott (2005) estimates productive plantations as transitional between agricultural crops and native forest. In native forests it is not possible to model the total water use via growth and yield whereas it is possible for agricultural crops. However, in timber plantations there is a strong correlation between growth rate and transpiration (Dye 1996). In native forests, the transpiration declines with age but in a plantation the trees are harvested before this decline happens. Thus, there is no time of decreasing transpiration and therefore no possibility to recharge the ground water reservoir.

2.2.2 Effects on biodiversity

By definition, biological diversity means “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems” (United Nations 1992).

This literature review surveys the influence of tree plantations on biodiversity in general and of Eucalyptus plantations in particular. Biodiversity is not only important per se, it plays a significant role in obtaining ecosystem functioning (Hooper et al. 2005; Balvanera et al. 2006) as there is for example the better resistance of plantations afforested with higher species diversity against pests and diseases, the resilience against changes in climate, the prevention of erosion and improving of soils fertility.

Generalizing the effect of tree plantations on biodiversity is not possible. The size and direction of the effect, whether the plantation induces positive or negative changes in biodiversity, depends on the vegetation that is being replaced and on the location of the plantation within the landscape. Additionally, it is important to distinguish between the scales of biological diversity. It is possible to measure biodiversity on a local level (α-biodiversity), on a regional level (β-biodiversity) or between regions (γ-biodiversity) (Whittaker 1960).

Carnus et al. (2006) made a review on planted forests and biodiversity and described four components of special relevance for the biodiversity of plantations:

- the genetic diversity
- the diversity in species
- the structural diversity
- the functional diversity

In general, the genetic diversity is low in pure monoculture plantations. They consist mainly of one species that was bred and is adapted to specific aims, e.g. herbicide, pest and
pathogen resistance, improved timber quality and increased vigor (Mathews & Campbell 2000). Moreover, in exotic tree plantations new genes may only be introduced through breeding programs because there is no genetic exchange with indigenous trees.

In the last years the use of genetically modified organisms in the plantation forestry has grown. The overall aim is to increase the productivity by decreasing the rotation period. Environmentalists raise concerns about the possible gene exchange between native forests and modified indigenous plants (Mathews & Campbell 2000). For plantations consisting of exotic trees, concerns are about an invasion of these trees and an outcompeting of indigenous plants which would lead to a loss of biodiversity and an alteration of the hydrological regime (Mathews & Campbell 2000; Gill & Williams 1996). Additionally, breeding programs may narrow the genetic base of plantation trees and reduce their ability to cope with pest damages and diseases (Ciesla & Donaubauer 1994).

Much research on comparing interspecific diversity of plantations with naturally regenerated stands and other habitats has been carried out in the last decades. Carnus et al. (2006) provides evidence for plantation forests being less favorable as habitat than naturally regenerated stands and other habitat. A large number of special research in this respect that has been carried out on bird species (Helle & Mönköknen 1990; Baguette, Deceuninck & Muller 1994; Gjerde 1997; Fisher & Goldney 1998; Twedt et al. 1999), carabid beetles (Fahy & Gormally 1998), arthropods in general (Chey, Holloway & Speight 1997) and dung beetles (Davis, Huijbregts & Krikken 2000) confirmed in general the decline of biodiversity within the plantations. Only in case of fungal and invertebrate communities in conifer plantations in Great Britain some studies show a comparable species diversity in plantations with that in naturally regenerated stands (Humphrey et al. 1999; Humphrey et al. 2000; Humphrey et al. 2002).

An important contributor to species and structural diversity on stand level is the kind of understory that develops under the canopies of the main tree species. If and what kind of understory develops is dependent on the management of the site. Intensity of site preparation, stand establishment, control of competing vegetation, thinning and timing of harvest largely influence the understory and the complexity of the stand structure. Short rotation periods with even-aged trees tend to prevent the growth of undercover, limit the extent of a complex understory development and thus, they affect the suitability of the plantations for wildlife species. Furthermore, short-rotation clear-cuts support erosion (Menne 2013).

The impact of plantations on the β-biodiversity or γ-biodiversity is even more difficult to predict as the effects may be both positive and negative.
According to Gill & Williams (1996), Estades & Temple (1999), Brockerhoff et al. (2008), Parrotta, Turnbull & Jones (1997) and Silva (2009) positive effects of plantations may be achieved when they

- are established on former agricultural or degraded land and create new habitats that improve connectivity and provide linkages allowing animal disperse
- contribute to the halt of desertification processes on unstable land or in areas prone to desertification
- contribute to biodiversity through habitat supplementation or complementation for forest species, e.g. by protecting natural forest remnants within the plantations or through buffering effects
- provide catalytic effects on degraded land in regeneration of native flora and fauna by creating suitable environmental conditions that enhance the dispersal of native forest plants

On the other hand, Silva (2009) and the Forest Stewardship Council (2004) expect negative effects on biodiversity in cases where plantations

- replace natural or semi-natural vegetation
- prevent the connectivity between patches of natural vegetation on landscape level
- consist of exotic trees with a potential danger of invasion

In addition, the usage of agrochemicals within plantations tends to lower the biodiversity. Hartley (2002) reviewed their effect and found out that the application generally reduces plant species and structural diversity of young stands, not only the diversity of target-species.

It is often assumed that the establishment of plantations releases harvesting pressure on natural forests. An example supporting that opinion is New Zealand. According to MacLaren (1996; in Carnus et al. 2006) the importance of plantation forestry has allowed the protection and conservation of natural forests. Contrary to this, in Chile the harvesting pressure on natural forest actually increased as plantation production grew (Clapp 2001). Carnus et al. (2006) explained that with the complexity of the world-wide wood market and the reasonable time lag between the establishment of a plantation and their production of wood products that would otherwise be obtained from natural forests.

Out of these literature reviews and researches it may be concluded that in general, plantations lower species diversity and this reduction likely effects the long-term ecosystem health (Jactel et al. 2002; Woods 2003).

Because of the worldwide introduction of the species and its economic importance, the effect of especially Eucalyptus plantations on biodiversity was subject of several studies that
more or less confirm the findings listed above. In general, Eucalyptus plantations with a rotation time below 15 years are considered as fast-wood plantations with a low conservation value because of their little contribution to biodiversity (Brockerhoff et al. 2008).

In a study conducted in the Congo savannah about the effect of tree plantations (Eucalyptus hybrids, Acacia auriculiformis and Pinus caribaea) on the undergrowth composition, Bernhard-Reversat (2001) showed that Eucalyptus spp. depressed forest species more than Pine or Acacia plantations. However, he could not determine whether the reason is the allelopathic influence of Eucalyptus litter (cf. chapter 2.2.3) or environmental conditions. Obviously, there is a relation between the vegetation richness of the understory and the diversity of forest invertebrates. In a study on the diversity of butterflies in tropical Eucalyptus plantations, Barlow et al. (2008) showed that the diversity of the native understory vegetation had the strongest independent effect on the richness of butterflies and that plantations may help conserve only a limited number of forest species. Similar effects were observed by Ratsirarson et al. (2002) who compared the leaf-litter invertebrate communities of indigenous forests with Eucalyptus and Pine plantations in the Cape Peninsula National Park, South Africa. The highest amount of species was counted in the indigenous forests followed by the Eucalyptus and then the Pine plantations. The potential maximum number of species in the indigenous forests was 1.8 times higher than in the Eucalyptus plantations.

In several countries, e.g. in southern Europe (Spain, Portugal), eucalypts escaping from plantations invade native forests and replace natural vegetation (Carnus et al. 2006).

As the above analyzed studies show, the most important aspect to determine the effect of plantations on biodiversity is the initial setting: plantations generally provide less suitable habitat for flora and fauna than the ecosystem they replace, especially when the plantation consists of exotic, even-aged monocultures. Only in cases when the ecosystem that is being replaced is already substantially degraded, plantations may provide additional biodiversity or even catalyze the restoration of native flora and fauna on former afforested land. The rotation length plays a significant role in defining the biodiversity value of plantations; increasing the rotation length is widely advocated to increase the biodiversity of plantations.
2.2.3 Effects on soil quality

First, the influence of Eucalyptus plantations on the nutrient cycle is documented; afterwards the allelopathic effect of the Eucalyptus litter is explained. In the end, two examples of studies about the soil fauna and the soil organic matter under Eucalyptus are given.

The effect of Eucalyptus plantations on the soil nutrients is mostly dependent on the harvest cycle. The more often the harvest, the larger is the amount of nutrients which is exported. The cumulative effect of nutrient removal through such successive rotations could add up to substantial amounts over long periods of time (Poore & Fries 1988; Du Toit 2003). However, the effect on the nutrient cycle is likewise dependent on the vegetation being replaced by plantations. It seems that nutrient requirements of Eucalyptus and Pine stands are of the same order of magnitude, however, they are generally higher than those of native ecosystems (Grove, Thomson & Malajczuk 1996; Poore & Fries 1988).

In the long term, it is not possible to restore soil fertility under plantations only by replenishment through weathering, by inputs through precipitation or by humification of litter. Annual litter fall of Eucalyptus is low compared to other fast-growing trees or compared to many natural tropical forests (Loubelo 1990, Bernhard-Reversat 1993 in Bernhard-Reversat 2001). The site management and harvesting practices play an important role for the nutrient availability in soils. If only the stem is removed, the export is lowest because the highest amount of nutrients is in the leaves, the branches and the bark (Heaton 2004). By burning the harvest residues, nutrients vanish through surface run-off and seepage. The best practice is to retain the harvest residues as it favors the conservation of nitrogen after logging (O’Connell 2004). However, calcium, phosphorous and nitrogen will not be sufficiently supplied in natural inputs to replace removals and in addition will be further depleted by natural outputs (Poore & Fries 1988; Bernhard-Reversat 2001). Plant available nitrogen is of particular importance because it depletes the fastest. The export of nutrients by harvesting leads, at least on naturally acid and nutrient poor soils in grassland ecosystems, to a stronger acidification (Ministry of Water Affairs and Forestry 1997). Hence, to achieve optimum tree growth on nutrient poor soils, fertilization and mitigation measures against acidification are required (O’Connell 2004; Bernhard-Reversat 2001).

Another negative influence of industrial harvesting on the soil is the impact of large harvesting machinery on the site. It modifies the soils physical characteristics and may lead to increased erosion risks (Silva 2009; Forest Stewardship Council 2004).

On the other hand, there are few studies showing no significant differences between soil under plantations of Eucalyptus and soil under natural vegetation. Couto & Betters (1995) quote a study carried out by the Fundação Centro Tecnologico de Minas Gerais in 1984 which compared soils under Eucalyptus plantations with soils from natural savannah. The
chemical, physical, and biological analyses of the soil samples showed no significant differences. Another example they cite is a research conducted by Fonseca in 1984 that compared the chemical, physical and biological soil analyses of 25-year-old *Eucalyptus citriodora* and *Eucalyptus paniculata* plantations with those of soils from nearby native forests and pastures. The soil under Eucalyptus had more microorganisms and nutrients and contained more litter than that under native forest. The higher amount of litter may be due to the high C/N ratio of Eucalyptus litter which leads to slower decomposition (Madeira, Andreaux & Portal 1989). The improved soil fertility under Eucalyptus may be explained by the developing of mull-humus, but only under non-cropped stands (Poore & Fries 1988).

A great deal of research has been carried out on the effect of allelopathic substances from litter of some Eucalyptus species on the soil micro fauna and flora (del Moral & Muller 1970; Al-Mousawi & Al-Naib 1975; Poore & Fries 1988; Molina, Reigosa & Carballeira 1991; Lisanework & Michelsen 1993; Bernhard-Reversat 1999; Khan, Hussain & Khan 2008). The comparison of research shows that a generalization of the impact is hardly possible, as the influence always depends on the species and the environmental circumstances.

Allelopathy is either defined as “any process involving secondary metabolites produced by plants, algae, bacteria and fungi that influences the growth and development of agriculture and biological systems” (Roger, Pedrol & González 2006) or as the capability of substances produced by one plant to inhibit another plant (Willis 2007). Allelopathy is an important ecological factor that has the ability to influence succession, dominance, species composition, community structure and productivity (del Moral & Muller 1970).

In case of Eucalyptus plantations effects of these substances are for example a low concentration of nitrifying bacteria in the soil (antibiotic effect) which leads to further depletion of nitrogen and the inhibition of growth of the understory (Florenzano 1956 in Couto & Betters 1995; Bernhard-Reversat 2001). In experiments with rice seedlings and their reaction to leachates from the litter of Eucalyptus hybrids Bernhard-Reversat (1999) noticed a sharp decrease of root length and an increase of root weight/root length ratio with a decrease in the number of lateral roots of the seedlings. However, the effect may substantially vary with the quality of litter as well as with the quality of the soil. In the above mentioned experiment leachates from litter older than five days did not exhibit any effect.

Also the soil obtained under a Eucalyptus plantation used in a greenhouse experiment to grow beans did not show any difference in comparison to trials on other soil (Fundação Centro Tecnologico de Minas Gerais 1984 in Couto & Betters 1995). These different results may be due to the fact that not the leachates of Eucalyptus litter but the soil of different quality was used in the experiments. As del Moral & Muller (1970) showed, the allelopathic effect is dependent on the soil: According to their findings Eucalyptus fails to inhibit annual herbs
on sand whereas conditions for allelopathic interference seems to be optimal on soils that were poorly drained, poorly aerated, shallow, and high in colloidal content. These factors permit toxin concentrations to reach physiologically significant proportions.

The high competition ability of Eucalyptus is not only explained by the allelopathy, there are observations that the competition for soil nutrients and water during the rapid growth phase is even more important than any direct toxic influences (Couto & Betters 1995; Poore & Fries 1988). Eucalyptus water competing ability is high due to the deep rooting system and the large amount of fine roots close to the surface (O’Grady, Worledge & Battaglia 2005) (cf. chapter 2.2.1).

Studies on the soil fauna under Eucalyptus plantations are rare. Bernhard-Reversat (2001) observed the population density of free-living nematodes and compared it with their density on savannah soil. The density under a six year old plot of Eucalyptus was one tenth of the density under savannah, several thousands to several hundred individuals per liter of soil. More research is needed to understand the possible causes of this impact.

Another point of interest is the development of soil organic matter under Eucalyptus plantations. According to Bernhard-Reversat (2001) soil organic matter changes are strongly related to plot age, but the accumulation of organic matter did not begin before six to seven years after planting. Contrary to this the nitrogen content of the soil organic matter decreases continuously with plantation age due to efficient nitrogen mineralization and tree growth needs. This might result in a severe lack of nitrogen in aging coppice stands and to the requirement of nitrogen fertilization.
3 Eucalyptus plantations and their impact on wetlands on the Maputaland Coastal Plain – a GIS analysis

This chapter presents the study area and the methods to analyse the extent of the Eucalyptus plantations within. After that, the results are presented and discussed.

3.1 Materials and Methods

The chapter Materials and Methods is divided into an introduction of the study area and into an explanation of the different analyses which were conducted with the help of a geographic information system (GIS).

3.1.1 Study Area

First, the natural conditions including climate, geology, soil, hydrology and natural vegetation are described. Afterwards, the human influences within the study area with special regard to timber plantations are presented.

3.1.1.1 Natural Conditions

The study area is located in the north-east of the South African Province KwaZulu-Natal (Figure 3). KwaZulu-Natal is situated in the south-east of South Africa and has borders to the Provinces Eastern Cape, Free State and Mpumalanga as well as to the States of Lesotho, Swaziland and Mozambique.

The study area is part of the Maputaland Coastal Plain which is likewise part of the East African Coastal Plain. The latter extends down the eastern margin of Africa from Somalia in the north through Kenya, Tanzania, Mozambique and South Africa. In the South African part the Maputaland Coastal Plain ranges in the west-east direction from the Lebombo Mountains and Swaziland to the Indian Ocean. In the north it is confined through the border between South Africa and Mozambique and in the south through the Mkuze River and Lake St. Lucia (Moll 1980). Another definition describes the southern boundary as a line extending from the southern termination of the Lebombo range to the St. Lucia Estuary Mouth (Watkeys, Mason & Goodman 1993). The area of the South African Maputaland Coastal Plain is triangular shaped, with about 75 km width in the north, about 152 km length from north to south and the narrowing down to a point in the south.
The name "coastal plain" derives from its flat, slightly undulating landscape with elevations between 45 m–70 m above sea level. Exceptions are the dunes close to the Indian Ocean which reach heights up to 175 m (Botha & Porat 2007).

