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Project

*State and prospects of the *Castanea sativa* population in Belasitsa mountain: climate change adaptation; maintenance of biodiversity and sustainable ecosystem management.*

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Report

Simulating implications of chestnut blight and management on species composition along an altitudinal gradient in the Belasitsa mountains, Bulgaria

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1 Introduction

Since about 15-20 years the chestnut blight caused by the fungus *Cryphonectria parasitica* (Murrill) Barr. is causing severe mortality in *Castanea sativa* in the forests of the Belasitsa mountains in the south of Bulgaria. After about 15 years of infection about 60% to 80% of the adult chestnut trees are infected. Authorities and stakeholders are concerned about the future fate of *Castanea sativa* in the region. Recently, a research project had been initialized with the aim to assess the current status of *Castanea* forests in the Belasitsa mountains and to investigate possible silvicultural means to maintain *Castanea* populations. However, as the research was based on one-time measurements no reliable time series data on the infection history nor in the temporal autecological and synecological effects of the disease were available. In order to shed some more light on these questions a model-based analysis was initiated and implemented in 2011.

2 Objectives

The overall objective of the current study was to analyse the implications of chestnut blight and different silvicultural management concepts on species composition along an altitudinal transect in the Belasitsa mountains in Bulgaria.

Specifically we aimed at

- (a) enhancing an existing ecosystem model for the simulation of chestnut blight
- (b) calibrating the model for chestnut forests in the Belasitsa mountains
- (c) simulating different management scenarios along the altitudinal gradient
- (d) identify the effect of chestnut blight and management on the persistence of *Castanea sativa* in the Belasitsa mountains

3 Study sites

The study site is located in the south-west of Bulgaria in the Belasitsa Mountains. An altitudinal gradient with three sites has been chosen for the simulation experiment. The altitudes of these sites are 475 m a.s.l., 650 m and 825 m respectively.

The soils in the case study region are eutric cambisols. As a representative soil for all three sites an eutric cambisol with a water holding capacity (WHC) of 138 mm, a pH value of 5.5 and 61 kg/ha/yr plant available nitrogen was chosen for the simulation experiment (Zlatanov et al., 2011).

Climatic conditions at the three sites were characterised by climate data taken from the CCTAME project. For details we refer to Rammer et al. (2010). Some summary statistics regarding climatic conditions at the sites are shown in Table 1.

Table 1: Climate characteristics of the study sites.

Site	Annual mean temperature [°C]	Annual mean precipitation [mm]	Annual mean summer precipitation (May-Sep) [mm]
Low	13.85	503	179
Intermediate	12.8	559	197
High	11.75	615	215

At each of the three sites initial stand conditions were defined to represent the major stand conditions in the respective altitudinal belts in the Belasitsa mountains. The characteristics of the three stands are presented in Table 2, the initial diameter distribution of the three stands is presented in Figure 1. In general the stands can be characterized as uneven-aged mixed broadleaved forests with a distinctive share of trees of coppice origin. At the lowest site *Quercus petraea* and *Castanea sativa* are approximately present in equal shares, at the site in the intermediate elevation belt *Fagus sylvatica* is an additional admixed species. *Castanea sativa* is the dominant species there. Finally, at the highest site *Fagus sylvatica* dominates the canopy, *Castanea sativa* is admixed, *Quercus petraea* present only in minor shares.

Table 2: Basic stand characteristics of the three stands.

Stand	Basal area [m ²]	Stem number	Volume [m ³]	Dominant height [m]
Low	47.3	667	276	18.6
Intermediate	55.9	298	308	20.4
High	59.3	495	364	20.9

