Assessing the Potential Tree Line and Suitable Areas for Afforestation in the Chong-Kemin National Park, Kyrgyzstan

Rechenmacher, A.,[1] Immitzer, M.[2] and Vacik, H.[1]
[1]Institute of Silviculture, University of Natural Resources and Life Sciences Vienna, Peter Jordanstr. 82, A-1190 Vienna, Austria, E-mail: harald.vacik@boku.ac.at
[2]Institute of Surveying, Remote Sensing and Land Information, University of Natural Resources and Life Sciences Vienna, Peter Jordanstr. 82, A-1190 Vienna, Austria

Abstract
Although forests cover less than 5.6% of the territory of the Kyrgyz Republic, they are a valuable natural resource. With the increasing human settlement the mountain forests have been exploited for timber, fuel wood, and charcoal in recent years. These unsustainable land use practices, along with hay-making and over-grazing of cattle, sheep and goats, have resulted in a decline of the yields of forest products and the degradation of the natural regeneration. The long-term objective for the State Agency of Environmental Protection and Forestry of the Kyrgyz Republic is to increase the forest cover up to 6% by 2025 – 2030. Choosing only suitable areas for afforestation can be rather difficult under an arid, mostly continental influenced climate. This contribution aims to estimate the potential forest tree line and deviation from the current forest distribution with remote-sensing data as a basis for further afforestation planning. Using different spatial data (forest map, satellite images, digital terrain models, global irradiation, temperature and precipitation) the limits for forest growth are modelled in the Chong-Kemin National Park, Kyrgyz Republic. The gap between the potential tree line and the actual upper and lower forest line can be used as an indicator for a likely anthropogenic influence on today's forest distribution.

1. Introduction

One of the main tasks of Kyrgyz forest authorities is to prevent and fight soil erosion, landslides and avalanches (Fet, 2007, Undeland, 2012 and Zeidler et al., 2016). Forests are considered an important source for both wood-products (fire- and construction timber) and non-woody forest products (mushrooms, herbs, fruits) (Lal et al., 2007). Additionally the livelihoods of local people strongly depend on forest products such as fruits, nuts, firewood and honey (Jalilova et al., 2012). The aim of Kyrgyz forest authorities is therefore to increase forest area from actual ~5.0% (2009) to 6.0% of total country area in 2025. This is an increment of approx. 200,000 ha (Dzunusova, 2008 and Orozumbekov et al., 2009). The single forest farms (Leshoz), are responsible for the implementation on site (Orozumbekov et al., 2009 and DFHGI 2015).

Due to different human- and non-human induced reasons, the Kyrgyz forest area is reduced in respect to its natural distribution (Cantarello et al., 2014, Klinge et al., 2015 and Zeidler et al., 2016). In Soviet ages, forest area diminished to about half of the actual area. In this decades, timber harvest was on average 3.7 times higher than the current increment (Undeland, 2012). After clearings, former forest land was (and is still) used as grazing land leading to negative consequences such as erosion and degradation of soils (FAO, 2014). Many areas all over the National territory are currently subjected to erosion processes (DFHGI, 2015). These phenomena are intensified by prolonged summer- and autumn rains and rapid spring thaw (FAO and UNESCO 1978 and Lal et al., 2007).

To accelerate the desired reforestation, Kyrgyz authorities also apply afforestation measures. Around 9,000 ha of new forests were planted from 1993 to 2008. Most of the new forest areas are derived by natural regeneration followed by a land use change stopping grazing (Undeland, 2012). However, not all planted trees survive losses are sometimes high (Orozumbekov et al., 2009). It is therefore crucial to know under which climatic and morphological criteria forest is able to grow successfully in order to save time and economical effort. The potential forest distribution can be considered as a function of topography and climate parameters. In Central Asian Mountain areas, water supply during the vegetation period is often a limiting factor for trees to establish. On South oriented slopes, forests are mostly missing due to the above-mentioned dry periods in summer months and a high irradiation due to clear skies. Considering the effect of various climatic and morphological parameters would allow to identify their most suitable combination for successful reforestation projects. A part from water and nutrients availability, temperature regime during the growing period influence the growth performance of trees. A steadily low temperature restricts trees to have high increment rates. Also trees are, due to their height, stronger coupled to the atmospheric conditions than low growing plants (Harsch and Bader 2011 and Körner 1999). The length of the vegetation period seems not to be correlated with tree line elevation (Körner, 1999). But the temperature regime within the vegetation period is a good indicator for determine the tree line of conifers (Paulsen and Körner, 2001). The vegetation period is based on a combination of both, moisture and temperature. For moisture-limited areas in Central Asia a mean value of 178 days (st.dev. = ±69) was found for the vegetation period (Lal et al., 2007). Precipitation patterns, especially the ones during summer months, are important for determining forest growth and the tree line (Heikkinen et al., 2002 and Weemstra et al., 2013). In this context potential evapotranspiration allows to determinate plant growth as it is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply (Pidwirny and Jones, 2009). Insolation is another driving force for all physical and biological systems on earth's surface (Fu and Rich, 1999). A part from the latitude, also slope and aspect of ridges play an important role when it comes to radiation intensity. A statistic model should therefore be developed to identify areas where forest growth is theoretically possible when all climatological and morphological parameters are favorable. These areas can be compared with the actual forest distribution in order to draw conclusions for forest management. The following research questions will be addressed:

- What is the actual tree line and the current distribution of forests in the Chong Kemin National Park?
- Which climatic and morphologic parameter can be used to predict forest cover?
- Which discrepancies can be identified between predicted and actual forest cover?

