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PREFACE

Challenged by the persistent drought and heat of the summer 2003 French and German forest scientists initiated an expertise “Drought 2003” involving scientists from different disciplines beyond the national borders. Besides visible, immediate or short-term impacts of this weather phenomenon on forests, the scientists expected further effects in long term. These effects are related to tree physiology, soil properties and nutrient availability in soils and trees, as well as to the root system reducing tree growth and vitality, having an impact on environmental, social and economic goods and services provided by forests. While numerous investigations have been undertaken on each of those topics, a synthesis about drought effects on forests taking different climatic scenarios into consideration is purposed by the expertise “Drought 2003” resulting in the international scientific conference on the topic “Impacts of the Drought and Heat in 2003 on Forests”, 17 – 19 November 2004 in Freiburg, Germany.

One of the aims of this conference is to present and discuss the first results of the multidisciplinary expertise, and to identify poorly covered fields that would require additional investigations. Indeed, this discussion will be an effective and important step of the expertise itself and a powerful contribution to the elaboration of the synthetic texts that will be the final product of the expertise. Every input to this process will be welcome! Among the expected outcomes of the conference and of the expertise are indeed an overview of the extent of damages and an improved understanding of the process that induced them. Gaps in our present understanding of the impacts of drought, heat and other climatic hazards on forest ecosystems, and areas and questions that would require additional research efforts need also to be identified. We wish this conference will be a further step towards these goals.

The conference proceedings consist of nine abstracts giving an overview of the expertise results. 37 further abstracts of oral presentations and 15 poster abstracts cover drought related topics considering meteorological aspects, forest monitoring, pests and diseases as well as fire and ozone, forest growth, water balance and tree physiology, soil processes, tree nutrition and root dynamics.

Freiburg, October 2004

The organizers:	François Charnet	Guy Landmann
	Horst Delb	Kaisu Makkonen-Spiecker
	Erwin Dreyer	Heinrich Spiecker
	Sandrine Landeau	Konstantin von Teuffel

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1.1 PART 1: IMPACTS OF DROUGHT AND HEAT ON FOREST FUNCTIONS

1.1.1 Heat and drought 2003: a climate analysis

M. Rebetez, H. Mayer, O. Dupont, D. Schindler, K. Gartner, J. Kropp, A. Menzel

Summer 2003 was exceptionally hot and dry in summer 2003 over Western Europe. The temperature analysis shows that the 3 months period June – July – August had never been so hot. June and August were hottest. On an average value, the hottest place was centred over a region stretching from France to Northern Italy, Western Switzerland and Germany. But the heat concerned a wider area, ranging from Spain to Hungary and from Iceland to Greece.

The drought culminated in August, but precipitation sums had been below average since the beginning of the year and stayed largely below the long-term normal values long after. Insolation was clearly above normal during all of the year 2003, while air humidity was clearly below normal.

Here we analyse the intensity of the heat and drought 2003 and compare it to normal and record values from previous years. Our perspective is that of possible consequences on forest ecosystems. We also put it into a long-term perspective within trends of observed climate change. Although the temperatures were clearly exceptional in summer 2003, they were less so compared to normal values of the turn of the 21st century than they would have been in the beginning of the 20th.

1.1.2 The potential of in situ- and remote sensing activities to address drought effects on forest ecosystems

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A general concern over the state of the environment and the impacts of global change on ecosystem services and functions has highlighted the need for high-quality, long-term-datasets for detecting environmental change. Such long-term observations are the basis for understanding long-term ecological interactions at multiple spatial and temporal scales. They are needed and called for by stakeholders to provide measures of baseline conditions and for informing decisions on ecosystem management and environmental policy formulation. This paper will evaluate the potential of existing in situ- and remote sensing activities to address drought effects on forest ecosystems.

1.1.3 Enhanced effects of forest pathogens promoted by drought: patterns, mechanisms and focus on a few case studies

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Disease development in plants, including trees, is the result of complex interactions between the host, the pathogen and the environment, where man can play a key role. Water availability, as a primary factor influencing both host and pathogen physiology, is of foremost importance in determining the outcome of host-pathogen interactions. Accordingly, drought has long been considered as a major factor involved in the origin and severity of several forest diseases and declines. The drought and heat wave of the summer 2003 in Europe has caused an increased concern about the potential effects of these extreme climatic events, which may become less unfrequent with global climate change.

This presentation will review the available knowledge on drought-forest pathogen interactions, with the aim of synthetising the current understanding of the processes and the possible implications for management strategies. In a first part, the different patterns and mechanisms of interactive effects of drought and pathogens will be presented. The second part will focus on a few case studies chosen for their importance from past studies (root pathogens and decline syndroms) or their relevance in the context of climatic change (thermophilic and water stress favoured pathogens such as *Sphaeropsis sapinea* on pines or *Biscognauxia mediterranea* and other canker diseases on oaks).

1.2 PART 2: IMPACTS OF DROUGHT AND HEAT ON FOREST FUNCTIONS

1.2.1 Ecophysiological response of forest trees and stands to drought and heat

N. Bréda, H. Rennenberg, A. Granier, B. Longdoz, H. Cochard, B. Köstner,
S. Rambal, D. Le Thiec, R. Matyssek

Drought (basically soil water depletion) induces a reversible regulation of gas exchange through stomatal closure: both water consumption and carbon assimilation are reduced, but not necessary in the same proportion, so that water use efficiency, i.e. the ratio between both fluxes, also changes as drought increases. This degree of water loss control is highly variable among species, and examples of the diversity of stomatal response will be illustrated, including coniferous species, temperate and Mediterranean broad-leaved trees. Nevertheless, when scaling up from leaf to canopy, one may observe a lower diversity of canopy conductance changes. In the same way, whatever tree species stand transpiration decreases when soil water deficit drops below 40% of soil extractable water. This apparent loss of diversity in responses between leaf/tree and canopy/stand scales will be discussed. In any case, the protective role of stomatal closure, preventing both xylem embolism and ozone damages, will also be discussed.

Water relations in trees are changed during drought, and an analog to Ohm's law is the classical way of analysing such changes. Sap flux density decreases as drought increases, and leaf water potential drops. The hydraulic conductance from the soil-root interface to the leaves decreases. A large research effort has been devoted to the description of vulnerability to cavitation and of hydraulic architecture of several tree species. The distribution of resistances to water transfer within the shoots has been mapped. Only few studies included the root resistance and even less quantified the soil-root interface increase of resistance as the soil dries out. The soil to leaf water transfer model was recently re-visited by Sperry *et al*. (2002), who proposed a conceptual way to link both hydraulic architecture in trees and the soil-root resistance, which is the largest as demonstrated by modelling approaches.

Forest tree response to heat is much less documented, and the reasons for this may be that (i) such events are more exceptional than drought episodes; (ii) trees are highly resistant to temperatures up to 40°C; and (iii) high temperatures frequently occur during drought, which impact is largely predominant. A recent review of experimental data on photosynthesis responses to high temperatures revealed the occurrence of a large inter-specific diversity and acclimation potential at several levels of the photosynthetic process. Surprisingly, quite high and similar temperature optima were compiled for most of the species. In the context of the 2003's heat wave, the question is then to quantify the increase of leaf temperature in the presence to the pre-existent stomatal closure due to drought. Such estimates will be presented and the consequences of leaf temperature increase on photosynthesis and tissue mortality will be discussed.

Finally, the long term consequences of photosynthesis limitation, xylem embolism, and temperature damage will be addressed and the most recent hypotheses explaining the time-lag in physiological responses and the ability of trees to recover or not in the long term, will be discussed.

1.2.2 Impacts of drought and heat on tree and forest growth – A synthesis of studies on short-, medium- and long-term effects observed under temperate climatic conditions –

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Shortage in water supply is the most widespread limiting factor for tree growth. Trees have developed various strategies to mitigate or avoid drought stress. Stress responses range from short-term physiologic accommodation, to medium-term modificative and long-term genetic adaptation. Depending on strain intensity small effects might be recognized only as weakened vitality being completely reversible. Whereas severe disturbances might lead to plastic shifts associated with irreversible organ and tissue damages and increased mortality.

Based on retrospective observational data on forest growth taken from selected case studies as well as from systematic surveys the role of droughts and heat in the past is analysed. Special emphasis is laid on medium- to long-term effects on growth. Historic drought events are compared with the 2003 drought, and the validity of the historical analogues concept is critically discussed.

Only very few data are available which already cover the growth in the year 2003. High resolution data from dendrometer measurements on spruce and beech sample trees on selected sites in different elevations give insight in the specific magnitude and also intra-annual development of radial growth in 2003 as compared to preceding years.

The presented synthesis focuses on the following questions:

(1) To which extent has forest growth changed in 2003?
(2) What are the most affected forest tree species?
(3) What are the most affected sites?
(4) What are the most affected forest stands?
(5) What conclusions can be drawn for tactic and strategic forest management to decrease risk and increase drought-resilience and -stability of forest ecosystems in the future?

1.2.3 Drought and soil processes

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Soils are the space for transport processes between atmosphere, lithosphere and hydrosphere as well as the chemical and biological reactor for the transformation of chemical elements, material and/or energy. They serve as store for organic matter and exchangeable elements, which are the equilibrating buffer for nutrition and water supply for trees and define the filter- and buffer capacity leading to a purification of the seepage water. Drought is an extreme variation of weather conditions, which leads to severe disturbance of all biologic populations being adapted to a water regime with low temporal change around the site specific water availability. The items of this presentation are direct edaphic implications of water storage in the soil as well as more indirect after-effects of a drought period. Therefore the themes which will be treated will be subdivided into 3 topics:

Dynamics of soil water storage, direct effects of drought and heat

Besides the soil water storage capacity, its exhaustion by drought and the mean matrix potential in the rooting zone, the delay of recharging the soil water store at different soil types and soil textures is a factor, which defines the site specific effect of drought on trees and soil biota. Matrix potential will be a tool to predict the intensity of drought stress. It will be discussed whether the lack of water availability and/or high temperatures or both are the main stress -inducing factors for trees. Especially the response of trees in terms of fine root turnover and mycorrhiza associated root tips will we discussed. In order to derive such information not only for individual sampling plots of monitoring networks or ecosystem studies rather than for whole landscapes, the parameterizing of pedotransfer function is necessary in order to assess soil physical status parameters for whole landscapes. Model results on different capacitive and intensive parameters of the water balance will be presented at landscape level using examples from the level II network of Bavaria and Baden-Wuerttemberg, which were among the most affected states by the drought of 2003 in Germany. From the material of Bavarian environmental monitoring, examples for quantifying tree reactions on drought (as defined by a lack of plant available soil water) will be given in terms of needle loss and stem growth patterns.

Mineralization of organic matter

Mineralization pulses can be generated by drought periods, because during the drought over-proportionally high amounts of dead fine root material accumulates in the rooting zone. During the drought period or during the following rewetting, NO_3- and DOC-pulses are subsequently occurring in the seepage water. By means of data from individual ecosystem studies the identification of drought induced leaching pulses will be done. Ideal side conditions for this purpose are given in “roof experiments” like the EU-EXMAN project or in ecosystem studies with long time series. In an approach of differential diagnostics, the effects of drought will be evaluated in combination with stand characteristics like e.g. tree species composition, spatial stand structure etc.. This evaluation will be performed using data from Bavarian Level II plots and from the Conventwald ecosystem study.

Drought and tree nutrition

Tree nutrition and its variation in time depend substantially on water supply and thus are influenced by drought. The macro – element, which mostly is influenced by drought, is potassium. At loamy sites with a normally high potassium stock in the bulk soil, trees suffer from frequent potassium shortages after drought periods. This is due to the structure of loamy soils where the potassium is very good available in the inner parts of soil aggregates but not at aggregate surfaces. There the potassium supply breaks down, when the recharge from the inner parts of the aggregates is interrupted by drought. Also the equilibrium / disequilibrium between potassium- and nitrogen supply is of interest in the context of drought. The induction of specific nutrient deficiencies after drought periods often is linked to a die – back of fine roots or to restricted root growth, which can been demonstrated by the results from “ingrowth core” studies.

1.2.4 Drought and forest biodiversity

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Strong alterations in forest biodiversity have been an immediate effect of the 2003 drought event. Current state of knowledge suggests that a decrease in ecosystem productivity and an increase of mortality are the most general consequences of drought. Some ecosystems seem to be particularly sensitive, with disturbed ecosystems often being less stable than undisturbed systems. Concerning differences between taxonomic groups, competitive species, species adapted to cold and wet conditions as well as species with low reproduction rate and/or mobility are particularly sensitive. Mechanisms such as avoidance (e.g. via moving to more protected areas) and resistance (e.g. via modifying transpiration rate) further modulate the species-specific response to drought. Long-term consequences of drought are difficult to predict. There is evidence, however, that recurrent periods of drought may even increase biodiversity by reducing competitive interactions. Moreover, the fact that responsive species seem to recover more rapidly than drought-resistant species may induce considerable shifts in community composition. Consequences of drought on ecosystem functioning and its relationship to biodiversity are poorly understood. They are probably closely related to the many indirect effects of drought, including increased fire frequency or a higher level of pathogenic infection. Such effects must be evaluated in the context of other drivers of global change. Considering the high probability of drought frequency and intensity to increase in the near future, interdisciplinary research initiatives on this issue are urgently needed. These should apply a variety of approaches (experimental, observational and modelling) for both better understanding the complex environmental effects of drought and devising management options.