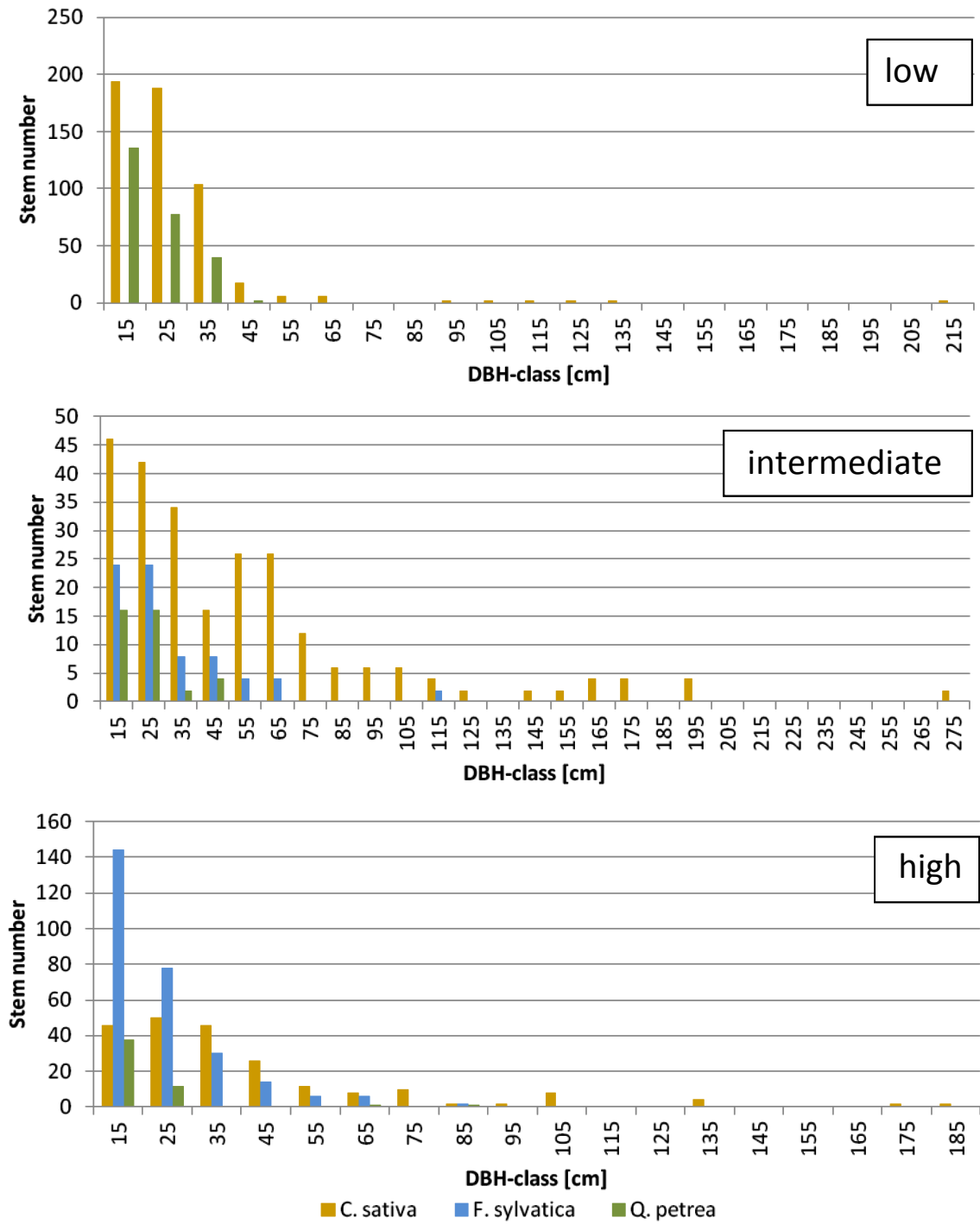


Figure 1: Diameter distribution of the initial stands at the study sites.

4 The ecosystem model PICUS v1.4.31

The hybrid patch model PICUS v1.5 (Seidl et al., 2005) is a modular modeling framework. It combines the ecological generality and applicability of patch models and the physiological foundation of process-based models. PICUS v1.5 retains the structural frame of a patch model (Lexer and Hönninger, 2001), and incorporates the production module of the process model 3-PG (Landsberg and Waring, 1997). The strengths of both approaches are combined within its model structure: elements of inter- and intra-species competition, a complex 3D light regime, individual tree structure, concepts of natural regeneration and mortality are incorporated. Net primary production is calculated according to the principles of radiation use efficiency as proposed in 3-PG (Landsberg and Waring, 1997). These model components are linked on annual time steps via the leaf area of the simulated forest (Seidl et al., 2005). A thorough model evaluation study by Seidl et al. (2005) showed sound results in both the simulation of potential natural vegetation species composition along environmental gradients (timescale: 1000 years), and the accurate prediction of timber yield and forest structure (e.g., diameter distribution) of intensively managed, structured multi-species stands (timescale: decades). Further components of PICUS v1.5 include a sub-model for the simulation of forest management interventions based on management scripts allowing for high flexibility in terms of spatially and structurally explicit harvesting and planting operations.

Coppice shoots

Natural regeneration of former PICUS versions was limited to generative regeneration. In order to be able to investigate coppice forests a sprouting module was implemented in PICUS v1.5. The sprouting is initiated by management activities. For the species which are able to regenerate via sprouts, new parameter sets were developed to take account for the differences in growth, mortality and regeneration. In general the capability of a stump to produce sprouts is dependent on species, diameter and stump age. The potential number of sprouts is calculated from stump diameter. A mature tree (60–70 cm in DBH, aged 60–70 years) produces at least 3–5 coppice shoots. Trees 100–150 cm in DBH can easily produce 8–10 shoots (Zlatanov, personal communication). The actual number of sprouts is chosen randomly between 0 and the potential, as field data provided by Rafailova et al. (2011, unpublished) showed no strong correlation between diameter and number of sprouts. However, according to this data set a decrease of the resprouting potential of 4 percent was assumed per rotation. Thus, with an increasing number of coppice cuts the number of stumps which do not support any shoots after the cut increases.

Sprouting trees are treated as ordinary individuals in PICUS with one exception: In order to compensate the increased competition an additional self shading modifier was developed for shoots sharing a stump.

To be able to simulate *Castanea sativa* forests the tree species had to be parameterized. A core element in the parameters of a tree species is the potential height growth function which was derived from data provided Zlatanov et al. (2011, cf. Figure 2).