2. Methods

2.1 Description of the Study Area

The study area of the Chong Kemin National Park (NP) is situated in the northern part of the Kyrgyz Republic (Figure 1). The NP is characterized by steppe vegetation, forests and alpine meadows. Each of these vegetation types is represented by various groups of plants, influenced by climatic conditions, terrain, exposure and steepness of slopes (DFHGI, 2015). The shrub vegetation in the lower parts of the Chong Kemin valley are followed by a layer of coniferous forest which is, together with Juniper, forming the tree line at around 2,900 m above sea level (a.s.l.). Above the tree line, the tall grass meadows at elevations between 2,900 and 3,500 m a.s.l. are followed by low/short grass meadows which can reach up to 4,000 m a.s.l.

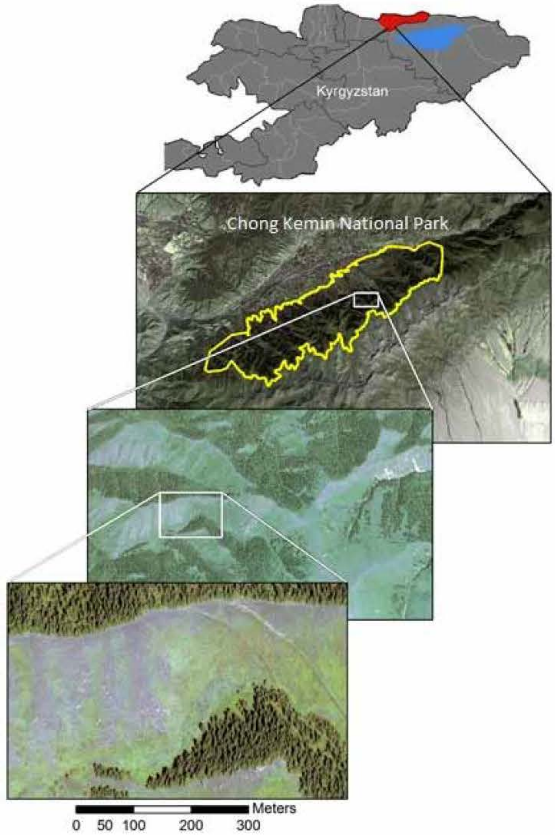

Figure 1: Overview and detail of the study area (yellow edged outline)

The bottom belt of the mountains and the valley bottom is covered by steppe vegetation. Due to different farming activities, original vegetation is seldom here (Undeland, 2012). Because of the low precipitation and high temperature peaks in summer many woody plants do not grow.

Ascending, on North-facing slopes, the forest belt is located. The main species is Shrenk's spruce (*Picea schrenkiana*). It is a semi-shade-tolerant species (Cantarello et al., 2014). According to Klinge et al., (2015), Schrenk's spruce needs 250 mm/y of precipitation as a minimum to grow. A positive correlation has been found between summer precipitation and growth for the Schrenk's spruce (Magnuszewski et al., 2015). Especially the period from April to September of the precedent year significantly influenced tree ring increment. Even if it is growing in rather arid environments such as part the Kyrgyz mountains, spruce is a hygrophilous tree species. This means it relies on the precipitation of this year's vegetation period to build up organic substance on the next season (Magnuszewski et al., 2015). Other tree-forming species in the Chong Kemin NP are *Pinus* sp. (planted), birch (*Betula pendula* Roth), poplar species and willow.

A so-called diffuse tree line is formed by clustered groups of single trees and sometimes by a gradual transition from closed forest to single (progressively smaller) trees. In many environments a tree line-forming *Krummholz*-zone can be found (Harsch and Bader, 2011) with stumped and multi-stem trees. This form of tree line is missing in the study area. Only single-stem trees (in most cases *Picea shrenkiana*) are present. There is no presence of noteworthy rock faces or screes. The entire area is situated at the foothills of a mountain ridge with a maximum elevation of approx. 3,900 m a.s.l. This means forest/tree line separates 1,000 m elevation from the rocky summits. The area between tree line and peaks is characterized by a typical alpine and finally nival traits.

Generally, a sharply continental climate prevails in the Chong Kemin National Park area. In the lower parts of the Park, the typical steppe climate prevails. Winters are cold (-20°C possible) and summers are dry. Winter (January) precipitation is dominated by snow and the average date of first frost in autumn is September 20 and for late frost May 20.