1.2.5 Socio-economic impacts of natural or human threats on the forest sector: some results of the French German expertise on drought and heat 2003

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All sorts of damages follow phenomena due to climate events or human activities such as heat, drought, frost, storms, diseases, pollution or global changes. They might occur immediately or in the future, directly or indirectly. They might be visible or not, certain or less predictable, concentrated on a specific area or more diffused. They concern not only forests but also forest-related activities and uses. They are influenced by the context in which they take place and by both prevention (ex-ante) and mitigation (ex-post) policy measures. All these issues have to be analysed on an economic point of view in order to assess the actual consequences of such phenomena. This assessment helps to define the right strategies and policies, then to evaluate decisions. However, it can only be rigorously drawn with delay. Consequently, past experiences are very valuable to prepare this work, foresee some impacts, adapt efficient methods, estimate parameters and, finally, point out remaining questions that could necessitate additional researches.

From the analysis of existing literature, widely published or not, most of socio-economic impacts of natural or human threats on the forest sector have been studied together with associated evaluation methods in the frame of the French German expertise on drought and heat 2003. They comprise direct consequences on forests, direct and indirect consequences on forest activities and uses, feedback effects on forests, prevention measures, background influence, and mitigation measures. From this analysis, a first assessment of the main consequences of drought and heat 2003 is possible. Recommendations for risk management can be provided (prevention measures). Mitigation measures are also discussed. Later on, recommendations for future monitoring and research result from this analysis.

1.2.6 Can foresters better cope with severe drought episodes?

Bernard Roman-Amat

ONF, France

Faced with more frequent episodes of severe drought, forest managers have to improve their knowledge and their practices.

In forests that went recently through such an episode, reaction involves (i) appropriate methods to decide which trees have to be harvested, (ii) efficient commercial ways to sell those trees, (iii) development of treatments that will limit epidemic-size pest invasions, (iv) replanting damaged young stands.

On a broader scale, more emphasis certainly has to be put on preventing the foreseeable effects of severe drought episodes. This implies primarily the replacement of stands stocked with non-adapted species, and a greater attention put on favouring on each site the species that are well adapted to it. As a result, the area of sites on which the production of timber is not the first priority could increase. Specific silvicultural treatments aimed at increasing the resistance of forest stands to drought also have to be extended; for instance growing high forests with lower than usual LAI (Leaf Area Index), and on shorter periods of time.

Reducing the impact of severe drought episodes seems to be compatible with some other aims of forest management, such as increasing resistance to wind, preventing forest fires or improving the flow of water downstream. However, the techniques used might also result in lowering the per-area timber production, and in increasing the year-to-year heterogeneity of wood, thus possibly modifying the parameters of economic profitability of forestry.

Overall, the foresters seem to have the right techniques to cope with the emerging new situation of more frequent episodes of drought. However, some large scale consequences of their likely reactions look important. The area of productive forests could be reduced; forests where timber sales are limited or absent, and where foresters have to rely on other sources of income, will expand. In productive stands, a possible reduction of income would have to be matched by a lowering of management costs.

2 PARALLEL SESSIONS

2.1 SESSION A – METEOROLOGICAL ASPECTS, FOREST MONITORING

2.1.1 A 500 year pheno-climatological view on the 2003 heat wave in Europe assessed by grape harvest dates

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In 2003, Europe was affected by a record-breaking heat wave in summer, which is statistically extremely unlikely. However, there are indications that comparably anomalous warm summers could have occurred in the more distant historical past. Dates of grape harvesting in Western Europe, starting in 1484, allow a concise assessment of growing season temperatures. The maturity of grapes strongly depends on growing season temperatures, and 84% of the year-to-year variability is explained by April to August temperature. When reconstructing the growing season temperatures by these historical grape harvest dates, the heat wave of 2003 stands out as an extreme, not only for the instrumental period, but also during the preceding 500 years.

2.1.2 The regime of precipitation in 2003 in Romanian Forests

Ion Barbu, Ionel Popa

Romania

The results are obtained in the frame of the National Research Project “Drought Risk Monitoring In Romanian Forests” - started in 2001 – which tries to estimate in real time the risk of drought in the whole Romanian forest found, with the objective to assist the management decisions for each Forest Direction and Forest District.

The authors present on the ground of the measurements network in the plots located in 400 forest districts the monthly and seasonal variation of rainfall parameters registered in 2003 in Romanian forests. On the ground of modern computing and viewing systems (GIS, geostatistics) the real data concerning the total rainfall and effective rainfall (precipitation – evapotranspiration) are transformed in indicators of drought (relative precipitation fall - %) deficit / exceeding of rainfall and standardized index of precipitation (SPI). This index measures how far the real rainfall is (for the last 1 … 12 month) from the mean value (for the same period) in standard deviation units (SD). Eg. SPI = -2 means that the rainfall are 2SD les than the mean value, and SPI = 2 mean that rainfall are 2 SD more than mean value of rainfall in the analyzed period. Using this Index, 5 level of drought intensity and 5 level of exceeding of rainfall can be viewed and mapped. According with these indicators, an accurate evaluation of monthly, seasonal and yearly parameters are analyzed for different regions of Romania.

In 2003 the winters were rich in precipitation in Eastern, South eastern, Western and South western regions of Romania and normal in the rest. Spring was moderately droughty (SPI = -1 … -1,5) mostly in the North, South and East Romania and very droughty (SPI = -1,5 … -2) in north western and north-eastern regions.

Summer of 2003 was very droughty – extremely droughty in SE, W, NW and Central regions and moderately – very droughty in other regions.

Autumn was very wet in south regions and near normal in the rest. In the growing season the rainfall regime in 2003 was extremely droughty very droughty in the western regions and central Transylvania and moderately droughty very drought in the eastern regions.

For the whole year 2003 the rainfall regime was excessively dry in NW and central regions, very dry in N, NE and W regions and moderately dry – near normal in southern and eastern regions of Romania. Suggestive maps and forecasts concerning the soil water regime are presented too.

2.1.3 10-Year Time Series of Climate Parameters and Ozone Flux and their Effects on Growth of Beech and Spruce in Rhineland Palatinate

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Time series from year 1990 to year 2003 of meteorological data from six forest climate stations of the federal state Rhineland-Palatinate (ZIMEN-Messnetz, Waldmessstationen) are evaluated.The main attention is directed to the parameters air temperature, vapour pressure deficit, radiation and ozone concentration to assess risk of ozone effects. The available half hourly means of meteorological parameters are used to calculate leaf conductance and to estimate the ozone flux in beech and spruce forests with the EMBERSON (2000) Model (used by EMEP and UNECE). With these calculations it is possible to characterize the stomata opening and the influence of meteorological parameters to gas exchange of beech and spruce. Furthermore, it allows a spatial and temporal analysis of meteorological effects on potential gas exchange. The results are compared to drought periods defined by soil water content of level II stands near ZIMEN climate stations.

In 2003, the opening of stomata and therefore the potential gas exchange was reduced extremely by high vapour pressure deficit during a drought period in July and August. When relating calculated ozone fluxes of the extreme drought year 2003 to calculated ozone fluxes of a 10-year period (1990 – 2003), 1992, 1995 and 2003 appear as years with similar high ozone stress. Periods with high ozone concentrations are always hot and dry, usually resulting in drought stress.

The time series of meteorological input parameters, calculated ozone flux as well as AOT 40 and maximal permissible ozone concentration (MPOC, compare KRAUSE et al. 2002) are compared and correlated with radial growth of stems and fructification index of forest stands near ZIMEN stations. High ozone fluxes correspond with decreasing growth parameters. Correlations between indicators for ozone stress and growth, shifted by a time period of one or two years, gave nearly similar results than correlation within the same year.

2.1.4 Drought 2003 at a Scots pine forest

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In the year 2003 the weather at the forest meteorological experimental site Hartheim, located in a Scots pine (*Pinus sylvestris*) forest in the Upper Rhine Valley, was exceptionally warm and dry. Monthly mean values of global irradiance and air temperature surpassed the monthly mean values during the period 1978-2002 especially in June and August. The annual precipitation sum 2003 was below the average precipitation sum during the period 1978-2002. Beginning with June, as a result of the intensive global irradiance and the high evapotranspiration rates, the soil water content at the forest meteorological experimental site partly decreased below the permanent wilting point. The effect of the weather 2003 on the Scots pine forest water balance is simulated with the hydrologic model BROOK90. Compared to the mean soil water availability during the period 1978-2002, the soil water availability in the vegetation period 2003 was clearly reduced. As an indicator of temporary water shortage for the Scots pine forest the modelled ratio of actual and potential transpiration (transpiration index) is used.

Since the edaphic conditions (no root access to groundwater) lead to periodic water shortage at the forest meteorological experimental site Hartheim, the modelled effects of the weather 2003 on the Scots pine forest water balance are exemplarily supplemented by measurements during 1993 and 1994 on water relations of Scots pine at the leaf- (porometer measurements), tree-, and forest-canopy level (sap flow measurements).

The results provide basic information for the parameterisation of stand gas-exchange models for Scots pine including periods of restricted soil water availability. Further, the findings confirm the adaptive response of Scots pine to drought, which enables the species to exist along a broad environmental gradient.

2.1.5 Impact of the heat and drought 2003 on ecological parameters and growth in Austrian forests

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In Austria the weather conditions in summer 2003 were extreme as well as in many parts of Europe. It was the hottest summer since the beginning of regular measurements. The average temperatures of the summer months, especially in June and August, were above the long-term values. In June the temperature was between 4 and 6°C and in August about 4 to 5°C higher than the long-term value.

The situation was aggravated by a lack of precipitation. In June and August many regions in Austria received precipitation amounts only between 25 and 75 percent of the long-term value. In some regions in the eastern part of Austria even less than 25 percent were reached. Only in July most part of the country received normal precipitation. Such extreme conditions influenced nearly all ecological factors within a forest stand. Here we show results of our measurements on permanent observation plots of the Austrian Federal Office and Research Centre for Forests (BFW).

The extreme air temperatures in June and August caused high temperatures in the soil. The extent of this warming differed according to soil type and the forest stand. High temperatures together with low amounts of precipitation let the soil moisture drop to a very low level and in some cases the wilting point of the soil was reached. For this reason it became very difficult for the trees to get enough water from the soil and the water consumption was strongly restricted by the closure of the stomata. This is shown by results of our sap flow measurements.

As a general consequence of these stress-factors the growth of the trees was restricted. The consequences on growth were observed on some trees equipped with permanent girth bands. Three tree species at three sites were assessed and a distinct pattern of growth was found. While a marked reduction was found on spruce at lower sites, the effects were by far less on beech nearby at the same altitude. Spruce and larch at higher elevation showed only small growth reduction in 2003 in comparison to the year 2002.

2.1.6 Spatial Modeling of Drought Using Artificial Neural Networks

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Periods of severe drought place tremendous stress on forests and other vegetative communities. Such events typically occur across a broad spatial scale with some degree of local variability. Assessing this local variability can play a key role in understanding the specific impacts of drought events on forest health; however, we seldom have spatially explicit measurements of environmental conditions in forests. While remote sensing is one means of assessing the spatial extent and variability of environmental conditions, it is often difficult to put such measurements in a historical context as the period of record is so short.

Many places around the world have long time series of routine weather observations (temperature and precipitation) that could be useful in evaluating historic drought conditions. This network of observing stations is very irregular with high concentrations of weather stations near heavily populated areas and relatively few in remote forested areas. The key to using this irregular network of observations to examine spatial patterns in drought is the method of spatial interpolation. Artificial Neural Networks (ANNs) provide a highly adaptive nonlinear method for performing this spatial interpolation.

In this study, an ANN is constructed to spatially interpolate temperature and precipitation. Network inputs include location (latitude and longitude), topography (slope, aspect and elevation) and land cover type. The ANN derived temperatures and precipitation are then be combined to form a simple drought index useful for wildland fire control planning, the Keetch Byram Drought Index. The result will be a 5 kilometer grid of estimated drought conditions across a large geographic area, France and Germany.

2.1.7 Bavarian Forest Ecosystem Monitoring Program: a useful tool to analyze the drought 2003 and its effects on forests

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The Bavarian Forest Ecosystem Monitoring Stations Programme was build up as a result of the discussions within the theme of forest dieback. As a part of the European intensive monitoring program (Level II) its primary purpose is the continuous observation and documentation of complex physical/chemical and biological processes in forest ecosystems under present and future environmental conditions, and its impacts on the ecosystems. Factors of influence are measured within the forest stands at the same locations where the effects are observed. The range of the Bavarian programme exceeds the minimum requirements of Level II clearly. Therefore it encompasses the complete set of environmental factors and state variables. All of the 22 Bavarian plots contain automatically meteorological observations. Soil water content is measured directly at 6 locations in different layers using TDR technology. This enables an observation and evaluation of the effects of the last year drought and heat on forest sites in Bavaria. The most important results of the last year will be summarized briefly.

