Tree Mortality Processes in Natural Forests – short review

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Abstract Tree mortality processes are some of the most complex and hard to describe ecological processes within the forest ecosystem. This short review describes first the concepts of tree mortality and virgin forest, then it focuses on current approaches regarding the study of tree mortality. A few insights are shown of the classical forest dynamics models such as JABOWA, FORET 1, SILVA 1, SORTIE and their respective mortality sub-routines are shortly described; these models were developed both in Europe and the US, but there are examples from other regions also. A special attention is given to the dendrochronological approach on the tree mortality studies. The results from a mortality study conducted in the Romanian virgin (natural) forests is briefly described.

Key words tree mortality, natural forests

Forests are the most complex ecosystems on Earth. This complexity explains the multifunctional role of the forests which draw the attention of all specialists in the last years. The new challenge in forest management is to produce quality timber and simultaneously to maintain (or even improve) the biological diversity. The forests with high degree of naturalness, so called „the virgin forests”, are the most rich and complete information sources regarding the structure and functioning of forest ecosystems. Understanding the organization and dynamics of these forests represents the key for developing the best silvicultural measures for sustainable management of the forest resources. This study will focus on the ecological process of continuous, regular mortality in the most important beech virgin forest of Europe: the Nera forest.

Definitions and concepts

a. The virgin forest

From the very beginning of the forest sciences, specialists had a particular interest and respect for the ancient, virgin forests. To express this concept of the virgin forest, many definitions were issued along the time, and probably the most complete one was recently (2002) stated by Professor Josef Fanta1 (Wageningen University, The Netherlands):

“[The virgin forest] is a natural forest, where the species of trees and shrubs are in different stages of their life cycles (seedlings, young growth, advanced growth, maturity and old growth) and where dead wood (standing or laying) is in different stages of decay, thus resulting more or less complex vertical and horizontal structures, as a result of a dynamic process, which assures to the natural community of trees a continuous existence without a limit in time, on the specific territory. In the virgin forests, the own dynamics of the living systems is closely related to the ecological characteristics of the dominant tree species (including their longevity), to the impact of other organisms (for example, the insect attacks) and to the impact of the abiotic factors related to the soil, climate, the topographic complex and the level of waters (such as the floods, abundant snowfalls, windbreaks). One sequence of this dynamics is constituted by the temporary appearance of gaps, or even stages without trees on larger surfaces in the forest. Inside a specific phyto-geographical zone, the virgin forests are different, forming many specific types of forest communities with characteristic composition, spatial structure, dynamics and global diversity, determined by the altitude, topography, macro-climat, nutrients and water resources. Hereby, the virgin forests reflect the natural harmony between the forest community and the abiotic conditions, perfectly consolidated during a millenary development, continuous from the Holocene Era.”(Radu et al. 2004).

b. The tree mortality process

The mortality of the trees is one of the most important ecological processes in forest population dynamics, with a key role in maintenance of biological and structural diversity of the forest (Bigler and Bugmann 2003). This process is difficult to study because of the longevity of the trees and because of the high variability in space and time of the tree death (Bigler and Bugmann 2004a). A complex of different environmental factors, such as windthrows, fire, droughts, insect or fungi break-outs, intra- and inter-specific concurrence, senescence, etc.,
acting together, is responsible for the death of the forest trees (Bigler and Bugmann 2004a). When one of these factors is maximized and becomes dominant, it clearly is responsible for the tree death. Generally speaking, tree mortality occurs from two major categories of causes:

- Causes with accidental appearance, such as diseases, major insect attacks, severe and prolonged droughts, massive windthrows, large fires, etc.; these causes lead to episodic or irregular mortality;
- Causes considered as “normal”, such as competition and senescence, which leads to continuous or regular mortality (Bigler and Bugmann 2004a).

The tree mortality process is strongly related to the tree growth process (Kozlowski et al., 1991, cited by Bigler and Bugmann 2004a). When the trees are affected by the complex of factors mentioned above, their general health status becomes poor, which is directly reflected in growth level. It is observed that only the continuous, regular mortality is reflected in growth, being also a relatively slow process that can take a few years; accidental tree death is characterized by being very quick and having no relationship with physiological processes that can induce a slow growth rate. In literature exists the idea that the very big, dominant trees from the upper canopy die by a growth-independent mortality process (Ozolinicius et al. 2005); we assume that before death occurs, for at least a few years, those trees’ small increments show a poor health and vitality condition; from these increments the death of such trees can be predicted, so the process is growth-dependent.

