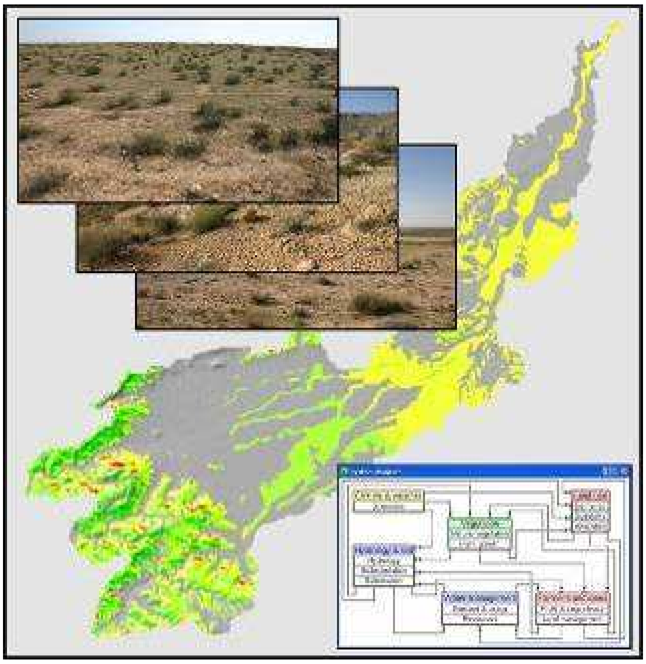
Centre for Geo-Information

Thesis Report GIRS-2008-12

Adaptation, calibration and application of the MedAction Vegetation Model: Opportunities of remote sensing based data sources

Job de Jong

May 2008



WAGENINGEN UNIVERSITY
WAGENINGEN UR

Adaptation, calibration and application of the
MedAction Vegetation Model:
Opportunities of remote sensing based data sources

Job de Jong

Registration number 81 02 12 404 040

<u>Supervisors</u>:

Prof. dr. ir. Arnold Bregt
Dr. ir. Lammert Kooistra
Ir. Hedwig van Delden

A thesis submitted in partial fulfilment of the degree of Master of Science
at Wageningen University and Research Centre,
The Netherlands.

May, 2008
Wageningen, The Netherlands

Thesis code number: GRS-80436
Thesis Report: GIRS-2008-12
Wageningen University and Research Centre
Laboratory of Geo-Information Science and Remote Sensing

Preface

I am glad to present this thesis report about modelling of natural vegetation dynamics, and the role of remote sensing in this. It has been a period of hard work, in which the progress was not always as I would have liked. Due to the birth of my son Sam, my mind often was on other issues than the thesis work, but thanks to the support of many people around me I was able to finish the work and to present the results in this report. I would like to thank all of those who have helped me during this project.

First of all I would like to express my gratitude to my supervisors. I was privileged to have three supervisors around me: Arnold Bregt, Lammert Kooistra and Hedwig van Delden. Thanks for the interest, explanations and ideas for my work, especially for the times when progress was a bit disappointing. It has been a great support during the process.

Beside Hedwig, I would like to thank the other colleagues from RIKS. It has been a great time working in Maastricht with you. Thanks for the support and good time during the weeks working at RIKS. I would like to thank Patrick for the discussions and explanations on the MedAction model, and the ideas during the modelling work.

From the IRA, I would like to thank Azaiez Ouled Belgacem in particular. Thanks for the ideas and patience to explain the characteristics of natural vegetation in the Jeffara region. Furthermore, I would like to thank the other people from IRA who I have worked with. Thanks a lot for the great hospitality and support during my stay at the institute. I have really enjoyed working with you!

Job de Jong

April 2008, Wageningen, The Netherlands

Abstract

The MedAction Policy Support System (PSS) is a dynamic spatial model that focuses on land degradation problems. The model incorporates socio-economic and physical processes, and is designed as a support tool for policy makers in Mediterranean areas dealing with land degradation. It gives the opportunity to explore autonomous trends and effects of policy options on both social and physical indicators like water shortage, farming profits and the Environmentally Sensitive Areas (ESA) indicator. For this study, the main objective was to adapt and apply the part of this model related to natural vegetation for the Jeffara region in South-East Tunisia, and to investigate the role of remote sensing based data sources in this process. Firstly, natural vegetation dynamics of the area where studied and compared to the conceptual model and adaptations were made where necessary. Main adaptations were defining area specific natural vegetation type classes and the introduction of locally defined grazing intensity into model calculations. Calibration was done with the Natural vegetation and Plant growth model components separately from the integrated model, without dynamic variable input concerning plant growth suitability for a cell. Adapting parameter values was done in an iterative process, aiming at model outcomes which reflect expected vegetation development based on expert knowledge. Validation was done based on comparison with known historical vegetation developments from literature and observed NDVI trends from MODIS time series. Although the model did show expected vegetation development in terms of seasonal variation and vegetation height development, the overall successional trend and the influence of grazing on this trend could not be modelled successfully yet. Furthermore, the influence of slope and aspect on plant growth was too large. Remote sensing based data sources within this study were mainly used for the initiation of the model. MODIS NDVI images where used to define the initial biomass amounts for the study area by linear regression of NDVI values with observed vegetation characteristics from field visits. A vegetation type map for the initial situation was derived from this biomass map. Due to the assumptions that had to be made to calibrate the model (using fixed input variables for the whole study area) observed trends in MODIS, NDVI developments could not be directly compared to the model results. Therefore the role of remote sensing in the calibration and validation phase was limited.

Keywords: Policy Support System; Land degradation; Spatial Modelling; Natural vegetation dynamics; Remote sensing

Table of contents

1 Introduction

Various types of models that predict or describe land-use change have been developed from different disciplinary backgrounds (Verburg et al., 2004). These dynamic spatial models estimate the change from one land use type to another by exploring the effects of different driving forces on the land use. The models give opportunities to examine autonomous developments in land use and to explore policy options that influence these developments. They can be applied to a wide range of topics. One of these topics is land degradation. Land degradation and desertification are increasing problems in arid, semi-arid and dry sub humid areas worldwide. Scenarios of future development show that, although magnitude and impacts of desertification vary greatly from place to place, if unchecked, desertification and degradation of ecosystems in drylands will threaten future improvements in human well-being and possibly reverse gains in some regions (MEA, 2005).
The MedAction Policy Support System (PSS) is a dynamic spatial model that focuses on land degradation problems. It has been developed by a consortium of RIKS B.V, Maastricht and King's College London. The aim of this model is to provide a support tool for policy makers confronted with land degradation, desertification and land use change in Mediterranean watersheds and regions. It incorporates socio-economic and physical processes, and is implemented in the GEONAMICA application framework (Van Delden et al., 2007). MEDACTION is intended to support planning and policy making in the fields of land degradation, desertification, water management and sustainable farming at a spatial resolution of 100x100m. The model gives the opportunity to explore indicator values in these fields like the Environmentally Sensitive Areas (ESA) indicator, Water Shortage indicator, and farming profits.

A system diagram of the different components within the model is given in figure 1. This system is generic for Mediterranean regions and previous versions of the system have been applied to the Marina Baixa (Spain), the Argolidas (Greece) and the Guadalentín river basin (Spain) (Van Delden et al., 2004; Van Delden et al., 2007).

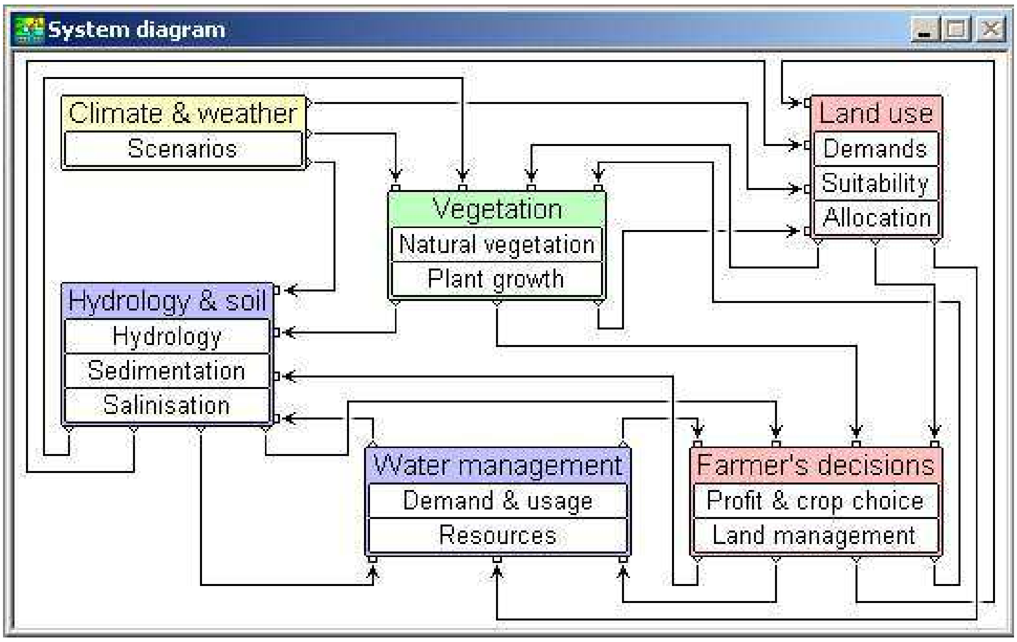


Figure 1.1; System diagram of the MedAction Policy Support System

Currently, RIKS B.V. and King's College London in cooperation with the Tunisian Arid Regions Institute (IRA) are involved in applying the MEDACTION PSS to the Jeffara region in South-East-

Tunisia. In Tunisia, more then 75% of the total land surface shows severe human induced desertification (FAO/AGL, 2005). Desertification can be defined as; 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' in which degradation implies reduction of resource potential by one or a combination of processes acting on the land (UNEP/GEF, 2002).

Land degradation and desertification problems in Tunisia are mainly caused by unfavourable environmental conditions, cultivation and overgrazing and over harvesting of Alfa grass (Puigdefabregas & Mendizabal, 1998; Baban et al., 1999; Ping An et al*.,* 2006). One of the areas in Tunisia that is particularly exposed to the risk of desertification, like many of the arid or semi-arid Mediterranean regions, is the Jeffara region in the South-East. For about 40 years now, pressure on resources has strongly increased, especially on water stocks. Ecological studies reveal, in addition to the disturbing erosion of original vegetation, an increasing overall uniformity of the flora and hence a loss of biodiversity (Genin et al., 2006). Desertification has become the principal environmental problem in Southern Tunisia, and does not stop worsening (Ben Salem et al., 2007).

1.1 Problem definition

The MEDACTION PSS could support planning and policy making in Tunisia concerning the land degradation issues. To analyze the models' suitability in the Tunisian context, the model has to be adapted to the circumstances as they occur in the study area. Application of a model in a new setting requires appropriate data for the new circumstances.

For this research, the natural vegetation part of the model was analyzed for the study area, consisting of a natural vegetation component and a plant growth component. Other model parts (figure 1.1) were adapted by RIKS B.V., Kings College London or IRA.

The natural vegetation Model Building Block (MBB) simulates the dynamics of 'natural' vegetation in terms of succession and response to disturbance, where 'natural' is defined as all non-agricultural and non-urban vegetation (Van Delden et al., 2004). The model calculates for each natural vegetation cell the natural vegetation type group as well as its height. The temporal resolution of the model is one month.

Dynamic parameters like vegetation height, fractional cover and availability of seeds define whether transition from one vegetation type to another takes place. Furthermore, there are two policy options that influence this transition; fire prevalence and grazing. Each of these options is taken into account by means of a map representing the fire return period and the grazing intensity respectively for each cell.

The plant growth MBB calculates developments in amounts of biomass for both natural vegetation covered cells as well as for agricultural crops. Biomass values are calculated separately for different plant parts, and based on these values variables like Leaf Area Index (LAI), vegetation cover and yield are calculated. Increment rates are dependent on a cells' suitability for plant growth. The temporal resolution of the model is one day. A more detailed model description of both the natural vegetation and the plant growth MBB is given in paragraph 1.3.2 and 1.3.3.

MedAction is initiated with several variables concerning vegetation. In this study, the use of remote sensing based data sources in defining these variables was investigated. Remote sensing plays an important role in land degradation monitoring and modelling (Hill and Peter, 1996; Stéphenne and Lambin, 2001; Dall'Olmo and Karnielli, 2002; Shoshany and Svoray, 2002). The advantages of remotely sensed data, such as in repetivity of data collection, a

synoptic view, a digital format that allows fast processing of large quantities of data, and the high correlations between spectral bands and vegetation parameters, make it the primary source for estimation of vegetation characteristics like above-ground biomass, especially in areas of difficult access (Lu, 2006).
For several steps in modelling vegetation dynamics, the characteristics from the real vegetation situation have to be used as input for the model. Many studies have been conducted on methods to estimate vegetation parameters like leaf area index (LAI) or above ground biomass, among which methods using remotely sensed data. Methods to estimate vegetation parameters based on remote sensing based data sources include spectral unmixing (Asner and Lobell, 2000; Shoshany and Svoray, 2002), regression analysis (Todd et al., 1998, Jensen and Binford, 2004), K nearest-neighbour (Fazakas et al., 1999), artificial neural network analysis (Jensen and Binford, 2004), and vegetation canopy models (Zhang and Kondragunta, 2006).
Huete et al. (2002) demonstrated that the MODIS Vegetation Indexes (VIs) are sensitive to multi-temporal (seasonal) vegetation variations, land cover variations, and biophysical parameter variations. Both the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) demonstrated a good dynamic range and sensitivity for monitoring and assessing spatial and temporal variations in vegetation amount and condition. The ranges in NDVI and EVI values for each biome type showed the NDVI to have a higher range in values over the semiarid sites, but at the expense of a lower dynamic range over the more humid forested sites.
The NDVI has been found to be highly correlated with vegetation parameters such as above ground green biomass and percentage vegetation cover in semi-arid regions (Elmore et al., 2000) or in Tunisia specifically (Wellens, 1997), although other studies suggest that vegetation monitoring based on the NDVI was found to be limited in describing biomass and percentage vegetation cover, especially at low density cover (Shoshany et al., 1996).

A good understanding of the land-use change process requires historical reconstruction of past land-cover conversions. This can be achieved by analysis of remote sensing data, which provides a consistent and reliable source of information on land cover in the past. Where discrete thematic maps often differ much between countries or regions concerning spatial and thematic accuracy, remote sensing products could form a consistent and reliable data source at initiation, calibration and validation stages of the modelling process (see e.g. Plummer, 2000; Wegehenkel et al., 2005; Campo et al., 2006).

1.2 Research objectives and research questions

This study will focus on the natural vegetation related parts of the MEDACTION PSS. The main objective of this research can be formulated as;

To adapt and validate the MEDACTION PSS Natural vegetation and Plant growth model for the Jeffara region in Southern Tunisia, and to investigate the role of remote sensing based data sources in this process.

In order to come to the main objective of this research, a couple of initial steps had to be taken. These steps can be translated into the following research questions:

A - How can the Natural vegetation related model building blocks from the MEDACTION policy support system be adapted to Tunisian circumstances?
B - What parameter values and transition rules give optimum model outcomes?
C - How well does the model simulate the real natural vegetation dynamics in the study area?
D – What opportunities do remote sensing based data sources give in the modelling process?

1.3 Model description

The MedAction PSS is a dynamic spatial integrated model which integrates 15 individual models, or Model Building Blocks (MBBs). The integration of all these models has lead to a complex system. The natural vegetation MBB for example has direct links to the Profit & crop choice MBB, the Plant Growth MBB and the Land use allocation MBB. The way the Natural vegetation MBB and the Plant Growth MBB are integrated in the model (figure 1.1), and the calculations within these MBBs will be explained in this paragraph.

The different MBBs, all written in programming language C++, are integrated within the MedAction PSS and form a complex network of links between each other. This makes it possible for the model to pass on effects from a certain MBB to other MBBs and to link physical and socio-economic processes. It also gives a lot of opportunities to use updated information as dynamic input by creating so called feedback loops. For example, soil moisture is calculated in the hydrology MBB and is used to calculate biomass in the plant growth MBB. Biomass in turn, however, is an input in the calculation of soil moisture through the dependence of soil evaporation and transpiration on leaf area index and root biomass (Van Delden et al., 2007). An overview of the different MBBs and the links between them is presented in the system diagram, in figure 1.1.
The Natural vegetation MBB models the development of all the natural vegetation cells within the modelling area at community level. Changes in vegetation properties like vegetation height and vegetation cover determine when and how a cell's vegetation type will change. Possible changes are dependent on potential transitions and transition rules as defined by the user, which together form a successional state transition network.
The main driving force of the succession of natural vegetation is the development of biomass. Vegetation height and vegetation cover are directly calculated from biomass with vegetation type specific conversion parameters. Biomass development is calculated within the Plant Growth MBB, but since it is the main influencing factor for the natural vegetation MBB, a short overview of the plant growth MBB simulation as described by Van Delden et al. (2004) will be given.

1.3.1 *Plant Growth MBB*

> The Plant Growth MBB calculates the biomass of the different plant types covering a cell. For this reason plants are grouped into functional types and is each plant divided into five parts: leaf, live stem, wood, root and yield. During daylight hours the maximum growth of the plant is calculated based on the efficiency with which it can convert energy from solar radiation into biomass. This growth is diminished because of respiration for growth and maintenance as well as stress factors like a lack of fertile soil, too saline soil, too steep slopes or suboptimal soil moisture and temperature. The amount of growth diminished for maintenance respiration is influenced by the daily temperature and by the amount of biomass at a cell at the previous time step. No maintenance respiration is calculated for the woody plant parts and for the underwater roots. For all the other plant parts, maintenance respiration can actually be higher then growth, resulting in biomass reduction.
>
> Based on the biomass, other plant structural properties are calculated which are essential for understanding the dynamics of radiation interception as well as the hydrological impact of plants:
> -The vegetation cover, which describes the fraction of a cell covered by leaves;
> -The leaf area index, which describes the leaf area per area covered.
>
> During the simulation the biomass is updated each day. When transitions from non-vegetated land uses (urban residential, rural residential, tourism, ex-patriots, industry & commerce) to natural vegetation take place, the natural vegetation type group is set at annual grasses with a very small biomass (10 grams) allowing vegetation to grow from this point onwards.

The vegetation cover as well as the Wood Biomass and the Live Stem Biomass are direct input for the Natural vegetation MBB. A detailed description of the plant growth MBB together with all the equations is given in appendix 1.

1.3.2 *Natural Vegetation MBB*

Natural vegetation dynamics are modelled within the natural vegetation MBB as transitions between different vegetation types. The transition from one natural vegetation type to another (either regressive or progressive succession) is based on the possible transitions and the transition conditions for each transition. A description of the simulation is given by Van Delden (2004):

> The natural vegetation MBB models vegetation at the 'community level' whereby the internal (possible species mixtures and competition) and external (e.g. soil water controlled growth rates) properties of floristically defined vegetation types or states are reasoned with in order to make predictions about overall vegetation dynamics. To make such predictions the possible vegetation types for a region are linked by potential transitions to construct one or more successional state transition networks. Changes in community level vegetation properties over time then determine when and how a cell's vegetation will change state according to the constraints of the state transition network being followed. First is determined in the land use module what the number and location of the natural vegetation cells in the region is.

For cells that were previously occupied by agriculture the natural vegetation type group is determined by the last crop type occupying the cell. Changes in the natural vegetation type groups are determined with a set of rules comprising the following properties:

'Non-anthropogenic' driving forces:

The availability of seeds, calculated on the basis of the natural vegetation types present and the distance over which their seeds can be dispersed;

The vegetation cover, calculated in the plant growth model;

The vegetation height, calculated on the basis on the wood and live stem biomass from the plant growth model.

Land management options that may affect dynamics:

Periodic burning (which may be both naturally occurring or man-made) is handled by the setting of a 'fire prevalence' variable for each cell with either a value of 0, representing a fire return period of between 5 and 20 years or a value of 1, representing a return period of between 20 and 50 years;

Grazing is handled by the setting of a 'grazing animals' variable for each cell with either a value of 0, representing none to low grazing animal density or a value of 1, representing a medium to high grazing animal density. The qualitative distinction between no to low and medium to high impact severities is left to the model user although representative figures (number of animals per hectare) for sheep and goats are 0 to 1 for none to low grazing presence, and > 1 for medium to high grazing presence. The 'grazing animals' variable affects the growth and mortality of the vegetation. The biomass grazed by animals is therefore subtracted from the leaf biomass in the plant growth model.

The MedAction PSS calculates the 'non-anthropogenic' driving forces as well as the location of natural vegetation cells dynamically. The land management options can be installed by the user who can change them during a simulation run, thereby representing changes in fire management regimes or grazing animal stocking levels. The user can also adapt, add or delete the transition rules.

Model's Algorithm

The land use model calculates the number and location of natural vegetation cells at the beginning of the simulation and at the first day of each year. These cells are complemented with the abandoned cells from the crop choice module, so defining the total area of natural vegetation for this year. Subsequently initial calculations are carried out to determine what natural vegetation type groups are occupying the new natural vegetation cells. Based on the natural vegetation type group covering a cell possible transitions into other natural vegetation type groups are then calculated. Transitions of one natural vegetation type group (NVT_{m-1}) into another (NVT_m) take place on the basis of a set of rules checking the following:

-a certain minimum or maximum canopy height (CH_{m-1});

-a certain minimum or maximum vegetation cover level (VC_{d-1});

-whether the fire prevalence (FP_{d-1}) of a cell is high (return period between 5–20 years) or low (return period between 20–50 years), based on a static map;

-whether or not the cell is susceptible to grazing (GR_{d-1}) under medium – high grazing animal density, based on a static map;

-whether or not seeds (SE_{m-1}) of the (target) vegetation type are dispersed in the cell.

In which; $_m$=month
$_d$=day

Each rule describes the condition in which one natural vegetation type group will change into another, based on the values of the five properties mentioned above. Only if the values for all properties are satisfactory, the change will take place. It is also taken into account if a property is relevant or not. The rules describing the transitions can be found and adapted in the user interface. They are processed in order of their sequence. The transition values for each of the properties can be adapted by the user, as well as the sequence of the transition rules.
The height of the new natural vegetation type group in a cell is determined through the wood and live stem biomass calculated in the MBB: Plant growth and a plant type specific parameter defining the conversion from biomass to height. The height is bounded by a plant specific maximum canopy height (CH):

$$CH = \min\{(B_{LS,d} + B_{W,d}) \cdot HSB_{qd}, CH_{\max,qd}\}$$

In which
$_q$=vegetation type q
B_{LS} = Live stem biomass
B_W = Wood Biomass
HSB = Height per stem biomass
CH_{max} = Maximum canopy height

The seed dispersal (SE) map shows for each cell if seeds for a specific natural vegetation group are present. Based on the canopy height of a cell is determined if the minimum height for seed dispersal is reached. Using this information together with the plant type specific seed dispersal distance, the seed dispersal maps are updated. If a cell is susceptible to grazing under medium – high grazing animal density, the leaf biomass is decreased by a vegetation specific reduction fraction in the plant growth model. Using the new values of the natural vegetation type group and height a number of indicators is calculated:

-The number of cells covered by each natural vegetation type group.

-The average height (CH) for each natural vegetation type group:

$$CH_{avg,q} = \frac{\sum C_{NV,q} \cdot CH_q}{C_{NV,q}}$$

In this equation is C the collection of natural vegetation cells occupied by plant type q.

The average vegetation cover (VC) for each natural vegetation type group:

$$VC_{avg,q} = \frac{\sum C_{NV,q} \cdot VC_{ini,q}}{C_{NV,q}}$$

1.4 Outline report

The steps that were taken to answer the different research questions will be described in chapter 2, materials and methods. First of all, a brief description of the study area in the Jeffara region in Southern Tunisia will be given. Next, a list of datasets that were used in this study will be provided. Details on acquisition and accuracy will be given. Furthermore, the methodology of the steps taken in this study will be described. This methodology is separated into five parts; model adaptation, model initiation, model calibration, model validation and the use of remote sensing based data sources in these modelling steps.
The results will be presented in chapter 3, separated into four parts; model adaptation, model initiation, model calibration and model validation. The use of remote sensing based data sources, together with the context in which the results should be seen are described in chapter 4 (Discussion). Finally, conclusions and recommendations are given in chapters 5 and 6 respectively

2 Materials and Methods

2.1 Study Area

The study will be focussing on the pre-Saharan region of Jeffara in South-Eastern Tunisia. By its position, the climate in the study area is of the arid Mediterranean type. The coldest month is December, with occasional freezing (down to –3 °C).The period between June and August is the warmest of the year, during which temperatures can reach as high as 48 °C. The temperature in the region is affected by its proximity to the sea and its altitude. Altitudes in the study area go up to about 750 m above mean sea level. The average annual rainfall in the study area lays between 150 and 240 mm, with high irregularity both in time and space. The prevailing winds affecting the area are cool and humid eastern/north-eastern winds in winter, and hot and dry south-eastern winds called Chhili or Guebli, in summer (IRA, 2003).

The extent of the study area is based on the limits of the catchment of Zeuss-Koutine. The catchment stretches out from the south-west, in the Matmata mountains near Béni Khdache and Toujane, going through the Jeffara plains, towards the Gulf of Gabès (Mediterranean sea), actually ending in the saline depression (Sebkhas) of Oum Zessar (figure 2.1). The distance from the mountains in the south-west to the sebkhas in the north-east is approximately 48 km, with a maximum catchment width of about 15 km.

Figure 2.1; Location of the Zeuss-Koutine catchment (from Google Maps ©)

2.2 Datasets

2.2.1 MODIS Vegetation Indexes (MOD13Q1)

MODIS is a sensor on the Terra satellite launched in December 1999. MODIS has been delivering measurements for several products at different temporal and spatial resolutions from February 2000 onwards. One of these products is the MODIS Vegetation Indices product (MOD13) which was used for the initiation of the MedAction model. From MOD13, several sub-products are made, among which a near global coverage 16 day composite Vegetation Index product, (MOD13Q1) with a pixel size of 250 x 250m. This product contains surface spectral reflectance for blue, red, near infrared and middle infrared bands (centred at wavelengths 466 nm, 646 nm, 857 nm and 2114 nm), quality indicators and vegetation indices like the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) (Huete et al., 1999).

NDVI is calculated as following:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

EVI is calculated as following:

$$EVI = G \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + C_1 \cdot \rho_{RED} - C_2 \cdot \rho_{BLUE} + L}$$

In which:
ρ_x = Atmospherically corrected surface reflectance in band x
G = Gain factor
C_1 and C_2 = Coefficients of the aerosol resistance term
L = Canopy background adjustment factor

For MODIS, these coefficients are found to be as follows;
L= 1, C_1 = 6, C_2 = 7.5, G = 2.5 (Huete et al., 2002).

MOD13 is based on an estimate of the surface spectral reflectance (MOD09) as it would have been measured at ground level if there were no atmospheric scattering or absorption. The correction scheme includes corrections for the effect atmospheric gases, aerosols, and thin cirrus clouds (for details, see Vermote et al., 1997).