Extreme temperatures were measured last summer even in the large forest areas marked by a more balanced climate than in open land. Average air temperature during the vegetation period 2003 (May until August) exceeds the normal values up to 5 K. Also the global radiation was clearly increased, while the total amount of annual precipitation is nearly 40 % lesser than the long term average, much lesser in the vegetation period. By the measurements of the soil water content using the TDR technology it was stated that the soil water reservoir emptied rapidly at many forest sites. Physically deterministic water regime modelling figured out a complete consumption of plant-available water contents at many plots until August and September 2003. Therefore trees had to reduce the transpiration substantially. Since the last year was simultaneous a full mast year at many stands, the drought 2003 met the forests particularly hard. In the context of the phenological observations drought damage announced from middle of July up to October from almost all plots in Bavaria. Green, dry leaves and needles on the forest floor were particularly remarkable. Measurements of litter fall confirm the prematurely throw off of leaves. By weekly diameter measurements it became evident that radial growth decreases in 2003 up to 40 per cent in comparison to the previous year. In addition branches of the spruces were strongly underdeveloped, fruits were partly diminished and the needle yellowing of spruce was more frequently than in the previous years. Deciduous trees and pine showed less strong reactions.

2.1.8 Effect of water deficit on tree growth, leaf discolouration and litter fall in Swiss ICP-Forests level II plots

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On 15 out of 17 Swiss ICP-Forests level II-plots stem diameter radial growth had been measured on 10 stratified randomly selected trees of each main tree species in the years 2002 and 2003. For several years on 8 plots, litterfall has been measured in four week intervals and on all plots tree transparency and leaf colour of the tree foliage has been observed recorded in the summer near to the on-line meteorological station for several years. In September 2003 crown transparency and discoloration was reassessed on 6 plots with deciduous tree species. The precipitation amounts were extraordinary low on some of the plots during summer 2003 ranging between 50% and 80% of the long-term average. Furthermore we observed that tree radial growth was reduced compared to other years on some of the plots.

We used the meteorological data to determine the water deficit by a) simply subtracting potential evaporation and transpiration from these precipitation amounts for the months March to August and b) by using a soil water balance model that incorporated the soil water holding capacity and modelled actual evaporation and transpiration. Both water deficit measures were compared with the stem growth and litter fall data. We found a close relationship between the obtained water deficit values in 2003 and the ratio between the radial growth in 2003 and the average of the radial growth in the moist year 2002. This relationship was applicable for all tree species and plots. On plots with high water deficit in 2003 tree growth was significantly reduced in comparison to growth in 2002, while on plots with no or little water deficit tree growth was in most cases not significantly reduced or even increased. By mid-summer tree transparency had not increased. Results from the Level-II site Vordemwald show that summer litterfall of *Abies alba* was higher than in previous summers, which might be an exception.

2.2 SESSION B – PESTS AND DISEASES, FIRE, OZONE

2.2.1 Direct and subsequent damages caused by the drought 2003 in the forests of Baden-Württemberg

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On the total surface of Baden-Württemberg much higher-than-average temperatures going together with low precipitation in comparison to the long-termed values combined with a high solar radiation occurred in 2003. Consequently two impacts of drought and heat on the forests appeared: on the one hand trees of almost all species and age suffered from insufficient water supply leading to an early loss of foliage or, when water supply collapsed, to the death of the trees. The drought caused die back of trees continues until now.

On the other hand the populations of harmful insects, mainly bark beetles *(Scolytidae*), exploded within a short time and caused a bigger quantum of dead trees than the drought itself.

Since the drought and heat of 2003 mainly spruce is attacked by *Ips typographus* and *Pityogenes chalcographus*, but also fir, pine and larch are affected by bark beetle damage. Surprisingly also beech trees are killed by bark beetle attacks (see DELB), while oak is almost not affected by bark beetle damage so far.

Moreover harmful moths (*Lepidoptera*) like the gypsy moth (*Lymntria dispar*) were favoured by the drought and heat of 2003: in the warm regions of Baden-Württemberg the gypsy moth populations were seen in 2004 to be distinctly higher than in 2003. In some oak stands a total defoliation has already taken place in summer 2004.

In order to minimize damages caused by harmful insects and fungi, our forest protection group gives advice to the forest staff and the forest owners concerning control strategies. In addition to this, recent studies have been initiated in order to modify and to improve the known strategies of integrated pest management.

2.2.2 Range expansion of the pine processionary moth: the effects of the high temperature of the summer 2003

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Many insect species and phytophagous insects in particular, are expected to show relatively rapid responses to the rising temperatures by shifting their geographic range boundaries upward and northward. The winter pine processionary moth, *Thaumetopoea pityocampa*, offers a possibility to test for the effects of the increase of temperature on an insect population over a wide area of the Mediterranean basin and southern parts of Europe, where it is the most important pest of pine forests (*Pinus* spp.). In the last three decades a substantial expansion of the outbreak area has taken place both latitudinally and altitudinally, resulting in outbreaks in areas previously largely unaffected by the insect. The case deserves special interest for the implications it may have on the management of European forests and plantations, as well as on ornamental trees. The pine processionary moth is of particular concern also due to the public health risk (contact dermatitis) associated with the urticating hairs produced by late-instar larvae. We report about the effects of the high temperature of the summer 2003 on the moth dispersal and the consequent colonization of extreme sites in the Alps and in the Paris Basin. The further expansion observed in the winter 2003-04 can be explained by higher dispersal of female moths in the warm nights of June and July 2003. These insects are generally characterized by low mobility but in the summer 2003 they expanded as much as they did in the last two decades. Some of the expanding populations have been monitored by genetic markers and it has been shown that most individuals of the core populations are participating to the expansion. The sampling carried out in the spring 2004 showed that colonies have been successfully established in the extreme sites, posing new problems for the insect management in a wider area.

2.2.3 Infestation of bark-breeding beetles on beech as a consequence of drought and heat

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Following the extreme drought and heat of the summer of 2003 an unusual infestation of bark-breeding beetles on standing European beech (*Fagus sylvatica* L.) has been detected in many areas in the Southwest of Germany. The main agents are the small beech bark beetle (*Taphrorychus bicolor* Hrbst.) and the buprestidean beech agrilus (*Agrilus viridis* L.). The infestation is often apparent at the edges of stands which originated from wind damages, as in the 1999 “Lothar” storm. In contrast to the infestation of beech bark beetle, which had already been observed in autumn 2003, the infestation of the beech agrilus, with very few exceptions, did not emerge before 2004.

Damages caused by outbreaks of beech bark beetle following a drought year are known, i.e. from Hessen in 1976. Without an increased susceptibility of the beech trees, as it was the case in the current extreme drought year 2003, the beech bark beetle is apparently not of relevance to forestry.

As it is known the beech agrilus occurs in outbreaks after years of drought and heat. Around 1950 a massive outbreak which mainly affected older beech trees occurred in Middle Europe. According to experiences gained at this time, beech on shallow sites, on edges with a high ground exposure to the sun and on southern exposed steep slopes are especially endangered.

Due to the current alarming infestation by bark breeding beetles, a study area was set up at the end of 2003 to asses the objective danger and effects of these beetles on beech. The investigations take into account the future weather conditions and vitality of beech stands.

Aside from the monitoring of swarming time and dispersion process, the question is asked whether old infested beech trees located at the edge of the wind throw die as a consequence of the infestation. In addition, the risk of these trees as a source of infection to the nearby closed beech stand should be assessed.

Based on the results of these studies, the present strategy and the recommended measures to limit wood destruction and to reduce population density in order to secure beech forests will be enhanced. In the same way silvicultural and economic consequences should be determined.

2.2.4 *Armillaria* Infection Following Drought in Forest Stands

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At present forest enterprises experience unusual economic damage by *Armillaria spp*. on hundreds of hectares. In spruce stands especially in the middle Black Forest and in the Swabian-Frankish forest the specific mycelial fans of *Armillaria* invaded the cambial layer from the roots to the stem base. This invasion became evident for the first time in spring 2004 when bark was removed accidentally during logging damages. A previous infestation by bark beetles was not given. It could be shown, that the mycelial front invaded into the white healthy cambium. This indicates the aggressive character of the fungus. Before bud break, no symptoms in the crown were visible. At this time the infestation could be overlooked easily so far. But most the trees were already bound to die due to girdling by the fungal mycelium.

Regarding the reasons for this outbreak of *Armillaria* it can be stated, that the fungus may be present in most of the forest stands, probably due to some sylvicultural aspects. The fungus can outlast on stumps over many years and spread from there with its rhizomorphs through the forest soil. Disposition to root infection was given by the extreme drought of the summer 2003. *Armillaria* rhizomorphs are able to grow in the cambial layer more than 2 m per year. Therefore, it can be concluded, that the root infection may have taken place after rewetting of the forest soil in autumn 2003.

Silver fir as well as Scots pine are at least as sensitive to *Armillaria* spp. as spruce. Also oaks are endangered by *Armillaria* after drought stress. For these tree species the infestation may become evident with delay. Some consequences of the fungal infection for the timber in terms of storage and decay will be discussed.

2.2.5 A meta-analysis of forest pest and disease response to water stress

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Drought is often viewed as a main causal factor of phytophagous insects and pathogenic fungi outbreaks in forest ecosystems. However, the experimental evidence that support the hypothesis of higher susceptibility of water-stressed trees are still controversial. To provide objective results concerning the role of water stress in pest and disease dynamics in forest, we performed a meta-analysis of published studies that met the following criteria: stress treatments had to be compared to an appropriate control, stress intensity had to be rigorously qualified using predawn leaf or xylem water potential, and statistical data about tree damage or pest performance had to be available. With the meta-analysis we could evaluate the sign and the magnitude of the response (effect size) to water stress across studies. In order to test the effect of drought intensity, we further computed a water stress index (WSI) as the ratio of the water potential recorded in control and stressed trees ($WSI=1-WP_{control}/WP_{stress}$). Both damage and pest performance were lower (negative effect size) in slightly drought stressed trees ($WSI<0.3$) than in control trees and higher (positive effect size) on moderately stressed plants ($0.3<WSI<0.7$). Pest performance then decreased (negative effect size) on severely water stressed trees ($WSI>0.7$) whereas tree damage remained high. The importance of this result is that the response of forest insect and fungi performance to water stress is non linear, depending on stress intensity. Similar parabolic response patterns were found irrespective of the type of biotic agent (insects vs. fungi), and the climate (temperate vs. warm). By contrast, young (<5years) and xerophilous trees appeared to be more drought resistant than mature and mesophilous trees respectively, as their parabolic response curves were shift toward higher stress values. Considering moderate water stressed trees, where damage and pest performance were always higher than in control trees, we found a significant effect of the tree phylum and the insect guild: broadleaved species were more damaged than coniferous and phloem feeders performed better than leaf feeders. These results are discussed with reference to the main theories that relate water stress to changes in plant physiology, namely the plant-stress and the growth-differentiation balance hypotheses.

2.2.6 Analysis of the forest fire damages in the year 2003 through the European Forest Fire Information System (EFFIS)

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European Commission - JRC

This article describes the evolution of the 2003 forest fire campaign as monitored through the European Forest Fire Information System (EFFIS) (San-Miguel-Ayanz et al, 2003). The year 2003 was recognized as one with the hottest summer period in the last centuries (Luterbacher et al, 2004). Temperatures were above average temperatures for a long period starting in early June. The high temperatures and absence of rain in the Mediterranean region caused the desiccation of the vegetation which elevated the risk of forest fires across the EU Mediterranean region. Although forest fires are a common phenomenon in the EU Mediterranean region, their number and intensity in the year 2003 had no precedent. The figures available for the EU Mediterranean region for the number of fires and the area burned by these show that the year 2003 has caused the largest forest damage in the last decade. A total of 740379 ha were burned only in the EU Mediterranean countries. This figure has only been topped by the 983447 ha burnt in 1985 within the last 24 years for which statistics are available (European Communities a, 2004). However, fires not only destroyed forests but also human lives. Over 40 casualties were reported in direct connection with forest fires in the summer of 2003.

The summer of 2003 started with above-average temperatures all over Europe. These produced large fires in June and July. At the end of July very large fires affected the south of France. However, the meteorological conditions worsened at the beginning of August to conclude the worst forest fire season ever in Portugal. Intensive fires started simultaneously in Spain and Italy. This evolution of the 2003 forest fire season was monitored through the European Forest Fire Information System (EFFIS) and the Monitoring and Information Centre of the European Commission in Brussels in order to coordinate international collaboration in forest fire fighting.

EFFIS provides, since the year 2000, fire risk forecast maps for the European territory on the basis of weather forecast models. It operates from the first of May until the end of October and computes fire risk using six different meteorological fire risk models. These are distributed to the forest and civil protection services in Europe through Internet. The mapping of large fires and the assessment of fire damages is performed in EFFIS at the end of each fire campaign (Barbosa et al. 2002). However, in 2003, given the severity of the forest fires, the evaluation of forest fire damages was carried out through the processing of daily TERRA and ACQUA satellite imagery. Reports on the fire situation were produced for all the EU Mediterranean countries. In some cases, updates of these reports were produced several times during the season. For instance, 3 reports were produced for Portugal and 2 reports for France to update damages as large fires occurred (European Communities b, 2004).

2.2.7 Heat, Drought and Wild land Fires in Eurasia in 2003

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During the Northern Hemispheric Summer of 2003 Eurasia (Europe and the Russian Federation) was affected by heat and drought episodes of different intensities and duration. The combination of wild land fire danger (determined by weather), fire risk (ignition probability) and fire hazard (availability of fuels) determined occurrence and severity of wild land fires. Examples of countries in three regions are given in which the combination of these three factors resulted in quite different fire seasons.