Present approaches to (regular) tree mortality processes’ study

Tree death is caused by a complex of different environmental, ecological and physiological factors; usually, one of this factors is dominant and it is stated as the cause of death. The mortality process is one of the key processes of the population dynamics in forests. Due to the high complexity of different factors involved in mortality, on one hand, and the longevity of forest trees and the high variability in space and time, on the other hand, the mortality of forest trees is one of the ecological processes very hard to study. Because of these difficulties, relatively few studies were conducted in this field (compared to other ecological processes in the forest); one of the linking points of these studies is that all of them use mathematical modeling of the complex mortality process. The attention focuses mainly on the regular, growth dependent mortality processes. The accidental tree mortality processes, which are induced by extreme natural events like windstorms, fire, major insect outbreaks, etc., are also studied with mathematical modeling methods, but the key element is the prediction and study of the mentioned extreme natural events, not the forest or the individual trees.

During the last decades, as personal computers developed in more and more powerful calculating machines, many very complex models of forest dynamics appeared. A short presentation of 4 of these models will be given as it follows.

One of the most complex forest growth and change over time is the JABOWA model (Botkin 1993), used for the forests from the North-East of the US. The main characteristics used for individual trees are the maximum age, diameter and height, also the relationships between height and diameter, leaf biomass and diameter, photosynthesis rate and the available light, the tree growth and the climate (Dinca 2004, Botkin 1993). The simulation is made using 10 x 10 m surfaces, for each simulation year. The software of the model has 3 important subroutines: GROW, which indicates the annual growth of each tree, BIRTH, which adds natural regeneration, and KILL, which indicates the trees that die naturally (Dinca 2004, Botkin 1993).

In his book “Forest dynamics. An ecological model”, Botkin (Botkin 1993) explains the model of mortality processes for individual trees. The JABOWA subroutine for tree mortality considers two ways of three death occurrence:

- the inherent risk of death, which represents the death expected to occur to any healthy tree from a favourable environment, independent of other tree concurrence. This kind of death is an event assumed to be exponentially distributed, its probability depends on the known longevity of the species (Botkin 1993). This is represented by an age independent function of the maximum observed longevity of the trees of a species, with an additional assumption that only a few exemplars will reach that maximum longevity age. In the JABOWA model, the percentage of the trees that are expected to reach that maximum age is considered to be 2 % of the population. A random value is designated to each tree every year and this value is compared with the annual probability of death; by comparing this value with the probability it will be established if the tree dies on that specific year or not (Botkin 1993). Different longevities and annual probabilities of death can be used for different species (Botkin 1993).
- the competition induced death, representing the death occurring to poorly growing trees (Botkin 1993). This type of mortality process is a function of the current year’s growth. The trees with very small growth are considered more vulnerable to death than healthy, normally growing trees. They are many causes of mortality in this case, among others: these weakened trees are unable to produce sufficient secondary compounds in order to resist insect outbreaks and deseases; this weakness increases the probability of
windblow. The mortality function approximates the sum of these effects. The software tests each tree if the annual increment is smaller than a specific, fixed value (characteristic for each species) and if the increment stays below that minimum value for 10 successive years, the survival probability for the tree is 1%. The annual mortality rate resulting is 0.368; the minimum growth increment factor is set to all species to 0.01, in despite of the fact that it is a species-specific factor. The dying trees are also selected randomly from the population, like in the first mortality function (Botkin 1993).

Botkin concludes that in the mortality subroutine of his JABOWA model 3 parameters are taken into account for the tree mortality processes: the minimum annual growth below which the probability of tree death is very high; the percentage of the healthy trees for each species expected to reach the maximum longevity age and the percentage of the trees expected to survive after 10 years of very small growth (Botkin 1993). The model works well with the considered parameters and this mortality routine was not adapted further by the specialists (Botkin 1993).