The spatial resolution of MOD13Q1 is lower than the modelling resolution of 100 meter. Higher resolution imagery from Landsat was only available from at least eight years prior to the field visit and therefore not useful for the initiation of the model considering the lack of ground truth data from the date of acquisition and the modelling period of 22 years. Despite the shortcoming in spatial accuracy, MODIS was considered appropriate to use. The main advantages of MODIS products are the high temporal resolution and good data availability. From large parts of the world, 16 day composites of the product can be downloaded and used free of charge (http://lpdaac.usgs.gov/). This made it possible to directly compare field observations like vegetation cover and vegetation type with the satellite measurements from the same period.
For this study, images of the MOD13Q1 product were used dating from February 2000 until October 2007. Images where imported and reprojected to UTM 32N using ERDAS imagine. A

subset of the area was made from available images. Images where stacked as layers into one image file to be able to conduct time series analysis.

2.2.2 Quickbird satellite images

Satellite images from the Quickbird satellite, which are available on Google Earth in natural color, have been used in this study. The quickbird satellite, launched in 2001, is a commercial earth observation satellite providing images in the blue, green, red and NIR wavelengths (centered at 479.5nm 546.5nm 654nm 814.5nm respectively) at 2.4 meter spatial resolution, and a panchromatic image with a spatial resolution of 62 cm (DigitalGlobe, 2002).
The used images were available on Google Earth (accessed between October 2007 and Ferbruary 2008), where orthorectified images could be accessed with acquisition dates 19-08-2004 and 22-09-2006. Most of the study area and areas visited during the field trips were covered by these Quickbird images.

2.2.3 Ground Truth data

During field visits in October 2007, ground truth data was collected for interpretation of satellite images. From several natural vegetation covered areas throughout the Jeffara region, locations were recorded with a hand held Garmin GPS-receiver. For each location, the vegetation type, vegetation cover and vegetation height was described based on visual interpretation of the author and natural vegetation expert Dr. Azaiez Ouled Belgacem. In some cases, a brief description of the extent of the described area or remarks concerning surrounding land use was given. A list of coordinates and descriptions is given in appendix 2.

2.3 Methods

2.3.1 Model adaptation

To answer the first research question ("How can the Natural vegetation model from the MEDACTION PSS be adapted to Tunisian circumstances?"), the applicability of the model in the Jeffara region was examined. The model had to be compared with the different factors influencing vegetation dynamics in the Jeffara region. This comparison was done by getting a clear insight in the models' calculations and behaviour and by studying the vegetation dynamics of the Jeffara region. The latter was done by literature study, discussions with a natural vegetation expert of the Arid Regions Institute in Medenine Tunisia, and during a field visits in October 2007. If the conceptual model was insufficiently covering the influences on natural vegetation dynamics for Jeffara, possible improvements were discussed and adapted in the model by Patrick Luja, software developer at RIKS B.V.

2.3.2 Model Initiation

The Natural Vegetation MBB has direct links to other MBBs and gets various dynamic input variables from other model components (see table 2.1). Each of the input variables and parameter values within the mode that influences the development of natural vegetation had to be adapted in order to represent the situation in the Jeffara region. The difference between a variable and a parameter in this study can be defined as follows. A variable is a representation of a factor influencing vegetation development that can vary throughout the modelling period and which is calculated dynamically during the modelling period. A parameter is fixed for the whole modelling period and will be adjusted to improve developments of variables and model outcomes during the calibration phase in this study. A list of the input variables and parameter values is given in tables 2.1.

Table 2.1; Variables influencing natural vegetation development

Input variable	MBB	Units
Land use	Land use	categorical
Vegetation type	Natural vegetation	categorical
Biomass	Natural vegetation	gr/m2/day
Daily sunlight hours	Climate & weather	hrs/day
Monthly average temperature	Climate & weather	ºC
Soil depth	Hydrology & soil	m
Soil salinity	Hydrology & soil	gr/m3
Slope	Hydrology & soil	degree
Soil moisture	Hydrology & soil	m3 water / m3 pores
Precipitation	Climate & weather	mm/day

In order to be able to run the natural vegetation MBB, some input from other MBBs is inevitably needed. Some variables could be taken as static values. A selection of input variables and parameter values that were used for further analysis and calibration of the natural vegetation MBB was made based on availability of data and progress in setting up of other MBBs by other parties. For some parameter values and input variables, no data was available for the Jeffara region specifically. If these variables were essential for running the natural vegetation or plant growth MBBs, values were copied from the calibrated model version for the Guadelentín basin in Spain. These values were adapted to circumstances in the Jeffara region in a later stage.
The methodology for defining each of the variables listed in table 2.2 will be shortly described.

2.3.2.1 Land use
The land use map is a map in which the dominant land use is defined for each cell within the study area. This map is used by most of the MBBs and the initial land use map (t=0) has been created by IRA for 2004. For the natural vegetation, this map originally contained three different classes covering all the areas of natural vegetation. The classes were; Halophyte rangelands, Mountain rangelands and Plain rangelands. The cells defined as these three natural vegetation classes were used for a classification of the newly defined natural vegetation type classes as described in section 2.3.2.2. Other land use classes were agricultural (cereals and olives), industry and rural residential.

2.3.2.2 Initial vegetation type
The natural vegetation classes from the original land use map were used as a mask to create a new natural vegetation type map, although the low spatial and categorical accuracy of this land use map probably led to errors in the final natural vegetation type map (see results and discussion). The classes as defined in the existing land use map were inappropriate to use for the natural vegetation model since these classes were more or less geographically assigned classes. The natural vegetation MBB defines the natural vegetation type of the cell mainly based on quantitative developments of plants within each cell. Therefore a new classification of natural vegetation in the Jeffara region was made. Different plant communities as described in literature where grouped into six different vegetation types according to similarity in quantitative characteristics like above ground biomass, vegetation height and vegetation cover. For each of the new vegetation type classes a range of fractional cover, vegetation height and above

ground biomass was defined. Each natural vegetation cell in the study area was assigned to one of the classes according to their corresponding vegetation biomass value, which was determined as described in section 2.3.2.3.

2.3.2.3 Initial biomass

The selected strategy for initiation of the model in terms of biomass, vegetation cover and vegetation type in this study was linear regression analysis of vegetation indexes (VIs) from a Moderate Resolution Imaging Spectroradiometer (MODIS) composite image from 16-30 October 2007. Despite the fact that other strategies have been found to be more precise in vegetation parameter estimation (Jensen and Binford, 2004), the limited amount of ground truth data like spectral signatures (for spectral unmixing), appropriate information to feed vegetation models and sufficient amounts of ground-truth data for artificial neural network analysis were not available for the study area. From the two available MODIS VIs (EVI and NDVI), NDVI was considered to be most appropriate for vegetation parameter estimation in the Jeffara region and was used for linear regression. Temporal and spatial variation in NDVI was higher, giving more opportunities to separate different vegetation types or densities based on observed values. These differences are illustrated in the graphs presented in appendix 5. The difference corresponds with differences found in literature were NDVI is considered to be more sensitive in low density vegetation (Huete et al., 2002).

The difficulty in vegetation monitoring using remote sensing data like the MODIS VIs is that their spectral resolution is low. The spectrally distinct features of foliage, litter, wood, and soil of arid ecosystems are relatively narrow, making narrowband optical data a necessity for detailed quantitative biophysical assessments (Anser et al., 2000). Another problem of estimating vegetation parameters using MODIS data is the coarse spatial resolution. The above-ground biomass estimation using coarse spatial-resolution data is still very limited because of the common occurrence of mixed pixels and the huge difference between the size of field measurement data and pixel size in the image, resulting in difficulty in the integration of sample data and remote sensing-derived variables (Lu, 2006).

During two field visits in October 2007 which were both covered by one MOD13Q1 image composite period, GPS points where collected covering several different vegetation types in the study area. No special sampling strategy could be used because of lack of time and transportation means. At both field visits, GPS locations were recorded from the natural vegetation covered areas in and directly around the study area. Next to the location, information about vegetation type, coverage area, fractional vegetation cover, vegetation height and plant community was recorded (all based on visual interpretation of the author and vegetation expert from IRA). In total, 58 GPS points and descriptions of several different vegetation types were collected (Appendix 3).

For each of the different points collected in the field, NDVI values were extracted from the MOD13Q1 composite image. These values were compared with the observed vegetation cover values. The best fit linear function was used to create the vegetation cover map for the natural vegetation parts of the study area. Since vegetation cover is not a direct input for the model, values had to be translated into biomass values. No field data on biomass levels could be collected directly due to limited time and complexity of methods for biomass estimation.

As described in the 'Initial vegetation type' paragraph (section 2.3.2.2) of this chapter, both biomass and vegetation cover ranges were defined for each vegetation type. The vegetation cover values as estimated with linear regression were translated into corresponding biomass values. It was assumed that these two parameters are correlated in the sense that the minimum vegetation cover of a vegetation type, relates to the minimum biomass value of that same vegetation type, and maximum cover relates to maximum biomass. The biomass values that correspond with the estimated vegetation cover values (figure 3.6) were used as initial biomass values for the model.

2.3.2.4 Daily sunlight hours
Sunlight is modelled in the Climate & weather MBB, and is based on the location of the study area on the earth, and is calculated for each day. Details on calculation of available sunlight can be found in the user manual and model descriptions (Van Delden et al., 2004).

2.3.2.5 Monthly average temperature
Monthly average temperature is also calculated in the Climate & weather MBB. For the Jeffara region, this part of the model was not yet calibrated at the time of study. Data from the Argolidas region in Greece was used to be able to have seasonal variability within the calculations of plant growth. Average monthly temperatures from this region are about 3.5ºC higher than observed temperatures in the Jeffara region, varying from around 5ºC in December to about 33 ºC in august.

2.3.2.6 Soil depth
A map of soil depth data with a spatial resolution of 100 x 100 meters was available from IRA and could be used for the model.

2.3.2.7 Soil salinity
No data on soil salinity was available, so soil salinity was set at 0 for each cell. By taking a value of 0, influence of soil salinity on natural vegetation development was excluded.

2.3.2.8 Slope
A slope map of the region was available from IRA and could be used for the model. The spatial resolution of this map was 100x100 meters.

2.3.2.9 Soil moisture
No data on soil moisture was available for the region. Since the hydrology & soil MBB was not yet calibrated at the time of this study, no reliable information

2.3.2.10 Precipitation
Precipitation is also calculated in the Climate & weather MBB. For the Jeffara region, this part of the model was not yet calibrated at the time of study. Like for average temperature, data from the Argolidas region in Greece was used for the Jeffara region. Since annual precipitation in the Argolidas region is about 4 times higher than in the Jeffara region, a precipitation offset of 0.25 was used for each cell resulting in reduced precipitation rates, comparable to the average amounts of precipitation in the Jeffara region.

Due to the limited availability of input data, the model could not be initiated completely. This was mainly influencing natural vegetation dynamics by the lack of information on the dynamic plant growth suitability factor per cell. The way in which this lack of information was coped with in this study is described in paragraph 2.3.3.

2.3.3 Model calibration

The ability of the model to simulate developments in natural vegetation types for the Jeffara region is based on the accuracy of the parameters and input variables, and on the applicability of the conceptual model to the region. The different parameters within the Natural Vegetation and Plant Growth MBB are given in table 2.2. An overview of the links and influences of parameters and input variables on the Natural Vegetation MBB within MedAction is given in figure 2.2.

Table 2.2; Parameters influencing natural vegetation development

Parameter	MBB	Units
Leaf density	Plant growth	g/m2
Radiation use efficiency	Plant growth	g/MJ
Initial leaf fraction	Plant growth	g/g_{tot}
Initial root fraction	Plant growth	g/g_{tot}
Initial wood fraction	Plant growth	g/g_{tot}
Initial live stem fraction	Plant growth	g/g_{tot}
Leaf fraction	Plant growth	g/g_{tot}
Root fraction	Plant growth	g/g_{tot}
Wood fraction	Plant growth	g/g_{tot}
Live stem fraction	Plant growth	g/g_{tot}
Maximum height	Natural vegetation	m
Stem biomass per meter height	Natural vegetation	g/m
Leaf biomass grazed daily	Natural vegetation	gr/m2/day
Plant growth ability*	Plant growth	0-1

*Plant growth ability can be defined for Soil depth, soil moisture, salinity, slope and temperature separately

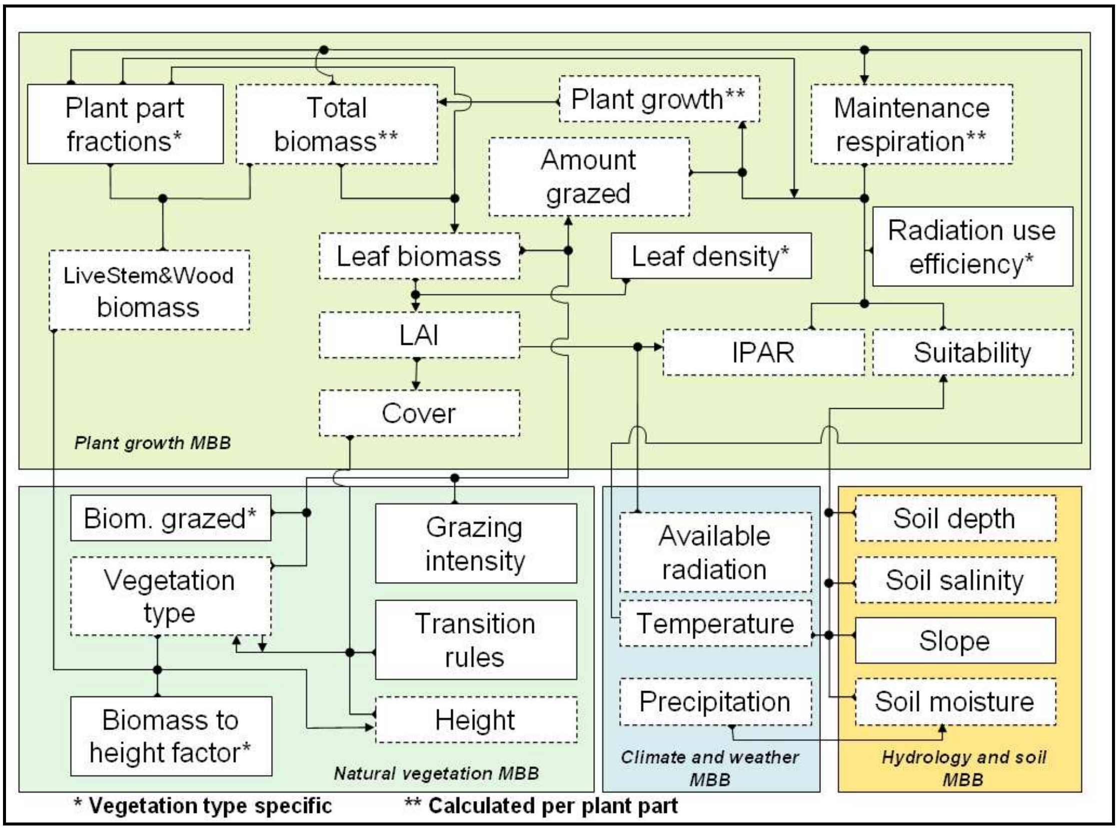


Figure 2.2; Overview of links between the main model components influencing the natural vegetation MBB. Dynamic variables are shown with a dashed line

The only direct input variables influencing developments in the Natural vegetation MBB are Livestem&Wood biomass, and the vegetation cover, both from the Plant growth MBB. Since most of the parameters within the natural vegetation model itself are based on expert

knowledge and literature study (paragraph 2.3.2.3), calibration of the Natural Vegetation MBB separately, without dynamic input like biomass and cover rates would not make sense. Therefore a combination of the plant growth MBB together with the natural vegetation MBB was used for calibration.
Within the Plant growth MBB, several input variables were assumed to be constant due lack of reliable information on input variables. For plant growth ability, a fixed value of 0.5 was used, resulting in half the amount of optimal growth. Where the model originally limits plant growth dynamically due to limited Fertile Soil Depth or unfavourable conditions of soil moisture, soil salinity, slope and temperature, the whole study area was treated equally by taking suitability factor 0.5. A reduced value for plant growth was used to have a more realistic simulation of natural vegetation dynamics than with optimal growth, since circumstances in the Jeffara region are far from optimal for plant growth, mainly due to limited availability of soil moisture. By taking a fixed suitability value for all cells, influences of lack of soil salinity data and possible errors in modelled precipitation were excluded from analysis. The suitability set at 0.5 for the whole modelling period, so plant growth was assumed independent from amounts of precipitation, soil salinity and soil depth. Slope and temperature still play a role in plant growth calculations as can be read in appendix 1.
The dynamic suitability part of the plant growth MBB can only be taken into account if useful input could be produced by the Climate & weather and the Hydrology & soil MBBs. Since these MBBs were not calibrated yet at the time of this study, these factors would only have distorting effects on the model outcome if dynamic input from these MBBs would be used.

For the calibration, a strategy of several steps was used. For the first calibration step, grazing intensity for the whole study area was set at 0 to be able to get a good view on the plant growth, and therefore indirectly on vegetation dynamics, without disturbing influences of grazing. Since most of the parameter values were defined in the model initiation part prior to this calibration, a global behaviour test of the model using these standard input values was made as a first step. This iterative process of studying model behaviour was done using standard model input based on knowledge from the circumstances in the Jeffara region, in combination with parameter values for the previously calibrated model for the Guadelentín Basin in Spain and the Argolidas region in Greece. A list of all parameters was made. Sensitivity of the different parameters was analysed by estimating the influence of each of the parameters on the model behaviour.
A second step was adapting the parameters to values that lead to model results that reflect vegetation developments as could be expected based on expert knowledge and observed historical trends in MODIS NDVI. Beside the MODIS composite image that was used for the initiation in terms of biomass and vegetation type, a time series of similar MODIS images was available from February 2000 onwards. For each of the visited locations in the field, the development of the NDVI, and thereby indirectly of vegetation cover and biomass values, were available for a period of nearly eight years. This time series was used to calibrate the model in terms of biomass development and vegetation type development.
The first image from the time series (February 2000) was used to create the initial biomass map and vegetation type map for the calibration period of eight years. It was assumed that ratios between NDVI values and vegetation cover were constant and that the function for the creation of the initial biomass map for 2007 could be used for 2000 as well. The same strategy as described in the model initiation paragraph (paragraph 2.3.2) was used to create input maps for 2000.
Based on findings from the global behaviour test and the sensitivity analysis, several scenarios were examined with possible parameter values to improve the standard-input modelling result.

Terms of success were defined in advance in which the expectation of a successful modelling result was formulated. The expected trends in vegetation type, biomass, vegetation height and vegetation cover development where defined based on discussions with IRAs natural vegetation expert and literature study. Terms of success were formulated in such a way that they were directly comparable with modelling results.
The modelling results were tested with the terms of success. The best result was selected for further calibration of parameters and input variables.
The model offers several options to follow developments of variables within the model on a detailed base. One of the options was to write all variable values from one cell to an excel file for each time step (cell 258,192). This option, together with several output maps, was used to examine the functioning of the model. The selected cell for analysis of development of the variables had an average initial biomass (vegetation type Open perennial), and is located near the centre of the study area.

In a second calibration round, grazing was turned on and biomass increment was modelled with grazing influences. The parameter 'leaf biomass grazed daily' was defined by taking the average daily leaf biomass increment per vegetation type from the calibrated model as described in step one. This amount of leaf biomass increment was calculated by taking the average leaf biomass of a cell initially covered with that particular vegetation type for the period in which the cell remains the same vegetation type. The amount of leaf biomass increment was divided by 365 (number of days). This gives the average daily leaf biomass increment of each year. This increment rate was extracted from the model with the log function (writes the variable values from selected MBBs to an excel file at each time step). For each vegetation type initially present in the study area (all types except for shrub vegetation) a cell was chosen in a more or less flat area to exclude distorting effects of slope and aspect (see paragraph 3.3.3). The cells that where logged where 82-331 (AL); 141-322 (DP); 258-192 (OP); 213-268 (DWP); 323-51 (WM). By taking this daily increment value for the 'leaf biomass grazed daily' parameter, leaf biomass consumption in areas with a grazing would averagely be the same as leaf biomass increment, resulting in a more or less stable situation. Further details on the calculations of grazing and amounts of biomass grazed are given in paragraph 3.1.2, where a model adaptation on grazing intensity is explained.
The optimum model settings in terms of initial variable and parameter values as found during this calibration phase will be used to explore vegetation dynamics in the future.

2.3.4 Model Validation

The aim of the model is to simulate real developments of natural vegetation in the Jeffara region over a period of 20 to 30 years. Since no data on the development of natural vegetation in the future is available, validation on the ability of the model to simulate this development had to be done in another way. Two types of validation were applied after running the model from January 2008 to January 2030.

Firstly, global model behaviour was analysed by the author. Expectations of vegetation development based on literature, observed trends in the past and experiences during this study were compared with model outcomes.
The global trend of biomass development for the whole study area as well as the variation in development throughout the study area was examined. Furthermore, the magnitude of seasonal variation was analysed and compared with expected variation as described in a previous stage of this study, in the terms of success.

Secondly, the model outcomes were validated based on expert judgement of IRAs natural vegetation expert dr. Aziez Ouled Belgacem. A description of the assumptions made for the model like fixed suitability, grazing intensity and climatic input, together with the model outcomes like vegetation type and biomass development curves were send to judge. Judgement was asked for on the following topics:

-Overall vegetation type development; does the simulated development in natural vegetation types throughout the area reflect the expected development?
-Structure of vegetation type distribution; to what extend do the structures as shown in the output vegetation type map meet the expected vegetation structure distribution (e.g. structure of large homogeneous areas or scattered heterogeneous vegetation type distribution)?

Unfortunately, results of this expert judgement could not be included in this report. No results were available yet at the time of printing.

2.3.5 Evaluate opportunities of remote sensing data sources

For the initiation, calibration and validation of the model in this study, remotely sensed data sources have been used. An overview of the extent to which remote sensing data was used will be given and discussed in a separate paragraph in the discussion chapter (chapter 4). The importance of this data in the process, together with the (dis)advantages will be examined by evaluation of the process and comparison with alternative data sources. Methods used in setting up previous model versions will be evaluated and recommendations on improvements or alternative methods will be given in chapter 6 (recommendations).

3 Results

The results of each of the steps as they were described in the methodology chapter (chapter 2) will be presented in the same order.

3.1 Model adaptation

The applicability of the model for the Jeffara region had to be examined by comparing the conceptual model with the natural vegetation characteristics and its dynamics. An overview of the natural vegetation will be given. After literature study and consulting IRAs natural vegetation expert, the vegetation can be described as follows.

3.1.1 Vegetation types

The natural vegetation of the Jeffara plain is considered to be of the chamaephytic steppe type (Wellens, 1997), meaning that the majority of the plants (herbaceous or woody) have perennating buds close to the ground, at no more than 25 cm above soil level (Raunkiær classification system, (Raunkiær, 1934)). Some areas are dominated by grasses (*Stipa tenacissima)* and can be considered as hemicryptophyte steppe. In the Jeffara region, succession of vegetation is strongly dependent on the soil characteristics, frequency of cultivation and grazing intensity. Within the study area, four main soil types can be found, each having its own plant communities and limiting factors concerning plant growth (Floret and Pontanier, 1982). In the south-western part, in the Matmata Mountains and the foot slopes, calcareous silty soils can be found. These soils, with limited soil depths and slopes up to about 35% are originally covered by *Juniperus phoenicea – Rosmarinus officinalis* and *Stipa tenacissima* (Alfa grass) plant communities. Towards the Gulf of Gabès (Mediterranean Sea), sandy plains stretch out in north-eastern direction. These soils, which are under particular pressure of cultivation encroachment (Genin et al., 2006) are originally covered by the *Ranterium suaveolens* plant communities, with low perennial shrubs.

A few saline depressions (sebkhas) that are occasionally flooded in winters cover the most north-eastern point of the catchment. These sebkhas are characterized by high salinity and temporal water saturation due to occasional flooding. This results in plant communities that have the ability to grow under these extreme conditions.

Several streambeds are running throughout the study area. Due to the relatively high moisture availability and plant communities, these areas are considered as a separate group within this study.

Because of the different soil characteristics and plant growth limitations, each of the different soil types has different plant communities and succession potentials. Succession of natural vegetation from an ecologist's point of view is dependent on various, mainly qualitative factors such as species properties, composition and species richness. The MedAction PSS though, only simulates quantitative developments like biomass, vegetation height and vegetation cover. For this reason, the plant communities as they occur within the study area were grouped on their similarity in biomass per hectare, vegetation height and fractional vegetation cover. These factors also give a better indication of land degradation risks and are a direct input to other MBBs for calculation of run-off, water infiltration, evaporation etc.

Six different vegetation types where defined. The different vegetation types are (from high to low biomass and fractional vegetation cover); shrub vegetation (SV), woody matorral (WM), dwarf woody perennial (DWP), open perennial (OP), degraded perennial (DP) and abandoned land (AL). An overview of the vegetation types and their corresponding plant communities per soil type is given in table 3.1.

Table 3.1; Plant communities of the Jeffara region, and the soil type on which they occur, grouped into newly defined vegetation types for the MedAction model. The plant communities are grouped based on similarity in vegetation cover and amount of biomass.

Soil type → / Vegtetation type ↓	Sandy soils	Silty/ Calcareous soils	Gypsic soils	Saline soils	Streambeds
	Dominant Species				
Shrub Vegetation	X	*Juniperus phoenicea / Rosmarinus officinals*	X	X	*Retama raetam*
Woody Perennials Matorral	X	*Rosmarinus officinalis / Stipa tenacissima*	*Callicotome villosa*	*Nitraria retusa*	*Retama raetam / Tamarix articulata*
Dwarf Woody Perennial	*Rhanterium suaveolens*	*Stipa tenacissima*	*Anarrhinum brevifolium / Zygophyllum album*	*Traganum nudatum*	*Retama raetam*
Open Perennial	*Astragalus armatus / Lygeum spartum*	*Artemisia herba-alba*	*Astragalus armatus / Lygeum spartum*	*Suaeda mollis / Limoniastrum guyonianum*	*Retama raetam*
Degraded perennial	*Astragalus armatus / Peganum harmala*	*Stipa carpensis / Hammada scoparia*	*Atractylis serratuloides*	*Arthocnemum indicum / Halocinemum strobilacem*	X
Abandoned Land	*Artemisia campestris / Cynodon dactylon*	*Deverra tortuosa*	X	X	X

For each vegetation type, average biomass values and fractional vegetation cover values were taken from the plant communities within that vegetation type as described by Floret and Pontanier (1982). These values are based on average annual values, and will averagely be up to 20-30% higher or lower during wet and dry seasons respectively. During the wet seasons, the amount of biomass is increased by presence of annual vegetation and higher amounts of leaf and livestem biomass. Especially vegetation cover rates can vary much between different seasons.

Vegetation height data is based on expert knowledge and observations in the field. A table with the characteristics of each of the vegetation types is given in table 3.2.

Table 3.2; Quantitative characteristics of the vegetation types as defined for the MedAction model.