In the Russian Federation Southeast of Lake Baikal the extreme drought between 2002 and 2003 provided the conditions for large-scale fires caused by economically motivated arson and the consequences of weakened institutional capabilities to manage wildfires. At the end of the fire season more than 20 million ha of forest and other land were affected in the Transbaikal region.

In the five southern European countries (France, Greece, Italy, Portugal, Spain) the total area burned in 2003 was comparable to five fire seasons within the last two decades. However, Portugal experienced wildfires of extreme intensities in plantation forests and other land subjected to land-use change and alterations of fuel complexes. With a total area burned of 420,000 ha more than eight percent of the forest estate was destroyed by wildfires, which also burnt 2500 houses and buildings in the country – for a total economic cost of €1 billion. France experienced an extreme fire season, especially in the 15 Départements of South-Eastern France (including Corsica) where more than 61,000 ha land were affected by wildfires. In July 2003 more than 20,000 tourists had to be evacuated from recreation sites endangered by wildfires. Despite high fire danger the total area burned in Spain was relatively low as compared to similar drought conditions in earlier years.

In Central and Western Europe the fire situation was dependent on the preparedness of the fire services. Extreme fire danger in Germany did not result in large or extremely dangerous fires. With a total area burned of 1300 ha the year 2003 resulted in similar or less area burned as compared to four years of the last decade (1992: 4908 ha; 1993 – 1493 ha; 1994 – 1114 ha; 1996 – 1381 ha). Similar to previous years the average fire size was 0.5 ha. Despite the average low meteorological fire danger conditions prevailing in Germany in 2004 the actual wildfire hazard has been increased as a consequence of mortality of forest vegetation due to heat-stress in 2003, resulting in high loads of available fuels. In the United Kingdom, however, severe drought conditions resulted in high-intensity wildfires which were difficult to control.

By evaluating the 2003 wild land fire season in three Eurasian regions it must be stated that drought alone does not determine the occurrence, extent and damages of wildfires. The intensity (energy release, degree of controllability of a fire), the severity (ecological impact of wildfires, including resulting secondary disasters such as erosion, runoff, landslides and flooding) and economic damages of fires depend on ignition sources, values at risk and vulnerability at the interface between vegetation complexes and other land-use systems.

2.2.8 Ozone and/or drought: differences or similarities in leaf tissues?

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Although drought is an environmental stress playing a detrimental role in natural and man-made ecosystems, whose importance can only increase with the predicted climate change, scientific work is only 10-20 % of that done on the influence of anthropogeneous ozone. Little is known on the interaction of both stresses, which occur simultaneously or consecutively.

Controlled experiments showed, that during leaf formation, both stresses lead to smaller leaf area, whereas stomatal density is influenced in contrasting directions, lowered by drought and increased by ozone (in birch). In mature leaves drought leads to stomatal closure and therewith to reduced ozone uptake, and also ozone leads to stomatal narrowing and therefore to reduced water uptake. Both stresses direct the cell metabolism to increase cell wall thickness at least partly triggered by intercellular oxidative stress. Cell collapse occurs primarily in the assimilative tissue with ozone and in the conducting tissue with drought. Similarly the secondary metabolism is enhanced by both stresses, as indicated by the formation of tannins, but in the different target tissues. Finally both stresses induce accelerated senescence originating apparently along the water pathway (drought) or in the palisade parenchyma (ozone). The differential diagnosis by microscopy therefore often can distinguish between drought and ozone by the processes occurring in different tissues.

Beech appears to be sensitive to drought and ozone. Samples were therefore harvested from five Swiss Level II plots (LWF-plots and LESS light exposed sampling sites) in the exceptionally hot summer 2003. Preliminary results will show whether the tannin reactions, as validated by microscopic analyses, relate to the strength of the ozone or drought stress.

2.3 SESSION C – DROUGHT EFFECTS ON FOREST GROWTH

2.3.1 Impacts of the Drought in 2003 on Forest Condition in Germany - Results of a Study by the Federal Ministry of Consumer Protection, Food, and Agriculture

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The Institute for Forest Ecology and Forest Assessment of the Federal Research Centre for Forestry and Forest Products was assigned by the Federal Ministry of Consumer Protection, Food, and Agriculture to acquire in charge a study on the impacts of the drought in 2003 on forest condition in Germany. In addition other institutes of the Federal Research Centre and the Forest Research Centre of Brandenburg in Eberswalde contributed with own shares. These are in the fields of:

- Environmental Monitoring 2003 in Europe; Contribution of the Institute for World Forestry
- Genetic aspects for the evaluation of drought on forest condition and silviculture; Contribution of the Institute for Forest Genetics and Forest Tree Breeding
- Economical consideration concerning the drought-problem; Contribution of the Institute for Economics
- Stress-physiological reactions of Scots-pine stands of the Level II-plots in Brandenburg and Berlin during the drought year 2003; Contribution of the Forest Research Centre of Brandenburg in Eberswalde
- Actual information on the situation of forest protection by the Main Agency of Forest Plant Protection; Contribution of the Forest Research Centre of Brandenburg in Eberswalde

Subject matter of the presentation by the Institute for Forest Ecology and Forest Assessment are the quantification of the drought by the climatic water balance, the soil water storage capacity with their regional differentiated occurrence, the effects of drought and heath on tree and stand growth and the modelling of the impact of climate on growth and vigour of forest trees and stands.

The mean temperature of the summer 2003 (June – August) in Germany was about 3,4 °C higher than the reference-value of the last 103 years. This summer was the warmest since 1901. Concerning the amount of precipitation of about 151,8 mm the year 2003 comes in fifth rank. The degree of drought was regionally varying. The climatic water balance is used as a suitable parameter to quantify the potential drought exposure of a special region as a long standing mean as well as the actual exposure by precipitation deficiency during shorter time intervals. For the whole area of Germany a water deficit of about –261 mm was calculated relating to the long standing mean.

The hydrological processes in forest are considerably influenced by soil properties. An important parameter, which describes soil water budget and its storage capacity, is the usable field capacity (amount of soil water usable for plants). The soil water availability together with the soil-depth-dependent water dynamics enables the characterisation of the cause-and-effect chain between precipitation deficiency, soil desiccation and plant reactions. Using the relative soil water disposability, the effects of meteorological drought can be evaluated on size and intensity of soil desiccation of selected level II-plots and of regions with differentiated soil properties.

In the fields of effects of drought impact on growth and vigour of trees and stands methods of acquisition are discussed. Further a case study comprising the region and the climatic conditions of the north-eastern German lowlands is presented. Valuable findings can be obtained by high-resolution measurements of intra-annual diameter changing; the comparison of the growth behaviour of Scots pines and beeches in pure stands and in mixed stands reflects the differences of sensitivity and reactions of the two species relating to drought. Especially the synopsis of the courses of intra-annual growth, temperature, precipitation, relative soil water disposability and daily growth activity enables the identification of meteorological and soil water conditions where growth activity drops down. Adjacent, findings from tree ring analysis are shown. Examples from level II-plots of Berlin and Brandenburg show the dramatic growth-trend-breaking impact of the year 1976 in this region. By the analysis of pointer years in tree-ring time series of these plots three region-transcending striking negative pointer years are detectable. These are the years 1969, 1976, and 1996 which are marked by hot and dry summers, but also by long lasting cold winters or very cold spring times.

Aiming at the modelling of climatic effects on yearly growth reactions a new method of objectified variable selection was employed. This method provides significant variables to the following multiple regression procedure. This procedure consists of special features (cross-validation, marking of data sets) to sharpen fidelity of mapping by the model. The fitted parameters of the regression model can be used to illustrate the effects of deviations of temperature und precipitation on increment in that range what is represented by the data in the time series of tree rings and climate.

2.3.2 Impact of 2003 climate conditions on radial growth and state of health according to soil water balance for the main coniferous species of French Mediterranean area

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The objective of this paper is (i) to describe the direct and delayed effects of climate of year 2003 on the radial growth of the main coniferous trees in the French Mediterranean region, (ii) to compare this effect to that of previous droughts and (iii) to assess possible consequences of the repetition of such events according to future climatic scenarios.

Consequences of 2003 drought and previous droughts on tree rings were observed on a pre-existent experimental design, intended to estimate the long-term impact of climate change on *Pinus halepensis* and *P. sylvestris*. This experiment includes a transect of 26 plots being spread out between 300 and 1100 m of elevation, distributed in 3 water balance levels : it aims at studying the effects of climate, water availability in the ground and their interaction on the growth and survival of both pines.

This device made it possible to establish climate-growth models which were used to estimate changes of productivity during the last century and to predict future growth according to scenarios of climatic change. At the end of 2003, we predicted by using these models the 2003 annual ring-width at our plots. In June 2004, cores were taken from all the plots to measure the actual ring-width and compare it with predictions. Cores of *Cedrus atlantica*, *Pinus pinaster* and *Pinus pinea* were also taken around the plots.

The 2003 ring is most of the time very narrow and it depends on ground water reserve. It is characterized by the absence or the extreme narrowness of the latewood, attesting the early occurrence of an abrupt water shortage. All the observed pine crowns have lost between 50 and 80 % of their needles in 2003.

In 2004, the earlywood is hardly wider than that of 2003, and very narrower than the one predicted by models: the traumatism of 2003 had delayed effects. Many *Pinus sylvestris* trees on bad soil conditions died in 2004 early spring, as well as *Pinus halepensis* that were weakened by snow breaks in 2001. The bad state of health and the much reduced growth of many individuals at the end of spring let us foresee high death rates in summer 2004. At this stage, direct and delayed effect of 2003 drought is far more serious than those of any drought of the last century.

Our models foresee the collapse of the growth of *Pinus sylvestris* in the Mediterranean hinterland within a few decades as climate warming goes onwards and the withering of large areas in case of repeated events. *Pinus halepensis*, which has been favoured up to now in France by climate warming, should later on suffer also from the far warmer climate and repeated severe water stresses.

2.3.3 Tree rings reveal prolonged stress prior to drought-induced tree death

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In summer 2003, a severe drought occurred throughout Europe. Several trees died in many forest stands. We studied pine (*Pinus sylvestris* L.) mortality in South Tyrol (North Eastern Alps, Italy). We observed that, at the same site, some trees died whereas some others survived. Trees in deeper soils seem to have suffered more than trees growing on rocks and in very shallow soils. In particular, we analysed trees which died after summer 2003 ("dead trees"), and trees which survived the summer drought ("survivors"), at three different sites. We found that "dead trees" had faster growth rates than "survivors", until a first major drought in 1976. After 1976, "dead trees" were already weakened and had very slow growth rates, in comparison with those of the "survivors". At the beginnings of the 90s, the "dead trees" had a further abrupt growth reduction in comparison with the "survivors". Tree-ring carbon stable isotopes show clearly that "dead trees" had a significantly reduced stomatal activity during the past ten years prior to their death, which occurred in 2003, in comparison with the "survivors". Thus, the drought in 2003 can be considered as a letal factor that finally lead to death trees which were already suffering for a long time span. Tree-ring stable carbon isotopes may therefore enable us to identify trees which will not survive future major drought events.

2.3.4 Growth reactions of beech, Norway spruce and silver fir after summer drought: Analyses from old growth and yield data of Switzerland

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During the summer 2003 leaves of beech in the Central Plateau of Switzerland turned into autumn colours or even fell off already at the end of July or beginning of August, two months earlier than usual. The question arose on how these trees will react, whether they will survive or die. Possible answers to these questions can be obtained by analyzing data from long-term growth research plots.

90 research plots, pure even-aged beech, fir and spruce stands as well as even-aged and uneven-aged mixed stands containing these species were already observed in the years 1947 and 1949 in which occurred similar summer drought events. In all the pure beech research plots a striking decrease of basal area increment was observed. This observation led to a closer analysis of basal area increment of all research plots containing one of the mentioned species and an observation period starting before the 40ies and lasting after 1950. These growth patterns were compared with meteorological data and site characteristics. It can be shown that the increment decrease is more pronounced at lower altitudes and for beech, whereas at higher altitudes in the same period even an increment increase e.g. for spruce was observed.

In addition, we analysed the harvest recorded in the years following drought, to assess whether there was an increased amount of normal or compulsory felling. This can be an indicator of drought-induced die-back.

From a number of surviving trees stem disks were collected approximately fifty years later. Growth reaction of trees to drought year by year can be analysed only on the basis of these stem disks, because data from yield plots do not have annual resolution.

On the basis of these results conclusions are inferred on the possible consequences of the drought of 2003. However it has to be mentioned that environmental conditions may be different than those of the 40ies and therefore these conclusions have to be interpreted with caution.

2.3.5 Drought signals in tree rings – markers in the past as scenarios for future risks

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Radial growth is a sensitive indicator of water availability as well as vitality at most of our tree species. On many sites pointer years and growth variations are related to water deficit in single years. Dendroecological investigations at different sites and with different tree species in Southern Germany revealed a wide spectrum of responses to drought periods in the past (Dittmar and Elling 1999, Elling und Dittmar 2001, Dittmar et al. 2003). Water availability was estimated by water balance modelling (Rötzer et al. 2004) using site specific meteorological data and soil properties. Responses in and after years with pronounced drought periods (e.g. 1904, 1911, 1934, 1947 and 1976) remarkably differ from site to site and from tree species to trees species. Norway spruce appears as very drought sensitive tree species, whereas Silver fir and Common beech are much more drought resistant as often expected, on condition that they are not affected by additional stress factors. This can be also demonstrated on examples including increment growth during the vegetation period 2003.