The study area is located in the most northern part of the Maputaland Coastal Plain. The boundaries are clockwise from the north: the border with Mozambique; the coastal line; large industrial timber plantations and a change of vegetation units in the east. The most northern point of the study area is located at 32°53′4 E 26°51′32 S, the most eastern point is located at 32°53′36 E 26°51′35 S, the most southern point at 32°48′17 E 27°12′10 S and the most western point at 32°30′30 E 27°7′28 S. The study area covers 1 037 km².

The Maputaland Coastal Plain is one of the most remarkable areas of biodiversity in Africa (van Wyk & Smith 2001 cited in Grobler 2009). It is part of the Maputaland-Pondoland-Albany Biodiversity Hotspot (Conservation International Southern African Hotspots Programme & SANBI 2010) for which more than 2 500 vascular plant species with about 9.2% endemics were described (van Wyk & Smith 1991 cited in Sliva et al. 2004). Furthermore, at least 470 bird species have been discovered in Maputaland (Harrisson et al. 1997 in Sliva et al. 2004). This high biodiversity is caused inter alia by east-west variations in geology and climate and by the location within the subtropical-tropical transition zone. Several plant and animal species reach their southernmost distribution limit on the Maputaland Coastal Plain.

There are three protected areas designated within the study area. A part of the iSimangaliso Wetland Park is located along the shores. The well-known Kosi Bay with the Kosi Bay lakes belongs to that park being part of a relatively pristine estuary of Syadla River. The second one is the Sileza Nature Reserve situated approximately 18 km south west of the village Manguzi. It protects wooded grassland, sand forests and freshwater wetlands (Ezemvelo KZN Wildlife 2013). The last one is the small Manguzi Forest Reserve – a relic of the rare sand forest located right in the centre of Manguzi.

From the administration point of view, the study area is situated within the uMhlabauyalingana Local Municipality which is enclosed by the Umkhanyakude District Municipality. The seat of the Local Municipality is in Manguzi (also called KwaNgwanase) and the seat of the District Municipality is the town Mkuze.
Figure 3: Study area (Source of the Protected Areas: SANBI 2007)
Climate

The Köppen climate classification ranks the climate in Maputaland as humid subtropical climate (Kottek et al. 2006). It is moist-subtropical in the coastal eastern part to moderately dry-subtropical in its inland western portion. Distinctive are hot, wet summers and mild, dry winters. The climatic conditions are transitional between the tropical conditions in the north and the sub-tropical coastal conditions in the south. A significant warming influence comes from the Agulhas current which flows down the east African coast from 27°S to 40°S (Gordon 1985) and transports a substantial amount of warm water from the Indian Ocean to the Atlantic. It has a temperature maintained above 21 °C throughout the year. Prevailing regional winds tend to be parallel to the coast, coming from the north-east or from the south-west (Watkeys, Mason & Goodman 1993).

The climate diagram in Figure 4 shows the mean temperature and rainfall data of the study area (rainfall was measured at Kosi Bay whereas the temperature data was taken from Manzengwenya which is located about 50 km south of Kosi Bay). Both the mean annual temperature and rainfall change with distance from the Indian Ocean. Regarding temperature it is 21 °C along the Lebombo Mountain range, 23 °C in the central region between the Lebombo Mountains and the Indian Ocean and 22 °C further east along the coastal margin (Schulze 1982 in Watkeys, Mason & Goodman 1993). The mean annual precipitation varies from about 950 mm at the coast to 600 mm at the foot of the Lebombo Mountains, declining constantly with increasing distance to the ocean (Figure 6). Due to the wet summers, about 60% of the mean annual precipitation is falling between October and April. However, the annual rainfall values vary between the years.

Figure 5 pictures the monthly rainfall values from January 2011 to March 2014. It is noticeable that the precipitation in the years 2011 and 2013 was much below the mean value for Manguzi of 881 mm (cf. Table 2) whereas the annual precipitation in 2012 exceeded this value by 130 mm. In 2014, the total rainfall of 2013 was reached already after the first three months.

Periodically, strong rainfall events come from the summer cyclones which emerge from the south-west Indian Ocean. Not all of these cyclones reach the coast of South Africa, but for example in 1976 700 mm rain fell in three days (Maud 1980) and in 1984 the cyclone Domoina reached the South African coast (Kovacs et al. 1985). The last one was cyclone Leon-Eline in February 2000 (Reason & Keibel 2004).
Obviously, the long-term mean value of precipitation for the Maputaland Coastal Plain alone is not satisfactory to describe the temporal pattern of precipitation. Investigations of long-term weather data indicate a periodical alternation of wet and dry periods with a duration of 6 to 13 years (CRU 2013 in Grundling 2014; Arndt 2014).

Main bioclimatic variables for Manguzi are presented in Table 2. The wettest quarter of the year is at the same time the warmest quarter which leads to a high evaporation. Vice versa, the driest quarter is the coldest quarter.

Mean annual pan evaporation over a six-year period is reported to be 6.7 mm per day, with 4.3 mm on average in a dry month (June) and 9.5 mm on average in a wet month (January) (Maud 1980). Individual daily evaporation rates up to 10.7 mm and annual evaporation rates up to 1 904 mm are possible (Maud 1980; Mucina & Rutherford 2006). Mean daily sunshine hours are reported to be 7.6 hours (original data, weather station in Makatini). The relative humidity fluctuates between 65%-85% and may exceed 90% during the summer (Matthews 2007 in Pretorius 2012).

![Climate diagram of Kosi Bay](image)

*Figure 4: Climate diagram of Kosi Bay (from Lubbe 1997 in Grobler 2009)*
Figure 5: Rainfall in Manguzi from 01/2011 to 3/2014 (original data, recorded by Westhuizen, L.)

Table 2: Bioclimatic variables for Manguzi (Hijmans et al. 2005)

<table>
<thead>
<tr>
<th>Bioclimatic Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Mean Temperature</td>
<td>22.3 °C</td>
</tr>
<tr>
<td>Mean Diurnal Range</td>
<td>10.7 °C</td>
</tr>
<tr>
<td>Max Temperature of warmest month</td>
<td>30.9 °C</td>
</tr>
<tr>
<td>Min Temperature of coldest month</td>
<td>12.5 °C</td>
</tr>
<tr>
<td>Mean temperature of wettest quartet</td>
<td>25.3 °C</td>
</tr>
<tr>
<td>Mean temperature of driest quarter</td>
<td>19.0 °C</td>
</tr>
<tr>
<td>Mean temperature of warmest quarter</td>
<td>25.3 °C</td>
</tr>
<tr>
<td>Mean temperature of coldest quarter</td>
<td>19.0 °C</td>
</tr>
<tr>
<td>Annual precipitation</td>
<td>881 mm</td>
</tr>
<tr>
<td>Precipitation of wettest month</td>
<td>137 mm</td>
</tr>
<tr>
<td>Precipitation of driest month</td>
<td>28 mm</td>
</tr>
<tr>
<td>Precipitation of wettest quarter</td>
<td>366 mm</td>
</tr>
<tr>
<td>Precipitation of driest quarter</td>
<td>99 mm</td>
</tr>
</tbody>
</table>
Figure 6: East-west gradient of mean annual precipitation of the study area (data from Hijmans et al. 2005)
From a geological point of view, Maputaland is a relatively young place. The development of the coastal plain was initiated about 184 million years ago by the Gondwana break-up in the early Jurassic (Groenewald et al. 1991 in Watkeys, Mason & Goodman 1993). Afterwards, several sea level rises and declines happened and the shape of the coastal plain was formed.

The Lebombo Mountains which form the western border of the Maputaland Coastal Plain are built up by rhyolites from the middle Jurassic period. They are called the Jozini Formation and consist of volcanic lava. The oldest rocks are about 179 million years old (Allsopp et al. 1984 in Watkeys, Mason & Goodman 1993). This Jozini formation lies deep down under the whole Maputaland Coastal Plain and is overlain by Cretaceous marine sedimentsary rock and conglomerates. These settled when the coastal plain was repeatedly exposed and submerged as worldwide sea level rose and fell. The Maputaland Coastal Plain is underlain by late Mesozoic to Quaternary sequences.

On top of the Cretaceous formations, a thin layer of Tertiary sediments may be found (Maud 1980). These sediments are overlain by flat-lying partially consolidate sandy deposits of the Quaternary Port Durnford Beds which are not thicker than 50 m (Maud 1980). They consist of mudstone, lignite clay, sand and corals and are largely covered by unconsolidated, wind distributed and infertile dune sands which cover most of the plain (Watkeys, Mason & Goodman 1993). The Port Durnford Beds are impermeable and may form aquitards associated with an overlying aquifer.

After the last glacial maximum with low sea-levels (15 000-18 000 BP) and during the Flandrian Transgression (11 000-7 000 BP) the up to 180 m high coastal dune cordon was built up. The sea level reached the present height about 7 000-6 000 years BP (Tankard 1976 in Watkeys, Mason & Goodman 1993).

The coast is topographically dominated by a north-south tending coastal dune ridge with some of the largest vegetated dunes in the world (Botha & Porat 2007). The dunes are classified as vegetated, bi-directional parabolic dunes (Tinley 1985 in Watkeys, Mason & Goodman 1993).
Soil

Due to the mainly sandy Quaternary deposits, almost the whole coastal plain is made up of zonal infertile sandy soils, classified as Arenosols – deep sandy soils with low fertility, low water capacity and high water conductivity. (Werger 1974 in Sliva et al. 2004). The dunes are made up of pure quartz sand. The easterly younger dunes consist of whitish sands whereas on the westerly older dunes reddish to brownish sand with higher clay content may be found. On dunes with closed woody vegetation the soils are dark greyish brown with relatively high humus content (Weisser and Cooper 1993 in Sliva et al. 2004).

Azonal soils in the study area are classified as Alluvials and are situated close to river or wetland systems in the valleys. They consist of peat or sand with organic material and are at least periodically water saturated. If the soil is waterlogged permanently peatlands tend to develop.

The water table is generally high due to the impermeable Pleistocene Port Durnford Beds, especially in the interdunal depressions (Maud 1980). Particularly in the east, impermeable horizons occur within the soil profile due to leaching as a result of high rainfall (Watkies, Mason & Goodman 1993). Additionally, leaching leads to the soils being more infertile.

Soil moisture deficit is a problem during the winter months. It is increased by the sandy soils and their high water conductivity. Only the peat soils and the soils with a high content of organic material keep the soil moisture longer. Thus, agriculture is mainly restricted to these kinds of soils. Referring to the peatlands, Maputaland hosts the best-developed peat in whole South Africa. Altogether, 266 known peatlands exist in Maputaland with a thickness between 0.5 m and 10.0 m. About 60% from the estimated peat resources of South Africa are located within the Maputaland Coastal Plain (Grundling, Maxus & Baartman 1998). 50% of South Africa’s wetlands and 75% of South Africa’s known peatlands are located on the Maputaland Coastal Plain (Grundling & Grobler 2005 in Grundling, van den Berg, E. & Price 2013).

Hydrology

The occurrence of interdunal wetlands indicates a high water table. The ground water table is usually found 1 m to 6 m below the surface. However, the depth of the water table is enormous variable, in parts it is located deeper than 60 m (Matthews 2005).

The Maputaland Coastal Aquifer along the coastal plain consists of two primary porosity aquifers: a shallow, unconfined aquifer and a deeper, confined aquifer (Colvin et al. 2007 in Pretorius 2012). The upper aquifer is driven by rainfall events and according to Mucina & Rutherford (2006) it is entirely replenished by rainfall. The deeper, confined aquifer contains mainly ground water and the recharge mechanism is unknown (Rawlins & Kelbe 1998 in Pretorius 2012; Grundling, van den Berg, E. & Price 2013). In general, in Maputaland the
water table further west is deeper below the surface than the water table more close to the Indian Ocean and the ground water flow is directed from the west to the east. The highly permeable soils result in ground water moving rapidly through the system (Pretorius 2012).

Surface water exists in the area in form of non-perennial rivers, floodplains, estuaries, swamp forests and other wetlands, pans and coastal lakes (Kosi Bay lake system, KuShengeza, KuZilonde; cf. Figure 3). It is estimated that 5.7% of the northern Maputaland Coastal Plain are seasonal wetlands and 2% permanent wetlands (Grundling, van den Berg, E. & Pretorius 2012). Ground water is the main source of water for most of the lakes and wetlands.

There are only few perennial rivers on the northern coastal plain. The two most prominent are the Syadla River (also referred to as the Siyadla or Syhadla River) which is the largest river, and the Tswamanzi River. Smaller rivers flow only during the wet summer and usually drying up by mid-winter. They are being fed through water coming as seepage due to clay-layers within the sandy ridges and dunes.

Vegetation

According to recent phyto-geographical studies by Mucina & Rutherford (2006), Maputaland is located in the Bioregion Indian Ocean Coastal Belt that is divided into two zonal units – the Maputaland Coastal Belt and the Maputaland Wooded Grassland – as well as into several azonal vegetation units like swamp forest, northern coastal forest, sand forest, subtropical seashore vegetation, subtropical dune thicket and subtropical freshwater wetlands. As shown in Figure 7, all these units form a diverse mosaic. Their short description below bases mainly on Mucina & Rutherford (2006).

The Maputaland Coastal Belt was originally probably densely forested and is today composed of various forest types, thickets, primary and secondary grasslands, extensive timber plantations and cane fields. On the dunes close to the Indian Ocean it is assumed that about 30% of this vegetation unit is transformed for plantations, cultivation or urban sprawl and that only the open vegetation with Syzigium cordatum growing freely represents the remnants of still primary vegetation belonging to the Maputaland Coastal Belt.

The Maputaland Wooded Grassland consists of a flat landscape supporting a vegetation of dwarf shrubs, small trees and rich herbaceous flora. However, also here about 46% of this vegetation unit was transformed for plantations and cultivated land. Areas with a high water table of only one meter to two meters depth occur in that unit.

Swamp forests occur in the interdunal depressions with flowing water and organic soils. The trees are 12 m to 15 m tall. The soil is waterlogged and peat forming processes are possible. The water table is generally high. In the Kosi Bay area swamp forests disappear with
alarming spread, being transformed either into plantations or into fruit and vegetable gardens (Grobler 2009).

*Northern coastal forests* are species-rich, of tall height and grow on coastal plains and stabilized dunes. They have a species-rich understory. The original extent of these forests was lowered by agriculture, timber plantations and urban sprawl.

*Sand forest’s* main distribution is in Maputaland. It consists of either dense thicket of five meters to six meters or of tall forests reaching up to 15 m. The shrub layer of sand forest is well developed. An unknown portion of this vegetation unit was lost due to clearing for subsistence agriculture and grazing.

*The subtropical dune thicket* consists of dense shrubby thicket up to four meters height with poorly developed undergrowth due to the shading effect of the canopy. The area where this unit grows is characterized by high rainfall almost throughout the year.

The unit of *subtropical freshwater wetlands* is characterized by a flat or undulating topography supporting low beds dominated by reeds, sedges and rushes. Ollis et al. (2013) divides the wetlands occurring in South Africa further in seven different wetland types, five of them occur within the study area: Rivers, floodplain wetlands, channelled valley-bottom wetland, unchannelled valley-bottom wetland and depressions. As already stressed above, most of the wetlands are affected directly or indirectly by unsustainable farming practices and timber plantations.
Figure 7: Vegetation units covering the study area (Mucina & Rutherford 2006)
3.1.1.2 Human influences

First, the settlement history of the Maputaland Coastal Plain is presented. It is followed by a chapter about the land use with special regard to the timber plantations. Afterwards, parts of the South African legislation affecting the distribution of plantations and the outgrower schemes of the Maputaland coastal plain are described.

Settlement history

Humans lived in Maputaland since the early Stone Age. Human fragments were found in the Border Cave which were dated back reaching from approximately 110,000 years BP to 30,000 BP (Bruton, Smith & Taylor 1980). The Border Cave is located in the Lebombo Mountains on the border to Swaziland.

The younger history started with first farming settlements that appeared in the lake St. Lucia region (Hall and Vogel 1978 in Watkeys, Mason & Goodman 1993). It is assumed that these people have greatly reduced the forest cover by changing the vegetation from forest to secondary grassland. With the modern Bantu people and their knowledge of iron working the first extensive impact on the natural vegetation appeared. They reached the area about 1440 (Pooley 1980 in Bruton, Smith & Taylor 1980). Their use of fire to clear agricultural plots and their felling of hardwood to make charcoal for iron smelting likely reduced the extent of the forest (Bruton, Smith & Taylor 1980).