2.2 Dataset

The base map of forest types was obtained from the Department of Forest, Hunting and Ground Inventory. The forest types are classified by the Kyrgyz authorities according to the canopy closure (10-50%, 50-80%, > 80%). Additionally a very-high-resolution (VHR) WorldView-2 image was acquired covering an area of 26 km². The spatial resolution of the panchromatic band was approx. 0.5 m. Taken in August 2012 with an almost zero cloud cover percentage, it was appropriate to digitalize, together with the forest map, the forest types present in the study area. A climate data set by Böhner (2006) covering Central Asia with a spatial resolution of 1.0 arc seconds was used. In total 150,851 single points were used as climate database were each of these points representing an area of approx. 390 ha contains information about Elevation [m a.s.l.], Global radiation [Joule/cm²/day], Monthly Temperature means [°C] and Precipitation [mm] for January, July and annual mean. Radiation-, temperature- and precipitation values represent monthly means from 1961 to 1990.

According to (Klinge et al., 2015) the data where generated with empirical models by statistical downscaling from coarse resolution atmospheric fields from GCMs (General Circulation Models). Temperature and precipitation records were obtained from around 400 meteorological stations scattered in whole Central and High Asia (Böhner, 2006). A detailed description of the dataset and the modeling approach are given in (Böhner, 2006 and Böhner and Antonic, 2009). Radiation is an important factor when it comes to tree growth in arid climatic conditions (Klinge et al., 2015). To calculate radiation in the study area the ASTER Global digital elevation model is used as basis for the calculation. The amount of incoming solar radiation was estimated with the Solar analyst tool of ArcGIS of the Environmental Systems Research Institute. The calculation is depending on sky transmissivity, rainfall and clouds, latitude, elevation and topography. For the study area the 'Diffuse proportion' was set to 0.35 because during the vegetation period, especially in the summer month, sunny weather conditions over several months can be expected. For the transmissivity a value of 0.5 was used, indicating clear sky conditions.

2.3 Estimating Vegetation Period and Tree Line

To model the forest tree line and forest distribution the vegetation period has to be determined. The aim was to find the time span with a mean daily temperature more than 0°C for the study area. The elevational difference from the bottom line (1,700 m a.s.l. up to the upper boundary line (elevation 2,900 m a.s.l.) is 1,200 m. It comprises the montane and sub-alpine level (see 2.1). The temperature difference between upper and lower forest border is about 7°C in April and around 9°C in September. The annual mean values vary around 8°C from the bottom to the top. To calculate the vegetation-period-length, the starting point was set to April 15 where a daily mean air temperature of around 0°C can be expected at the upper boundary line.

The remaining part of the study area has a higher mean temperature but should mostly fall into the 0-5°C interval.

2.4 Logistic Regression Model

For the analysis of the influence of multiple independent variables on a categorical dependent variable the logistic regression is a suitable method (Zeidler et al., 2016). Forest types represent the independent variables and climatological and morphological parameters are the dependent variables. Probabilities of assignment can be determined (maximum likelihood assignment) as well as influences on their probabilities when the value of an observed (independent) variable is changing (Backhaus et al., 2007).

To "train" the model, forest pixels where randomly sampled as well as non-forested pixels in the same quantity. Both data-types (independent and dependent variables) were generated with ArcGIS. Raster datasets were created and further processed with the statistic software R 3.0.2. Logistic regression modelling as well as generating plots and graphs was done with R as well (R Core Team, 2013). As coefficient of determination, Nagelkerke's R squared was calculated. It describes how good the model can explain the dataset. RN^2 greater 0.2 can be considered as acceptable, values greater than 0.4 can be considered as good and values higher than 0.5 as very good (Backhaus et al., 2007).

A correlation matrix of all the morphological and climatological parameters which could explain forest growth, was made in R. Four of the variables showed no correlation ($<\pm 0.5$) with the other variables: slope, aspect, April temperature and radiation. Therefore they were used to explain forest growth or no-forest growth. The April temperature was not considered but instead the variable elevation was used. To test nonlinear (unimodal) response the squared term of the variables were also tested (Immitzer et al., 2014).

To work with spatial high resolution climate data in Geographic Information systems (GIS), Böhner (2005) proposed geostatistical Kriging as an appropriate method. The ArcGIS Geostatistical Analyst toolset contains different Interpolation tools. The 'Empirical Bayesian Kriging' tool was used to bring the resolution of the different climatological parameters from around 2,300 m x 2,300 m to the lowest resolution used in this work, which is 27.28 m x 27.28 m.

3. Results

3.1 Actual Forest Cover

Forests actually occur from ~1,700 to ~2,900 m a.s.l. with an even distributed pattern. At lower elevations, there are large parts with no forest cover, forests are not growing on all aspects, on southern slopes, no forests occur.

Juniper forest is growing exclusively at elevations above 2,300 m a.s.l (Figure 2). Its distribution trend is towards higher elevations with a peak between 2,700 and 2,800 m a.s.l. It is therefore also occurring at tree line elevations and forming tree line (2,900 m a.s.l.). Juniper growth seems to be influenced very little by aspect. Only on direct-South-facing slopes it does not grow. There is, however a slight preference to grow on Northwest-North-Northeast (NW-N-NE) facing slopes. The inclination values (slope) of Juniper growth follow the overall slope values and do not show preferences.