The potential of dendroecological investigations enabling temporal and regional comparisons should be used to estimate drought impacts on the vitality and sustainability of forests. Including responses to the severe drought 2003 they offer the development and analysis of scenarios reflecting the expected climate changes, its consequences and risks.

2.3.6 Tree radial growth response to climate: a synthetic study of pointer years in French forests

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Dendroecological studies began 20 years ago at the Phytoecological Laboratory of the National Agronomic Research Institute in France (INRA). Large surveys have been carried out in several geographical regions and forests allowing the study of radial growth of individual trees during the past 150 years.

This contribution focuses on the analysis of pointer years and summarizes the results obtained for 8 species (*Fagus sylvatica*, *Quercus petraea*, *Quercus robur*, *Fraxinus excelsior*, *Abies alba*, *Pinus uncinata, Pinus sylvestris, Picea abies*) and 12 regions (with an average of 500 analysed trees for each study). This first dataset is supplemented by the data collected on 40 sites and 5 species of the French Permanent Network for the Monitoring of Forest Ecosystems (RENECOFOR – European Network – Level II plots).

The frequency and amplitude of pointer years are discussed according to the species and the sampling areas. A multivariate analysis of the sites x pointer years table allows an ordination of species according to their sensitivity to climatic factors. *Fagus sylvatica* seems to be the most "sensitive" species to inter-annual climatic variations whatever its location and, for the whole sample, regional and species effects are pointed out. The number of pointer years observed in a given stand is strongly correlated with the average site dryness, clearly showing that spatial variations of drought control tree radial growth. We finally analyse the interannual correlation between water stress variations and pointer years.

2.3.7 Evidence of the effect of the climate of year 2003 on Douglas-fir and larch wood formation in France

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In different regions of France, Douglas-fir and larch were visibly affected by the 2003 drought and heat wave: in many trees, variable parts of the foliage turned red in a few days by mid August 2003.

At the end of winter 2003-2004, wood samples were collected in 2 forest stands:

- a Douglas-fir plantation located in Marcilly en Villette, Loiret (10 increment cores on 10 trees);
- a hybrid larch experimental plantation located in Beaume-les-Dames, Jura (160 increment cores on 160 trees).

The increment cores were analysed using indirect X-ray microdensitometry and radial (from pith to bark) microdensity profiles were produced. Figure 1 shows the average Douglas-fir microdensity profile.

A comparison of the density profile of ring 2003 with the density profiles of the 4 previous rings (from 1999 to 2002) was conducted on both samples using analysis of variance. The results demonstrated that:

- in both species, there is a highly significant year effect on wood microdensity,
- this year effect is completely (in Douglas-fir) and essentially (in larch) accounted by ring 2003,
- the part of the ring concerned is mainly the transition zone between earlywood and latewood and the latewood itself.

Hence ring 2003 is significantly different of rings 1999 to 2002: as an average, the ring 2003 is narrower with a thinner and lower density latewood. Our preliminary interpretation is that latewood formation stopped earlier in 2003 than during the 4 previous years in both species. Large between-tree variation for the features of ring 2003 was observed in both species. From our point of view, this variation is an illustration of the genetic variation of tree reaction to the unusual climate characteristics of year 2003. Such information is very important for all aspects related with the management and the utilisation of the adaptive diversity of these forest species.

2.3.8 Impact of severe drought on beech regeneration in Germany – Are Polish beech provenances more adaptive?

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In Germany, current silviculture practices favour the regeneration and introduction of European beech into coniferous plantations, and thereby the area of beech-dominated forests is increasing. There are several indications that beech, and in particular beech regeneration, can be highly drought sensitive (e.g. Geßler et al. 2004). In the North German lowlands, the assumed future climatic conditions of a warmer and dryer local climate are quite similar to the recent continental climate in Central Poland. Therefore, Polish beech provenances may be more adaptive to a future climate in Germany with extended periods of severe spring and summer drought.

To compare drought sensitiveness of different beech ecotypes, beech seedlings of 10 local German and Polish provenances were cultivated. The selected provenances cover a gradient of increasing climatic continentality from West Germany to East Poland. During summer, 2004 laboratory and garden experiments simulating a six-week severe drought period are established to test the drought sensitiveness of the one-year old beech plants. Pre-dawn water potential, $\delta^{13}C$ and $\delta^{18}O$ isotope composition of plant tissues and plant growth are measured to evaluate the drought stress impact on beeches of different provenances. The results will enable the discussion of the appropriateness of the different beech provenances for future cultivation in Germany under changed climate conditions.

2.4 SESSION D – WATER BALANCE AND TREE PHYSIOLOGY

2.4.1 Understanding time lag effects of the drought 2003 on physiological and phenological behaviour in oak and beech trees

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Dendroecological studies have clearly pointed out delayed effects of climatic stresses on radial growth, especially drought: tree ring width is reduced the year of drought, but the following tree ring is often narrower than the climate would predict. Moreover, we already demonstrated that stand leaf area index is reduced one or several years after a severe drought. Nevertheless, the underlying physiological processes are up to now not demonstrated. One may hypothesize that reduced photosynthesis due to stomatal closure will first stopped tree growth (direct effect) and secondly limited carbohydrates storage. This reduced storage would impair the following spring through reduced foliation, partial mortality and limited growth.

The aim of the presented study is to analyse the effect of drought 2003 on the replenishment of total non-structural carbohydrates amount in oak and beech trees. In a 35-40 year old beech stand, we selected 35 couples of dominant trees with premature (end of August) or normal leaf fall (end of October). We cored trees to analyse stem TNC content at the end of the growing season (October 2003). The premature defoliated beech exhibited significant lower starch content than normal defoliated tress, but no dead tree was observed in the 2004 spring. Phenological observations in Spring 2004 showed twigs mortality, heavy fructification, small leaves and we will discussed links between theses events and the 2003 physiological status (defoliated or not, TNC content).

The Harth forest (Alsacian Plain) is an oak forest highly responsive to soil water shortage as a result of low soil holding capacity, high proportion of stones and high stand leaf area index. The recent oak decline has been retrospectively ascribed to recurrent droughts. In this forest, only light premature leaf-fall was observed in 2003 but brown and burned leaves were noted. More than 450 sessile or pedunculate oaks were there cored in October 2003, percent of brown leaves and leaf fall evaluated and TNC content quantified. We computed several water stress indices, taking into account local soil properties, stand leaf area index and species composition, as well as climatic data. We analysed the within and between stands variability of TNC content, especially starch, with respect to Spring 2004 foliation, twigs mortality and stand water balance. The relationships between drought intensity and phenological responses or carbohydrates reserves status of the two oak species will be discussed.

2.4.2 Drought effects on carbon and water fluxes of Norway spruce (*Picea abies*) at the tree and stand level: comparison of 2003 with preceding years

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Among the important ecosystem services of forests much attention has been paid to carbon sequestration during the last ten years. Both forest inventory and continuous measurements of carbon dioxide and water vapour exchange on flux towers by micrometeorological eddy-covariance technique indicate significant carbon sinks in European forests. This beneficial behavior of forests may change with increasing frequency of soil drought. Therefore, not only carbon fluxes or forest growth but also their relationships to soil water resources and tree water consumption are important for the future development of forests carbon sinks.

At the flux tower site Tharandt Anchor Station (375 m a.s.l.) in the Tharandt Forest (20 km SW of the city of Dresden) continuous measurements of carbon dioxide and water vapour exchange are performed since 1996. The site is dominated by 110-year-old Norway spruce (*Picea abies*) and contributes to international, long-term observations of ecosystem carbon-exchange (CarboEurope-IP, FLUXNET). Water use of trees is measured by sap flow technique since 2001. Tree growth was determined from stem disks and stem cores of sample trees scaled-up to the stand level by biometric data from permanent plots in the vicinity of the tower. Both carbon and water fluxes at tree and stand level were found to be lowest in the year 2003 compared to all preceding years of observation. While reductions in annual tree growth (2.52/4.48 t/ha/a for 2003 and 2002, respectively) and tree water-use (166/252 mm/a for 2003 and 2002, respectively) were of similar magnitude, total net ecosystem exchange of carbon was relatively less reduced in the dry year (438 and 572 g $C/m^2/a$ for 2003 and 2002, respectively). Growth rates, tree water-use and canopy evaporation will be discussed with respect to changes in relationships between carbon and water fluxes (water-use efficiency) at different levels of integration and regional climatic trends in the Erzgebirge (Ore Mountains).

2.4.3 The drought of 2003 in Western Europe: consequences on forest ecosystems functioning

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In order to assess the drought intensity in 2003 and its effects on the European forests functioning, a daily water balance model was implemented in intensively monitored sites. This model (BILJOU) estimated the water fluxes and the temporal variation of soil water content in the root zone. Water stress intensity indices and duration were calculated from the estimated day-to-day soil water deficit. We used climate and flux data – when available - from 12 European sites, most of them belonging to the Carboeurope network. We first assumed "constant" physiology and soil condition, i.e. a unique set of stand and site parameters was used, that allowed at calculating a "potential" water stress. Among all the investigated sites, water stress intensity and duration varied to a large extend, from wet to exceptionally dry condition. Water stress duration ranged from 20 to 128 days during the vegetation period according to the sites. A map showing the geographical distribution of water stress intensity was drawn.

In 9 sites, carbon and water flux were measured in 2002 and 2003 by the eddy covariance method. Their temporal variation were analysed and the annual carbon and water balances were calculated. Soil water content depletion in summer provoked water and carbon fluxes decrease in the second half of June till end of October in most sites. This flux reduction occurred when relative extractable water in the soil decreased below 40%. On the whole year, the decrease in net ecosystem exchange (NEE) was not very large, ranging from 0 to 150 g C m^{-2}, because both gross assimilation and ecosystem respiration were reduced by drought. In some sites, a clear effect of drought development on circumference growth was evidenced *via* an earlier growth cessation than usually observed.

Besides the direct impact of the year 2003 drought on fluxes and tree growth, the differed effects, due to leaf area index decrease, variation in rooting, carbohydrate reserves decrease, can not yet be evaluated.

2.4.4 Responses of photosynthesis to high temperatures in trees: acclimation of the thermal break point of photochemistry to heat and drought

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The physiological processes contributing to photosynthesis (i.e., photochemistry, carbon reduction cycle, CO_2 diffusion through stomata and to the chloroplasts) display different responses to high temperatures that still need to be better documented, despite the knowledge acquired during the past decades. The thermal optima of photochemistry and rubisco activity have been found to be around 35 and 38 C; but neither the inter and intra-specific diversity of this parameter, nor the ability of these optima to acclimate to rapidly changing environmental conditions have yet been clearly established. The thermal breakpoint of chlorophyll fluorescence is frequently used as one of the indexes for the thermostability of PSII and thylakoid membranes. This breakpoint is usually close to 45 C in many species. Recent experiments have shown that it is highly plastic, increases by up to 10 C being induced either by drought or by gradually increasing temperatures. In this presentation, we will summarise the information available in this field, as well as show the latest evidence documenting the plasticity of this parameter and the consequences it might have for the photosynthetic functions as a whole, basing on experiments with oak trees.

2.4.5 Drought responses in *Populus euphratica*: effects on water relations, growth, hydraulic properties and gas exchange

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Populus euphratica species is famous for its ability to cope with high salinity. Moreover, its distribution area comprises deserts with very hot and dry summers (and very cold winters). All species of the *Populus* genus are know to be drought sensitive and a phreatophytic behaviour of *P. euphratica* may explain its ability to grow in such dry areas. In this experiment, we studied the ecophysiological responses of *P. euphratica* to an increasing drought stress. Plantlets of *P. euphratica* were obtained by *in vitro* culture (from Ein Avdat natural park, Israel). After *ex vitro* acclimation, they were transferred and acclimated to Nancy's greenhouse. Climatic conditions depended on outside weather but temperature was regulated between 15 and 32°C.

A moderate, increasing drought stress was applied and controlled for 6 weeks. Soil volumetric water content was measured one to two times a day depending on the intensity of the stress (TDR and weighting). Plantlets were progressively brought to 5 stress levels: 10%, 7.5%, 5%, 3% HV and back to fully available water. Although soil water content decreased down to as 3.5%, predawn and minimum water potentials remained above –0.8 and –1.1 MPa, respectively. At this stage, relative leaf water content had declined from 96 to 89% and severe stress symptoms such as leaf yellowing, wilting and shedding were observed. Diameter growth significantly decreased as soon as soil volumetric water content (SWC) reached 16% and then very rapidly stopped. Height growth was affected at SWC around 12%, but reached 0 only when SWC has dropped to 6%. Leaf emission rate was affected 4 days after diameter growth reduction. Stomatal conductance (gs) decreased very early, as soon as soil moisture was less than 10%. Net CO_2 assimilation decreased later than gs, only when SWC reached 7-8%. A complete recovery of net CO_2 assimilation occurred about 5-6 days after rewatering but stomatal conductance did not completely recover even after 11 days. Water stress had no effect on total chlorophyll content. Soil-to-leaf hydraulic conductance (gL) decreased with drought. Embolism developed early, when drought was rather weak and progressed with increasing stress to 60% PLC. For a given stress level, roots were less embolised than stem.