Vegetation Type	Biomass (kg dm/ha)	Vegetation cover (%)	Vegetation Height (m)
1 Shrub Vegetation	>5000	>65	1,5-3
2 Woody Perenn. Matorral	2500-5000	50-65	0,5-1,5
3 Dwarf Woody Perennials	750-2500	25-50	0,3-1
4 Open Perennials	400-750	15-25	0,3-0,5
5 Degraded Perennials	150-400	7,5-15	0,2-0,3
6 Abandoned Land	0-150	0-7,5	0-0,2

3.1.2 Grazing

Grazing is one of the main factors of degradation of natural vegetation within the Jeffara region. Due to increasing conversion from steppe area to cultivated land, the pressure on the remaining natural vegetation increased (Hanafi et al., 2004; Ouled Belgacem et al., 2006). Grazing (mainly by sheep and goats) has a strong impact on the development of the natural vegetation. Beside a shift in species composition, with decreasing densities of palatable species, a decreased vegetation cover of 50-60% was found in areas under continuous extensive grazing in Southern Tunisia compared to areas protected from grazing (Ouled Belgacem et al., 2006).

In the previous model version, the influence of grazing was taken into account by reducing a vegetation type specific amount of grams dry matter of the leaf biomass per day, on cells where grazing was taking place (based on a static grazing map, either non to low or medium to high). Since grazing plays a major role in the vegetation dynamics of the Jeffara region, a more complex modelling strategy for grazing was developed. The pressure of grazing on different areas in reality is influenced by several factors such as distance to villages and watering points, slope, vegetation type and state, and possible protection or zoning strategies within the study area. In order to better represent the effects of grazing on the development of natural vegetation, the intensity of grazing per cell was taken into account. The different influencing factors were used to estimate the grazing intensity within the modelling area if appropriate data was available.

First of all, a static grazing intensity map was created, based on distance to villages, slope, vegetation type and state, and possible protection or zoning strategies. This map gives an indication of the intensity of grazing scaled from 0-2. The value of each cell will be used as an multiplication factor for the actual amount of leaf biomass that is reduced by grazing. This 'leaf biomass grazed daily' parameter should be calibrated in such a way that biomass development will be more or less stable. In this way a cell with a grazing intensity of >1 would result in gradual degradation of natural vegetation. Areas with a grazing intensity <1 would show progressive succession because of gradually increasing biomass.

As a starting point, the assumption was made that standard grazing intensity takes place over the whole area (intensity=1), because almost all pre-Saharan Tunisian rangeland are now grazed continuously without any restriction on stocking rate (Ouled Belgacem et al., 2006).

Cells with slopes higher then 10% get a reduced grazing intensity, gradually increasing to reduction by 0.9 at the highest slopes (33%). Although goats and sheep may move on steep slopes at ease, shepherds tend to avoid such areas (Röder et al., 2007). A reclassification of slopes above 10% was made resulting in the intensity values presented in table 3.3. Values under 'Reduced intensity' are subtracted from the grazing intensity value according to the corresponding slope of a cell.

Table 3.3; Reclassification values for reduced gracing intensity on slopes.

Slope	Reduced intensity
0-10	0
10-15	0.3
15-20	0.5
20-25	0.7
25-30	0.8
>30	0.9

Because of the characteristic plant communities on the saline soils in the North-Eastern part of the study area, the intensity of these areas was reduced by 0.5. These saline natural vegetation areas are only lightly grazed by camels during winter. Furthermore, the intensity of areas within a 2 km buffer around the villages was increased. Higher grazing intensity is expected in these areas since the concentration of livestock in these areas is higher than in the remote areas. The intensity of grazing around villages was increased by 1, gradually decreasing by 0.1 every 100 meters. As a result, areas directly around villages had a grazing intensity value of 2.

Some areas within the region have special protection regulations for grazing (Genin et al., 2006). For these areas a fixed grazing intensity of 0 was used. No appropriate data was available on allocation of water drinking points. Although it has been shown that distance to watering points has a direct influence on species composition and vegetation cover in Southern Tunisia (Tarhouni et al., 2006), this factor could not be taken into account.

Combining the factors mentioned above resulted in a grazing intensity map that was used to calculate the actual reduction of biomass by grazing for each cell. It is assumed that all factors that were taken into account to create this map are static, if looking at the 22 years modelling period. No dynamic updating of this map is expected to be necessary throughout the modelling period. Slope and soils are fixed values, and villages are not expected to rapidly change during the modelling period. If necessary, grazing intensity values can be manually changed during the modelling period.

A diagram of how the grazing intensity map was created is given in figure 3.1.

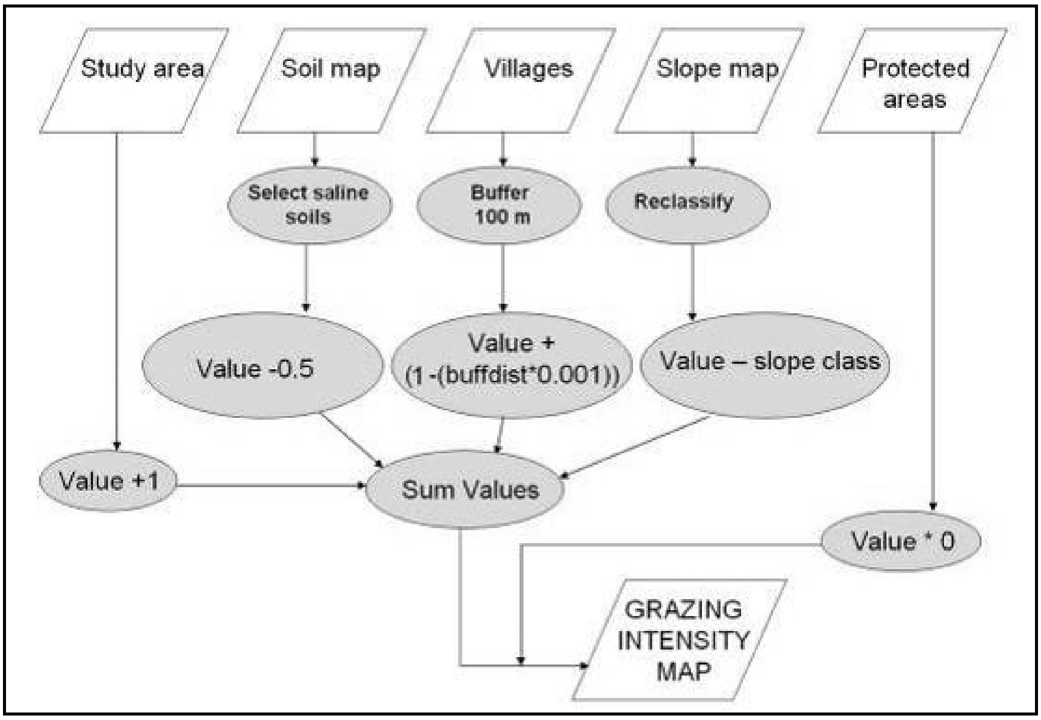


Figure 3.1; Diagram of the method used to define the grazing intensity for the Jeffara region

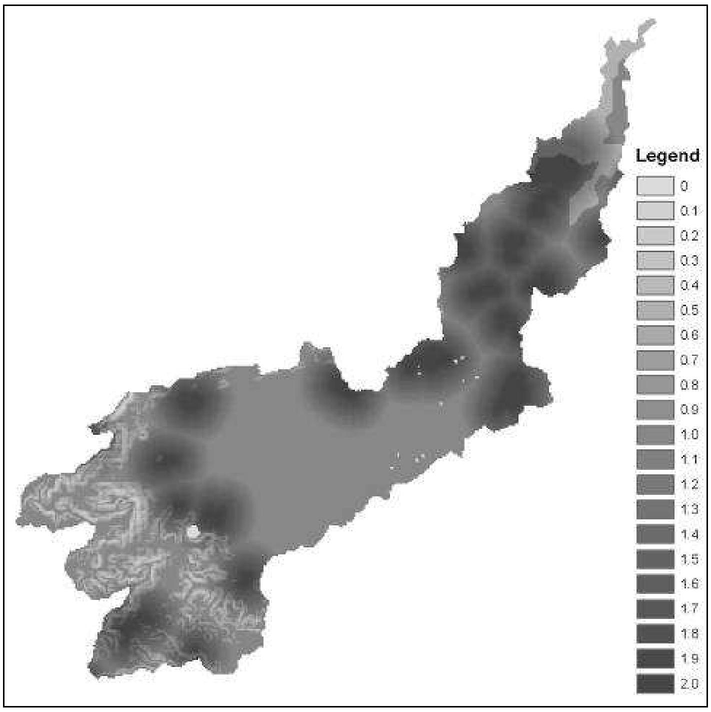


Figure 3.2, Grazing intensity map of the Zeuss-Koutine catchment. Values indicate relative grazing intensity

3.1.3 Fire

Due to the low biomass and vegetation cover values for natural vegetation in the Jeffara region, fire does not play a role in the vegetation dynamics. For all transitions between the different vegetation types the influence of fire was not taken into account by setting fire prevalence of all transitions at 'don't care'.

3.1.4 Seed dispersion

In the original natural vegetation MBB, transitions take place if seeds of the intended vegetation type were available in the field, or seed availability was set at 'don't care'. Seed availability was calculated based on the vegetation type specific seed distribution distance and the vegetation types present around the cell. In the Jeffara region, seed dispersion was excluded from the simulation for two reasons. The first reason is that due to the dry conditions, hardly any successful generative regeneration of key species takes place. Perennial plants mainly reproduce vegetatively by resprouting of shoots. A second reason why seed dispersion is left out of the calculations is that the different vegetation types are in fact grouped plant communities with similar quantitative characteristics. The vegetation type from a cell does not really say anything at species level but on quantitative parameters like biomass, fractional cover and height. Vegetation types are a mix of species, where species composition is dependent on the soil conditions of that cell. For this reason seed dispersion could not be taken into account. If occurrence of one particular plant community would have been dependent on seed availability, it should account for all plant communities from the same vegetation type similarly to take this into account.

3.1.5 Vegetation height calculation

In the previous model version vegetation height was calculated by multiplying the amount of wood and life stem biomass with a vegetation type specific 'stem-biomass per meter height' parameter. It was found that by calculating height in such a way, the development in height

makes a sudden increase or decline each time when the cell changes in vegetation type, since these parameters differ for each type. In reality though, height of vegetation under natural succession shows a gradual increase or decline with progressive or regressive succession respectively.
In order to better represent this realistic height development a new way of calculating height development was used. Initial height is calculated as before, but for each new time step (t), the new height is calculated by multiplying the 'stem-biomass per meter height' parameter with the delta biomass of wood and live stem, and adding this value to the height value of the previous time step. The height is still limited by the maximum height parameter as in the previous model version. Calculating in this way results in a development of height in a gradual way, in which the order of magnitude of this development is mainly dependent on the development of live stem and wood biomass. The new calculation is as follows:

$$CH = \min\left\{ H_{d-1} + \frac{(B_{w,d} - B_{w,d-1}) + (B_{LS,d} - B_{LS,d-1})}{HSB_{qd}}, CH_{\max,qd} \right\}$$

In which;
B_{LS} = Live stem biomass
B_W = Wood Biomass
HSB = Height per stem biomass for natural vegetation type q
CH_{max} = Maximum canopy height for natural vegetation type q

3.2 Model initiation

3.2.1 Variables

The Land use map of 2004 that was provided by IRA for the initiation of the model is given in figure 3.3. This map is a product of a visual interpretation and classification of aerial photographs from the study area. The newly defined natural vegetation type classes had to be defined for each of the natural vegetation cell of this map.

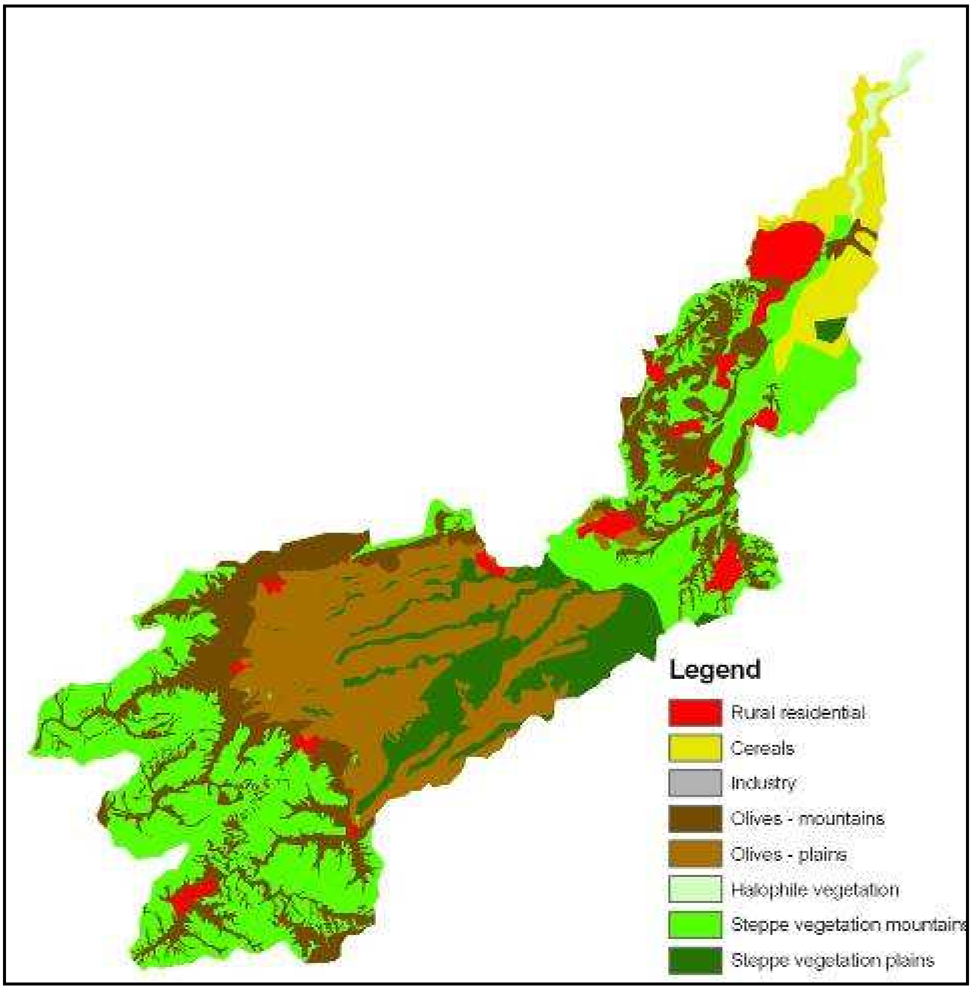


Figure 3.3; Land use map of 2004 for the study area, as provided by IRA

For the initial biomass map, which was used to determine the vegetation type of the natural vegetation cells, coordinates for 58 points were collected in the field. After linear regression of the vegetation cover values observed in the field with the NDVI values of these locations, it turned out that correlation was very poor, with an R^2 of about 0.15 (see figure 3.4).

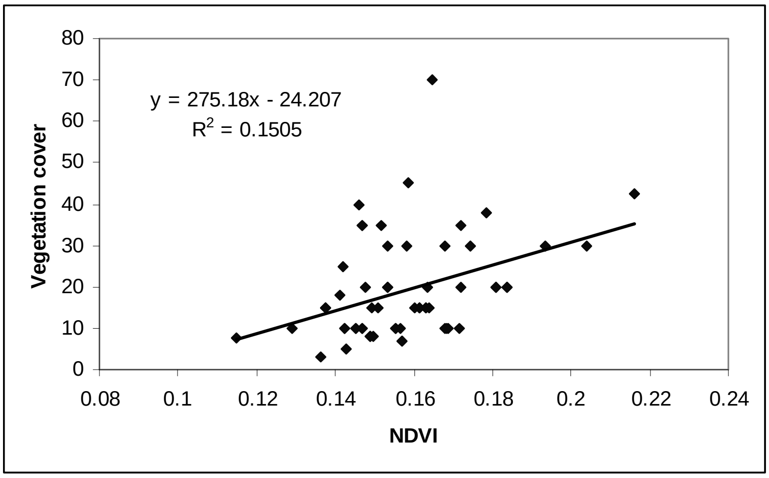


Figure 3.4; Vegetation cover of locations in large, homogeneous areas, in comparison with MOD13Q1 NDVI observations

The main reason for this was that the pixel size of MOD13Q1, from which the NDVI values were subtracted, is 250 meters. Many of the locations visited in the field did not have a homogeneous area that would even cover one pixel of the MODIS image. These NDVI values are influenced by surrounding land cover types, other than the intended natural vegetation type. Therefore, a selection of points was made that did have homogeneous vegetation to cover at least one pixel on the MOD13Q1 image. For some of the locations, the extent of the area was described in the field (see appendix 3). For the rest of the locations, the extent of the vegetation type at that point was determined with high resolution images from Google Earth. These images (Quickbird satellite, acquisition date 08-2004 and 09-2006) have a pixel resolution of about 0.60 meters and could be used to determine homogeneous areas with similar cover as the visited locations based on visual interpretation. Examples of these images are given in appendix 4.

Locations with homogeneous vegetation cover area smaller than 250 by 250 meters were excluded from further analysis. The total amount of locations that were considered to be suitable for interpretation of the NDVI image was 11. Not all vegetation types were covered equally by the visited locations. No large homogeneous areas from the vegetation types ‘abandoned land’ and ‘shrub vegetation’ were recorded in the field. For vegetation types ‘woody matorral‘, ‘open perennial’ and ‘degraded perennial’ only 3 locations had a sufficient extend. For these vegetation types, locations with similar vegetation cover were selected from the Quickbird satellite images to bring the total amount of locations to 4 per vegetation type. Satellite images of the selected areas for analysis are given in appendix 4.

After linear regression with the NDVI extracted from the MODIS image from October 2007, the function 330.62*NDVI-31 was found with an R^2 of about 0.66 (see figure 3.5.)

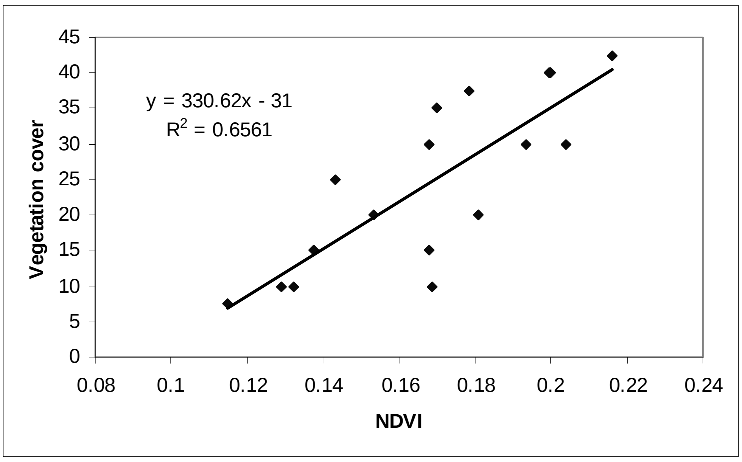


Figure 3.5; Vegetation cover of locations in large, homogeneous areas, corrected for seasonal variation, in comparison with MOD13Q1 NDVI observations.

The linear function was applied to the NDVI image and led to the vegetation cover values for all natural vegetation cells in the study area. Each vegetation cover has a corresponding biomass value according to the curve as shown in figure 3.6. The curve is a best fit polynomial function (2nd order) of vegetation type characteristics of the different vegetation types as previously presented in table 3.2. The function follows the relation between given biomass and vegetation cover values quite well with a R2 of 0.95. This function was applied to translate the vegetation cover map into the biomass map which was used as input for the MedAction plant growth model (figure 3.7).

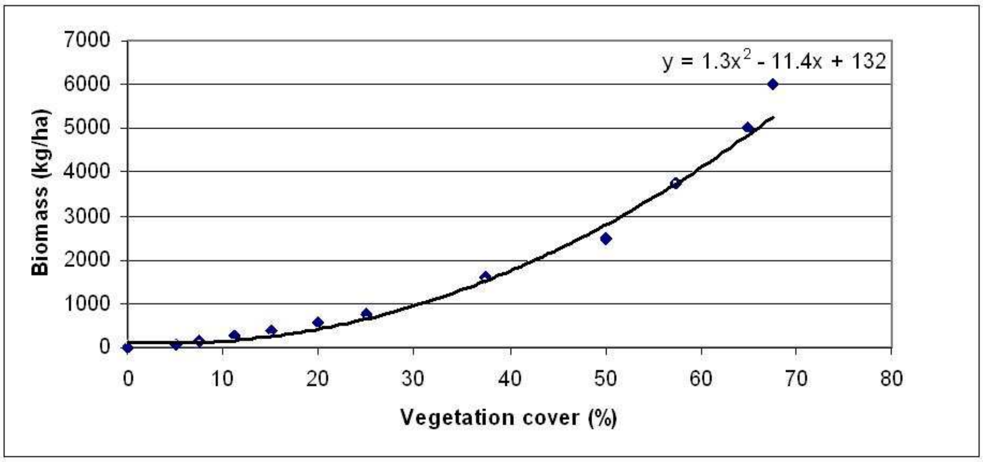


Figure 3.6; Relation between vegetation cover and above ground biomass for vegetation types in the Jeffara region. Values are based on plant communities in the Jeffara region as described by Floret and Pontanier (1982). The 2nd order polynomial function presented in this graph was used to calculate biomass levels from vegetation cover values.

As described in paragraph 3.1.1, the natural vegetation classes that were used in the Natural Vegetation MBB are the classes; high shrubs, woody perennials, dwarf woody perennials, open perennial, degraded perennial and abandoned land to better represent the vegetation characteristics of the Jeffara region. These classes can be separated based on their fractional vegetation cover and amount of biomass per hectare, with high to low values for shrub vegetation to abandoned land respectively (table 3.2). The initial distribution of vegetation types over the study was based on the initial biomass map (figure 3.7) and is given in figure 3.8.

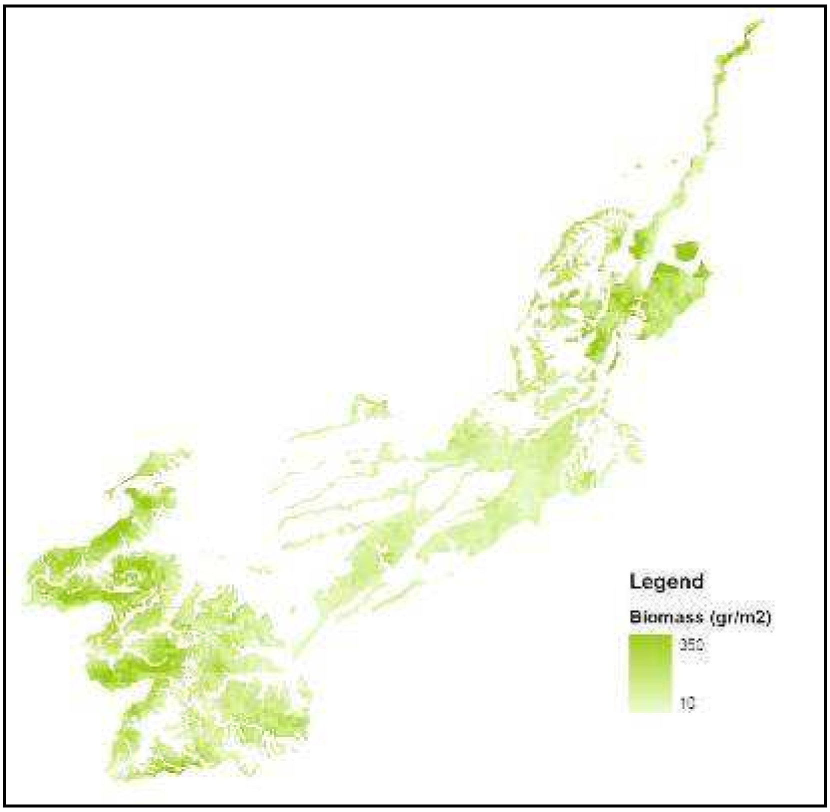


Figure 3.7; Initial biomass map for areas with natural vegetation in the Jeffara region

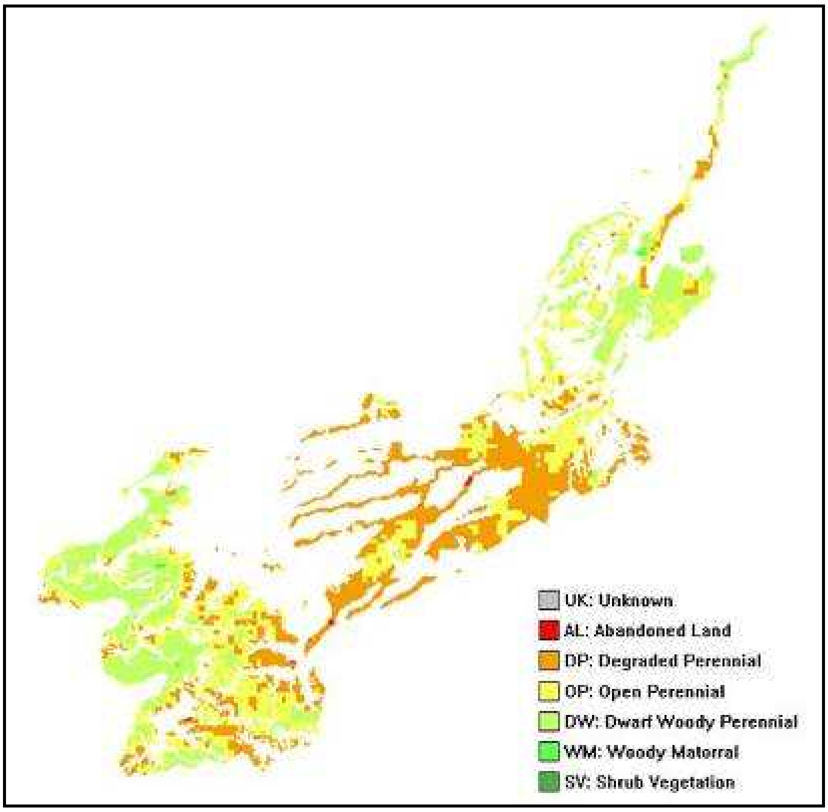


Figure 3.8; Initial vegetation type map for the Jeffara region

3.2.2 Parameter values and transition rules

Standard parameter values were either taken over from the Guadalentín application, or if data was available, region specific values were used. The values that were taken over from the Guadalentín model were taken from the most similar vegetation types. These vegetation types were abandoned fields – annual grasses (for abandoned land), Perrennial Grassland w/ *Brachypodium* (for degraded perennial), Espartal Steppe w/ *Stipa tenacissima* (for open perennial) and Degraded Matorral w/ *Ulex parviflorus* (for shrub vegetation). Transition rules for possible transitions between the different vegetation types are given in table 3.4, and are based on the characteristics per vegetation types as found in literature. The parameter values for standard input are given in table 3.5.