The first Europeans who explored Maputaland were Portuguese sailors. Vasco da Gama explored the east coast of South Africa from 1497 onwards. Afterwards came the hunters, starting in the beginning of the 18th century (Bruton, Smith & Taylor 1980). By eliminating almost the whole elephant population and other large mammals, the impact of the hunters on the ecology of the area was large: the vegetation changed due to the missing grazing and new options for urban development and farming appeared. The age of hunting did not last long, by 1870 the extensive shooting was over: The game population sizes were too low for successful hunting.

Soon after people started to discuss about nature conservation and the first national parks were established. One national park which was established in 1950 is Kosi Bay (Bruton, Smith & Taylor 1980) and today the area is part of the iSimangaliso Wetland Park (formerly St Lucia Wetland Park).

The present inhabitants of Maputaland are a mixture of Nguni and Thonga (also spelled Tonga) people (Bruton, Smith & Taylor 1980). The largest Thonga clan is the Tembe clan which migrated southwards from the Delagoa Bay in Mozambique in approximately 1554 (Junod 1927 in Bruton, Smith & Taylor 1980). The Thongas were conquered by a group of refugees from King Shaka in the first quarter of the 18th century and assimilated into the
Zulu kingdom (Bruton, Smith & Taylor 1980). They live on both sides of the border between South Africa and Mozambique.

In spite of the rich settlement history and although Maputaland offers a warm, humid climate, humans were not abundant in the past due to various animal and human diseases which were spreading during the last centuries, like the cattle disease (*Trypanosomiasis*) carried out by the Tsetse-fly (*Glossina*), Malaria and recently HIV/AIDS (Taylor 1988). In 1950 the Tsetse-fly was eradicated using DDT (Watkeys, Mason & Goodman 1993). The next important factor of former low human density was also the low productivity from agricultural systems (Taylor 1988). Only in the last 60 years the population started to grow rapidly and therefore land use and pressure on the fertile wetland soils grew. Today, Maputaland in general and the Manguzi region in particular, show a rapidly growing but already impoverished rural community (Watkeys, Mason & Goodman 1993).

**Land use with special regard to timber plantations**

In the past, the subsistence farming represented the most important land use practice, although the agricultural success fluctuated widely due to locust plagues, floods, elephant damages and infertile soils (Alfers 1955 in Bruton, Smith & Taylor 1980; Taylor 1988). Nowadays, the subsistence or semi-commercial agriculture is still being practiced as farming close to or in the drained wetlands. Taylor (1988) divided the agricultural systems into gardening, swamp farming and dry land cropping. Although the study is 26 years old, the agricultural systems and the main crops have not changed. Banana (*Musa spp.*), madumbe/taro (*Colocasia esculenta*), sweet potato (*Ipomea batatas*), cabbage (*Brassica oleracea*), manioc/cassava (*Manihot esculenta*), spinach (*Spinacia oleracea*), maize (*Zea mays*) and sugar cane (*Saccharum officinale*) are the main crops being cultivated (Taylor 1988; Grundling, Maxus & Baartman 1998; Sliva et al. 2004; Arndt 2014). On the sandy soils away from the wetlands peanut (*Arachis hypogaea*) is the most widespread crop. Additionally, in the area close to Kosi Bay the locals go fishing and they harvest the leaves of the Raphia palms (*Raphia australis*) and reeds as building material.

In areas away from the wetlands there is nearly no other land use than plantation forestry and extensive cattle grazing. Present is a small chili (*Capsicum spp.*) plantation with an irrigation scheme and there are some small incentives of establishing *Moringa oleifera* plantations but the Eucalyptus plantations are by far the largest land use.

Due to its small amount of natural forest, the recent forest history of Maputaland is a history of plantations in Maputaland. Although the first known foresters lived in Maputaland to exploit the Rubber Vine (*Landolphia kirkii*) for rubber in 1903 and 1904 (Bruton, Smith & Taylor 1980), the afforestation potential of the area was soon discovered. In 1940 first re-
ports on afforestation schemes of the Maputaland Coastal Plain appeared (Marwick 1973 in Bruton, Smith & Taylor 1980).

The first Eucalyptus tree was introduced to South Africa in 1828 by the Governor of the Cape Colony who brought the seedlings from Mauritius. The species was *E. globulus* which soon started spreading on its own (Coppen 2002). 125 years later in 1953 the first use of Eucalyptus trees was documented also for Maputaland. Shelter-belts were planted close to Mbazwane to encourage cultivation but the scheme failed (Bruton, Smith & Taylor 1980). In 1958, the Department of Forestry started an extensive Pine afforestation program and by 1980 over 17 395 ha of plantations were established (Bruton, Smith & Taylor 1980). Nevertheless, in the early 90-ties plantation forestry was still classified as a minor land use (Watkeys, Mason & Goodman 1993) until it changed to the today's state.

The Eucalyptus trees in Maputaland (Figure 8) are mainly grown for pulp production which is being used in paper manufacturing. Species grown are mainly clones with genetic material from different Eucalyptus species. In a newspaper article from 1999 it is written that mainly hybrids of *E. grandis* and *E. europhylla* are grown in northern KwaZulu-Natal due to their heat tolerance (Meadows 1999).

Figure 8: Eucalyptus plantation close to Manguzi

The production cycle takes six years in areas close to the coast, otherwise seven to eight years (Cairns 2000). The plantations are owned by either the South African Pulp and Paper Industry (SAPPI), communal trusts or by private growers. Most of the private growers are part of an outgrower scheme (cf. page 43). The Eucalyptus trees grown in Maputaland are transported to the Richards Bay paper mill.
In 1993, Watkeys, Mason & Goodman classified the primary land uses in Maputaland in the order of importance and stated the subsistence agriculture as the most important one, followed by conservation and tourism and then by plantation forestry. A land use dataset prepared by the iSimangaliso Wetland Park for the northern Maputaland Coastal Plain had only two types of land use: unspecified and subsistence agriculture (Land use dataset iSimangaliso wetland Park 2008 cited in Grundling, van den Berg, E. & Price 2013). Nowadays, the importance of plantation forestry has increased. In terms of area it may be meanwhile the largest type of land use. The recent Eucalyptus plantations as a new land use in the region awoke hopes among the local population regarding a new and stable source of income. Nevertheless, small-scale subsistence agriculture is still the most important land use regarding the number of people that are dependent on it.

Limitations in the agricultural use of the land have contributed to the preservation of large areas of intact natural ecosystems that are currently designated as nature protection areas (Tembe Elephant Park, iSimangaliso Wetland Park, Sileza Nature Reserve). Due to the unique landscape scenery and nature diversity, ecotourism as an important economic factor begins to develop. However, the ecotourism economy is significant mainly in places close to Kosi Bay or to Tembe Elephant Park and its seasonal character lowers the number of people benefitting.

Industry does not play a role in northern Maputaland because industrial options are generally limited. The area is lacking of mineral wealth (Watkeys, Mason & Goodman 1993) and the local population is largely unskilled and has a low education level.

Table 3 and Figure 9 show the land cover of the study area in 2005. The table displays the extent of the different land cover classes in relation to the extent of the study area; the map shows their spatial distribution. The large amount of plantations south and west of Manguzi is shown as well as the scattered character of the settlements.
<table>
<thead>
<tr>
<th>Type of Land Cover 2005</th>
<th>Extent (ha)</th>
<th>Extent in percent of the study area (1 037 km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Sand</td>
<td>4 847</td>
<td>4,67</td>
</tr>
<tr>
<td>Bushland</td>
<td>7 005</td>
<td>6,75</td>
</tr>
<tr>
<td>Degraded bushland (all types)</td>
<td>2 552</td>
<td>2,46</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>139</td>
<td>0,13</td>
</tr>
<tr>
<td>Degraded Grassland</td>
<td>10 937</td>
<td>10,54</td>
</tr>
<tr>
<td>Dense Bush</td>
<td>6 247</td>
<td>6,02</td>
</tr>
<tr>
<td>Forest</td>
<td>7 495</td>
<td>7,23</td>
</tr>
<tr>
<td>Grassland</td>
<td>31 851</td>
<td>30,71</td>
</tr>
<tr>
<td>Grassland / Bush clumps mix</td>
<td>6 238</td>
<td>6,01</td>
</tr>
<tr>
<td>Permanent orchards (cash-ew)</td>
<td>19</td>
<td>0,02</td>
</tr>
<tr>
<td>Plantation</td>
<td>2 301</td>
<td>2,22</td>
</tr>
<tr>
<td>Plantation clearfelled</td>
<td>1 450</td>
<td>1,40</td>
</tr>
<tr>
<td>Rural dwellings</td>
<td>11 925</td>
<td>11,50</td>
</tr>
<tr>
<td>Subsistence (rural)</td>
<td>21</td>
<td>0,02</td>
</tr>
<tr>
<td>Urban</td>
<td>857</td>
<td>0,83</td>
</tr>
<tr>
<td>Water</td>
<td>6 256</td>
<td>6,03</td>
</tr>
<tr>
<td>Wetlands</td>
<td>3 557</td>
<td>3,43</td>
</tr>
<tr>
<td>Wetlands-mangrove</td>
<td>25</td>
<td>0,02</td>
</tr>
</tbody>
</table>
Figure 9: Land Cover of the study area 2005 (from the 2005 Ezemvelo KZN Wildlife Dataset)
Due to South Africa’s small amount of natural forest (0.3% according to Mucina & Rutherford 2006), people started planting exotic timber plantations as early as 1875 (van der Zel 1995 in Dye 2013). The first plantations were Pinus radiata plantations, but the potential of growing Eucalyptus was soon discovered.

Nowadays timber plantations cover between 1.25 million ha and 1.75 million ha (Dye 2013; FAO 2010), i.e. about 1.2%–1.8% of South Africa's land. Pine grows on more than half of that area (52.5%), followed by Eucalyptus growing on 39.1% and by Wattle (Acacia mearnsii) with an area of about 7.6% of the total planted space (Dye 2013). According to the FAO, the area has only slightly increased since 1990 when plantations covered about 1,62 million ha (FAO 2010). South Africa is the 12th largest producer of pulp in the world with SAPPI and MONDI being the largest companies involved in pulp production (Mayers, Evans & Foy 2001). In 2001 47% of all South African plantations were owned by these two companies, 30% by the state and 22% by small private enterprises and individuals. Only 1% was owned by small or micro-growers (Mayers, Evans & Foy 2001). In 2011, 12% of the total plantation area was owned by individuals, partnerships or family trusts, 70% by companies and 17% by the government (Republic of South Africa 2012).

Due to profitability, the Eucalyptus plantations are generally established in areas with an average rainfall above 700 mm (Albaugh, Dye & King 2013). Overall, South Africa receives about 450 mm mean annual rainfall (Greeff 2010). Areas with more than 600 mm cover about 20% of the country and are important source areas for rivers and catchment recharge. The potential natural vegetation of these areas is mostly grassland or fynbos which are dormant during summer time. By establishing trees which do not have a dormant season, the yearly evaporation increases and the catchment water yield decreases (see chapter 2.2.1).

First concerns about the effect of timber plantations on water yield and catchment hydrology have already been raised in 1915 (Dye 2013). Following these concerns, afforestation within 20 m of all perennial streams and water bodies was forbidden in 1932 (Dye 2013). In 1935 the decision to thoroughly investigate the influence of timber plantations on the catchment hydrology was made in the course of the empire forestry conference (Dye & Versfeld 2007). As consequence, the South African paired catchment experiments for comparing water use of timber plantation with water use of grassland and other vegetation started in 1937 and still exist. The results of these experiments provided the scientific background for the first laws regulating afforestation in sensible catchments.

In 1972 the Afforestation Permit System came into effect. It aimed at regulating the previously unlimited expansion of timber plantations especially in catchments were water use was already heavily committed. The major catchments were classified in three categories of allowable reductions in streamflow based on downstream demand. In each category, afforestation was allowed to the point where the 1972 mean annual runoff was reduced only by a specific percentage. In class
one, no further reduction was allowed, in class two, 5% reduction below pre-1972 mean annual runoff was allowed and in class three, 10% reduction was allowed (Department of Water Affairs and Forestry 1999). 500 000 ha timber plantations were authorised by the Afforestation Permit System (van der Zel 1995 in Department of Water Affairs and Forestry 1999). However, small woodlots with less than 10 ha did not require planting permits (Cairns 2000).

The Afforestation Permit System was updated several times but in 1998, it was detached by the National Water Act.

The paired catchment experiments showed that the low flow which occurs in the dry season is more critical to the functioning of the ecosystem than the reduction of the mean annual runoff. As a result, the reduction of the low flow replaced the reduction of the mean annual runoff as important indicator for the influence of plantations on the hydrology. Since plantations do not have a dormant season, they transpire even in the dry season and therefore have a huge impact on low flows.

With the National Water Act the type of managing water changed from a consumer-level to a catchment-level. The Act recognized the linkage between every water consumer in a catchment. Another important aspect is that from 1998 onwards, water has been seen as a public good which is not possible to own. Furthermore, it gives the environment and basic human needs priority over all other demands for water.

All water users are required to register and licence their use of water and to pay for that water. Existing lawful users have retained their allocation and received a licence.

Every new user since 1998 needs to apply for a water use licence which will only be granted if the resource is considered to meet current and new demands. Only exceptions are small-scale users drawing water solitary for household and non-commercial use (all plantations are seen as commercial use (Dye & Versfeld 2007)). Essential for the consideration is not only the current demand but also basic human needs (25 l per person per day) and the ecological reserve which is defined as the amount of water required for safeguarding and sustaining healthy stream and river ecosystems. Hence, the ecological reserve needs to be calculated before it is possible to serve users (Republic of South Africa 1998; Dye & Versfeld 2007).

Altogether, 19 water management areas were delineated in South Africa, each of which is to be managed by a catchment management agency representing all user groups. The aims are to optimize the water use, to allocate water equitably and beneficially for the public interest and to link the water use to the economic benefits of a crop. In some catchments problems are evident due to the ecological reserve which is not met. Thus, water needs to be put back into the system. Therefore, catchment management agencies have the possibility of “compulsory licencing”. Water licences may be taken away to meet the ecological reserve or may be given to previously disadvantaged people such as resource-poor farmer or forestry small-growers. This process is only allowed after a reserve assessment.
Existing timber plantations either received a licence by proving that the plantation was established prior to 1972 or by showing the permit from the Afforestation Permit System which was required after 1972. In former homeland areas like the study area, afforestation that existed prior to 1994 was accepted as lawful and owners obtained also licences. It is not possible to licence unlawful timber plantations and the removal of these plantations may be ordered by law (Dye & Versfeld 2007). Nowadays, new afforestation only takes place once the activity has been licenced. Since the application of the new licensing regulation some unlawful timber plantations were detected (Dye & Versfeld 2007).

Forestry is the only streamflow reduction activity to be declared. Every new afforestation requires a streamflow reduction activity licence which costs about R23 000 (Howard et al. 2005). The licencing is therefore not possible for small growers without being supported by the government or by a company. For example, SAPPI was able to negotiate community permits for certain areas (Cairns 2000). Generally, the licence application process takes a minimum of a year and in some cases even much longer (Howard et al. 2005). It includes for example the advertisement of the intention of the applicant in a local and provincial newspaper, an inspection of the site by officials and a recommendation from the Licence Assessment Advisory Committee.

The expansion of large plantations after the enforcement of the National Water Act in 1998 was much slower than before. However, in Maputaland the total area of Eucalyptus plantations further increased (cf. chapter 3.2.1) because of a fast spreading of small private and communal woodlots. Although the regulations of the Act take effect even for small private and communal woodlots, their unlawful establishment is mostly tolerated by the local government.

Most of the woodlots of the Maputaland Coastal Plain are part of so-called outgrower schemes. There were two main outgrower schemes in northern KwaZulu-Natal. The first one is the SAPPI “Project Grow” outgrower scheme and the second one was the Mondi "Khulanathi outgrower scheme". The Mondi scheme closed in 2007 but a new company, Khulanathi Forestry, was founded by former employees of the Mondi scheme (Scherzer 2010).