Although *P. euphratica* is tolerant to salinity, our results demonstrate that it is definitely a drought sensitive species; trees may grow and survive only when the access to a water source such as a water table is possible. This clearly explains why this species is mostly confined to river banks in arid zones.

2.5 SESSION E – SOIL PROCESSES

2.5.1 Potassium deficiency as induced by drought

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Trees take up most of the nutrients from the soil solution. That applies especially for basic cat-ions like Calcium, Magnesium and Potassium. Therefore a dependency of the tree supply with these essential nutrients from water supply and its periodic variation can be expected. Hildebrand demonstrated in model experiments, that the spatial distribution of the exchangeable Potassium pool is extremely heterogeneous, and that this heterogeneity follows the spatial structure of soil compartments in the meso-scale. At the surface of soil aggregates, especially of loamy soils, the exchangeable potassium pool is widely depleted, whereas in the inner parts of soil aggregates enough Potassium is available. This finding can be explained on the background of the following theory: Trees cannot enter the intra-aggregate pore space because of the lack of oxygen there. Therefore they do not have direct access to the Potassium pool in the inner parts of soil aggregates. Subsequently the exchangeable Potassium pool in the area of the aggregate surfaces is depleted due to root uptake and leaching processes as been caused by acid depositions. The link between the Potassium stock in the inner parts of soil aggregates and the roots at the surface of soil aggregates is the intra-aggregate soil solution. There Potassium cat-ions are transported in the direction towards the surface of soil aggregates by diffusion, following the gradient of concentration. This mechanism was confirmed by results from the state-wide monitoring network on tree nutrition, which was performed in the years 1983, 1988, 1994 and 2001.

It is a well known matter of fact in tree nutrition, that especially the supply with potassium displays a certain dependency on water supply and that Potassium deficiency is often triggered by precedent drought periods. The theory of the spatial heterogeneity of Potassium distribution in the soil helps to understand this dependence of the Potassium supply from the water supply. Since the diffusive transport Potassium from the inner parts of soil aggregates to their surface is hindered or ceasing during drought periods, when soil aggregated are dried out, one would expect Potassium deficiency occurring during and after drought.

Using these data from the nutrition monitoring network and additionally the nutrition data from the 10 Level II plots, which were investigated every 2 years, as target variables, the relation between weather and Potassium supply was examined by means of multiple linear regression analysis with monthly values of the drought index after de Martonne as predictors. Into this examination the drought indices from the actual year and additionally the three precedent years were included.

2.5.2 Examination and advancement of soil water balance parameters by soil water content measurements in the drought 2003

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At the 22 Bavarian Forest Ecosystem Monitoring Stations (Level II) complete meteorological data sets are measured. Additionally soil water content and tension were measured at 6 Level II plots in different depths by TDR probes and tensiometers, respectively. This enables the simulation of the water balance at the Bavarian Level II plots by the application of the water balance model LWF–BROOK90, which was advanced by us during the last years. The measured water content is used to examine the simulations. Soil water balance parameters (porosity, field capacity, permanent wilting point) which are derived from soil physical parameters by the pedotransfer function HYPRES can be examined too.

In the drought 2003 a great natural field experiment took place. An extreme dehydration of the soils was observed. At many Bavarian Level II plots the whole plant available water supply was consumed. This field experiment now allowed examining the used model parameters in a wider range. The examination showed, that the soil water balance parameters of the pedotransfer function HYPRES in some cases are not consistency with the observed field data.

Therefore it is necessary to make more systematic soil physical and soil hydraulic measurements at forest soils to advance and validate pedotransfer functions for forest soils. Now we have a good opportunity for a selective examination of pedotranfer functions of forest soils within the level II program. Data of level II plots where complex meteorological measurements took place in 2003 should be used for that purpose. A proposal for a project outline for the advancement of pedotransfer functions for forests sites will be presented.

2.5.3 Drought effects on soil solution chemistry at Bavarian Level II plots

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Drought in ecosystems reduces seepage, transpiration and plant uptake while mineralization continues. Experimental droughts in forest ecosystems indicate changes in soil solution chemistry, e.g. nitrate fluxes increasing after rewetting (see roof experiments in EU EXMAN-Project). 22 Bavarian Level II plots provide 6 to 12 year time series of monthly element concentrations in the solution of humus and 3 to 5 soil layers. Recent modelling of the soil water budget with LWF-BROOK90-Modell allows estimations of element fluxes.

The year preceding 2003 drought was wettest since beginning the measurements. Long time series and two consecutive extreme years (wet and very dry) permit detailed description of changes in soil water chemistry related to soil water budget. First analysis of 2003 data reveal altered concentrations and correlations of ammonium, nitrate, DOC, potassium, etc. during and after drought mainly in humus layer. Single plots already show a remarkable increase of nitrate concentrations in upper soil layers in the late 2003. Generally upper soil layers lack sample numbers sufficient to describe changes in 2003, due to frequently failing suction cups. Ongoing incorporation of 2004 data will clarify possible flushes of nitrate and other elements. Yearly nitrate losses of the forest ecosystems were low in 2003, especially when compared to the wet year 2002. Analysis of drought effects on soil chemistry until summer 2004 will be presented.

2.5.4 Species-specific method of short-term drought stress level assessment

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An assessment of the drought impact on tree species is one of the hottest issues of forest research in recent years. Even if there are many methods and indices that have been developed for this purpose we can encounter several problems in solving this task. The first one is that most of them are general and they do not consider specific demands of individual species. It can produce serious difficulties in an interpretation because the same value of an index is used to represent the same drought stress level for different species. Since most of available drought indices are calculated for longer periods as are months, years or growing periods the next possible problem can appear in the case of a short-term drought assessment.

The presented method has been developed to deal with all disadvantages mentioned above. It is based on daily values of the main meteorological variables affecting a water balance as well as soil water holding capacity, which also plays an important role in the water regime of terrestrial ecosystem. The index representing a drought stress level is calculated by a simple ratio of an available water amount in a soil and actual transpirative demand of tree species. It is a simple system open for next development and improvement by using new knowledge of species-specific physiological requirements or by implementing a more detailed water balance system. However, there is still a need of its verification by a comparison with a real data taken from living trees in a field.

2.6 SESSION F – TREE NUTRITION, ROOT DYNAMICS

2.6.1 Consequences of the 2003 drought on nitrogen nutrition and water balance of adult European beech (*Fagus sylvatica* L.) on calcareous soil

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In Central Europe, drough sensitive European beech (*Fagus sylvstica* L.) is the dominant deciduous tree species of the potential natural vegetation and is recently favoured by forest policy to substitute parts of monocultural spruce forests. In 2003 Central European ecosystems were exposed to an enduring period of drought during the vegetation period. This drought permitted comparative studies at already established experimental field sites on the performance of beech trees under the dry conditions of 2003 and under the conditions experienced in preceeding and subsequent years with more abundant precipitation. The experimental site analysed in this study is located in southern Germany in a low mountain range (Schwäbische Alb) and consists of two beech forest stands growing on opposing slopes of a narrow valley. The slopes are subjected to different local climatic conditions due to the different geographical exposition (north-east vs. south-west). Sampling campaigns were performed in May, July and September of 1999, 2002 and 2003 to assess seasonal changes in the physiological performance of beech trees. Total soluble nonprotein nitrogen (TSNN) compound profiles in xylem sap, leaves and phloem - indicating the nitrogen nutrition status of the trees – were analysed, as well as total N and C contents in leaves and phloem. To assess the water balance of the studied trees, stable isotope signatures of carbon were determined in leaves and phloem in 2002 and 2003.

The sum of TSNN in xylem, leaves and phloem of May reached comparable values in 1999, 2002 and 2003. Yet, in July 2003, a significant reduction of xylem loading compared to 1999 and 2002 was detected in the stands of both aspects, indicating impaired nitrogen availability – an effect already observed under drought stress conditions in greenhouse experiments with beech seedlings. However, signs of protein degradation and osmoprotectant synthesis were not found, suggesting a lack of compensatory reactions. In July 2003 also the total C contents in leaves from both aspects were significantly lower than in the preceeding years. This effect may be explained by a frequent closure of the stomata to reduce transpiration, leading to lower rates of photosynthesis and, hence, decreased C assimilation in the leaves. However, isotope signatures of leaf carbon, expected to increase during periods of stomatal closure, were significantly decreased at the same time. This indicates severe metabolic disturbances in the leaves during the prolonged period of drought in 2003.

2.6.2 Norway spruce fine roots and seasonal drought – results of a three-year field experiment in southern Finland

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The effects of seasonal drought periods on Norway spruce (*Picea abies* [L.] Karst.) especially, were widely discussed in Finland during the early 1990´s, and again, after last years´ severe drought periods.

In 1998, we started a study to determine the effects of seasonal drought and an elevated soil nitrogen status on Norway spruce in a field experiment. One sub project concentrated on fine root (< 2 mm diameter) dynamics. We hypothesised that, if the effects of drought on trees are not only caused by a decreased availability of water and nutrients but also due to damage to fine roots, then the recovery from drought may take longer. A higher N status may be beneficial during drought but it may also change the pattern of carbon allocation in the trees, favouring aboveground growth.

The treatments included control, N fertilization 630-1000 kg/ha (80-180 kg N/ha given every five years during a 35-year period), drought for three months (May-July during three summers 1998-2000), and N fertilization combined with drought. The experimental stand was 67 years old and growing on a fertile site type. The drought treatment was carried out by covering the 900 m^2 plots with a plastic roof 1-4 m above ground level. The moisture content of the top soil (down to a depth of 15 cm) after seven weeks drought was 9-13 % of the water holding capacity on the drought-treated plots, and 23-35 % on the plots without drought.

Fine roots were sampled with soil coring and using ingrowth cores before, immediately after, and two months after the end of each annual drought period. The diameter growth of the trees was monitored using automatic girth bands. In addition, soil, soil water and tree nutrient status were determined.

Norway spruce fine roots, foliage and diameter growth reacted rather rapidly to water deficiency in soil. The biomass production of fine roots was lower on drought treatments - 170 g/m^2 during the growing season in 2000 while it was 190 g/m^2 on the control plot. The ingrowth core results showed that fine root mortality was high on drought plots, resulting into clearly lower fine root biomasses compared with the control at all samplings during the study period.

The results on fine root dynamics are discussed in relation to results on diameter growth and soil and tree nutrient status.

2.6.3 Fine root dynamics of *Fagus sylvatica*: Interacting effects of soil temperature, drought and ozone treatment

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Fine root dynamics of mature *Fagus sylvatica* trees (European beech) was studied from March to December 2003 using minirhizotrones on the site of the SFB 607 near Freising, Germany. In this field experiment ozone levels in the canopy were doubled compared to ambient levels. Experimental setup consisted of four pairs of minirhizotrones in each plot (control and ozone fumigated) with soil probes for temperature (5 cm depth) and water content (15 cm depth) placed between each pair. The vegetation period in 2003 was characterized by high temperatures, partial high ozone concentrations and drought. Daily mean soil water content (volumetric percentage) steadily decreased from 30.8 –32.0 % in April to 13.2 - 13.9 % to the end of September.

Fine root density in the control plot increased from 17.3 in mid March to 20.0 roots dm^{-2} to the end of July and decreased rapidly afterwards to 11.6 roots dm^{-2} at the end of October. This course was the result of the interaction of high rates of root formation in the first half of the vegetation period and high rates of root die off in the second. There was only a weak correlation between fine root density and soil water content and no correlation with soil temperature. Turnover rate (i.e. the sum of appeared and disappeared roots dm^{-2} d^{-1}) correlated significantly with soil temperature (R^2 = 0.79, $p < 0.001$) but was not effected by soil water content ($p = 0.76$).

In the ozone-fumigated beech plot fine root density remained constant at about 12.1 roots dm^{-2} from March until end of July and then decreased to 6.9 roots dm^{-2} by end of October. Root density decreased exponentially below 20 % soil water content. In comparison with the control plot, maximum die off of fine roots under ozone influence occurred much earlier and peaked concurrently with root formation. Root turnover of ozone treated trees ceased already in October whereas there was still root activity in the control. The correlation to soil temperature was slightly weaker than in the control plot (R^2 = 0.55, $p < 0.01$) and again no relationship was found to soil water content. Thus, although beech trees were faced with severe drought, the current data suggest that soil temperature is the predominant factor in determining fine root turnover. Impact of ozone additionally increased the sensitivity of beech fine roots to drought.

2.6.4 The exceptional summer of 2003 as a test scenario for the root competition between adult beech and spruce forest trees

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The summer of 2003 was characterised by above-average insolation, distinctly enhanced daily mean temperatures and exceptional drought conditions. These extremes regarding Central-European summer conditions were setting the stage for examining the below-ground competition between 60-year-old beech and spruce trees in a mixed forest near Freising. Competitiveness for gathering soil resources was viewed in terms of the structural investment into roots that is required to ensure efficient sequestration and exploitation of below-ground space. Thus, the availability of water became a crucial factor in the exacerbating competition between the forest trees during the assimilation period of 2003. It was hypothesized that the two tree species contrast in their structural and functional investment/return strategies with respect of competitiveness for water.