Table 3.4; Transition rules for possible transitions between vegetation types

From type	To type	Vegetation height	Vegetation Cover
Abandoned land	Degraded perennial	>=0.2	>=0.1
Degraded perennial	Abandoned land	<=0.1	<=0.05
Degraded perennial	Open perennial	>=0.3	>=0.2
Open perennial	Degraded perennial	<=0.2	<=0.1
Open perennial	Dwarf woody perren.	>=0.3	>=0.3
Dwarf woody perren.	Open perennial	<=0.2	<=0.2
Dwarf woody perren.	Woody mattoral	>=0.5	>=0.5
Woody mattoral	Dwarf woody perren.	<=0.4	<=0.4
Woody mattoral	Shrub vegetation	>=1.5	>=0.6
Shrub vegetation	Woody mattoral	<=1	<=0.5

Table 3.5; Standard parameter values for the plant growth and natural vegetation MBBs. Values taken over from the Guadelentín model are given in *italics*.

Parameter	Units	AL	DP	OP	DWP	WM	SV
Leaf density	g/m2	*300*	*300*	*300*	*300*	*300*	*300*
Radiation use efficiency	g/MJ	*5.5*	*5.5*	*5.5*	*5.5*	*5.5*	*5.5*
Initial leaf fraction	g/g_{tot}	*0.987*	*0.8*	*0.783*	*0.1*	*0.1*	*0.013*
Initial root fraction	g/g_{tot}	*0.05*	*0.1*	*0.1*	*0.1*	*0.1*	*0.019*
Initial wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.797*	*0.797*	*0.797*
Initial live stem fraction	g/g_{tot}	*0.013*	*0.01*	*0.01*	*0.003*	*0.003*	*0.0*
Leaf fraction	g/g_{tot}	*0.95*	*0.85*	*0.76*	*0.681*	*0.681*	*0.681*
Root fraction	g/g_{tot}	*0.0*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*
Wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.15*	*0.15*	*0.15*
Live stem fraction	g/g_{tot}	*0.05*	*0.05*	*0.04*	*0.033*	*0.033*	*0.033*
Maximum cover	m2/m2	0.075	0.15	0.25	0.5	0.65	1
Maximum height	m	0.2	0.3	0.5	1	1.5	3
Stem biomass per meter height	g/m	*400*	*400*	*400*	*4000*	*4000*	*4000*
Leaf biomass grazed daily	Gr/m2/day	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

3.3 Model calibration

3.3.1 Terms of success

Both literature study as well as discussions with IRAs natural vegetation expert, led to the conclusion that succession of natural vegetation in the Jeffara region is going at a very slow rate. Since the main influencing factor on this degradation trend is overgrazing (Genin et al., 2006), a gradual recovering trend in natural vegetation can be expected when grazing intensity is set at 0 for the calibration period. The following terms of success were formulated:

- Vegetation type: It is expected that the natural vegetation areas will either remain in their initial state, or recover to the next following successional state at maximum within the given calibration time of 8 years (2000-2007).
- Biomass: For biomass, an overall increasing trend of approximately 10% per year is expected.
- Vegetation height: Developments in vegetation height should show an overall increasing trend with gradual changes over time (considering the new way of calculating vegetation height). Seasonal fluctuations should lead to differences of about 20-30 % of the average annual height. The average height should stay between the maximum and minimum values as defined per vegetation type.
- Vegetation cover: For vegetation cover, average annual cover values should also stay within the defined minimum and maximum values per vegetation type, with a gradual increasing trend over time. The seasonal differences should be about 20-30% from the average annual value.

A first model run was done using parameter values as described in the model initiation paragraph (3.2). For the initial biomass and vegetation type map, the same strategy was used with an image of February 2000 (the first available MODIS image for the time series). Calibration was done over the same period as there where MODIS images available, from 2000 to 2008, to be able to compare with observed NDVI values.
Standard model input resulted in biomass development as shown in figure 3.9. Although biomass shows a strong increase in the first year (up to 15 times higher after one year), the vegetation type degrades one step to degraded perennial and stays the same for the rest of the modelling period. Biomass values reflect the seasonal fluctuation which is caused by the limited temperature and limited available radiation during period of minimum growth in October / November. Vegetation cover values are low but increase to the maximum value as soon as the vegetation type changes. Vegetation height also follows the seasonal fluctuations but is limited by the maximum height at the top of the growing season, and decreases to 0 in winter. This is probably causing the degradation in vegetation type. It was furthermore found that vegetation height for areas with a vegetation type containing woody vegetation was only gradually increasing, making regressive succession impossible when looking at the transition rules related to height.
The vegetation type map of December 2008 (figure 3.10) shows a degradation of most of one or two vegetation types. In the mountains, at the South-East side of the study area, some areas show progressive succession.

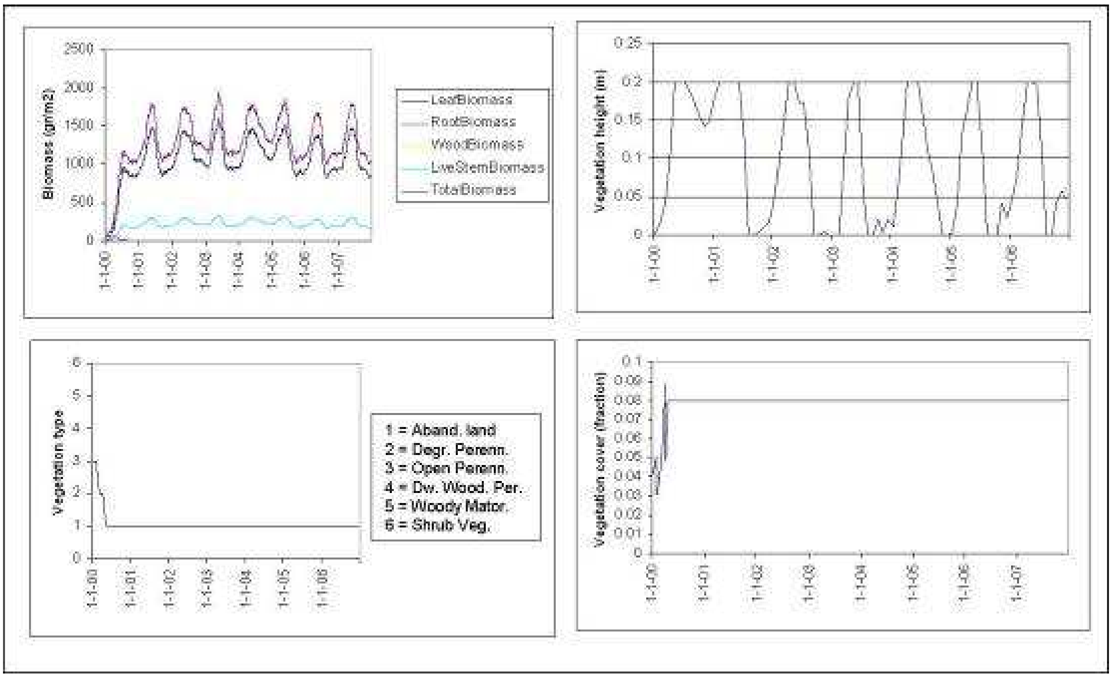


Figure 3.9; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for the model run with standard parameter input.

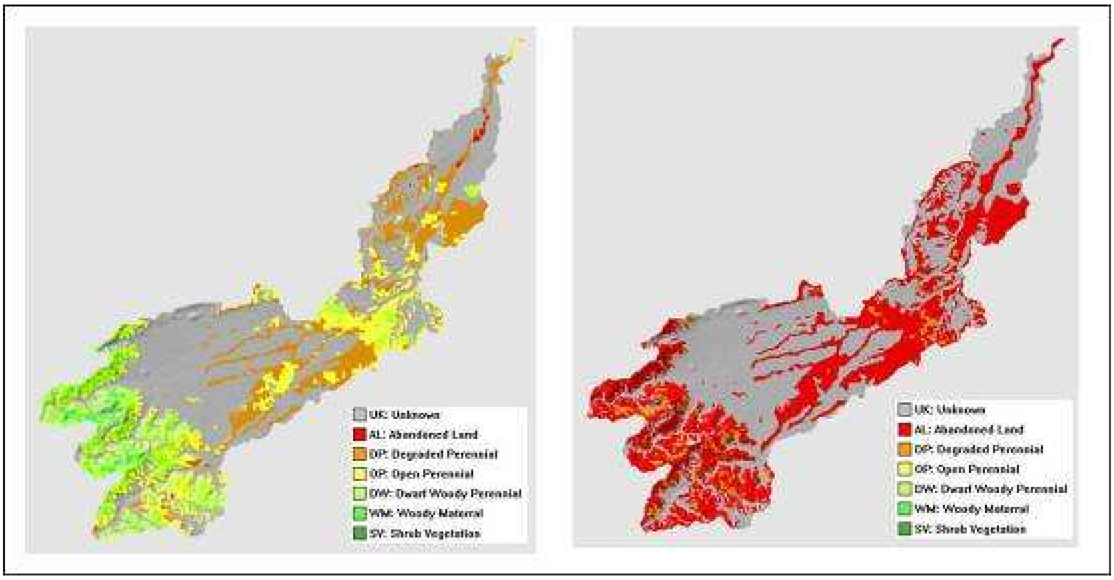


Figure 3.10; Vegetation type distribution at the start of the calibration period (left) and distribution after model running for 8 years with standard input (right)

After an iterative process of running the model several times and testing effects of changing parameter values, an insight on global model behaviour and on the sensitivity of the different parameters was achieved. Based on this insight, different options were tested to improve the models' ability to simulate natural vegetation dynamics. This ability was evaluated by comparison with the terms of success.

3.3.2 Optimizing parameter values

Calibration was done by aiming at a certain improvement in the model outcome (for example; reducing biomass increment or increasing vegetation height), and then adapting the parameters related to these outputs. After adaptation, the influence on the output was checked and improved again until no more improvements were achieved with adapting these parameters. An example of this calibration strategy is given below.

Calibration example
After some test runs, the model was run with the following parameter values, resulting in developments as shown in figure 3.11.

Table 3.6; Parameter values for calibration example before adaptation

Parameter	Units	AL	DP	OP	DWP	WM	SV
Leaf density	g/m2	*100*	*100*	*100*	*120*	*120*	*120*
Radiation use efficiency	g/MJ	*2*	*2*	*2*	*2*	*2*	*2*
Initial leaf fraction	g/g_{tot}	*0.8*	*0.8*	*0.5*	*0.4*	*0.25*	*0.1*
Initial root fraction	g/g_{tot}	*0.05*	*0.1*	*0.1*	*0.05*	*0.05*	*0.05*
Initial wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.5*	*0.65*	*0.82*
Initial live stem fraction	g/g_{tot}	*0.45*	*0.4*	*0.4*	*0.05*	*0.05*	*0.03*
Leaf fraction	g/g_{tot}	*0.910*	*0.9*	*0.9*	*0.89*	*0.89*	*0.89*
Root fraction	g/g_{tot}	*0.03*	*0.025*	*0.025*	*0.054*	*0.054*	*0.054*
Wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.001*	*0.001*	*0.001*
Live stem fraction	g/g_{tot}	*0.06*	*0.075*	*0.075*	*0.055*	*0.055*	*0.055*
Maximum cover	m2/m2	0.075	0.15	0.25	0.5	0.65	1
Maximum height	m	0.2	0.3	0.5	1	1.5	3
Stem biomass per meter height	g/m	*400*	*400*	*400*	*400*	*400*	*400*
Leaf biomass grazed daily	Gr/m2/day	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

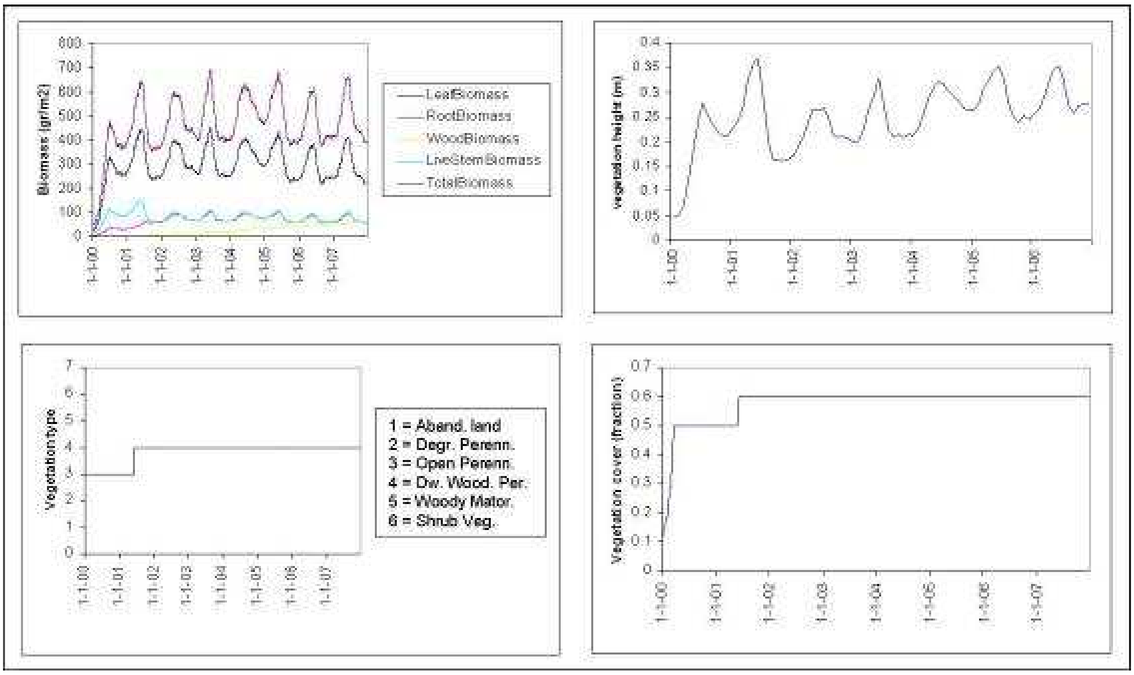


Figure 3.11; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for calibration example before adaptation.

The aim in the following step was to reduce the biomass increment, and to increase the vegetation height to values between 0.3 and 0.5 m. The reduction of the biomass increment was done by reducing radiation use efficiency to 1. Improving the vegetation height was done by dividing the amount of average initial live stem and wood biomass per vegetation type by the average height for that vegetation type and using this value as the biomass per meter height parameter.

Table 3.7; Parameter values for calibration example after adaptation

Parameter	Units	AL	DP	OP	DWP	WM	SV
Leaf density	g/m2	*100*	*100*	*100*	*120*	*120*	*120*
Radiation use efficiency	g/MJ	*1*	*1*	*1*	*1*	*1*	*1*
Initial leaf fraction	g/g_{tot}	*0.8*	*0.8*	*0.5*	*0.4*	*0.25*	*0.1*
Initial root fraction	g/g_{tot}	*0.05*	*0.1*	*0.1*	*0.05*	*0.05*	*0.05*
Initial wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.5*	*0.65*	*0.82*
Initial live stem fraction	g/g_{tot}	*0.45*	*0.4*	*0.4*	*0.05*	*0.05*	*0.03*
Leaf fraction	g/g_{tot}	*0.910*	*0.9*	*0.9*	*0.89*	*0.89*	*0.89*
Root fraction	g/g_{tot}	*0.03*	*0.025*	*0.025*	*0.054*	*0.054*	*0.054*
Wood fraction	g/g_{tot}	*0.0*	*0.0*	*0.0*	*0.001*	*0.001*	*0.001*
Live stem fraction	g/g_{tot}	*0.06*	*0.075*	*0.075*	*0.055*	*0.055*	*0.055*
Maximum cover	m2/m2	0.075	0.15	0.25	0.5	0.65	1
Maximum height	m	0.2	0.3	0.5	1	1.5	3
Stem biomass per meter height	g/m	*34*	*36*	*58*	*138*	*263*	*298*
Leaf biomass grazed daily	Gr/m2/day	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

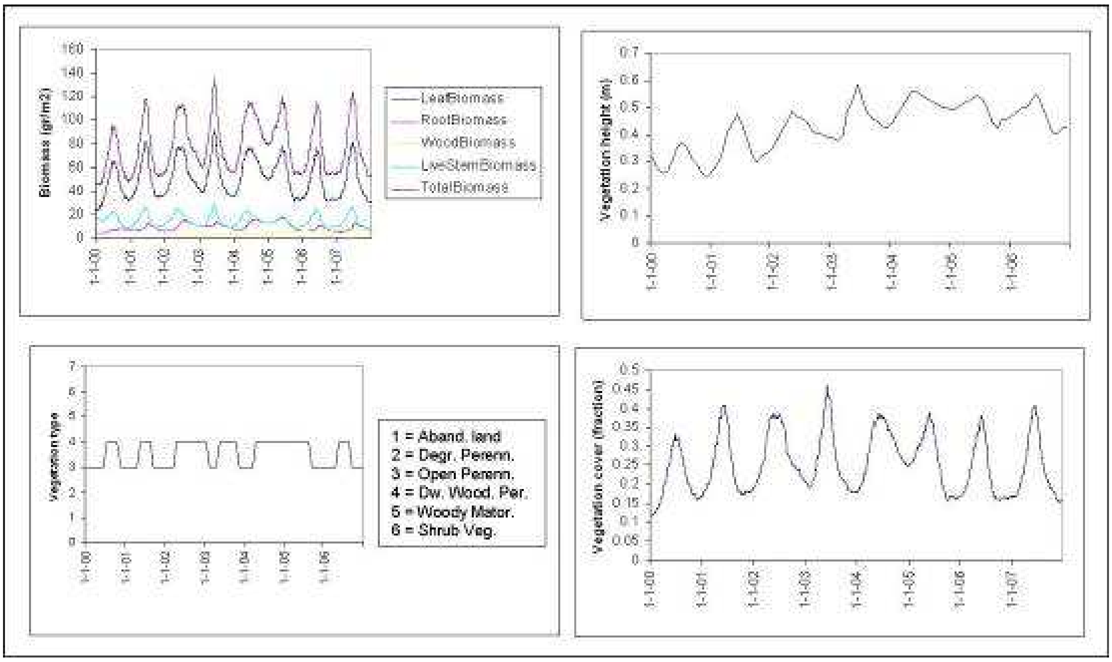


Figure 3.12; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for calibration example after adaptation.

The adaptations in parameter values led to the desired result as can be seen by the reduced biomass development and increased vegetation height values in figure 3.12. In a next step, the ratio between leaf and live stem biomass could be improved by increasing the live stem fraction at the cost of leaf fraction. Furthermore, a slightly higher biomass increment rate could be achieved by increasing either the leaf fraction (which would result in higher LAI and therefore higher IPAR and growth, or by adjusting the radiation use efficiency again.

By continuing this strategy, an optimum in model outcome was achieved, given the available time for this study. The optimal parameter values for the model are given in table 3.8. The results of the model using these values are given in figure 3.13. Note that the graphs are based on one cell only, and that other cells do show different trends. A detailed review on the models' results is given in the next paragraph.

Table 3.8; Optimum parameter values as found for this study.

Parameter	Units	AL	DP	OP	DWP	WM	SV
Leaf density	g/m2	90	120	120	120	120	120
Radiation use efficiency	g/MJ	0.75	1.03	1.17	1.32	1.45	1.45
Initial leaf fraction	g/gtot	0.850	0.700	0.500	0.300	0.200	0.050
Initial root fraction	g/gtot	0.050	0.100	0.100	0.100	0.100	0.100
Initial wood fraction	g/gtot	0.0	0.0	0.0	0.500	0.600	0.800
Initial live stem fraction	g/gtot	0.100	0.200	0.400	0.100	0.100	0.050
Leaf fraction	g/gtot	0.920	0.900	0.875	0.874	0.874	0.874
Root fraction	g/gtot	0.030	0.025	0.025	0.025	0.025	0.025
Wood fraction	g/gtot	0.0	0.0	0.0	0.001	0.001	0.001
Live stem fraction	g/gtot	0.050	0.075	0.100	0.100	0.100	0.100
Maximum cover	m2/m2	1	1	1	1	1	1
Maximum height	m	0.5	0.8	1.0	1.5	2.0	3.5
Stem biomass per meter height	g/m	35	75	75	250	250	300
Leaf biomass grazed daily	Gr/m2/day	-	-	-	-	-	-

The transition rules did also change from the standard values as described before. It turned out that the vegetation types which contained woody plant parts (shrub vegetation, woody matorral and dwarf woody perennials) could not make a regressive transition (degradation to lower density vegetation types). Since no maintenance respiration is calculated for woody plant parts, the wood biomass levels in these cells would at least have the same level as with model initiation, even if these cells would show degradation during the whole modelling period. As a consequence, height is hardly reduced, since it is based on the wood and live stem biomass. This means that cells that where initially covered by one of these types could not degrade to the previous successional stage when a certain minimum height is defined for this transition. Therefore, the transition rule for height for these regressive transitions was set at >=0.001. In this way, height is not taken into account, and the transition is only based on vegetation cover.
Another change in transition rules is the overlap between different vegetation types. In the standard transition rules, transitions took place when a minimum height from the next vegetation type was achieved. Transition vice versa took place when the vegetation height was 10 cm below this minimum height again, so with a slight overlap to prevent transitions due to seasonal fluctuations. This overlap turned out to be insufficient as can be seen in figure 3.12. Overlap of variable values for transitions were increased to the values as presented in table 3.9.

Table 3.9; Adapted transition rules for possible transitions between vegetation types

From type	To type	Vegetation height	Vegetation Cover
Abandoned land	Degraded perennial	>=0.3	>=0.25
Degraded perennial	Abandoned land	<=0.1	<=0.05
Degraded perennial	Open perennial	>=0.5	>=0.4
Open perennial	Degraded perennial	<=0.2	<=0.1
Open perennial	Dwarf woody perren.	>=0.65	>=0.55
Dwarf woody perren.	Open perennial	>=0.001	<=0.2
Dwarf woody perren.	Woody mattoral	>=0.85	>=0.6
Woody mattoral	Dwarf woody perren.	>=0.001	<=0.4
Woody mattoral	Shrub vegetation	>=2	>=0.8
Shrub vegetation	Woody mattoral	>=0.001	<=0.5

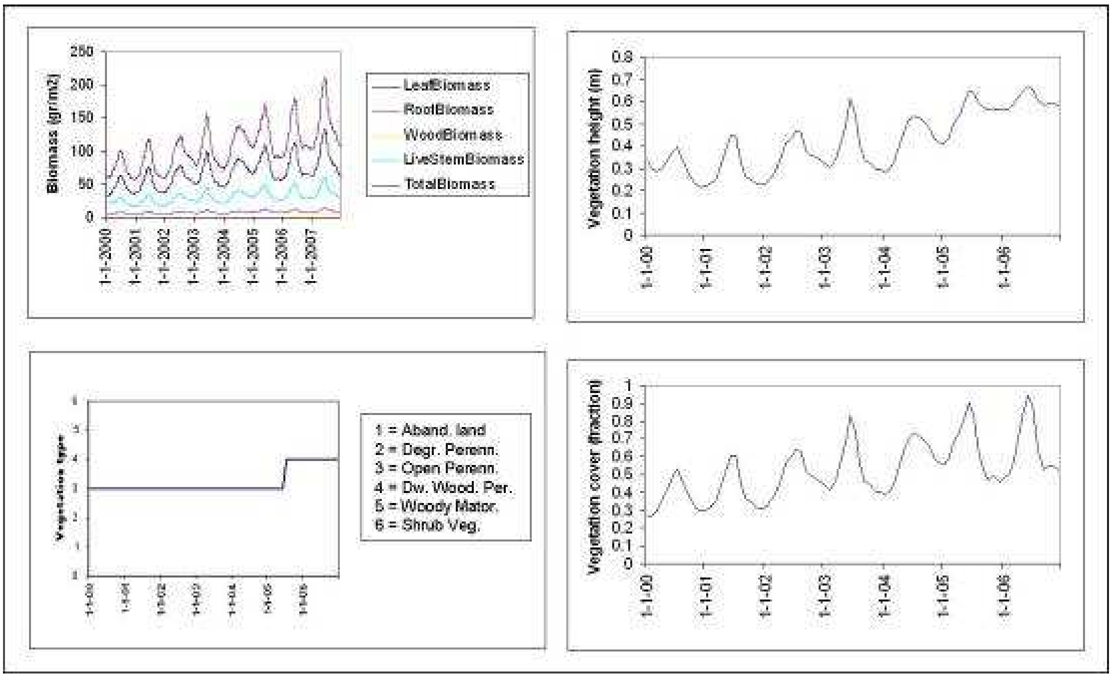


Figure 3.13; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for the calibrated model without grazing influence.

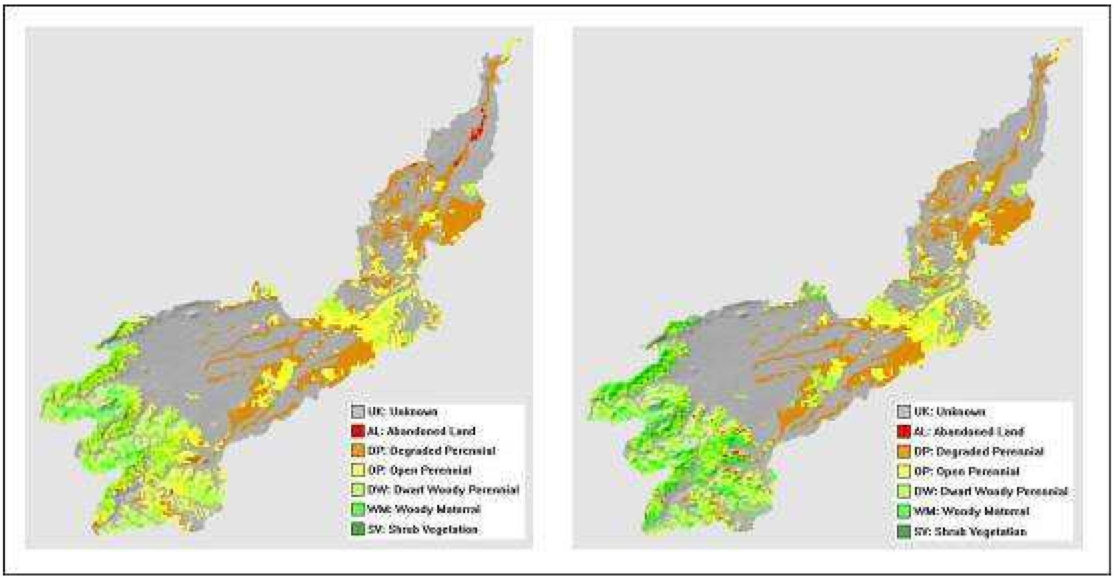


Figure 3.14; Vegetation type distribution at the start of the calibration period (left) and distribution after model running for 8 years (right) for the calibrated model without grazing influence.

3.3.3 Vegetation type development

The changes in successional state of the natural vegetation cells during the modelling period, do not meet the terms of success. As figure 3.13 shows, the successional state of the analysed cell did show one progressive change in successional state for the calibration period of 8 years, like defined in the terms of success. Other areas though, show changes that were not expected. In the mountain areas for example, some cells show a progressive change of 4 successional states (from degraded perennial to woody matorral. Other areas even show a degradation of 4 successional states (from dwarf woody perennial to abandoned land). The spatial difference in developments is caused by a difference in aspect and slope. With the parameter values as found for this study, the aspect and slope of a cell determine the growth to a large extent. Where on the plains, developments in biomass and vegetation types do meet the terms of success; areas with higher slopes tend to produce wrong results. Cells having a North-facing slope receive less sunlight and therefore have a lower PAR, resulting in lower growth rates. On the other hand, South-facing slopes have higher PAR rates, resulting in higher growth rates. This difference is illustrated in table 3.10.