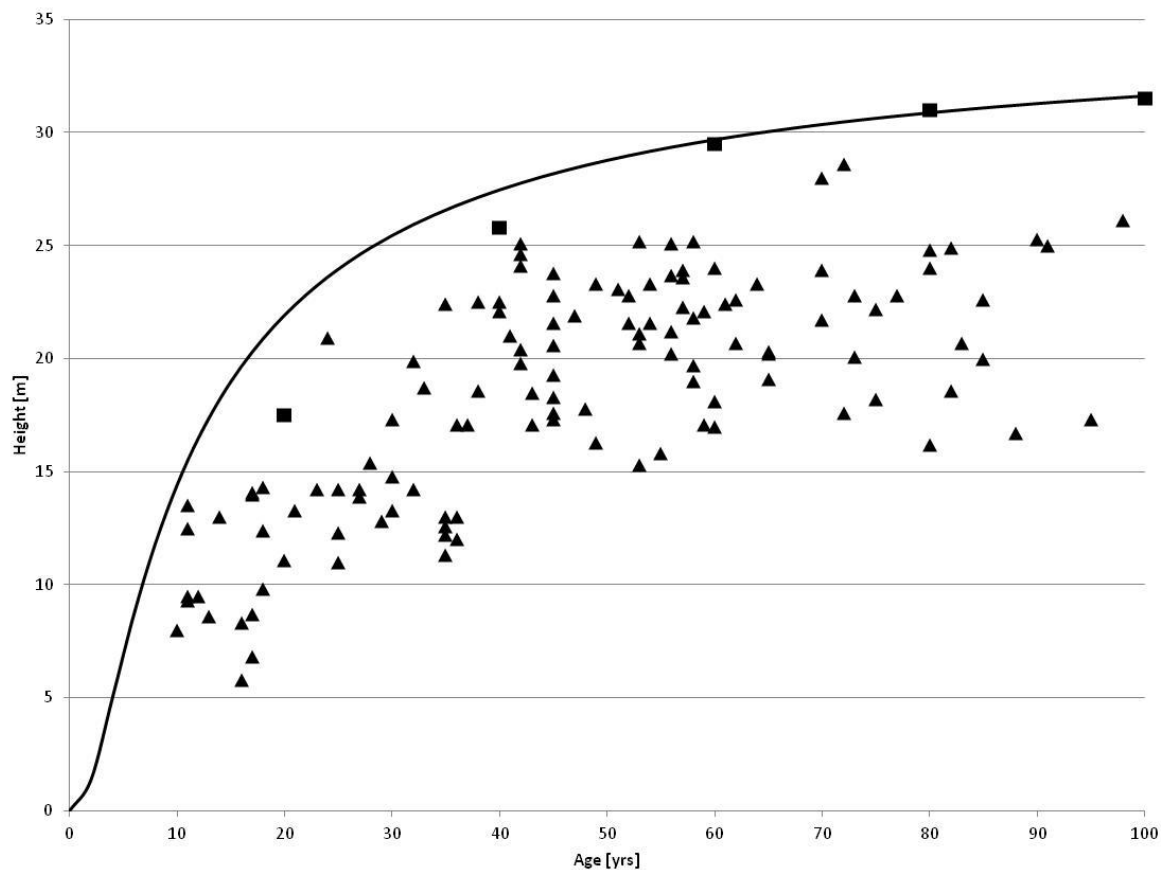


Figure 2: Height potential of *C. sativa* based on yield table data (squares) and data from dominant trees in the Belasitsa mountains (triangles, Zlatanov et al. 2011). The potential height is a function of age: $h_{pot} = \exp(3.3180 - 9.7074 / (\text{Age} + 1)) * 1.26$.

Infection

In the Belasitsa mountains an important disturbance agent in forests with a share of sweet chestnut (*Castanea sativa* Mill.) is the chestnut blight which is caused by the fungus *Cryphonectria parasitica* (Murrill) Barr. The infected trees show symptoms of increasing defoliation and decreasing vitality resulting in death after a time span of up to 30 years after infection. Based on data collected by Zlatanov et al. (2011) in the Belasitsa Mountains (south-west Bulgaria) an annual infection rate has been calculated for three altitudinal belts. This infection rate has been implemented in PICUS as a probability for each tree to become infected every year of the simulation. The infection probabilities decrease with increasing altitude, 6% for 400-550 m, 5% for 550-750 m and 4% for 750-900 m.

Not only adult trees, but also seedlings and coppice shoots can be infected. Based on observations by Zlatanov (personal communication) 7% of the shoots are infected per year. This rate was derived from observed infection rates collected in course of a regional forest inventory in the Belasitsa mountains. Seedlings have a smaller risk of infection: it has been set at 5% of all seedlings after five years. This is modeled as a 1% risk for seedlings to become infected. Once a tree has become infected two additional parameters need to be set. First, the time until death is defined. This is the maximum period an infected tree can survive. For the low elevation site the range of feasible values is 10-20 years, at the

intermediate site it is 10-30years, and at the high elevation site it is 15-30 years. Second, the defoliation status at the time of tree death is selected randomly from the interval 80-99% for each infected tree.

Chestnut blight effects

In the model the disease has several effects: (a) the reduction of leaf area, (b) the reduction of growth, and (c) the reduction of seed production. A major effect is the reduction of leaf area until the death of the tree. Based on observational data the decrease is modeled linearly. When a tree becomes infected, values for "time-to-death" and "remaining-leaf-area" are randomly selected from the given ranges for the elevational sites (see above). As the disease reduces leaf area the growth of an infected tree is reduced and thus it is more susceptible to stress and more prone to the stress-related mortality.

Reduced tree growth is modeled as a reduced "bottom up" diameter growth, thus reducing the amount of assimilates allocated for infected trees. In addition, the top-down (3PG) NPP is reduced accordingly as reduced leaf area of infected *Castanea* trees captures less light and consequently the NPP for the respective species pool will be lower than without the disease. Infected sprouts do also show a reduced growth. This is modeled by reducing the annual height growth potential of sprouts by 50% during the first ten years of life. For infected seedlings the height growth potential is reduced by 33% during the first 10 years.

The effect of seed production is modeled as a linear decrease of the seed potential down to a terminal value of 5%.

A *Castanea* tree can die from the intrinsic background mortality, a stress-related mortality related to competition or unfavourable environmental conditions or from the chestnut blight. If infected, a *Castanea* tree will die at the latest based on the assigned "time until death" parameter.

Model initialization

To initialize the stands besides stem number per DBH-class and species, tree height and age for each initialized individual tree are required. Field data was used to fit regression models for tree height and tree age as function of DBH (cf. Figures 3 and 4).