The SAPPI scheme “Project Grow” started in 1983 in northern KwaZulu-Natal. Whereas in the beginning only three growers with 5 ha of land participated, in 2000 more than 3 500 growers on more than 9 000 ha of land took part (Cairns 2000). Further five years later, Howard et al. (2005) report already 9 810 members in the outgrower scheme and 15 000 ha, but this numbers also encompasses the northern part of the eastern cape. After Cairns (2000) the success of the scheme relies on word of mouth and good history to spread whereas the Mondi Khulanathi scheme was aggressively marketed through tribal authority meetings and extension officers.

The contract between the outgrower and the company regulates the inputs of the two parties. All land and labour inputs were provided by the farmer whereas the company provides tree saplings, silvicultural training, planting supervision, assistance with water licence application and an interest-free loan that is paid back when the timber is harvested and sold (Howard et al. 2005; Tewari 1997). In the end, the company buys the six to eight year old trees.
The main reason for private persons to enter a contract with a company and become part of an outgrower scheme is to increase the income of the household. Other reasons are the easier management compared with food crops, that the land was not suitable for other crops or to secure the rights over unutilised land (a household’s right to unutilised land may become weakened when the male household head dies). Furthermore, through being part of an outgrower scheme the access to credits may be easier because of the timber value in possession of the outgrower. For timber grower previously not part of an outgrower scheme the accessibility to new markets and the physical inputs, for example the superior seedlings provided by the company, are important reasons (Cairns 2000).

Although outgrower timber usually provides only smaller proportions of the whole timber production of a company (3% of the Mandini mill’s throughput in 2000 (Cairns 2000) but likely substantially higher proportion today) and is expensive per ton, it is a possibility for the company to extend the area under cultivation to land which would otherwise be unavailable because it is not owned by the company (Mayers, Evans & Foy 2001). Another reason to initiate outgrower schemes is the allocation of risk. The producer, in an outgrower scheme the private person, takes the higher risk of production whereas the contractor, for example SAPPI, takes the lower risk of the well predictable marketing (Mayers, Evans & Foy 2001). Furthermore, the company uses the scheme to create a positive image of itself because of the promoted social value of the schemes. The above is summarized in Table 4.

*Table 4: The main reasons to join the outgrower schemes for the farmer and for the company (after Cairns (2000))*

<table>
<thead>
<tr>
<th>Reasons for the farmer to join an outgrower scheme</th>
<th>Reasons for the company to have a contract with farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing the household income</td>
<td>Distributing the risk of production to the farmer</td>
</tr>
<tr>
<td>Securing the rights over unutilised land</td>
<td>Accessibility to new land</td>
</tr>
<tr>
<td>Only possibility to use the land</td>
<td>Creating a positive picture of the company in public’s mind</td>
</tr>
<tr>
<td>Easier management compared with other crops</td>
<td>Cheap forms of labour may be utilized (family labour)</td>
</tr>
<tr>
<td>Access to credits</td>
<td></td>
</tr>
<tr>
<td>Physical inputs</td>
<td></td>
</tr>
<tr>
<td>Accessibility to new markets</td>
<td></td>
</tr>
</tbody>
</table>

Calculation of the net profit for the private grower is difficult because of low data availability and of dependence on several factors such as the soil and local climate. A study from 1993 calculated with R2 124 per ha in six years (Cairns 1993 in Tewari 1997). More recent, a calculation made in 2000 came to the result that the average net profit of one hectare over six to eight years is
R8 912 (Cairns 2000). From a financial point of view, Cairns (2000) concluded that it is not possible for the schemes alone to take households out of poverty. But the income of a woodlot is between 12% and 45% of the income needed to remain above the upper-bound poverty line (R620 per month in 2011 (Statistics South Africa 2014)). A critical point is that growers often fell the timber too early in order to obtain urgently needed cash but in the last two years of the production cycle woodlots double in value (Cairns 2000).

A private person who wants to become part of an outgrower scheme obtains information about the scheme either from an extension officer of the company or by promotion through word of mouth from other growers. In the SAPPI “Project Grow” outgrower scheme no minimum size of the land dedicated for the plantation is known, but for the Mondi Khulanathi scheme the minimum size was 0.3 ha (Cairns 2000). Every farmer needs the permission of the local Induna or Inkosi (which is the local chieftain) and a permit to plant issued by the Department of Water Affairs before the work on the field may start. However, this official procedure has been widely ignored in the rural areas of Maputaland and its implementation is hardly controlled.

SAPPI provides free tree seedlings. The planting density is about 1 754 spots per hectare. The operations carried out by the grower are land preparation, ploughing, pitting, planting, fertilization, weeding in the first two to three years up to a height of about 1.5 m and fire protection. After each successfully completed operation the grower gains a certain amount of money from the company (Cairns 2000). Sometimes the work is performed by a local contractor which is either hired by the company or by the grower himself.

In an interview with an officer of SAPPI in the local office in Manguzi in November 2013 the officer said that they had no new outgrowers under contract since 1998. It could not be found out whether this information is correct, but since in 1998 the National Water Act became effective (see chapter legislation) it became much more difficult to obtain water use licences for afforestation. However, as the investigations show (see next chapters) the afforested area grew also between 1998 and 2012 in spite of the strict restrictions of the National Water Act. This means that there are a large number of not-permitted plantations that where established without the official support of the SAPPI outgrower scheme. Although they buy and harvest the timber from these plantations, they do not have a contract with the land owner. An interview with a local plantation owner, who established the plantation only four years ago, confirmed that. The owner does not have a contract with the company, but in time the timber is ready to harvest the owner intends to contact an official outgrower nearby. If this official outgrower plans to harvest a woodlot, the woodlot of the private grower is also harvested.

3.1.2 Methods

First, the delineation of the study area is presented. After that, the different GIS-analyses which were conducted within the study area are described.
3.1.2.1 Delineation of the study area

The study area was determined by searching for artificial or natural boarders in the surroundings of Manguzi. This approach led to a 1 037 km² large area bordered by the Indian Ocean in the east, the Mozambican border in the north, the Tembe Elephant park in the west (which is a natural border due to the change of vegetation unit from Maputaland Coastal Belt to Tembe Sandy Bushveld, cf. Figure 7) and by the large industrial timber plantations in the south (cf. Figure 9).

3.1.2.2 Development of the plantation area

To analyse the development of the plantation area within the study area, the years 1990, 2000, 2008 and 2011/2012 were examined. Plantations were delimited on aerial photographs and satellite imagery. Ortho-photographs provided by the Department of Land Affairs and georeferenced by Jonas Arndt (Arndt 2014) were used for the years 1990 and 2000. SPOT5 satellite imageries were used for the years 2008 and 2011/12. Due to availability of both 2011 and 2012 SPOT scenes, the most up-to-date delineation of plantations was carried out by comparing the image from 2012 with 2011 whilst delineating. This led to a more exact value of the plantation area because it was possible to detect plantations in 2012 that could not be identified in 2011 due to their young age. On the other hand, plantations that were only detected in 2011 were delineated as well because it was assumed that the plantation will be replanted. This approach may lead to a slight overestimation of the growth rate from 2008 to 2011/12 because only in 2011/2012 a more detailed delineation based on two consequent scenes was applied. However, because of the substantial overall increase of the afforestation area in this period, this slight over-estimation is negligible.

The remote sensing data was analysed with ArcGIS 10.2.

3.1.2.3 Plantations within wetlands

To examine the extent of plantations reaching into the wetlands, an intersection (name of the ArcGIS tool – it computes the area where two layers overlap) of the delineated plantations and the Ezemvelo KwaZulu-Natal (EKZN) Wetland Layer (Scott-Shaw & Escott 2010) was computed.

The wetland layer was compiled from 2007 to 2010. It is a revision of the 2002 KwaZulu-Natal GIS wetland coverage layer. The data source of the wetland boundaries for the state KwaZulu-Natal is from the South African National Biodiversity Institute, from Mondi, from eThekwini, from Msunduzi and Ilembe municipalities and from the Ezemvelo Kwa-Zulu Natal forest coverage layer for mangrove and swamp forest (Scott-Shaw & Escott 2010).

For the classification of the wetlands also the examination of altitude, river occurrence and air temperature was used (Scott-Shaw & Escott 2010). The map does not indicate whether extent
and distribution of a wetland are related to seasonal or extreme rainfall events and whether the boundaries of the wetlands are well defined or variable. Thus, some of the wetlands within the study area were visited for ground validation together with Ms. M. L. Pretorius.

### 3.1.2.4 Buffer zones

A common practice used worldwide for the protection of riverine areas and wetlands is the delineation of buffer zones.

Buffers in general are defined as vegetated zone of a certain width between a natural resource and adjacent land use subject to human alteration (Castelle, Johnson & Conolly 1994). In this particular case this means the buffer between the wetland (resource) and the timber plantations as the affecting land use.

Benefits of wetland buffers are, inter alia, the stabilization of the soil to prevent erosion; the filtering of suspended soils, nutrients and harmful or toxic substances; the moderation of water level fluctuations; the providing of essential habitat for wetland associated species; the reduction of the adverse impacts of human disturbances on wetland habitats and the reduction of direct human disturbance from dumped debris, cut vegetation and trampling (Department of Water Affairs 2013).

In case of wetlands and intensive timber plantations, it should be a common sense that the buffer width is defined before establishing the plantations. If the buffer width has been defined after the trees were planted there may be arguing about the correct or optimal solution – a width which should protect wetland functioning without limiting the land available for the plantations.

To determine this width there are different approaches which all depend on the protection target and on the aim of the protection.

One approach for the determination of wetland buffer zones is "one size fits it all", which is in most of the cases a political enforced approach without scientific background. Other approaches consider modifying factors such as position in the landscape or the kind of wetland. The latter one leads to different buffer widths for every wetland. Castelle, Johnson & Conolly (1994) propose four criteria to determine adequate stream buffer sizes for wetlands: (i) the resource functional value (wetlands functional value), (ii) the intensity of adjacent land use, (iii) the buffer characteristics and (iv) the specific buffer function required.

In case of the wetlands within the study area, the main aim of the buffers is to protect the wetland from drying out or, for seasonal wetlands, from staying dry even in the wet periods. This means to protect the wetland from being affected by the lowering of the ground water table which the timber plantations are likely to induce.

Since no field measurements were carried out for this work, the determination of the width is only possible by reviewing literature about buffer widths.

The buffer zones proposed by Dennis (2013) – refer to results p. 60 – were visualized using ArcGIS 10.2.
3.1.2.5 Recharge area and cone of depression

To determine the correct buffer widths, the influence of the plantations on the hydrology needs to be calculated. This may be done by calculating the recharge area, which is the zone needed to recharge the extra amount of water that is used by the plantation in comparison with the natural vegetation. Another method is to compute the cone of depression, which is a zone where the groundwater table is lowered by the plantations due to their high water use. For both zones, a calculation method is presented. It is presumed that the area is underlain by an unconfined aquifer. This is the requirement for both zones to develop equally around the plantations. For keeping the calculation as simple as possible and because no reliable data is available, the other presumption is that ground water inflow equals ground water outflow.

The first method (Wohlrab 1992; Auerswald 2014) calculates the water balance of an area by comparing the evapotranspiration-values of the plantations and of the surrounding vegetation, which in this case is presumed to be only grassland. Presupposed that the water balance of the plantation is negative (i.e. it uses more water from the system than comes into the system by rainfall); an area of specific size with a positive water balance is needed to equalize the negative water balance from the plantation. This area is the area which is hydrological influenced by the plantation (Figure 10). It is assumed that the interception of the Eucalyptus plantations is only slightly higher than the interception of the grassland, thus it may be ignored (cf. chapter 2.2.1; Dye, Olbrich & Everson 1995; Scott & Lesch 1997). To keep the calculation as simple as possible, it is supposed that the evapotranspiration rates of all plantations are the same although the rates surely differ with age of the trees and location of the plantation within the landscape.
\[
WBP \ast AP + WBG \ast AG = 0
\]

WBP = Water balance plantation = rainfall (R) - evapotranspiration plantation (EVP) (mm)
AP = Area plantation (ha)
WBG = Water balance grassland = rainfall (R) - evapotranspiration grassland (EVG) (mm)
AG = Area grassland

AG is the value which needs to be known.
The minimum grassland area (AG) that is needed to compensate the WBP of the plantations is then

\[
AG = - \frac{(R - EVP) \ast AP}{(R - EVG)}
\]

\[Figure \ 10: \ Schema \ of \ the \ water \ balance \ equation\]
The second method is to calculate the cone of depression. It is derived from the Sichardt-formula developed for well construction (Bieske, Rubbert & Treskatis 1998). The equation calculates the radius of influence from a certain depth of the well. Within this radius the ground water table is lowered through water abstraction. The equation is based upon empirical evidence – the units do not fit together.

Formula 2

\[ R = 3000 \times s \times \sqrt{k_f} \]

**R** = radius of influence

**s** = depression under the well (plantation) in m

**k_f** = hydraulic conductivity of the soil (which is generalized for the study area \(1.006 \times 10^{-4}\) m/s (Grundling 2014)

![Figure 11: Schema of the Sichardt Formula](image-url)
3.2 Results

This chapter presents the results of the GIS-analyses. The development of the plantation area from 1990 to 2011/12 is shown on the basis of satellite imagery. Plantations within wetlands were detected and examples of conflicts with the legislation are shown. Proposed buffer zones and their impact on the distribution of plantations were visualized. Furthermore, recharge and depression areas were calculated and visualized.

3.2.1 Development of the plantation area

Figures 12, 13 and 14 (page 51) show the development of
- the total plantation area within the study site
- the mean plantation size
- the total number of delineated plantations within the study area

from 1990 to 2011/12. Additionally, Figure 15 and 16 (page 52 and 53) show the spatial distribution of the plantations within the study area in the investigated years.

In 1990, only 25 plantations within the study area were identified. A total plantation area of 204 ha was calculated. The mean plantation size at that time was 8.16 ha with the largest plantation being 44.62 ha large and the smallest 0.39 ha. Due to the small plantation number, no core area could be identified.

Ten years later, the number of delineated plantations rose to 149 with a total plantation area of 2 687.7 ha and a mean plantation size of 18.04 ha. The largest plantation was 387.81 ha, i.e. almost nine times larger than in 1990, whereas the smallest plantation covered an area of 0.14 ha. The core areas are located in the south, the south-west and the west of the Manguzi centre as well as a smaller interconnected area right close to the Mozambican border point.

In the next eight years, from 2000 to 2008, these core areas grew further but additionally, an excessive number of small plantations close to these core areas appeared. Especially close to the Mozambican border and in the south of the study area the large number of small dots is noticeable. These small plantations are also evident in the statistics, the number of delineated plantations more than doubled in eight years to 392 and the total area planted with Eucalyptus grew to 5 749.6 ha. The mean plantation size dropped due to the large number of small plantations to 14.67 ha with the smallest plantation being 0.11 ha small and the largest covering 1 389.7 ha.

Although the next period is only a step of four years, the number of plantations grew between 2008 and 2012 from 392 to 594. The small-sized plantations are now even more noticeable close to the main road to the Mozambican border and in the southern part close to the border of the study area. The total planted area grew to 6 799.2 ha with a mean plantation size of 11.64 ha being again lower than four years before. The largest plantation covers now an area of 1 559.9 ha and the smallest plantation covers an area of 0.06 ha.
The fast spreading of new woodlots is associated with an improvement of the roads leading to the plantations. These roads are often in a better condition than roads connecting small settlements with the main road (own observation, 2013).

**Figure 12: Total plantation area from 1990–2011/12**

**Figure 13: Mean plantation size from 1990–2011/12**

**Figure 14: Count of delineated plantations from 1990–2011/12**
Figure 15: History of the plantations in the northern part of the study area (Year and source of the satellite image: SPOT 2011)
Figure 16: History of the plantations in the southern part of the study area (Year and source of the satellite image: SPOT 2011)
3.2.2 Plantations within wetlands

Figure 17 shows an example of plantations growing within wetlands close to the Mozambican border. The wetland types are derived from the category “feature” which is given by the EKZN wetland layer.

It is shown that the plantations only grow on former sedge wetlands. This is also true for the whole study area. Figure 18 displays the area of wetlands covered by plantations for the different wetland feature types. 95.5% of the plantations growing on wetlands grow on sedge wetlands, 3.7% grow on wetlands which are not classified, 0.7% grow on wetlands classified as non-perennial pan and 0.03% on wetlands classified as Marsh Vlei.

Figure 19 shows the number of plantation fragments within a wetland. Every piece of plantation growing in a wetland was considered as fragment. If three parts of an interconnected plantation grow in a wetland they are counted as three fragments. It is shown that the number of fragments is constantly rising from 5 in 1990 to 122 in 2011/12.