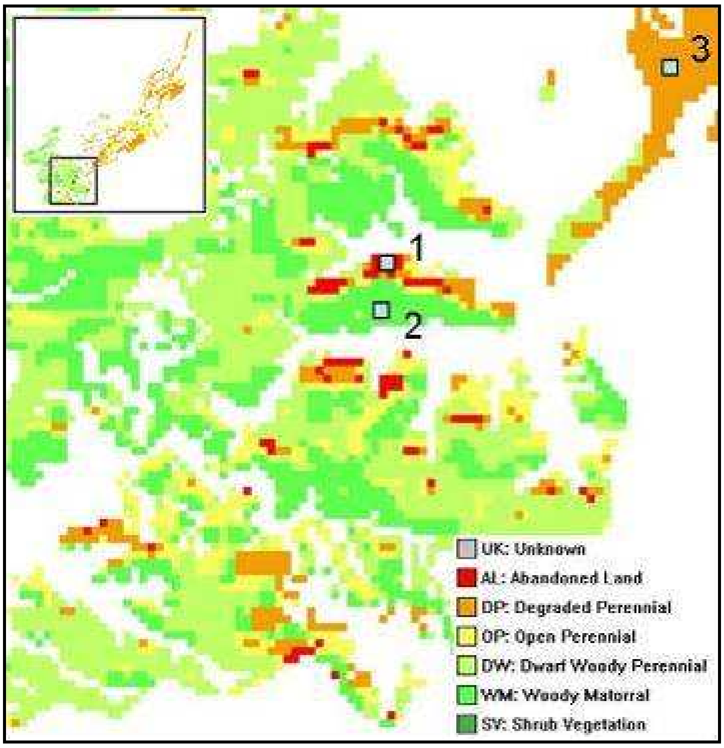


Figure 3.15; Locations of cells for analysis of difference in PAR by aspect and slope. Location 1 is a North-facing slope (19.6 %), location 2 is a south facing slope (18.9%) and location 3 is a flat area (slope of 0.5%).

Table 3.10; Difference in intercepted photosynthetically active radiation (PAR) at different slopes and aspects throughout the study area.

Year	PAR of North face slope	PAR of South face slope	PAR of flat area
2000	0.52	0.79	0.69
2001	0.52	0.80	0.69
2002	0.52	0.79	0.69
2003	0.51	0.79	0.68
2004	0.52	0.80	0.69
2005	0.51	0.79	0.68
2006	0.54	0.81	0.70
2007	0.55	0.81	0.71
Average	**0.52**	**0.80**	**0.69**

The consequence of these high differences in PAR is that when the model is calibrated for the flat part of the area (as in this study), growth rates in areas with higher slopes will be either too high or too low for South- and North-facing slopes respectively.

3.3.4 Biomass development

The biomass of the cell that was analysed for this calibration did show an overall increasing trend. The average annual increase was 10.04%, almost similar to the intended increase of 10% per year. The differences per year were highly variable (min 2.97%, max 20.68%), as can be seen in table 3.11. There are two independent dynamic variables that influence this net biomass development. These variables are temperature, which influences maintenance respiration, and intercepted photosynthetically active radiation (PAR), influenced by the amount of hours daylight (from the Climate & Weather MBB), and the cloudiness of the atmosphere (from the Climate & Weather MBB). No direct relation between one of these variables and change in biomass increment rates was found during this study as can be seen in table 3.11. Correlation between PAR and biomass increment was 0.30, and correlation between temperature and biomass increment was -0.11.
The seasonal variability in biomass is quite high. The difference between the maximum amount of biomass and the average is about 42%. The difference between minimum biomass and average is about 31%. This large seasonal fluctuation has a strong impact on calculations of vegetation cover and vegetation height, which in the end determine possible transitions between vegetation types.

Table 3.11; Average annual total biomass development and influencing variables of the logged cell throughout the calibration period.

Year	Average amount of biomass (kg/m2)	Biomass increment (kg/m2)	Biomass increment (%)	Average annual intercepted radiation (MJ/m2/hr)	Average annual temperature (ºC)
2000	72.75	-	-	0.685	18.12
2001	77.79	+5.04	6.93	0.690	17.58
2002	93.88	+16.08	20.68	0.686	16.26
2003	100.19	+6.31	6.72	0.679	17.28
2004	112.30	+12.11	12.09	0.694	15.85
2005	120.16	+7.86	7.00	0.679	17.33
2006	123.73	+3.57	2.97	0.705	19.08
2007	143.00	+19.27	15.58	0.709	19.17

3.3.5 Vegetation height

The development in vegetation height does seem to meet the terms of success. The overall increasing trend in vegetation height is reflected. Seasonal fluctuations stay within the limits as defined per vegetation type. Furthermore, seasonal fluctuations come close to the 20-30% deviation from average values. In the wet periods, vegetation height is about 31% higher than average values; in dry periods vegetation height decreases with 26%.

The development of average height per vegetation type is given in figure 3.16. All vegetation types have an average height within the defined limits per type. Note that the amount of cells per type is variable and that a decline in average height could either mean a reduction of height of the cells in that vegetation type or a succession from cells into the next vegetation type.

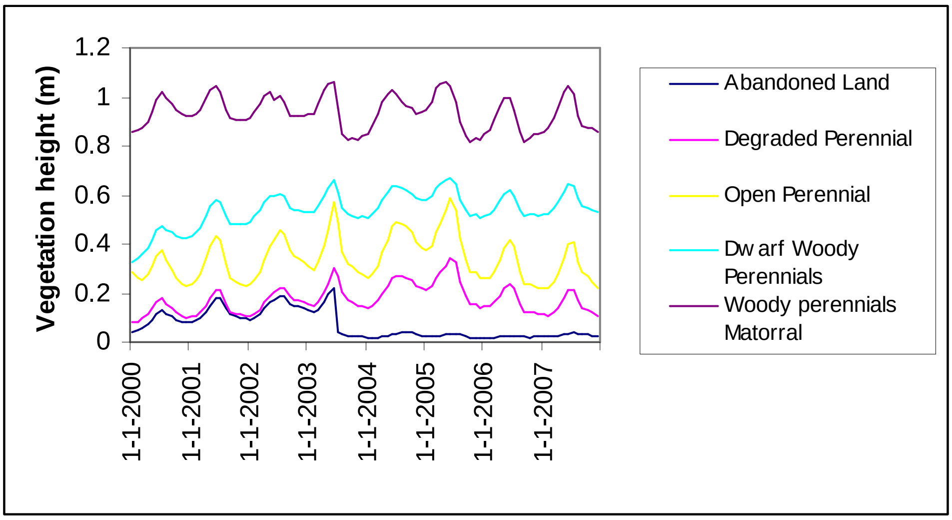


Figure 3.16; Development of average height per vegetation type for all natural vegetation cells.

Vegetation types containing woody plant parts however, only seem to grow in terms of height. No maintenance respiration is calculated for woody and woody root parts of plants. For all the other plant parts maintenance respiration can actually be higher than growth, resulting in biomass reduction. The consequence of this calculation method for the development of height is that a reduction in vegetation height can only be caused when life stem biomass decreases.
This means that all vegetation types which initially contain woody plant parts (dwarf woody perennial, woody matorral and shrub vegetation) will keep their wood biomass levels at least as high as the original value, even after degradation during the whole modelling period. This also has consequences for the height. Since the growth in woody plant parts is not diminished for respiration, the height of these cells is only reduced by the live stem fraction of the biomass. This does not reflect real developments in the Jeffara region. On the long term, degradation of natural vegetation due to diminishing biomass rates should also lead to lower vegetation heights. As found in literature, field evidence suggests a degradation cascade of the Tunisian steppe vegetation, from arboreal steppes to grass- and shrub steppes (Puigdefabregas and Mendizabal, 1998).
As mentioned before, transition rules were adapted to make degradation from woody vegetation types possible. As a consequence, cells that degraded from woody types into lower successional states would still have relatively high wood biomass values and therefore too high vegetation height values.
A solution for this problem is to include maintenance respiration for woody plant parts as well. This will be further discussed in the recommendations.

3.3.6 Vegetation cover

The overall increasing trend in vegetation cover does meet the terms of success. Vegetation cover rates however are too high when looking at the vegetation type characteristics listed in table 3.2. Average vegetation cover for the time that the cell was occupied as open perennial was 50%, were vegetation cover of this vegetation type should stay between 15 and 25%.
The seasonal variation between the average and the maximum and minimum was also too high. The deviation between annual maximum and average was about 42%, and between annual minimum and average about 30%. This is higher than the aimed 20-30% deviation as defined in the terms of success.

3.4 Including grazing influence

After calibration of the model without taking grazing influence into account, grazing was included in the calculations as a second calibration step. The development of leaf biomass per vegetation type and the average daily increment calculated from it are given in table 3.12. These values are used as parameter values for 'leaf biomass grazed daily'. For shrub vegetation, the same value as for Woody Matorral was used.

Table 3.12; Leaf biomass development and average daily increment rates for the different vegetation types. The values used for 'leaf biomass grazed daily' are given in bold and are based only on the values in which the cell remained the initial vegetation types (gray highlight).

	Amount of LeafBiomass (gr/m2)					Average daily increment				
Year	**AL**	**DP**	**OP**	**DWP**	**WM**	**AL**	**DP**	**OP**	**DWP**	**WM**
2000	15.9	27.2	44.5	62.9	108.8	-	-	-	-	-
2001	22.4	28.9	49.5	83.2	149.8	0.018	0.005	0.014	0.056	0.112
2002	31.9	35.3	59.8	101.8	173.8	0.026	0.017	0.028	0.051	0.066
2003	37.3	39.7	63.7	102.8	169.6	0.015	0.012	0.011	0.003	-0.012
2004	42.7	46.1	71.5	113.9	185.5	0.015	0.018	0.021	0.030	0.044
2005	46.8	49.6	76.3	110.7	175.9	0.011	0.010	0.013	-0.009	-0.026
2006	36.4	33.2	77.4	84.1	146.6	-0.028	-0.015	0.003	-0.073	-0.080
2007	36.9	30.2	87.9	86.5	152.7	0.001	-0.008	0.029	0.007	0.017
					Average	**0.020**	**0.005**	**0.017**	**0.009**	**0.017**

The implications of grazing on the models' results will be examined in a similar way as for the first calibration step. Detailed development will be given for the same cell as before. This cell, initially covered with open perennial, has a grazing intensity of one, which should result in a more or less stable situation concerning plant growth and succession in natural vegetation type. The results of the model in which grazing was taken into account are given in figures 3.17 and 3.18.

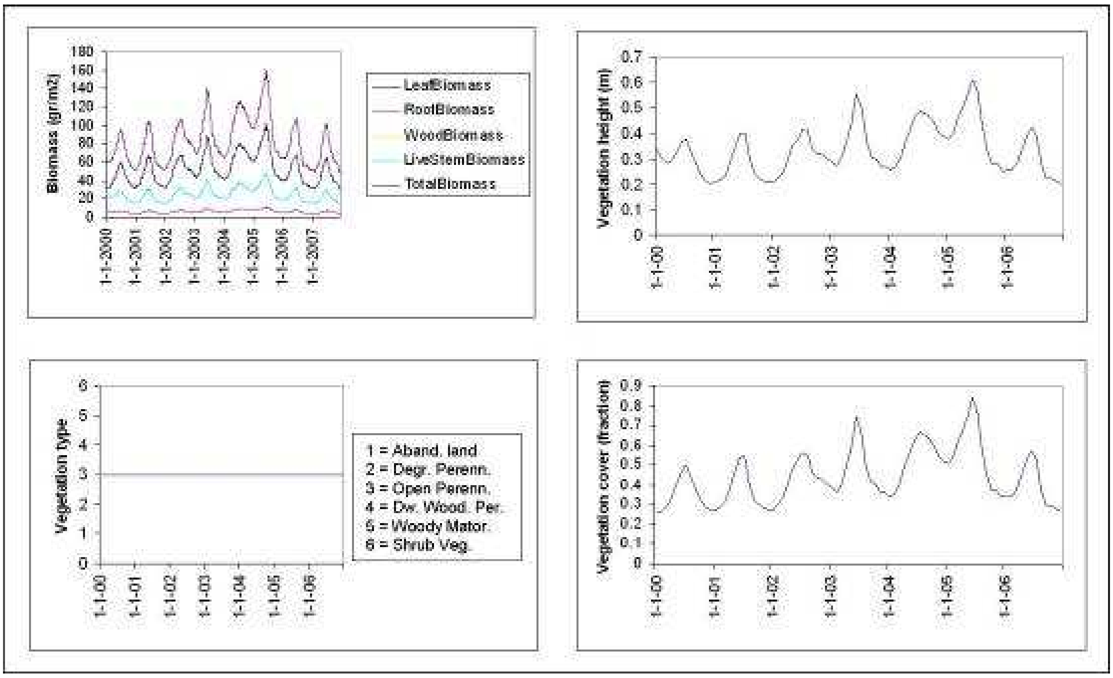


Figure 3.17; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for the calibrated model with grazing influence.

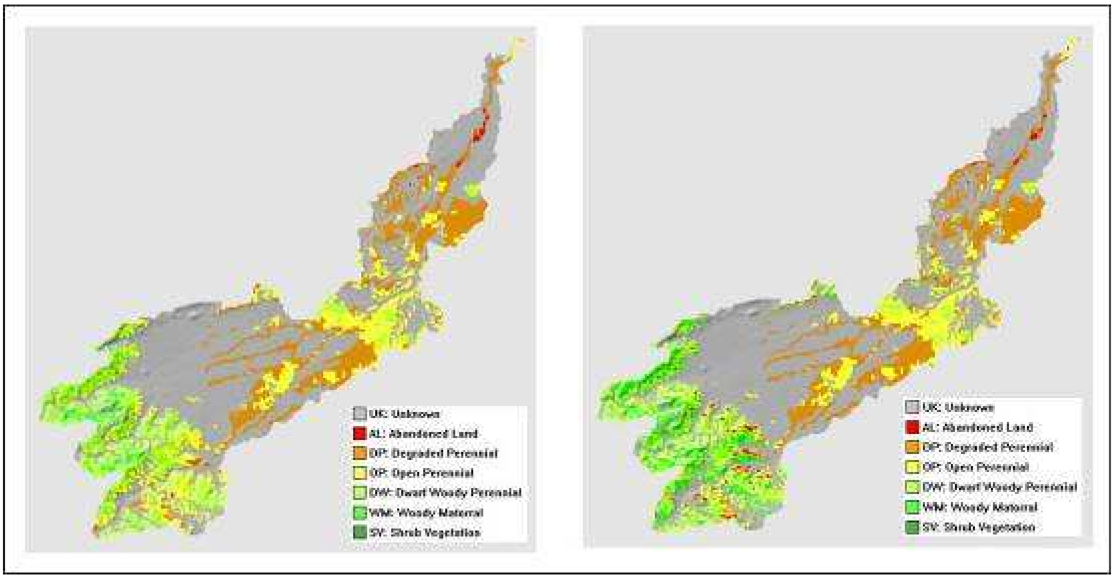


Figure 3.18; Vegetation type distribution at the start of the calibration period (left) and distribution after model running for 8 years (right), for the calibrated model with grazing influence.

Grazing has a clear effect on the developments within both the plant growth MBB as well as the natural vegetation MBB. The natural vegetation type did not change during the calibration period contrary to the situation where no grazing was taken into account. Furthermore, biomass, vegetation cover and vegetation height levels seem to be stable. Differences due to grazing intensity can already be seen throughout the study area (figure 3.18, compare with grazing intensity map; figure 3.2). The mountain area for example has a lower grazing intensity due to the higher slopes. In these areas, a progressive succession from dwarf woody perennials to woody matorral was found. In areas where grazing intensity is higher (on the plains and around villages) hardly any succession and in some cases even degradation took place. This difference due to grazing intensity can also be found back when different grazing intensities are tested at the same cell. In figure 3.19, the development of a cells' total biomass with different grazing intensity rates is presented. For grazing intensity 0, a gradual increase in biomass was found, where for grazing intensities 1 and 2, the total amount of biomass was stable or slightly declining respectively. This was also found back in the successional state development of the cell. For grazing intensity 0, the cell changed from open perennial to dwarf woody perennial after six and a half years, where for both other grazing intensities the vegetation type was stable.

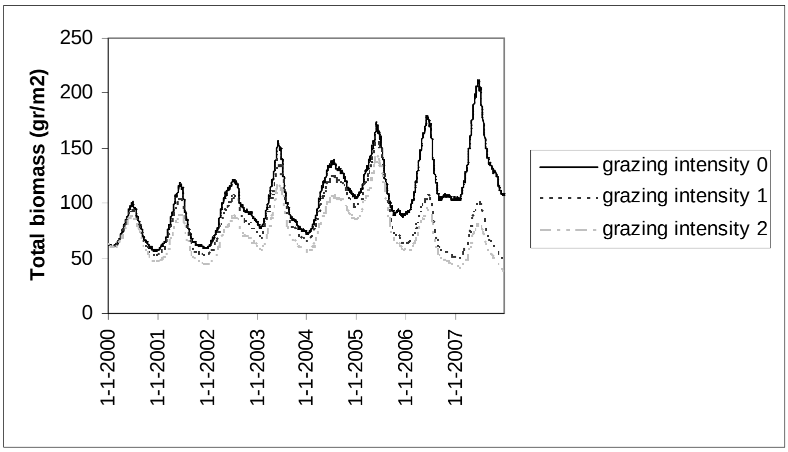


Figure 3.19; Total biomass development of an open perennial cell at different grazing intensities.

3.5 Comparison with MODIS NDVI

The fact that only a part of the model was used in this study makes it difficult to compare the models' results with observed trends in the MODIS NDVI time series. Dynamic factors that do have important influence on vegetation dynamics in reality, were left out of the analysis or taken into account as fixed variables. The most important variable that could not be dynamically taken into account is soil moisture. Since plant growth ability concerning soil moisture was taken as a fixed value for the whole area and modelling period, precipitation differences in time and space were left out of this study.

In reality however, there is a high irregularity in precipitation both in time and space (IRA, 2003). Furthermore, significant relations have been found between precipitation and developments in NDVI (Wellens, 1997). It was found that vegetation cover rates increased after periods with precipitation and that rainless periods usually correspond with periods of low or declining NDVI values. This makes it difficult to directly compare the models' results with the observed time series of MODIS NDVI as presented in figure 3.20. In this figure, developments of locations with known vegetation cover values in 2007 are presented, grouped per vegetation type. The same locations per vegetation type as for the calculation of the initial biomass map were used (see paragraph 3.2.1). Location specific observed NDVI trends can be found in appendix 2.

Although the observed trends in NDVI cannot be directly compared with the models' results, it does give insight in some aspects of vegetation dynamics. First of all it is evident that there is a high irregularity in NDVI values over the analysed period for all of the locations. When comparing the NDVI trend to observed precipitation rates in Medenine (approximately 20 km West of the study area), some peaks in precipitation can be found back as peaks in NDVI (e.g. Dec-2000, Apr-2003, Feb-2006) but other peaks seem to have no influence (e.g. Jan 2002). On the other hand, some periods in which NDVI values are high throughout the study area cannot be related to a peak in observed precipitation (e.g. Oct-2004). A possible reason for this is the high irregularity in space. Precipitation rates of one location (in fact located outside the study area boundaries) seem insufficient for explaining NDVI trends for the region.

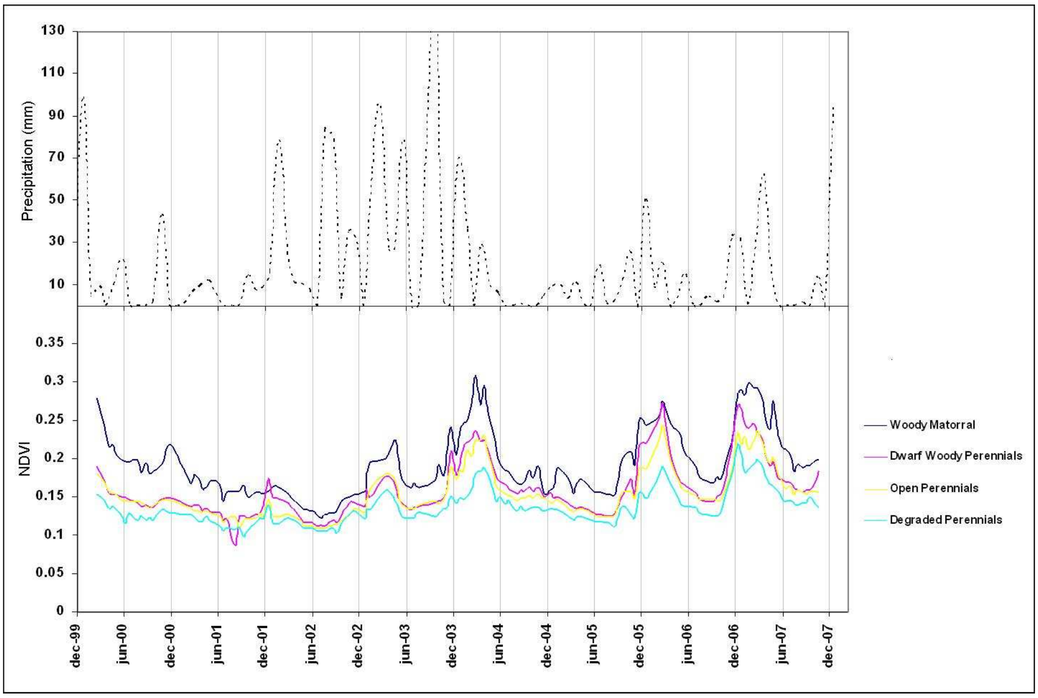


Figure 3.20; Observed monthly precipitation rates in Medenine against NDVI values per vegetation type between Feb-2000 and Oct-2007.

If the observed vegetation cover trend based on observed NDVI is compared with the modelling result of a similar vegetation type (figure 3.21), a few conclusions can be drawn. Firstly, vegetation cover trends from observed NDVI are lower than from the modelling result. Where the model produces values from about 22 to 85% vegetation cover, the NDVI based cover rates do not exceed 50% and go down to about 7% at minimum.

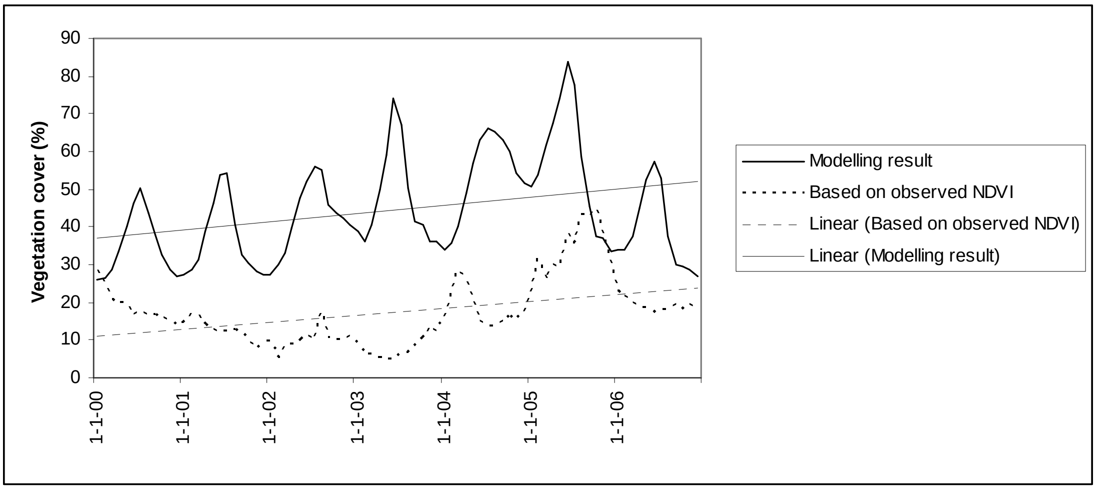


Figure 3.21; NDVI based vegetation cover development of open perennial vegetation compared with the vegetation cover of an open perennial cell as output from the natural vegetation MBB.

Furthermore, the model based cover rates show a clear annual trend with peaks around July, whereas the NDVI based cover does not really show an annually repeating trend. The peaks that can be found back in the NDVI based vegetation cover trend occur at different seasons (Mar-2001, Aug-2004, Oct-2005). This confirms the strong irregularity of precipitation in time. If this irregularity could be taken into account in the model, the annually repeating trend of the model based vegetation cover would be less strong. Dry years would then reduce the vegetation cover rates, and could result in more similar trends as the observed NDVI based vegetation cover development.

The period covered by the time series is rather short for analysing vegetation dynamics. The overall trend of degradation of natural vegetation areas as mentioned in literature and by vegetation expert Dr. Azaiez Ouled Belgacem can not be found back in the observed NDVI values over the analysed period of Feb-2000 to Oct-2007. For all of the locations, there even was an increasing linear trend in NDVI values over the period (see graphs in appendix 4). Whether this increasing trend actually means a recovering trend of the natural vegetation for the study area cannot be concluded from these values only. Due to the high irregularity in NDVI values and the relatively long term perspective of ecological trends, a much longer period of observations would be needed to draw firm conclusions on trends like this.

3.6 *Model application*

After the calibration phase, the found optimum parameter values were used to explore the vegetation dynamics in the future. The model was run for a period of 22 years, from January 2008 until January 2030. For the initial situation, vegetation type distribution and biomass values from the time of the field visit were used. Similar ways of presenting modelling results of the calibration phase will be used to present model outcomes. The graphs in figure 3.22 are based on an open perennial cell at the centre of the study area.

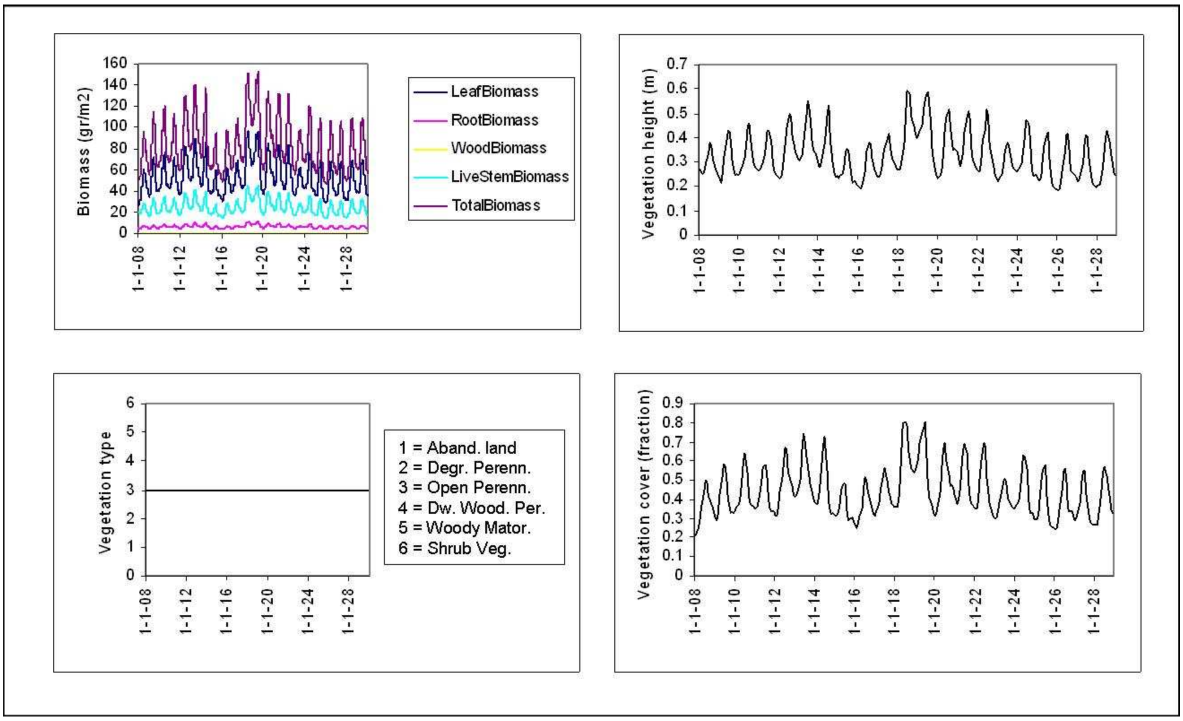


Figure 3.22; Development of biomass (upper left), vegetation height (upper right), vegetation type (lower left) and vegetation cover (lower right) for the modelling period of 2008-2030.