Another complex model, the FORET 1 model, is derived and adapted from the JABOWA model and it is specific for the forests from the South of the US. It uses for simulation circular plots with an area of 1/12 ha, the number of analysed species increases to 33, a new subroutine is added, SPROUT, which simulates the sprouting type of regeneration, dominant in the mentioned zone (Dinca 2004).

The SILVA 1 model was developed at the University of Munchen and it is a complex model used for simulating silvicultural operations, tree growth and climatic changes (Dinca 2004). It was developed as a result of long-term research on tree physiology and interactions with the environment. These investigations are still ongoing and the results are constantly integrated in the model.

SORTIE is a stochastic model of forests from North-Eastern US. It simulates the local competition among trees from nine species based on individual tree responses (Pacala et al. 1996). These species are dominant or subdominant species from mid- and late-successional stands. SORTIE is a simple model consisting of two subunits: a routine that measures the local availability of the critical resource (light) and the life history responses for all nine species, such as patterns of growth, reproduction, and mortality as direct or indirect functions of light (Pacala et al. 1996). Field data was recorded concerning the water and nitrogen relations in the forest, but because it was not relevantly associated to tree performance it was not included in the model (Pacala et al. 1996). This model deals with the human impact on forests by increasing the mortality of the trees. During the simulation, two regimes of increased tree mortality were used and compared: the increased individual mortality and the disturbed forest, where groups of trees are destroyed (Pacala et al. 1996). The results are quite different, because of the different ecological characteristics of each species. The increased mortality of all species is not neutral from the competition point of view; the increased gap opening favours the pioneer, fast growing species. Experiments were conducted on a 300 x 300 m square area (9 ha) (Pacala et al. 1996).

On the other side, different research projects were developed to have a modelling component, issued by using the data collected from the forest and designed to predict some events. The major approaches to the mortality studies will be presented as it follows.

One interesting approach to the tree mortality processes is the simulation using connectionist networks in uneven-aged stands (Hasenauer et Merkl 1997). The study represents an application of the neural networks using the unsupervised learning process for the individual tree mortality prediction as part of a forest growth model. The data used for the study was collected in permanent sample plots in uneven-aged spruce stands from Austria. The trees were described by 3 features: competition after crown release, crown ratio and diameter at breast height at the beginning of each 5 years growing period (Hasenauer et Merkl 1997). This set of data was also used in a LOGIT classical model to predict the individual mortality of trees. The mortality simulation was undertaken as calculating the probability of tree death within a period of 5 years. This kind of simulation is vital for the forest growth models because tree death reduces the density of the stands and directly influences the remaining tree growth (Hasenauer et Merkl 1997).

The best results for individual tree mortality in uneven-aged Norway spruce stands were described by a network of 64 units arranged in 8 x 8 square; smaller and larger nets gave less precise prediction results for tree mortality (Hasenauer et Merkl 1997). Comparing the results of an 8 x 8 neural network and a classical LOGIT model on an independent data set shows better performances for the neural network than the conventional LOGIT approach (Hasenauer et Merkl 1997).

A mortality study was conducted in the Lithuanian forests. The mortality of the trees from the upper layer (mortality beyond self-thinning) is considered by the authors (Ozolincius et al. 2005) as a growth-independent mortality. [In our conception, these dominant trees have very small increments prior to death, so growth is strongly related to mortality processes]. Long-term observations were undertaken on 420 plots and data from 900 permanent plots was collected; the stands investigated were 20 – 120 years
old and the major tree species were Pinus sylvestris, Picea abies, Populus tremula, Betula pendula, Betula pubescens, Fraxinus excelsior, Quercus robur, Alnus glutinosa and Alnus incana (Ozolincius et al. 2005). The measurements were made periodically in the experimental plots at 5 – 10 years and annually in the monitoring plots. The average annual mortality rate found was 0.55 % in experimental plots and 0.62 % in monitoring plots; the lowest rate corresponds to Pinus sylvestris, Quercus robur and Fraxinus excelsior and the highest mortality rate has been noticed on Betula spp., Picea abies and Populus tremula (Ozolincius et al. 2005). The mortality of the tree species with the lowest mortality rate increased when age increased; over 60% of the dead trees shown signs of wind damages (Ozolincius et al. 2005).

