FORESTS´ FUTURE:
Consequences of Bark Beetle Calamity for the Future of Forestry in Central Europe

Book of Abstracts

Forestry and Game Management Research Institute

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2020

The workshp was organized under the auspices of the Czech Minister of Agriculture
Miroslav Toman

MINISTRY OF AGRICULTURE OF THE CZECH REPUBLIC

And under the auspices of the Vysočina Region

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Dear colleagues,

for several years the bark beetle infestation was of increasing importance until it has developed to the most serious threat to forests that the modern forestry remember. This is particularly true for my country, where forests are composed of the Norway spruce in 50% and of Scotch Pine in 16%. Nevertheless, all the Central European region is affected not only by the forest decline but also by slump of the wood market. This situation led us to the idea to organize a common workshop of European scientists, researchers and forest owners, where we can openly discuss the problem and try to find some common strategies for the future. The Forests´ Future.

Now you hold the Book of Abstracts of the Workshop, which has not been realized in the end. The corona virus COVID-19 epidemic closed us in our countries and in our homes and we had to cancel the meeting. There may be the time to beat swords into ploughshares, but now came the time to alter the conference bags (which were already prepared) into the protective masks.

The meeting itself will be realized next year, from 22nd till 25th March 2021. The situation with the bark beetle will be different from today, most probably more dramatic, partly also because the society in general will have more burning issues to tackle. Please safe the date, your voice will be needed.

Until then take care and stay in contact.

We are looking forward to see you in Jihlava in March 2021

Vít Šrámek

on behalf of the organizing committee

director of Forestry and Game Management Research Institute, Strnady

Dear participants of the workshop,

since dry period 2015–2018, the bark beetle calamity has been spreading through forests of our country. This situation is particularly new from several points of view: the amount of sanitary cutting is the highest in the history, it was nearly doubled every year, since 2015. We are also aware, that not all the infested trees can be properly treated due to limited logging capacities. Finally, the oversaturation of the wood market causes vital economic problems to all the forest owners fighting the calamity.

Norway spruce, representing 50%, is the most common tree species in the Czech Republic, covering more than 1.3 million ha of the forest area. The change of the species composition to more stable, mixed and broadleaved forests, is ongoing – the proportion of the broadleaves in artificial forest regeneration is nearly 45% - but successive change needs some reasonable time. Currently we are facing vast deforestation, even higher than the two major cases in our modern forest history – gypsy moth calamity in 1919–1927 and the air pollution decline in 1970–1985. Large clear-cuts are of environmental risk, represented by soil erosion, deterioration of hydrological functions or impaired carbon sequestration. The demand of suitable reproductive material is increasing, new methods for reforestation of the vast clear-cuts are used. Successful regeneration, however, is complicated also due to economic situation of the forest owners, who have to deal with high reforestation cost in one side and negligible income from the felled wood in the other.

The Ministry of Agriculture of the Czech Republic takes measures to tackle the situation, starting from changes in legislation, which allow to the foresters to concentrate their capacities and effort to forest protection in the most endangered areas. Also the financial contribution to the forest owners has achieved record amount in the last year. The government of the Czech Republic has agreed the new Forest Policy Conception, reflecting the bark beetle calamity, in February 2020. At the same time, we know that this is not an isolated problem of our country. Wider, European view, can bring us substantial benefit in sharing knowledge and experiences. For this I personally appreciate your active participation in this Forests´ Future workshop and I wish you a fruitful and successful meeting.

Miroslav Toman

Minister of Agriculture of the Czech Republic

The Forests of the Vysočina Region and the bark beetle calamity

The forests in the Vysočina Region occupy more than 30% of its territory. According to 2015 data, the forests were made up of 72% of the Common spruce. The next most represented wood species were Scotch pine at 10% and the Common beech at 4%. Thanks to the high value of the production capacity of the woody plants, soils suitable for growing spruce and up to 2015 suitable weather conditions resulted in above-average production.

The region has been well aware of the low ecological stability of forest stands from the very beginning of its existence and created conditions for the growth of species to become more varied in terms of forest regeneration. Thanks to the state and regional subsidy policy and the exercise of delegated powers (e.g. discussions and approval of forest management plans) have led to achieving a state in which the newly emerging forests over the past 20 years are almost about half more colourful than the requirement under Act No. 289/95 Coll., on Forests and Amendments to some Acts (The Forest Act) as amended by subsequent legislation.

Emerging etiolation of spruce and five years lasting extremely dry and above-average temperature period, in combination with other factors, caused a devastating disintegration especially of spruce forests. This is currently the most affected region. The expansion of the bark beetle calamity occurred despite the fact that since its beginning a number of activities has been developed to stop its spreading. As a result the spread of bark beetle calamity was not prevented in the Vysočina Region either, as in the Moravian-Silesian Region, the Olomouc Region, the Zlín Region and the South Moravian Region, from where the calamity originally moved to the Vysočina Region.

The experts from the Forestry and Game Management Research Institute (public research institution) date the beginning of the bark beetle calamity in the Czech Republic to the last years of the last century, when the disintegration of spruce stands in North Moravia occurred gradually, starting from the lowest localities. The bark beetle calamities in the Czech Republic grew in strength over time and hit the Vysočina Region in full force on such large scale that it was not possible to handle it without a considerable help by favourable weather conditions. The shortage of workers, logging capacity, timber transport, including related forest technology did not help to solve the problem either. Wood oversupply on the market due to a significant contribution by the small forest owners caused the trade with the bark beetle material very competitive, resulting in even worse situation.

Forest managers in the Vysočina Region are faced with another huge challenge – to reforest large calamity clearings as quickly as possible. The state and the Regional Authority try to help them in this problem through a subsidy policy among other things. In order to establish species-rich forests, many difficulties have to be overcome. In addition to many practical obstacles, there is one that can be called sector conservativeness.

Forest owners are experiencing a very difficult time. Let us hope that they will be able to overcome all obstacles and that the Vysočina will gradually be covered by forests which will bring the maximum benefit to society and will be sustainable even in times of climate change It is the duty of the whole society to help them in this difficult task.

Ing. Bc. Martin Hyský

Forestry and Water Management, Agriculture and Environment
Vysočina Region

Content:

Session 1: Current State and Close Future of bark beetle infestation in Central Europe

Session 2: Ecology of Forest Stands after bark beetle infestation

Session 3: Reproductive Material

Session 4: Silviculture

Session 5: Impact on Economy of Forest Management and Forest Owners

Current state of bark beetle outbreaks in Poland

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In Poland, current problems of forest protection are primarily related to the deteriorating health of stands due to climate change. The systematic impact of climate-related phenomena, especially droughts, reduce the health condition of stands that are massively attacked by bark and wood boring beetles or colonized by fungal pathogens. For example, long-term droughts prevailing in the last two decades have significantly contributed to the reduction of the health condition of *Picea abies* stands, particularly in Southern and North Eastern Poland. This process intensified when fungal pathogens (mainly *Armillaria* spp.) caused the decrease in the health of spruce stands, which were consequently attacked and killed by *Ips typographus*. Prolonged drought combined with high air temperatures, especially in the summer of 2015, caused a rapid decrease in groundwater levels resulting in large-scale weakening of *Pinus sylvestris* stands. Currently, bark and wood boring insects and fungal diseases are the most important factors causing the death of pine forests. Of the insects, *Ips acuminatus* and *Phaenops cyanea* belong to the most dangerous secondary pests of Scots pine.

The aim of the presentation is to provide information on the latest history and current state of outbreaks of the two bark beetles, i.e. *I. typographus* on Norway spruce and *I. acuminatus* on Scots pine, in Poland. Factors contributing to the observed expansion of outbreak range of these two insect pests are discussed. Methods of bark beetle control in forests under various ownership categories and management/conservation regimes are presented. Studies on the new methods of population monitoring and management of bark beetles are briefly discussed.