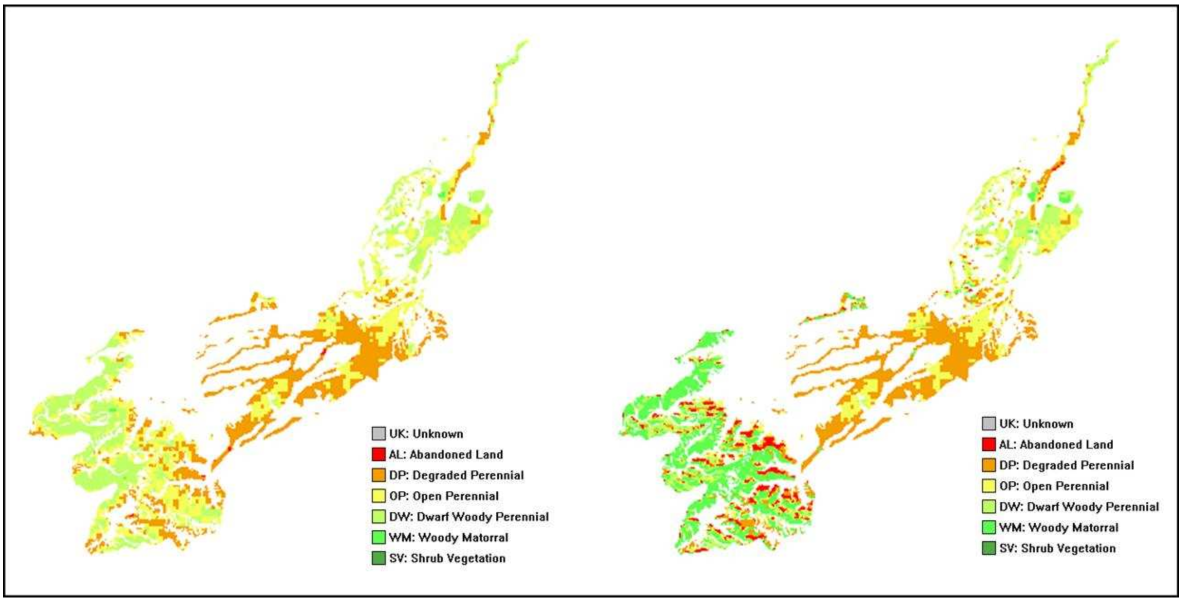


Figure 3.23; Initial vegetation type distribution (left) and distribution after running the model for 22 years (right)

3.7 Model Validation

To examine the ability of the model in simulating vegetation dynamics, two methods were used as described in the methods (paragraph 2.3.4).

3.7.1 Model Behaviour analysis

Biomass, vegetation height, vegetation type and vegetation cover levels stay more or less stable when running the model for 22 years for the open perennial cell which was analysed in detail. Seasonal variation did not change compared to the results from the calibration period. For vegetation cover, the seasonal variation between the average and the maximum and minimum cover values was too high, with an average of 36%. For vegetation height, average values stay within the limits as defined per vegetation type (0.3 to 0.5 m for open perennial). For the seasonal variation, maximum values are in fact too high, with too large differences between maximum and average vegetation height values, sometimes going up to 50%.

The influence of aspect and slope on development of natural vegetation type as described in paragraph 3.3.3, is becoming more clear in the mountain areas in the vegetation type distribution map of 2030 (figure 3.23). Almost all natural vegetation cells with a high slope either degraded to abandoned land or developed to woody matorral vegetation. For other areas it was expected that influence of grazing would have more effect on the development of natural vegetation, and that areas with a grazing intensity >1 would show gradual degradation in biomass levels, vegetation height, vegetation type and vegetation cover levels. However, patterns in the grazing intensity map do not clearly appear in the vegetation type distribution map of 2030. Most of the cells on the plains remain their initial vegetation type after 22 years, even if grazing intensity for areas is at its maximum. Plant growth rates are probably not sufficient to result in succession of vegetation types with the parameter values used in this study. Areas with low grazing intensity were expected to show gradually increasing biomass, height, cover and vegetation type levels. These areas also seem to remain the same levels as the initial situation. The influence of grazing with the values used in this study is therefore too low.

Another point of attention is the fact that most of the areas initially covered with abandoned land show progressive succession, for some areas (in the centre of the study area) even up to woody matorral. Cells with a different initial vegetation type directly neighbouring these cells remained their initial type, where these abandoned land cells show progressive succession under similar circumstances (PAR, temperature and grazing intensity). This big difference is not realistic. When studied in detail, the fast development was mainly caused in the first five years. During this period, cells were having the abandoned land and degraded perennial vegetation type and average vegetation height doubled almost every two years. If radiation use efficiency for degraded perennial and abandoned land would have been lower, succession would not have gone this fast and vegetation development would probably have been simulated more realistically.

3.7.2 Expert judgement

As explained in paragraph 2.3.4, a second validation method beside comparison of results with expected vegetation development by the author was expert judgement of IRAs natural vegetation expert. Unfortunately, no validation was given at the time of printing yet. No expert validation could be given on the results of the model in this study.

4 Discussion

In this chapter the results as described in the previous chapter will be put in the context in which they have been achieved. Putting the findings in context is done to get a better view on what the results actually mean regarding the objectives and research questions of this study. Results will be discussed in the same order in which they were previously presented.

4.1 Model adaptation

The first adaptation described in this report was the definition of new vegetation type classes for the Jeffara region. This was an inevitable adaptation since the classes for previous model versions do not occur in Tunisia. The choice was made to group the different plant communities from the region into six new vegetation types based on similarity in vegetation cover and biomass. This new class could have been either more detailed or more general, which both have their advantages and disadvantages. More detailed classes would imply a more complex model for which it would be more difficult to simulate real developments. On the other hand, more classes also means a better representation of reality, since vegetation in the Jeffara region shows much more variation than the six classes as defined in this study.

Fewer classes would have led to a more general and more simplistic view on reality, which would have been less complex to calibrate.

It might have been better to group the different plant communities into fewer classes than the six classes defined now. Since the seasonal variation of the defined classes is high, there is a large overlap between possible vegetation cover and biomass values between vegetation types throughout the year. By taking two relatively narrow classes like degraded perennial and open perennial as one class, the complexity of the model could be reduced without losing much information in model outcomes in terms of vegetation cover and biomass rates. If fewer classes would have been defined, it would not directly influence the main purposes of the model (support planning and policy making in the fields of land degradation, desertification, water management and sustainable farming).

A second adaptation in the model was taking grazing intensity into account. Since grazing is one of the main influencing factors on vegetation development, a more detailed method of simulating effects of grazing was needed. Where in the previous model version grazing was taken into account with a map of grazed areas and a fixed amount of biomass grazed per vegetation type, factors like distance to villages, slope and grazing protection were used to define grazing intensity per cell for this study. Only a few cells in the study area are currently protected for grazing, which would mean an equal grazing intensity for the rest of the area in the previous model version. In reality though, it was found that degradation of natural vegetation due to grazing was highly variable throughout the study area, influenced by factors like distance to villages and slope.

The grazing intensity per cell was based on interpretation by the author and could be improved by adapting values based on more detailed knowledge on the actual grazing strategies in the region.

An advantage of the new way of calculating amounts of grazing is that it does not necessarily have to be used in areas that will be modelled in future. The new calculation method can also be applied to regions that were previously modelled (Guadelentín, Argolidas), without further need for data on grazing intensity in the area. If for grazed areas a grazing intensity value of one is used (same value as grazed areas in grazing map of the previous model version), there will be no difference in model outcomes compared to the calculation method in the previous model version. For future study areas this means that if grazing is less important as in Tunisia, and grazing intensity is hardly improving model outcomes, it is optional to put effort in a grazing intensity map.

A third adaptation is a different strategy in calculating vegetation height. The method in the previous model led to large differences in vegetation height when a cell changed transitional state. The new method (change in height based on change in biomass) did lead to a more gradual height development, and is therefore considered successful.

It is expected that the model is able to simulate vegetation dynamics of the Jeffara region sufficiently without further adaptations, except for including maintenance respiration for wood biomass in the calculations as mentioned before (see recommendations). When plant growth suitability could be taken into account as a dynamic and adaptable factor, the speed of vegetation development can be calibrated more easily.

4.2 Model initiation

The amount of variables that were actually used in the model was limited since some variables were excluded or taken into account as fixed variables due to limited availability of representative data for the study area. The input variables that were used are; initial land use, initial biomass, initial vegetation type distribution, temperature, sunlight and slope.

The initial land use map has a strong influence on the initiation of other variables. The areas that were assigned as natural vegetation were actually selected from the land use map as provided by IRA. Since no data was provided on the accuracy of this map, a large uncertainty factor is included by assuming that these cells actually are covered with natural vegetation. For the interpretation of the satellite images for these areas, this means that if cells in reality have a different or a mixed land use, variable estimation based on measured reflectance on these locations would certainly lead to wrong estimation of biomass and vegetation type. The initiation of variables using methods with remote sensing based data will be further discussed in the 'role of remote sensing' section within this chapter.

Input data for temperature value generation for the model was based on the situation in Argolidas in Greece. Although the observed temperatures in the Jeffara region are averagely 3.5 ºC lower than the used temperatures, the seasonal variability and the warmest and coldest month in the year are equal. Since temperature values influence the amount of biomass reduced for maintenance respiration, parameter values will have to be adapted to compensate differences in plant growth if Jeffara region specific data is used. In the end, similar model outcomes are expected if parameters are adapted to updated temperature values.

A slope map of the study area was provided by IRA and was considered to be appropriate to use for the model.

Calculation of sunlight for the model is based on the latitude and longitude of the study area, and the slope and aspect of a cell. Since these values are well known for the study area, values for sunlight are considered to be correct.

4.3 Model calibration

Calibration of the model was done with some variable values taken into account as fixed values. In reality, these variables are dynamic, and taking their variation into account would lead to a more complex model and probably a more difficult calibration. Even with some fixed variables, calibration of the model covered most of the time of this study. Calibration was done by aiming at model outcome improvements part by part, by adapting parameters with trial and error. Due to the complexity of two integrated MBBs with feedback loops and many vegetation type specific parameters, a more structured calibration strategy was not found.

An example of the variables that were taken as fixed values, are the variables that define the suitability of a cell for plant growth. A fixed suitability of 0.5 was used for all cells where the original model calculates a cells' suitability by taking soil depth, soil moisture, soil salinity, slope and temperature into account. Better results can be expected when all suitability factors could be used, especially on spatial variation throughout the study area. Areas around streams for example will probably show higher increment rates whereas the sebkhas in the North-East or the mountains in the South-West will probably show relatively lower increment rates due to higher salinity and limited soil depth respectively. For the influence of grazing on vegetation dynamics, hardly any calibration was done. Grazing was applied by using the grazing intensity map for the study area based on assumptions by the author, together with amounts of biomass grazed based on leaf biomass increment rates for not-grazed areas. Results could be improved by further fine tuning the intensity map and amounts of biomass grazed, especially when looking at influence of grazing for longer modelling periods.

Calibration was done with the defined terms of success in mind. Although it was expected in advance that calibration could be done based on observed historical trends in NDVI development, more general terms of success had to be formulated. The observed NDVI trends were subject to variation in variables that were taken as fixed values for the model. Comparing the modelled trend with these real developments was therefore considered inappropriate. Still, aiming model outcomes on terms of success based on expert knowledge was found to be a suitable way of calibration. Clear quantitative expectations, directly comparable with model outcomes, could be formulated based on discussions with IRAs vegetation expert and literature.

Most of the adaptations in parameter values were based on detailed analysis of a single cell, combined with observed results in several output maps from the whole study area. If unexpected results were found in the output maps, detailed analysis was done by analysing developments of a single cell within that area. Since this interpretation of output maps was done by visual interpretation, it can not be guaranteed that all errors within the model results have been mentioned. Due to limited availability of time, no structural analysis of all developments within the model could be done.

4.4 Model validation

Validation of the outcomes of the model had to be done based on comparison of results with expected vegetation development by the author only. Due to the assumptions that had to be made to calibrate the model (using fixed input variables for the whole study area) observed trends in MODIS NDVI developments could not be directly compared to the model results. Beside the fact that some external influences could not be taken into account in the model, the relatively short period of NDVI trends made it impossible to use this data for validation of modelled vegetation developments.

Unfortunately, validation by expert judgement could not be included in this report in time. If it could have been included, a better and firmer view on model results could have been presented.

It has to be said though that no real independent judgement could be made. The expert who was asked to do the validation was partly the same source of information used to define terms of success in the calibration phase. It would have been better to have an independent judgement by an expert or dataset that was not involved in previous modelling steps. Using the same source of information for initiation, calibration and in the end also for validation could lead to pre-occupied judgement of the result. For interpretation of results concerning validation of the model outputs from this study this has to be kept in mind.

4.5 Role of remote sensing

The main role of remote sensing based data in this study has been initiation of total biomass and the distribution of vegetation types over the study area. For this initiation, MODIS NDVI images in combination with field observations from October 2007 have been used. The method chosen to interpret this image was linear regression with observed values of vegetation cover as described in the data and methods chapter of this report (chapter 2). Suitable locations for interpretation of MODIS NDVI were selected, partly based on visual interpretation of area extent on Quickbird satellite images available from Google Earth. Furthermore, indirect use of remote sensing based data sources was made by use of a remote sensing based land use map that was provided by IRA (visual interpretation of aerial photographs) and by use of the elevation model.

The method of satellite image interpretation for the initial biomass and vegetation type map was considered to be the best option. The available information of land use within the study area concerning natural vegetation was limited. The areas in the map that were assigned as natural vegetation were subdivided into three different classes based on their location (mountains, plains and salty depressions). For the model, a classification of vegetation types based on successional state was required. It was not possible to reclassify the classes available from the land use map into the different vegetation types as required for the model. Therefore a new map had to be created.

For the interpretation of satellite images, relevant reference data is required. In the case of interpretation of amounts of biomass or natural vegetation types, the time between the collected reference data and the satellite images cannot be too long considering the relatively dynamic character of natural vegetation. In the case of the Jeffara region, seasonal variation in natural vegetation is high and irregular. Since no historical ground truth data was available, it had to be collected within this study, and for the initiation of biomass and vegetation type for the area, a recent satellite image was required.

Since MODIS data is available free of charge approximately 2 weeks after acquisition, MODIS NDVI was considered to be most appropriate to use for creation of the mentioned initial maps. By using this data source, field observations could be directly compared to measured NDVI values. Other available data sources free of charge were a Landsat MMS image from December 1975, a Landsat TM image from January 1987 and a Landsat ETM+ image from December 1999. The time span between the field observations and the mentioned images was too large to be useful for interpretation.

For the initiation of the model for the Guadelentín region in Spain, a reclassification of CORINE land cover classes was used to define initial vegetation type distribution over the study area (Van Delden et al., 2004). Initial biomass values were defined by giving each natural vegetation cell a vegetation type specific amount of biomass, based on expert knowledge. In this method there was no variation of initial biomass between cells of a similar vegetation type.

The advantage of initiation of biomass values with remote sensing based data sources is that information on the variation in amounts of biomass within the study area is used for the model. Different areas within the study area have different amounts of biomass, although they are considered as the same vegetation type. A character of natural vegetation is that there is a gradual change from the lowest to the highest successional state. Some areas within a certain vegetation type could be closer to the previous successional state where other areas from the same vegetation type could be closer to the next successional state. By making use of the variation in NDVI values for the initiation of biomass, these differences can be included in the initial situation for the model. This is an advantage compared to the method used for the initiation of the model for the Guadelentín region.

The methods used to create the biomass map could be improved. If more effort would be put in gathering of ground truth data, more reliable output products can be expected. Interpretation of NDVI values in this study were based on a limited number of field observations. Field observations that were used for image interpretation consisted of visually determined vegetation cover values for certain areas, that were linked to corresponding biomass values as described in paragraph 2.3.2.3. The variation in vegetation cover is relatively high due to the limited amount of foliage during dry periods. The amount of biomass though is much less susceptible to seasonal variation since the major part of biomass is stored in wood and life stem plant parts for which seasonal variation is low.
The link between observed vegetation cover and corresponding biomass value can in fact only be justified if vegetation cover values are around their annual average. Whether the vegetation cover values as observed during the field visits are around their annual average is to be doubted. Seasonal variation in vegetation cover is very irregular with some years showing large variation and other years showing hardly any variation. This can be seen in observed NDVI values over the past years in figure 3.20. For most of the years, the observed NDVI value in October is lower than the annual average. This means that the observed vegetation cover values during the field visit could correspond to higher biomass values than the values used in this study. This would mean that some cells should actually be classified as higher transitional state vegetation type. It might have been better to use the average measured NDVI value over the year before the field to define biomass levels and vegetation type distribution.
Estimation of biomass levels at the locations visited during the field visit would have led to much more reliable image interpretation. Due to limited availability of time and the difficulty of biomass estimation methods, this data could not be gathered within this study.
Another drawback of the used method is the limited number of points used for image interpretation. Only sixteen out of 58 visited locations were found suitable for image interpretation of which five locations were selected from Quickbird satellite images from Google earth. Selection was done by finding similar vegetation patterns within visited areas that did have the right extent to be used to compare with MODIS NDVI, having a pixel resolution of 250x250m. The Quickbird images available from Google Earth were from at least 13 months earlier than the field visit. Although the visual interpretation of these high resolution images was done based on similarity of areas on the same image, there is a possibility that the two areas changed independently between the acquisition date and the field visit. This would mean that for interpretation of the MODIS image from 2007, a wrong estimation for vegetation cover was used. The chance that the locations developed in a different way is not big though because dynamics of natural vegetation areas are low, especially for remote areas.
If more ground truth data would have been collected, it would certainly increase the products derived from image interpretation. A structured way of sampling and estimating vegetation parameters would lead to a more reliable image interpretation.
Furthermore, if higher resolution satellite imagery was used, more visited locations would have been suitable for image interpretation. Although images from Landsat or Spot satellites were not available free of charge, using them would also lead to a better interpretation result.

The use of remote sensing data in the calibration and validation phase of this study was limited. There are fundamental differences in modelled vegetation development (without influences of precipitation and soil etc.) and observed NDVI development, where all these factors did have influence. Due to these differences, a direct comparison was not possible. There certainly are opportunities though to use the historical NDVI development to validate model outcomes. If the links between calibrated MBBs like hydrology & soil are established and dynamic input like soil moisture development could be taken into account, a comparison with observed NDVI could be used to evaluate modelling results.

5 Conclusions

The objective of this study was formulated as follows; To adapt and validate the MedAction PSS Natural vegetation and Plant growth model for the Jeffara region in Southern Tunisia, and to investigate the role of remote sensing based data sources in this process. Whether this objective has been met will be evaluated by giving answers to the each of the research questions as defined at the start of this study.

How can the Natural vegetation related MBBs from the MedAction PSS be adapted to Tunisian circumstances?

The model has been adapted to circumstances of the Jeffara region with a wide range of materials and methods. First of all, a good insight of the circumstances concerning natural vegetation was achieved by literature study, consulting an expert in natural vegetation from the region and field visits. The model was adapted to the circumstances by defining region specific vegetation types, introduction of a cell specific grazing intensity, an adapted height calculation method and adaptation of input variables and parameter values. For the initiation of the input variables ‘total biomass’ and ‘vegetation type distribution’ MODIS NDVI images were used in combination with collected ground truth data.

What parameter values and transition rules give optimum model outcomes?

Optimum model outcomes for the region were found by using a calibration strategy in which terms of success were defined in advance. Terms of success were based on expert knowledge on vegetation characteristics, vegetation developments, grazing influences and seasonal variation. The model was run for a period of eight years, corresponding to the period for which MODIS NDVI developments were known, starting in January 2000. Adaptation of parameters was done by firstly gaining insight in model behaviour in an iterative process of testing parameter influences. Secondly, certain model improvements regarding the terms of success were aimed at and parameter values were adapted until satisfactory results were achieved, given the available time for this study. Due to lack of reliable input variables like soil moisture and soil salinity, some variables were taken into account as fixed values. Due to this adapted, unrealistic simulation of natural vegetation development, no direct comparison between model outcomes and observed historical vegetation development from MODIS NDVI could be made.
The optimum found parameter settings and transition rules are characterized by low vegetation density values and relatively low growth rates compared to regions for previous model application like Argolidas, Greece and Guadelentín, Spain.

How well does the model simulate the real natural vegetation dynamics in the study area?

Whether the model simulation reflects real vegetation dynamics in the study area is hard to evaluate. Some assumptions had to be made due to lack of reliable input data. Assumptions like a fixed soil moisture rate for the whole study area over the modelling period made it hard to directly compare modelled vegetation dynamics with real dynamics.
There are some conclusions that can be drawn from the model outcomes, if run for a period of 22 years. First of all, the effect of slope and aspect on vegetation development is distorting. Where the model shows a relatively stable state of natural vegetation for areas with low slopes, areas with higher slopes show too fast regressive or progressive development for North-faced

and South-faced slopes respectively. Furthermore, effects of grazing on vegetation development are too low for the model as it was set up in this study.

What opportunities do remote sensing based data sources give in the modelling process?

Remote sensing based data sources within this study were mainly used for the initiation of the model. For the initial biomass values for the natural vegetation cells, a MODIS NDVI image was used from the same period as the field visit. Linear regression analysis with observed vegetation characteristics was applied to create the biomass map and to define the distribution of natural vegetation areas. For the selection of suitable ground truth locations, high resolution Quickbird satellite images were used.

In the calibration and validation phase of the process, use of remote sensing based data sources was limited. The simulation of vegetation dynamics by the model was not directly comparable with real vegetation dynamics due to lack of influencing variable input. There certainly are opportunities though to make use of observed vegetation development trends from remote sensing based data sources, if the integrated model could be run with reliable input variables. It should be kept in mind that due to the highly irregular variation in vegetation densities for the study area, together with the long term perspective of processes concerning natural vegetation, a long period of remote sensing observations is required to be able to draw conclusions on trends like degradation.

To define natural vegetation characteristics for an area where existing data is lacking like for this study, use of remote sensing based data sources were found to be the best opportunity. Improvements of image interpretation could be made by increasing the amount of ground truth data.

6 Recommendations

Most of the time in this study has been spent on the calibration of the model. Some recommendations will be given that could lead to a more structured calibration phase in adapting the models for a new region.
The integrated model has quite a complex structure in which full the influence of parameters and variables is often hard to follow based on the model description. For adapting the model, it would certainly increase the effectiveness in the process, if a short description of parameters in terms of possible range, relative sensitivity and implications for the model would be described. Furthermore, a log file of the calibration process could be kept in which the different steps in improving model results are described. Unfortunately there was no time to structurally describe the steps taken in this study, and calibration was done mostly based on trial and error of adapting model parameters.
Another recommendation is to do further research on calibration of integrated models. The complexity of the model, together with the lack of a fixed structure or objective concerning calibration in this study made it a time consuming and difficult process. If guidelines could be formulated in which steps for a structured calibration process could be presented, better results could be achieved in a more efficient way.

For the initiation of variables based on remote sensing data it is strongly recommended to take more time for gathering of ground truth data. In this study, ground truth data was collected on two days where visually interpreted data was collected on natural vegetation covered locations encountered during a field trip. By selecting areas to be visited based on unsupervised image classification or analysis of high resolution satellite images from Google Earth, a better dataset could be created which would certainly improve image interpretation results. Structured ways of estimating or measuring ground truth data like vegetation cover or biomass rates could certainly improve image interpretation results.

As mentioned before, it is recommended to include maintenance respiration for woody plant parts in the model. In the current model calculation, woody plant parts will either grow or remain their initial value. As a consequence, vegetation height of the types containing woody plant parts will always be as high as this amount of biomass multiplied by the biomass per meter height factor. However, in a scenario in which a long period of degradation takes place, which is certainly not uncommon for the Jeffara region, it is expected that woody plant parts will also disappear, and that vegetation height will be diminished. This trend is also described in literature, where a degradation of the Tunisian steppe vegetation, from arboreal steppes to grass- and shrub steppes is described (Puigdefabregas and Mendizabal, 1998). To be able to model this trend, model adaptation in terms of introducing maintenance respiration for woody plant parts is recommended.

This change would imply change from:

$$G_{W,d-1} = P'_{W,d-1} \cdot G_{d-1}$$

(see also appendix 1, model description Plant Growth MBB)

Into:

$$G_{W,d-1} = P'_{W,d-1} \cdot G_{d-1} - R_M \cdot B_{W,d-1}$$

In which
$G_{W, d-1}$ = Growth of woody plant part
$P'_{W, d-1}$ = Fraction of woody plant part
R_M = Maintenance respiration
$B_{W, d-1}$ = Amount of woody biomass

Since maintenance respiration for woody plant parts will probably be less than for other plant parts, a fraction of this respiration factor could be used as well (like for respiration of yield which is multiplied by 0.4). If fractions like this could be adapted in the user interface, it would make calibration of biomass growth of specific plant parts easier.

Due to the limited availability of time, not all parts of this study could be worked out to a satisfactory level. Many improvements could be made on different parts of the process as could be read in the discussion and conclusions. A part of the reason for this is the wide range of modelling steps that were taken in this study. The process included modelling steps from model development to validation and all steps in between. If more focus would be put on specific modelling steps and other steps would have been left out of this study, results would probably be less uncertain, and firmer conclusions could have been drawn.