Spruce forest grows from ~1,700 to ~2,900 m a.s.l. with a slightly left skewed distribution curve (Figure 2). Concerning the aspect, spruce is completely absent on Southeast-, South- and Southwest-facing slopes. Slope seems not to influence the growth of spruce forest. It is occurring on all the different inclinations.

Bushes have the same elevational amplitude as spruce, growing therefore from ~1,700 to ~2,900 m a.s.l., almost following the trend of the total elevation distribution but with a light peak at lower elevations. Their growth behavior regarding the aspect is different from the one of the other forest types. They do not avoid South-facing slopes whereas on North-facing and adjacent slopes, their distribution seems to be limited (Figure 2). Slope seems not to influence the growth of bushes in the study area. It is occurring on all the different inclinations.

Birch forest occurs mostly at lower elevations between 1,700 and 2,300 m a.s.l.. Birch forest is completely avoiding Southeast- and South-facing slopes but growing sparsely on Southest-facing slopes (Figure 2). The inclination (slope) distribution shows a slight trend towards flatter areas.

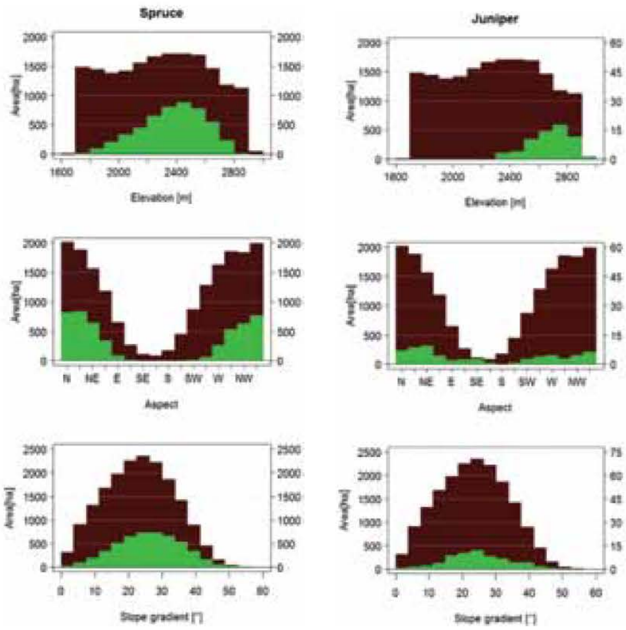

Figure 2: Frequency distribution (in hectares) of morphological parameters of the total study area (brown columns and left Y-axis) in relation to spruce forest as well as juniper forest (green columns and right Y-axis). Mind the possible diverging Y-axis scaling

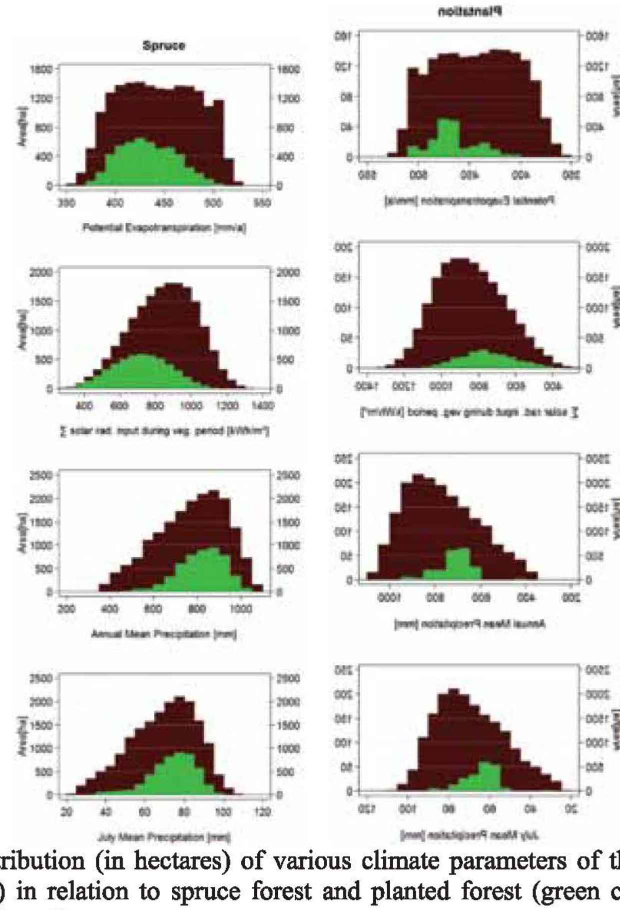

Figure 3: Frequency distribution (in hectares) of various climate parameters of the total study area (brown columns and left Y-axis) in relation to spruce forest and planted forest (green columns and right Y-axis). Mind the diverging Y-axis scaling.