Acknowledgements:
This work was supported by the project *The short-term forecast of the occurrence of major pests and infectious diseases of forest trees in Poland* funded by the Polish State Forests, National Forests Holding.

Development of bark beetle outbreaks in Slovakia from 1960 to 2019

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The prevalence of insect outbreaks and various diseases in spruce and pine forests in Slovakia has intensified in recent years and stands are declining rapidly. The current bark beetle outbreak is most severe in recorded history. While in 1960 the sanitary felling due to bark beetles reached 99 thous. m^3, in 2018 it was 3.8 mil. m^3 and in 2019 a similar volume. The area of coniferous species has been decreasing; since 2005 from its original 41% down to 37.2% in 2017. The most declining tree species is Norway spruce, whose percentage decreased by 3.8% (from 26.3% down to 22.5%) since 2005. Area of spruce forests is approximately 460 thous. hectares. Pines, mostly Scotch pine and Black pine cover 7%.

Bark beetles attacking predominantly Norway spruce (97%), far fewer Pines (2%) and other tree species. Out of that, 98% of damages on Norway spruce is caused by *Ips typographus*, and 2% by *Ips duplicatus* and *Pityogenes chalcographus*. *Ips acuminatus* and *Ips sexdentatus* are dominant species on Scotch pine.

There are two major factors of bark beetle outbreaks in Slovak spruce forests. First are wind disturbances (central mountains) and second are droughts in interaction with Honey fungus (*Armillaria* spp.) which are located in the northwest part of Slovakia (sandstone mountains).

The current bark beetle outbreak in Slovakia was caused by large wind storms from 2004 and 2014. Another important factor was the implementation of a law on ”Nature protection” from 2003 which forbids windthrow removal and salvage logging of infested trees in areas with a higher level of protection. Uncleared windthrow areas in protected localities initiated bark beetle outbreaks throughout Slovakia.

We believe that newly implemented law on ”Nature protection” from 2019 which is even more strict about the management of protected areas and its surroundings, climate change, low price of infested spruce wood, and lack of forest labor will aggravate an already bad situation in our forests.

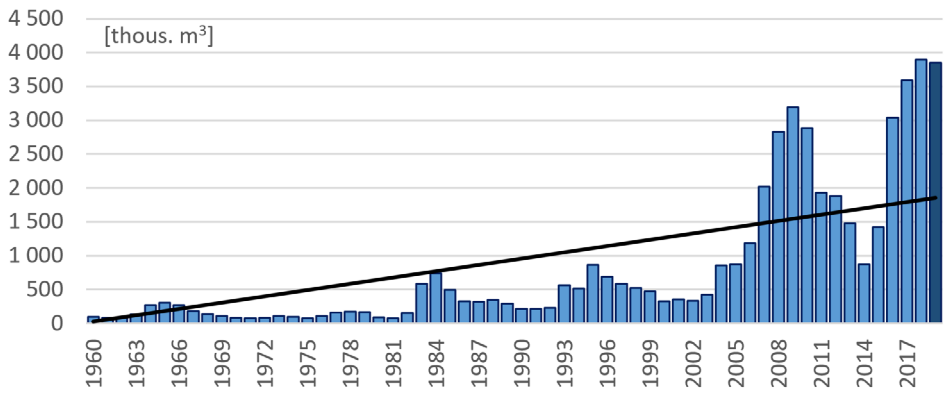

Fig.1: Development of bark beetle outbreaks in Slovakia

The outbreak of *Ips typographus* in Northern Austria

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Since August 2015 spruce bark beetles have been causing massive damage in spruce forests of Northern Austria; the first intensive attacks became apparent in the region Waldviertel (Province Lower Austria). Extreme drought affected this area in the summer. *Pityogenes chalcographus* caused unusually high damage besides *Ips typographus*; one third of the totally damaged volume of 2.4 mio m³ was attacked by the former species. Bark beetle attacks increased in the successive years and reached the all time record of 5.2 m³ attacked volume in 2018. *I. typographus* was the clearly dominant species and accounted for 90% of the damage. The ongoing bark beetle outbreak mostly affects the areas along and north of the Danube. In other parts of Austria, no unusually high bark beetle damage was recorded. The massive attacks in the affected areas continued in 2019. A correlation of bark beetle damage with climatic conditions is obvious. Damage rate by bark beetles in the outbreak regions Mühlviertel and Waldviertel from years 2003 to 2018 were positively correlated with spring-summer temperature and negatively correlated with annual precipitation. Other than in earlier outbreaks no massive damage by storm preceded the gradation of the beetle. Damage by ice breakage was recorded in December 2014; however, the area was clearly smaller than the area affected by bark beetles in summer 2015. Temperatures in the last years allowed development of three generations of *I. typographus* in the outbreak areas; on the other hand spruce suffered from very low precipitation since 2015. Besides spruce, bark beetle attacks increased also on *Pinus sylvestris*; *Ips acuminatus* was the dominant species followed by *Ips sexdentatus*. Also other tree species have been affected by drought and attacks by bark beetles or fungal infections of woody organs.

The most important strategy for control has been early detection and rapid removal of infested trees. There are big differences between forest owners; the diverse ownership structure in the most affected areas complicates bark beetle management and is a major obstacle for any attempt towards a regional approach. Great effort was put into raising awareness among forest owners with information campaigns and info material. The extend of the affected area as well as the high amount of infested wood made management difficult; lack of work capacity in the forest as well as transport capacity and problems on the timber market turned out to be major problems. Safe storage of infested wood that could not be immediately processed has become an important issue. Various approaches have been considered and tested. Forest growth models under climate change scenarios indicate that conditions for spruce will further become problematic in the outbreak areas. In this context, we need to see the current bark beetle outbreak as one symptom of ongoing climate change. A change in forest tree species composition and management will be inevitable in these regions. No decline in spruce growth is predicted under climate change scenarios in mountainous areas in the near future; however, increasing temperatures will also create more favorable conditions for bark beetles and hence increase the risk for outbreaks in these areas.

Forest protection situation and measures against bark beetles in Germany

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With a share of nearly 25 percent of the forest area, spruce is currently the most important tree species in Germany. Damage caused by bark beetles, in particular the European spruce bark beetle (*Ips typographus* L.) and the six-toothed spruce bark beetle (*Pityogenes chalcographus* L.), occur regularly. They cause the most serious biotic damage to the German forests.

On the basis of the recorded amounts of damaged wood in the period between 1990 and 2019, two waves bark beetle gradations from 1991 to 1996 and from 2003 to 2009 and the start of a third from 2015 can be shown for Germany. The Outbreaks always resulted from devastating storm or snow damage in combination with droughts or from 2003 also exclusively from summer heat and dry periods. In 2015, the first bark beetle damage occurred in Bavaria after the storm “Niklas”. The situation was exacerbated by the storms “Kolle”, “Xavier” and “Herwart” (2017), “Friederike” and “Fabienne” (2018) and “Eberhard” (2019) in combination with the extreme summer droughts and heat waves in 2018 and 2019. The main areas of damage are in the states of North Rhine-Westphalia, North Rhine-Westphalia, Rhineland-Palatinate, Lower Saxony, Hesse, Saxony-Anhalt, Thuringia, Saxony and Bavaria. The main areas of damage are in the states of North Rhine-Westphalia, North Rhine-Westphalia, Rhineland-Palatinate, Lower Saxony, Hesse, Saxony-Anhalt, Thuringia, Saxony and Bavaria. Storms and bark beetles caused a total of 105,000 m³ of harmful wood in 2018 and 2019. 200,000 hectares need to be reforested.

The extent of the damage caused by bark beetles is partly due to errors in the reprocessing of stormwood. The processing of stormwood was started too late and large areas were processed in front of small areas or individual trees. Private forest owners are overwhelmed with the detection, cutting and removal of infested trees. There is a lack of processing resources like forest workers, harvesters and storage places outside the forest.