References

Asner, G. P., Wessman, C.A., Bateson C.A. and J. L. Privett, 2000, Impact of Tissue, Canopy, and Landscape Factors on the Hyperspectral Reflectance Variability of Arid Ecosystoms, Remote Sensing of Environment 74, 1, 69-84

Asner, G.P. and D.B. Lobell. 2000. A biogeophysical approach for automated SWIR unmixing of soils and vegetation. Remote Sensing of Environment 74, 99-112

Baban, S.M.J., Foster, I.D.L and Tarmis, B., 1999, Environmental protection and sustainable development in Tunisia: An overview, Sustainable Development 7, 191–203

Ben Salem, F., Tarhouni, M., Ouled Belgacem, A., and Neffati, M., 2007, Impact of Drought on Plant Cover Dynamics in Two Natural Areas of Southern Tunisia, Journal of Biological Sciences 7, 8, 1539-1544

Campo, L., Caparrini, F. and Castelli, F., 2006, Use of multi-platform, multi-temporal remote-sensing data for calibration of a distributed hydrological model: an application in the Arno basin, Italy, Hydrological processes 20, 2693–2712

Dall'Olmo, G. and Karnieli, A., 2002, Monitoring phonological cycles of desert ecosystems using NDVI and LST data derived from NOAA-AVHRR imagery, International Journal of Remote Sensing 23,19, 4055 – 4071

DigitalGlobe, 2002, QuickBird Imagery Products – Product Guide. DigitalGlobe Inc., pp 78 available at: http://www.digitalglobe.com/digitalglobe2/file.php/511/QuickBirdImageryProducts-Product_Guide.pdf (accessed 04-2008)

FAO/AGL, 2005, National Soil Degradation Maps, Land and Water Development Division, Food and Agriculture Organisation-AGLL, available at: http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp (accessed 06-09-2007)

Fazakas, Z., Nilsson, M. and Olsson, H., 1999, Regional forest biomass and wood volume estimation using satellite data and ancillary data, Agricultural and Forest Meteorology 98, 99, 417-425

Floret C., Pontanier R., 1982, L'aridité en Tunisie Présaharienne, Climat, Sol, Végétation et Aménagement, Travaux et Documents de l'ORSTOM Paris, N° 150, pp. 544

Genin, D., Guillaume, H., Ouessar, M., Ouled Belgacem, A., Romagny, B., Sghaïer, M. and Taâmallah, H. (Eds), 2006, Entre désertification et développement - La Jeffara Tunisienne, Co-edition IRD, Cérès Editions, IRA, 345 p

Hanafi A., Genin D. and Ouled Belgacem A., 2004, Steppes et systèmes de production agropastorale dans la Jeffara tunisienne: quelles relations dynamiques?, Options Médit. 62, 223-226

Hill, J. and Peter, D. (Eds), 1996, The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin, Proceedings of an expert workshop by JRC/IRSA and DG XIII/D.2, D.4, Valencia, Spain, 06-1994, European Commission, Science Research Development, EUR 16732 EN, p 235

Huete, A., K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira (2002), Overview of the radiometric and biophysical performance of the MODIS vegetation indices, Remote Sensing of Environment 83, 195– 213

Huete, A. R., C. O. Justice, and Van Leeuwen, W., 1999, MODIS Vegetation Index (MOD 13) Algorithm Theoretical Basis Document (ATBD-MOD-13), version 3, available at: http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf (accessed 22-11-2007)

IRA, 2003, Watershed of Zeuss-Koutine (Médenine, Tunisia) Overview and Assessment Methodology, UNU-UNESCO-ICARDA Joint Project Sustainable Management of Marginal Drylands (SUMAMAD) 2nd International Workshop, Shiraz (IRAN) November 2003, 13 p.

Jensen, R. R. and Binford, M. W., 2004, Measurement and comparison of Leaf Area Index estimators derived from satellite remote sensing techniques, International Journal of Remote Sensing 25, 20, 4251 - 4265

Lu, D., 2006, The potential and challenge of remote sensing-based biomass estimation, International Journal of Remote Sensing 27, 7, 1297 - 1328

MEA, 2005, Millennium Ecosystem Assessment—Ecosystems and Human Well-Being: Desertification Synthesis, World Resources Institute, Washington, DC, 2005

Ouled Belgacem, A., Tiedeman, J., Chaieb, M. and Neffati, M.,2006, Response of Stipa *lagascae R. and Sch.* to protection under arid condition of Southern Tunisia, Pakistan Journal of Biological Sciences 9, 3, 465-469

Röder, A., Kuemmerle, T., Hill, J., Papanastasis, V.P. and Tsiourlis, G.M., 2007, Adaptation of a grazing gradient concept to heterogeneous Mediterranean rangelands using cost surface modelling, Ecological Modelling 204, 387–398

Ping, A., Shinobu, I., Nanwen, Z., Xiangjun, L., Fadul, H.M. and Mars, M., 2006, Plant species as indicators of the extent of desertification in four sandy rangelands, African Journal of Ecology 45, 94–102

Plummer, S.E., 2000, Perspectives on combining ecological process models and remotely sensed data, Ecological Modeling 129, 169-186

Puigdefabregas, J. and Mendizabal, T., 1998, Perspectives on desertification: western Mediterranean, Journal of Arid Environments 39, 209–224

Raunkiær, C., 1934, The Life Forms of Plants and Statistical Plant Geography. Introduction by A.G. Tansley. Oxford University Press, Oxford, pp 632

Röder, A., Kuemmerle, T., Hill, J., Papanastasis, V. and Tsiourlis, G., 2007, Adaptation of a grazing gradient concept to heterogeneous Mediterranean rangelands using cost surface modelling, Ecological Modelling 204, 387-398

Shoshany, M., Kutiel, P. and Lavee, H., 1996, Monitoring temporal vegetation cover changes in Mediterranean and arid ecosystems using a remote sensing technique: case study of the Judean Mountain and the Judean Desert, Journal of Arid Environment 33, 9-21

Shoshany, M and Svoray, T., 2002, Multidate adaptive unmixing and its application to analysis of ecosystem transitions along a climatic gradient, Remote Sensing of Environment 82, 5 –20

Stéphenne, N. and Lambin, E.F., 2001, A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU), Agriculture, Ecosystems and Environment 85, 145–161

Tarhouni, M., Belgacem, A.O., Neffati, M. and Hench, B., 2007, Validation of some ecosystem structural attributes under the effect of seasonal drought and animal pressure around watering points in the Tunisian arid zone, Belgian Journal of Botany 139, 2, 188-202

Todd, S. W., Hoffer, R. M. and Milchunas, D. G., 1998, Biomass estimation on grazed and ungrazed rangelands using spectral indices, International Journal of Remote Sensing 19, 3, 427 - 438

UNEP/GEF, 2002, Protecting the Environment from Land Degradation- UNEP's Action in the Framework of the Global Environment Facility, United Nations Environment Programme (UNEP), pp. 36

Van Delden, H., Luja, P., Engelen, G., 2004. MedAction PSS. Final Report for Work Undertaken as Part of 'MedAction: Policies to Combat Desertification in the Northern Mediterranean Region'. EU-DGXII, Brussels (contract EVK2-2000-22032)

Van Delden, H., Luja, P., and Engelen, G., 2007, Integration of multi-scale dynamic spatial models of socio-economic and physical processes for river basin management, Environmental Modelling & Software 22, 223-238

Verburg, P.H., Schot, P.P., Dijst, M.J. and Veldkamp, A., 2004, Land use change modelling: current practice and research priorities, GeoJournal 61, 309-324

Vermote, E. F., N. El Saleous, C. O. Justice, Y. J. Kaufman, J. L. Privette, L. Remer, J. C. Roger, and D. Tanré, 1997, Atmospheric correction of visible to middle-infrared EOS-MODIS data over land surfaces: Background, operational algorithm and validation, Journal of Geophysical Research, 102(D14), 17131–17141

Voinov, A., Fitz, C., Boumans , R., and Costanza, R., 2004, Modular ecosystem modeling, Environmental Modelling & Software 19, 285–304

Wegehenkel, M., Jochheim, M. and Kersebaum, K.C., 2005, The application of simple methods using remote sensing data for the regional validation of a semidistributed hydrological catchment model , Physics and Chemistry of the Earth 30, 575–587

Wellens, J., 1997, Rangeland vegetation dynamics and moisture availability in Tunisia: an investigation using satellite and meteorological data, Journal of Biogeography 24, 6, 845–855

Zhang, X., and Kondragunta, S., 2006, Estimating forest biomass in the USA using generalized allometric models and MODIS land products, Geophysical Research Letters 33, L09402, doi: 10.1029/2006GL025879

Appendix 1; Model Description Plant Growth MBB (from Van Delden et al., 2004)

This module calculates the biomass of the different plant types covering a cell. For this reason plants are grouped into functional types and is each plant divided into five parts: leaf, live stem, wood, root and yield. During daylight hours the maximum growth of the plant is calculated based on the efficiency with which it can convert energy from solar radiation into biomass. This growth is diminished because of respiration for growth and maintenance as well as stress factors like a lack of fertile soil, too saline soil, too steep slopes or suboptimal soil moisture and temperature. The relation between the stress factors and the different plant types can be found in the user interface, where they can be adapted.

Based on the biomass other plant structural properties are calculated which are essential for understanding the dynamics of radiation interception as well as the hydrological impact of plants:

- The vegetation cover describes the fraction of a cell covered by leaves;
- The leaf area index describes the leaf area per area covered. Since leaves can be stacked it is possible to have a leaf area index greater than 1.

During the simulation the biomass is updated each day using the equations described below. Exceptions are made for land use transitions to natural vegetation, new crop types choices and crop harvest:

- When transitions from non-vegetated land uses (urban residential, rural residential, tourism, ex-patriots, industry & commerce) to natural vegetation take place, the natural vegetation type group is set at annual grasses with a very small biomass (10 grams) allowing vegetation to grow from this point onwards. For bare rock no initial biomass is set since it is assumed that no vegetation can grow here;
- When new crop types are chosen, the current biomass of the cell is replaced by the sowing biomass. For perennial crops growth of this sowing biomass takes place from the beginning of the year in which the crop type is chosen. For annual crops growth of the sowing biomass starts at the first day of the sow month;
- For annual crops the complete plant is extracted from the ground at the harvest date. Perennial crops are only removed when the crop type changes. For these crops the dry yield biomass is set at 0 at the harvest day. As an indicator and an input to the profit and crop choice module the dry yield biomass for each crop type is converted into a wet yield biomass.

Assumptions

- The assumption is made that leaves will only start to stack after the maximum vegetation cover is reached. The maximum vegetation cover can be adapted by the user for each plant type, but has a standard value of 1. From this follows that given a maximum vegetation cover of 1 and a leaf area index (LAI) in a certain cell ≥ 1, the assumption is made that the whole cell is covered with leaves (vegetation cover (VC) = 1);
- All plant processes only take place during daylight hours;
- For annual crops yield growth is calculated only for days between the sowing and the harvest day (the first day is the day after the sowing day, the last day is the harvest day). Each crop can only be sowed and harvested once every year.

Constraints

- To assure that plant growth, the leaf area index (LAI) always needs to have a value greater than 0 (for values < 0.001 the value is set at 0.001). For computational advantages the maximum LAI is set at 20, this being a value that normally is not exceeded in Mediterranean regions;
- Before the sow month and after the harvest month the biomass is set at a very small value (10 g) for computational purposes.

Equation, rules or algorithm

On the first day of the month is determined what plant type is covering a cell, based on the land use, natural vegetation and crop type map. For this plant type characteristics are taken from the table plant properties that can be found by clicking the Plant growth rectangle in the system diagram of the user interface.

Biomass calculations
The biomass of each plant is divided is several plant parts: leaf (L), live stem (LS), wood (W), roots (R) and yield (Y). Initial calculation of these parts is carried out on the basis of the initial biomass. For newly sowed crops the sow biomass is taken and for natural vegetation the initial biomass is determined based on the transition that has taken place. For each part the new biomass is calculated on a daily basis by adding the growth to the old biomass:
(Abbreviations are explained in the tables at the end of the model description)

$$B_{p,d} = B_{p,d-1} + G_{p,d-1}$$

The total biomass then becomes:

$$B_{T,d} = \sum_{p} B_{p,d}$$

The growth of plants is based on the photosynthetically active radiation on the cell and the possibility of the plant to use this radiation, expressed by the radiation use efficiency of the specific plant type and the leaf area index of the plant. The growth is diminished by respiration for growth and maintenance as well as several stress factors: lack of fertile soil, saline soil, steep slope and suboptimal temperatures and soil moisture.
Overall growth
First calculations for the growth of the total plant biomass are carried out. It is assumed that plants only grow during daylight hours; for this the hours between sunrise and sunset are calculated. It is assumed that the minutes on which sunset and sunrise take place are included in the daylight hours. The equation then becomes:

$$HDL_{d-1} = \frac{Sun_{S,d-1} - Sun_{R,d-1} + 1}{60}$$

Growth is induced by the photosynthetically active radiation (PAR), the part of the radiation spectrum that can be used for the growing of the plants:

$$PAR = 0.5 \cdot SSTAC$$

The interception of photosynthetically active radiation (IPAR) by a plant canopy during the day is calculated according to Beer's Law:

$$\mathrm{IPAR}_{d-1} = 0.95 \cdot (1 - e^{-0.7\,LAI_{d-1}}) \cdot \mathrm{PAR}_{d-1} \cdot HDL_{d-1}$$

This is converted to plant growth through multiplication with the efficiency with which a plant type uses radiation to produce dry matter. The growth is diminished by a factor for growth respiration RG.

$$G_{Max,d-1} = \varepsilon_q \cdot \mathrm{IPAR}_{d-1} \cdot (1 - R_G)$$

If there is not enough fertile soil (FSD), the soil is too dry, too wet (θ), too saline (S), the slope is too steep (Sl), or the temperature (T) is too high or too low, only a fraction of the maximum growth will take place. This fraction is determined by suitability maps for each aspect. The maps are constructed on the basis of a map per aspect (soil moisture, soil salinity, fertile soil depth, temperature and slope) calculated in different sub-modules, and the plant specific relations between the values of the different aspects and the suitability for plant growth. The calculations are similar to the ones in the dynamic suitability module, only in this module daily values are used:

$$G_{d-1} = G_{Max,d-1} \cdot \mathrm{Min}(\mathrm{Sui}_{Daily,\theta,d-1}, \mathrm{Sui}_{Daily,S,d-1}, \mathrm{Sui}_{Daily,FSD,d-1}, \mathrm{Sui}_{Daily,T,d-1})$$

Growth per plant part

For the calculations of the biomass, a plant is divided into five fractions: leaf, live stem, wood, roots and yield (Note that for a correct simulation the fractions of the plant occupying the cell at the previous time step have to be taken into account). The different parts are defined as:

$$P_{L,d-1} = Frac_{L,qd-1} \cdot \theta_{P,d-1}$$

$$P_{R,d-1} = Frac_{R,qd} - (1 \cdot \theta_{P,d-1})$$

$$P_{LS,d-1} = Frac_{LS,qd-1}$$

$$P_{Y,d-1} = Frac_{Y,qd-1}$$

$$P_{W,d-1} = Frac_{W,qd-1}$$

With a total that sums up to:

$$P_T = P_L + P_R + P_{LS} + P_Y + P_W$$

The sum of these parts should be one, the total growth, therefore the parts are re-scaled:

$$P_p' = \frac{P_p}{P_T}$$

The growth of each of the parts can now be calculated by multiplying the different parts (p = leaf, root, live stem, yield, wood) with the total growth as described in the following general equation:

$$\mathrm{G}_{\mathrm{p,d\text{-}1}} = \mathrm{P'}_{\mathrm{p,d\text{-}1}} \cdot G_{d-1} - R_{\mathrm{M}} \cdot \mathrm{B}_{p,d-1}$$

In this equation is included the respiration for maintenance, which is biomass dependent. Maintenance respiration is defined as:

$$\mathrm{R}_{\mathrm{M,d\text{-}1}} = 0.015 \cdot 1.5 \frac{T_{d-1} - 15}{10}$$

There is no maintenance respiration for the woody parts of the plant and the underwater roots, so based on the general equation the growth for the different parts becomes:

$$\mathrm{G}_{\mathrm{L,d\text{-}1}} = \mathrm{P'}_{\mathrm{L,d\text{-}1}} \cdot G_{d-1} - R_M \cdot \mathrm{B}_{\mathrm{Ld\text{-}1}}$$

$$\mathrm{G}_{\mathrm{R,d\text{-}1}} = \mathrm{P'}_{\mathrm{R,d\text{-}1}} \cdot G_{d-1} - R_M \cdot (\mathrm{B}_{\mathrm{R,\,d\text{-}1}} \cdot (1\text{-}\,\mathrm{P'}_{\mathrm{W,d\text{-}1}}) \cdot (1\text{-}\,\theta_{\mathrm{P,d\text{-}1}})$$

$$\mathrm{G}_{\mathrm{L,d\text{-}1}} = \mathrm{P'}_{\mathrm{L,d\text{-}1}} \cdot G_{d-1} - R_M \cdot \mathrm{B}_{\mathrm{Ld\text{-}1}}$$

$$\mathrm{G}_{\mathrm{Y,d\text{-}1}} = \mathrm{P'}_{\mathrm{Y,d\text{-}1}} \cdot G_{d-1} - 0.4 \cdot R_M \cdot \mathrm{B}_{\mathrm{Yd\text{-}1}}$$

$$\mathrm{G}_{\mathrm{W,\ d\text{-}1}} = \mathrm{P'}_{\mathrm{W,\ d\text{-}1}} \cdot G_t$$

When filling in the growth in the equation at the beginning of this page, the new biomass for the different plant parts can be calculated:

$$B_{p,d} = \mathrm{B}_{p,d-1} + G_{p,d-1}$$

The leaf biomass of natural vegetation is then reduced through grazing for locations where grazing is allowed. The daily grazed biomass
is plant type (q) specific:

$$B'_{L,d} = \mathrm{B}_{L,d} - B_{Gr,q,d-1}$$

The total biomass becomes:

$$B_{T,d} = \sum_p B_{p,d}$$

The dry yield biomass (BY) is converted to the wet yield biomass (Y) using a plant type specific parameter (w):

$$Y_d = \frac{\mathrm{B}_{\mathrm{Y,d}}}{\mathrm{w}_{\mathrm{q}}}$$

The new leaf area index is calculated using the leaf biomass and the plant specific leaf density:

$$LAI_d = \frac{B'_{L,d}}{LD_{qd}}$$

Based on the leaf area index and the maximum vegetation cover per plant type, the vegetation cover can be calculated:

$$VC_d = \min(LAI_{d-1}) \cdot VC_{\max,qd}$$

The canopy storage capacity for each cell can be calculated:

$$CC_d = SWR_{qd} \cdot LAI_d$$

Parameters

Name	Description	Units
ε_q	Radiation use efficiency, a constant describing the efficiency of the conversion from radiation to growth for plant type q.	g/MJ
LD_q	Leaf density of plant type q.	g/m2
SWR_q	Specific water retention for each plant type q. Constant describing the amount of water that can be stored per square meter of leaf of plant type q.	m3/m2
VC_{max}	Maximum vegetation cover of plant type q.	–
$Frac_{L,q}$	Leaf fraction of the biomass of plant type q.	g/g
$Frac_{W,q}$	Wood fraction of the biomass of plant type q.	g/g
$Frac_{R,q}$	Root fraction of the biomass of plant type q.	g/g
$Frac_{LS,q}$	Live stem fraction of the biomass of plant type q.	g/g
$Frac_{Y,q}$	Yearly yield as a fraction of the biomass of plant type q.	g/g
w_i	Wet yield per dry yield for crop type i.	–
An_i	Parameter stating if crop type i is an annual crop type.	0/1
B_s	Sowing biomass.	g/m2
Ir_i	Boolean describing if crop type i is an irrigated crop type.	yes/no
$M_{start,\theta,q}$	Begin month in which soil moisture plays an important role in the growth of plant type q.	–
$M_{end,\theta,q}$	End month in which soil moisture plays an important role in the growth of plant type q.	–
$M_{start,T,q}$	Begin month in which temperature plays an important role in the growth of plant type q.	–
$M_{end,T,q}$	End month in which temperature plays an important role in the growth of plant type q.	–
$S_{g,q}$	Graphs representing the relation between the soil salinity and plant type q.	g/m3
$Sl_{g,q}$	Graphs representing the relation between the slope and plant type q.	degree
$FSD_{g,q}$	Graphs representing the relation between the fertile soil depth and plant type q.	mm
$\theta_{g,q}$	Graphs representing the relation between the soil moisture and plant type q.	m3 water / m3 pores
$T_{g,q}$	Graphs representing the relation between the temperature and plant type q.	°C
B_{Gr}	Grazing biomass	g/m2·day
V_{ini}	Initial vegetation map, with different vegetation types; natural vegetation as well as crops, comprised from the initial crop type and initial natural vegetation types..	categorical
$B_{ini,q}$	Initial biomass for leaf, wood, and root fraction for plant type q.	g
R_g	Growth respiration.	–

Input

Name	Description	Units	Source
Sun_R	Sunrise at day d.	min after 0.00 hr	MBB: Climate & weather: Solar radiation
Sun_S	Sunset at day d.	min after 0.00 hr	MBB: Climate & weather: Solar radiation
$SSTA_C$	Solar radiation below the clouds.	MJ/m2·hr	MBB: Climate & weather: Solar radiation
T	Monthly average maximum day temperature at cell x, y.	°C	MBB: Climate & weather: Temperature
Ri_{frac}	River fraction of cell x, y.	–	MBB: Hydrology: Runoff
$\theta_{P,Day}$	Soil moisture of cell x, y at the end of the day expressed as the volume of water per volume of pores.	m3 water / m3 pores	MBB: Hydrology: Soil moisture

Name	Description	Units	Source
ME_r	Maximum erosion of fertile soil, accumulated over the simulation period.	mm	MBB: Hydrology: Erosion & deposition
LU	Land use of cell x, y.	categorical	MBB: Land use allocation
CT	Crop type presently occupying agricultural cell x, y.	categorical	MBB: Profit & crop choice
NVT	The natural vegetation type group presently occupying natural vegetation cell x, y.	categorical	MBB: Natural vegetation
Gr	The grazing animal stocking density at cell x, y where '0' is none to low and '1' is medium to high.	0/1	MBB: Natural vegetation
$B_{Gr,q}$	Grazing biomass per natural vegetation type group q.	g/m2·day	MBB: Natural vegetation
Sal_S	Salinity of the soil of cell x, y: the amount of salt converted to amount of salt per volume soil.	g/m3	MBB: Salinisation
Ha_i	Harvest month for crop type i.	–	MBB: Land management: Planning
So_i	Sow month for crop type i.	–	MBB: Land management: Planning
MA	Model area: the Guadalentín river basin. Map with resolution 100 x 100 m.	0/1	MBB: GIS
Sl	Slope of the soil surface. Map with resolution 100 x 100 m.	degree	MBB: GIS

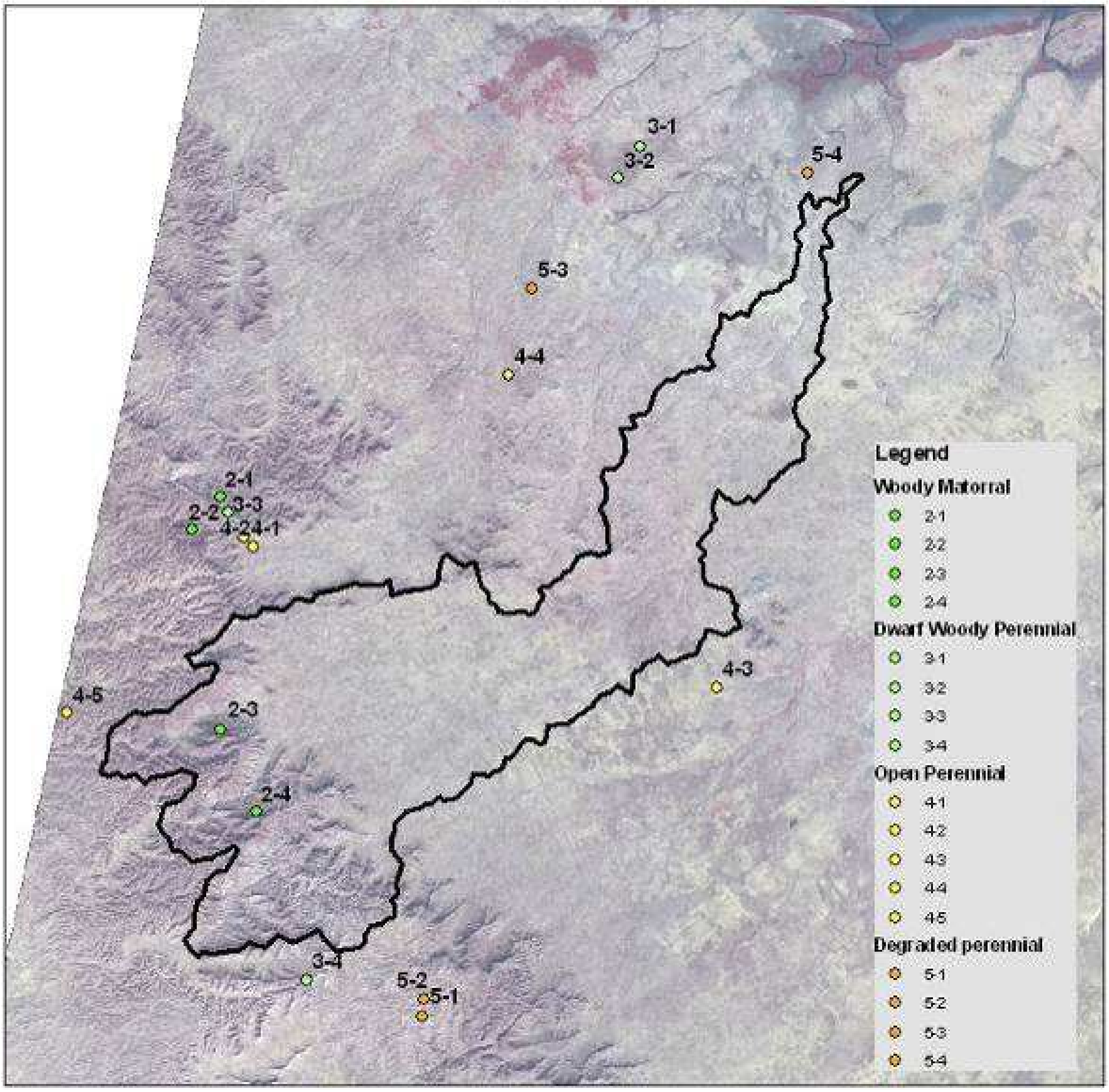
Internal variables

Name	Description	Units
PAR	The photosynthetically active radiation received at cell x, y.	MJ/m2·hr
IPAR	Intercepted photosynthetically active radiation received at a site/cell.	MJ/m2·hr
R_M	Maintenance respiration.	g/g biomass·hr
G	Growth.	g dry weight
P_i	Fraction of plant part i, i is leaf, live stem, root, wood, yield.	fraction g
B_p	Biomass of plant part p.	dry weight
HDL	Hours daylight; time between sunset and sunrise.	hours