Planted forest areas occur mostly at elevations between 1,800 and 2,400 m a.s.l. and only on a few spots up to 2,700 m a.s.l.. No occurrence is statable on Southeast-, South- and Southwest- facing slopes. The distribution of planted forest regarding slope values shows an even distribution (Figure 2).The forest-distribution graph shows a clear trend of forest to grow on areas with precipitation sums > 600 mm/year. Below 600 mm/year, only a small percentage of the total forest can be found. A very similar behavior shows the forest distribution when it comes to July-precipitation pattern. At the lower edge of the study area there are around 25 mm of rain in July. On the upper border around 100 mm. Very few forests grow on areas with July-precipitation values below 50 mm. At areas between 50 – 90 mm, forest is establish best.

Juniper forest grows at sites with relatively low Potential Evapotranspiration values (about 400 mm/year). Areas with PET values higher than 430 mm/year are not populated with Juniper. When it comes to the solar radiation input during the vegetation period, Juniper grows on spots with very low (400 kWh/m²) but also on spots with very high values (1,200 kWh/m²). There is, however a higher occurrence at areas with relatively high radiation values (between 800 and 1,000 kWh/m²). Juniper growth inside the study area is limited to yearly precipitation sums between 800 and 1,000 mm. A similar pattern shows Juniper growth and July-precipitation: growth is only happening between ~80 and 95 mm.

Spruce forest grows on areas with PET values between 370 and 510 mm/year with an agglomeration between around 400 and 470 mm/year (Figure 3). Is does not grow on spots with radiation values higher than 1,100 kWh/m² during the vegetation period. A culmination of growth can be found on areas with radiation values between 600 and 800 kWh/m². The spruce forest distribution is limited to areas with precipitation values between 500 and around 1,050 mm/year whereas below 600 mm/year, almost no forest occurs. July precipitation values show similar patterns: spruce forest growth happens between ~40 to 100 mm whereas below 60 mm only a negligible part of spruce forest is established.

The range where *planted forest* is growing, reaches from 400 to 510 mm of Potential Evapotranspiration per year (Figure 3). It grows on sites with a solar radiation input of between 300 and 1,100 kWh/m² during the vegetation period. This distribution is very similar with the one of spruce forest. Planted forest growth inside the study area is limited to a small range of yearly precipitation sums between 600 and 900 mm. A similar pattern shows Plantation growth and July-precipitation: it is only occurring between ~50 and 90 mm.

Birch forest occurs on areas with annual Potential Evapotranspiration sums between 430 and 510 mm/year. The range of insolation values where it occurs is 400 – 1,100 kWh/m². Birch forest distribution in the study area is on sites with annual precipitation sums from 450 and 850 mm.
The range of July precipitation where it is growing is between 30 and 80 mm.

Bushes are growing at sites with a wide range of PET per year. It goes from 380 to 510 mm from a total annual range in the study area between 350 and 530 mm. Solar radiation input seems also to not influence bushes to grow. The range is the same as the total range of the study area. They also grow on areas with the lowest precipitation values. Only on sites with highest precipitation values (>1,000 mm/year), they cannot be found. A similar pattern shows the bushes distribution regarding the July precipitation. Here, a small gap with no bushes occurrence is statable between 40 and 50 mm whereas the range goes from 30 to 90 mm of precipitation in July.

3.2 Predicting Forest Area

The four parameters which were selected to be used in the logistic regression model are: elevation, slope, aspect, radiation. The fact that they do not correlate with other morphological and climatological parameters (see Table 1 and Table 2), makes them suitable for being used to explain forest growth or no-forest growth. The elevation variable was squared because there is an upper and a lower forest line. Forest is therefore growing between 1,700 and 2,900 m a.s.l.. Regarding the aspect, it is evident that forest growth is very likely to occur on North facing slopes (315-0° and 0-45°) and rather unlikely to occur on South facing slopes (135-225°). This effect is stronger in spruce forests.

The probability of forest growth can be explained quite well with changing elevation values. This is true for the overall forest growth and for spruce forest growth. Slope does hardly not influence overall forest growth whereas it has an impact on spruce growth. The steeper the terrain is the more unlikely spruce forest occurs. Radiation (solar energy input on a defined area) is influencing forest growth at the study site. Total forest and spruce forest are growing where the radiation is lower. Until a certain amount of radiation, the effect is not strong; growth probability is not changing with changing radiation intensity. After a certain threshold, however (at around 500 kWh/m² on total forest and around 600 kWh/m² on spruce forest) growth probability is decreasing almost linear with increasing radiation values. The statistical power of the model (accuracy) is 0.76 for the total forest model (Figure. 4) and 0.80 for the spruce forest model (Figure 5). The coefficient of determination RN² (Nagelkerke's R squared) is 0.44 for the total forest model and RN²=0.54 for the spruce forest model.