Root responses observed in 2003 were compared with those of 2002. Emphasis was on the standing biomass, growth increment as well as the respiration of fine roots, the water transport in coarse roots and the proportion of autotrophic in total soil respiration. In 2003, the signature of $\delta^{13}C$ in the biomass of newly formed fine roots reflected enhanced WUE in both competitors, although the rate of fine root recovery was reduced by 80% for spruce as growing in monoculture. In addition, premature dormancy of the fine roots appeared to exhibit stress avoidance in response to drought. In contrast, beech displayed less constraint on the structural and physiological performance of the root system and appeared to reflect drought tolerance. Root architecture was related to the distribution patterns of precipitation and soil properties in the stand towards mechanistic interpretations of the species-specific strategies in competitiveness under the harsh summer conditions of 2003.

It is concluded that the greater structural and physiological plasticity of the root system of beech in tolerating drought periods substantially contributes to the documented high competitiveness and dominance relative to spruce at many forest sites of Central Europe.

3 POSTER PRESENTATIONS

3.1 VARIOUS DROUGHT EFFECTS ON FORESTS

3.1.1 Influence of droughty conditions on a state of poplars

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The droughts of last decades have attracted attention of scientists and foresters with the purpose to develop measures on avoidance of harmful consequences of these phenomena. In Western Europe the 2003 was critical. In Russia such was 1972. As USSR meteorological service informed in that time such drought, as in 1972, happens one time per 600 years. Therefore it is interest to recollect, how on a background of such drought felt the representatives of one of fast-growing genre of temperate zone of earth - poplar (*Populus* L.). Besides it would be expedient to establish, as the representatives various sections of poplars tolerate deficiency of moisture in irrigation conditions.

The researches on revealing resistance of poplars to a drought were carried out in Central forest-steppe (Voronezh region) and in North Caspian semi desert (Astrakhan region). In the Voronezh region (yearly precipitation - 500 mm) the observations were carried out on one-year vegetative plants of a poplar in a collection plantation. In the Astrakhan region (yearly precipitation - 180 mm) were investigated poplars of different age in irrigated conditions.

On the data of Voronezh agro meteorological station, the most unfavorable meteorological conditions were observed in July - September 1972. The store of a moisture in dark grey forest soil in a layer 20-30 cm (middle of root horizon) has decreased from 22 mm in April to 13 mm in August and September, and in a layer 30-40 cm, according from 26 up to 17 mm.

From 126 investigated here clones only 12 % had no damages from a drought. At 61 % of plants the leaf withering was observed, top part of draws was hanging downwards. At others 27 % of plants were observed particulate damages of leaves, they was yelled and began of drying up. More drought-resistant have appeared of a white poplars (*Albidae* Dode). In a subgenus of the present poplars (*Eupopulus* Dode) tolerated a drought of a black poplar (*Aegiri* Dode) better. By most sensitive to action of a drought were balsam poplars (*Tacamahaca* Spach.) (all testing clones were damaged).

In a semi desert the drought resistance estimated on indirect (evapotranspiration rate in 3-year's age, concentration of cell sap) and straight line (safety and state after the stopping of irrigation in 7-year's age) attributes. The P. *bolleana* No145 has best drought resistance. The group of euramerican hybrids (Robusta-236, Vernirubens, Sacrau-59, Brabantica-235, Bachelieri etc.) has also high drought resistance. The weak drought resistance was at the Pioneer poplar, and most sensitive has appeared a hybrid of balsam poplars (4B).

Thus, more drought-resistant in conditions of insufficient humidification or in critical on humidification the years have appeared of a white pyramidal poplar and group of “old clones” of euramerican poplars. Balsam poplars should be excluded or essentially limited for cultivation in such conditions.

3.1.2 Environmental GIS database for desertification studies in the Brazilian north-eastern areas

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This paper provides spatial and georeferenced information related to the susceptibility to desertification of several areas of the Northeast of Brazil. We aim to test the usefulness of spatial analysis methodologies to capture spatial-temporal heterogeneity from environmental gradients, for the assessment of desertification process at Remote Sensing data. In this sense, the analysis and integration of geo-environmental variables and the creation of environmental indicators associated with the development of the desertification process was performed, based on the use of spatial modeling procedures applied to data from the semi-arid portion of the Northeastern Brazil region.

A set of fifteen-year period of Landsat 5-TM and Landsat 7-TM images were explored for vegetation and soil study and local analysis of association and variability of spectral data were performed. The selected environmental indicators were divided into two groups. The first group was composed of human activities that could cause desertification (cattle rising, agriculture, irrigation, forest resource exploration, urbanization, and mining). The second group was associated with the risk of environmental degradation by processes that were more directly related to the development of the desertification (erosion, salinization, and loss of biodiversity). The integration of the georeferenced data, related to these indicators, allowed the identification of five different levels of susceptibility to desertification (very high, high, moderate, low and very low), and the geographic domain of each class.

Based on the analysis of the dynamics of the vegetation cover and on the evaluation of field data, we can establish that the main results refer that there is a decrease of the biomass at the region, associated either with the dense vegetation areas, but more important, with the scrub areas. From an environmental perspective, the decreasing biomass level associated with scrub areas is according to the negative feedbacks of the desertification process. Considering the last five-year periods of comparisons, the spatial variances leave almost different, which means that heterogeneity pattern, is increasing very considerably. This fact means an explicit expansion of spatial heterogeneity of the desertification landscapes, during the last years.

3.1.3 Modeling Ecosystem Water Stress and Fire Risk Under Drought Conditions

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Drought can damage ecosystems by reducing water availability to trees and other organisms, reducing ecosystem productivity and nutrient fluxes. Under persistent dry atmospheric conditions, plant stomata close to conserve stored water, reducing exchange of water and carbon with the environment. Persistent drought leads reduced growth and increased risk of wildfire disturbance, which further damages ecosystems, especially those not adapted to periodic drought.

This study investigates water stress and fire risk of ecosystems during a severe drought event. A land-surface model is first used to simulate water stress. This model predicts variations of water and temperature in soil and canopy based on the water and energy conservation equations and parameterization schemes for various fluxes. The atmospheric fields and processes, including air temperature and humidity, precipitation, and radiation, are simulated with a limited-area climate model, which is coupled with the land-surface model. For comparison, simulation is also performed for a severe flood event. Wildland fire danger indices are then estimated based on the simulated water content and other fields. The results indicate that soil water content is close to its wilting point during the drought period and is much smaller than that during the flood period. This suggests a drier and slower growing ecosystem during the drought period. This difference is validated by the AVHRR satellite remote sensing measurements. The estimated fire danger indices point out a high risk of wildfire with the drying ecosystem, which is in agreement with the actual wildland fire frequency and intensity as indicated in fire records.

3.1.4 Intensive spruce forest decline in northern Slovakia: symptoms, localization, and possible causes and mitigation measures

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A new type of spruce forest decline represents serious problem in northern Slovakia. The decline had regional character in the past and became intensive in last years, especially in year 2003. Recently damaged areas turn out to be a compact zone. Particular symptoms of decline have been described earlier. Unfortunately, the knowledge about distribution, symptoms, spreading and mitigation measures of this type of decline is still limited. This type of forest decline had different symptoms than "classical forest decline" caused by air pollution in elevated areas at mountains or forest mortality caused by gale disaster and subsequent bark beetle outbreaks.

There does not exist typical symptoms of this kind of forest decline. Symptoms are different inside and also outside affected regions. The final stage of this decline is spruce mortality. Initial stages of decline are characterized by diffused chronical mortality of spruce in all age classes. Stands could be affected by honey fungus (*Armillaria* spp.) and other pathogens. Bark beetle outbreaks are frequent (*Ips typographus, Ips duplicatus*, *Pityogenes chalcographus*, *Polygraphus poligraphus*, *Ips amitinus*). This type of forest decline affects spruce stands in altitudes under 1000 above see level in northern Slovakia. Similar damage occurs in neighboring areas in Poland and Czech Republic.

Possible causes of this decline are nor completely clear. The decline could be caused by following primary factors:

(1) Internal factors:

- Several generation of planting spruce monocultures (mostly of unknown origin) outside of natural areas.
- Problems with managing of local bark beetle outbreaks in 1996-1998. (initialization of stand mortality by migrating bark beetles).

(2) External factors:

- climatic changes (abnormal meteorological condition in winter, spring and summer 2002/2003)
- air pollution (mostly in past)

The use of direct mitigation measures against is very limited. The liming and fertilization are expensive and possible effect to this decline is not sure. The only effective measure is IPM (integrated pest management) of bark beetles.

From long-term point of view, the problem could be solved by conversion of spruce monocultures to mix stands and higher differentiation of their structure.

3.1.5 Transpiration of mountain climax spruce forest in the Poľana Biosphere Reserve in The central Slovakia during dry vegetation period

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Presented paper contains results of the evaluation of site conditions (selected meteorological factors and soil moisture) on the sap flow and on the amount of transpirated water of Norway spruce (*Picea abies* L.) during dry vegetation period in 2003 in a climax spruce stand within the Poľana Protected Landscape Area. The research was crried out in a mature, natural spruce stand with an admixture of common beech (*Fagus sylvatica* L.) on the locality called Predná Poľana (19^{o}28'N, 48^o 37'E, 1347 m a.s.l.) with annual precipitation around 1100 mm and mean annual air temperature about 3.5°C. The sap floe in three model spruce trees was established by tree-trunk heat balance method (THB) by Čermák and Kučera. Air temperature, air humidity, wind speed, solar radiation were measured above canopy at height 25 m above ground automatically in 10 minutes interval. Precipitation were measured daily at height 2 m in an open area about 500 m from the stand being studied. There were observed long dry periods during July and August with insufficient soil water content below 20 mm. The amount of transpirated water determined by measurements in period form June to October was 6559 l in spruce No.1, 5178 l in spruce No.2 and 3995 l in spruce No.3. Spruce No.1 that enjoyed the most favourable conditions in terms of its social status, transpirated a maximum of 116 l per day (14th august 2003) on warm, clear sky day after rain in the previous day. In spite of soil drought the transpiration limitation was not observed in daily courses. The sap flow was correlated most strongly with the global radiation (R_{yx}=0.62), air temperature (R_{yx}=0.79) and the air humidity (R_{yx}=0.66).

3.1.6 Diagnostics in beech exposed to chronic free-air o_3 fumigation in the Exceptional Summer 2003: Ozone uptake and gas exchange responses of adult Trees

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Since spring 2000, 60-year-old beech trees (*Fagus sylvatica*) have been exposed throughout the growing seasons to an enhanced O_3 regime (2 x ambient O_3 at the site) using a “Free-Air Canopy O_3 Exposure” system at the “Kranzberg Forest” research facility. Trees under the ambient O_3 regime serve as a control. To prevent acute O_3 injury, the experimental regime is confined to a maximum of 150 nl O_3 l^{-1}. Scaffolding and a research crane provide access to the sun and shade crowns of the trees being 27 m in height. Given the ample information on short-term responses of juvenile trees, the study aims at clarifying the sensitivity of adult forest trees to chronic O_3 impact. The growing season of 2003 provided the opportunity to analyze the interaction between the exceptional drought conditions and ozone impact.

For creating a mechanistic basis of quantitative risk assessment, diagnostic findings on O_3 effects are scaled from the leaf to the tree level. Gas exchange and chlorophyll fluorescence are measured simultaneously to assess changes in photosynthetic performance. Leaf injury is quantified by the novel “Imaging-PAM” technique that provides a two-dimensional analysis (patches of 3.7 cm²) of chlorophyll fluorescence as reflected in quantum yield, ETR and non-photochemical quenching. The false-color images can be used as a tool for detecting early leaf responses *prior to* discoloration. Light dependence of chlorophyll fluorescence within the patches is analyzed for quantifying responsiveness. Symptoms detected by “Imaging-PAM” are validated in comparison with microscopic and histochemical assessments (cooperation with “Ozone Validation Centre”, Birmensdorf / Switzerland). CO_2 fixation is assessed by porometry (analysis of light and CO_2 dependence) for parameterizing models that allow scaling (in combination with structural data) to the crown level and the calculation of O_3-affected C gains of the whole tree.

The duration of the assimilation period is determined through phenological observations. During the past five years, the assimilation period became significantly shortened in the sun crowns due to accelerated leaf senescence under the enhanced O_3 regime, with the largest effect occurring in 2000. Similar trends of shade crowns were not significant. Lammas shoots initiated in beech in response to stress appear to support the conception that their high photosynthetic capacity, stomatal conductance and maximum quantum yield may counteract photosynthetic limitations in the foliage of the spring flush.

The persisting drought caused the pre-dawn water potential to drop to –1.4 MPa, and stomatal conductance was lowered by more than 50% as compared to previous years, which resulted in decreased ozone uptake.