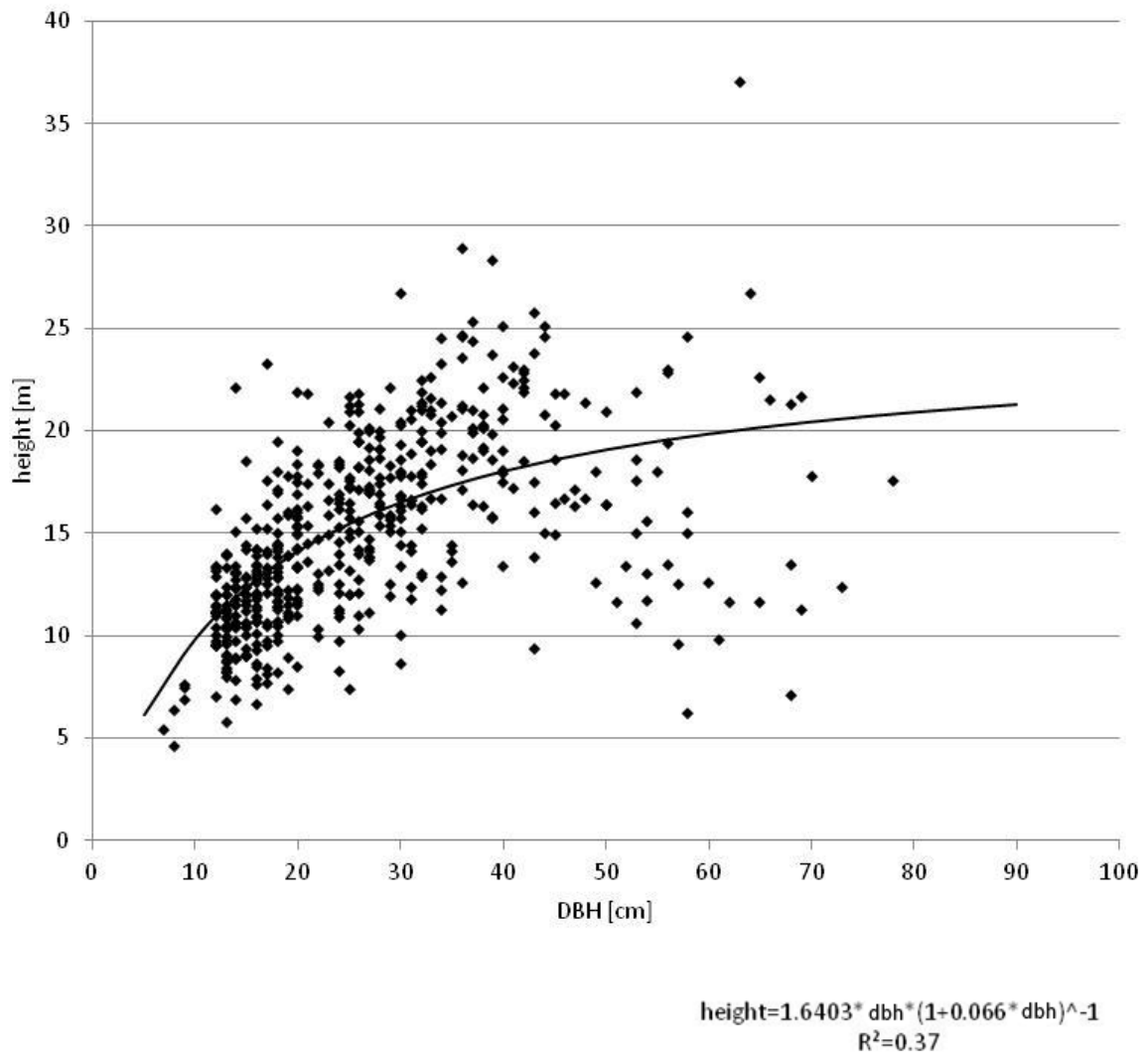


Figure 3: Height curve for *C. sativa* derived from field data provided by Zlatanov et al. (2011).

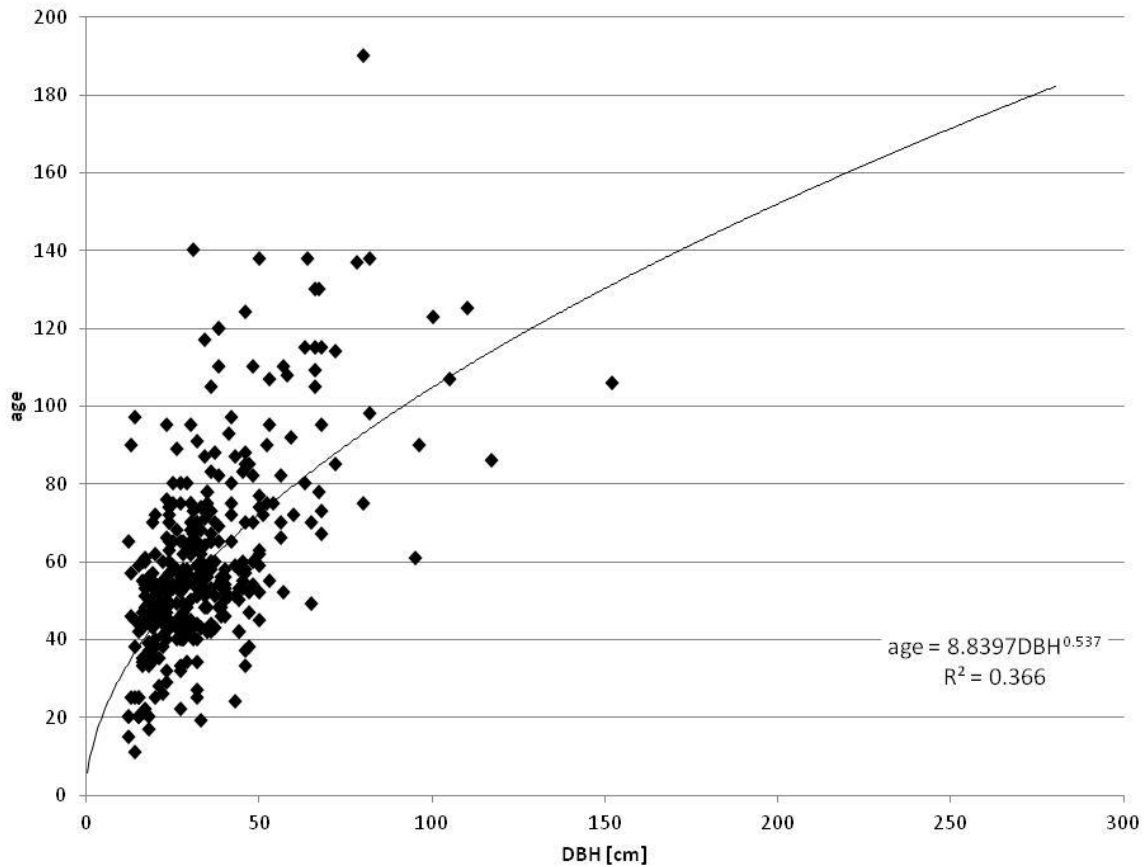


Figure 4: Field data (diamonds) were used to fit a function for age in dependency of DBH.