Output variables

Name	Description	Units
VC	Vegetation cover on cell x, y.	–
CC	Canopy storage capacity for cell x, y: maximum amount of water that can be stored per area ground.	mm/m2
LAI	Leaf area index of cell x, y: leaf area per area covered.	m2 leaf / m2 cover
$M_{start,\theta,q}$	Begin month in which soil moisture plays an important role in the growth of plant type q.	–
$M_{end,\theta,q}$	End month in which soil moisture plays an important role in the growth of plant type q.	–
$M_{start,T,q}$	Begin month in which temperature plays an important role in the growth of plant type q.	–
$M_{end,T,q}$	End month in which temperature plays an important role in the growth of plant type q.	–
C_{par}	Parameters describing the characteristics of different crop types.	diverse
Y	Yearly yield from cell x, y expressed in kilograms of the harvested crop.	Kg/ha
$S_{g,q}$	Graphs representing the relation between the soil salinity and plant type q.	g/m3
$Sl_{g,q}$	Graphs representing the relation between the slope and plant type q.	degree
$FSD_{g,q}$	Graphs representing the relation between the fertile soil depth and plant type q.	mm
$\theta_{g,q}$	Graphs representing the relation between the soil moisture and plant type q.	m3 water / m3 pores
$T_{g,q}$	Graphs representing the relation between the temperature and plant type q.	°C
BW	Wood biomass of cell x, y.	g dry weight
BLS	Live stem biomass of cell x, y.	g dry weight
PT	Plant type presently occupying an agricultural or natural vegetation cell x, y.	categorical
V_{par}	Parameters describing the characteristics of different plant types.	diverse
Ir_i	Boolean describing if crop type i is an irrigated crop type.	yes/no

Appendix 2; Locations of points used for analysis of NDVI projected on a false color Lansat TM image from December 1999



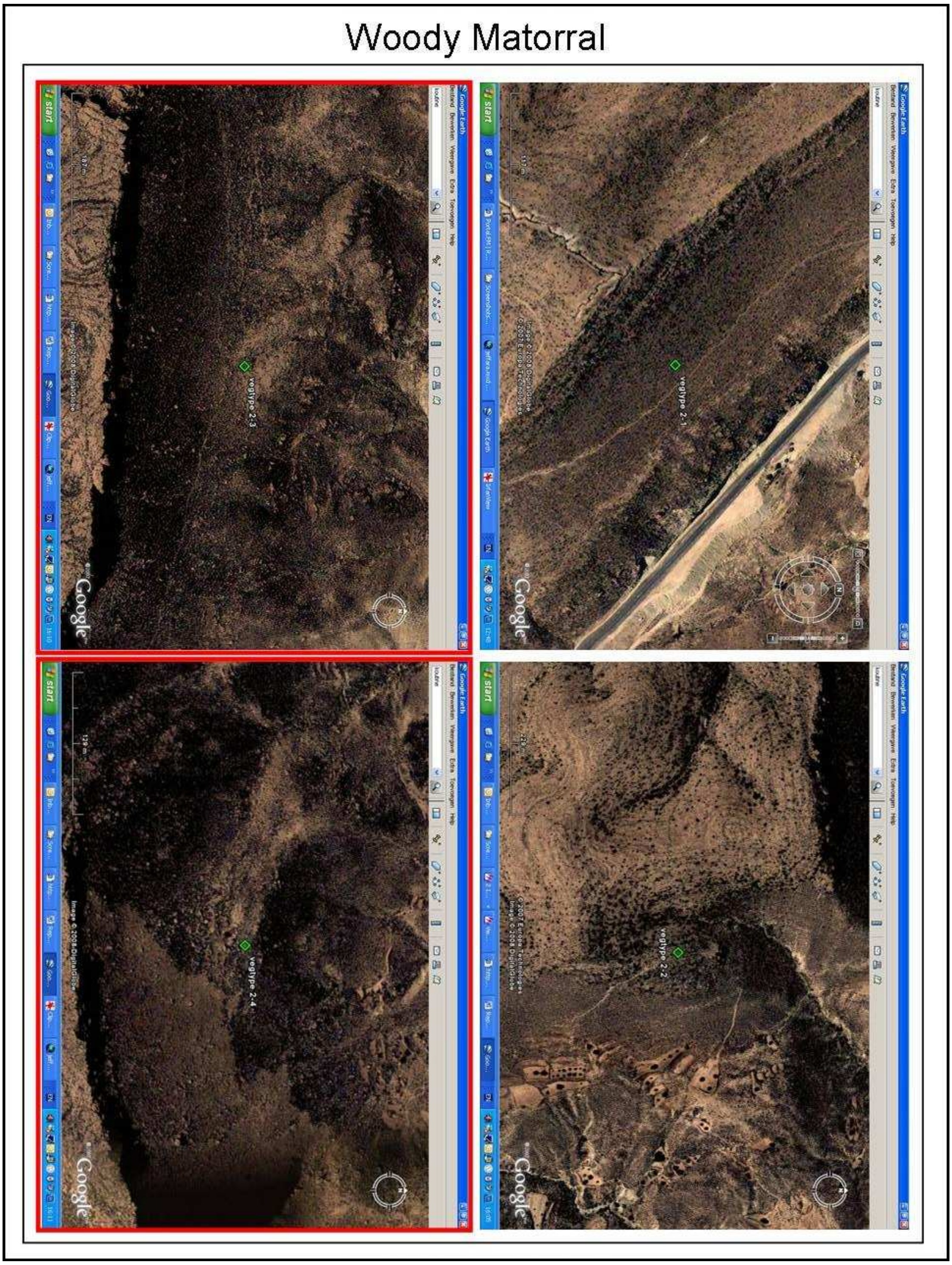
Appendix 3; Coordinates and descriptions of locations visited during field trips

ID	COOR X	COOR Y	DESCRIPTION	Nat Veg.	VEG. TYPE *	HEIGHT (M)	PLANT COVER (%)	PICTURE	MODIS NDVI
1	630493	3693576	Pinus halepensis on gyps soil, H 4m, PC 50	N		4.0	25	8611, 8612	
2	629629	3693916	Ranterium suaveolens, hardly green biomass,big area towards SW&S, H 0,5, PC 15	Y	4	0.5	15	8615, 8616	0.1375
3	629636	3693918	Ranterium suaveolens, hardly green biomass,big area towards SW&S, H 0,5, PC 15	Y	4	0.5	15	8615, 8616	0.1375
4	622544	3696594	Retama reatam combined with agr, H 1,5, PC 10 small isolated areas	Y	2	1.5	10	8618, 8619	
5	622627	3696564	Retama reatam combined with agr, H 1,5, PC 10 small isolated areas	Y	2	1.5	10		
6	611458	3700273	Urban area, from road	N					
7	606832	3702531	unknown point	N					
8	606832	3702531	Rosemarinus officinalis/Stipa t., PC 35-40, H 1	Y	2	1.0	38	8623, 8624	0.1785
9	606820	3702543	Rosemarinus officinalis/Stipa t., PC 40-45, H 1	Y	2	1.0	43		0.2160
10	605536	3703238	Urban area, from road	N				8630, 8641	
11	604673	3703462	Source	N				8651	
12	607403	3702333	Road, 100 m N of Stipa veg H 0,5, PC 30	Y	3	0.5	30		0.1468
13	607888	3701313	Artemesia h-a, H 0,5, PC 10 Large are toards SW	Y	4	0.5	10		0.1682
14	607844	3701279	Artemesia h-a, H 0,5, PC 10 Large are toards SW	Y	4	0.5	10		0.1680
15	614695	3701359	Large small scal agricultural area, from road	N					
16	614720	3701538	Large small scal agricultural area, from road	N					
17	614904	3702393	Large small scal agricultural area, from road, Olives plantations + bare soil	N					
18	615020	3703020	Large small scal agricultural area, from road, Olives plantations + bare soil	N					
19	615852	3704214	Narrow strip of type 3 Retama steppe in streambed H 0.8, PC 35 from road	Y	3	0.8	40		0.1462
20	616978	3704297	Village just North of steppe 4 , from road	Y	4	0.4	20		0.1535
21	617589	3704841	Agriculture, from road	N					
22	618208	3706507	Stream bed on left hand, from road	N					
23	619211	3708270	Steppe vegetation H 0.45 PC 30 surrounded by agriculture, from road	Y	3	0.5	30		0.1581
24	619695	3708372	Hammada scoparia steppe, from road H 0.5 PC15	Y	4	0.5	15		0.1638
25	620276	3708742	Hammada scoparia H 0,5, PC 15	Y	4	0.5	15	8669, 8670	0.1614
26	620268	3708750	Hammada scoparia H 0,5, PC 15	Y	4	0.5	15		0.1604
27	620266	3708742	Hammada scoparia H 0,5, PC 15	Y	4	0.5	15		0.1614
28	620327	3708733	Road between crops	N					
29	620911	3710142	Astragualus armatus & agriculture mosaic	N					
30	621590	3712494	Hammada scoparia H 0,3, PC <10	Y	5	0.3	7	8671, 8672	0.1570
31	621601	3712481	Hammada scoparia H 0,3, PC <10	Y	5	0.3	7		0.1570
32	621951	3714032	Road crossing	N					
33	622336	3716746	Residential area	N					
34	622873	3718937	Large area of olive plantations	N					
35	624184	3719312	Eucalyptus / Callicutum philosa-Lygeum s. boundary between trees and steppe	N					
36	624207	3719291	Callicutum philosa-Lygeum s. H 1, PC 20, Gyps+sand deposits	Y	3	1.0	20	8674, 8676	0.1837
37	624268	3719268	Callicutum philosa-Lygeum s. H 1, PC 20, Gyps+sand deposits	Y	3	1.0	20		0.1837
38	624171	3719331	Eucalyptus plantation, H 6, PC 60	N		6.0	60		
39	626412	3719377	Ranterium suaveolens steppe, grazing protected, large area towards S-SE H 1.2, PC 30	Y	3	1.2	30.0	8679, 8680	0.1678
40	626404	3719347	Ranterium suaveolens steppe, grazing protected, large area towards S-SE H 1.4, PC 35	Y	3	1.2	35.0		0.1719
41	626383	3719301	Ranterium suaveolens steppe, grazing protected, large area towards S-SE H 1.2, PC 30	Y	3	1.2	30.0		0.2038
42	627753	3719272	Ranterium suaveolens, from road, H 0,5, PC 20	Y	4	0.5	20		0.1809
43	628535	3719183	Agriculture, from road	N					
44	629207	3719101	Ranterium suaveolens type 4, from car, H 0,5, PC 20	Y	4	0.5	20		0.1809
45	631394	3718646	Sebkhas, Gypsum vegetation small scale, H 0,5, PC 10-20	Y	4	0.5	15	8684, 8685	0.1630
46	631394	3718644	Sebkhas, Gypsum vegetation small scale, H 0,5, PC 10-20	Y	4	0.5	15		0.1630
47	631503	3718655	Sebkhas, Gypsum vegetation small scale, H 0,5, PC 10-20	Y	4	0.5	15		
48	632017	3718504	Attractylis serr.-Astr. arm.- Lyg sp overgrazed on Gypsum between sebkhas H 0,3, PC 10	Y	5	0.3	10	8690, 8691	0.1468
49	632004	3718487	Attractylis serr.-Astr. arm.- Lyg sp overgrazed on Gypsum between sebkhas H 0,3, PC 10	Y	5	0.3	10		0.1453
50	631990	3718463	Attractylis serr.-Astr. arm.- Lyg sp overgrazed on Gypsum between sebkhas H 0,3, PC 10	Y	5	0.3	10		0.1468
51	631978	3718429	Attractylis serr.-Astr. arm.- Lyg sp overgrazed on Gypsum between sebkhas H 0,3, PC 10	Y	5	0.3	10		0.1453
52	634136	3716722	Gyps vegetation from road, H 0,3, PC 15-20	Y	4	0.3	18		0.1412
53	635123	3716273	unknown point	N					
54	635209	3716179	Tamarix vegetation in streambed, H 1,5, PC 30-40	Y	2	1.5	35	8693, 8694	0.1467
55	635155	3716152	Tamarix vegetation in streambed, H 1,5, PC 30-40	Y	2	1.5	35		0.1467
56	635147	3716151	Tamarix vegetation in streambed, H 1,5, PC 30-40	Y	2	1.5	35		0.1516
57	635190	3716208	Road between Tamarix streambeds	N					
58	637651	3715397	Argriculture bare soil, from road	N					
59	638142	3715878	Argriculture between sebkhas, from road	N					
60	639446	3716906	Road between gypsum steppe type 3 H 0.75, PC 25 (north-west) and agriculture	Y	3	0.8	25		0.1421

ID	COOR X	COOR Y	DESCRIPTION	Nat Veg.	VEG. TYPE *	HEIGHT (M)	PLANT COVER (%)	PICTURE	MODIS NDVI
61	639934	3717291	Agriculture, from road	N					
62	641571	3718758	Large scale olive plantations in all directions, from road	N					
63	642084	3718724	Large scale olive plantations in all directions, from road	N					
64	642718	3718648	Sebkhas, no vegetation, from road	N					
65	643166	3718707	Road between Gypsum steppe (l) and patchy sebkhas ⌐	N					
66	643951	3718734	Road between agriculture (l) and Gypsum steppe 5 (r) H 0.1, PC 5-10	Y	5	0.1	8		0.1147
67	645944	3718664	Sebkhas with vegetation, from road	N					
68	648066	3716844	Small village in olive plantation, from road	N					
69	648256	3716360	Olive plantation, from road	N					
70	648748	3716175	Agriculture with Rantherium steppe 3 mosaic, from road H 0.6, PC 35-40	Y	3	0.6	38		0.1760
71	649589	3716127	Olive plantation, from road	N					
72	650303	3716015	Olive plantation with Steppe Mosaic, from road	N					
73	651387	3715440	Olive plantation, from road	N					
74	652901	3714443	Olive plantation, from road	N					
75	653046	3714354	Olive plantation, from road	N					
76	653858	3713871	Village, from road	N					
77	652634	3707755	Front IRA building	N					
78	618792	3682088	Stipa tenn south of road H 0.5, PC 20	Y	4	0.5	20	8759	0.1721
79	618711	3681146	Stipa tenn south of road H 0.5, PC 20	Y	4	0.5	20		0.1534
80	618880	3680831	Small degraded area with hardly any vegetation H <0.1, PC 0-5	Y	6	0.1	3		0.1365
81	616435	3679600	Stipa large homogeneous area H 0.30, PC 5-10	Y	5	0.3	8		0.1495
82	616189	3679194	Stipa large homogeneous area H 0.30, PC 5-10	Y	5	0.3	8		0.1487
83	616131	3678834	Stipa large homogeneous area H 0.30, PC 5-10	Y	5	0.3	8		0.1487
84	614304	3678581	Homogeneous area type 4, H 0.35, PC 15	Y	4	0.4	15		0.1493
85	612520	3679332	Residential area	N					
86	612250	3679512	Residential area	N					
87	611704	3679896	Large area mountain vegetation	N					
88	611231	3680470	restaurant near Ben Keddache	N				8761-8774	
89	611198	3680470	Stipa tenn.steppe type 3 H 0.6, PC 30 on south east side, taken from bridge over streambed	Y	3	0.6	30		0.1534
90	606539	3680944	Stipa tenn.steppe type 3 H 0.6, PC 30 on south east side, taken from bridge over streambed	Y	3	0.6	30		0.1935
91	605788	3682194	Boundary study area, from road	N					
92	606526	3682683	Steppe Vegetation type 4 H 0.3 PC 10	Y	4	0.3	10		0.1553
93	606718	3682816	Steppe Vegetation type 5 H 0.3 PC 5-10	Y	5	0.3	8		0.1553
94	607574	3684180	Oase, rond dorp	N				8775, 8776	
95	608731	3685032	Stream bed Tamarix vegetation H 2.5, PC 40-50	Y	2	2.5	45	8783	0.1584
96	611453	3686715	Northslope type 5 H 0.2, PC 10, Southslope type 3 H 0.5, PC 30, from road	Y	5	0.2	10		0.1715
97	611734	3686611	Northslope type 5 H 0.2, PC 10, Southslope type 3 H 0.5, PC 30, from road	Y	3	0.5	30		0.1743
98	614226	3687403	Road crossing GCP, NE of El Bhayra	N					
99	614391	3687640	Tabias	N				8793, 8794	
100	614592	3687879	Fig plantation, small scale	N				8796	
101	615659	3688941	Large scale tabia with olive plantations	N					
102	616321	3689466	Large scale tabia with olive plantations	N					
103	616991	3690069	Large scale tabia with olive plantations and waterput	N				8799	
104	618407	3691438	Tabias	N					
105	618774	3691774	Irrigated crops, potatoes	N				8806, 8807	
106	620220	3693059	Irrigated crops, unknown tree crops	N				8810	
107	620396	3693210	Irrigated crops, potatoes + peppers + olives	N				8812, 8814	
108	622008	3694634	Ranterium steppe, some Astragualus armatus, small area type 3, H 0.5, PC 20	Y	3	0.5	20	8817	0.1477
109	622372	3694961	Astragualus armatus type 4, H 0.4, PC 15-20 small area	Y	4	0.4	18		0.1634
110	623229	3695713	Mix of olive in rangeland type 4	N					
111	623519	3695968	Road crossing	N					
112	624256	3696719	Hammada scoparia type 5, H 0.3, PC 10	Y	5	0.3	10	8818, 8820	0.1291
113	624268	3696668	Hammada scoparia type 5, H 0.3, PC 10	Y	5	0.3	10	8818, 8820	0.1424
114	624272	3696646	Hammada scoparia type 5, H 0.3, PC 10	Y	5	0.3	10	8818, 8820	0.1424
115	624646	3697117	Overgrazed steppe near village, small area type 6 H <0.1, PC 5	Y	6	0.1	5		0.1428
116	625059	3697332	Steppe type 5, H 0.2, PC 15	Y	5	0.2	15		0.1510
117	625968	3697802	Artemesia campestris steppe type 5 H 0.25, PC 10	Y	5	0.3	10	8825	0.1567
118	626817	3698517	Artemesia campestris steppe type 5 H 0.25, PC 10	Y	5	0.3	10	8825	0.1689
119	627143	3698953	Check dams	N				8826, 8830	
120	627240	3699282	Trees in riverbed, small narrow strip, H 4.0, PC 70	Y	1	4.0	70	8832	0.1647
121	627404	3699344	Recharge well	N				8831	
122	629968	3701334	Olive plantation, near koutine	N					

* Vegtype 1=Shrub vegetation, 2=Woody matorral, 3=Dwarf woody perennial, 4=Open perennial, 5=Degraded perennial, 6=Abandoned land

Appendix 3; Screenshots of selected locations for analysis of NDVI values on high resolution images from Google Earth

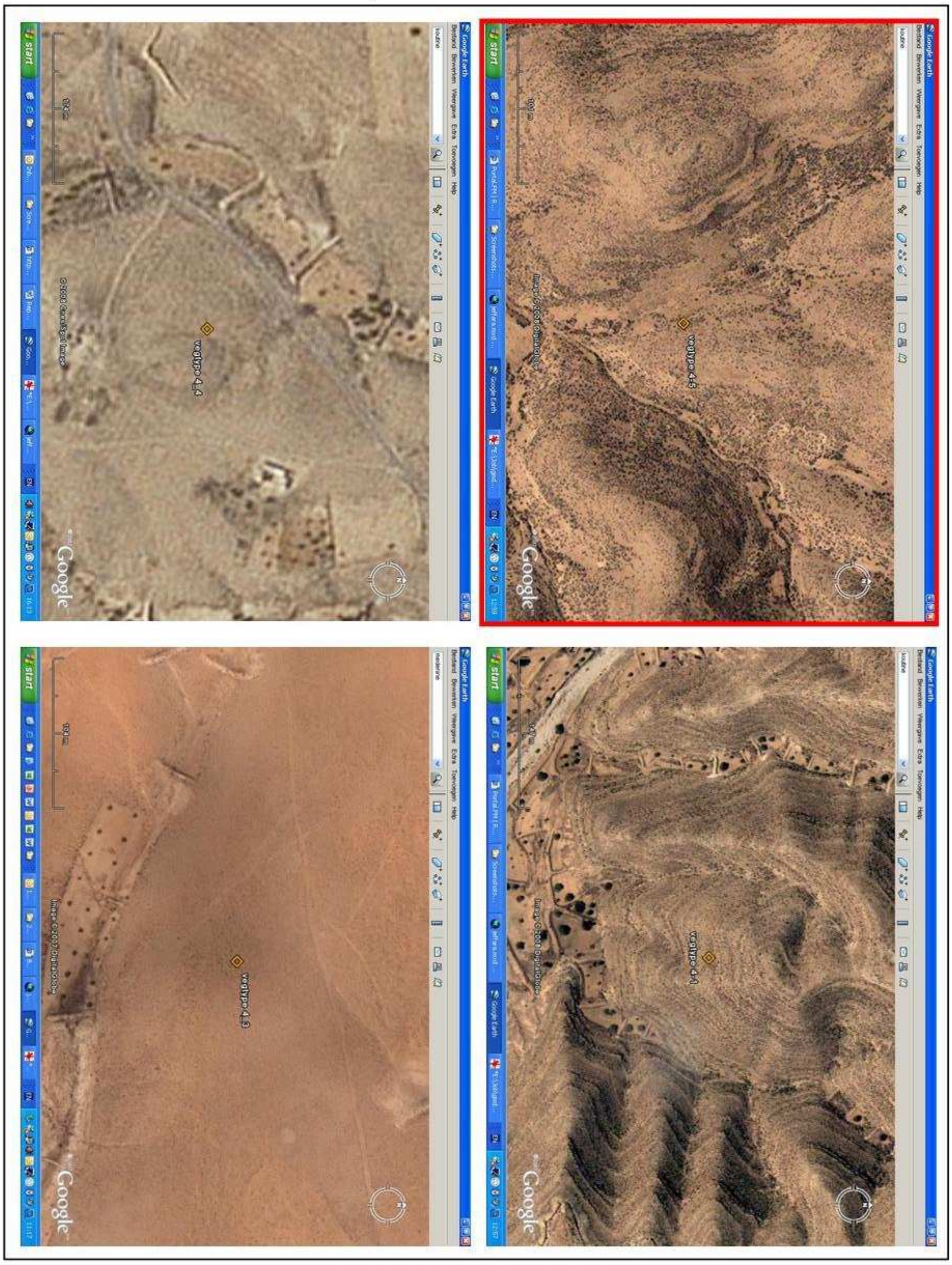


UL to LR 2-3, 2-1, 2-4, 2-2

Dwarf Woody Perennial

UL to LR 3-3, 3-4, 3-2, 3-1

Open Perennial

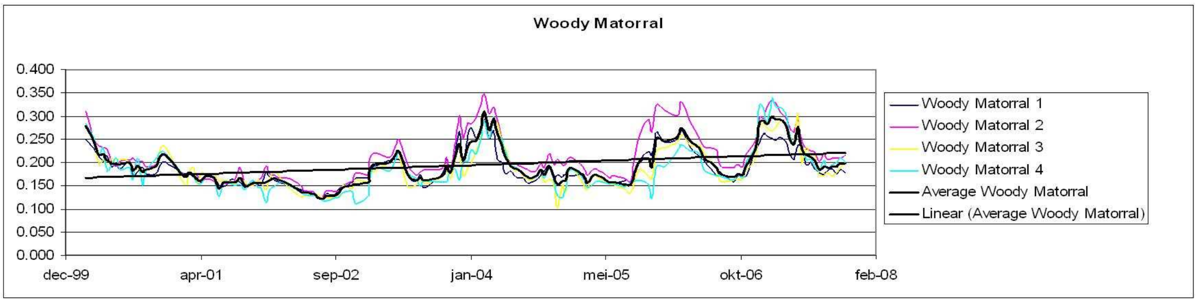


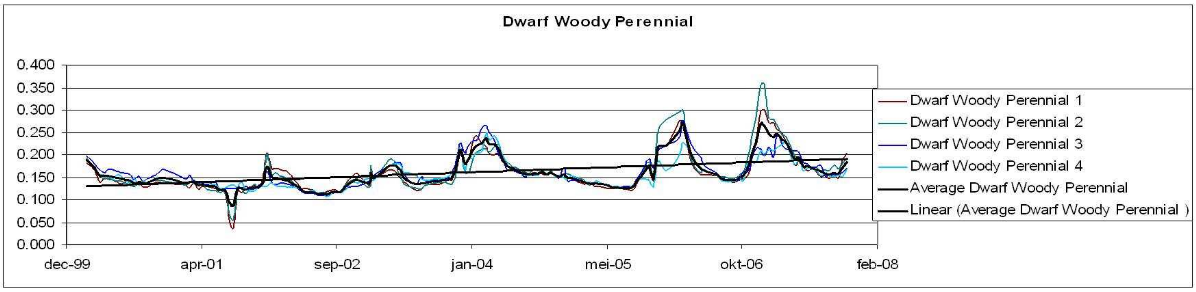
UL to LR 4-4, 42, 4-3, 4-1

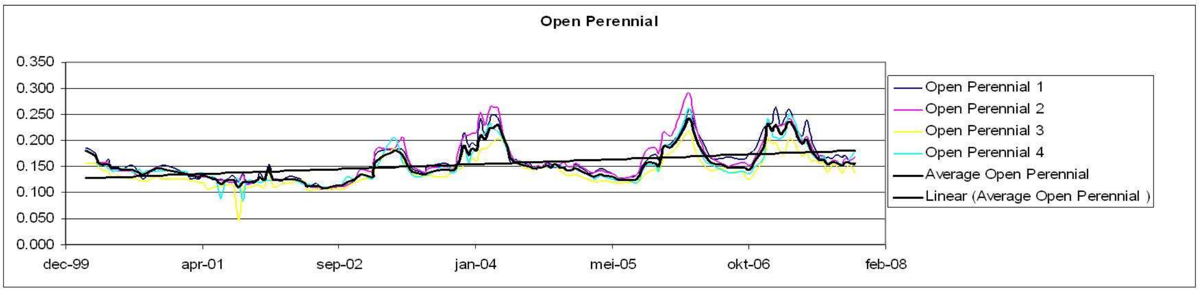
Degraded Perennial

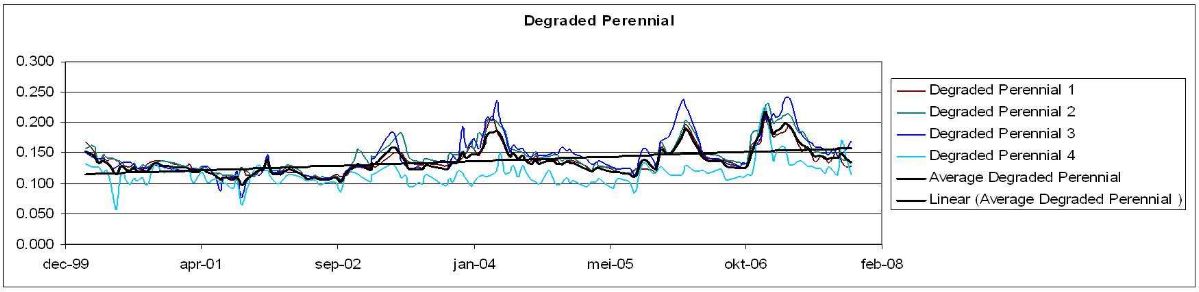
UL to LR 5-3, 5-1, 5-4, 5-2

Appendix 4; Observed NDVI trends of selected locations for image interpretation









Appendix 5; Difference in trends per vegetation type between EVI and NDVI