The damage to the spruce stands has already changed the landscape regionally and will continue in 2020. Forest protection measures aim to prevent the formation of large areas of damage and to gain time for the adaptation of forests to climate change.

Recent forest and bark beetle damages in the Federal State of Saxony

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Damages in a previously unknown scale caused by bark- and woodbreeding beetles characterize the current situation in the forests of Saxony. A special role is played by bark beetles (Scolytidae). The causes of this development are a series of abiotic damages (storm and snow) since 2017 and especially the extremely warm and dry growing seasons 2018 and 2019. Particularly affected stands of Norway Spruce in the hill country and the lower highland are infested by *Ips typographus*. On these sites, which are unsuitable for this tree species, large-scale disintegration of the spruce stands occurs. A lot of these forests are in private hands, one reason, that the large-scale implementation of an integrated bark beetle pest control is very complicated. Above-average damages also occur in spruce stands in the middle and higher altitudes.

Increased outbreaks of *Ips cembrae* were recorded in larch stands. In the pine-dominated forest areas in northern Saxony, infestations by *Ips acuminatus*, *Ips sexdentatus*, *Phaenops cyanea* and other species caused the dissolution of particularly predisposed stands. Also in deciduous tree stands an increased mortality can be observed. Reasons therefore are mostly drought, partly in combination with beetles and fungi.

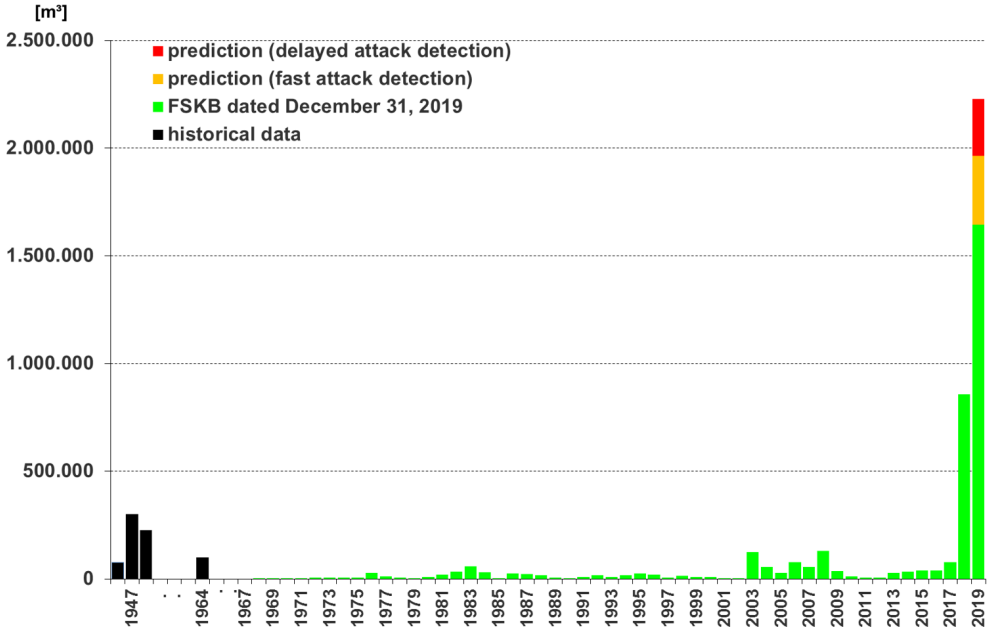

Fig.1: Long-term statistic for volume [m³] of infected Norway Spruce by *Ips typographus* (partially with *P. chalcographus*) on Saxon territory (Forstschutzkontrollbuch (FSKB), January 17, 2020, Franz Matschulla)

Spruce bark beetles: Actual mass attack, strategies and management in Switzerland

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Ips typographus, the spruce bark beetle, is considered the most important endemic forest pest in Switzerland, as in much of central Europe. Data on the relative size of populations have been recorded since 1984 mainly based on the reported volume of spruce timber infested and killed. At present, the second highest infestation of bark beetles ever recorded occurs in Switzerland. This poses a great challenge for forest services and forest owners. The situation is aggravated by the fact that not all of the attacked timber can be harvested and sold.

The government's strategy is to intervene mainly in protection forests, pursuing a traditional forest protection. These activities are financially supported by public funds. If the owners do not act in time, substitute measures can be taken in critical cases. But on the other hand, the law does not prescribes a general duty of management. In some cases, also unmanaged protection forests are able to fulfill important functions.

Outside protection forests, the strategy is delegated and determined by the cantons, usually in cooperation with the forest owners. There are less regulations for these stands, and mainly only recommendations are made. Their implementation and the activities taken vary considerably and often depend on the structure of forest ownership and the financial and technical resources available to it.

The following points are of primary importance when authorities define strategies for measures and recommendations:

a) Safety for forest visitors, forest workers, buildings, traffic routes and power lines.
b) Priority setting in space and time according to the main forest functions and harvest and sales opportunities of damaged timber.
c) Structure and condition of existing forest stands and risk of bark beetle infestation spreading over a large area.
d) Prospects of success of potential measures.

The Swiss Federal Research Institute WSL consults the authorities on demand. The national „storm damge" handbook (see reference) will be revised and adapted to the actual damage by climate change and bark beetles.

New for Switzerland is the temporary storage of infested timber in bark outside forests. To this end, individual cantons are making financial contributions and coordinate the provision of storage sites. But despite all efforts, under the actual conditions more bark beetle infested trees will regionally remain in stands and will not be harvested, even in production forests, this at the owners economical risk and loss.

Reference

BAFU (Federal Office for the Environment FOEN) 2008: Sturmschaden-Handbuch. Vollzugshilfe für die Bewältigung von Sturmschadenereignissen von nationaler Bedeutung im Wald. UmweltVollzug Nr. 0801. Bundesamt für Umwelt, Bern. 3. überarbeitete Auflage, 241 p.

Recent spruce bark beetle calamity in Czechia

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The current bark beetle calamity (or catastrophe) has evolved progressively since 2015. The reason of the calamity is primarily a combination of climatically extreme periods and an ineffective forest protection system. Extremely warm weather and lack of precipitation weakened the forest stands by drought. The key problem is the late processing of bark beetle infested trees. The calamity spreads by both, natural and human means, from the north-eastern part of Czechia (northern Moravia and Silesia) south and westward, to south Moravia and nearly whole southern half of Bohemia. This areas are currently disastrously affected (except in the north-east, where the disaster has lasted already for many years). The main bark beetle species causing the outbreak is *Ips typographus*.

The prognosis is negative for the coming years, in the sense of a further increase of volume of infested stands by bark beetles. There is an annual 1.5 to 2-fold increase in this volume (in 2019 was infested about 30 million m^3 of spruce woods), for the following year, 2020, is a similar assumption. At present, only a favourable weather for at least two years could significantly influence this trend. Next actual the most endangered forests due to the bark beetles are pine stands.