In the drained peatlands from Northern and Central Finland a modeling study of the mortality of the individual trees was conducted (Jutras et al. 2003). In order to predict 5 year mortality of Pinus sylvestris and Betula pubescens, multilevel logistic models were issued. The tree mortality data was obtained from 2 successive measurements of the National Forest Inventory from permanent sample plots of pure and mixed pine-birch stands (Jutras et al. 2003). The mortality rate observed was (for 5 years) 2.73 % for scots pine and 2.98 % for pubescent birch. Stepwise logistic regression and multilevel model methods were applied when constructing the mortality models. The tree mortality was explained for both species by tree size, competitive position, stand density, species mixture, site quality (Jutras et al. 2003). These multilevel models showed the lowest systematic errors in the modeling data; they were tested with independent data sets and incorporated for testing in a stand simulator. Starting with different site conditions, a 100 year simulation indicated for these models a 72 % and 66 % higher total mortality rate for trees number , respectively, compared to previously used models (Jutras et al. 2003). These models will improve the predictions of the forest stands in the peatland areas from Central and Northern Finland (Jutras et al. 2003). The tree mortality processes have a major importance for different studies in the United States. The dead trees and the mortality factors have been monitored by USDA for a long time; a special attention to these issues is given by the US legal system.

In Georgia, for instance, a new approach to mortality models has been developed, represented by a new systematic tree mortality model and simulation integrating statistical models and geographical information systems (Meng et al. 2003). The method starts with variable preselection using multiple linear regression models and logistic models and adds spatial autocorrelation detection and random sampling (Meng et al. 2003). In order to reduce the influence of spatial autocorrelation, 3 random sampling methods were used and compared; the systematic random sampling (significantly reducing the spatial autocorrelation) was used for the final variable selection and model fitting (Meng et al. 2003). The data from Forest Inventory and Analysis for the State of Georgia was used and with the help of this method significantly better results are expected in future tree mortality studies (Meng et al. 2003).

An other study located in Georgia was focused on prediction of the survival of the individual trees (Rose et al. 2006). The data was collected from 146 loblolly pine permanent plots through 10 years starting with age 1; measurements were undertaken annually. The authors (Rose et al. 2006) consider that in the classical manner of the individual tree survival modeling the multiple sources of heterogeneity were not considered; because permanent plots are periodically measured, the data is interval-censored (the death of one tree is known to have been occurred between two measurements). This study adopts the complementary log-log function for modeling permanent plot interval-censored individual tree survival data, function that is derived from a likelihood function of a statistical model counting for interval-censoring (Rose et al. 2006). In this model, some silvicultural trataments have been taken into account, such as herbicide, fertilization, both of them and none of them for the experimental plots. The individual tree survival predictions were quite accurate, independent of the inclusion of random effects (Rose et al. 2006).

Natural disturbance regime and especially the wind regime was determined to be the most important mortality factor for trees in Illinois (Lin et al. 2004). The study focused on 3 fragments of deciduous forest, old-growth remnants from a larger forest in the past. Wind was considered to be the primary cause for the spatial patterns of dead trees both as forest fragment and individual tree levels (Lin et al. 2004). Wind-caused types of mortality and dead trees were expected to be increased at forest edges, on poorly drained soils, on windwards and in the proximity of gaps in the canopy. Wind-related mortality dimensions were determined by comparing spatial and temporal patterns of mortality and the characteristics of the dead trees killed by singular windstorms against all dead trees. In the forest fragments studied, 25 x 25 m quadrats were randomly located for sampling at forest edge as well as in the forests interior. Types of mortality (standing dead wood, snapped-off or uprooted) were recorded, as well as DBH and direction of fall for each tree (Lin et al. 2004). The same measurements were performed in two areas damaged by heavy windstorms. As result of the study, just poor evidence suggested that wind caused dead wood patterns; more evident was the domino effect in the individual tree level for spatial patterns (Lin et al. 2004). Tree mortality was much stronger related to preexisting gaps. The frequency was not higher at the edges, on windward aspects or on poor drained soils, as the preliminary assumptions showed. The study demonstrates the high complexity of the spatial patterns of the dead trees in the studied forest
fragen; the important domino effects demonstrated that the dead trees’ occurrence was not random, but caused by previous disturbances of the ecosystem (Lin et al. 2004).