3.1.7 Drought 2003 impact on sapling mountain forest trees: Results of an experimental design

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In the scope of a post-cultural woodland dynamic study an experiment was performed on abandoned south slopes of Northern French Alps. On 8 study sites representing the St Michel de Maurienne south slopes conditions we have delimited a plot under forest canopy and a plot in a clear cut gap. Each plot was subdivided in 8 subplots herbaceous neighbours were removed from 4 subplot. In spring 2003, in each subplot, we planted three saplings of five tree species (*Acer pseudoplatanus* and *Fraxinus excelsior*, actual dominant species and *Fagus sylvatica*, *Picea abies* and *Abies alba*, potential last successional species) in different conditions of light, herbaceous neighbours, and water soil content. Survival of these 1920 saplings was monthly recorded during summer. A total mortality rate of 58, 3 % was recorded in October 03. 24,6% of sapling was dead before the middle summer, and 30% of the survivors did not reach the end of the growing season.. The mortality rate was been heterogeneous, some difference had been noted between species and the effect of biotic interactions on mortality differed too between experimental conditions. Survival of the actual dominants was significantly higher than survival of the last successional species (30% vs 12% for actual dominants in the middle of the summer). Survival was also enhanced by the presence of herbaceous neighbours in the driest sites. We finally discussed the discrepancy which was observed between the stress tolerance aptitude of the species and their responses to this exceptional drought. Under these conditions, from the landscape scale, the selection of sapling could be different from growth seasons average and the future woodland physiognomy could testify of this drought episode.

3.1.8 The affect of drought on artificial regeneration in Slovakia in 2003 and the possibilities to increase plant adaptability after plantation in Central Europe

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Recently, the annual artificial regeneration is made on area about 11 000 ha in Slovakia. The primary species for this regeneration is beech and Norway spruce. The bare-rooted planting stock is dominated by artificial regeneration (95%). Generally, the bare-rooted plants are planted in spring and autumn plantation is connected with using of containerized plantings stock (mainly Jiffy and Lännen 1 or 2-years seedlings).

The extreme weather conditions caused enormous plantation failures in 2003. Generally, the precipitation deficit was about 150 mm from February to September in Slovakia but this deficit reached over 200 mm in Central part of Slovakia. In the summer, it were noted the most temperature extremes during last 200 years. This drought negative affected the afforestation program. The plantation failures for spruce and beech seedlings were 29% and 39% respectively on areas with precipitation deficit > than 45%.

There are many possibilities to increase survival of forest regeneration. Generally, it is increasing of using of natural regeneration under suitable forest stands. The primary goal is decreasing of transplanting shock on plants by artificial regeneration (choice of suitable tree species, planting time, using of containerized planting stock, etc.). The very important factor is planting stock quality (above all physiological quality) and therefore it is necessary to determine the actual physiological injury. The method of measurement of electrolyte leakage from root system is suitable method to prevent using of planting stock with physiological injury.

In addition, the application of new procedure in afforestation program can improve the survival of plants. The significance of hydrogels application increases in Central Europe. During the previous two years, hydrogels STOCKOSORB® have been tested in artificial regeneration and planting stock production in forest nurseries in Slovakia. The results showed that STOCKOSORB application positive effected on adaptability of plants after plantation. The survival rate by treated plants was about 15% higher than by control (untreated) seedlings in year 2003 and the hydrogels application positive affected the growth of plants (height and root collar diameter).

Finally, the affect of drought on forest regeneration is very serious problem and it has many aspects. The solution of this problem need a closely cooperation (at minimum on European level), because the present problems with extreme drought in Central Europe were in South Europe before 10-15 years and probably these problems are going to North Europe during following years.

3.1.9 Drought induced damages and mortalities in *Pinus nigra* Arn. subsp. *pallasiana* (Lamb.), *Pinus sylvestris* L. and *Abies cilicica* (Ant. et Kotschy.) Carr. species in Semiarid Central Anatolia Region of Turkey

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Tree mortalities in the stands of *Pinus nigra* Arn. subsp. *pallasiana*(Lamb.), *Pinus sylvestris* L. and *Abies cilicica* (Ant. et Kotschy.) Carr. in Central Anatolia Region of Turkey were investigated to identify main reasons causing mortality. Three of the most affected area of the region, Ankara, east of Yozgat and south of Konya was chosen for this purpose. Needle, branch, bark and sapwood and root samples from affected trees have collected. Soil and needle samples taken from damaged areas were analyzed for pH, Ca, Mg, Na, K content, lime content and salinity. Thorntwaite's method for the period 1992-2001 was used to determine water deficits. Also, in the case of insect damage, affected shoot and needle samples were brought to laboratory to identify species type of insect.

Damages to P. nigra subsp. pallasiana were observed in plantations around 40 year-old and old natural stands around Ankara and Konya. Many trees were dead; others showed extensive dieback and browning. Similar symptoms were observed in natural stands of P. sylvestris in south of Yozgat and in natural stands of A. cilicia in south of Konya. Most of the damages occurred in the areas with shallow soil and southern aspects. Insects were observed only on a few affected trees. As a result of isolation of samples in PDA (Potato Dextrose Agar) medium, only saprophyte fungi Alternaria sp. and Stemphylium sp. were detected. Insect species belongs to the Aphidoidea, Coccoidea families and Leucaspis pini Harting from Diaspidae family were determined on several damaged needles. Soil analysis showed that amounts of Ca, Mg, Na, K nutrients and salinity of soils were in normal ranges but soils had high pH (max. 9.1) and total lime (max. 17.8 %) values for conifers, though this pH and total lime values reflect the general characteristics of the Central Anatolian Region. Needle analyses showed that there wasn't any significant difference between damaged and healthy trees in terms of nutrient contents in Ankara. Evaluation with Thorntwaite's method indicated that yearly water deficits were higher in 1999, 2000 and 2001 than mean of long period (50 years). The highest temperature observed in the summer of 2001 was 40.8 oC.

In conclusion, any fungal or bacterial disease agents, insects or mineral nutrition deficiency that caused severe damages could not be identified. Climatic conditions seemed to play a main role in these damages, especially in the case of exceptional droughts in 1999, 2000, and 2001.

3.1.10 Impact of summer conditions of growth (drought, defoliation, …) on freezing tolerance of trees

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Low temperature represents one of the most important environmental constraints limiting plant productivity and the distribution.

For freezing tolerance, winter starch mobilization resulting in sucrose increase was an essential step on the way to cold hardiness.

The efficiency hardening may change with the summer conditions of growth. (e.g., Late July defoliation)

The aim of this study is to characterize the freezing tolerance and hardening status of different tissues and organs in relation to their carbohydrate status as induced by contrasted summer conditions of growth (drought,…).

3.1.11 A water balance model on an oak mixed forest in the Italian Alps: effects of the unprecedented drought of summer 2003

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A water balance has been set up in a thermophilous oak forest grove in the Italian Alps, to investigate relationships between water stress and plant damages. In the experimental site a meteorological station is operated since 1993, which provided data series for modelling. The calculation approach has been adapted from a protocol developed for an European pilot study a Penman – Monteith's "one step" method has been used for calculation of evapotranspiration; resistance coefficients have been evaluated according to maximum values found in literature and adapted to a daily step for the water balance model. *Ad hoc* equipment installed in the site and measures performed - under-canopy precipitation, soil moisture, LAI - allowed an experimental verification of the results of single parameterisations. Water balance model, and particularly relative transpiration, allowed a good description of last years' dry periods, and particularly for 2003, whose summer turned out to have a major impact on the phytosanitary state of plants. Water stress data of the previous decade were analysed and correlated with data of defoliation and discoloration of permanent monitored tree species growing in the area. Links between stress indexes and health tree status of the studied species have been investigated and discussed.

3.1.12 Drought risk monitoring research program in Romanian forests

Ion Barbu, Ionel Popa

Romania

In the last 4 years The Romanian Forest Research Institute has developed in the frame of the National Research Program MENER (Environment Energy Resources) the project "Drought Risk Monitoring in Romania's Forest" which tries to estimate in real time the risk of drought occurrence on the ground of a network of precipitation measurement in whole forested area (about 400 forest districts). In 2002 were installed the rain measurement network in representative plots located in each forest district. The deficit/excess of rainfall in relation with the multi annual mean of precipitations are computed and mapped using the modern tools (database, geostatistics, GIS etc).

On the ground of manuals and training programs the foresters from the forest districts measure and send the data of total and effective (precipitation – evapotranspiration) rainfall to coordinators of the project at each Forest Directorate. The data are faxed or e-mailed in the first 3 days of each month to the database in the Forest Research Station Campulung Moldovenesc.

Raw data is checked, validated and processed in the first 7 days of each month (fig. 1). Results are presented in an e-mail report (4-6 pages) and 8-16 maps showing the rainfall indices for the last 1-12 month, on the site www.icassv.ro/seceta. At the end of the year an annual report summarizes the dynamics of rainfall regimes and their potential impact on the forests.

The access of our beneficiaries (decision-makers) to the real data in real time allows a better objectification of the decisions concerning the forest management. On the other hand data from this monitoring project are useful for the evaluation of the impact of rainfall deficit on the health state of trees and on the incidence of other disturbing factors on the forest (forest fires, insects, pests, grazing etc.).

Data used for the monthly reports is obtained from 402 forest districts in which rainfall samplers are installed in couples of 2 total rainfall (P) and 2 effective rainfall (P-ETP) which permit a good estimation of the monthly rainfall in each point of the network. The drought indices are computed in relation with the multiannual mean of precipitations in each point. The flowchart of the data processing is presented in Barbu & Popa, 2003.

For the evaluation of the level of the deficit/excess of precipitation we use the standardized precipitation index (SPI) computed for each point of the network. The SPI represents the number of standard deviations that the observed values deviate from the long term means for a normally distributed random variable.

For the computing of SPI we use the relation (assuming the normal distribution of precipitations)

$$SPI = \frac{P_i - P_m}{SD_i}$$

, in which

P_i = precipitation registered in the period i (1...12 months)
P_m = mean of precipitation in the period i
SD_i = standard deviation of mean precipitations in period i
Transforming the SD in coefficient of variation (*s*)

$$s\% = \frac{SD}{P_m} * 100$$

The SPI can be computed with the formula

$$SPI = \frac{\frac{P_i - P_{mi}}{P_{mi}}}{s_i}$$

Using this simple formula it is possible to estimate the SPI for every point of the land on the ground of measured precipitations in the “i” period and the multianual mean values of precipitations (P_{mi}) and the coefficient of variation estimated for the territory, and mapped for different periods (Barbu, Popa 2003).

3.1.13 Structural diagnostic of drought effects on forest tree vitality - An approach combining crown transparency and architecture -

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France

At the beginning of the Eighties, the European forests underwent important deteriorations. It appeared necessary to set up a follow-up of the health of the forests using simple indicators of the tree vitality and applicable on a large scale (European inspection network in 1987).

Following important divergences of notation, the Department Health of the Forests (Département Santé des Forêts) developed a method evaluating the aspect of the crown based on the crown transparency, the mortality of perennial branches and the distribution of the foliar mass. This protocol leads to the definition of 5 classes of crown aspects. This method provides an instantaneous estimation of the vitality state of the trees related to more or less dramatic climatic events. Applied once per annum, almost all the species and only at the adult stage, this method makes it possible to establish an evolution of the state of foliation of the trees in the course of time (improvement or degradation). Although this method largely contributed to clarify the situation, it finds its limits with the new questions in connection with the reactivity and of the rebuilding patterns of the trees and their future.

To characterize the physiological state of a single tree or a particular species or a great population of forest trees or to set up a system of monitoring at the European level require different suitable techniques. In addition, the changes visible at the crown level can be brutal or progressive, with sometimes symptoms not appearing before 6 to 7 years after the cause. Lastly, certain symptoms are momentary, while others are irreversible. These difficulties support the need for integrating the recent assessments in vegetable architecture into this first tool for evaluation.

Architectural description is based on the crown organisation. The architectural description consists in breaking up total architecture into 2 images: a first image which presents all the sequential structures "foreseeable" formed during the main development of the tree (trunk, great main branches, secondary branches, forks of reiteration, shoot) and a second image which exhibits the "unforeseeable" structures appeared during the development in reaction to disturbances (root suckers, stock suckers and epicormic branches). The superposition of the 2 images makes it possible to define the stage of development of the tree, the history of its development and to specify its state of deterioration raised by method DEPEFEU.

The combination of the 2 quoted methods should make it possible to establish a typology of the trees most exposed to the dramatic climatic events and to come to a conclusion about the modalities and capacities of recovery of the trees.

3.1.14 Drought as a factor in forest health in Denmark

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Since 1989 forest health monitoring have been carried out in Denmark. The main tree species are Norway spruce (*Picea abies*), beech (*Fagus sylvatica*) and oak (*Quercus robur / petreae*). For these three species summer drought can be seen to influence the health of forest stands. However, the effect is often more pronounced when biotic factors occur at the same time, mainly insect attacks. The importance of drought in forest health only becomes apparent when a long time series of monitoring is available.

3.1.15 Effects of drought on the hydrology of different forest stands in Denmark

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Water balance is one of the most limiting factors in forest ecosystems influencing forest health and growth. Climate change is predicted to have a major effect on the hydrology of forests. Effects of increased temperatures and changing precipitation were studied using a simple water balance model. The model was set up for 8 study sites in Denmark representing five different forest stands of (Norway spruce (*Picea abies*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotuga menziesii*), beech (*Fagus sylvatica*) and oak (*Quercus robur*), different climate, soil and forest management gradients in Denmark. The model predicts interception, evaporation and transpiration, daily soil moisture content and drainage. The model was validated with 18 year time-series. The model results were also used to calculate seasonal and annual drought stress indices. The model was then used to predict the effects of increased temperature combined with changing precipitation amounts and seasonal distribution. This study showed that a better knowledge of the seasonal distribution of precipitation under climate change is necessary to estimate the effects of increasing temperature.