Figure 20 shows the overall area of plantations within wetlands. The five fragments in 1990 covered an area of 0.59 ha. This area grew to a value of 458.21 ha in 2011/12.

Seven of the wetlands which are at least partly covered by plantations were chosen for visit for validation (Figure 22, 23 and 21, page 57 and 58). It turned out that all of the visited wetlands were at most seasonal; most of them are likely to be flooded only after significant rainfall events. Although, the vegetation of the visited wetlands indicated a high, eventually fluctuating water table. All of them had a high content of organic matter within the upper soil in comparison with the soil profile of the dunes.
Figure 17: Wetlands and plantations close to the Mozambican border (Wetland Data EKZN Wetland Map, Satellite image SPOT 2011)
Figure 18: Type of wetland covered by plantations in the year 2011/12

Figure 19: Number of plantation fragments within a wetland

Figure 20: Sum of Area of plantations within wetland
Figure 21: Map of the visited wetlands close to Manguzi (Wetland Data EKZN Wetland Map, Satellite image SPOT 2011)
Figure 22: Plantation close to a wetland (red point nr. 1 in Figure 21)

Figure 23: Plantation within a side defined as wetland in the EKZN wetland layer (red point nr. 1 in Figure 21)
3.2.3 Conflicts with the legislation

When comparing the South African legislation which refers to timber plantations and their water use (cf. page 40) with the current state of distribution of Eucalyptus plantations within the study area some conflicts are obvious.

There are plantations that grow, according to the wetland layer, in wetlands. The legislation allows plantations only outside a radius of 20 m from a wetland. When applying this buffer zone to the wetlands, there are an additional 139 fragments of plantations with a cumulated area of 78.09 ha growing within this zone. Figure 24 shows one example of a plantation growing within the 20 m buffer zone.

Another striking point is the increase of new woodlots after the National Water Act became effective in 1998. Theoretically, every new woodlot would need a water use licence. Since SAPPI denies having the owner of these woodlots under an outgrower-contract, the owners either apply for a licence on their own which is expensive and takes a great deal of time (cf. page 42; Howard et al. 2005) or just plant the trees without licencing. The latter one is common practice because of the missing of a regulatory body for the relative young National Water Act. Furthermore, it is hard to control when the woodlots were established and who is the owner of the woodlot. Additionally, the remoteness of the area stimulates this process.

The National Water Act prioritizes water use for basic human needs over all other demands for water. If subsistence farming may be counted as basic human need, every timber plantation adjacent to subsistence gardens that lowers the water table violates the law by drying out subsistence farming gardens.

Furthermore, the ecological reserve has not been calculated for the catchment of the study area yet. According to the National Water Act, water use licences may only be granted after the ecological reserve has been calculated or at least after a preliminary determination happened.

Figure 24: Plantation within a buffer zone of 20 m
3.2.4 Buffer Zones

The Forestry Industry Environmental Committee (2002) advises 20 m buffer strips in riparian areas. According to these guidelines, it should be established from the outer edge of the temporary zone of a wetland.

The Department of Water Affairs (2013) proposed different wetland buffer widths dependent on the desired function of the buffer. For ground water recharge the buffer zone width range from 6.3 m to 225 m – but in special cases and after determining the impact of the land use with a geo-hydrological model the width may be more than 225 m.

A differentiated approach for buffer zones was already proposed by Kotze (2004) who developed guidelines for managing wetlands in afforested areas for the MONDI wetlands program and who understands buffers as key mechanism for the wetland protection. According to the guidelines, a 20 m buffer area is in most cases satisfactory. However, the document lists certain cases where even trees far outside of the wetland margins tend to definitely reduce the base-flow supply to a wetland. Under these particular situations are named (i) wetlands predominantly supported by ground water with catchments having sandy soils and high hydraulic conductivity as well as (ii) landscapes where tree plantations occur in areas with relatively shallow water tables. Both cases apply clearly for the study area with sandy soils with a high hydraulic conductivity and a shallow water table.

The above findings lead to the conclusion that for the wetlands within the study area, a 20 m buffer zone is by far not enough.

The North-West University in South Africa prepared a report about possible impacts of new afforestation on the upper ground water aquifer and wetlands, inter alia within the study area (Den-nis 2013). The authors propose that every abstraction taking place within a 2 km zone of sensitive wetlands should precede a detailed hydrogeological wetland study. Furthermore, they recommend protection zones (buffer zones) around the lakes of the study area, based on the capture zones for the lakes. They calculated buffer zones of 4 km for Lake KuShengeza, of 9 km for the Kosi Bay Lakes and of 3 km for Lake KuZilonde. These buffer zones are shown in Figure 25 (page 64). Wetland buffers were not added because it is not known which wetlands are sensitive ones. Buffer zones of 2 km around swamp forest were included because swamp forests are rare and sensitive habitats (Grobler 2009).

The above mentioned studies propose buffer zones with widths between 20 m and 2 km depending on the soil conditions, purpose and settings. As an example of a possible width, Figure 26 (page 65) shows the buffer zones of Figure 25 with the addition of a 200 m buffer for every wetland. Most of the plantations growing within the study area are now at least partially covered by these buffers. Only 111 of the 594 plantations are completely outside of any buffer zone or wetland area.
(highlighted in Figure 26). They cover an area of 724 ha. The other 6 200 ha of plantations grow either within the buffer zone of a wetland or lake or directly within a wetland.

3.2.5 Recharge area and cone of depression

The Formula 1 (page 48) was calculated with different values derived from the literature review (cf. chapter 2.2.1, Table 1). Pre-afforested vegetation in the forestry regions of South Africa is known to use between 700 mm and 900 mm/year (Bosch & Gadow 1990 in Dye & Versfeld 2007). Since Maputaland does not count as forestry region, the grassland evapotranspiration may be different. Daily evaporation of dry grassland in the St. Lucia Eastern Shores area not far from the study area was measured to be between 0.3 mm in the dry season and 2.0 mm in the wet season (Clulow et al. 2012). On an annual basis this would be between 109 mm and 730 mm. For not underestimating the evapotranspiration of grassland, the equation was calculated with 700 mm/year. AP was mapped and is about 6 800 ha in 2011. The evapotranspiration of the plantations was estimated to be between 1 000 mm and 1 200 mm.

\[
AG = \frac{-(750 \text{ mm} - 1 000 \text{ mm}) \times 6 800 \text{ ha}}{(800 \text{ mm} - 700 \text{ mm})}
\]

The above equation was calculated for three different values for rainfall (750 mm, 800 mm and 850 mm) as well as for the evapotranspiration of the plantations of 1 000 mm and 1 200 mm (Table 5).

Table 5: Different values for the calculation of the recharge area (EV= evapotranspiration; A= Area)

<table>
<thead>
<tr>
<th>Rainfall (mm)</th>
<th>EV Plantations (mm)</th>
<th>EV Grassland (mm)</th>
<th>A plantations (ha)</th>
<th>A Grassland (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>1 200</td>
<td>700</td>
<td>6 800</td>
<td>15 900</td>
</tr>
<tr>
<td>850</td>
<td>1 000</td>
<td>700</td>
<td>6 800</td>
<td>6 800</td>
</tr>
<tr>
<td>800</td>
<td>1 200</td>
<td>700</td>
<td>6 800</td>
<td>27 200</td>
</tr>
<tr>
<td>800</td>
<td>1 000</td>
<td>700</td>
<td>6 800</td>
<td>13 600</td>
</tr>
<tr>
<td>750</td>
<td>1 200</td>
<td>700</td>
<td>6 800</td>
<td>61 200</td>
</tr>
<tr>
<td>750</td>
<td>1 000</td>
<td>700</td>
<td>6 800</td>
<td>34 000</td>
</tr>
</tbody>
</table>

*Rounded to hundreds

The values selected lead to an area between 6 800 ha and 61 200 ha grassland needed to equalize the negative water balance of the plantations.

The area of the land cover class "grassland" (cf. Table 3) within the study area is 31 851 ha in 2005. If the areas of the land cover classes "bare sand", "bushland", degraded bushland", "de-
graded grassland", "dense bush" and "grassland/bush clumps mix", which are likely to have the same or less evapotranspiration, are added, the accumulated area accounts for 69 677 ha.

Exemplary for the upper right part of the study area Figure 27 (page 66) shows the grassland recharge area which would be needed to counter-balance the ground water-use of the plantations. The size of the area was calculated using the above formula with a rainfall of 800 mm and an evapotranspiration of the plantations of 1 200 mm. For every plantation, the recharge area is exactly fourfold the plantation area.

About 2 570 ha of that recharge area is located within wetlands according to the EKZN. The overall wetland area within the study area is 13 056 ha (without the Kosi Bay Lake System) according to the EKZN Wetland Layer. Thus, about 20% of the wetlands are located within the recharge areas.

For calculating the radius of the cone of depression, the maximum drawdown directly under the plantations needs to be known. Kienzle & Schulze (1992) modelled the depth of the depression under timber plantations on the Zululand coastal aquifer. They calculated with a water table under natural vegetation about 9 m deep, whereas under eucalypts with different maximum rooting depths of 10 m, 15 m and 20 m depressions of 4 m, 6 m and 12 m were calculated, respectively. The radius of influence calculated by the Sichardt formula (Formula 2, page 49) for the three different depression depths is shown in Table 6.

<table>
<thead>
<tr>
<th>Rooting depth (m)</th>
<th>Depression under the plantation (m)</th>
<th>Radius of influence (m) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4</td>
<td>120</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>181</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
<td>361</td>
</tr>
</tbody>
</table>

*rounded to the closest meter

Now it is possible to buffer every plantation with these values and to calculate the area being influenced by the drawdown.

For the maximum rooting depth of 10 m and the radius of influence of 120 m the overall area hydrological influenced by the plantations is 9 157 ha. For a rooting depth of 20 m with a radius of influence of 361 m the hydrological influenced area is 42 212 ha. These two values lie between the minimum and maximum values calculated with the water balance equation.

For comparing the wetland area affected by the cone of depression with the wetland area affected by the recharge area, a buffer of 200 m width around every plantation was drawn with ArcGIS. It covers an area of 11 694 ha, of this area 1 306 ha are classified as wetlands (according
to the EKZN Wetland layer). This is about 10% of the overall wetland area of 13 056 ha (without the Kosi Bay Lake System).

The wetland area affected by the plantations according to the different calculation methods is summarized in Table 7.

*Table 7: Affected wetland area*

<table>
<thead>
<tr>
<th>Calculation method</th>
<th>Affected Area (ha)</th>
<th>Affected wetland area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cone of depression (200 m width)</td>
<td>11 694</td>
<td>1 306</td>
</tr>
<tr>
<td>Recharge area (1200 mm evapotranspiration, 800 mm rainfall)</td>
<td>27 200</td>
<td>2 570</td>
</tr>
</tbody>
</table>
Figure 25: Buffer zones of swamp forest and lakes (after Dennis 2013)
Figure 26: Plantations completely outside of any buffer zone (highlighted)
Figure 27: Calculated recharge area around the plantations (Rainfall 800 mm; EV Plantations 1200 mm)
3.3 Discussion

The aim of this study was to examine the impact of the timber plantations within the study area on wetland conservation and restoration. Therefore, several GIS-related analyses were carried out. Additionally, an in-depth literature review to this topic was conducted. This chapter discusses first the results of this literature review and applies them to the study area. Then, the calculations of the recharge and of the cone of depression are critically discussed and the effect of the timber plantations on the wetlands is examined.

3.3.1 Transferring knowledge from the literature review to the study area

The results of the literature review show that most likely the plantations have a substantial impact on the hydrological regime of the region. A depletion of the ground water reservoir is likely when the trees reach the ground water with their roots. Due to the deep sandy soil on the Maputaland Coastal Plain and the already known development of sinker roots to the water table (Haigh 1966 and Scott 1993 in Le Maitre, Scott & Colvin 1999) it may be concluded that it is likely that:

- Eucalyptus trees reach the ground water table.
- evapotranspiration of the trees is higher than annual rainfall.
- the ground water reservoir is successively depleted.
- the plantations lower the ground water table.
- the impact on the ground-water fed wetlands depends on the cumulative area of the plantations and thus, on the degree of lowering the water table in the particular region.

The biodiversity on the Maputaland Coastal Plain is likely to decrease as a result of the afforestation with Eucalyptus. Due to the short rotation time of six to seven years there is no chance for an understory to develop within the plantation. Additionally, natural vegetation was replaced and the study area is fragmented by the plantations. Since Eucalyptus is an exotic species and known to be invasive in South Africa, there is a danger of outcompeting natural vegetation by Eucalyptus which leads to a lower diversity. Additionally, eucalypts are classified as harmful to surface water resources which also concerns considerably the aquatic biodiversity (Le Maitre, Versfeld & Chapman 2000). It may be concluded that the low biodiversity within the plantations and the effects on the surrounding may have a negative effect on long-term ecosystem health.

Eucalyptus plantations do not favor an accumulation of soil organic matter – they deplete soil nutrients reserves and inhibit the growth of an understory. Due to the short rotation cycles of six to eight years the amount of nutrients that is exported is high. Management could help to minimise these exports by leaving leaves, branches and bark on the plot without burning them. Additional Nitrogen depletion through allelopathic effects is possible (low concentration of nitrifying bacteria in
the soil as result) although these effects might be low because the deep sandy soils limit the accumulation of allelopathic substances.

3.3.2 Recharge area and cone of depression

Two different approaches were used to calculate the affected area. The author is aware that both approaches have one significant weak point, namely that the overlapping of recharge area or of the cone of depression of two neighbouring plantations is not factored in (Figure 28). Thus, the values for the real affected area are likely to be higher than the GIS-based calculated values. It means that both the real areas needed for the water recharge as well as the areas affected by the cone of depression are most likely larger than the calculated ones. However, the calculated values may be seen as the minima values.

![Figure 28: Example of the overlapping of recharge areas](image)

The calculation of the recharge area is only a rough and imprecise calculation because the values for evapotranspiration of the plantations and of the grassland were not measured and may be higher or lower. The same accounts for the interception rates of grassland and plantations which were assumed to be equal to keep the calculation simple. Furthermore, the rainfall changes from the coast to the inland and over the years (see chapter 3.1.1.1, page 26). Another weak point of this calculation is that the study area is no entire catchment area. This calculation assumes that ground water inflow equals ground water outflow which may be a wrong assumption. Nonetheless, the different calculations deliver a range of calculated areas being influenced by the plantations.
The minimal and maximal values of 6 200 ha and 61 200 ha grassland needed to equalize the negative water balance of the plantations are still being covered by the actual sum of grassland and woodland area (69 677 ha) within the study area (land cover data from 2005). The critical point is the distribution of these areas. For not affecting the wetlands the recharge should happen close to the plantations. However, most of the grass- and woodland area is located in the south and east of the study area whereas the plantations are located mainly in the north and west of the study area.

The values derived from calculating the recharge area are presumably the more reliable results. The cone of depression was calculated with a formula used in well construction. The transferability to the calculation of a cone of depression under a plantation may be questioned. Especially the fact that interaction effects amongst the single trees are not factored in may lead to a wrong calculation. Moreover, the value derived is independent from the size of the plantations – the radius of influence is only calculated from the edge of every plantation. Nevertheless, the equation showed that the radius of influence is between 120 m and 361 m, depending on the rooting depth of the Eucalyptus trees.

### 3.3.3 Wetlands and timber plantations

When looking at the results about plantations growing in wetlands (cf. chapter 3.2.2) one could assume that due to waterlogging, Eucalyptus does either not grow within wetlands or consequently the sedge wetlands delineated in the EKZN wetland layer are no wetlands. This assumption may be refuted by referring to the changing hydrology of the study area. In August 2001, 18 months after the cyclone Leon-Eline in February 2000, nearly all of these sedge-wetlands were covered with water. Figure 29 (page 71) shows a detail of the northern part of the study area in August 2001 together with the contours of the wetlands according to the KZN mapping. It is shown that every wetland is at least partially flooded (black colour means water on the ground). A reason for that is the high ground water table to that time. Although the heavy rainfall occurred 1 ½ years before the satellite imagery was taken, the wetlands are still flooded which means the drawdown is taking place over a long period. It is only possible to speculate whether the successive drawdown of the ground water table caused by the Eucalyptus plantations leads to a reduction of such floods.