In the tropical rainforests, much less accessible than the temperate forests, a new approach to tree mortality processes was issued: the quantifying of mortality using high spatial resolution satellite data (Clark et al. 2003). Little information exists about the mortality processes in the tropical rain forests. For studying this process, 1 m resolution panchromatic IKONOS and 0.7 m resolution QuickBird satellite date was used (acquired in 2000 and in 2002), to evaluate tree death rates in old-growth tropical rain forests of Costa Rica (Clark et al. 2003). A calibration factor was determined by ground inspection of the dead trees and used to calibrate data from satellite images. The annual death rate was determined to be 2.8 %. This study suggest many new ways in tropical forest ecological reserch, particullary on the tree mortality and canopy related issues (Clark et al. 2003).

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Probably the most challenging approach to tree mortality processes is the one that uses dendrochronological data, assuming the fact that the “living” vigor of the trees is accurately reflected in the increments and the trees with poor health status show specific low-increments prior to death. Ellaborate studies were undertaken in this field and a short review on these researches will be presented in the next chapter.

**Individual tree mortality analysis using dendrochronological methods**

Bigler and Bugmann issued a research project concerning the individual tree mortality modeling using dendrochronological data on Picea abies in Switzerland (Bigler et al. 2004a). The first part of the study focussed on the developing of mortality models based on the information contained by tree rings. The objectives of the study were the following: to determine the growth patterns –growth levels and growth trends– in different time frames in order to discriminate between dead and living trees; to optimize the growth variables in the logistic models and to assess the impact of competition on recent growth in linear regression models (Bigler et Bugmann 2003). Pairs of dead and living trees having the same diameter were sampled in 3 Swiss forests; the total number of viable samples came from 119 trees (Bigler et Bugmann 2003). The logistic model of mortality issued by the authors classified correctly 80 % of the trees to be dead or alive. More than 50 % of the recent growth’s variability could be attributed to the influence of competition for the living trees and only 25 % for the standing dead trees (Bigler et Bugmann 2003). The model was fit (and validated) using data from one of the sites (Davos) and validated using data from the other 2 sutes (Scatle and Bodmeren). In the 2 additional validation sites, the model correctly predicted 71 % and 81 % respectively of the trees’ status; the authors concluded that the model can be used to predict individual tree mortality through the subalpine Norway spruce forests from the Alps (Bigler et Bugmann 2003). Growth trends, as additional parameters to growth level, improve significantly the prediction accuracy in mortality models (Bigler et Bugmann 2003).

The second phase of the research introduces a new approach to tree mortality modeling based on different growth patterns of the tree ring series (Bigler et Bugmann 2004a). Classically, tree mortality functions included in forest succesion models are based on theoretical considerations and are poor predictors of the tree death’s timing; these theoretical mortality functions and the empirical mortality functions have not been sufficiently tested for precise prediction of tree death (Bigler et Bugmann 2004a). Many models were generated; their performance was tested by 2 criteria for classification accuracy and 3 criteria for prediction error. The 6 models with the highest performance classified correctly 71 – 78 % of all dead trees and 73 – 75 % of all living trees; 44 – 56 % of the of the dead trees were predicted to die 0-15 year prior to the true year of death. A maximum of 1.7 % of all dead trees and 5 % of all living trees were predicted to die more than 60 years prior to the last measured year (Bigler et Bugmann 2004a). The most reliable models from the prediction accuracy point of view were the models using relative growth rate and a short-term growth trend as explanatory variables (Bigler et Bugmann 2004a). These models successfully predicted tree mortality on 2 independent data sets from the Swiss Alps, which leads to the conclusion that they are sufficiently accurate and general for the given geographical zone (Bigler et Bugmann 2004a).