The state of the disease was assessed in the field according to the defoliation status of chestnut trees (see Zlatanov et al. 2011). Five classes have been distinguished. Class 1 (defoliation up to 25%) contains trees which are assumed to be healthy, class 2 (defoliation from 25 to 60%) contains infected trees, class 3 (defoliation larger than 60%) contains heavily infected trees and class 4 comprises trees which have died from the disease. For PICUS the same classes are used to characterize the simulated tree populations.

The defoliation percentage is deducted from the leaf area a healthy tree of the same size and crown length would actually have. To initialize a stand with chestnut trees with a consistent health status requires some additional assumptions:

Each tree which is initialized for a simulation is assigned a random value for “time until death” from the range of feasible values (see above) and a value for “defoliation status at time of death” (between 80 and 99%; see above for details). With this information and the assumption of linear decrease in leaf area with time the current status of the “time until death” counter can be calculated.

5 Simulation experiments

The stand development was simulated with the forest ecosystem model PICUS. To each of the three stands, four management regimes were applied. The four management regimes are:

- (A) a clearcut with subsequent tending and thinning,
- (B) a clearcut without any further management interventions,
- (C) group selection cutting with subsequent tending and thinning
- (D) no management

Under management regime A a clearcut is performed at the beginning of the simulation period. Thereafter tending operations are conducted three times every three years. For these operations maximal stem numbers and ranges for each of the occurring tree species are defined. After reaching the pole stage the stands are thinned from above four times until the rotation age at 80 years is reached. In the thinning operations 15-20% of the basal area is removed (table 3).

Table 3: Characteristics of management regime A on the three sites.

Site	Desired share of <i>C. sativa</i>	First tending	Second tending	Third tending	Thinnings
Low	30 to 40 %	three years after the clearcut the stem number is reduced to 6000	six years after the clearcut the stem number is reduced to 4000	nine years after the clearcut the stem number is reduced to 2000	four thinnings beginning in pole stage are conducted, 15 to 20 % of basal area are removed every 10 to 20 years by thinning from above
Intermediate	Up to 80 %	three years after the clearcut the stem number is reduced to 6000	six years after the clearcut the stem number is reduced to 4000	nine years after the clearcut the stem number is reduced to 2000	four thinnings beginning in pole stage are conducted, 15 to 20 % of basal area are removed every 10 to 20 years by thinning from above
High	30 to 40 %	three years after the clearcut the stem number is reduced to 6000	six years after the clearcut the stem number is reduced to 4000	nine years after the clearcut the stem number is reduced to 2000	four thinnings beginning in pole stage are conducted, 15 to 20 % of basal area are removed every 10 to 20 years by thinning from above

Management regime B is similar to A, but with the difference that no tending or thinning operations are conducted.

Management regime C relies on group selection cuts of a size of 1000 m². After 1 and 11 years three of those gap cuts are performed and after further 10 years the remaining stand is cleared. The regeneration within cleared areas is tended like in management regime A. Also the thinnings are applied as in management regime A, however the rotation age is increased to 100 years.

In management regime D no operations at all are conducted.

The simulation period depended on the management regime and spanned from 80 to 100 years. To take stochastic events into account for each stand x management regime combination three replicates have been simulated. These simulations have been conducted with and without disturbance by chestnut blight. For analysis detailed stand outputs were generated for 20 year intervals.

6 Results

6.1 The null model: management alternatives without chestnut blight

In order to isolate the effect of chestnut blight a simulation series was implemented without the disease but otherwise with identical data and assumptions as in the experiments with chestnut blight.

Under the no management regime (D) without considering chestnut blight the share of *C. sativa* decreases strongly over the simulation period of 100 years, indicating that *C. sativa* is naturally not dominant in older growth stages at the simulated sites. Similar but weaker effects were found for the other management scenarios, where management interventions were able to support the persistence of *C. sativa* according to the management goals. However the results of management scenario B (clearcut at the beginning and no other management interventions) show that *Castanea* is actually very competitive in young stand development stages, especially when regenerated from sprouts, which has also been confirmed by the field data (cf. Figure 5).