Table 1: Result of the logistic regression model to predict the total forest area

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-5.07E+01	3.81E-01	-133.316	<0.0001	***
Elevation	4.81E-02	3.35E-04	143.746	<0.0001	***
Elevation²	-1.02E-05	7.21E-08	-141.779	<0.0001	***
Slope	-4.01E-03	7.14E-04	-5.615	<0.0001	***
Aspect	-1.53E-02	3.07E-04	-49.764	<0.0001	***
Aspect²	4.22E-05	8.43E-07	50.044	<0.0001	***
Radiation	-5.08E-03	4.95E-05	-102.596	<0.0001	***

Table 2: Spruce forest, table of coefficients

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-6.77E+01	5.43E-01	-124.69	<0.0001	***
Elevation	6.29E-02	4.73E-04	132.98	<0.0001	***
Elevation²	-1.32E-05	1.01E-07	-131.08	<0.0001	***
Slope	-1.37E-02	9.00E-04	-15.21	<0.0001	***
Aspect	-2.06E-02	3.80E-04	-54.37	<0.0001	***
Aspect²	5.89E-05	1.05E-06	56.31	<0.0001	***
Radiation	-6.24E-03	6.26E-05	-99.75	<0.0001	***

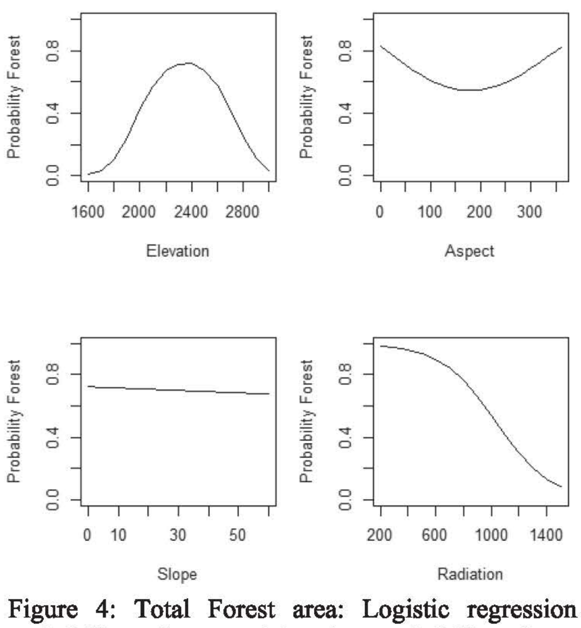

Figure 4: Total Forest area: Logistic regression probability plots explain the probability forest growth according to the selected four variables, Elevation is in m a.s.l, Aspect is in degree (N=315-0° and 0-45°, E=45-135°, S=135-225°, W=225-315°), Slope = inclination of the terrain in degree (°), Radiation is the solar insulation input in kWh/m² during the vegetation period

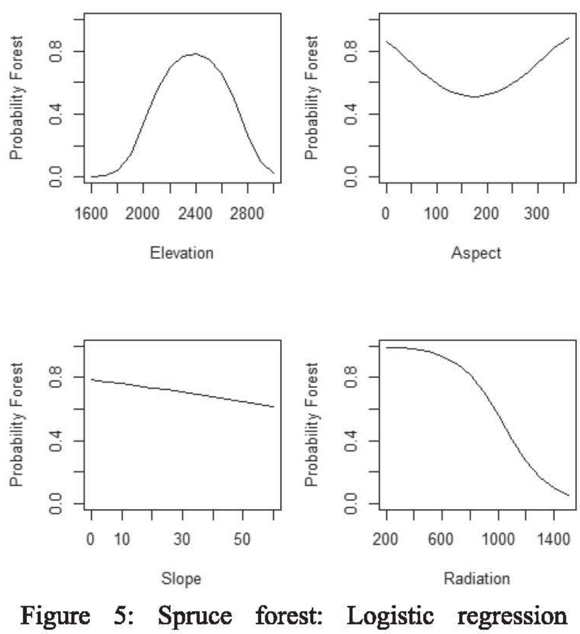

Figure 5: Spruce forest: Logistic regression probability plots explain the probability spruce growth according to the selected four variables. Elevation is in m a.s.l, Aspect is in degree (N=315-0° and 0-45°, E=45-135°, S=135-225°, W=225-315°), Slope = inclination of the terrain in degree (°), Radiation is the solar insulation input in kWh/m² during the vegetation period

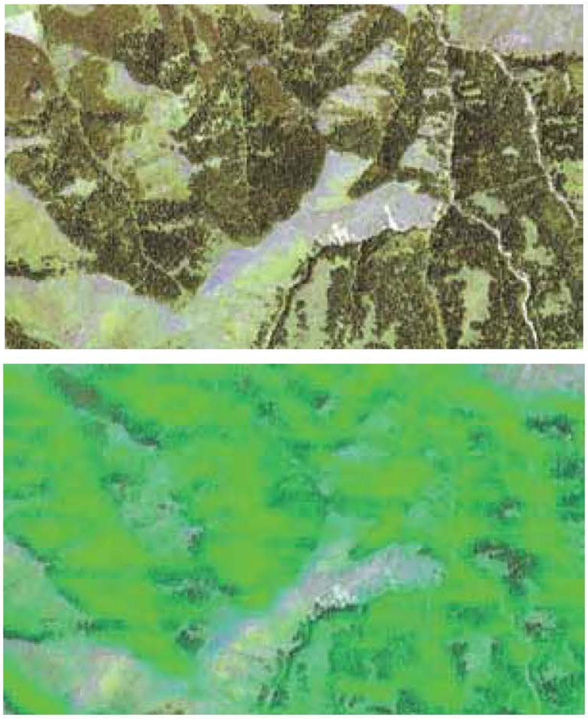

Figure 6: Detail of forested area at the upper forest boundary (upper image, darker areas=forest) and model-predicted forest areas (light green areas, lower image)