The performance of the theoretical and empirical mortality functions was compared in the last phase of the research (Bigler et Bugmann 2004b). The theoretical mortality functions considered for the study were the ones used in gap models; the empirical mortality functions were derived using logistic regression from growth patterns of tree-ring series (Bigler et Bugmann 2004b). Three of four empirical mortality functions had better performances on all 3 sites; 3 out of 4 theoretical mortality functions had worse performances. The 3 empirical mortality functions correctly classified 71 – 78 % of the dead trees (48 –72 % for the theoretical mortality functions) and 79 % of the living trees (49 – 64 %); 44 – 54 % (21 – 25 %) of the dead trees were predicted to die within 15 years prior to actual death and 0 – 2 % (7 –10 %) of the dead trees and 5 % (19 – 31 %) of the living trees were predicted to die over 60 years prior to
the last measured year (Bigler et Bugmann 2004b). The conclusion was that the theoretical mortality functions should be optimised for individual species, otherwise they are not appropriate to predict the time of tree death; a huge improvement in forest succession modeling will happen if in these models species-specific empirical mortality functions will be used (Bigler et Bugmann 2004b).

A dendroecological study concerning the regeneration patterns, demography and forest-use history in a Quercus robur and Fagus sylvatica mixed forest was issued in Northern Spain (Rozas 2003). The trees’ ages and the disturbances regime were reconstructed using dendrochronological methods; ages and locations of the trees were used to reconstruct tree establishment patterns (Rozas 2003). The study used also historical documents regardind the land use. As major outcomes, the forest structure was reconstructed from the past, the “generations” of trees (the so called cohorts) for each species were identified spatially and temporally and the regeneration patterns were reconstructed (Rozas 2003).

**Tree mortality studies in Romania**

Tree mortality studies are quite rare in Romania. The only extensive study was conducted by Turcu (Turcu, 2012) between 2009 and 2011 in one of Europe’s largest natural forests, the Izvoarele Nerei Nature Reserve, located in the South-Western part of Romania. The Izvoarele Nerei Nature Reserve covers 5260.3 ha, of which 4772.9 ha represent the strict reserve and 487.4 ha are buffer zone. The exact coordinates are 45°5' - 45°10' Northern latitude and 22°2’30’' - 22°6’40” Eastern longitude. It is situated on the Southern slope of the Semenic Mountain. This forest covers the upper basin of the Nera river. The geomorphology is very diverse, with accentuated slopes and narrow valleys, but in the middle of the reserve it is a smooth ridge, like a plateau. The lithological basis is represented by mica-schists and just a few granites (less than 5% of the surface). These kind of rocks, associated with the high slopes and the high fragmentation due to many small streams and the particular climatic conditions, lead to the genesis of brown acid soils, fertile and very favourable for beech. The site types and also the forest types are specific for the phyto-geographic zone of beech. The climate is temperate-continental with some mediteranean influences, such as short springs, long, warm and moist summers, gentle winter temperatures and huge quantities of snow. After the last ice-age, the colonisation of the Carpathian range with beech begun with the Semenic mountains, so the area represents a link between pre-glacial and post-glacial periods (Băndiu et al. 1995). The mean annual temperature is 7.5 °C in the middle of the reserve (4 °C at the top of the Semenic mountain). The annual quantity of precipitation is 900-1050 mm in the reserve, with a maximum of over 1300 on the top. These abiotic conditions, or site conditions (rock, geomorfology, climate and soil) are very favourable for beech. Due to this fact, the South-Western part of Romania is considered to be a home-country for the beech. The Nera virgin forest is considered to be a very stable climax forest (Tomescu et al. 2004–2006, Turcu 2012).

The most important characteristics of this forest are the following (Tomescu et al. 2004–2006, Turcu 2012):

- This size of the territory – approx. 5300 ha – is large enough for developing complex scientific studies, which take in consideration different aspects varying on gradients (climatic, soil, altitudinal gradients);
The composition – pure beech forest with only a few exemplars of Ulmus montana, Abies alba, Acer pseudoplatanus, Betula pendula, Populus tremula - indicates the fact that the site conditions are perfect for the beech species (climax situation);

A long disposition on the altitudinal gradient, from (650) 700 to 1400 m, with semnificative differences in the forest structure along this gradient, allows researchers to investigate the structure and dynamics of this ecosystem on different altitudinal levels;

The presence of all stages of the trees, from seedling to very old and big trees, assures the fact that no human intervention was made in the past. The dynamics of this forest was not disturbed by humans (except the incidental activities such as grazing and mushroom collecting, and of course the indirect influences, like global warming caused by human society). This presence of all stages of the trees offers good opportunity for research on forest dynamics;

Also related to the idea above, really impressive trees are present, with diameters frequently over 1 m and heights over 50 m; the standing volume can rise up to over 1200 m³/ha;

The presence of large quantities of deadwood (combined with the presence of really big trees) offers good opportunity for mortality process studies and for biodiversity studies (Tomescu et al. 2004-2006, Turcu 2012).