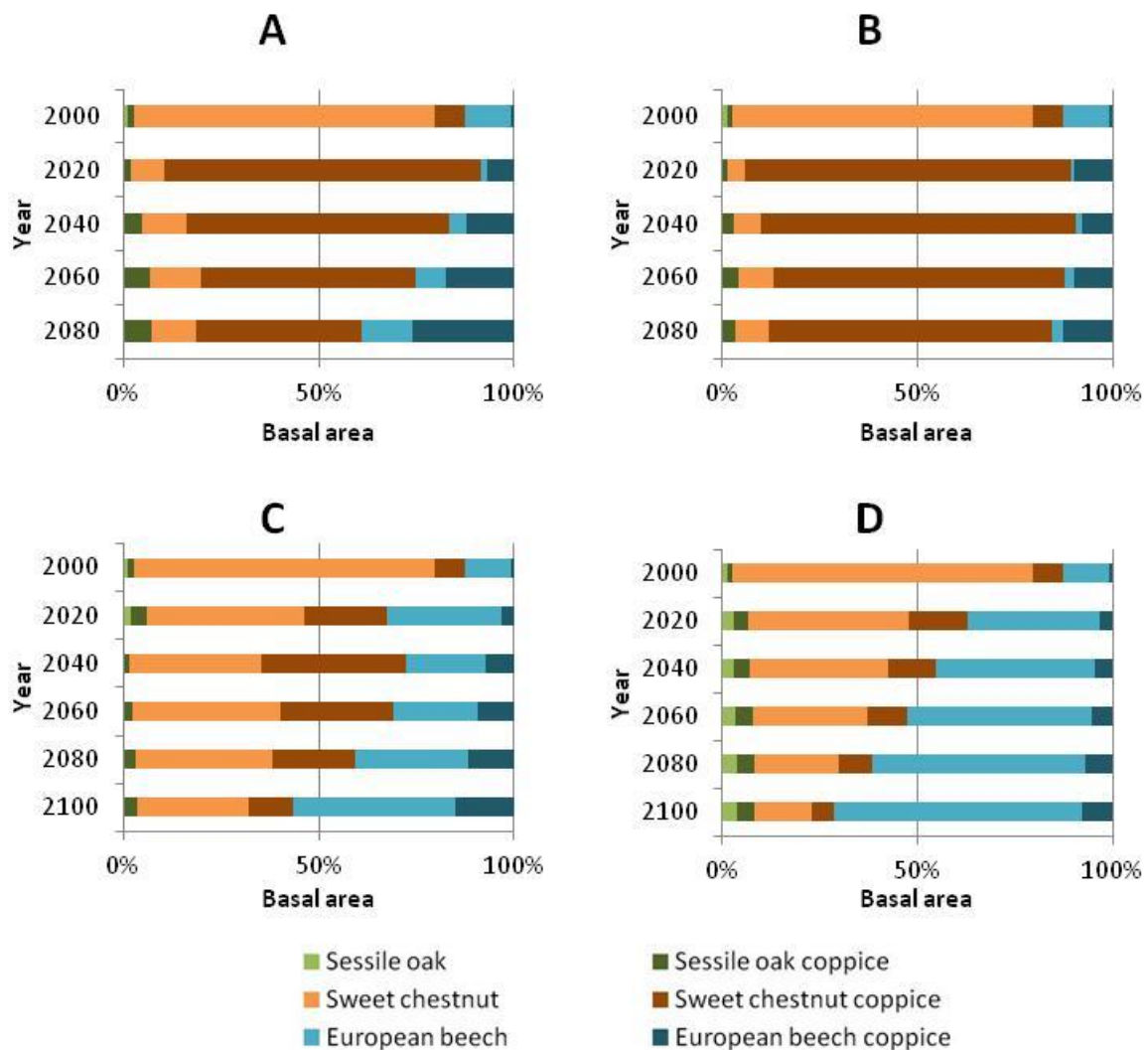


Figure 5: Results of the simulation runs of the intermediate site without chestnut blight. A = clear cut/tending, B = clear cut/no tending, C = group selection/tending, D = no management.

6.2 Effects of management and chestnut blight

When taking chestnut blight into account the results indicate that doing nothing (management D) is the least favourable of all analysed management scenarios. The share of infected chestnut trees increases over time and after 60 years the share of *Castanea sativa* in overall stand composition was substantially reduced at all three sites (compare Figure 6).

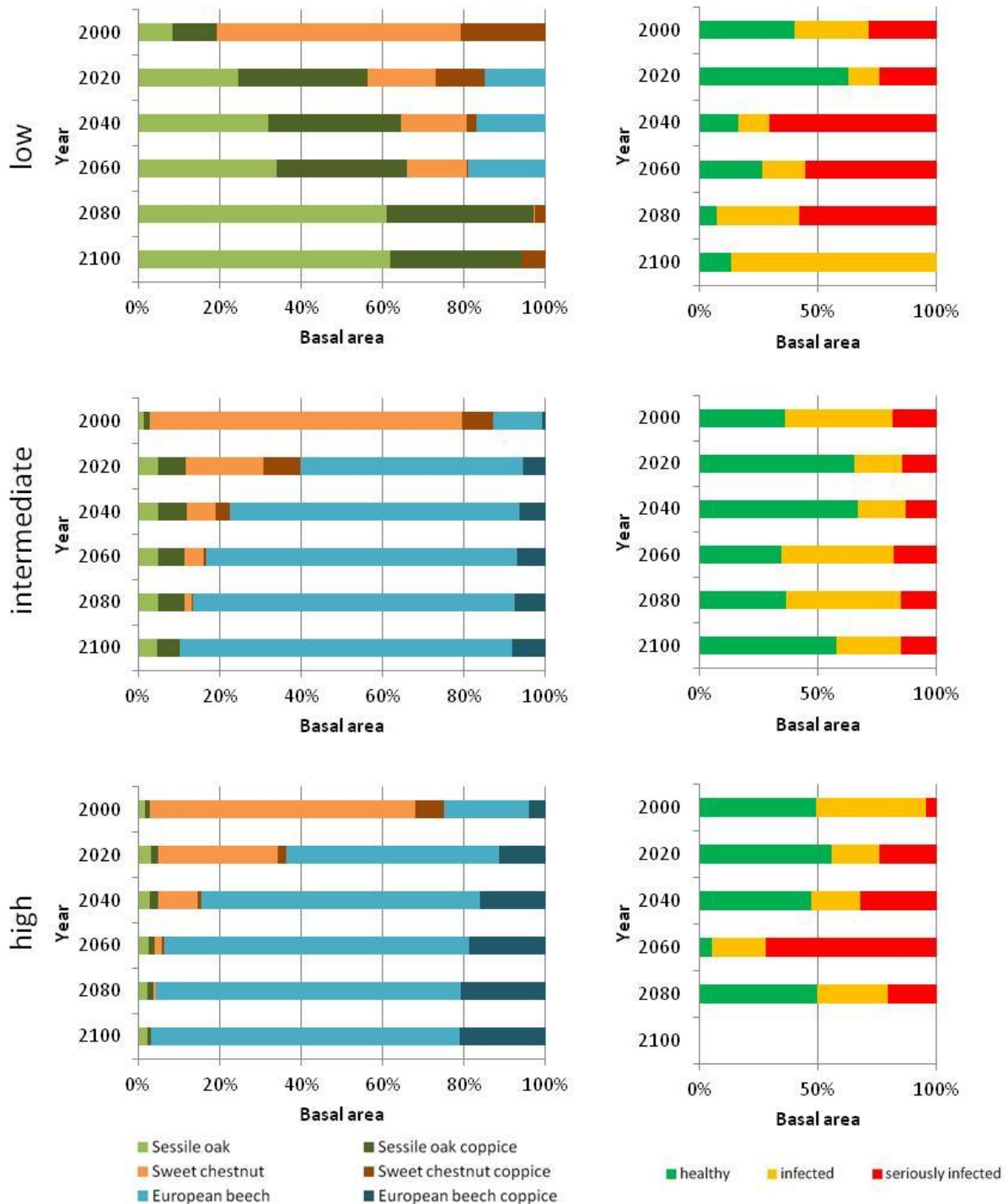


Figure 6: Species composition under the no-management regime (D) and chestnut blight. The low and the high elevation site showed distinct increases in infected trees (healthy = defoliation less than 25 %, infected = 25 to 60 % defoliation, seriously infected = more than 60 % defoliation).