Nevertheless, the EKZN Wetland layer shows only approximate borders of the wetlands. It is not possible to delineate the exact boundaries due to the quickly changing hydrology of the region and because of the seasonal or temporary character of the majority of the wetlands. There are different approaches how to delineate a wetland and the unique setting of the Maputaland Coastal Plain creates an even more difficult task (Pretorius 2012). It is not known which one is used for this layer. Hence, every plantation in wetlands detected by the overlap of the plantation area with this layer shall be validated in the field.
It has been reported that the size and extent of the wetlands within the study area is decreasing. Grundling (2014) reports an 11% decrease of wetlands between 1992 and 2008. This decrease is exemplary shown in Figure 30 (page 72). A magnified segment of aerial photographs and satellite images from a former lake in the upper right corner of the study area is shown. From 1942 until 2000 the lake was always at least partially flooded. In 2007, the water disappeared for the first time and the area of the lake has remained dry until today. This is only a single case example and it is not possible to transfer it to the whole study area. However, taking into account that the area planted with Eucalyptus grew from 204 ha in 1990 to 5 749 ha in 2008, it is likely that the growing number of timber plantations does have an effect on this decrease. The rainfall pattern with an average annual rainfall of 586 mm between 2002 and 2012 may count as an additional reason for the decreasing wetland size since the long-term average over the previous 23 years is 753 mm. Nevertheless, other impacts like other variations in climate and other human impacts, such as the number and intensity of water extractions, do play a role (Grundling 2014).

3.3.4 Buffers as management possibility

A buffer zone which prohibits plantation forestry in the surrounding of a wetland is at least a mid-term solution for protecting the particular wetland. However, a „one-size-fits-it-all“ method is the wrong approach. The extent of the buffer zone needs to be calculated on the basis of wetland hydrology, e.g. the catchment of the wetland.

This study shows two rough approaches on how to calculate the area which is being hydrological influenced by the plantations. Wetland buffer width determination may be based on a more detailed calculation with reliable values for evapotranspiration and rooting depths.
Figure 29: Landsat imagery from 2001 with marked wetland contour (EKZN Wetland layer)
Figure 30: Time series of aerial photographs and satellite imagery showing the lake in the upper right corner of the study area.
4 Alternative land use options for the Maputaland Coastal Plain – a literature review

The previous chapters showed that the use of Eucalyptus plantations as cash-crop for local communities on the Maputaland Coastal Plain may be seriously questioned because of the environmental impacts they induce. Under these circumstances the major challenge is to find suitable land use alternatives that contribute to the social and economic development of the region without putting constraints on the ecological sustainability of the area.

This review introduces some possible land use alternatives. First, ways of increasing subsistence and semi-commercial farming are showed. After that, possible plants for a commercial utilization of agrarian products are introduced followed by three chapters about exotic trees for non-timber products, the commercial cultivation of indigenous trees and agroforestry. The last chapter examines horticulture with hydroponics as possible alternative. None of these proposed alternatives is a stand-alone solution, it is important to support a development of a diversified mixture of alternative land uses. The ideal solution is likely to lie within a blend of several different alternatives. Proposing this, the diversification plan should be based on the knowledge already existent in the local population. However, it may be important to also have a look at new crops.

4.1 Increasing efficiency of subsistence and semi-commercial farming

Cultivation on the Maputaland Coastal Plain is faced with substantial constraints. Due to the sandy soils with low nutrients, low soil organic matter and poor water holding capacity (chapter 3.1.1.1, page 30), subsistence agriculture and semi-commercial farming is mainly restricted to the borders of wetlands or happens directly within. To remove pressure from these wetlands, it is of utmost importance to increase the efficiency of subsistence and semi-commercial farming on the sandy soils. Some field crops, for example the nitrogen fixing crop peanut (*Arachis hypogaea*), are already planted and show a good performance and yield.

The main limiting factor in enhancing the productivity is the missing of irrigation schemes. People are dependent on the rainfall. It is too work intensive and too expensive to build boreholes or dwells, even if the first aquifer is only two meters to six meters below the surface. Despite these difficulties, some households maintain successful vegetable gardens. They are cultivated with the
help of hand irrigation and the application of manure. The complicated hand irrigation could be simplified by providing pedal pumps, wind mills or solar pumps for pumping the water out of boreholes or dwells and for helping distribute the water.

The water scarcity can be lowered by harvesting of rainwater from the roofs. Additionally, greywater from the household may be used for irrigation.

Another restriction is the missing of nutrients. Soil productivity may be increased by wise manure application. It is common practice to leave cattle manure on the soil surface, exposed to sun and heat (Sliva et al. 2004). This results in an increased loss of nitrogen through volatilization. More effective would be the storage of manure in a cooler, shady location and the digging of the manure into the soil immediately after the application. Furthermore, the planting of nitrogen fixing crops and the incorporation of crop residues and composted household waste into the soil may enhance soil productivity.

Table 8 summarizes the restrictions affecting subsistence gardening on the Maputaland Coastal Plain and shows ways of avoiding them.

Table 8: Restrictions for farming on the Maputaland Coastal Plain and ways of avoiding them

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Ways of avoiding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation is too difficult</td>
<td>• Providing boreholes, dwells, pedal pumps, wind mills, solar pumps</td>
</tr>
<tr>
<td>Water is scarce/low water holding</td>
<td>• Harvesting of rainwater from the roofs</td>
</tr>
<tr>
<td>capacity of the soils</td>
<td>• Using greywater from the household for irrigation</td>
</tr>
<tr>
<td>Soils are infertile</td>
<td>• Planting nitrogen fixing crops (e.g. peanut)</td>
</tr>
<tr>
<td></td>
<td>• Increasing the incorporation of crop residues and other organic material</td>
</tr>
<tr>
<td></td>
<td>• Application of composted household waste</td>
</tr>
</tbody>
</table>

These recommendations only apply for small household gardens. On a larger scale grey water and water from the roof is surely not sufficient for irrigation, furthermore the nutrients coming from composting and from manure are only applicable on a small scale.
4.2 Commercial cultivation of agrarian products

The aim of sustainable agrarian cultivation should be to simultaneously satisfy the economic viability, the ecological processes and the social acceptability. For all three points, the optimization of key ecosystem processes is of utmost importance. The nutrient cycle should be as close as possible, a hydrological balance should be achieved, biodiversity should be enhanced and the resilience of these processes should be strengthened against perturbation (Bell & Seng 2005). Sustainable agriculture is not possible without knowledge about the capabilities of the soil. There are intrinsic factors like texture and structure which are not possible to definitely change and others like pH and organic matter which may be handled (Moody et al. 2005).

The main problems for commercial cultivation of agrarian products on the Maputaland Coastal Plain are the sandy soils which are responsible for nutrient deficiencies, acidity, water stress and poor physical attributes (chapter 3.1.1.1, page 30). Some of these problems have always existed, some are man-made. Due to land use change from the natural vegetation to rural dwellings and Eucalyptus plantations, a decrease of soil organic matter, total N and of cation-exchange capacity is likely (Wu, Chen & Sun 2005).

For keeping the nutrient cycle as close as possible the importance of coarse plant debris and the soil biota must be recognized. They are controlling most of the physical, chemical and biological soil properties (Blanchart et al. 2005). On sandy soils, the coarse organic fraction (>50 μm) is the main determinant of fertility, nutrient storage, aggregate stability and microbial and enzymatic activity (Feller et al. 2001).

Possible ways to facilitate the build-up of soil organic matter are (Vityakon 2005; Bell & Seng 2005; Golabi, Denney & Iyekar 2005):
- the continuous recycling of organic residues produced within the system
- no burning of harvest residues
- the reduction of tillage to a minimum for not disturbing the destruction process, as well as for avoiding the fast mineralisation of the organic matter and the release of nutrients
- the usage of composted organic waste as fertilizer.

It is important to know which nutrients in the soil are limiting the plant growth. The common use of N-fertilizer does not help if N, P, K and/or micronutrients limit the crop production, which is often the case on sandy soils (Bell & Seng 2005). Over-utilization of one fertilizer is reducing farm profits, creates a risk of soil degradation and causes environmental pollution (Golabi, Denney & Iyekar 2005). Fertilizer should match to the demands of the crop and the soil.

Another approach to improve the soil is through increasing the cation-exchange capacity (CEC). On sandy soils, a large problem is the small CEC which is the reason for fertilizer being useless and washed out because the soil may not hold the nutrients. In a study by Berthelsen et al. (2005), the authors used clay based soil ameliorants (bentonite clay) to increase yield through increased water holding capacity, nutrient availability and reduced nutrient loss. The critical point of
this method is the expense factor. Increasing the soil of a large area may be impossible if the next source of clay based soils is far away.

To achieve a hydrological balance, irrigation methods should be adapted to the climate, to the soil and to the crop. A study of Golabi & Akhoonali (2005) showed that the drip and porous pipe irrigation system needs small technical knowledge, is easy to handle and is well suited for light textured soils. Such system provides water to the root system at minimum level, minimizes deep percolation and requires minimum pressure to operate.

Suitable crops for subtropical sandy soils are for example peanut, cassava, amaranth, corn, sorghum, eggplant, sweet potato, tomato, watermelon, avocado, mango, papaya or passion fruit (Martin 2013). However, it is not possible to detect the sole optimal crop for Maputaland. The selection depends on much more than the climate and the soil. For example the acceptance of the people is important, the local knowledge about the crop, the availability of markets to sell the crop, as well as know-how and technology chains for storage, processing and utilisation.

Banana (Musa spec.), for example, is a plant that does not grow well on sandy soils but is a broadly used crop in Maputaland. Therefore, it is grown on the edges of the wetlands or in the swamp forests where it consumes a great deal of water and nutrients (Grobler 2009).

On the other hand, peanut (Arachis hypogaea) is grown on the sandy soils of Maputaland. This crop fits well to the sandy soils. At the coastline of India for example peanut is the major crop on sandy soil. Improving the fertility of the soil for peanut production is achieved by the mycorrhizal activity of the crop (Rhizobium, cf. 4.2.1) and it may be further enhanced through the application of bio resources like composted organic material (Singaravel, Prasath & Elayaraja 2005).

As examples for annual or short-term crops the Peanut (Arachis hypogaea) and the Chili (Green pepper; Capsicum annuum) are presented. Both are already grown small-scale on the Maputaland Coastal Plain and have the potential for a more intensive, semi-commercial and commercial agriculture.

4.2.1 Peanut (Arachis hypogaea)

The plant peanut (Arachis hypogaea) belongs to the plant family Fabaceae. First evidence of agricultural use is dated back to about 3 900–3 750 years before present in Peru (Hammons 1994). The crop is native to South America and the date of domestication is unknown. It is cultivated in many countries between 40°N to 40°S. About 80% of peanut production occurs in seasonally rain fed areas of the semi-arid tropics (Wright & Nageswara Rao 1994). The peanut is an herbaceous annual plant.

The peanut may be eaten raw but it is also famous for its wide range of processed products. Worldwide it is primarily grown as source for edible vegetable oil, especially in India and China which are the largest producers, and for making peanut butter.
It counts as a legume and builds subterranean fruits with one to four seeds per pod. Like most plants from the family *Fabaceae*, the peanut is a nitrogen fixing crop with nodules inhabited by soil organisms known as rhizobia. Optimal growing temperature is about 30 °C. The root-system is fairly well-developed with the main parts in a depth of 5 cm to 35 cm and within a radius of 12 cm to 14 cm. The taproot tend to reach length of about 130 cm. Flowering happens about 25 days after emergence and continues with the most pronounced flowering between 5 to 11 weeks after planting (Ramanatha Rao & Murty 1994).

Time from fertilisation to full maturity is roughly 60 days. The podding zone is about four cm to seven cm below soil surface and the optimum soil temperature for a good development of the pods is between 31 °C and 33 °C. Unique in pod development is the gathering of nutrients directly from the soil rather than by transportation from roots to shoots and back to the seeds. Researchers have found out that Calcium is needed in the surrounding soil for optimal production. Furthermore, high humidity is essential for successful peanut production because water stress reduces yields (Coolbear 1994). However, the peanut is a drought tolerant crop with its nodules being less sensitive than those of some other legumes. Sprent (1994) found out that peanuts respond to drought by increasing its proportions of roots below 30 cm. Water use is estimated to be between 550 mm and 600 mm per growing period for optimal pod yield performance (Wright & Nageswara Rao 1994). Irrigation is beneficial but is not needed throughout the vegetation period.

The following points may optimize the yield of peanut on the Maputaland Coastal Plain (Coolbear 1994; Wright & Nageswara Rao 1994; Vinh 2005; Vityakon 2005):

- The usage of Calcium as fertilizer to decrease pod and seed abortion rates.
- The exposition of the plant to a drought during the pre-flowering phase (but only if afterwards adequate water availability is guaranteed).
- Mulching and intercropping (e.g. with cashew).
- The usage of groundnut residues as organic fertilizer.

The peanut is already established on the Maputaland Coastal Plain and is well distributed in home gardens. However, there is still no commercial production established which may be an alternative for the Eucalyptus plantations. Since it grows well on sandy soils the only constraints are the missing nutrients and the water deficiencies. With a well balanced fertilizer and an adapted irrigation system these constraints may be avoided. The Calcium supply may be guaranteed using the local sources (limestone occurrence in the eMbonisweni area west of Manguzi), which could also contribute to job creation.

Furthermore, the home garden production may be increased by spreading information about the useful stover which may be used as mulching material or as organic fertilizer.
4.2.2 Chili (Green pepper; *Capsicum annum*)

The genus *Capsicum* is known under a broad range of names. Chili, Chilli or Green Pepper are only some examples for the wide variety. Its origin lies in South America and it belongs to the plant family of *Solanaceae* which also includes tomatoes and eggplants. It was at least five times independently domesticated and was brought to Europe by Christopher Columbus (Bosland & Votava 2000). Afterwards, the plant spread rapidly to Asia and Africa and was accepted in the local cuisines.

It is used as flavouring in food, in medicine, as colouring for cosmetics and as ornamental plant. As food it is consumed as fresh vegetable or as dried spice. Furthermore, the heat inducing compound capsaicin is used in medicine to alleviate pain and as medication for arthritis (Bosland & Votava 2000).

Green pepper is grown under broad climatic conditions and on all continents except Antarctica. Optimal conditions are (Bosland & Votava 2000; Hatutale 2010):

- A long, frost-free season with an average temperature above 18 °C (the highest yield tends to be achieved with daily air temperatures between 18 °C and 32 °C).
- Water availability of about 600 mm during the growing season (for South Africa from November to March).
- A deep (effective rooting depth is between 400 mm and 700 mm), well drained sandy loam with a high water-holding capacity and rich in humus.

Green pepper is a self-pollinating plant and its fruit does not ripen once harvested unripe (Hatutale 2010).

In arid or semi-arid climates irrigation is needed for optimal production because the plant is susceptible to drought. Borosic et al. (1998) found out that a combination of drip irrigation and mulching is the best water management. Furthermore, the water use efficiency (dry matter production per unit of crop transpiration) with mulching is higher than without (Hatutale 2010). Another factor steering the productivity is the planting density. Planting may either be carried out by direct sowing or by transplanting. The density depends on the cultivar used – recommendation for South Africa is to plant between 20 000 plants/ha and 50 000 plants/ha (Anonymous 2000 in Hatutale 2010).

An important aspect is the pest and disease control as well as the fertilization. A soil analysis for figuring out the optimal fertilizer mix should be performed before planting.

Hand-harvesting is the preferred harvesting method. Benefits are that mouldy, under-ripe, over-ripe and damaged fruits may immediately be discarded. Additionally, fruits are much cleaner and fewer leaves and stems are inadvertently picked during harvesting (Bosland & Votava 2000).

In South Africa, the fresh yield ranges between 50 t/ha and 100 t/ha (W. Wessels 2008 in Hatutale 2010). In 2009, the total production of peppers in South Africa was 36 200 tons with a revenue of 220 million Rand.
*Capsicum annuum* is one possible plant to grow on the Maputaland Coastal Plain. Although it needs some effort to establish a plantation, good revenues are feasible due to the good rainy season during the vegetation period and due to the deep soils. Constraints are the low humus content of the soils and the low fertility. But with an efficient fertilizer, an outbalanced irrigation system and mulching the constraints may be avoided. Water need for irrigation is low when compared with the water use of a Eucalyptus plantation. Values obtained through personal communication with the owner of a 10 ha chili-plantation (Figure 31) range between 156 mm/year and 312 mm/year (Dludlu 2013).