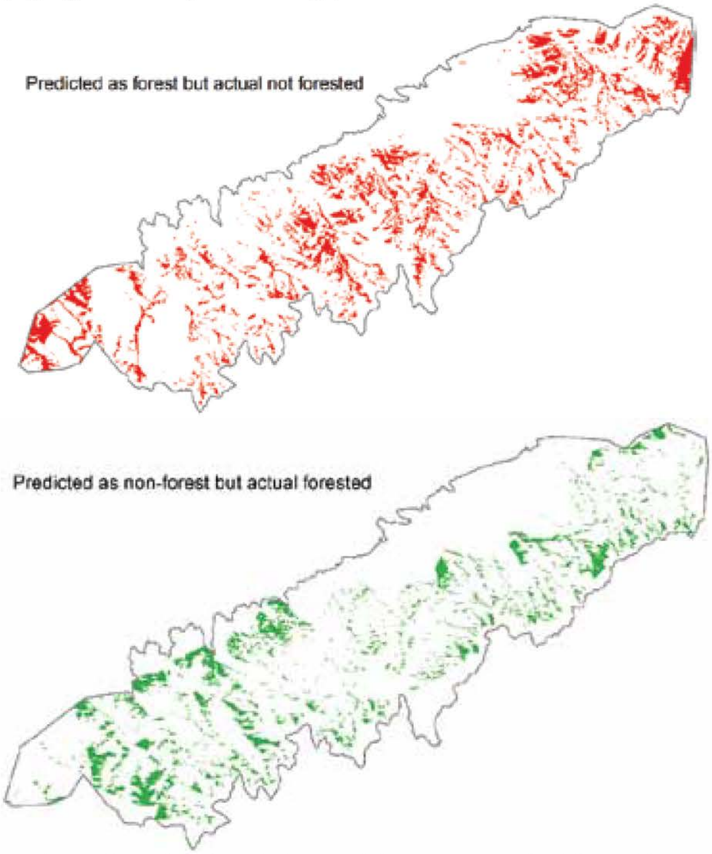

Figure 7: Comparison of predicted and observed forest area in the Chong Kemin National Park

This means the model is able to explain the total forest dataset well. The spruce dataset can be explained even better by the logistic regression model. With the logistic regression model, forest occurrence was estimated and plotted (Figure. 6). The predicted forest area confirms for the most part of the study site the actual forest area. The model predicted 8,078 ha to be forested and 9,771 ha to be non-forested area. However, the actual (true) forest area though is around 6,618 ha and the non-forested area 11,231 ha. There are therefore parts which are classified as forest by the model, but no forest is growing on them (1,459 ha of mismatch).

The accuracy of the model is not the same for the entire study area. Some of the model-predicted forest areas match very good with the real forest occurance, others don't. The model can overestimate the forest, i.e. predict forest where there is no forest actually and the model can underestimate, meaning to predict non-forest where there is actual forest occurring. Areas with overestimation are distributed all over the study site with a higher occurrence at the westernmost and easternmost borders. The lower parts of the study site in the Northeast show almost no forested areas whereas the model would have expected forest to grow there. In addition, the model expected on some spots the tree line to be at higher elevations (Figure 7). At some spots, the model predicted no forest to grow, but there is forest growing. Especially in the southern and southeastern parts, there is an accumulation of such areas of underestimation. The amount of underestimated forest areas is smaller than the amount of overestimated areas. In the central part of the study area, there are a lot of overestimated but almost no underestimated areas.

4. Discussion

The aim of this study was to identify the forest cover of a study area inside the Chong Kemin National Park of the Kyrgyz Republic. After that, a computer-based logistic regression model was developed to predict forested areas according to morphological and climatological parameters. The model was trained on the real forest occurrence on site based on digitalized forest maps and satellite images. At the end, it was possible to estimate forest growth and non-forest-growth with a model-accuracy of around 80%. Klinge et al., (2015) obtained an accuracy of 89% for their forest and tree line forest distribution-, and prediction-model based on remote sensing data of Central Asia. The tree line of the study area can be found at elevations of around 2,900 m a.s.l. Körner (2012) found the tree line to be between 2,750 and 2,920 m a.s.l. for the Kyrgyz Tien Shan. As mentioned also in Schickhoff et al., (2015), tree line is often formed by Juniper forests. All over Central Asia, *Juniper sp.* are able to grow on elevations where no other tree species occurs. However, spruce is the most dominant species in the study area and therefore the most present species at the tree line.

Forest in the study area (and especially spruce forest), grows mainly on North-facing slopes. Klinge et al., (2015) came to the same result for Schrenk's spruce analyzing it`s geographical distribution in the mountainous regions of Central Asia. On South-facing slopes almost no forest occurs. Bushland is the only woody vegetation type growing on the South-exposed parts of the study area. All the other species apparently avoid this environment. The aspect seems therefore to play a crucial role in this study. Also Zhao et al. (2005) found much higher solar radiation values on South-facing slopes than on other cardinal directions. In fact, the probability of forest occurrence was shown to decrease with higher radiation values reaching an almost zero-growth-probability at areas with maximum radiation input. On the other hand, the calculated likelihood of forest growth was highest at areas with the lowest radiation values. For the study area, radiation values from 300 to 1,300 kWh/m² during the vegetation period were found. Forest occurred on areas with radiation values not higher than 1,250 kWh/m². Klinge et al., (2015) found slightly higher values for Central Asia but with a vegetation period assumed to be longer than the one used in this study. Their calculated total solar radiation input was 650 – 1,550 kWh/m² whereas forest occurred on areas with values not higher than 1,450 kWh/m². Spruce forest cannot grow on slopes with high solar radiation due to a lack of moisture. Only if there is an additional source of water coming from the ground (permafrost, slope water, surface channel), Schrenk's spruce establishment is possible (Zeidler et al., 2016).

Whether solar insolation becomes a limiting factor for plant growth or not is also strongly related on the temperature regime of an area. With higher summer temperatures, forest vegetation gets more prone to suffer water deficits (Way and Oren, 2010). The radial increment as well as the height increment of Schrenk's spruce are low in areas with high summer temperatures and low precipitation values (Magnuszewski et al., 2015). Seedling and sapling establishment was shown to correlate positive with higher soil moisture values. Soil moisture is, among others, directly correlated with precipitation patterns (Schickhoff et al., 2015). It can therefore be assumed that the combination of high temperatures during summer months combined with low precipitation - and high insolation values lead to a missing tree seedling establishment on exposed slopes.

Large parts of the study area have rather high slope inclination values. Steep slopes can lead to a faster surface and belowground water runoff, which means faster drying of the soil. Magnuszewski et al., (2015) found that areas with slope values lower than 25 degrees of inclination can be effective in retaining water in the ground and keep it available for the plant. Only around one third of the study area fulfills these requirements. The rest of it shows slope values higher than 25°. This leads to the assumption that on spots that are exposed to high radiation, slope can be an additional hindering factor for woody plants to establish. The logistic modelling results showed a slight probability reduction of spruce growth with increasing slope values. This seems to aggravate the situation, where the actual problem is a lack of forest on steep slopes. Lal et al., (2007) recommend to plant forest on steep slopes in order to protect against soil erosion. Of course, this makes sense just in case of an ensured success of the planting. The planted and established forest of the study area can also be found on rather steep terrain up to 45° inclination. But, only on North-facing slopes where solar radiation values are again distinctly lower.

The logistic regression model to predict the potential forest area was fed with the morphological parameters elevation, slope, aspect and radiation. Like in Zhao et al., (2005) and Klinge et al., (2015) these where the best fitting input variables to predict forest growth. Also, they did not show statistic correlation with all the other parameters what made them suitable to be used in the model. The forest prediction model showed clear discrepancies of predicted forest and actual forest area. Especially in some of the lower parts of the study area, in the North and in the South, the model predicted vast areas which have the morphological and climatic requirements which would lead to forest growth. The reason why there is no forest growing could be the vicinity to the villages and relatively low slope values which makes the forest easier to access for timber use and at the same time suitable for agricultural purposes (FAO, 2007).

Beside the theory of a human-induced lack of forest, another plausible explanation could be unknown pedological factors. Also, a combination of these two factors seems possible. A former, inappropriate cut of a forested area and a later mismanagement could have led to a missing establishment of a new forest.

Like most Kyrgyz forests, human influence reduced their distribution or led to tree line- and forest border shifts (Lioubimtseva et al., 2005). This is mostly due to animal (over) grazing, agricultural cultivation and illegal woodcutting with no reforestation. All of this factors often lead to a permanently deterioration of the former woodland (Dzunusova, 2008). On the other hand, there is the "underestimation" of forested land. The model predicted no forest growth for an area but there is actually forest growing. There are much less of these spots than the "overestimated" ones but it is worth to have a closer look. These areas are mostly plantation-, birch- and bush-forest types. Again, they are occurring predominately on North- but also on East- and West-facing slopes. The fact, that on South- facing slope is almost no forest occurring and that a large share of slopes are North-facing, means that slope direction has probably no influence here. Spruce is by far the most dominant species in the study area (~76% of total forested area). The logistic regression model was therefore trained with mostly spruce-forest-pixel-types leading to an output strongly related to spruce growth pattern. This could explain the discrepancies for this "underestimated" spots.

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