At all three sites the share of *C. sativa* decreases substantially in the first 40 years. Clear cut areas of a reasonable size establishing conditions of full light with subsequent tending and thinning can help to maintain substantial shares of *C. sativa* a bit longer, about 20 years in minimum. The size of the clear cut should be chosen in a way that the strong light demand of chestnut is met. The 1000m² patches of the group selection management regime (C) are not sufficient for that and especially at higher elevations these relatively small gaps favor European beech to the cost of oak and *Castanea*. However, due to the longer regeneration period the group selection management regime (C) is able to maintain a distinct share of chestnut over a period of up to 60 years after the final felling despite substantially lower numbers of *C. sativa* regeneration compared to the clear cut regimes. The reason is that, although *Castanea* is present in the regeneration layer in lower numbers, the longer overall regeneration period for the entire stand increases also the time period where uninfected new *Castanea* trees continue to grow into the overstorey.

Castanea sativa, especially when sprouting, is very vigorous in early development phases, therefore it was very successful in the regeneration after clear-fellings (cf. Figure 7). However the susceptibility of sprouts to chestnut blight is larger than for seedlings, therefore it is important that trees of seed origin are fostered when management interventions are implemented. Therefore, assisting *C. sativa* regeneration by tending and thinning helps to maintain the species share in course of stand development (Figure 8).

Tending and thinning contribute to increase the period with presence of *C. sativa*. In general, chestnut blight increases tree susceptibility to stress and reduces competitiveness due to lower leaf area and reduced growth which increases the rate of stress related mortality. As infected *Castanea* trees on average have a higher risk to die from stress-related mortality the cumulated overall effect is that the mean survival period of an individual infected chestnut tree is lower than would be expected from the "time until death" parameter values.

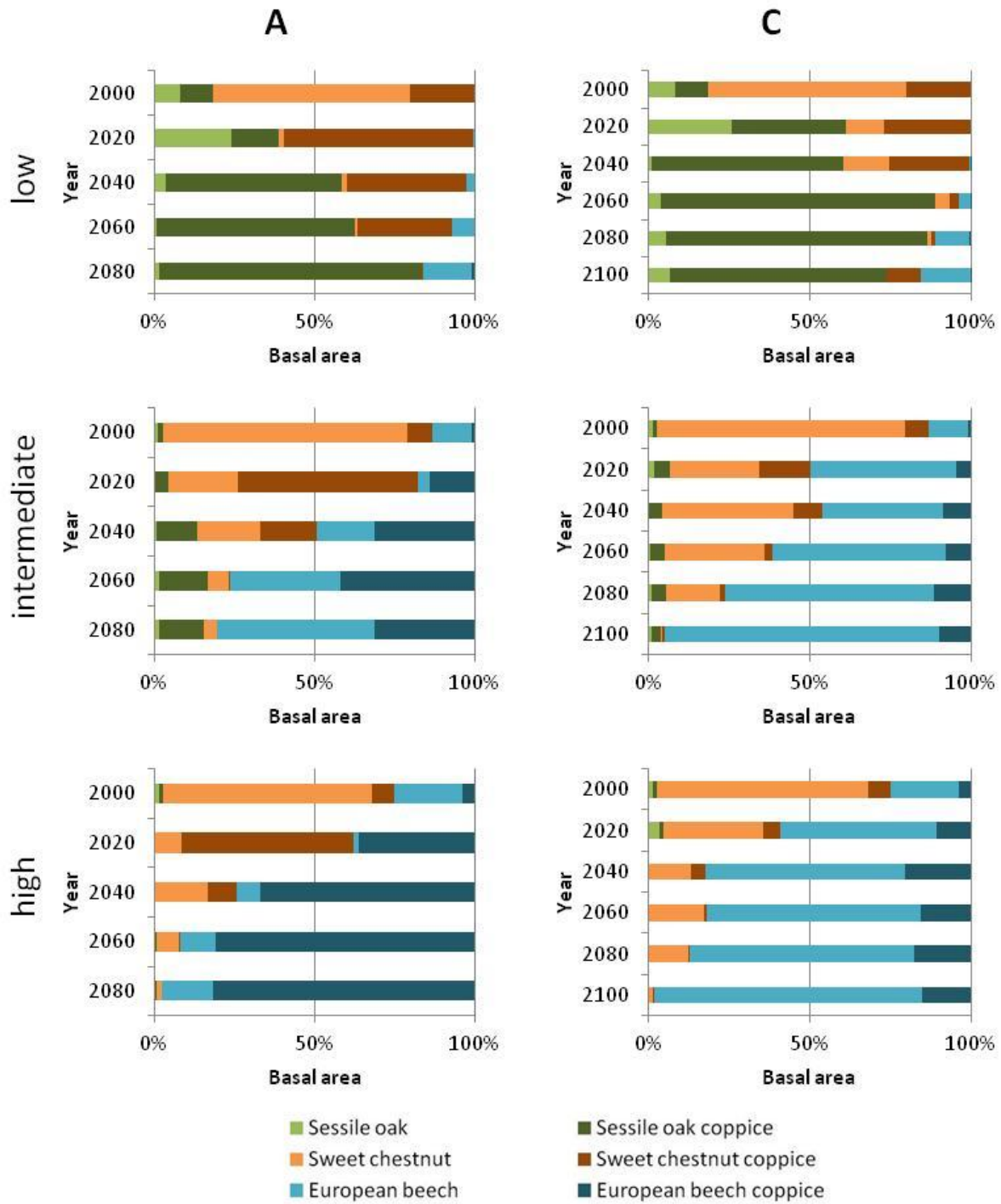


Figure 7: Results for the management regimes A (clearcut) and C (group selection) including chestnut blight at three sites. Clear cutting favors *C. sativa* in the regeneration. Despite less *C. sativa* in the regeneration the group selection is able to preserve *C. sativa* to a comparable extent over the same time due to a longer regeneration period of over 20 years.