![Figure 31: Chili plantation in Maputaland (Hartl 2013)](image)

4.3 **Exotic Trees for non-timber products**

The following chapters introduce possible non-indigenous fruit trees for commercial cultivation. The mango (*Mangifera indica*), the cashew nut tree (*Anacardium occidentale*) and the horseradish tree (*Moringa oleifera*) are presented. The mango and the cashew nut tree are already grown small-scale on the Maputaland Coastal Plain. The mango is a widespread tree in Manguzi which is not commercially grown, but fruits from backyard trees are sold on the market (personal observation 2013). The cashew has been grown on 1 000 ha close to Lake Sibaya (Ramiakajato 2001). At the moment, the cashew plantation is out of order due to different claims of property (personal observation 2013). Contrary to the first two trees, the horseradish tree is not yet established on the Maputaland Coastal Plain.
4.3.1 Mango (Mangifera indica)

Mango (Mangifera indica) belongs to the genus Mangifera of the plant family Anacardiaceae where for example the cashew tree is located. Its origin lies in tropical Asia. The greatest number of species occurs in Borneo, Java, Sumatra and the Malaysian Peninsula.

Mango is a tree which may reach 15 m to 30 m height and grows from sea level to about 1 200 m in tropical latitudes. It tolerates precipitation between 400 mm and 3 600 mm per year. It is a fast developing tree with growth rates above 1.5 m/year in ideal conditions. Mango is used for its fruits, for silvo-pasture, for medicinal purposes and for its timber. This may be used in furniture, for carving, as wall and floor panelling and utensil manufacture (da Silva, da Cunha Campos & Azevedo 2009; Zziwa et al. 2006). Other uses of the tree are as windbreak, in home gardens and as livestock shelter (Bally 2006).

Mango grows well on deep, light textured soils. Soils which dry out fast after a wet period are favourable because they force the tree into a dormant period which is essential for heavy flowering. It has a long taproot that often branches just below ground level, forming between two and four major anchoring taproots that may reach six meters deep into the ground (Bally 2006). Optimal growth is within the temperature range of 27 °C to 36 °C.

The first fruiting takes place between the age of two and four and may continue up to more than one hundred years. Optimal fruit production occurs when the tree is exposed to a dry period in winter. However, the tree needs a great deal of water during fruit growth in summer time. The evapotranspiration is reported to be between 2.6 mm/day and 4.3 mm/day in the summer months (Department of Agriculture, Forestry and Fisheries 2000; da Silva, da Cunha Campos & Azevedo 2009). Irrigation should be not as high as potential evapotranspiration because too much water reduces the yield. The evapotranspiration rate of intensive mango plantations is at least as high as that of Eucalyptus plantations (cf. Table 1).

Fertilization, especially on sandy soils, is required (Department of Agriculture, Forestry and Fisheries 2000). Every tree is a fruit-bearing tree because hermaphrodite and male flowers occur on every inflorescence. Propagation happens through grafting or seed planting. A disadvantage is the bad storage quality of the seeds. They lose viability rapidly after being removed from the fruit due to desiccation (Bally 2006).

In South Africa, mango is grown commercially. Main production areas are in the Northern Province and in Mpumalanga (Department of Agriculture, Forestry and Fisheries 2000).

Due to its high water and irrigation demand for optimal fruit production the mango should not be planted in large-scale monoculture plantations on the Maputaland Coastal Plain. It may be mixed with other species or used as a backyard tree. Due to the high rainfall in the summer months in the Manguzi area, trees are susceptible to diseases like Anthracnose or bacterial Black Spot which are rain-linked and cause fruit-drop (Department of Agriculture, Forestry and Fisheries 2000).
4.3.2 **Cashew** (*Anacardium occidentale*)

The cashew belongs to the plant family *Anacardiaceae* where for example the mango is located. The cashew is native to northeast Brazil and was brought to India by the Portuguese (Cochin 1578 in Ramiakajato 2001). To Africa it came during the second half of the sixteenth century. Nowadays it occurs throughout the tropics and in Africa the cashew is purposely grown over the eastern part of the continent as well as on Madagascar.

Products from the tree are oil extracted from the nut and sweets, jam, jelly, alcoholic and non-alcoholic beverages processed from the cashew-apple (Ecocrop 2007). The wood of the cashew is water resistant and may be used for the construction of boats and ferries (Ramiakajato 2001).

The cashew is a tree that develops to heights of 10 m to 15 m. It grows at altitudes up to 1200 m even on stony outcrop but it ripens the best on deep, well drained sandy soil. It tolerates a climate with four to seven dry months per year and an annual temperature range of 21 °C to 28 °C. High temperatures support good growth; in its native habitat 40 °C are not unusual. Absolute minimum and maximum temperatures are 5 °C and 45 °C (Ohler 1979 in Ramiakajato 2001). Rainfall may range from 500 mm to 4000 mm but heavy rainfall or insufficient water may lead to excessive vegetative growth, irregular flowering, flower drop, crop losses and to infections like anthracnose (Agnoloni & Giuliani 1977 in Ramiakajato 2001).

The cashew is only resistant to drought under conditions where roots may penetrate deeply into the soil and draw water from the water reserves. It does not tolerate waterlogging. The optimal water level should be at depth of five meters to ten meters. The taproot of the cashew has an extensive lateral root system (Ohler 1979 in Ramiakajato 2001). For example, a 42 month old tree had a 2.3 m deep root and the root size of a five month old tree was reported to be about 1.2 m (Tsakiris and Northwood 1967 in Ramiakajato 2001). In general, roots tend to extend over five meters deep and they grow not only deep but in a large horizontal radius (Carr 2014).

The water use of cashew is difficult to predict. The values appearing in literature range between 73 mm/year (Carr 2014) and 469 mm/year (Department of Agriculture, Forestry and Fisheries 2004) for mature Cashews with a growing density of 100 trees/hectare and between 245 mm/year and 1126 mm/year (Carr 2014) for young trees with a density of 240 trees/hectare.

The growth rate of cashew is about one meter per year and the canopy diameter increases by 1.5 m to 2 m per year for the first five to six years. After that period, growth slows down. Growing time is all year round especially when rainfall is well distributed (Ohler 1979 in Ramiakajato 2001).

The first flowering happens on average three years after planting and may continue for about 20 years. At the end of the rainy season, new flushes grow and the terminal ends of the new developed shoots produce the inflorescence. Flowering only happens after a dry period. The flowering period in Mozambique where the growing region is located close to the Maputaland Coastal...
Plain is from September to December and the fruiting period from October to February (Roe 1994). Male and hermaphrodite flowers occur on the same panicle.

Irrigation for optimal fruit production is supposed to be beneficial during the period from flowering to the start of harvest (Carr 2014). Fertilization also is beneficiary (Ramiakajato 2001).

The fruits mature in two to three months. The kidney shaped nut grows at the end of the cashew “apple” which is the true fruit of the tree and contains a single seed. The nut is mainly used as an export product whereas the apple is consumed by the local inhabitants. It is too soft for long-distance transport.

South Africa is the southernmost cashew cultivation area. Cashew plantations were established in KwaZulu-Natal, Northern Province and Mpumalanga. The South African production is relatively new and not sufficient to meet the high demand. Therefore South Africa imports cashew nuts mainly from Mozambique (Department of Agriculture, Forestry and Fisheries 2004), which means that there is still an unsaturated market for this crop.

The cashew fits well on the Maputaland Coastal Plain. It bears high temperatures and the water use is not excessive. However, rooting depth and water use should be monitored.

4.3.3 Horseradish tree (*Moringa oleifera* Lam.)

*Moringa oleifera* (syn. *Moringa pterygosperma* Gaertn.), also known as horseradish tree or drumstick tree, is a fast growing evergreen or deciduous tree (depending on the climate (Morton 1991)). It grows up to ten meters to twelve meters in height and up to diameter at breast height of 20 cm to 40 cm. The horseradish tree is classified as drought resistant pioneer species. The tree has a short, straight stem that starts branching at a height of 1.5 m to 2 m. The foliage consists of feathery tripinnate leaves with a length of 20 cm to 70 cm and the bark is whitish, thick and corky (Parrotta 1993). Flowering happens within the first sixth months after germination. It is a fast growing tree, for example a growth rate of 2.5 m in three months was reported (Morton 1991). In its native range the tree has a high phenotypic variation from which a high genetic diversity may be concluded. *Moringa oleifera* is a diploid organism with 28 chromosomes (Ramachandran, Peter & Gopalakrishnan 1980). It is easily propagated by cuttings (Parrotta 1993). In India there are several insect pests that occur on Moringa, furthermore it is highly susceptible to wind damage (Parrotta 1993).

The Moringa genus is the only genus in the family of the *Moringaceae*. 13 different species are classified in that genus (Olson 2010). *Moringa oleifera* is native to south-east Asia where it grows in the Himalayan foothills from the north-eastern Pakistan to northern West Bengal (India).

In its native habitat the seasonal climate fluctuates with temperatures ranging from -1 °C to 48 °C. The rainfall varies from 750 mm to 2 200 mm. The soil is mainly sandy or gravelly alluvium which is well drained and low in organic matter. The water table is usually located within the maxi-
mum rooting depth of the tree (Parrotta 1993). *M. oleifera* is a strongly light demanding species (Parrotta 1993) but with a low demand for soil nutrients and water (Foidl, Makkar & Becker 2001).

The *Moringa oleifera* tree was introduced to countries all over the world, namely other parts of India, Pakistan, Afghanistan, Bangladesh, Sri Lanka, West Asia, the Arabian peninsula, east and west Africa in the beginning of the 20th century (Foidl, Makkar & Becker 2001) and from Mexico to Peru, Paraguay and Brazil. It is highly drought tolerant and was cultivated in semiarid and arid regions of India, Pakistan and east Africa with annual rainfall less than 400 mm (Odee 1998 in Foidl, Makkar & Becker 2001; Parrotta 1993).

It is mainly grown for its non-timber products. Edible parts are the fruits, leaves, flowers, roots and seeds. Furthermore, highly valuable oil may be extracted out of the seeds. It is used for human consumption, in cosmetics, for making soaps and for illumination (Parrotta 1993). In its origin almost all parts are used for medicinal purpose (Ramachandran, Peter & Gopalakrishnan 1980). For example, the juice from the leaves has strong antibacterial and antimalarial properties (Eilert, Wolter & Nahrstedt 1981; Gbeassor et al. 1990). An additional use comes from the crushed seeds; it was found out that they remove turbidity and reduce bacterial contamination from water (Jahn 1988 in Maroyi 2006; Ndabigengesere & Subba Narasiah 1998; Foidl, Makkar & Becker 2001).

From the edible products especially the leaves and the pods are sold. Leaf fresh weight yield is between one kg to five kg per tree per year (Radovich 2011) but it varies widely between seasons, variety, rainfall regime or irrigation and the use of fertilizer. The leaves are favoured for their richness in provitamin A, vitamin B and C, minerals and the sulphur-containing mineral amino acids methionine and cystine (Foidl, Makkar & Becker 2001). The main product for selling is a powder made out of the dried leaves. It is supposed to be healthy and to help fight malnutrition. The pods are consumed as vegetables, for example in the Pacific (Radovich 2011). A large *Moringa oleifera* industry which produces 1.1 million ton pods on 38 000 ha per year is located in India (Radovich 2011).

The leaf powder of Moringa is the main trading good because it may be stored for a long time. The pods and the fresh leaves should be consumed within days or weeks. The price for the powder is highly different between Europe and South Africa due to different target groups and marketing strategies as well as different economic levels. In Europe it is being sold as miracle powder (Simonsohn 2014) for about €20 (~R240) for 100 g (MoringaGarden Europe 2014) whereas in South Africa the same amount is sold for R30 to R60 (~€2.10 to €4.5) (Africa Moringa 2014; Moringa Leaf Powder 2013).

Maroyi (2006) conducted a case study about the utilization of *Moringa oleifera* in Zimbabwe. The tree was introduced to Zimbabwe from India and is grown for its edible leaves, seeds and pods. On the menu of the Tonga people of Zimbabwe, Moringa has become a permanent feature with its leaves being used as spice. Furthermore, leave juice is used for medicinal purposes. The author found out that the tree has become an important source of income because several villag-
ers have started nurseries to grow Moringa for sale in large quantities. The four most important reasons to plant Moringa are the need for food, the medicinal use, the source of income and the diversity of other uses. The author states that during years of drought, the cultivation of Moringa becomes more important because of its good ability to cope with low rainfall.

In 2012, the Moringa South Africa Reforestation Project started in Maputaland planting trees for carbon sequestration and for local development on an area up to 3 000 ha (Moringa South Africa Reforestation Project 2014). However, in December 2013, the first pilot plot was not well managed, fences were broken and leaves were eaten by cattle (personal observation, 2013) (Figure 32).

Advising commercial Moringa oleifera plantations for northern Maputaland is critical. The tree is not yet well investigated and it may start invasive spreading just like Eucalyptus. Additionally, there is no data available about the water-use of Moringa. The tree possibly drains a high amount of water when it reaches the ground water. Furthermore, the acceptance of Moringa plantations by the locals is unknown and should be examined first before starting the large-scale planting and before awaking false hopes for the local communities.

Benefits of Moringa are the well distributed work all over the year. The first pod harvest may already be at an age of six months to eight months and then every six months (Radovich 2011). The leaves of a tree at the age of three years onwards may be harvested six times to eight times a year (Moringa South Africa 2014; Olivier 2014). Furthermore, the tree is delivering diverse products.
Table 9 summarizes benefits and disadvantages of Eucalyptus and Moringa plantations.

Table 9: Summary of benefits and disadvantages of Moringa oleifera and Eucalyptus plantations in the Maputaland Coastal Plain

<table>
<thead>
<tr>
<th></th>
<th>Eucalyptus</th>
<th>Moringa oleifera</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>+</strong></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Already established</td>
<td>Uses a high amount of water</td>
<td>Regular income</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unknown water use (but likely to be less than Eucalyptus uses)</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>Benefits only for the landowner and some workers</td>
<td>6 to 8 harvests per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No experience with Moringa in the area</td>
</tr>
<tr>
<td>Easy to sell</td>
<td>Only one product</td>
<td>Several products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large uncertainties (yield, market, acceptance)</td>
</tr>
<tr>
<td></td>
<td>Invasive species with negative influence on the biodiversity</td>
<td>Benefits for more people because of more and regular work</td>
</tr>
<tr>
<td></td>
<td>Adapted to sandy soils and drought</td>
<td></td>
</tr>
</tbody>
</table>

A suggestion is to start pilot experiment fields with Moringa plantations and to monitor the yield and the need of irrigation or fertilization as well as the water use. An examination where and what kind of Moringa products may be marketed, for example in the Durban area which is the closest densely populated region to the Maputaland Coastal Plain, is advisable.

4.4 Commercial cultivation of indigenous trees

The commercial cultivation of indigenous trees is a promising alternative for the extensive Eucalyptus plantations. The commercial utilization of indigenous trees could lead to a sustainable land use with an increasing income for the local communities and a large development potential. Although it needs much time, it is a sustainable growing method and may be conducted by local communities. In a broad study about forest-related people researchers have found out that farmers engaged in the cultivation of indigenous trees have higher returns to labour, used more intensive
production technologies and produced more tree products per hectare than those relying on the wild. Moreover, they benefited from a more stable resource base (Ruiz-Perez et al. 2004).

The following two chapters present research about the domestication of indigenous fruit trees and about the harvest potential of indigenous sand forest. Ways of applying this use to the Maputaland Coastal Plain are shown.

### 4.4.1 Indigenous trees for the harvest of fruits

Since 1989, the World Agroforestry Centre initiated research-and-development work on more than 20 priority indigenous fruit trees in southern Africa. The aim of this agroforestry tree domestication program is to cultivate, improve and add value to these fruits. Although this work focuses on the Miombo savannah which occurs in Zimbabwe, Zambia, Mozambique, Angola, Tanzania and Malawi, some of its results may be transferable to the Maputaland Coastal Plain. Especially because the research included four trees that are native to the study area (Akinnifesi et al. 2006): *Strychnos cocculoides* (Monkey orange), *Sclerocarya birrea* (Marula), *Vangueria infausta* (African medlar) and *Syzygium cordatum* (Water berry). There may be more suitable trees on the Maputaland Coastal Plain than just the above mentioned.

The main goals of domesticating fruit trees are to increase their quality and productivity, to create opportunities for marketing their products and to empower smallholder farming communities to cultivate and conserve them. Aims for a specific species are for example the reduction of the time to first fruiting and a selection for large, sweet fruits with high pulp content (Akinnifesi et al. 2006).