The individual tree mortality study was conducted in this virgin forest as part of a larger and long-term scientific investigation, covering the study of the forest’s structural characteristics and the forest dynamics. During 2004-2006, a network of 12 permanent sample plots of circular form and covering 1 ha each was settled in the Izvoarele Nerei Nature Reserve, located on 4 altitudinal levels (3 plots / altitudinal level, respectively): 800, 1000, 1200 and 1350 m (Tomescu 2004-2006, Turcu 2012). Within these plots, a complex methodology of assessing the forest structural characteristics was applied, a total number of 4531 trees were measured (mean value per ha: 378 trees); from this total number, 278 trees were dead at the moment of the first measurement (23 trees/ha, 6%) (Tomescu 2004-2006, Turcu et al. 2009-2010, Turcu 2012, and Stetca 2006).

All 12 plots of 1 ha each were re-investigated after a period of 5 years; the trees which died during this interval were inventoried and recorded, together with their cause of death, damages and specific conditions (Turcu et al. 2009-2010, Turcu 2012).

The mortality causes were divided in two major categories: natural or normal death and accidental death, with sub-categories: natural (normal) death: competition, senescence, competition+senescence; accidental death: unknown cause, wind, snow, other tree fall, lightining. The injuries of the trees were recorded for each tree: tree break (top, crown, stem break), uprooted tree, presence of rot inside, presence of trunk injury (wound), presence of fungi, presence of insects. The special conditions favourising or influencing tree death were also recorded: steep slope, superficial soil, location on the ridge – which induces wind break sensibility (Turcu et al. 2009-2010, Turcu 2012).

During the 5 year interval from the first measurement, the research showed 188 dead trees (16 trees/ha, 4%) (Turcu 2012).

There is a similar percentage of natural and accidental death – 49%, respectively 48%; the remaining is the “contribution” of mushroom harvesters, which can be considered as the third death cause besides natural and accidental causes. For the natural death, the most frequent cause is competition, the case of senescence is rare; the research team concluded that big trees are most often mechanically destabilized, which leads to accidental death by wind/snow breaks, etc. For the accidental death, 49% of trees are killed by other tree fall; a close percentage to that is caused by wind breaks. Snow breaks are quite rare to cause tree death, and only in one case – for one tree – it was impossible to determine the cause of death and it was described as “unknown” (Turcu et al. 2009-2010, Turcu 2012).

The presence of injuries and special conditions (percentages) for all trees from the 12 plots was studied. The most important of the injuries is the presence of fungi on 45% of the dead trees; the insects were seen only on 32% of the trees. The second major injury is the stem break – 44% of the trees; this injury appears in both cases of natural or accidental death. Top break (15%) and crown break (4%) are less frequent. Uprooted trees appear with a frequency of 16%, mainly from accidental causes – wind and other tree fall. The presence of rot inside the dead trees was observed in 23% of the trees and the presence of wounds on the trunk prior to death, which can have a weakening influence on the trees, were observed in 9% of the cases (Turcu et al. 2009-2010, Turcu 2012).

The special conditions of living, depending on the spatial positioning of the trees, have an influence on the tree mortality processes. The steep slope influenced tree death in 22% of the cases; the superficial soil was recorded for 3% of the cases and the ridge conditions influencing the mortality processes by creating wind sensibility were identified in 9% of the dead trees (Turcu et al. 2009-2010, Turcu 2012).

Conclusion

Tree mortality processes are among the less understood ecological processes from the forest ecosystem; to study these processes is a challenge and the natural forests are the most suitable for this kind of reasearch.
Due to the very low human intervention in these types of forests, the natural dynamics of the forest (the matter and energy cycles) are undisturbed and the mortality processes can be observed and interpreted as they happen naturally in a virgin forest with high ecological stability. Understanding the natural tree mortality processes is useful for issuing the best measures for a sustainable management of the cultivated forests.

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