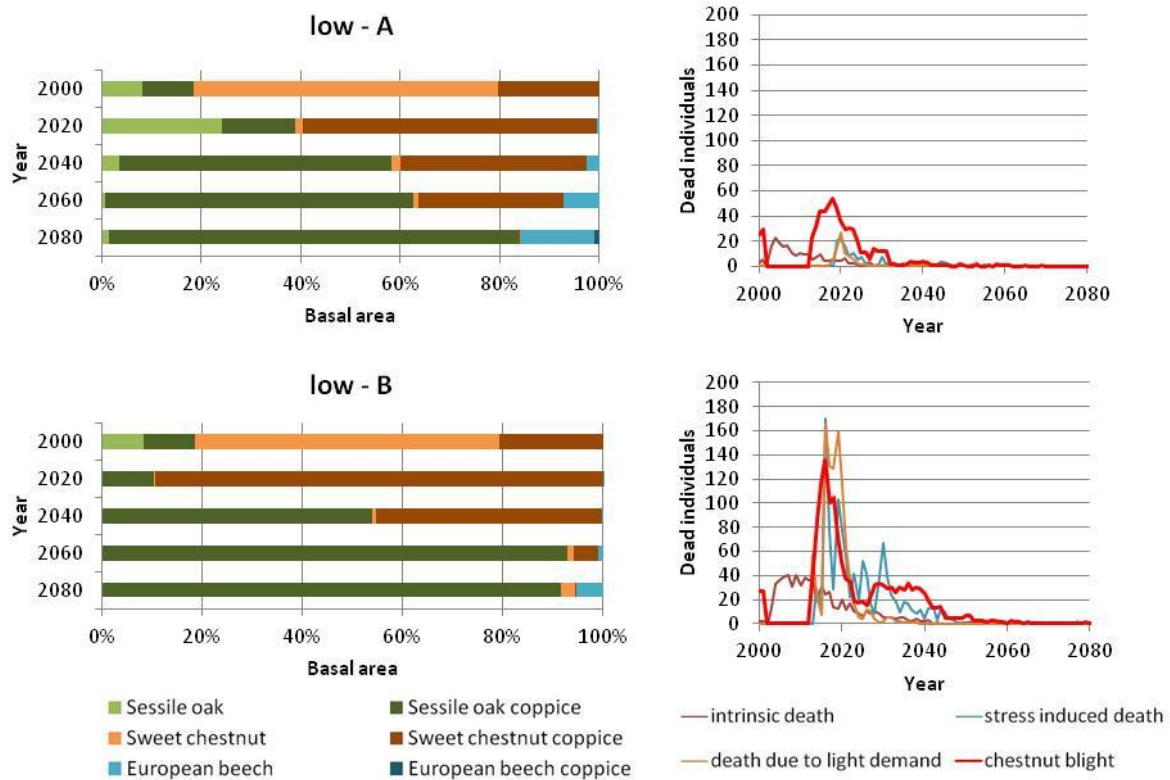


Figure 8: Comparison of mortality reasons of *C. sativa* under management A (clearcut with tending and thinning) and B (clearcut without any other management interventions) including chestnut blight for the low elevation site.

7 Conclusions

It has been shown in the model simulations that *C. sativa* is under strong competition from *Q. petraea* and *F. sylvatica* respectively. If no silvicultural interventions are implemented which support *Castanea* the share of chestnut in overall species composition at all analysed sites will decrease. This is expected to happen also in a situation without chestnut blight indicating that in the Belasitsa mountains chestnut would naturally not be able to maintain its presence at most sites.

Especially at the highest site the competitiveness of European beech is very strong. The results indicate that at this site it could be difficult to maintain *C. sativa* despite of less favorable conditions for chestnut blight. At the lowest site the disease is more vigorous, however due to the comparable ecological demands of *C. sativa* and *Q. petraea* it appears to be easier to preserve a reasonable share of *C. sativa* throughout stand development.

That the impact of management and its interaction with the chestnut blight disease can be complex has been demonstrated with the group selection approach (management regime C). There the longer regeneration period compared to the clear cut approaches (management regimes A and B) is responsible that *Castanea* can be maintained longer than under the clear cut regimes.

With more elaborated management regimes than the ones analysed in the current experiments the success of the management interventions to maintain *C. sativa* could be increased even more. For example, the size of the group cuts in management regime (C) could be optimized for *Castanea sativa*, likewise the selective thinning regimes as in Management alternative (A) and (C) could be optimized to maintain for an even longer period a higher share of chestnut trees in the stand.

From the simulation experiments it can be concluded, that no management for stands with a high number of infected chestnut trees is likely to result in total distinction of the chestnut population within a relatively short period of time (20-30 years). However, assuming that the main assumptions of the model simulations hold even with active management the share of *Castanea* is successively decreasing and after 50-70 years the share of *Castanea* is so low that a sustainable maintenance seems questionable.

To increase the reliability of the conclusions drawn from the presented simulation experiments even further, sensitivity analysis for major model parameters are recommended. Particularly the “time until death” once infected needs to be supported by observed data. To assess the ability of the model to mimic the competition situation among 3 tree species would require an extended series of model evaluation simulation runs.

8 References

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