Acknowledgement:

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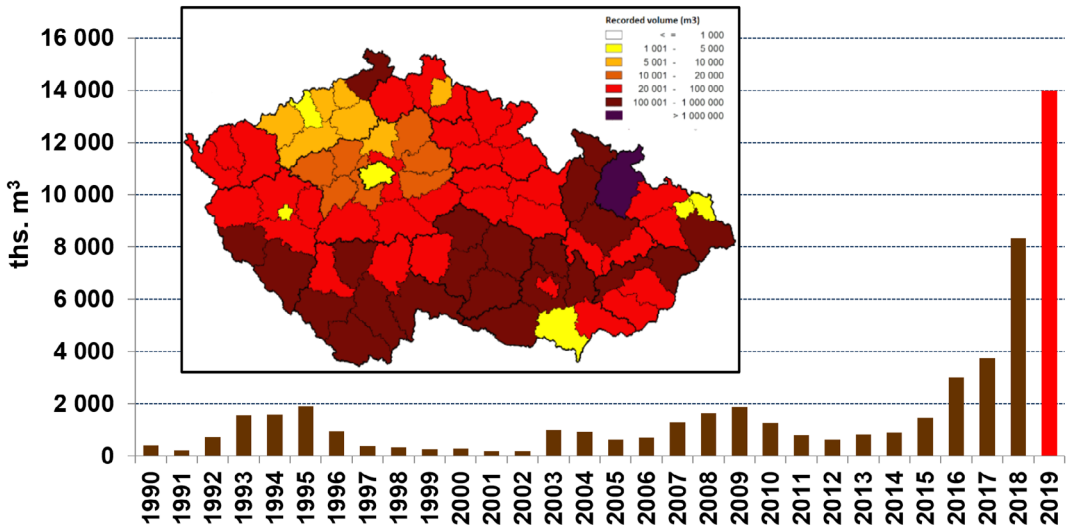

Graph: Recorded volume of felled spruce wood infested by bark beetles since 1990 (2019 – estimated volume; volumes based on 70% of the forest area in Czechia)

Map: Recorded volume of felled spruce wood infested by bark beetles in 2018

Bark beetle outbreaks in Norway – status and outlook for the north-western corner of Europe

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In Norway, spruce reaches the north-western corner of its distribution in Europe. Norway experienced an *Ips typographus* epidemic in the 1970s killing ~5 million m^3 Norway spruce. Despite massive ongoing bark beetle outbreaks in southern Scandinavia and Central Europe, Norway has not had an *Ips typographus* outbreak in almost 40 years. In 2018, severe summer drought challenged Norwegian spruce forests, damaging trees and enabling *Ips typographus* to complete two instead of one generation, but no outbreak was initiated. Here we discuss why Norway's spruce forests have avoided bark beetle epidemics for several decades, how climate change could increase outbreak risks in the future, and how these risks could be monitored.

Population dynamics of the spruce bark beetle in Sweden after the extremely warm and dry summer 2018

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The summer of 2018 was the warmest and driest ever recorded in many places in southern Sweden. This triggered the largest Swedish outbreak ever recorded for the spruce bark beetle *Ips typographus*: in 2018 3.5 million m^3 and in 2019 7 million m^3 was killed. It is well documented that tree mortality caused by bark beetles increase in drought years but the mechanisms are not fully understood. One hypothesis is that fewer beetles are required for overcoming the defenses of drought stressed trees. The outbreak offered a unique opportunity to study this. In the autumn of 2018 (i.e. the first year of the outbreak) and 2019, bark samples were collected from about 100 killed trees in southern Sweden. Attack density (density of maternal galleries) and reproductive success (daughters per mother) were estimated from the samples. The spruce bark beetle was the main bark beetle species. In 2018, the average density of maternal galleries was 294 per m^2 bark which is considerably lower than it usually is in standing trees and thus supporting the hypothesis stated above. The reproductive success was 5.1 daughters per mother, which is higher than usually recorded from standing trees. The low attack density, resulting in lower intraspecific competition, may explain the high reproductive success. The high reproductive success, in combination with reduced tree vitality, may explain the doubling of tree mortality from 2018 to 2019. In 2019, average attack density increased to 394 maternal galleries per m^2 bark while the reproductive success decreased to 2.3 daughters per mother. Increasing tree vitality, and high beetle densities, may have contributed to the higher attack density. Higher intraspecific competition may have contributed to the reduced reproductive success. Harvester logging of attacked trees is the main control method in Sweden. Challenges include timely cutting (i.e. cutting before the new generation emerge) and the risk that the bark, with bark beetles, fall of and remain in the forest. Protected areas only constitute a small proportion of the forestland in southern Sweden and thus do not influence outbreak development.

Ips typographus- population changes, control practices and success

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Spruce comprises approximately 18% of all Latvian forests. During recent years, damage to spruce stands caused by *Ips typographus* has significantly increased. According to monitoring data, population size of *Ips typographus* has increased more than two times in 2019 compared to 2018. However, bark beetle control plan was developed during the outbreak after storm of 2005. This plan includes silviculture practices as well as use of feromone traps in clearcuts. Ips typographus outbreak of 2007 was effectively reduced within two years (fig.1).

Currently *Ips typographus* outbreak is observed in Northern and central part of the country (Fig.2.). Practices used during outbreak of 2007-2009 are applied since 2019 mainly in state owned forest stands. Early results suggest bark beetle population decrease. Approximately one-half of the forests belongs to private owners. The major concern is how to plan forest protection measures in larger scale in privately ownf forest stands while average size of privately owned forests are less than 20 ha. 54% of forest owners own less than 5 ha of forest land.

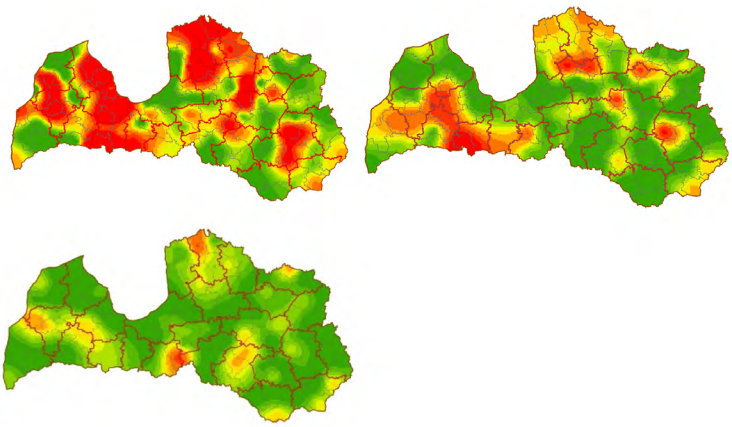

Fig. 1: Damage to forest stands by *Ips typographus* in Latvia from 2007 to 2009

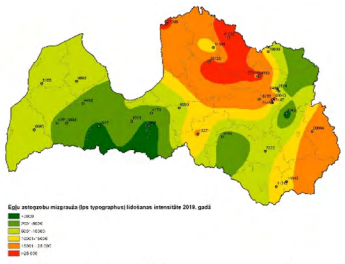

Fig. 2: Flight activity of *I.typographus* in 2019

The one of the major points in bark beetle control is to avoid selective sanitary cutting in affected stands from 1st of March until 1st of September. The main activity is clearcuts of heavily or moderately infested stands throughout the year and use of pheromone traps in clearcuts in summertime.

The effectiveness of Remote sensing data obtained from Sentinel satellite was tested for use as an early warning tool. However, it was concluded that these data currently show little perspective as an early warning tool, but it useful to assess extent of the damage when spruce canopies start to dry- meaning that bark beetles have already left these trees.

Decline of Norway spruce special cultures situated in North East of Romania

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To increase the pulpwood production in Romania, many broad-leaved stands in the hilly area have been replaced between 1972 and 1987 with Norway spruce special cultures. In Suceava County (NE of Romania) only, more than 1700 ha of special cultures were installed. After 1986 drought, the first debility symptoms were observed in some of these stands, mainly the reduction of annual radial increment (Olenici et al., 2010). Then, the health situation of these stands was significantly degraded by repeated attacks of the little spruce sawfly, *Prisiphora abietina.* Improper forest management, characterised by delayed and low intensity stand's thinning, favoured the gradual increase of competition between spruce trees and mass debilitation of them during more frequent, prolonged and intense drought episodes that occurred after 2000. Sanitation cuttings were also not timely applied. All these factors predisposed the trees to attack by bark beetle (mainly *Ips duplicatus*) and favoured the increase of bark beetle population. A large-scale outbreak took place between 2007 and 2014 and many spruce stands have been decimated. In the place of those cultures, new forests have been created using local deciduous trees species.

Fig.1: Norway spruce stand attacked by bark beetles

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Bark beetle infestation in Slovenia: causes, current state, impacts, lessons learned and perspective

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In the last decade, Slovenian forests have suffered a centennial-record attack by bark beetles. In the period 2014 – 2019 8 million m^3 of Norway spruce were cut due to infestation and 140 million EUR was the financial damage. The causes for infestation originate in climate changes through some natural phenomena: the largest ice sleet of the last 100 years in 2014 (9 million m^3 of logging, € 214 million of financial damage) and the largest wind-break in 2017 (3 million m^3, € 48 million of damage). And all mentioned above was going on in the circumstances which were very suitable for bark beetles: in hot and dry summers.

In these circumstances Slovenia Forest Service together with forest owners and all other stakeholders did a great job during last infestation and prevented much bigger possible damage than it happened. Almost one third of total 413.000 private forest owners were affected, widely also the state which owns 21% of the forest area. From previous 4 million m^3 average year cut rose to 6 million m^3 in the years after 2013. The share of N. spruce decreased from 32% in the stock to 30% and in spite of the calamity it almost preserved its total volume of 105 million m^3. In accordance with Slovenian forestry doctrine and already existing mixed stands the forest renewal was done only in about 5% by planting (with 23 tree species). One of important supportive measures was the increased hunt of large herbivores which are a traditional threat for the natural forest regeneration.

Early detection is a crucial step in managing forest pest outbreaks. Therefore, we have been working intensely on ways to improve the bark beetle monitoring system in Slovenia to improve early detection of bark beetle outbreaks in spruce forests. We develop short term prognoses for bark beetle outbreaks, which are publicly available at https://www.zdravgozd.si/. Also, we have developed phenological models that simulate the development of *Ips typographus* (RITY) and *Pityogenes chalcographus* (CHAPY) based on local conditions, which is one of the steps towards the optimization of the pheromone trapping system.

Bark beetle outbreaks that are predicted for the future, are expected to prepare the grounds for new threats, i.e. invasive alien species. Early detection and rapid response are crucial here as well. Untimely action has resulted in forest dieback due to ash dieback, chestnut blight, Dutch elm disease (to mention a few) throughout Europe. Slovenian forestry is actively involved in forest protection against invasive alien species through plant health surveys for quarantine pests in forests and training for forest owners, forestry professionals and other relevant stakeholders. Currently, we are preparing contingency plans for quarantine pests for forestry in Slovenia. In addition, the general public is actively involved in our efforts to contribute to the mitigation of possible negative effects against invasive alien species in Slovenian forests (www.invazivke.si).

Slovenian forestry is based on natural forest sites. Watching from nature's perspective the bark beetle infestation took away mostly the spruce from the sites where it wouldn't grow by nature or from the stands where the mixture of the species was too much in favour to N. spruce. Considering the processes on Earth over the last 500 million years and the current climate trends, we can conclude that the existence of forests, and even more of N. spruce, is questionable in many areas. But the chance to

survive without climate change mitigation, close-to-nature forestry, preserving wide gene pool, good monitoring system, effective state forest service and fast reaction in early stages of infestation the chances are even smaller. In that way also certain provisions of NATURA 2000 have to be modernized, because as it is now, it doesn't admit climate changes and evolution.

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Bark beetle population dynamics along the southern edge of Central Europe – intensified outbreaks in Croatian landscape since 2003

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Along with the growing instances of bark beetle outbreaks in Central Europe in recent years, the general dynamics of bark beetle populations in Croatian forests have "followed the trend". The widely registered and known 2003 is considered as first major climatic "trigger year" after which bark beetle outbreaks kept reappearing on two major conifer tree species: common spruce and silver fir. Along with repeated episodes of drought and extended hot periods, other abiotic extremes hit the country, two of the most prominent being ice storm in February 2014 and several instances of wind storms following "*Vaia*" in 2018. Still, the total bark beetle related damages were not nearly as devastating as they were in the neighbouring countries (Slovenia, Austria and further into the Central Europe). One of the proposed explanations is the preserved mixture of dominant tree species (particularly in the mixed beech-silver fir stands) that slowed down the bark beetle capability to reach epic population densities like in Central Europe. This closely relates with the long-term practised forest management in these areas where selective cutting lowers and disperses the risk of bark beetle populations that benefit when highly suitable timber and bark material is abundant in large contiguous patches. On the other hand, changes in forest harvest practices, unavailability or high price of forestry workers labour, heightened the risks and in some instances even stimulated local bark beetle outbreaks. Inappropriate or even lacking sanitary activities not performed in a timely manner contributed sometimes with prolonged local outbreaks. Not only have spruce and fir bark beetles intensified in their population dynamics, other conifer breeding species have followed (*Tomicus* spp, *Trypodendron* spp,). A very recent episodes of Mediterranean species acting far more aggressively than historically known (*Tomicus destruens*, *Orthotomicus erosus*, *Ips sexdentatus*) confirm the general consensus that conditions have changed and dynamic balance between the resilient forest and bark beetles is shifting. New element in the whole "picture" relates to the problem of invasive organisms, be it ash bark beetle growth conditioned by *Hymenosciphus fraxineus* destroyed ash stands or spreading of non indigenous bark beetles like *Xylosandrus germanus* facilitated by large amounts of breeding material Europe wide.

Monitoring of the bark-beetle disaster in the Czech forests

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The monitoring of the coniferous forests affected by the actual bark-beetle disaster is based solely on the remote sensing image analysis techniques. The resulting bark beetle infestation map is a GIS thematic layer classifying the Norway spruce (*Picea Abies*) forests based on the automated analysis of the vegetation indices from the PlanetScope satellite imagery covering the entire territory of the Czech Republic. Beside the Planet images, there are two important input data sources provided by the Remote Sensing department of the Forest Management Institute branch in Frýdek-Místek: 1) Actual coverage of the conoiferous forest stands - based on the Map of tree species of the Czech republic created at FMI in 2019 and the forest stand heights derived from the aerial stereo-image matching (nDSM) from national aerial imaging campaign of the State Administration of Land Surveying and Cadastre (ČÚZK), and 2) Actual distribution of clearcuts prior to 2018 - based on the time-series analysis of the change in leaf area index product developed by the FMI for Czech forests using the Sentinel-2. The Planet imagery were used for timely detection of recent sanitary loggings as a result of bark beetle-induced tree mortality as well as detection of dead standing wood in the forest which has to be removed from the forest during winter months. The result is being periodically updated since September 2018 and published (www.kurovcovamapa.cz and www.uhul.cz) three times a year.

According to those maps the Ministry of Agriculture of Czech Republic issued a „Public decree“ (legislation instrument to help forest owners by reducing the regulation of their obligations under the Czech forest law so that they can manage the bark beetle calamity) in April 2019 and updated on September 2019 and on December 2019. The outputs are also used for the General Plan for forest regeneration after a bark beetle calamity.

Development of innovated technologies for control of bark beetles based on semiochemicals, remote sensing and molecular biology

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We see that standardly used methods of bark beetle control have certain limitations. In conditions of climatic change and actual economic conditions, it is almost impossible to stop bark beetle outbreak in spruce stands in low elevations. However, in conditions of mountains forests, successful management of bark beetles should be possible.

Several innovated or new technics are in the stage of development. On way is to improve pheromone traps barriers (in combination with anti-attractants). Second way are improved methods of bark beetle attacked trees identification. Finally, the use of remote sensing or molecular biology methods for assessment of tree resistance to bark beetle attack could be also a good tool. Concepts and preliminary results will be discussed.

Acute drought predisposes Norway spruce stands to attack by the Eurasian spruce bark beetle

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The Eurasian spruce bark beetle *Ips typographus* is the main biotic disturbance agent in European Norway spruce forests, causing vast amounts of salvaged timber in the recent decades. Population densities have reached unprecedented levels from 2015 on in the Czech Republic, Bavaria and Austria. The constellations of predisposing factors differ with geographical region; yet, temperature sums available for generation development and drought were shown to significantly promote the hazard of bark beetle infestations in a study based on forest inventory and salvage cutting data of the Austrian Federal Forests. Stands where attack spots have already occurred in the previous year and showed high proportion of Norway spruce, increased stand age, and very low/high stand densities have been particularly susceptible to continued infestation. Even when the presence of alternative tree species cannot prevent attack during an epidemic phase in highly susceptible areas, predisposition assessment, simulation of bark beetle phenology and water balance models simulating drought proxies such as transpiration deficits are useful tools to evaluate future risks in not yet affected regions. Norway spruce constitutes one of the the main tree species in mountainous and alpine forest ecosystems which sustain important forest functions and ecosystem services in these sensitive areas.

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Predictors of bark beetle infestation – Overview and First Results of the IpsPro Project

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Bark beetles are damaging vast forest areas in central Europe with increasing pace. In order to plan forest management activities it is important to predict expected amounts of bark beetle damage. But causes of bark beetle infestation may have changed leading to an inaccuracy of current prediction methods. Therefore, IpsPro aims among other things to improve existing methods for risk assessment by identifying important predictors of bark beetle infestation. Based on historical data of previous beetle attacks and stand predisposition, dynamic factors such as the availability of breeding material or beetle pressure are used to estimate the probability of infestation. The project results will be incorporated into an online risk prediction tool that provides a 7 day forecast. In the "Long-term data" work package we identified important predictors of bark beetle infestation at the district level using "Boosted Regression Trees" (Elith et al. 2008). It was based on two model regions in Saxony, Germany (Fig. 1). The amount of damaged wood from the previous year, the climatic water balance and the amount of precipitation during the vegetation period could be identified as important predictors.

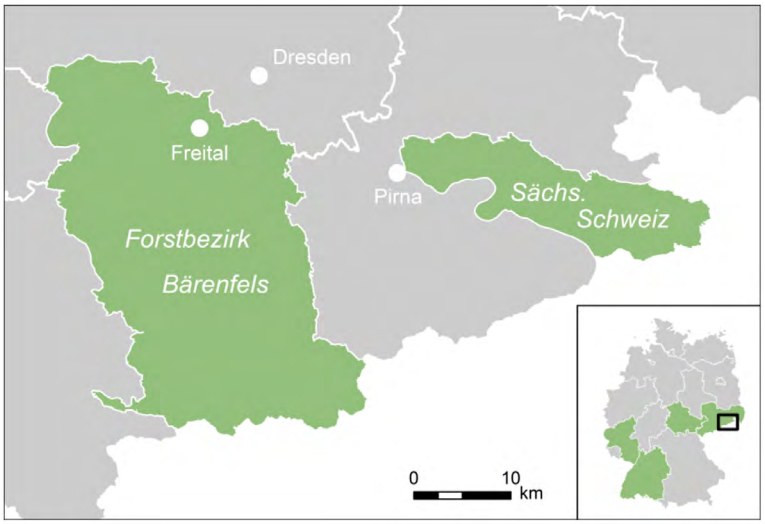

Fig.1: The two Saxon model regions forest district Bärenfels and national park Saxon Switzerland (big image) and the four federal states involved in IpsPro (small image)

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The Last Tree Standing: Study of Norway spruce (*Picea abies*) characteristics surviving *Ips typographus* outbreak in the Bohemian Mountain Forest using remote sensing and GIS methods

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Bark beetle calamities triggered by climate change, windfalls and drought, disturb monodominant Norway spruce forests across Central Europe. Despite severe herbivore populations, a minor proportion of trees survives. These last survivors are often referred to as Last trees standing, or LTS. Based on Google Earth Pro software aerial timeseries photography and a set of established criteria, we identified and mapped 184 LTS in 6 localities in Šumava National Park at the border of Germany, Austria and Czech Republic. We measured or estimated tree and stand level characteristics of LTS. Polygons with boundaries corresponding to the margins of 13861 Mha of disturbed area were created, LTS occurrence being 0.013 LTS per ha (1 tree in 2787 survives). To solve the issue of the absence of conventional 'control' group of trees, we generated 1.6 mln of points that represent initial positions of the original trees. Generation was based on the value of derived pre-outbreak stand density. Results of Hot spot and Cluster analyses uncovered clustering structure of LTS spatial distribution. LTS are presented at S, W and SW slopes of the disturbed area, at sites exposed to higher levels of solar irradiation and located at higher elevations than the simulated 'control' (beetle-killed) trees. We show that distance to the nearest living mature tree (inverse proxy of LTS occurrence) depends the proportion of shadowed stem in all localities. This supports our hypothesis that higher level of individual shading may protect tree stems from overheating and reduce insolation stress, facilitating better tree defences against beetles. In addition, lower bark temperature inhibits excessive emission of bark beetle primary attractants. We found that distance from LTS to the nearest LTS is modified by the proportion of shadowed stem and pre-outbreak stand density and varies among localities. Site conditions, individual and collective shading define a quarter of variability of LTS occurrence. Our results point to beneficial effects of thinning stands to an extent that ensures maximum crown length development.

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A large number of spruce bark beetles overwinter in the soil

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An effective control of forest pests requires a knowledge of their ecological requirements and bionomy. As a result of changing environmental conditions, some of the findings of earlier studies may no longer be valid. For example, spruce bark beetle (*Ips typographus*) is known to overwinter under tree bark and in the soil. The number of beetles which spend winter in the soil litter is traditionally considered marginal. Research studies report a proportion of about 10% of the population, while as the altitude increases, this proportion is even lower. Recently, we have observed that even when all bark beetle-infested trees are felled and removed from the area, there is a massive attack of bark beetles to the surrounding uninfested trees in the following year. The present study tests the hypothesis that the cause of this phenomenon lies in a large number of beetles overwintering in the soil litter. At six sites (central and northern Bohemia, 400–800 m a.s.l.), in the spring period of 2019 (April and May), we laid traps (modified photoeclectors) for bark beetles overwintering in the soil. At each location, we selected three sample trees not very distant from each other. One tree was not attacked, another was attacked with partial bark fallen and yet another was attacked but still without the bark fallen, fully remaining on the tree). For each sample tree, in two directions (south–north), three traps were placed under the crown in one-meter intervals from the base of the trunk, i.e., a total of six traps per tree, 18 traps per site. Before installing the traps, we removed larger pieces of bark lying on the ground. This prevented distortion of the results by counting beetles wintering in the bark.

The obtained results show significant differences among individual sites. However, the proportional differences among the different types of selected trees were similar. We found most spruce bark beetles under trees with fallen bark. In the area under the crown (within a three-meter radius from the trunk), these were thousands of individuals (the maximum observed was 23,000 individuals). Lower numbers of beetles were found under infected trees without the bark fallen. Negligible numbers (in the order of tens of individuals) were found under uninfested trees. In both types of infested trees, most beetles were recorded near the trunk. This finding suggests that these beetles were “originally” overwintering in the bark (before its fall). In contrast, the observed consistent occurrence of beetles under healthy trees indicates that the beetles under them originated probably from the nearby bark beetle infested trees. The results also show that the percentage of beetles overwintering in the soil is currently around 20–30%.

The experiment has shown that the soil under the trees can accommodate a large number of overwintering beetles. Their number depends directly on the amount of the fallen bark. Since it is well known that a large proportion of infested trees “spontaneously” lose amounts of bark during winter, it is crucial to remove as many infested trees as possible during the autumn season as part of defensive interventions.

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Photoeclectors used for trapping bark beetles overwintering in the soil

Spruce bark beetle population dynamics in Switzerland from 1984 to 2019

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Ips typographus, the spruce bark beetle (SBB), is considered the most important forest pest in Switzerland, as in much of central Europe. Data on the relative size of SBB populations have been recorded since 1984 mainly based on the reported volume of spruce timber infested and killed by SBB. Foresters are obliged to carry out salvage logging of such timber and report to the authorities the volume of salvaged and remaining (standing) infested timber. These valuable data are a reliable proxy for SBB population trends at local, regional and national scales, and they provide an excellent opportunity to study the various drivers affecting SBB populations including windthrow, drought, temperatures more or less favourable to beetle development, and, to some extent, the effectiveness of measures designed to mitigate SBB impacts. Historic outbreak patterns reflect changes in the availability of breeding material mainly due to windthrow from storms such as Vivian (in 1990) and Lothar (in 1999). In 2019, the second largest amount ever of salvaged timber due to SBB outbreaks has been recorded. Contrary to previous outbreaks, this event appears to be due to the extreme drought particularly in 2018 and subsequent related tree mortality that occurred in much of Central Europe and with only limited contribution of windthrow. However, SBB background populations had been building up prior to 2018 which is likely to have played a contributing role. These trends and factors involved in SBB outbreaks will be reviewed and examples of previous and ongoing research with these data will be presented.

Branch chipping decreases the occurrence of the large pine weevil

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The large pine weevil (*Hylobius abietis*) is a major pest of seedlings, especially coniferous trees. The damage caused by this pest is likely to increase in the future for two reasons. First, due to the bark beetle calamity, the area of clearings which need to be replanted with seedlings is constantly growing. Second, there is an increasing pressure from the society on environmentally friendly management, which is not very compatible with the use of chemical forest protection. For these reasons, I have explored alternative ways to decrease the damage to seedlings caused by the large pine weevil.

In the pine forests of eastern Bohemia, we observed the occurrence of beetles in areas with different management methods. In half of the plots, the branches after tree felling were left on the spot; in the other half, they were chipped and incorporated into the soil. In each of the patches under research, a pitfall trap was placed, consisting of a bucket covered with a perforated bowl. Other environmental parameters were measured as well, such as crown canopy, the amount of logging residues, undergrowth cover, the number of seedlings and the number of stumps in each plot.

A total of 1,100 beetles were captured in the twenty patches. Approximately two thirds of the beetles were caught in areas with the branches left unchipped. We have also found a statistically significant negative dependence of the number of caught beetles on the canopy openness and on the amount of undergrowth. The higher numbers of beetles in the areas with the branches left unchipped, and thus drying, can be explained by the higher amount of volatile organic compounds that could have been exuding from the branches and attracting the beetles for a longer time. Soil disturbance in areas with chipped biomass could also have had an impact, as it did not provide sufficient shelter for the beetles.

Based on the obtained results, the chipping of logging residues and their incorporation into the soil as well as leaving a lower canopy cover appear to be methods suitable for limiting the damage of seedlings by the large pine weevil. My results are in line with studies recommending the digging of soil and amassing around the seedlings with mineral soil as methods of protecting the seedlings against damage.

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Impact of bark beetle outbreaks on carbon sequestration in Slovak forests

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In the Central European region, Slovakia, in long-term, is the country with the highest volume of incidental felling caused by bark beetles per 1 ha of spruce forests. Due to repeated wind calamities, extremely dry and warm vegetation seasons, further limitation of management associated with leaving unprocessed calamity, no radical improvement of health status can be expected in Slovakia (Vakula et al. 2019). The current outbreak is the largest and the most severe in recorded history. Estimated volume of incidental felling caused by bark beetle insects is 4 million m^3 in 2018. This is a new maximum in Slovakia, an increase of 11% compared to 2017. Of this volume, about 97% of damage and loss of Norway spruce has been caused by bark beetle outbreaks (Vakula et al. 2019).

The aim of the study is to evaluate the influence of outbreaks on spruce stands and carbon sequestration. A modelling approach to estimate carbon sequestration by spruce forests with and without influence of bark beetle outbreaks is presented. Data for the modelling are based on forest management plans (state of forests, planned harvests), Slovak yield tables (growth curves; Halaj & Petráš) and forestry databases (harvested volumes). Carbon sequestration is calculated using gain-loss method according to the IPCC 2006 Guideline (IPCC 2006).

Two management scenarios of Slovak spruce forest development were simulated: (a) standard management without harmful factors; (b) actual management aimed mainly on sanitary logging caused by bark beetle attacks. The results of the simulations show the significant impact of sanitary logging on the age structure of forests, the reduction of sequestered carbon in spruce stands, as well as the increasing of greenhouse gas (GHG) emissions/decreasing of removals reported in the UNFCCC GHG inventory. The impact of bark beetle outbreaks on carbon sequestration by forests is eminent in Slovakia during last two decades.

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Carbon balance on differently managed forest sites after large scale destruction

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Carbon balance is a measure how ecosystem sequester CO_2, or C. Forest, same as other ecosystem is simultaneously carbon sink and carbon source. Annual difference between C uptake (photosynthesis) and C release (respiration) indicates whether an ecosystem mitigates or supports climate change.

Generally, forest in temperate zone acts as C sink. Disturbances, such as fire, wind throws or insect might turn damaged ecosystems into C emitters. Reduced canopy and disturbed assimilation surface fixe less C. On the other hand, more direct sun light, higher soil surface temperature and moisture stimulates decomposition of both soil organic material and fine tree litter resulting in more intensive mineralisation and thus CO_2 emission.

Increasing intensity of natural disturbances caused by changing climate and less intensive forest management are the main reasons for accumulation of dead wood in forest stands. In our study we analyse C balance of 15-year-old windthrow sites in natural Norway spruce forest in the Tatra Mts.

For estimation of C balance (net ecosystem production) on an ecosystem scale (hectares) we applied eddy covariance method. Two flux towers measured both C input (gross primary productivity) and output (ecosystem respiration) during 2019 simultaneously on managed windthrow (wood removed, site reforested, thinning applied) and non-managed site (fallen trees remained unremoved, no reforestation, no thinning). For estimation of component structure of ecosystem respiration (soil, trunk, leaves and deadwood respiration) we applied closed chamber measurement.

Based on eddy covariance measurement both managed and unmanaged sites 15 years after destruction acted as C sink. Managed site sequestered more C than unmanaged site. Elevated C emission on unmanaged site was caused by dead wood respiration which counted at least 8% out of total ecosystem respiration. This estimation might be strongly underestimated as dead wood respiration showed strong temperature dependence and measurement od dead wood respiration was done in relatively cold weather in late autumn.

Changes in upper organic soil layer as a result of clear-cutting

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Serious consequence of bark beetle calamity is the pronounced deforestation in regions of lower and middle altitudes; in Northern Moravia, however, even mountain areas are diseased. Currently the bark beetle affected area could be estimated at 150 thousands ha in the Czech Republic - major part was clearcuted but also the stands with death standing trees are increasing. Regarding the tree species composition more than 1 million ha can be considered as potentially endangered. This situation constitute serious risk for environmental function of forests as soil protection (erosion), hydrological properties (floods, infiltration) or even local climate.

Norway spruce stands are known for thick soil upper organic layer – humus, which contains substantial stock of ecosystem carbon and nutrients. In regions with a historical pollution load heavy metals are safely bound and deactivated in organic complex of soil humus layer. Exposed to the clear-cut microclimatic condition the increased decomposition of soil organic matter can be expected. In "standard" forest management the decomposition is perceived as a positive process which release important nutrients from organic compounds and thus supply growth of newly established forest. Standard forest management, however, allows the clear-cuts with maximum area of 1ha, the real average clearcut area is just of 0,3 ha. The situation can be quite different on large clearcuts due to bark beetle infestation with area of several dozen ha. Further complication may be postponed reforestation, which delays the biomass production and nutrient uptake from the soil. In such conditions we can be afraid of nutrient and dissolved organic carbon leaching to the deeper soil horizons, even to surface outflow from the ecosystems. Also the release of heavy metals in some regions can be potentially hazardous.

Most of bark beetle affected sites will be re-establish as broadleaved or mixed forests. This imply that the upper organic soil layer will be not established in its former thickness and volume which may influence the total carbon stock in forest ecosystems.

All these processes deserve close attention and should be monitored and studied carefully.

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Tracking the associations of tree-pathogenic fungi and bark beetles to prevent future outbreaks

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As a consequence of climate change and globalisation, bark and ambrosia beetles are reaching new territories. With the recent detection of four invasive beetles (*Xylosandrus germanus*, *Gnathotrichus materiarius*, *Cyclorhipidion bodoanum* and *Ips typographus*), the United Kingdom risks suffering similar bark beetle outbreaks than Central Europe. However, the country has not yet encountered any important bark beetle problem, which provides with the opportunity of studying these beetles while forests are not showing any pest or disease symptom.

To clarify the role of bark and ambrosia beetles in spreading tree-pathogenic fungi, it is necessary to understand which factors mediate in beetle-fungi interactions. With this aim, beetle-associated fungal communities were firstly explored for three major British forest types (pine, spruce and oak). Fungal communities were then compared among the beetles trapped on these forest types at a single location, the New Forest national park. To do this, fungal communities of the individual beetles were analysed through metabarcoding. This technique identifies entire fungal communities from individual beetle specimens through their DNA barcodes, which are short standardised sequences of DNA that work as unique species identification markers. This allowed us to unravel the effect of the tree species identity (forest type) on these fungal communities.

Results corresponding to the first experiment show that the beetle species play a major role to influence fungal community composition and abundance. The forest type also determines fungal communities, especially in oak forests, which showed lower fungal diversity than pine and spruce forests. This effect was driven by the presence of *Ambrosiella hartigii* and *Ambrosiella grosmanniae*, two fungal symbionts of the ambrosia beetles *Xylosandrus germanus* and *Xyleborus dispar*, which were heavily affecting the fungal community composition of three out of the seven beetle species.

This experiment was then broadened by conducting a biodiversity survey of fungi retrieved from 13 different beetle species trapped across the United Kingdom in order to correlate fungal communities with abiotic variables. This work is allowing us to unveil the fungal communities associated with bark and ambrosia beetles coexisting in the country.

We are currently investigating the adaptation capacity of *Ips typographus* to Norway and Sitka spruce, to try to disentangle the role that fungi could play on the facilitation of the beetle to colonise new territories. A major outcome of this project will be an improved methodology to monitor beetle-fungal communities using DNA from trapped beetles for early detection of pathogenic fungi.

Microclimate of nurse stands

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Monitoring of climatic conditions under birch stand and simultaneously on adjacent clear-cut is realised on localities Liběchov (300 m a.s.l.), Nemojov (450 m a.s.l.) and Pustina (470 m a.s.l.). Birch stands on these localities originated in natural regeneration on clear-cut in the years 2000 (Liběchov, Pustina) or 2007 (Nemojov). Air and soil temperatures, air and soil humidity, solar radiation and precipitation were recorded in 10 min intervals. The impact of nurse birch stands on the air temperature and the number and severity of temperature extremes is limited mostly to the ground layer. In the height of 200 cm, the differences between stand interior and clear-cut were already minimal. The temperature effects were highest in cloudless days. Greatest temperature differences between stand and clear-cut during spring frost periods were recorded after sunrise. Nurse stand reduced frost occurrence inside, but limited air heating after sunrise. Differences in extreme air temperature between clear-cut and nurse stands gradually decrease with stand age, advancing natural opening of the canopy decreases shelter effect of nurse stand (Fig. 1). Soil moisture under dense birch stands were significantly lower compared to clear-cuts due to interception and water consumption.

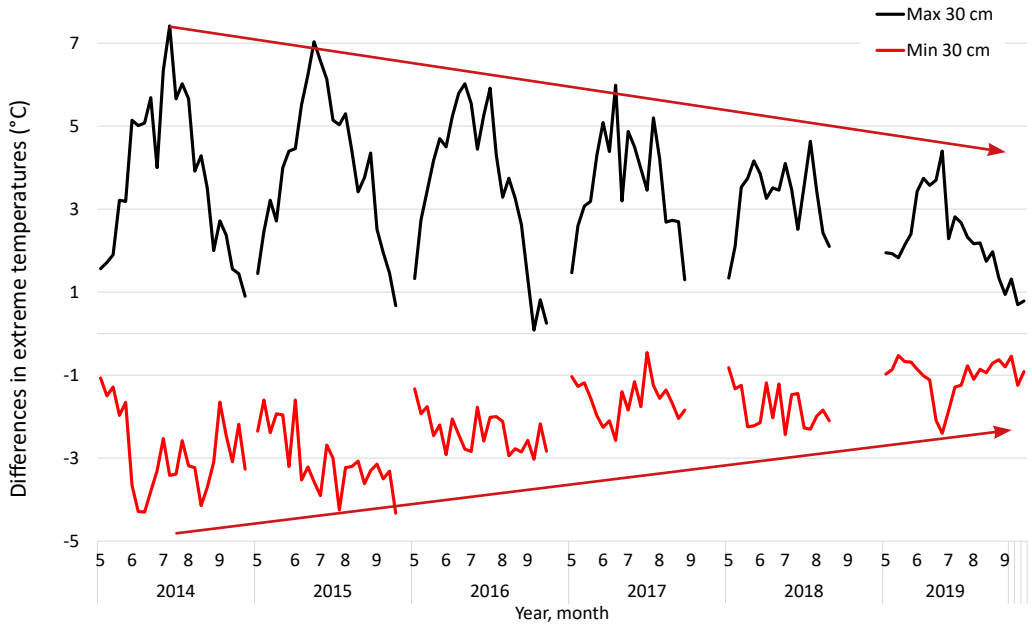

Figure 1: Figure 1 Differences in extreme air temperatures (weekly maxima and minima during growing seasons) in the ground layer between clearcut and nurse stand (locality Nemojov)

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Bark beetle outbreak interfered in measurements of carbon balance at a Norway spruce forest

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Forests play an important role in the carbon cycle and carbon sequestration at both local and global scale. The strength of carbon sequestration in the forest results from the difference between photosynthesis (CO_2 uptake from the atmosphere) and respiration (CO_2 release). If photosynthesis exceeds respiration, the ecosystem is a carbon sink – feature observed during the majority of days within growing season in undisturbed forests. Recent severe droughts and bark beetle attacks in the Czech Republic have resulted in an abrupt and extensive tree mortality and resultant tree harvests. The areas originally serving as substantial CO_2 sinks rapidly became carbon sources, effectively reversing their carbon balance. Harvest also increases decomposition of organic matter accumulated in the soil for decades. As decomposition is strongly dependent on temperature and moisture, it is a question what will be the resulting effect on the carbon balance under current warm but dry conditions.

Our research is carried out in a mid-altitude Norway spruce forest. For several years we monitored the forest ecosystem CO_2 exchange (net ecosystem production; NEP) using the eddy-covariance method and soil respiration measured by a chamber system. The yearly NEP ranged between 452.8 and 710.7 gC $m^{-2}day^{-1}$. The lowest NEP was found in 2015 and 2018, which were years with a very dry summer. Soil respiration rate amounted up to 3.5 µmolCO_2 $m^{-2}s^{-1}$ and was also affected by drought. The area where the research forest is situated was affected by bark beetle outbreak and the forest started to be harvested on the turn of 2019 and 2020. