Evaluating Forest Wood Production and Habitat Protection Functions Under Climate Change

- An example of two stands in the Palatinate Forest, Germany

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by

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Abstract

Climate change is expected to change the way forest develop. This is likely to affect the quality of goods and services offered by forests. Sustainable forest management needs to adapt to climate-induced changes. This requires information concerning the nature of these changes. The main aim of this study was to evaluate forest wood production and habitat protection functions under climate change. At the same time, the appropriateness of existing tools for use in the context of climate change was explored. The growth of trees under future (A1B climate of 2071 to 2100) and current (2001 to 2030) climate scenarios was simulated using SILVA forest growth model for a 30-year period with no thinning. Two 50m x 50m test plots from Merzalben (mixed oak and beech) and Johanniskreuz (pine and beech) were used for the simulation. The study revealed a statistically significant reduction in tree growth under the future climate at 95% confidence interval. The simulated average tree DBH increment under the future climate was 1.53 cm less for the oak trees and 1.50cm less for the pine trees than under the current climate. The reduction in growth was attributed to limited water availability during the vegetation period under future climate.

The future wood production and habitat protection functions in the same test plots under the current (2001 - 2030) and future climate (2070-2100) scenarios were evaluated using an existing evaluation framework currently used in the Rhineland Palatinate. According to the evaluation, there is no change in the suitability of the forest stands for wood production and habitat protection. Although the framework reflects spatial variation well, only a small percentage of the criteria are sensitive to temporal changes.

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Table of contents

List of figures

List of tables

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "the change in climate over time, as a result of natural and human actives that alters the composition of global atmosphere and that is in addition to the natural variability observed over time" (IPCC 2001). This is reflected by regional climate change and changing environmental conditions. World temperatures are expected to increase by 1.8-4.0 °C by the end of the 21st century relative to the temperature of 1980-1999, depending on future greenhouse gas emissions scenario (IPCC 2007).

Change in temperature and rainfall patterns will modify forest growth, the status of the main forest species, and species composition. The magnitude of the change depends on the specific tree species response to the climate factors (Pretzsch & Dursky 2002). Changes in the species composition and forest structure due to climate change will influence the goods and services they provide (Lasch *et al.* 2002).

What will be the nature of the changes brought about by climate change in forests and how will these changes affect the quality of goods and services provided by the forest? The answer to this question is important as forest planning and management needs to prepare for the challenges of adapting to climate change. This study seeks to evaluate wood production and habitat protection in forests under climate change. Wood production depends largely on the growth of trees in forest stands and so modification to tree growth could affect wood production. Forests play an important role in biodiversity conservation by providing habitat for different plant, fungi and animal species. Heterogeneous and complex forest structures are associated with habitat for a wider range of biotic life than homogeneous forest structure (Pommerening 2002). Changes in tree growth due to climate change could result in changes in forest structure and species composition.

This MSc research project is part of the "Transnational Forestry Management Strategies in Response to Regional Climate Change Impacts" (ForeStClim) project. ForeStClim seeks to develop transnational coordinated forestry management, protection and adaptation strategies for forestry in North-West-Europe (ForeStClim 2008). Among other objectives, it aims to secure sustainable timber production and efficient protection of forest ecosystems. This MSc project was carried out in Merzalben, Germany located in the Palatinate Forest. The Palatinate Forest is said to be the largest continuous forest in NW Europe and was designated as a biosphere reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1992 (UNESCO 2007).

1.1. Conceptual Framework

The conceptual diagram in Figure.1 attempts to show the interactions involved in forests and climate change. Gases that are emitted to the atmosphere include carbon dioxide, nitrous oxides and methane. They cause enhanced greenhouse effect which is reflected by increase in temperature and changes in precipitation patterns. This in turn causes changes in forest development and hence the functions they can fulfil.

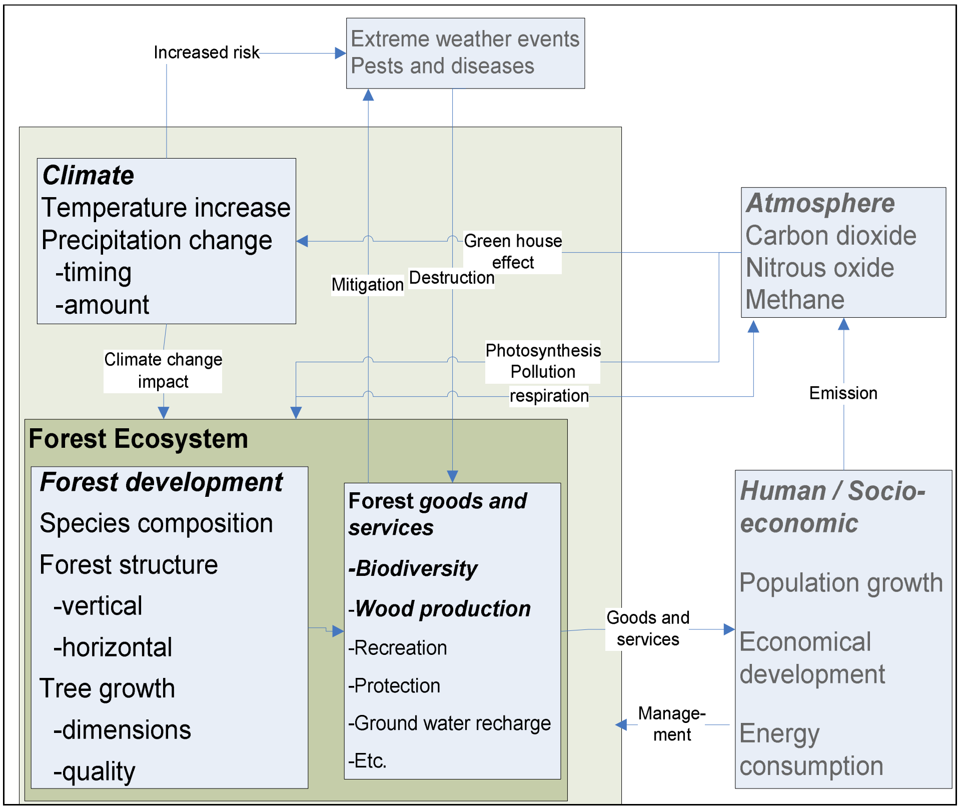

Figure 1. Conceptual framework for the interactions between climate change and forests

1.2. Research Problem and Justification

As effects of climate change in forests continue to show, it becomes increasingly urgent to develop forest management strategies for adaptation to climate change. Estimating forest development under possible future climate could provide information needed for the planning and management.

Forests are generally managed to meet certain objectives and derive certain forest functions. The owners or the communities mostly determine these objectives. However, environmental conditions (e.g. climate, soils, slopes and altitude) also play a major role in determining species that are suitable for a particular location. Previous studies in Finland (Briceño-Elizondo *et al.* 2006; Garcia-Gonzalo *et al.* 2007) have shown that changes in climate will result in changes in growth patterns of species like Norway spruce, Scots pine, silver fir and common beech. The impact of recent climatic changes on the plant development across Europe has shown changes in phenology as a result of an earlier onset of spring (Chmielewski & Rötzer 2001).

Forests provide goods (like wood and non-timber forest products) and services (like habitat and soil protection). With the trend in climate change, these forests will grow under warmer temperature, different precipitation patterns and higher CO_2 concentration. from what they are now (IPCC 2007). This will probably affect forest development, resulting in changes in forest structure and composition and their goods and services provision.

The Palatinate Forest is important for biodiversity conservation. UNESCO officially recognised it as a trans-boundary biosphere reserve in 1998. With the changes in climate, the question is whether the forest will maintain its habitat protection function for biodiversity conservation.

The Palatinate Forest has a wide spectrum of habitats worthy of protection and is important for biodiversity conservation. It is also important for wood production. In view of this, it was seen to be a suitable area to demonstrate how these forest functions (wood production and habitat protection) are evaluated with existing evaluation models.

This research was carried out in the context of the ForeStClim project, using tools that were developed and that are already being used by some partners in the project. This was done as part of the initial work to explore the potential and possible limitations of using these tools in the context on climate change. One of the tools is the Forest Growth Simulator SILVA (Pretzsch *et al.* 2002), developed at the Chair of Forest Yield Science at Technische Universität München for predicting forest growth under different management and environmental conditions. The other tools are the evaluation frameworks for forest wood production and for habitat protection developed by the Impact Planning department of Rhineland Palatinate Landesforsten (RLP). The forest functions that have been evaluated include wood production, forest habitat protection and recreation. The evaluation has been done in the state and community owned forest in Rhineland Palatinate to assess the current state of the forest with respect to the functions. This method of evaluation is so far unique to RLP.

1.3. Research Objective and Questions

Main objective

The main objective was to evaluate forest habitat protection and wood production functions under climate change[1].

Research Questions

To achieve the main objective, the research questions that were asked are

1. Will forest tree growth under future climate be different from forest tree growth under the current climate?

Ho: There is no difference in forest tree growth, specifically increase in diameter at breast height (DBH), under climate change and under the current climate

Ha: Forest tree growth under climate change will be different from forest growth under the current climate

2. To what extent will the evaluation score (based on the current practice) of habitat protection function change under future climate?

3. To what extent will the evaluation score of wood production function change under future climate?

The first research question was addressed using SILVA forest growth model. For the second and third research questions, the existing evaluation frameworks (for wood production and habitat

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[1] Climate change refers to the temperature rise, change in precipitation pattern and length of vegetation period under the IPCC A1B Scenario.

protection) that are used to assess forest functions in RLP will be used. This will help to explore the appropriateness of using these tools in the context of climate change.

1.4. Organisation of the Thesis

Chapter 1
The general background of the study, the conceptual framework, research problem as well as the research objectives and questions are covered in this chapter.

Chapter 2
Literature review on climate change, the effect of climate change on forests, forest functions and forest growth modelling is covered in this chapter.

Chapter 3
The description of the study area and methods used are given in this chapter.

Chapter 4
Results from the model and the evaluation are recorded in this chapter.

Chapter 5
The chapter focuses the limitations of the study the reasons behind results obtained

Chapter 6
This chapter contains the conclusions drawn from the work of this project

2. Literature Review

Climate change and forests are essentially linked in that through photosynthesis forests mostly act as a sink and storage for carbon dioxide, helping to mitigate climate change. At the same time, temperature and rainfall play a major role in vegetation growth and hence change in climate has an effect on tree growth and forest development in terms of structure and composition. With such changes taking place, it becomes important to ask the following question: Will the functions that a forest has remain the same or will they change?

This chapter gives background on climate change and its relationship with forests. Understanding the possible nature and magnitude of climate change to be expected is necessary to in order to estimate the gravity of the possible effects on forests. The relationship between forests and climate change showing why change in climate is an issue in forest development is also reviewed. Forest growth modelling is then looked at to show how future predictions on forest growth under certain conditions can be made. Finally, this chapter looks at the frameworks to be used in evaluating the wood production and habitat protection.

2.1. Climate Change

Climate change is the variation in the mean state of climate or in its variability which continues for extended periods which are typically decades or longer (IPCC 2007; CBD 2009). The earth's climate has changed throughout history due to natural processes such as plate tectonics, volcanism and solar variations. In recent years, increase in temperature has accelerated and this has been attributed to human activities (Reid 2006). The average warming rate over the last 50 years (0.13°C ± 0.03°C) is almost double that for the past 100 years (IPCC 2007). The frequency of extreme weather events (heat spells and floods), melting of ice caps and glaciers, sea level rise and global warming are some observed consequences of climate change which are expected to accelerate, while there is greater uncertainty in the nature of change in rainfall (IPCC 2001).

North Europe is likely to experience higher mean temperatures increases than the global mean (IPCC 2007). While the global increase in temperature was 0.6°C for the period 1901-2000 (IPCC 2001) and 0.74°C for the period 1905-2005 (IPCC 2007) that of Germany was 0.8°C for the period 1906-2005. The average temperature increase of Rhineland Palatinate for 1901-2004 is 0.8°C (LUWG 2007). In 2003 was the warmest summer, in 2006 the warmest autumn and in 2007 the warmest and driest April since the beginning of the systematic meteorological records (LUWG 2007). These new records in a short space of time are an indication that Germany is already experiencing climate change.

2.1.1. Scenarios in Climate Change

Because it is not possible to predict the future anthropogenic green house gas (GHG) emissions, therefore scenarios have been developed as a tool to analyse potential developments in the long range (IPCC 2000). These scenarios are just alternatives of how the future may unfold as opposed to forecasts or predictions. They allow for the consequence of alternative future GHG emissions on the climate and environment to be evaluated. The description of scenarios given in this section is based on the IPCC Special Report on Emissions Scenarios (SRES) (IPCC 2000) and illustrated in Figure 2.

The A1 is a family of scenarios representing a more integrated world, characterised by rapid economic growth with a global population that reaches 9 billion in 2050 and then gradually declines. There is also a quick spread of new and efficient technologies and extensive social and cultural interactions worldwide. There A1 family has subsets based on their technological emphasis. The A1B has a balanced emphasis on all energy sources with estimated temperature rise of 2.8 °C. The A1FI emphasises on fossil fuels and estimate temperature rise of 4.0 °C. A1T emphasises on non-fossil energy sources with a best estimate temperature rise of 2.4 °C.

The A2 scenarios are of a more divided world. They are characterized by a world of independently operating, self-reliant nations. There is continuously increasing population and regionally oriented economic development. Technological changes and improvements to per capita income are slower and more fragmented, estimated temperature rise is 3.4 °C.

The B1 scenarios are of a world more integrated, and more ecologically friendly. The B1 scenarios are characterized by rapid economic growth as in A1, but with rapid changes towards a service and information economy. Population rises to 9 billion in 2050 and then declines as in A1. There are reductions in material intensity and the introduction of clean and resource efficient technologies. Global solutions to economic, social and environmental stability are emphasised. An estimated temperature rise of 1.8 °C is expected.

The B2 scenarios are of a world more divided, but more ecologically friendly. There is continuously increasing population, but at a slower rate than in A2. Emphasis is on local rather than global solutions to economic, social and environmental stability. It is also characterised by intermediate levels of economic development, there is less rapid, and more fragmented technological change than in B1 and A1.

In the ForeStClim project, three scenarios A1B, A2 and B1 were chosen (ForeStClim 2008). In this project, the A1B climate projections from a regional climate model called WETTREG (UBA 2007) will be used.

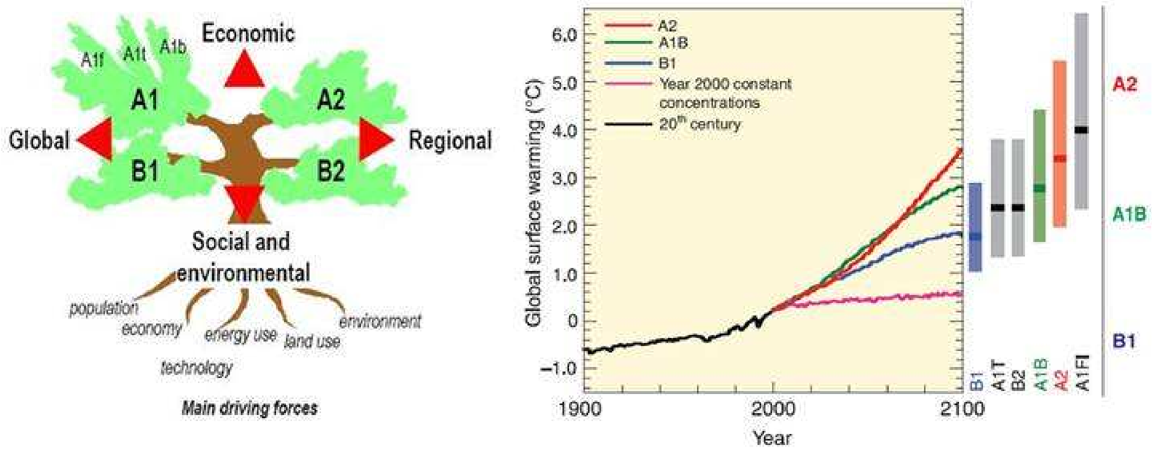

Figure 2. An illustration of the four storylines and Global average surface temperature from the IPCC Special Report on Emission Scenarios (SRES) – Source (IPCC 2000, 2007)

2.1.2. Models for Climate Change

Various climate models are employed in order to study and understand climate change. They are also used to evaluate possible future climate developments. These models refer to different emission scenarios A1family, A2, B1 and B2.

Global climate models (GCM) make simulations for the whole earth. However, they have a coarse resolution that does not represent regional effects well. In order to assess regional climate change aspects, downscaling from the global to regional scale has been done to produce several regional climate models (RCM). Regional climate models simulate defined regions and there are two different methods for downsizing from GCM to RCM, dynamic and statistical. Examples of RCMs used to make regional climate projections in Germany are REMO, which is a dynamic model and WETTREG, a statistical model (UBA 2007). WETTREG is downscaled from ECHAM5/MPI-OM, a global model developed by the Max Planck Institute for Meteorology in Hamburg, for the emission scenarios A1B, A2 and B1. It uses data from meteorological stations with time series of measurements and these are distributed all over Germany.

2.2. Forest Growth Models

Forests take long time to develop and our understanding of forest development under different conditions cannot rely just on forest experimental trials. It would take too long to get all the required results. Moreover, setting up such experiments with all the scenarios at play is expensive. Yet this information is needed to help develop management plans. Modelling is an alternative with lower costs and time.

Growth models comprise a system of equations which allow growth and yield predictions for forest stands under different conditions (Vanclay 1994). Various forest growth model types with different objectives and concepts have been developed simultaneously over time, and not as continuously improvement on former models (Porté & Bartelink 2002; Pretzsch *et al.* 2008). There are therefore many growth models that exist in forestry and they have been classified in different ways.

There are models that use an empirical approach and there are eco-physiological models. Traditionally forest growth models used the more empirical approach. They estimate tree or stand growth using descriptive relationships between environmental conditions and growth. Because of this, their application is limited to places where the empirical relationship is valid (Porté & Bartelink 2002). Eco-physiological models give insight into causal relationships between tree growth and environmental conditions (Pretzsch *et al.* 2008). These models are often demanding in the level of details needed to run them. Examples of eco-physiological models are BALANCE (Grote & Pretzsch 2002), an individual tree based model and 3PGN which is stand level based..

There is also a distinction between deterministic and stochastic growth models. In deterministic growth model, a given set of inputs will always give the same predicted result. Realistically, forests do not grow in exactly the same way but within an expected range due to natural variation in the environment. Stochastic model try to cater for the natural variation by giving different predictions, each having a specific probability of occurrence. Even with the same set of inputs, stochastic models may give different predictions. With stochastic models, a number of estimates are required to give useful information considering variability of predictions (Vanclay 1994).

Models are also classified according to their spatial resolution. There are whole stand, size class and individual tree models. In a whole stand model, the basic units of modeling are stand parameters such as basal area, stocking, stand volume and diameter distribution. They require relatively little information but also yield general information. Size class models have classes of trees as the basic unit for modeling and are a compromise between whole stand and individual tree models (Vanclay 1994). Individual tree models simulate growth for each individual tree in a plot. Gap-models are a special type of individual tree models which define and keep track of individual trees competing and growing in a restricted area, the gap (Porté & Bartelink 2002). Their strength in predicting the dynamics of forest structure (competition and succession) makes them attractive to study the response of forests to climatic change (Norby *et al.* 2001). FORSKA- 2V and BOREALIS are examples of gap models which have been used to simulate forest cover and general species composition under climate change in Canadian forests (Bugmann *et al.* 2001).

Tree growth models consist of diameter and height increment functions that predict the probability of growth. They, also have mortality equations to predict motility of each tree over a given time interval (Hasenauer 2006). Sub models are included to assess competition within a stand.

The following sections give a review on SILVA and BALANCE tree growth models. The effect of climate change on forest development will be investigated using semi-empirical individual tree -based forest model SILVA and a physiological -single-tree model BALANCE.

2.2.1. SILVA Forest Growth Model

SILVA is a semi-empirical individual tree -based forest model. It has been successfully used to show the effect of climate change in forest development and in the growth of particular species in the context of the project “German Forest under Climate Change” (Pretzsch & Dursky 2002). The model was developed by the Technische Universität München, a partner in the ForeSTClim project.

SILVA estimates 5-year diameter and height increment using potential dependent predictions (Pretzsch *et al.* 2002; Chair of Forest Yield Science - Technische Universität München 2008). Forest stands are represented as a mosaic of single trees. The maximum possible diameter and height increment within the model are calculated based on the species and site environmental conditions. SILVA considers the following environmental factors

- annual temperature amplitude (^{o}C),
- length of vegetation period (days with temperature higher than 10^{o}C),
- mean temperature in vegetation period (^{o}C), soil water availability (as coded by German site classification),
- precipitation in vegetation period (mm).
- soil nutrient supply (as coded by German site classification),
- nitrous oxides (NOx) concentration (ppb) and
- atmospheric carbon dioxide (CO_2) concentration (ppm)

Species-specific uni-modal dose-response functions for all environmental factors are aggregated into ecologically significant site variables which determine potential growth curves for each tree species (Pretzsch *et al.* 2002). The potential height and diameter increment are varied with a random error, which has two components. The first one is because there are unpredictable influences on growth at the individual level. The second component accounts for climatic variations between the simulation periods (Chair of Forest Yield Science - Technische Universität München 2008). For each tree, the potential growth is then reduced based on competition situation of that tree (Hasenauer 2006).

The growth and yield data given on stand and tree levels can be used to evaluate the wood production. The information on species abundance, stand structure and ecological indices (species mingling index, diameter differentiation indices and aggregation index) can be used for evaluating the habitat protection. For the purposes of this project SILVA is used, it gives the above outputs, which are used in evaluating the forest functions.

2.2.2. BALANCE

BALANCE is an eco-physiological tree growth model whose primary task is to calculate three-dimensional development of individual trees or forest stands under variable environmental conditions including climate and CO_2 concentration (Rötzer *et al.* 2005). Tree development is described as a response to individual environmental conditions. The model also has a feedback loop whereby environmental conditions are changed with tree development as well. BALANCE calculates dimensional changes annually.

The physiological nature of BALANCE allows it to investigate the effects of complex environmental changes like CO_2 concentration, precipitation, temperature and nitrogen deposition on tree growth (Grote & Pretzsch 2002). This makes it suitable to estimate forest responses to given environmental scenarios. It has mainly been used for scientific purposes by the Chair of Forest Yield at the Technische Universität München. It has been shown to realistically simulate the growth and vitality of forest stands for central European regions (Rötzer *et al.* 2005).

A summary of the main characteristics of the SILVA and BALANCE model are given in Table 1.

Table 1. The main characteristics of SILVA and BALANCE models

	SILVA	**BALANCE**
Input	Tree dimensions Site conditions incl temperature , rainfall, soil nutrients and atmospheric CO_2 concentration	Tree dimensions, site conditions, soil nutrients, daily meteorological data, atmospheric CO_2 concentration
Simulations	Growth Competition Mortality 5 year time step	Resource availability Physiological responses Biomass change Annual 3D development Physiological processes (nutrient uptake, assimilation and respiration)- ten day time step Resource availability (microclimate, water balance, phenology)- daily
Space	Max number of trees = 5000	Stand level (dimensions not given)
Output	Tree and stand information Timber grading / monetary yield Structural analysis Indices for biodiversity	Tree and stand information
Model type	Empirical - single-tree growth simulator	Physiological -single-tree model

2.3. Forests Functions and Climate Change

Forests and climate change are closely linked. Trees, through photosynthesis sequester atmospheric CO_2, one of the main green house gases that cause global warming. On the other hand, temperature and precipitation are among the most important environmental variables that affect tree growth, and therefore changes in climate will influence forest development.

Climate change will generally have a positive impact on forest productivity in northern Europe, when water is not limiting (Boisvenue & Running 2006; Alcamo *et al.* 2007). This is largely attributed to the increases in the rate of photosynthesis due higher temperature and other metabolic processes (up to an optimum), longer vegetation periods and higher CO_2 concentration which increase photosynthetic productivity (Lindner & Cramer 2002).

The changes in forest development because of climate change may influence quality of goods and services provided by the forest ecosystem. Forests which are regenerated today will grow under changing climate conditions, this may change their growth patterns and the composition of the forests (Lasch *et al.* 2002). When this happens, the nature and quality of goods and services they provide are likely to be different as well. In Europe, forest management objectives have generally shifted towards achieving multiple objectives (FAO 2006). The sustainability of goods and service provision by a forest also depend on the management of the ecosystem (Farrell *et al.* 2000). The management of forest ecosystems must therefore consider the influence of climate changes to avoid management practices that are incompatible with the future ecosystem characteristics. The suitability of forests for wood production and habitat protection (for biodiversity conservation) are the main focus of this research and will be considered more closely in sections 2.2.1 and 2.2.2 respectively.

2.3.1. Wood Production under Climate Change

Although there has been a decrease in area that is primarily for wood production, it is still an important aspect of forest management.

A study using climate projections for 2003-2053 predicted increased growth of trees under climate change in Finland (Kärkkäinen *et al.* 2008), meaning faster accumulation of biomass than in the current climate if predicted to enhance wood production. Forests will likely have significantly different yield potential under climate change resulting in the need to change management in terms of rotation periods and species selection (Lindner & Cramer 2002). Timber production is also affected by other factors like markets, which are changing (McCarl *et al.* 2000).

The following can be used as indicators when evaluating the wood production suitability of a forest site:

- Economic indicators – Timber quality
- Tree species and their suitability for timber production
- Dimension data – volume, height, diameter at breast height

The Landesforsten Rheinland-Pfalz (RLP) has evaluated the wood production, habitat suitability and recreation functions for the current state of the forest. The list of indicators and the method for evaluating the wood production function is shown in Table 2 (Section 2.4.1). The same criteria and indicators they used will be adopted for this study.

2.3.2. Biodiversity and Forest Habitat Function

Biodiversity is the variety of living organisms within species, among species and among the ecological processes that connect them (Vermeulen & Koziell 2003) . The variety encompasses numbers and variety of entities (composition), the evenness and physical organisation of their distribution (structure) and the variety in the ecological processes in the system (functional) (Hooper *et al.* 2005).

Forests provide habitat for a wide variety of live forms, most of which depend on each other for some or part of their life cycles. A forest is said to be sustainably used, when it maintains its environmental services provision and biological quality (Larsson 2001).

Forest biodiversity has already been affected by climate change as seen in shifts in species' ranges and ecosystem boundaries, changes in phenology and in species interactions (predation, pollination, competition and disease) (Reid 2006). In Germany, species are shifting increasingly to the north or higher altitudes with heat loving species migrate along the Rhine valley from the south (LUWG 2007). The phenology of migration and breeding is also changing (LUWG 2007). These changes may result in loss of synchronisation thereby threatening the wellbeing of interdependent species. There will often be winners and losers in the process making it difficult to objectively evaluate the impacts of climate change in forest landscapes on biodiversity in general.

As climate change continues, species may respond differently depending on their ecological requirements and attributes because there is no "one optimum climate for all" species (Watts *et al.* 2005). This may change the composition and structure of forests under climate change. Could it be that the value of a particular forest stand as "habitat protection" is enhanced or reduced when these changes take place?

With climate change, the frequency of extreme events is expected to increase (IPCC 2007). Climate change will also cause secondary effects like increased risk of pests and diseases, wildfires in forest. These are expected to have more direct but localised effects on biodiversity than the changes that result as a gradual increase in temperature and changes in precipitation patterns (Lindner & Cramer 2002; Reid 2006). What is known about these abrupt events is that they will increase in frequency, there is not much detail yet, and so they will not be considered as part of the evaluation.

2.4. Evaluating the Forest Functions

Forests protect habitats and biomes and this helps to maintain biodiversity. The most accurate way to evaluate biodiversity would be quantify the whole range of the biodiversity in forests. This is not possible because it is overly demanding. Variables which act as surrogates of biodiversity, such as species richness, composition and structural diversity are often used to evaluate forest biodiversity (Larsson 2001).

Indicator species are focal species selected to represent the wider elements of the woodland community and key ecological processes (Watts *et al.* 2005). They are one of the ways used to assess biodiversity. Another way to evaluate forest biodiversity is by using structural indices. These consider differences in vertical and horizontal spatial arrangement, size and age of different species in an area. Previous studies (McElhinny *et al.* 2005; Pommerening 2006) have shown spatial forest structure can be used as indicators of biological diversity. Heterogeneous and complex forest structure is associated with habitat for a larger variety of species and greater ecological stability (Pommerening 2002).

Evaluation tools exist at a range of scales, the habitat/forest stand scale to guide management at an operational level and at larger landscape scales to direct strategic planning and policy making. Policy makers and land managers are increasingly required to take decisions regarding biodiversity at the larger forest and landscape scale although they are hard to predict (Watts *et al.* 2005).

The evaluation is based on a set of criteria and indicators, developed by the Impact Planning department RLP.

2.4.1. Multi Criteria Evaluation

The following section on Multi Criteria Evaluation (MCE) is based mainly on the review of Voogd (1983), and on the discussion held in a meeting held with the Impact Planning department (RLP) team in Koblenz, Germany on 13 January 2009.

MCE compares alternatives based on a number of explicitly formulated criteria. These criteria are measured through indicators that reflect the nature of the criteria. The units of the indicators may vary, and they are made comparable through methods of standardization. MCE methods offer the allocation of weights to assessment criteria in order to prioritize criteria. Different aggregation methods aggregate partial performance of alternatives to give an overall ranking.

Multi-criteria decision methods have a wide range of applications. These include analysis of the spatial system, to select options from a predefined set of alternatives, account for proposed line of action and to test the likely appropriateness of a certain policy.

In this project, MCE will be used for analytical purpose. The Impact Planning department Rhineland Palatinate Landesforsten developed criteria and indicators for evaluating wood production, habitat protection in forests and recreation in Rhineland Palatinate. These are currently being used to evaluate the status of state and community owned forests. Maps are produced based on the assessment score for each of the functions in each forest stand. Feedback is then given that can be used for planning by forest owners and managers. Table 2 a and b below show the criteria and objectives used in the evaluation.

Table 2. The objectives, criteria and indicators used to evaluate (a) wood production and (b) habitat protection by the Impact Planning department (RLP)

Objective	**Criteria**	**Indicators**	**Unit**
High production level (20)	Revenue (100)	Profit Margin ≥ €12 (now €50) based on tree species, DBH and if or not passable with machines	Net profit €
High development potential (50)	Potential value (50)	Wood product ion target	0(no use) to 4 (high value)
	Level of Stand damage/health (25)	Intensity of peeling damage Intensity of splitter damage	percentage of damaged trees
	Site productivity (25)	Water supply- coded from 1=extremely dry, to 12 =wet	Coded 1=extremely dry, to 12 = wet (water balance prediction- WETTREG model used)
		Nutrient Supply – soil nutrient supply	coded from 1=rich (eutrophic) to 6= very poor and 9(calcareous)
Low risk factor (30)	Stability (50)	Proportion of trees suitable for the site	% of trees suitable to the area
	Stratification (50)	Number of layers	Number of layers

(2b) Criteria and indicators for habitat protection

Objective	**Criteria**	**Indicators**	**Unit**
Closeness to nature (40)	Naturalness of the forest plot (100)	Proportion of natural trees – natural to that particular soil type and conditions of the area	% of natural trees
Structural diversity (30)	Spatial structure (50)	stratification - number of layers	Index 1(even) to 5(multi-layered)
		step range - Number of steps with height difference more than 8 m	Index 0 (<20% of the area in the stand with 8m difference in height) to 3 (>60%)
		tree species diversity - proportion of main tree species	Percentage of area covered by dominant tree.
		mixed tree species number - number of tree species covering ≥ 5% of the total area	Number of tree species
		number of tree species - Total number of tree species	Number of tree species
		Age diversity -number of age groups – covering ≥ 5% of total area	Number of age groups
		Mosaics diversity -Distribution of tree species measured using	index from 1.0 (homogeneous) to 3.0 (clustered)
	Habitat features – (50)	Stocking - measure of stock density depends on intervention and tree species Heavy wooden share water supply – coded from 1=extremely dry, to 12 = wet nutrient supply – coded from 1to9	stock density
	Special structures (40)	Dead wood - volume of dead wood	0 (no dead wood) to 3 (> 3cm^3/ha lying and standing)
		Location diversity –area covered by substrate series of rare occurrence	% area covered
		Special local structures - Occurrence of special structures in the stand like spring, ditch, brook, lake, tarn, rocks, cave, and grassland.	yes or no
Protection of rare biotopes and species- (30)	Biotopes of the LUWG* (50) Protected areas (50)	Biotope – Number of biotopes / habitat types protected (NSG, NWR, Nuclear Biosphere reserve zones)	Number of biotopes / habitat types % area classified

2.5. Adaption of forest management to climate change

Since climate change may have great impacts on forests, there is a strong demand for reliable recommendations, such as how to adapt forest management to mitigate adverse effects of the projected climate changes (Lindner *et al.* 2000). Management decisions in forestry are associated with long time frames, therefore, decisions need to be made early to achieve sustainability in the future.

Adaptive forest management will provide a meticulous and structured approach as a basis of learning from the outcome of evaluation of the forest habitat function in the face of change (D'Eon 2008). It involves the continual learning process "that cannot be conveniently separated into functions like 'research' and 'ongoing regulatory activities', and probably never converge to a state of blissful equilibrium involving full knowledge and optimum productivity" (Walters 1986). Learning is linked with policy and implementation and it is a good strategy where uncertainty is high (Stankey *et al.* 2005). As an example, if evaluation reveals that habitat of an important species is threatened by climate change, adaptive management could involve identifying biological corridors for dispersal, sites to introduce the species and areas that need protection (Thuiller 2007). This highlights the importance of exploring the possible future forest conditions and finding strategies to adapt management for future needs.

The thinking is that the measures that would be taken in response to climate change would be "no regret" measures that bring benefits even if the expected changes were not to come (Smith et al 1996).

3. Materials and Methods

This chapter outlines the methods used in this thesis. A description of the study area is followed by an overview of the steps taken in this research. The third sub section shows the SILVA growth model was used to simulate forest growth to determine if forest growth under climate change would be different from under the current climate. Finally, the forth subsection outlines an evaluation which was done to determine whether climate change influences the value of forests for habitat protection and wood production.

3.1. Study area

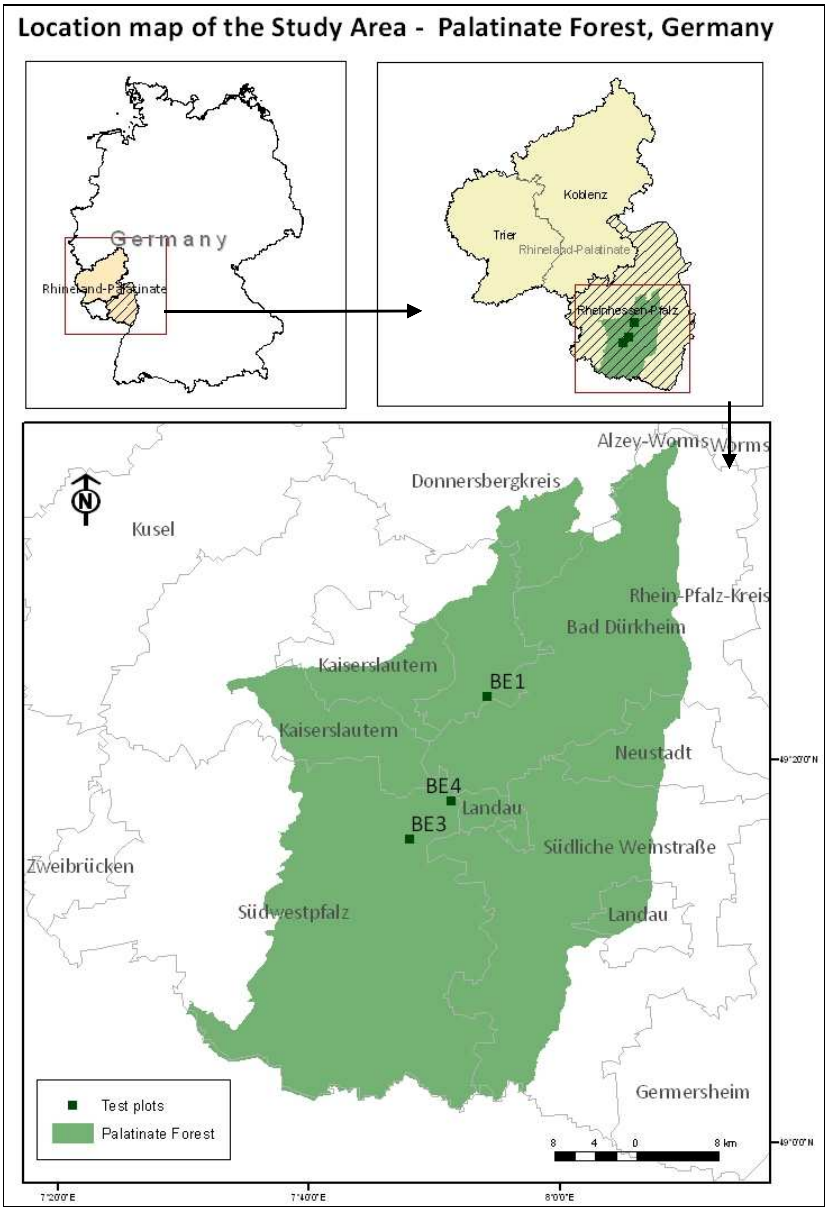

Figure 3. Location map of the study area, Palatinate forest , SW Germany

The ForeStClim project involves countries in NW Europe, and the Palatinate forest was chosen due to its value as a nature conservation forest as well as its importance for sustainable wood production. The location of the study area is shown in Figure 3.

3.1.1. Description of study area - The Rhineland Palatinate forest

The Palatinate Forest (German: Pfälzerwald) is located in the south of Rhineland Palatinate which is one of the 16 German federal states located in the South-west of the country. It is in a low-mountain region located from 49°02' to 49°37' N; 7°30' to 8°09' E and extending southwards to Northern France. The Palatinate Forest is one of the largest continuous forests in NW Europe covering 1,798 km², 75% of which is forest (Umweltbundesamt 2009). It has a wide variety of habitats and is important for biodiversity conservation. Because of its ecological importance, the Palatinate forest was declared a biosphere reserve[2] by United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1992 (UNESCO 2007) and chosen by the Environmental Specimen Bank in Germany as an example of a forestry ecosystem in a low mountain region in 2001 (Umweltbundesamt 2009).

Germany falls under warm temperate climate with mild winters and summers (LUWG 2007). The climatic conditions across the Rhineland-Palatinate vary considerably. The original tree species composition of the Palatinate forest is predominantly oak and beech but pine and spruce have increased in the last 150 years due to economic reasons (Umweltbundesamt 2009). Soils are generally nutrient poor sands derived from red bed sandstones and limestones (Behrens *et al.* 2006).

Existing level II[3] test plots located in Merzalben and Johanniskreuz areas in the Palatinate forest were used in this study. Test plots BE3, a mixed *Quercus petraea* (Sessile oak) and *Fagus sylvatica* (Common beech) and BE4 mixed *Pinus sylvestris* (Scots pine) with *Fagus sylvatica* (Common beech) were used to demonstrate how the effect of climate change on forests can be evaluated.

3.2. Research Approach

The research involved in two main stages. Firstly, forest growth under current and future climate was simulated over 30 years, to find out if tree growth would be significantly different between the two scenarios. This was followed by an assessment of wood production and biotope / habitat protection functions of the forest using an existing framework. The results from the simulation provided some of the input for the evaluation. The results were compared to the assessment score for current evaluation for the wood production and biotope / habitat protection functions.

Field work was carried out in forest stands that are managed by the Research Institute for Forest Ecology and Forestry Germany (FAWF). It involved establishing test plot boundaries, taking tree locations and DBH measurements. In one of the test plots, crown radii and height measurements were taken. The plots in which the measurements were taken during fieldwork were eventually not used in the simulations. This is because heights and crown measurements could not be completed since the

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[2] Biosphere reserves are international conservation designation established to promote and demonstrate a balanced relationship between humans and the biosphere (UNESCO 1995).

[3] Level II test plots are plots that were established for intensive monitoring of forests under the European Union initiative for monitoring the effect on pollution on forests.

trees still had leaves during the time of fieldwork. With leaves on trees, it is difficult to see the top of the tree and the boundary of each tree crown, which should be visible when taking height and crown measurements respectively. The height and crown measurement could not be completed in time for the data to be used in this project. Data from existing test plots were used and the data collection procedures are similar. It is therefore still relevant in that it shows describes how the data used were collected.

An overview of the methods used in this research is given in Figure 4.

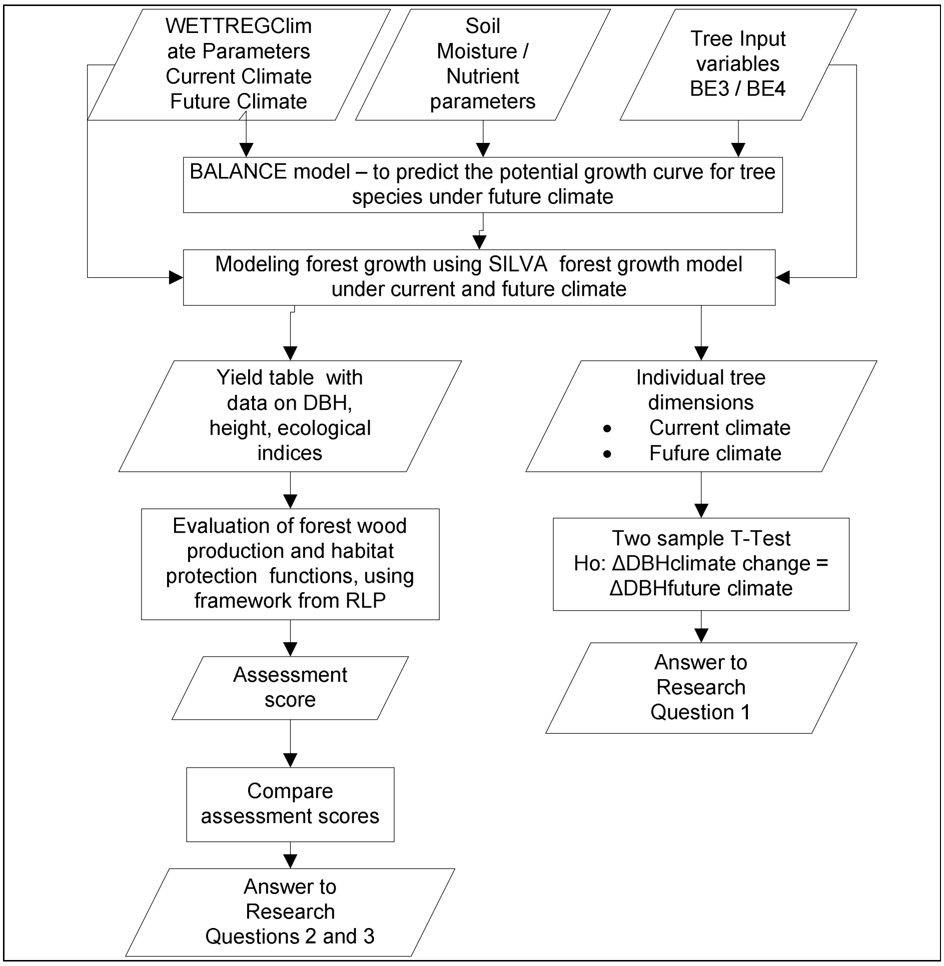

Figure 4. An overview of the methods used to in this thesis. DBH = Diameter at breast height,

Δ= increase / change in 30 years.

3.2.1. Field data collection – Obtaining data needed in the SILVA model

This section describes how tree measurements that are needed to initialise the SILVA model, were taken.

Tree diameters were measured at 130 cm above the ground to give the diameter at breast height (DBH). A tree diameter tape, which measures length in metric units (metres, cm and mm) on one side and the diameter corresponding to the circumference on the other, was used. To take the measurement, the tape is wrapped around the stem perpendicular to the stem axis. The metric side of the DBH tape displays the circumference, while the diameter side displays the DBH value which obtained by dividing that particular circumference by pi (3.14).

Height measurements were taken using a Vertex Hypsometer shown in Figure 5a, which comprises a transponder and the hand unit that uses sonic pulses to determine range from the tree. The hand unit contains an angle-reading device and a computer chip to calculate height above the transponder. The transponder is attached to a tree at breast height (1.3m above the ground) then measurements are taken from a spot where the transponder and the top of the tree are visible. The measurement is taken by looking through the hypsometer and aiming the red beam at the transponder then holding a red button until the cross disappears. The distance, angle and horizontal distance to the transponder are recorded. Next is to point at the treetop and press the red buttons, the tree height will instantly show.

Due to the presence of leaves on trees, crown radii measurements were taken also only for the test plots without broadleaves (Douglas fir test plot). The leaves on the trees to see where the crown end since there was overlap of the crown area. Crown radii were measured in eight directions, every 45^0 starting with 0^0 using a crown mirror, which is shown in Figure 5b.

a)Vertex Hypsometer transponder (left) and the hand unit

b)crown mirror for measuring crown radii

Figure 5. The Vertex hypsometer used to measure tree height, and a crown mirror that was used to measure crown diameter

3.3. Data Processing and Analysis

SILVA growth model was used to simulate the growth of trees in the mixed oak and beech (BE3) as well as mixed pine and beech (BE4) test plots. The accuracy of the SILVA predicted tree growth was first validated using past measurement data for the same plots as shown in 3.3.1.

However, for simulating growth under future climate, BALANCE model was to be used to derive the potential growth curves for the species in the test plots (Section 3.3.3). This was necessary because for SILVA, being an empirical model, the process of parameterising the model for site-specific growth and DBH increment under future climate has not yet been completed. BALANCE was used because as an eco-physiological model, it is able to simulate growth based species requirements and the growing conditions (e.g. soil, climate and terrain) (Porté & Bartelink 2002).

Below is an explanation of how the some terms were used in the context of this thesis, they were adopted from Vanclay (1994)

DBH- is diameter at breast height (1.3 m) over bark.

DBH increment – increase in the diameter at breast height.

Growth - the change in tree dimensions

Stand - SILVA refers to the area of forest that is being simulated as a stand. A stand is also defined as a group of trees having sufficient uniformity in composition and spatial arrangement to constitute a silvicultural entity or sampling unit
Test plot – The actual sample plots where the measurements used in this project were taken (BE3 – mixed oak and beech) and BE4 (mixed pine and beech)

3.3.1. Validation of SILVA model

A validation exercise was done to establish the accuracy of SILVA in predicting diameter and height increment in the two test plots BE3 and BE4. SILVA was initialised using tree measurement data from 1988 for the BE3 and 1985 for BE4which are the earliest measurement data available for the test plots. Tree measurement variables and soil parameters were taken and provided by FAWF RLP.

The tree measurements were initially only taken for the main tree species, oak for BE3 and pine for BE4. In 2005, measurements were not taken for all the tree species in the test plots. It was important to run the validation with all species present in order to show realistic interactions among the trees. The beech trees had to be included as part of the initial tree inputs data in the validation. These input values for the beech trees were estimated based on the 2005 measurements. This was done using trial and error simulations in SILVA.

The climate input data were also provided by FAWF and are the mean for the period 1971 to 2000 as calculated by the Potsdam Institute for Climate Impact Research in the framework of another project (IFOM) and they are shown in Table 3 below.

Table 3. Site conditions for test plots BE3 and BE4. These are the soil and climate conditions during the time of forest development. They are the same values in the SILVA simulation for the validation

	Soil Moistness (1-9)	Soil nutrient supply (1-5)	Vegetation period (Days)	Annual temp amplitude (^{O}C)	Temp in veg. period (^{O}C)	Precipitation veg. period (mm)
BE3	5	2	148	19.1	14.3	423
BE4	4	1	148	19.1	15.1	389

The model was run for a total of 20 years (5 periods) with 10 runs for each stand to account for the stochastic nature of the SILVA DBH and height increment as well as the mortality equations. In BE3, the initial measurements were taken in 1988, while the last measurements for the test plot were taken in 2005. However SILVA simulations have a time step of five years and so the simulations for BE3 was run from 1988 to 2008. For the validation, the simulation results had to be compared with the 2005 measured results. A new set of values were obtained by calculating an average of the 2003 and 2008 results. This set was used to represent the simulated 2005 results. A two-sample t-test in SPSS software was used to compare the measured with these “2005” simulated DBH and heights.

For BE4 ten simulation runs were done for a period of twenty years, from 1985 to 2005. The results from the ten simulation runs were averaged then compared with the measured values. A Two-sample T-Test in SPSS software was used to compare the simulated DBH and height with the measured values from 2005.

3.3.1.1. Two-sample t significance test

The Two sample t significance test is usually used to compare responses from two independent groups (Moore *et al.* 2007). To validate SILVA simulations for the test plots BE3 and BE4, tree measurements from 1988 and 1985 respectively, were used as input variable in a 20 year simulation forest growth. The results from the simulation were compared to those from the actual measurements taken in 2005. In this case, only the mean DBH and height for the test plots and not the individual trees could be compared. The following hypothesis was tested

Ho: mean DBH of trees from actual 2005 measurements = mean DBH of trees as simulated by SILVA and
Ha: mean DBH of trees from actual 2005 measurements ≠ mean DBH of trees as simulated by SILVA
The Two-sample t-test was compute

$$t = \frac{\bar{x}_1 - \overline{x_2}}{\sqrt{\frac{s_1}{n_1} + \frac{s_2}{n_2}}}$$

Where

$\bar{x}_1$ = mean measured DBH for the trees in each test plot

$\bar{x}_2$ = mean simulated DBH for the trees in each test plot
s_1 = standard deviation measured DBH for the trees in each test plot
s_2 = standard deviation simulated DBH for the trees in each test plot
n_1 = sample size measured trees
n_2 = sample size simulated trees

3.3.2. SILVA Simulation for Future Forest Development in Test Plots

SILVA was initialised using mensuration data from 2005 for the BE3 and BE4 test plots. These 2005 data provided by FAWF RLP are the latest available data for the stands. The SILVA simulation forest stands were generated using average measurement values as shown in Table 4, individual tree coordinates were not available[4]. The stands were generated using the STRUGEN sub-model. The STRUGEN sub-model generates tree positions using stand structure descriptions (such random, regular or clustered) and the tree density (N/ha) when coordinates are not available. Figure 5 shows the initial structure of the test plots in the simulation.

Growth of trees in the test plots was simulated under two climate scenarios:

1. Current climate scenario - Climate data from WETTREG regional climate model for the A1B emission scenario (Section 2.1.1) for the period 2001-2030 were used in the simulations for the current climate scenario. This will be referred to as the "current climate scenario"
2. Future climate – The climate of 2071 – 2100 as projected for the A1B emission scenario by the WETTREG climate change scenario were used for this scenario. This will be referred to as the "future climate scenario"

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[4] Silva can be initialised by individual tree data when the coordinates of the trees are known. Alternatively SILVA can be initialised using average values for tree height, diameter at breast height, age and tree density.

No thinning regime was applied in all the simulations. Natural mortality was active and the identification of removal trees was uniformly set to zero. Therefore, all tree removals were due to natural mortality. Only the remaining trees and no dead trees were considered for growth calculations.

Table 4. Initial values of tree variables (the same values used for Current Climate and Future Climate Simulations)

Test Plot	Tree Species	DBH cm	Max DBH cm	Height m	Age	N/ha
BE3	Oak	44.8	61.2	30.7	201	148
	Beech	12.9	25.9	14.9	96	692
BE4	Pine	42.5	59.2	25.5	129	200
	Beech	24.7	40.2	16.1	56	212
	Larch	38.4	42.2	27.8	60	4
	Douglas Fir	7.1	7.9	3.8	12	4

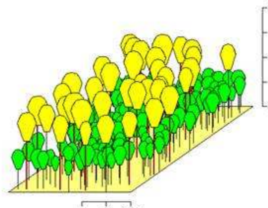
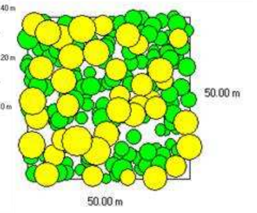
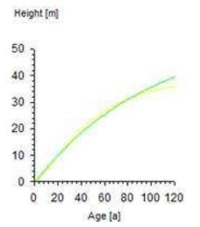
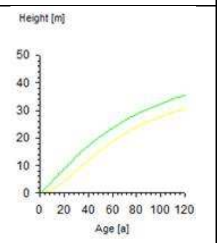
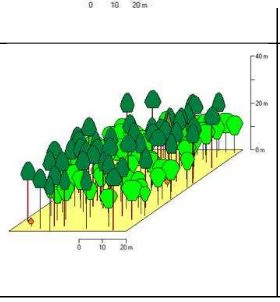
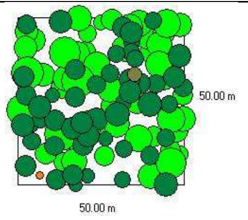
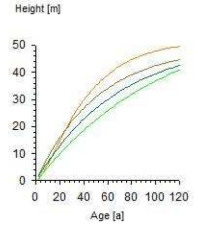
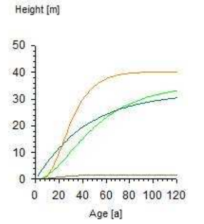
Test Plot	Test plot overview	Initial Crown Plot	Potential height growth	
			Current	Future
BE3 🟨 Oak 🟩 Beech				
BE4 ■ Pine 🟩 Beech 🟧 Douglas fir 🟫 Larch				

Figure 6. The initial structure generated by the Structure Generator sub-model "STRUGEN" in SILVA.

3.3.3. Parameters for SILVA Simulation

SILVA was parameterised using empirical data from trial plots from different areas including the Rhineland-Palatinate (Chair of Forest Yield Science - Technische Universität München 2008) . These data were used to define the SILVA model functions like the site-specific growth potential and diameter increment. However, the trial plots developed under past climate. Trees are expected to grow differently under future climate because of the different temperatures and precipitation patterns as well as increased CO_2 concentration.

SILVA uses a single average values for the climate parameters for a whole 5-year simulation period. The parameters considered are CO2 concentration, length of vegetation period, annual temperature amplitude, mean temperature in vegetation period and total precipitation during vegetation period.

The problem is that climate conditions from the past and those from the future may have the same average temperature and precipitation values, but different distribution patterns, which result in changed tree growth responses. These growth responses have not yet been parameterised for in SILVA.

To deal with this problem BALANCE, a physiological tree growth model, was used to predict the growth responses of tree species under the two climate scenarios. Tree measurement s from test plots BE3 and BE4 were used as input variables in BALANCE. Climate projections for A1B scenario from WETTREG for the years 2001- 2030 were used as current climate parameters and those of 2071-2100 as the future climate parameters. Table 5 shows a summary of the climate parameters that were used and Table 6 shows the soil conditions. The result was a set growth potential curves for the tree species in each plot. Rather than re-calculating the growth curves and programming them in SILVA, existing SILVA growth curves were matched with those derived from BALANCE. This created an ill posed inverse problem. Well posed problems are those whereby a solution exists, the solution is unique and the solution depends continuously on the data, in some reasonable topology (Tikhonov 2001). If any of these conditions are violated, a problem becomes ill posed. The potential growth curves derived from BALANCE do not have a unique combination of parameters in SILVA that match each of them, this means it is ill posed. The Technische Universität München (developers of the SILVA and BALANCE models) identified and provided one a set of parameters for each test plot. The set of new parameters values was used in simulation growth of trees in the test plots for this project.

Table 5. WETTREG projections for climate conditions under A1B scenario for 2001-2030, 2031-2060 and 2071-2100 for the Weinbiet Meteorological Station (The data was provided by Technische Universität München – Jan 2009)

	2001-2030	***2031-2060***	**2071-2100**
Precipitation mm	621	*631*	601
Temperature ^{0}C	8.3	*9.5*	10.7
Temperature (vegetation period) ^{0}C	15.2	*16.0*	16.8
Vegetation period (days)	156.8	*173.3*	188.8
Precipitation (vegetation period) ^{0}C	270	*266*	219
Temperature amplitude (month) ^{0}C	19.2	*18.4*	16.7
CO$_2$ concentration ppm	380		600

Table 6. Soil conditions in BE3 and BE4, they are the same in both test plots (Source: Technische Universität München, December 2008)

Depth in cm	Field Capacity in vol %	Wilting point in vol%
6	39.5	15.5
25	33.5	11.5
55	24.5	7
100	23.5	7

3.3.3.1. Influence of Climate Change Parameters on Forest Growth

Forest development in each test plot was simulated for a total of 30 years (6 periods of 5 years). There were 10 replicates to account for the stochastic nature in the SILVA equations for DBH and height increment. The stochasticity represents the unpredictable biological influences at individual tree growth level (Section 2.2.1)

For each of the simulation runs, results for the remaining individual trees in the final period, the 30th year, were extracted and pooled into one spreadsheet for each test plot. The two sample t-test was used to compare the DBH and height increments from the current and future climate scenarios. DBH and height values from 10 runs of each scenario for test plots BE3 and BE4 were averaged at each of the 5-year intervals. The averaged values were used to make graphs that show the trend in DBH and height for each scenario.

Individual parameters were examined to see how much they influence and which parameter has the greatest effect on the predicted tree growth in the SILVA simulation. This was done through a series of SILVA simulations which were run using the actual climate parameters (and not re-parameterised) for the current climate scenario. In each simulation run, only one of the five parameters (at a time) was replaced by that of the future climate. The parameters that were considered are CO_2 concentration, number of vegetation days, annual temperature amplitude, and mean temperature and precipitation in the vegetation period.

3.4. Evaluation of Forest Functions

The evaluation of future wood production and habitat protection suitability for the forest under current and future climate was based on criteria and indicators used in Rhineland Palatinate. Some of the indicators were taken from the SILVA simulation results. For those indicators that could not be obtained from SILVA, literature was used to estimate the future value under current and future climate scenarios.

3.4.1. Linking SILVA output with Evaluation

In order to allocate values to indicators in the evaluation framework the relevant SILVA outputs for the indicators were identified. Where possible the values from the SILVA simulation output were used to represent the future value of the indicator after 30 years of forest development under the current and future climate as predicted by SILVA. The steps taken to match SILVA results with the evaluation framework are shown in Table 7 below.

Table 7. The steps followed in linking the evaluation framework indicators with the output from SILVA and in allocating a score for the indicators in the wood production and habitat protection functions

Can SILVA provide input(s) to the value for the indicator?	YES →	Which variables from SILVA can be used in calculating the value for this indicator?
↓ NO		↓ Calculating the value for the indicator
Is there a variable from SILVA that is closely related to and can be used in place of an indicator?	YES →	Standardise it with / to the current framework ↓
↓ NO		Use it to calculate the value for the indicator
Is there information that indicates that the value is enhanced or reduced under climate change?	YES →	Consider this information to determine whether the value for the indicator declines or goes up. ↓
↓ NO		Calculating the value for the indicator
↓ The value for the indicator remains the same as the existing current value.		

The process of linking the indicators in RLP evaluation framework with predicted future values was concluded by allocating a score of 1 (bad), 2 (medium) or 3 to each indicators. The details of the score allocation are shown in the table given in Appendices 2 and 3. The scores that were allocated were used in multi criteria evaluation of the wood production and habitat protection functions in the two plots.

3.4.2. Multi-criteria Evaluation

Evaluation is the process of giving value judgement to a situation (Voogd 1983). Multi-criteria evaluation methods investigate a number of choice possibilities. These choice possibilities are alternatives that should to be compared, in the case of this project are the stand development simulated under two climate scenarios, current and future. In MCE, alternatives are compared based on many criteria. This evaluation can be represented as a matrix with alternatives in one of the dimensions and criteria on the other. A criterion score, which reflects the degree to which an alternative meets a particular criterion, is allocated in the matrix.

It is necessary to transform the scores into one measurement unit through a process called standardisation. In the RLP framework, the criterion scores are entered in a “standardised” format of an ordinal scale whereby 1 is a bad score, 2 is medium and 3 is a good score. Once the criterion score are standardised, the priorities attached to the various criteria have to be defined. These priorities can be expressed quantitatively as weights, or they can be expressed by ordinal expressions that reflect the priorities given to the criteria. Appendix 1 shows the weights allocated to the wood production and habitat protection evaluation criteria.

Once the criterion scores and weights have been allocated the final assessment score can be calculated. Definite (decisions on a finite set of alternatives) decision support software developed by the Institute of Environmental studies in the Vrije University of Amsterdam was used for this procedure. The following section describes how the evaluation was done

3.4.2.1. The Evaluation Procedure in Definite

In the problem definition, the current and future climate scenarios that were used in the SILVA simulation defined the alternatives. For the habitat protection, the three main criteria, referred to as “effects groups” were Closeness to nature, structural diversity and rareness. For wood production, they were grouped into production level, development potential and risk factor.

All the effects were considered as benefits because their values had been classified as already defined in the evaluation framework Table 14 (Section 4.2.1) as:

Bad = 1
Medium = 2 and
Good = 3

In order to rank the alternatives, current and future climate, the Multi-criteria analysis module of Definite was used. The software uses standardised values between zero and one, so the criterion scores were standardised to values between zero and one. For most of the effects, the goal standardisation with a minimum of “0” and a maximum of “3” was used. For those that were measured using ecological indices, the goal function was used with the minimum and maximum values represented by the index minimum and maximum. Weights were allocated according to percentages given in the existing framework (Appendix 1). The alternatives were ranked to show assessment scores for each of them, from 0 (bad) to 1 (good). The scores were multiplied by 3 to match the existing scale (of 1 to 3) used in the RLP framework. Finally, the assessment score was allocated to one of five classes defined as

< 1.40 = 1 (not suitable)
1.41 - 1.80 = 2
1.81 - 2.20 = 3
2.21 - 2.60 = 4
2.61 - 3.00 = 5 (very suitable)

The two alternatives (current climate and future climate) were compared based on the class allocated to their assessment score. The habitat protection and wood production functions under climate change under climate change were evaluated based on this comparison.

4. Results

This chapter shows the results of simulating forest growth model, and those from the evaluation of the forest wood production and habitat protection functions.

4.1. Validation of the SILVA Model

4.1.1.

A summary of the validation results is shown in Table 8 below. On average, the DBH from the simulation was 1.5 cm bigger than the measured DBH for the Oak trees in the test plot BE3. The average height from the simulation is 0.4 m shorter than the measured height. The number of remaining trees is understated in the simulation for both the oak by 8% and the beech by 19 % in BE3. For BE4 the simulated pine trees DHB is on average 0.31 cm less than the measured. The simulated height is 6.11 m higher than the measured height. The number of remaining pine trees is overstated by 28 % in the simulation while that of the beech trees is 49.5 % less than the observed value.

Table 8 Averages of measured and simulated tree DBH and heights

		DBH cm	**Height m**	**Number**
BE3	Oak 1988 – Measured	40.06	27.24	51
	Oak 2005 - Measured	44.8	30.69	37
	Oak 2005 Simulated	46.27	30.29	34
	Measured Growth 1988-2005	*4.74*	*3.45*	*-14*
	Predicted Growth 1988-2005	*6.21*	*3.05*	*-17*
	Difference (Simulated-measured)	*1.47*	*-0.4*	*-3*
BE4	Pine 1985 – Measured	37.5	26.39	71
	Pine 2005 – Measured	42.51	25.51	50
	Pine 2005 Simulated	*42.20*	*31.62*	*64*
	Measured Growth 1985-2005	*5.01*	*-0.89*	*-21*
	Predicted Growth 1988-2005	*4.70*	*5.23*	*-7*
	Difference (Simulated-measured)	*-0.31*	*6.11*	*14*

4.1.2. Validation Results for BE3 Stand

The Levene's test for equality of variances shows that the simulated and measured DBH values have the have equal variances. The t-test shows that the simulated DBH is not different from the measured DBH as shown in Table 9.

The significance value of the T-test is 0.005. The simulated height is statistically different from the measured height. The standard deviation for the height is however very low (1.16 m simulated and 1.4 m measured)

Table 9 Results from the two sample t-test for DBH and height increment in BE3

		Levene's Test for Equality of Variances.		T	Significance value. (2-tailed)	95% Confidence Interval of the Difference	
		F	Sig			Lower	Upper
DBH cm 2005	Equal variances assumed	0.636	0.428	-0.001	0.999	-3.368	3.364
	Equal variances not assumed			-0.001	0.999	-3.369	3.365
Height m 2005	Equal variances assumed	4.506	0.038	-2.894	0.005	-1.585	-0.291
	Equal variances not assumed			-2.953	0.004	-1.573	-0.304

4.1.3. Validation Results for BE4 Stand

The two sample t-test showed a t value of -8.14 and significance value 0.417 at $p<0.05$ for the DBH, therefore there is no significant difference between the simulated and measured DBH. The Levene's Test for equality of variance also shows an equal variance.
The two sample t-test for the height showed a t-value of 11.94 with a significance value of <0.001. The simulated height is significantly higher than the measured height. Table 10 shows a summary of the Two sample t-test.

Table 10 Results from the two sample t-test for DBH and height increment in BE4.

		Levene's Test for Equality of Variances		t	Sig. (2-tailed)	95% Confidence Interval of the Difference	
		F	Sig.			Lower	Upper
DBH cm	Equal variances assumed	.775	.380	-.814	0.417	-3.10	1.30
	Equal variances not assumed			-.794	0.429	-3.16	1.36
Height m	Equal variances assumed	61.502	.000	11.44	<0.001	4.88	6.92
	Equal variances not assumed			9.46	<0.001	4.64	7.16

4.2. Simulation Results for Future Tree Growth in Test Plots

Tables 11 and 12 below show the averaged DBH and height increment results of individual trees. These were obtained from 10 simulation runs of each scenario for test plots BE3 and BE4. Two sample t-test for the SILVA predictions show that under the future climate scenario, DBH increment is significantly lower for **oak trees** in BE3 at $p < 0.05$. **The beech trees** in the same plot show no significant difference in predicted DBH under the two scenarios at $p < 0.05$.

The two sample t-test also shows that the predicted increment in DBH is significantly lower under the future climate scenario for **pine trees** and for the **beech trees** in BE4 at $p < 0.05$.

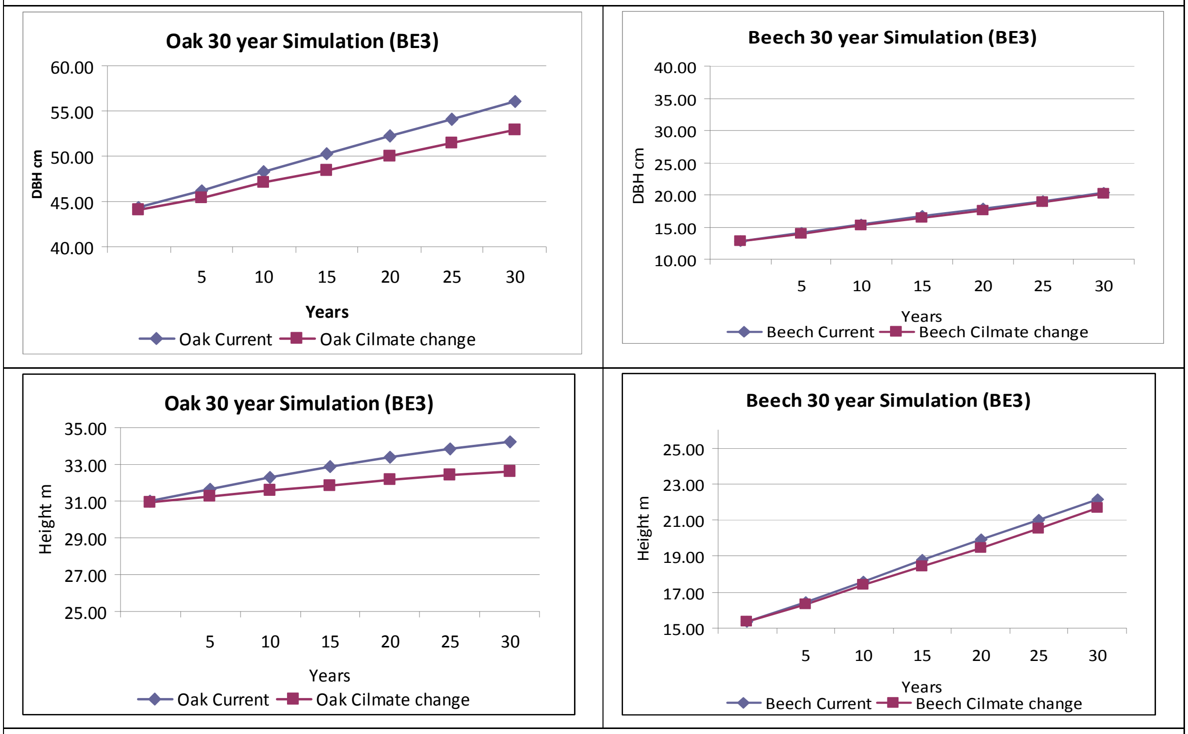
Table 11. DBH Increment for individual remaining trees after 30 year of simulations. These were derived from 10 runs of each simulation (The initial tree measurement variables for each test plot are the same for both climate scenarios.)

Test Plot		Climate Scenario	DBH increment - cm (Mean ± SE)	t-test value	Significance value. (2-tailed)
BE3	Sessile Oak	Current Climate	10.90 ± 0.36	3.12	0.002
		Future Climate	9.37 ± 0.33		
	Common Beech	Current Climate	7.02 ± 0.13	1.12	0.156
		Future Climate	6.77 ± 0.12		
BE4	Scots Pine	Current Climate	6.20 ± 0.30	3.23	0.001
		Future Climate	4.70 ± 0.33		
	Common Beech	Current Climate	13.56 ± 0.44	4.57	<0.001
		Future Climate	10.70 ± 0.41		

Table 12. Average Height Increment in the remaining trees – Using results from individual tree output

Test Plot		Climate Scenario	H increment - m (Mean ± SE)	t-test value	Significance value. (2-tailed)
BE3	Sessile Oak	Current Climate	3.43 ± 0.36	27.58	<0.001
		Future Climate	2.23 ± 0.33		
	Common Beech	Current Climate	6.48 ± 0.06	5.10	<0.001
		Future Climate	6.05 ± 0.06		
BE4	Scottish Pine	Current Climate	8.00 ± 0.03	176.0	<0.001
		Future Climate	1.10 ± 0.03		
	Common Beech	Current Climate	8.98 ± 0.06	-0.28	0.780
		Future Climate	9.00 ± 0.05		

BE3 - Oak and Beech Test Plot



BE4 - Pine and Beech Test Plot

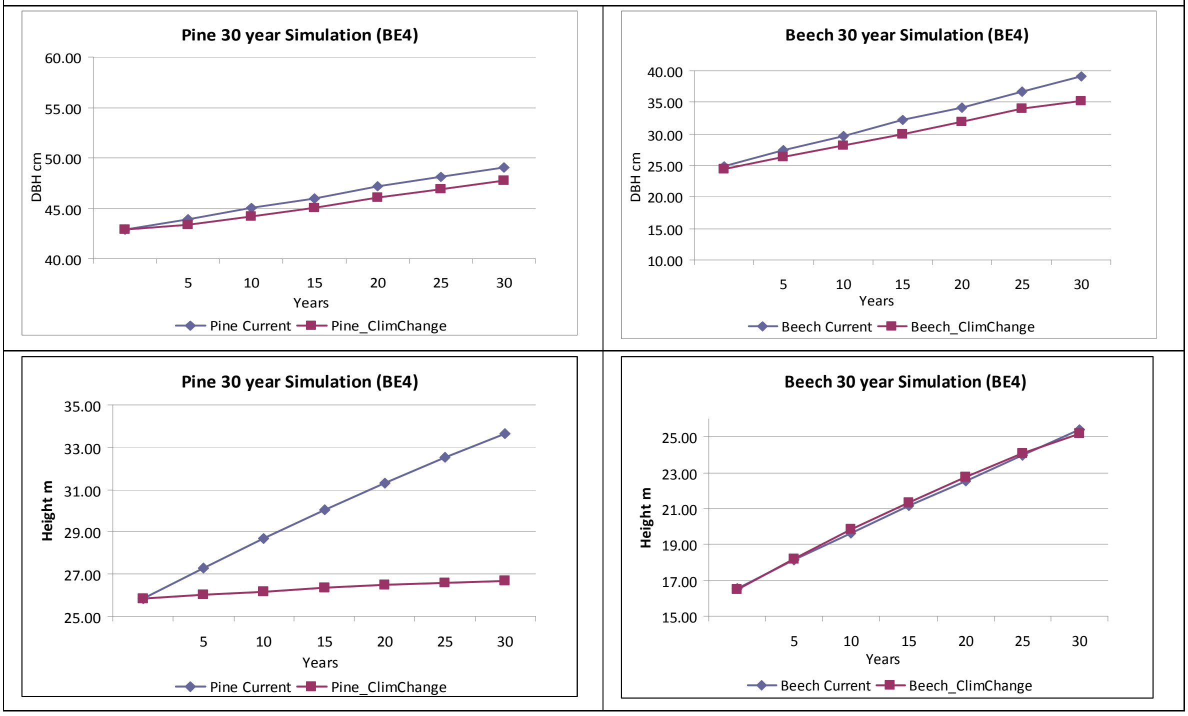


Figure 7. Graphs showing the increase in average DBH and Height for the tree species in BE3 (Oak and Beech) and BE4 (Pine and Beech). These are mean DBH values for the trees in each test plot averaged from 10 simulation runs.

The graphs show the simulated growth in DBH and height over 30 years (Figure 7). For the oak trees in BE3, DBH increment is lower under the future climate than the current climate while that of beech trees is almost the same under the two climate scenarios. The height increment is lower under future climate for both tree species in BE3.

In BE4, both the pine and beech trees show lower DBH increment under the future climate scenario. The pine trees show very little height increment under the future climate scenario and they are on average 7 m shorter compared to those from the current climate simulation after a 30-year simulation period. However, for the beech trees, the future scenario gives a slightly higher average height increment.

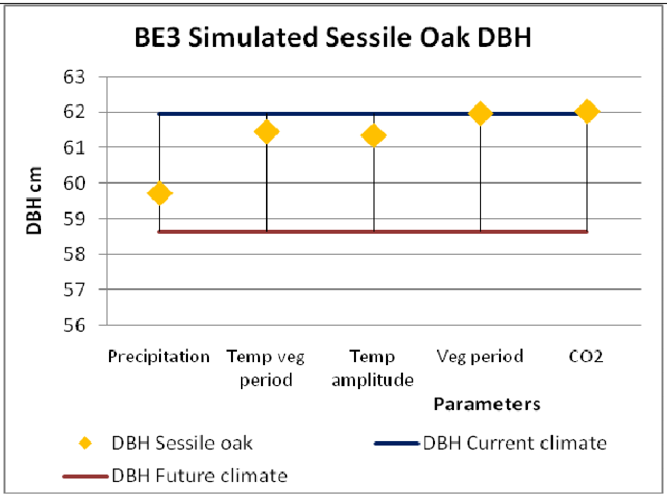
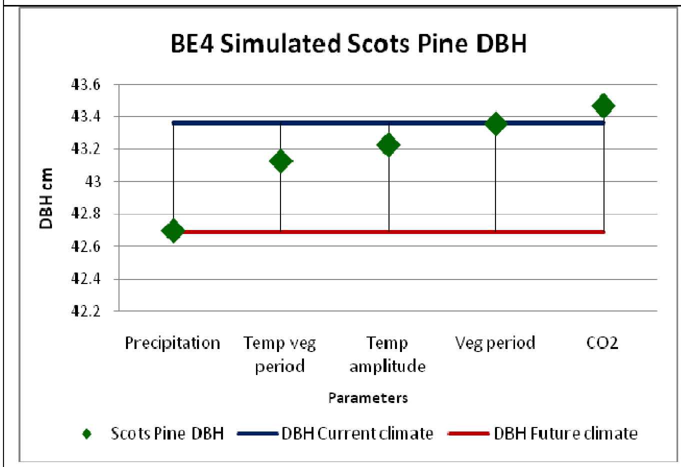
4.2.1. Influence of Climate Parameters on DBH increment

The following Table 13 shows the average of tree DBH results after running the SILVA simulation using the actual climate parameters (and not re-parameterised) for the current climate scenario. In each simulation run, one of the five parameters was replaced by that of the future climate.

A change in precipitation caused the highest reduction in DBH increment while the increase in CO_2 concentration slightly increases the simulated DBH increment for the oak trees and the pine trees in BE3 and BE4 respectively. Temperature amplitude and the increased mean temperature during the vegetation period caused a slight decrease in the simulated DBH increment for oak and pine trees. The increased mean temperature during the vegetation period seemed to affect the beech trees more negatively than the oak and pine trees. The longer vegetation period did not cause much change in the simulated DBH increment for all the tree species.

The SILVA simulation was also run using actual future climate parameters. The results show lower DBH increment than that that simulated using the current climate parameters for oak trees and pine trees. The simulated DBH increment under the future climate for the beech trees in both test plots was slightly higher than that simulated using the current climate parameters. This is not consistent with the results obtained using the re-parameterised climate values that showed a reduction in the DBH increment under future climate.

Table 13. The effect of changing the different parameters to future climate values, while other remain at the current climate level in the SILVA simulations

	Decrease in precipitation to the future climate value caused the highest reduction in the simulated DBH increment. The increase in CO_2 caused a slight increase in the simulated DBH increment. The mean temperature increase in the vegetation period and the reduced temperature amplitude caused a slight decrease in DBH increment
	For the pine trees, the simulated DBH increment was reduced the mostly by the drop in precipitation. The increase in CO_2 concentration resulted in a higher the DBH increment in the simulation. Temperature changes slightly lowered the DBH increment.

This section has shown results of the main simulation of tree growth in the test plots BE3 and BE4. It went on to show the results of an exercise that was done to validate the SILVA simulation of growth of trees in these test plots and to show that SILVA gives reasonable estimates of the growth parameters, DBH and height in particular. Lastly, the results showing the sensitivity of the simulated DBH for the species in the test plots, to changes of the different climate parameters were shown.

4.3. Evaluation of Wood production and Habitat protection functions

The results of evaluating the wood production and habitat protection functions under climate change are presented here. The evaluation involved three main processes, linking the output from SILVA to the appropriate indicators in the evaluation framework, allocating a score for each indicator and lastly calculating the assessment score for the functions.

4.3.1. Linking SILVA Output with the Evaluation Framework

The input data needed to calculate the values for each indicator in the evaluation framework were identified as shown in Table 14. For some of the indicators, the information to estimate their values could not be obtained from the SILVA simulation output. For these indicators, alternative source of information from literature were identified. Water supply is one example were the value for the indicator could not be taken from the SILVA output and so predictions from the WETTREG climate model were used. The precipitation during the vegetation period is predicted to decrease whilst potential evapo-transpiration increases, this has a negative effect on the water balance and therefore the value for the water supply indicator is reduced under the future climate.

The information on soil nutrient supply could not be obtained and it so the value remained the same as it is now for both climate scenarios. Still some indicators are not expected to change in the future. This applies for the stand damage, because both the peeling and splitter damage are took place in the past. The splitter damage because of metals from bullets and explosives form the Second World War, the peeling damage caused by deer usually takes place when the trees are young. In this case, trees in both test plots are old and have developed hard barks that prevent this damage. A summary of the link between SILVA and the evaluation framework is given in Table 14 below.

Table 14. This table shows the variables used to link outputs from the SILVA simulation to the evaluation framework for the wood production (a) and the habitat protection (b).

Objective	Criteria	Indicator	Explanation	Variables used	SILVA Link/ Comments
High production levels – 20	Net Profit – 100	Net margin/MBT	1 = bad <0 2 = medium ≥ 0 ≤ 12€ 3 = Good > 12 €	BA_1 = tree species BHD_1 = DBH size BEF = accessibility ANSATZ_BAZ = readiness for felling.	Tree species –from the Yield table
Develop-ment potential – 50	Potential value – 50	Wood production target	1= bad 0.0 - 2.4 2 = medium 2.5 - 3.4 3 = Good 3,5 - 4,0	FLA= area covered by each species PRODUKTZIEL_1=purpose for wood production WO_FLAE – total area	Krprz g(v) -the% Crown cover area from the Yield table
	Stand damage / health – 25	Peeling damage (deer) , Splitter damage	1 = badly> 66% 2 = medium ≤ 11% to 66% 3 = Good ≤ 10%	Take existing values If SCHAEL_1 and /or SPLITTER_1 ≠0 then (FLA/ WO_FLAE)*100	Remains the same
	Site productivity - 25	Water supply,	1 = badly 1-3, 11-12 2 = medium 4-S6, 10 3 = Good 7-9	information used is from the climate model prediction – soil moisture content (WHST_1)	Decreases with time – Lower precipitation, higher evapo-transpiration
		Nutrient supply	1 = bad entry = 5 or 6 2 = medium entry = 3 or 4 (7 and 8 are not used) 3 = Good entry = 1 or 2 or 9	TROPHIE_1 = soil nutrient level	No information so it remains the same

Low risk factor – 30	Stability – 50	Fraction of tree species suitable to the site	1 = share of bad area <33% 2 = medium surface share 33% - 66% 3 = Good surface proportion> 66%	BA_1, BA_SUBSTRAT_1= Substrate table matching trees with substrate FLA = area per species WO_SUBSTRA_1 (substrate series), WHST_1 =soil moisture content	Yield table – gives species composition -% of suitable species in test plot BE 3 -6/229- both species suitable BE4 -3/231 only pine is suitable beech is not
	Stratification – 50	Stratification / Layering	1= bad = 1	SCHICHT_1	Visualisation - overview and perspective view (A value of 2 for both plots (two layers in over 50% of stand)

14 b

Objective	Criteria	Indicators	Explanation	Variables used	SILVA Link
Closeness to nature 40	Naturalness of forest stand 100	Proportion of natural trees 100	Percentage of tree species natural in that particular soil type and moisture content of the area Bad 1 = < 40% Medium 2 = 40% - 80% Good 3 > 80%	BA_1 = tree species BA_SUBSTRAT_1= substrate WO_SUBSTRA_1 = substrate FLA , WHST_1 Auxiliary Table "natural Trees"	Yield table – gives species composition -% of suitable species in test plot BE 3 -6/229- both species suitable BE4 -3/231 only pine is suitable beech is not
Structural diversity 30	*Spatial structure 50* -horizontal and vertical diversity of forest	*Vertical structure 40*	1 bad = 1 (single) 2 medium = 2 (partially schichtig) or = 3 (double) 3 Good = 4 (multi) or = 5 (plenterartig)	Stratification/ number of vertical layers/ stratum	Species profile index (by Pretzsch) Visualisation - overview and perspective view (A value of 2 for both plots (two layers in over 50% of stand)
			1 bad = 0 (not stage) or = 1 (flat stage) 2 medium = 2 (horst stage as in some areas) 3 Good = 3 (horst as stage)	Stufung (step range)	vertical species mingling within the stand.
		Stock structure 25	1 share of bad area ≥ 80% 2 medium surface proportion> 50% and <80% 3 Good surface portion ≤ 50%	Baumartenvielfalt (tree species diversity) 34 HAUPT_BA_1=Main tree species WO_FLAE- area BA_1_Tree FLA –Crown area BG= stocking	Segregation index - horizontal mingling of tree species/ degree of mixing of tree of different species

			Number of different tree species with area coverage ≥ 5% of the total stand area 1 bad ≤ 2 different tree species 2 medium 3-4 different tree species 3 Good ≥ 5 different tree species	Mischbaumartenanzahl (mixed tree species number) WO_FLAE BA_1 FLA BG=stocking	Mingling index (proportion of the nearest neighbour tree to the reference tree with different species)
			1 badly <4 Trees 2 medium ≥ 4 trees and <6 Trees 3 Good ≥ 6 Trees	Number of tree species BA_1 SO_BA_1	Total number of tree species
		Mosaic diversity 25	1 bad 2,5-3,0 2 medium 1,7-2,4 3 Good 1,0-1,6	MISCHUNG FLA	Aggregation index values from 1.0 (homogeneous) – 3.0 (clustered)
		Age diversity 10	number of different age groups in the stand – covering ≥ 5% of total area 1 badly <3 ages 2 medium ages 3-4 3 Good> 4 ages	ALT=age WO_FLAE FLA	Can be obtained from yield table
	Habitat features 40	*Stocking 33*	1 bad > 1.0 or ≤ 0,3 2 medium Score ≤ 1.0 and ≥ 0.7 3 Good Score ≥ 0.4 and ≤ 0,6	BG (stocking) FLA WO_FLAE (area Waldort)	Yield Table - Stock density
		Heavy wooden share 33	Based on DBH. The higher the value the more the share. 1 badly ≤ 10% 2 medium 11% - 30% 3 Good> 30%	BHD – diameter FLA – crown area	Yield table – DBH
		Location potential 34	1 badly 4-6 2 medium 7-9 3 Good 1-3 or 10-12	WHST_1=water supply 1 (extremely dry) to 12 (wet)	Decreases with time – Lower precipitation, higher evapo-transpiration
			1 bad 4 or 5 2 medium 2 or 3 (7 and 8 are not used) 3 Good 1 or 6 or 9	TROPHIE_1=nutrient supply	Na
	(special structure)	*Dead wood 33*	1 bad enter 0 2 medium Entry 1 3 Good Entry 2 or Entry 3	TOTHOLZ_1= (Deadwood expression)	Na
		Location diversity 33	Rare soil type -if it occurs <5% then it is not good. But if >10% then it is good Diversity of the soil -if more than 2 soil types in the stand, then it is very good	BA_SUBSTRAT_1 FLA WO_SUBSTRA-1	Does not change
		(special local stuctures) 34	1 bad no note 3 Good entry	SONDERSTRUK (special structures)	Does not change
Seltenheit *(Rareness) 30*	Biotope des LUWG 50	Biotope	1 = share of bad area <33% 2 = medium surface share 33% - 66% 3 = Good surface proportion> 66%		Does not change
	Schutzgebiete *(protected area) 50*	NSG, Nuclear Biosphere reserve zones, NWR	1 share of bad area ≤ 25% 2 medium surface proportion> 25% and <50% 3 Good surface share ≥ 50%		Does not change

4.3.2. Evaluation Results for Wood Production and Habitat Protection

The evaluation results of wood production and habitat protection are presented here. Only the scores for indicators and the final assessment are shown here. A table with more detailed stages of assessment is in Appendix 2.

Wood production

The values for most indicators did not change for the wood production as shown in Figure 8. In BE3, the only value that changed was that for water supply which goes down under the future climate scenario. This gave the “development potential” a slightly lower value for the future climate, 0.88 compared to 0.92 for the current climate .In BE4, the profit margin under the current climate increased while that under future climate remained the same. The production level therefore had a higher value for the future under the current climate than under future climate.

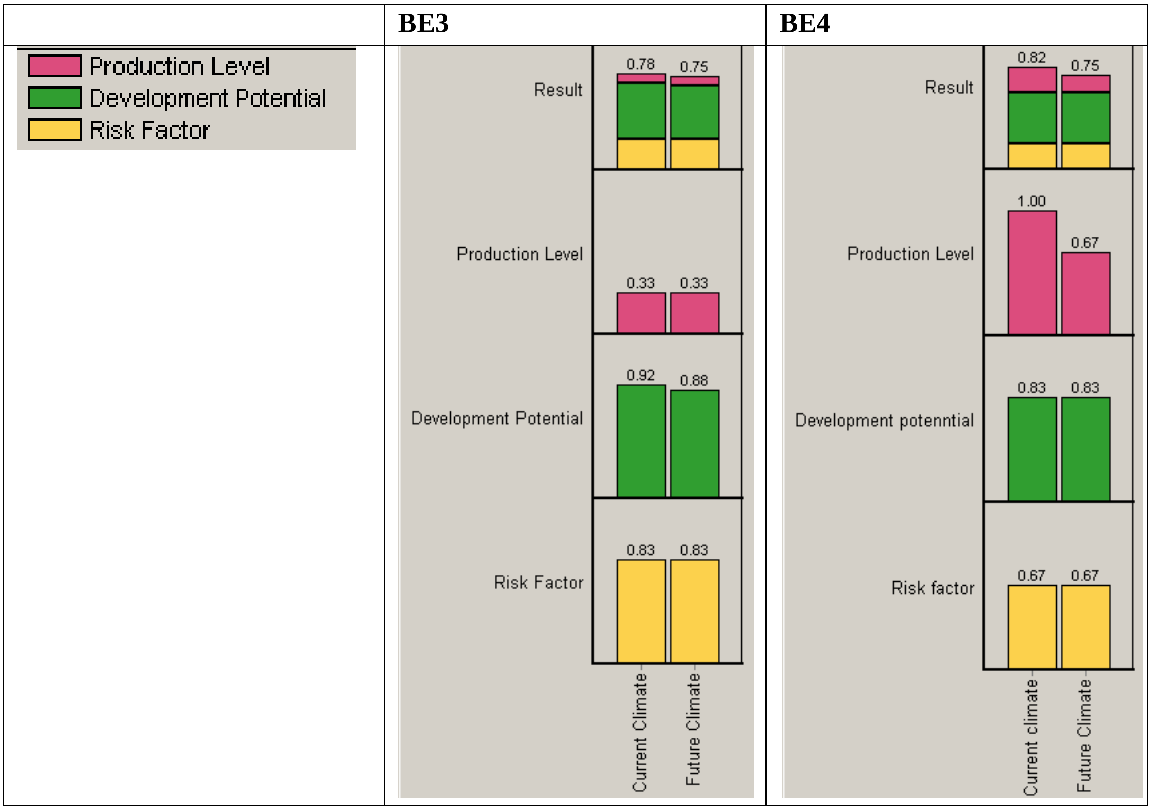


Figure 8. Final assessment score given by Definite for the wood production function in BE3 and BE4

Final evaluation

The final evaluation of wood production for the current and future climate scenarios after a thirty year simulation of forest growth is the same as the current evaluation as shown in Table 15 below.

Table 15. The table shows the current evaluation scores and the future evaluation scores for wood production

Test Plot	Climate Scenario	Final assessment score	Evaluation for current scenario	Evaluation for the future scenarios
BE3	Current	2.34	4	4
	Future	2.25		4
BE4	Current	2.46	4	4
	Future	2.25		4

Habitat protection

There was no change in the indicator values for habitat protection after 30-year simulation as shown in Figure 9 below. The habitat protection values for most indicators did not change. In both test plots, the structural indices were slightly different between the two climate scenarios. These differences only produced small differences in the final assessment score.

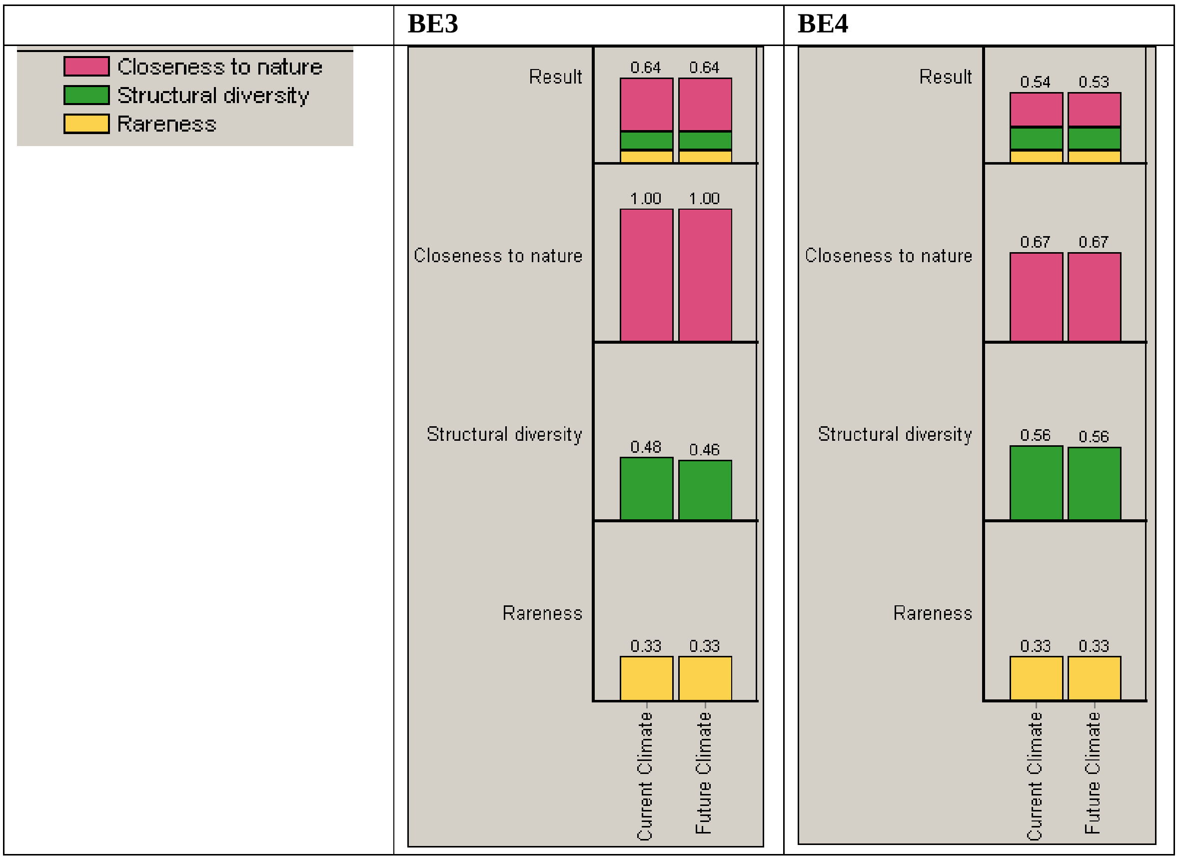


Figure 9. Final assessment score given by Definite for the habitat protection function in BE3 and BE4

Final evaluation

The final evaluation of habitat protection for the current and future climate scenarios after a thirty year simulation of forest growth is the same as the current evaluation as shown in Table 16 below.

Table 16. The table shows the current evaluation scores and the future evaluation scores for habitat protection

Test Plot	Climate Scenario	Final evaluation score	Evaluation for current scenario	Evaluation for the future scenarios
BE3	Current	1.92	3	3
	Future	1.92		3
BE4	Current	1.62	2	2
	Future	1.59		2

5. Discussion

In this chapter, the results of the simulated tree growth as shown by DBH increment, the validation of the SILVA simulation as well as the evaluation of the forest functions are discussed. The methods and sampling data used are also part of the discussion.

5.1. Simulations from the SILVA Model

The simulation results showed a reduction in DBH increment under future climate. Reduced water availability due to lower precipitation accounted for the largest part of the reduction in the simulated growth. This was confirmed a simple sensitivity test described in Section 4.1.2. Increased atmospheric CO_2 concentration resulted in higher DBH increment for these species in both stands. The overall results show a reduced DBH increment under the future climate scenario.

Although atmospheric CO_2 concentration almost doubles, there is a temperature increase of 1.6^{o}C and vegetation period increases by 32 days in the future scenario growth is still reduced under future climate. This combination would be expected to increase the growth rate since CO_2 enhances photosynthesis and water use efficiency, higher temperature increases the rate of photosynthesis and other metabolic processes (up to an optimum), and the longer vegetation period leads to a longer growth phase (Lindner & Cramer 2002). This is what has been demonstrated in other studies on the effects of climate change on forest development in the immediate future(Boisvenue & Running 2006; Alcamo *et al.* 2007). However, the predicted 51mm drop in precipitation during vegetation period becomes the limiting factor. The reduced growth due to lower precipitation is expected because it causes decreased water supply resulting in drought stress, impaired growth and drought damages (Zebisch *et al.* 2005). In the study area, the soils are sandy with low water holding capacity and this further reduces water availability.

Previous studies indicate that net primary productivity will likely increase where there is no limited water availability (Smith *et al.* 1996). The heat wave in Germany, the summer of 2003 demonstrated the effect of combined summer droughts and high temperature. The vitality of forests generally decreased and there was premature shedding of leaves and needles (Zebisch *et al.* 2005).

5.2. Validation of SILVA Model Predictions

Past measurement data from test plots BE3 and BE4 were used to simulate growth over twenty years. Only measurement data for the main species (oak in BE3 and pine in BE4) were available. Beech trees were considered to have more of an ecological value in both stands and there was no interest in taking their measurements until recently. The beech leaves provide nutrients to the soil in the pine stands. In the oak stands, they provide competition for light in the lower canopy of the oak stand, this helps to prevent having branches in the lower parts of the oak trees that would otherwise affect the oak wood quality. In order to run the simulations, the input variable for beech trees were generated from a “guestimate” through trial and error runs with the measurements taken in 2005 as target results.

Results from both test plots showed that the DBH increment simulated by SILVA was not significantly from the measured DBH values and so the simulation gave a reliable estimate for the DBH increment of the oak and pine trees in this stand. However, this could not be established for the beech trees because no beech measurements had been taken in the test plots before 2005.

The height increment from the simulation was significantly different from the measured heights in both test plots BE3 and BE4. According to personal communication with (Schröck 2008), this could be explained by snow damage which occurred in 2003, resulting tree heights that are even shorter than they were 20 years earlier. Using these height measurements would not be suitable for validation because of snow damage

The simulation by SILVA also had a 28 % over-estimation of remaining trees in BE4. This could also be explained by the snow damage of 2003, which as a result in 20 damaged trees having to be cut down. The number of remaining trees was only 8 % less than the actual for BE3, which is a fair estimate. In both test plots the simulated number of remaining beech trees was lower (19 % for BE3 and 49.5 % for BE4) than the actual numbers. In these stands, the beech trees are younger and smaller than the oak and the pine trees. The beech trees simulated in SILVA seem to have high mortality due to light completion. Beech trees are shade tolerant and SILVA tends to underestimate this shade tolerance, giving problems in simulating beech trees in the under canopy.

5.3. The Influence of the Sample Plots

The test plots used in this project, BE3 (mixed oak and beech) and BE4 (pine and beech) are level II plots, were measurements of tree variables of the main species are taken and updated every 5 years. The advantage of using such plots that are continuously monitored is that the past and present data is available and complete. It also allowed for validation of the model that was used in the simulation to be done. However, in both test plots the trees of the main species were rather old. The oak trees in BE3 were 201 years old and the pine in BE4 129 years old.

The problem with simulation their development in SILVA is that growth potential curves tend to flatten after the age of 120 years on average (Moshammer 2008) . The oak trees are almost at the end of the SILVA simulation period and pine trees are expected to be harvested by the time they reach 160 years. This limited the simulation period for both test plots, the simulation could not go beyond 30 years for the pine, it goes beyond the harvest time, and for the oak trees, going beyond 30 years would exceed the age limits they can be simulated for by SILVA. Nevertheless, the effect of climate change on the development of these old trees was still found to be statistically significant. If younger stands had been used, the simulated climate induced differences might have been even more substantial.

5.4. The Modelling Process

Like any other model, SILVA gives a simplified representation of individual tree growth in a forest stand. SILVA is an empirical model that is parameterised using en extensive database from plots in different parts of Germany. However, the parameterisation is based on empirical data from the past and has not yet been parameterised for the future climate scenarios. Simulations for the future climate scenarios using the current parameters may not always give the reasonable growth predictions. Because of this, parameters that correctly represent the growth of the mixed oak and beech and in mixed pine and beech under the site conditions of BE3 and BE4 had to be identified. BALANCE, an eco-physiological model was used to simulate the growth of trees in BE3 and BE4 test plots under current and future climate scenarios as predicted by the WETTREG regional climate model for the AIB climate change scenario. The result was a set growth potential curves for the tree species in each plot. This growth potential curve needed to be incorporated into SILVA to allow the simulations to be done.

Incorporating the potential growth curve from BALANCE created an ill posed inverse problem. This is because the potential growth curves derived from BALANCE do not have a unique combination of parameters (CO_2 concentration, length of vegetation period, annual temperature amplitude, mean temperature in vegetation period and total precipitation during vegetation period) in SILVA that match each of them. The Technische Universität München identified and provided one a set of parameters for each test plot. The set of new parameters values was use in simulation growth of trees in the test plots for this project. Table 17 shows a comparison of the actual climate parameters as predicted by the WETTREG climate model with the re-parameterised values that were used.

Table 17. A comparison of the actual climate parameters as predicted by the WETTREG climate model with the re-parameterised values and their predicted DBH increments after a 30-year simulation period.

BE3				
	Current climate		**Future Climate**	
Climate Parameter	**WETTREG 2001-2030**	**BE3 Re-Parameterised**	**WETTREG 2071-2100**	**BE3 Re-Parameterised**
Temperature (vegetation period) ^{0}C	15.2	15.0	16.8	15.0
Vegetation period (days)	156.8	142.0	188.8	145.0
Precipitation (vegetation period) mm	270	387	219	300
Temperature amplitude (month) ^{0}C	19.2	16.6	16.7	16.6
CO_2 concentration ppm	380	353	600	300
Predicted DBH increment Oak trees	11.70 ± 1.15	10.90 ± 0.36	9.32 ± 1.11	9.37 ± 0.33
Predicted DBH increment Beech trees	7.01 ± 0.40	7.02 ± 0.13	7.38 ± 0.41	6.77 ± 0.12
BE4				
	Current climate		**Future Climate**	
	WETTREG 2001-2030	**BE4 Re-Parameterised**	**WETTREG 2071-2100**	**BE4 Re-Parameterised**
Temperature (vegetation period) ^{0}C	15.2	15.0	16.8	19.0
Vegetation period (days)	156.8	130.0	188.8	150.0
precipitation (vegetation period) mm	270	400	219	383
Temperature amplitude (month) ^{0}C	19.2	16.6	16.7	17.6
CO_2 concentration ppm	380	353	600	347
Predicted DBH increment Pine trees	0.86 ± 1.08	6.20 ± 0.30	0.19 ± 1.15	4.70 ± 0.33
Predicted DBH increment Beech trees	12.63 ±0.97	13.56 ± 0.44	12.99 ±1.23	10.70 ± 0.41

There is not much difference in the predicted average DBH increment for both oak and beech trees in BE3 when simulated using the two different sets of parameters. According to expert advice from the model developers of both SILVA and BALANCE, the simulations from the re-calculated parameters give more accurate results because the recalculated parameters represent more accurately the growth in the future.

While climate factors are expected to change gradually over time, they are represented is such that there is one average value for the whole thirty-year simulation period. An alternative would have been to use five-year averages. However, because of the need to recalculate the parameters using BALANCE, the time available was not enough to allow for this.

5.5. Evaluation of Forest Functions: The method

The framework that was used for the evaluation was developed for assessing the current state of forests and inform the communities that manage them accordingly. The criteria were developed to suit this purpose of assessing the condition, rather than to monitor the trends in the condition over time. This framework was adopted, as it is in, order to allow for comparison of the different sets of assessments with the current assessment. However as seen from the results, there was not much change over time.

5.5.1. Evaluation of Wood production and Habitat Protection

In both test plots, the assessment score for wood production under future climate is slightly lower than that for than that under climate change, 3% lower in BE3 and 10% lower in BE4. However, these differences between scenarios did not show in the final evaluation because the small defences between them placed them in the same suitability class.

As shown in Table 18 in, a large proportion of criteria and indicators, which are useful in showing spatial variation, do not change much in the 30-year time frame. These indicators such as wood production purpose, peeling and splitter damage only change spatially but not over time even if the climate changes. Some of the criteria used for the evaluating habitat protection function were closeness to nature, structural diversity and rareness of the biotope type. As in the wood production a large percentage of the indicators used do not change over time. Table 18 shows that indicators contributing a total weight of 73.5 % will remain the same.

Table 18a . The table shows evaluation criteria with values that remain constant over time.

Criteria	Indicator	Remarks	% contribution to evaluation
Development potential	Wood production target	The purpose for the wood production in both plots is for high quality wood.	25
	Stand damage -(peeling and splitter)	The stand damage happened in the past and no further damage is expected for the future	12.5
Risk factor	Stability – proportion of suitable trees	100% in BE3, and will not change. BE4 – the current value is 2(medium) and it has a wide range (40% - 80%)	15
Total (Wood production)			**52.5**

Table 18b

Criteria	Indicator	Remarks	% contribution to evaluation
Closeness to nature	Proportion of natural trees	100% in BE3, and even ratio of species it will remain 100% BE4 – the current value is 2(medium) and it has a wide range (40% - 80%) so the 14% difference in the two scenarios lands then in the same class (2)	40
Rareness	forest nature reserves and nature protection areas,	These are designated already and if they change, the information cannot be obtained from SILVA.	30
Structural diversity	Local diversity Special local structures	These are structures in the stand like spring, ditch, brook, lake, tarn, rocks, cave, grassland	2
	Age diversity	The age differences are constant	1.5
Total (Habitat protection)			**73.5**

Indicators for habitat protection contributing to the remaining 26.5% include vertical structures, stock structure, and mosaic diversity, and stocking, share of heavy wood, water supply and nutrient supply. The SILVA simulation gave information on most of these indicators, the exceptions being water and nutrient supply. However, although there were differences in the values between the scenarios, the differences were too small to push the overall evaluations to different classes.

SILVA only simulates growth of trees with DBH larger than 5cm and in practice, only those with DBH greater than 7cm are considered when taking tree DBH measurements. This means that if there are any small trees, they are not considered in the simulation even though they contribute to real structural diversity in the forests.

The resolution used for the criterion scores, 1, 2 or 3 corresponding to bad, medium and good, may have made it difficult for small changes to be detected. In some cases, the ranges represented in one class were so wide that some differences where concealed.

Lastly, this evaluation was based on the changes in tree growth that are represented as gradual by the simulation. This may not be true in the reality of climate change. Extreme weather events that are likely to result from climate change as well as the issue of pests and diseases that are likely to be more prevalent under climate change could not be simulated and are outside the scope of this study.

The simulation results as well as the assessment scores are only representative of similar forests areas in Merzalben and Johanniskreuz for mixed oak and beech stands, and mixed pine and beech stands respectively. The parameters derived from BALANCE were very specific to the study area and tree species involved. The results also only represent just one many possible climate scenarios.

The evaluation framework was used with as little modifications as possible. It was done to allow for comparison of the evaluation of forest functions under climate change with the current state of the forests, based on the current practice in evaluation of the same functions.

5.6. Uncertainties in Climate and Forest Growth Modelling

The evaluation of wood production and habitat protection functions was partly based on the weights allocated to different criteria and outputs from the forest growth mode SILVA. The allocation of scores depends on who allocates, and from what perspective they are looking at the evaluation (economic, ecological or social). The simulation of forest growth by SILVA model was based on climate parameters from WETTREG regional climate model for the SRES A1B climate scenario and tree measurement variables from the test plots. WETTREG regional climate model was downscaled from ECHAM5/MPI-OM, a global climate model. The A1B is one of the climate scenarios based on green house gas emission scenarios as explained in Section 2.1.1. These scenarios are just alternatives of how the future may unfold as opposed to forecasts or predictions.

With such multiple model integration, it is important to identify and assess the uncertainties the propagation of such uncertainties at the different modelling stage. A concurrent MSc thesis looks at these uncertainties. In that thesis, a conceptual framework for uncertainties and sensitivity analysis for application in forest management was developed.

6. Conclusions and Recommendations

6.1. Answers to Research Questions

Research Question 1: *Will forest tree growth under future climate be different from forest tree growth under the current climate?*
This study revealed a statistically significant lower simulated tree growth (at 95% confidence interval) under future climate (WETTREG A1B SRES climate scenario of 2071-2100) than under current climate (2001-2030). This was indicated by the simulated DBH increment in the mixed oak and beech forest in Merzalben area. The reduction in growth was not attributable to the beech trees, which grow in the under-storey

- Oak with initial age of 201years: The simulated increase in average tree DBH over 30 years is **1.53 cm less for oak trees** under climate change and this is significant at 95% confidence interval.

This study has also revealed a statistically significant lower simulated DBH increment (at 95% confidence interval) in mixed pine and beech stands in Johanniskreuz area under future climate (WETTREG A1B SRES climate scenario of 2071-2100) than that of the current climate (2001 – 2030).

- Pine with the initial age of 129years : The simulated increase in the average tree DBH over 30 years is **1.50 cm less for pine trees** under the A1B climate change scenario and this is significant at 95% confidence interval
- Beech with the initial age of 56years : The simulated increase in the average tree DBH over 30 years is **2.86cm less for beech trees** under the A1B climate change scenario and this is significant at 95% confidence interval

Research Question 2: *To what extent will the evaluation score (according to the current practice) of habitat protection function change under future climate?*

The multi criteria evaluation showed that the future **wood production** evaluation score in both test plots BE3 and BE4 after 30 years would be that same as the current, under both the current and future climate scenarios. This reflected the following:

- The trees in the test plots are almost mature, their DBH is classified as large on a scale of 1- small to 4- large. The initial DBH is in the 4th class for the oak and 3rd for the pine. Even if they continue to grow, the criterion score does not get much better because oak is already in the maximum class and pine one class below the maximum.
- Some of the criteria used will, by nature not change over the 30-year period. These contribute to a total weight of 52.5% in the evaluation. This had a dilution effect to the small changes in the rest of the criteria.

Research Question 3: *To what extent will the evaluation score of wood production function change under future climate?*
The multi criteria evaluation showed that the evaluation score for future **habitat protection** function in both test plots BE3 and BE after 30 years would be that same as the current evaluation, under both the current and future climate scenarios. This can be attributed to the fact that

- The scores for most indicators are not expected to change over time. These constitute 73.5% of the total assessment score. If any change has to be seen, the changes in the remaining 26.5% of the weights have to be very strong.
- SILVA model only includes trees with diameter greater than 5cm in the initial input. It is possible that there may be other species that may not have been initially considered , but would be big trees after the 30 years.

6.2. Overall Conclusion

-The study showed that tree growth in the mixed oak and beech (201 years old oak and 96 years old beech) as well as the mixed pine and beech stands (pine-129 years old and beech - 56 years old) would be reduced under the future climate. The future climate is here representing the A1Bclimate scenario of 2070-2100 as predicted by the WETREG regional climate model. The reduction in the simulated growth is statistically significant at 95% confidence interval. However, this claim is valid only for the areas in the Palatinate Forest near Merzalben and Johanneskruz, were the site conditions (soil type, nutrient supply and climate) are the same as those in the test plots. This is because SILVA is an empirical model, and the parameters used (soil and climate conditions) in this study were specifically for the conditions in these test plots. The results can only apply to places with the same soil and climate conditions, as well as tree species in the same age range as those in the two test plots (BE3 and BE4).

- SILVA model simulates growth development in forest stands. The output from the SILVA model provided the right information for the criteria used to evaluate the wood production function. The model output also provided information just over 50% of the criteria used in evaluating the habitat protection function. SILVA therefore did not give complete information data to be used for evaluating the habitat protection function.

- Although the criteria used in the Rhineland Palatinate evaluation framework reflect changes that occur spatially, changes in the temporal dimension are not reflected sufficiently. This makes it difficult to use for in the context of climate change where changes take place over time.

6.3. Recommendations

This study is considered as preliminary research in evaluating forest functions in the context of the ForeStClim project. The fieldwork started barely a month after the project “kick-off”, there were some limits concerning the sampling data that could be used, and the modelling approach that could be taken. Regarding these points, the following can be considered if similar studies are to be carried out in the future research

6.3.1. Recommendations for Future Research

- The number of sample plots used for each type of forest stand could be increased to allow for comparison between stands with similar tree species.
- Young forest stands need to be evaluated, they will grow and mature under changing climate, the effects of climate change could be more visible in these trees than the older trees whose peak growing period has already passed.
- The use of gap and / or ecological models could be considered especially if the model output is meant for evaluating ecological functions like habitat protection

6.3.2. Recommendations for Future Forest Management

- If forest management has to consider climate change, the resolution of the standardization of indicators has to be improved. For example, instead of classifying the values for indicators with continuous values, such as DBH into three classes of small, medium and large, can be considered just as continuous variables.
- In using the framework in the context of climate change, the overall weight percentage could be reconsidered in favour of those criteria affected by climate change.
- An alternative would also be to develop a separate framework that is relevant in the context of climate change, which could be an adjusted current evaluation framework with criteria that are sensitive to changes that take place over time.

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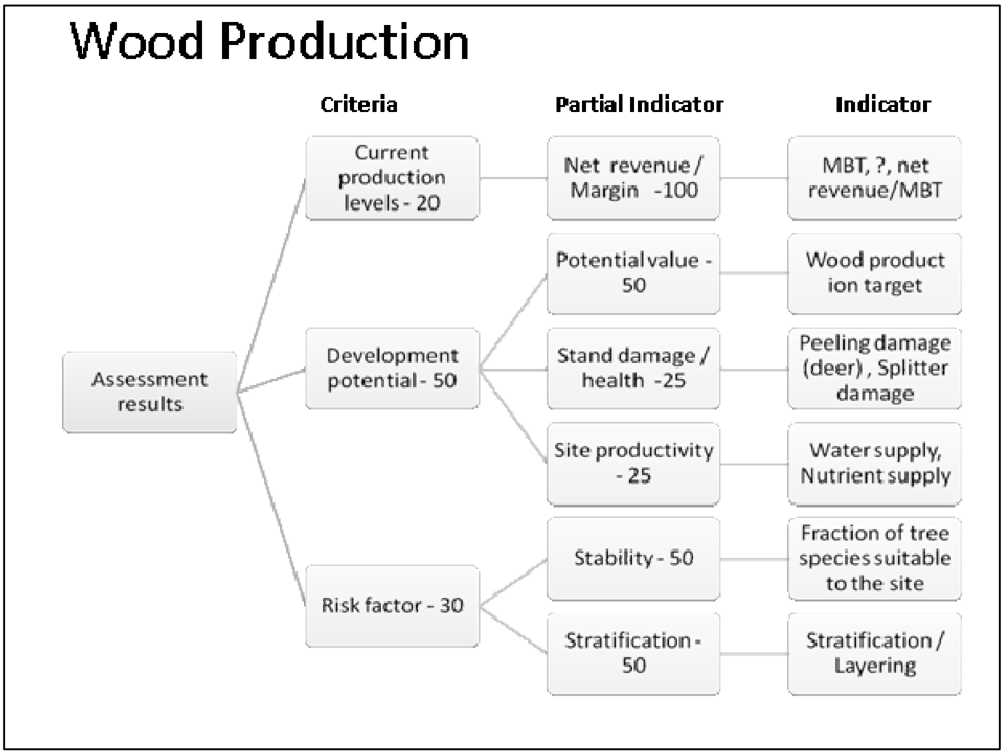
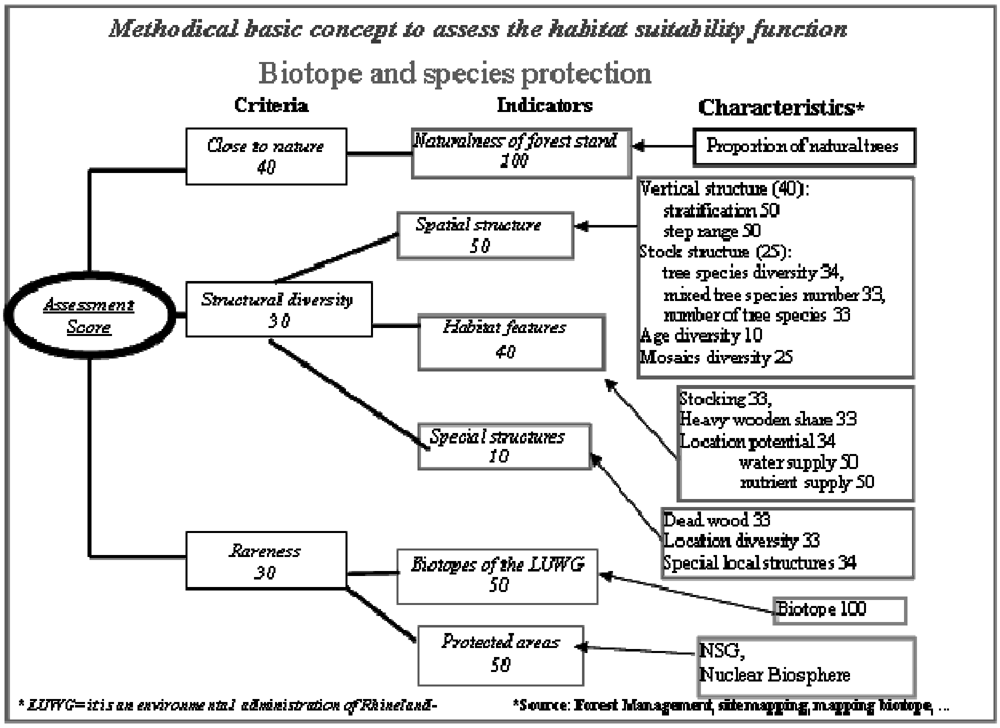
8. Appendices

Appendix 1 Criteria and Indicators used to evaluate wood production (a) and habitat protection (b) in Rhineland Palatinate.

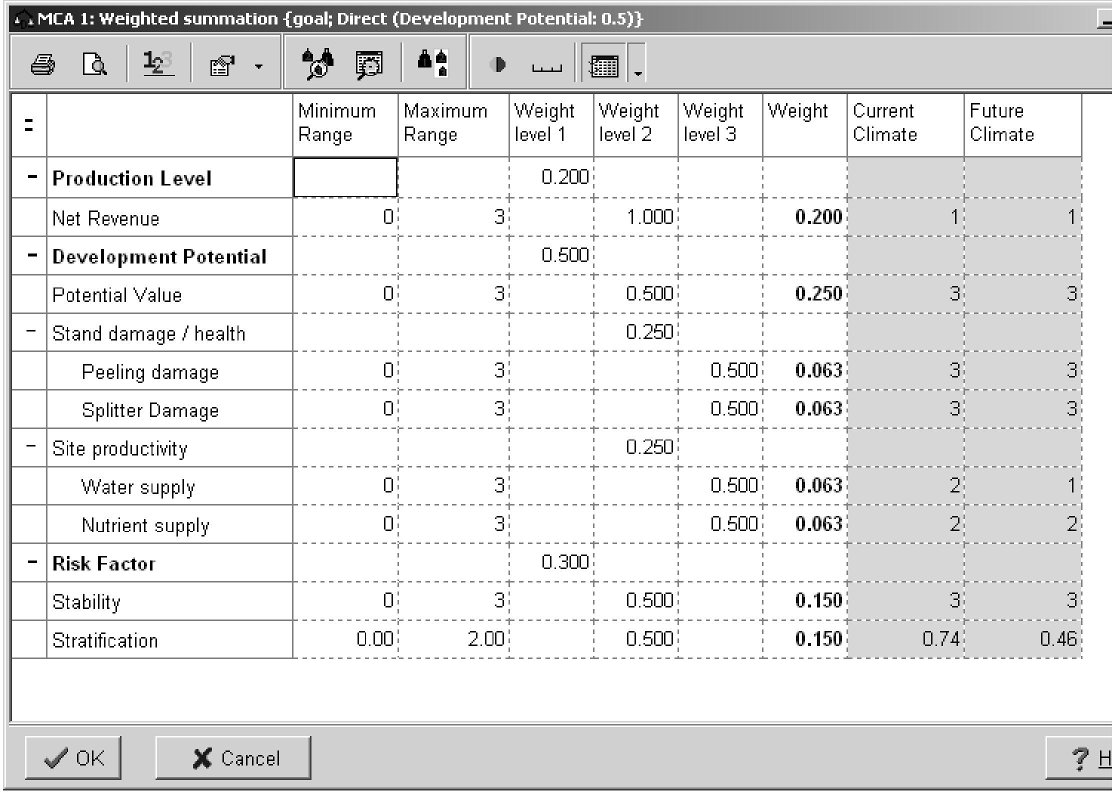


(b)



Appendix 2 The values criterion score allocation

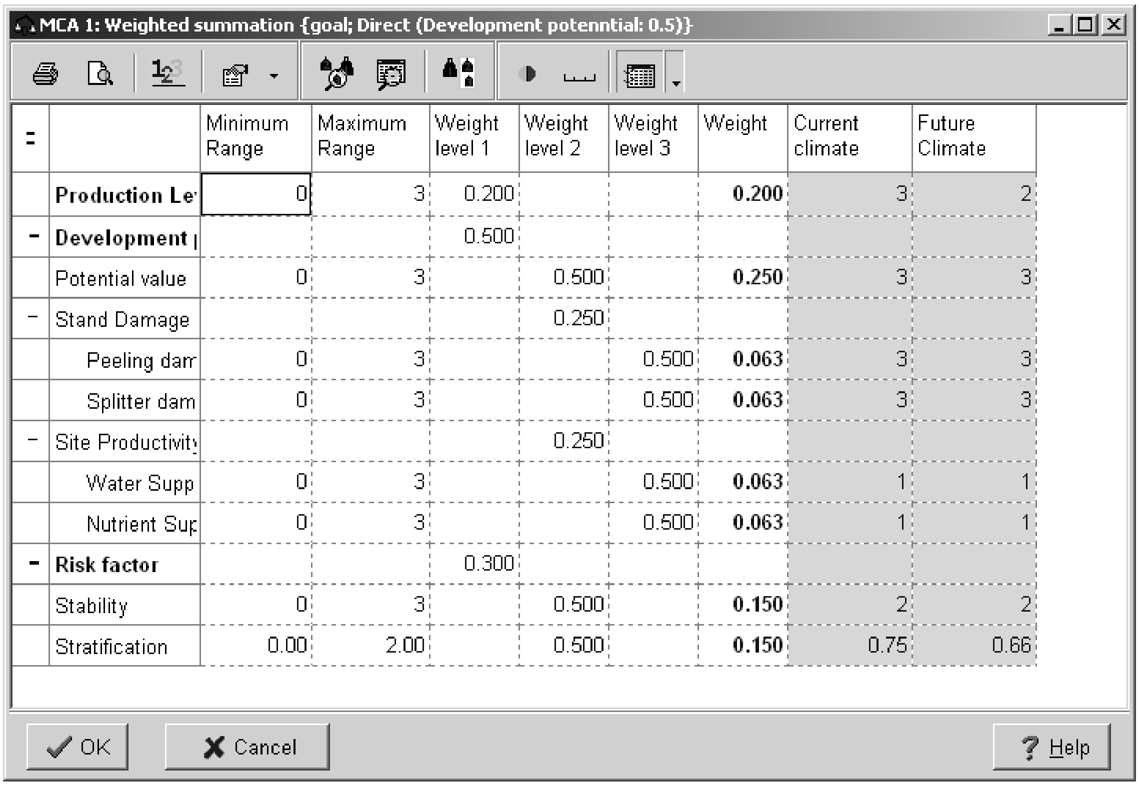
BE3 Wood production



MCA 1: Weighted summation {goal; Direct (Development Potential: 0.5)}

-		Minimum Range	Maximum Range	Weight level 1	Weight level 2	Weight level 3	Weight	Current Climate	Future Climate
-	**Production Level**			0.200					
	Net Revenue	0	3		1.000		**0.200**	1	1
-	**Development Potential**			0.500					
	Potential Value	0	3		0.500		**0.250**	3	3
-	Stand damage / health				0.250				
	Peeling damage	0	3			0.500	**0.063**	3	3
	Splitter Damage	0	3			0.500	**0.063**	3	3
-	Site productivity				0.250				
	Water supply	0	3			0.500	**0.063**	2	1
	Nutrient supply	0	3			0.500	**0.063**	2	2
-	**Risk Factor**			0.300					
	Stability	0	3		0.500		**0.150**	3	3
	Stratification	0.00	2.00		0.500		**0.150**	0.74	0.46

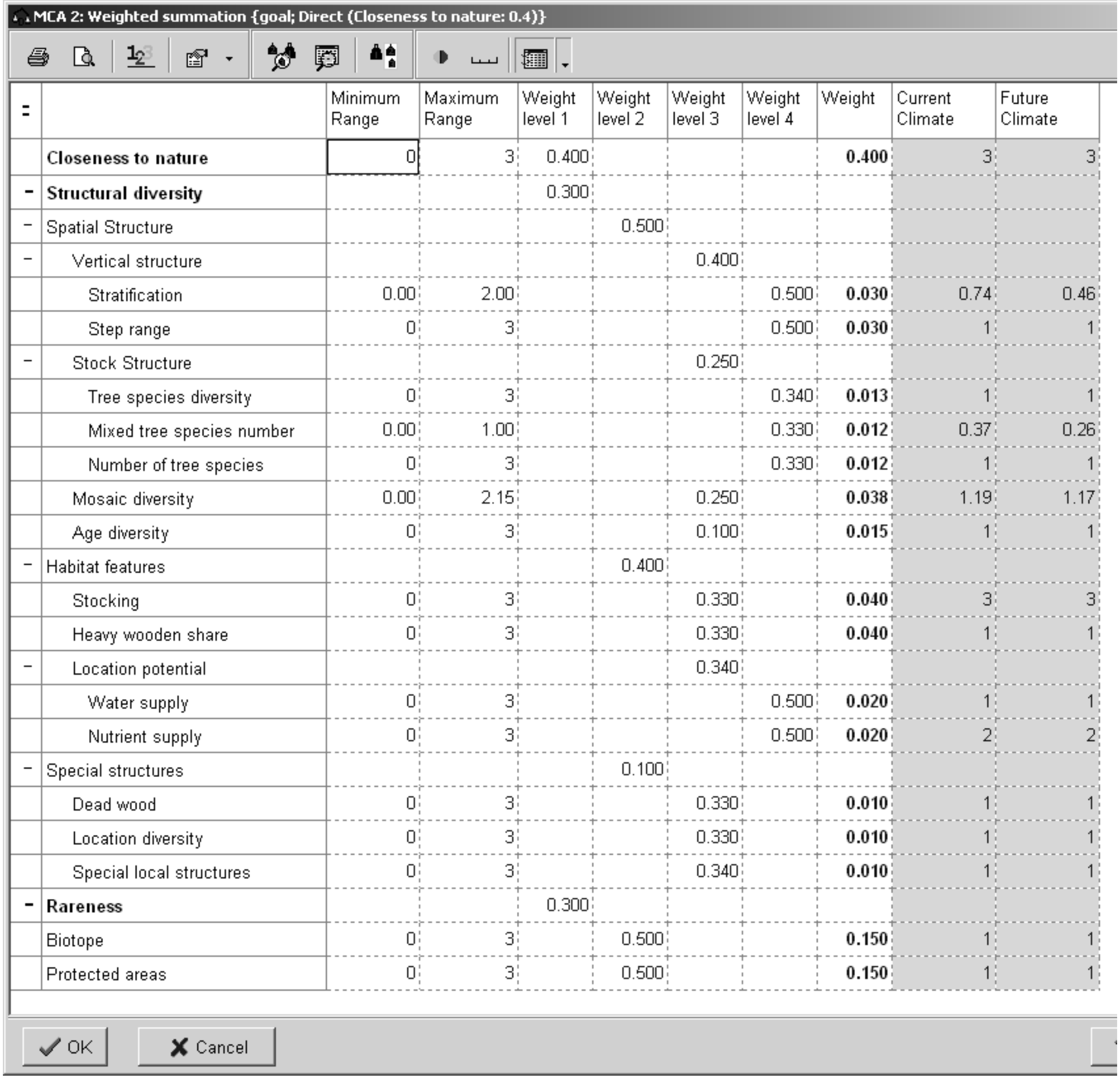
BE4 Wood Production



MCA 1: Weighted summation {goal; Direct (Development potenntial: 0.5)}

-		Minimum Range	Maximum Range	Weight level 1	Weight level 2	Weight level 3	Weight	Current climate	Future Climate
	Production Le	0	3	0.200			**0.200**	3	2
-	**Development**			0.500					
	Potential value	0	3		0.500		**0.250**	3	3
-	Stand Damage				0.250				
	Peeling dam	0	3			0.500	**0.063**	3	3
	Splitter dam	0	3			0.500	**0.063**	3	3
-	Site Productivit				0.250				
	Water Supp	0	3			0.500	**0.063**	1	1
	Nutrient Sup	0	3			0.500	**0.063**	1	1
-	**Risk factor**			0.300					
	Stability	0	3		0.500		**0.150**	2	2
	Stratification	0.00	2.00		0.500		**0.150**	0.75	0.66

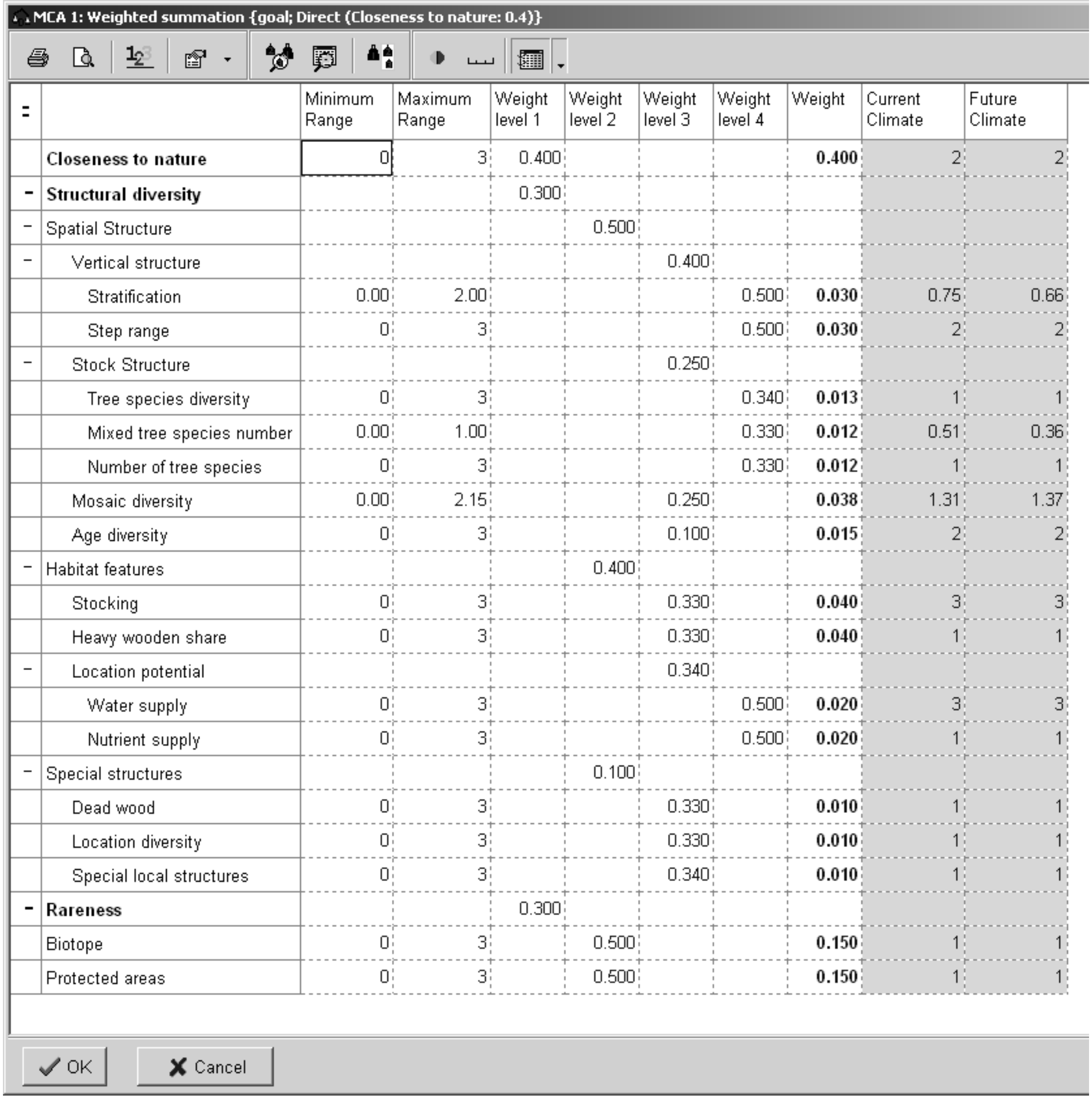
BE3 Habitat protection



MCA 2: Weighted summation {goal; Direct (Closeness to nature: 0.4)}

=		Minimum Range	Maximum Range	Weight level 1	Weight level 2	Weight level 3	Weight level 4	Weight	Current Climate	Future Climate
	Closeness to nature	0	3	0.400				**0.400**	3	3
−	**Structural diversity**			0.300						
−	Spatial Structure				0.500					
−	Vertical structure					0.400				
	Stratification	0.00	2.00				0.500	**0.030**	0.74	0.46
	Step range	0	3				0.500	**0.030**	1	1
−	Stock Structure					0.250				
	Tree species diversity	0	3				0.340	**0.013**	1	1
	Mixed tree species number	0.00	1.00				0.330	**0.012**	0.37	0.26
	Number of tree species	0	3				0.330	**0.012**	1	1
	Mosaic diversity	0.00	2.15			0.250		**0.038**	1.19	1.17
	Age diversity	0	3			0.100		**0.015**	1	1
−	Habitat features				0.400					
	Stocking	0	3			0.330		**0.040**	3	3
	Heavy wooden share	0	3			0.330		**0.040**	1	1
−	Location potential					0.340				
	Water supply	0	3				0.500	**0.020**	1	1
	Nutrient supply	0	3				0.500	**0.020**	2	2
−	Special structures				0.100					
	Dead wood	0	3			0.330		**0.010**	1	1
	Location diversity	0	3			0.330		**0.010**	1	1
	Special local structures	0	3			0.340		**0.010**	1	1
−	**Rareness**			0.300						
	Biotope	0	3		0.500			**0.150**	1	1
	Protected areas	0	3		0.500			**0.150**	1	1

BE4 Habitat Suitability



MCA 1: Weighted summation {goal; Direct (Closeness to nature: 0.4)}

=		Minimum Range	Maximum Range	Weight level 1	Weight level 2	Weight level 3	Weight level 4	Weight	Current Climate	Future Climate
	Closeness to nature	0	3	0.400				**0.400**	2	2
−	**Structural diversity**			0.300						
−	Spatial Structure				0.500					
−	Vertical structure					0.400				
	Stratification	0.00	2.00				0.500	**0.030**	0.75	0.66
	Step range	0	3				0.500	**0.030**	2	2
−	Stock Structure					0.250				
	Tree species diversity	0	3				0.340	**0.013**	1	1
	Mixed tree species number	0.00	1.00				0.330	**0.012**	0.51	0.36
	Number of tree species	0	3				0.330	**0.012**	1	1
	Mosaic diversity	0.00	2.15			0.250		**0.038**	1.31	1.37
	Age diversity	0	3			0.100		**0.015**	2	2
−	Habitat features				0.400					
	Stocking	0	3			0.330		**0.040**	3	3
	Heavy wooden share	0	3			0.330		**0.040**	1	1
−	Location potential					0.340				
	Water supply	0	3				0.500	**0.020**	3	3
	Nutrient supply	0	3				0.500	**0.020**	1	1
−	Special structures				0.100					
	Dead wood	0	3			0.330		**0.010**	1	1
	Location diversity	0	3			0.330		**0.010**	1	1
	Special local structures	0	3			0.340		**0.010**	1	1
−	**Rareness**			0.300						
	Biotope	0	3		0.500			**0.150**	1	1
	Protected areas	0	3		0.500			**0.150**	1	1