Domestication of trees that only occur as wild species requires a long-term, iterative and integrated strategy for tree selection and improving. Furthermore, research is needed for the promotion, use and marketing and the integration into agroforestry practices (Akinnifesi et al. 2004).

Domestication should go together with a participatory approach. Local farmers have the knowledge about inferior trees and the quality of the fruits, furthermore it is important to train community farmers in nursery management and domestication techniques like grafting (Akinnifesi et al. 2006). Commercialization of the fruit is as important as the domestication and must take place in parallel. This happens through the establishment of a functional supply chain with fruit storage and processing, product quality assurance, adding value, marketing, rural revenue generation and enterprise development (Akinnifesi et al. 2004). Access to markets and availability of transport are key factors in determining the commercialization of possible products.

Possible products from indigenous trees on the Maputaland Coastal Plain are non-alcoholic and alcoholic beverages, confectionaries, additives for other foods, dried whole fruits, oil, kernel butter and jam. There are already some local products like water berry jam (personal observation, 2013) which could be produced on a larger scale and marketed in a broader region to generate income. This is especially interesting in combination with tourism. Tourists like to consume local
products in their holidays and are willing to pay an extra amount for that. Furthermore, it adds a special value to the destination (Du Rand, Heath & Alberts 2003).

4.4.2 The use of indigenous trees for the harvest of timber

85% of the rural households in KwaZulu-Natal rely on wood resources for their basic household needs (Mander and Quinn 1995 in Gaugris & van Rooyen 2007).

Due to the lack of large indigenous forest areas and the conservation rules applied on the Maputaland Coastal Plain, locals have to either violate the law by harvesting protected forest areas or buy their timber from the timber companies in the towns which is often expensive.

Since sustainable harvest is only possible if the growth and regeneration rates of the trees are known, Gaugris & van Rooyen (2007) performed an extensive research about the use of indigenous sand forest trees. Their research area was the Tshanini Game Reserve which has a size of about 2 420 ha located close to the Tembe Elephant Park on the Maputaland Coastal Plain.

Sand forest generally has a low rate of regeneration with few seedlings and saplings (Malitz et al. 2003). Nevertheless, results of the study show that some trees may be used sustainable. Gaugris & van Rooyen (2007) measured the stem growth rate of tree species and calculated size class distributions. According to the results achieved they divided the sand forest tree species in four classes involving their population status and size class distribution in the Tshanini Game Reserve. No species were classified for “sustainable use” whereas 7 out of 23 tree species were classified as “cautious-use”. Cautious means that the size class distribution indicates a regenerative potential which may support exploitation but restrictions for the use are needed. Five out of 23 tree species were classified as “survey again” because the results about the regenerative potential were not clearly enough.

In a similar study conducted by Gaugris, Vasicek & van Rooyen (2007) the authors not only looked at the sand forest but at open and closed woodland as well. They found out that seven species of tall sand forest, four species of closed woodland and three species of open woodland may be harvested sustainably.

However, restrictions should be set by a sustainable use program based on demand and supply. In order to perform a sustainable harvesting without being detrimental to the tree stands, harvesting plans are needed according to the availability of resources, the rate of use (harvest quotas) and the renewal of resources (Matthews 2005; Gaugris, Vasicek & van Rooyen 2007; Gaugris & van Rooyen 2007).

The above studies indicate the possibility of sustainable harvesting of indigenous forest. Further research about the group of trees classified as “survey again” and about possibilities of a commercial afforestation using native trees is needed. The latter requires the establishment of nurseries for indigenous trees; one is already established close to Manguzi (personal observation, 2013). In any case the production chain of the timber supply from autochthonous afforestation
would create substantially more job opportunities (seed collection, nursery operation, etc.) than the clonal Eucalyptus plantations.

Moreover, indigenous forest is much more adapted to the local climate and hydrology than the Eucalyptus plantations. Although monetary benefits in the first decades are by far not of the same size as from Eucalyptus, other benefits like the production of non-timber forest products for the local people, adapted water use and the positive effects on biodiversity may outweigh the monetary benefits from an ecological point of view. A study of Everson et al. (2011) about the water-use efficiency of indigenous trees in South Africa shows that indigenous trees use substantially less water. The authors state that advantages of indigenous systems potentially include lower management costs, higher product values and a wider range of non-wood products and lower hydrological impact which may be the most important point for the Maputaland Coastal Plain.

However, as already stated above, the long time for the first financial benefits since the afforestation may hamper the utilization of native trees. The solution would be the launching of supporting and compensation programs by the state. The same applies for the costs related for fencing to protect the established woodlots against cattle damages. Finally at the moment there is low experience of large-scale planting indigenous trees. Thus, experimental plots and close-to-real trials should be established and monitored as soon as possible.

4.5 Intensive horticulture with hydroponics

Hydroponic is a noun derived from the Greek language and means working water (hydro = water; ponos = labour). The term hydroponics was invented in the late 1920s in California. By a strict definition it is defined as a method of soilless growing where the plant roots are suspended either in a static, continuously aerated nutrient solution or in a continuous flow or mist of nutrient solution which brings everything the plant needs. But it is common to use it for all ways of soilless growing, with aggregate or without. Hydroponic agriculture is a small agricultural sector, in 2004 there were about 22 000 ha hydroponic systems worldwide with the main users being Mexico, Canada and the USA (Jones 2005).

Hydroponic systems are classified by the medium in which the plants grow and by the type of nutrient solution application. The most widespread technique is the liquid system with the nutrient film application (Figure 33). It may be designed as a closed system where the solution is recycled and reused.
As equipment for a basic hydroponic system an irrigation system with a pump for the water and a pump to aerate the water, a tube and valves for adjusting the amount of nutrients in the solution are needed. The amounts of nutrients in the solution are possible to measure with an EC-meter. It measures the electronic conductivity of the solution which is a value for the amount of dissolved nutrients. Furthermore, a hydroponic system requires pH controllers and computer controls for monitoring the values of electronic conductivity, pH and the amount of water. Additionally, storage tanks for the nutrient solution and for the water are needed.

Hydroponic systems may be established in a greenhouse or outdoors. Outdoor use is crucial because there is the danger of diluting the nutrient solution by high rainfall.

In South Africa, a small hydroponic crop production is established. It is promoted by a small leaflet from the Department of Agriculture, Forestry and Fisheries (2011). The most popular crops are tomatoes, cucumber, lettuce, herbs and peppers. The common media used for hydroponic production in South Africa is sawdust (Safronovitz 2011). In general, it is much better to choose high valued crops in hydroponic production because of the high establishing costs.

For evaluating the possible benefit of hydroponics for the Maputaland Coastal Plain, Table 10 summarizes the general benefits and disadvantages of hydroponic crop production found in two standard publications.
Table 10: Benefits and Disadvantages of Hydroponic crop production *(Jones 2005; Mason 1990)*

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is possible to control nutrient and water level</td>
<td>Implementation cost is high</td>
</tr>
<tr>
<td>Higher yields than conventional agriculture</td>
<td>Trained personnel is needed</td>
</tr>
<tr>
<td>No soil needed</td>
<td>Compost and manure are not possible as fertilizers</td>
</tr>
<tr>
<td>Water stays in the system and may be reused, low water use</td>
<td>Diseases and pests may spread fast</td>
</tr>
<tr>
<td>No nutrient pollution is released in the environment</td>
<td>Fast reaction of the plant to bad managed nutrient solution</td>
</tr>
<tr>
<td></td>
<td>Reliable electrical power needed</td>
</tr>
<tr>
<td></td>
<td>Monitoring and periodic testing of the nutrient solution is required</td>
</tr>
<tr>
<td></td>
<td>Water quality needs to be known well</td>
</tr>
</tbody>
</table>

At the moment, hydroponics is not a feasible alternative land use for the Maputaland Coastal Plain in the large scale. The low water requirements with an average between 0.25 l and 1.25 l per day per square meter of growing surface *(Mason 1990)*, the fact that no soil is needed and the possibility of a closed cycle are very promising but the disadvantages outweigh the benefits. Due to the high implementation cost it is not a technique for the community. It provides only labour for skilled personnel. Furthermore, regular analysis of the water quality and the nutrient solution needs to be done but the possible conducting institutes are too far off the Maputaland Coastal Plain region.

More research is needed about easy to handle simple hydroponic systems. At the moment controlling the right amount of nutrients is a problem. Most nutrient solutions are too concentrated because the nutrients which the plant does not use accumulate in the solution. It may be questioned whether this changes in future. Jones *(2005)* states that only few are engaged in developmental research on hydroponic methods.
Agroforestry is a land use system where woody perennial trees are used together with agricultural crops and/or animals on the same land-management unit (Lundgreen and Raintree 1982 in Everson et al. 2011). Agroforestry systems are grouped in three different systems: agrisilviculture (crops and trees), silvopastoral (pasture/animals and trees) and agrosilvopastoral (crops and pasture/animals and trees) (Nair 1985).

A small traditional agroforestry system is for example a home garden in Manguzi: various tree species and subsistence crops grow together, sometimes cattle may be found.

The success of agroforestry is largely depending on the composition of trees and crops. Especially in an agrisilviculture system, spatial complementarity of trees and crops in terms of water use is important (Ong et al. 2002). The competitive effects between trees and crops should be as low as possible. Management options may be the pruning of lateral roots to reduce water and nutrient competition. In an optimal system trees should use the lower part of the soil water and crops the upper part. Moreover, by choosing the ideal composition, tree litter is beneficial for the crops by providing nutrients and the tree roots impede soil erosion and reduce runoff. However, for semiarid tropics, there have been only few tree species identified with limited competitive effect (Ong et al. 2002).

In Zimbabwe it is common to intercrop mango with herbaceous plants (Musvoto & Campbell 1995). There has been research about the possibility of mango trees in an agroforestry system in Zimbabwe and the outcome is in some ways positive. Although mango trees on cropland have a negative effect on crop yield, the effect on soil fertility and soil moisture is positive. Mango litter may be used as fertilizer to maintain or enhance soil Carbon and in general for soil amelioration (Musvoto & Campbell 1995; Musvoto, Campbell & Kirchmann 2000). Mango is also common in silvopasture systems. The young trees need to be protected from grazing in the first three to four years but the older ones are beneficial for the cattle. It feeds on fallen fruit and mango leaves, additionally the trees provide shade and shelter (Bally 2006).

In KwaZulu-Natal, commercial agroforestry is not common due to many challenges limiting the profitability, like the shortage of water, expensive fertilizers and a lack of suitable crops (Everson et al. 2011).

Since there has been no research about the possibility of commercial agroforestry on the Maputaland Coastal Plain, it is not possible to advice a specific system or even specific plants. Mango trees may be a part of an agroforestry system but the knowledge about complementary or competitive effects of mango in agroforestry is low.

Another possibility is to use indigenous trees in an agroforestry system. There has been research about the establishment of domesticated indigenous trees (see Chapter 4.4), but the knowledge about the effects of the combined use also is low.
5 Final conclusion

This chapter is divided into the discussion of the hypothesis, the presentation of possible future research topics and the conclusion as summary of the thesis.

5.1 Hypothesis

Eucalyptus plantations may harm the wetlands of the Maputaland Coastal Plain by changing the hydrological regime. There are environmentally friendly and economically comparable alternative land use options.

Although no field measurements were conducted for this work, the hypothesis may be accepted. The literature review shows numerous examples from South Africa and other countries where Eucalyptus and other timber plantations affect the hydrology, the biodiversity and the soil quality of a region. Knowledge gained from these studies could be transferred accordingly to the study area. The sandy soils and the high groundwater table in the Maputaland Coastal Plain intensifies the negative effect on the hydrology and therefore on the wetlands.

However, it has to be kept in mind that the effect of Eucalyptus plantations on wetlands is dependent on the particular wetland type. The ground water-fed wetlands in interdunal depressions are most affected by a lowering of the ground water table. Channelled valley-bottom wetlands which are fed not only by the ground water but also by a surface water inflow may react differently, as the inflow is dependent on the hydrological changes in the entire catchment area. Another reaction may be expected of wetlands developed by perched water above impermeable soil layers.

Chapter 4 shows different alternative land use options. Although none of them may be as profitable as Eucalyptus plantations in the short-term, in the mid-term and long-term their diversified mixture may provide a viable option that may substantially contribute to a healthy social and economic development of Maputaland without harming the environment.

5.2 Gaps of knowledge and future research topics

Future research topics are either connected with the influence of the Eucalyptus plantations on the wetlands or with possible alternative land uses.
The impact of the Eucalyptus plantations on the wetlands of the Maputaland Coastal Plain was only roughly calculated due to inexact and missing data. To improve the calculations, the following data needs to be recorded by measurements:

- Evapotranspiration values of different aged Eucalyptus plantations
- Evapotranspiration values of grassland and woodland
- Rooting depth of different aged Eucalyptus trees

For determining buffer sizes around wetlands, a comparison of the depth of the ground water table under and in the surrounding of a Eucalyptus plantation with the ground water table under natural vegetation should be made. This research could be done like the paired-catchment experiments conducted in South Africa. It may be started with a calibration of piezometric measurements of the ground water table to register the usual fluctuation. After the calibration is finished, a part of the measured area could be afforested with Eucalyptus. Due to constantly measured ground water tables under the afforested and under the non-afforested spot it is possible to determine how large the drawdown is that is only caused by the Eucalyptus plantations. The optimal buffer width for wetlands on the Maputaland Coastal Plain is the width behind which a ground water table change induced by the Eucalyptus plantation no longer may be measured.

Brites & Vermeulen (2013) already measured the change of the ground water in a time span of 17 years under different types of plantation close to lake St. Lucia, but they have not measured the change of ground water in the surroundings of the plantations.

Questions arising in connection with possible alternative land uses are:

- How much is the water use of the horseradish tree on the Maputaland Coastal Plain? Are 6-8 leave harvests per year feasible? May a market for selling products of the horseradish tree be established and what is the economic output?
- Which indigenous fruit tree species has the potential for domestication? What kind of products may be sold? Where do superior trees grow?
- How much is the water consumption of indigenous trees when planted as plantations? How are the growing rates and which trees are preferable?
- Are there (indigenous) trees and crops that can be used together in agroforestry?

5.3 Conclusion

25 years ago plantation forestry was classified as minor land use on the Maputaland Coastal Plain. In 2012, it has changed to the main land use system. The analysis of aerial photographs and satellite imagery shows that within the last decade of the last millennium the substantial expansion of the plantations started. Whereas in 1990 only 204 ha plantations were mapped, the area used
for plantations rose steeply to 2 700 ha, 5 800 ha and 6 800 ha in the years 2000, 2008 and 2011, respectively.

In the same period, a wetland decrease happened (Grundling 2014) and the local population reported a drying out of wells and small streams (personal communication, 2013). A dry period with less than average rainfall (Grundling 2014) and the Eucalyptus plantations are blamed for this negative development.

This study showed that the plantations have a significant impact on the ground water table. Although the increasing plantations are not the only reason affecting the ground water drawdown, their contribution is obviously substantial. Through their deep rooting system they tend to tap the ground water level and use that reservoir for evapotranspiration. As a result, they use more water than comes in through rainfall. The calculations in this study show that roughly, about 10%-20% of the wetlands within the study area are hydrological negatively influenced due to the huge water consumption of the Eucalyptus plantations.

Eucalyptus plantations are praised by industries as the best cash-crop for the local communities in the area. The industry promises that the plantations provide assured significant revenue for farmers that outcompetes income generated from any other alternative land use. However, these statements do not take into account the substantial cost of measures mitigating the direct and indirect damages on the wetlands, environment and the society, e.g. cost of the necessary water supply, deepening of wells, harvest failures, loss of areas for traditional use etc.

Alternative land uses were shown and discussed. Agroforestry as well as the use of indigenous trees are promising possibilities. None of them alone is as profitable as Eucalyptus trees in the short-term. However, they are more adapted to the local ecosystem and may lead into a sustainable development. Ways of improving the efficiency of subsistence farming were also presented. Already in 1993, Watkeys, Mason & Goodman stated that the "development should be directed towards the rationale and sustainable utilization of its (the authors refer to Maputaland) renewable natural resources. It is essential that the ecological impact of any further development is kept to a minimum". This may be reached by “improving subsistence agriculture rather than aiming for First World industrialization”. This statement that corresponds with the common sense should be also the guideline when developing the land use in Maputaland and when assessing the role and future of Eucalyptus plantations there.
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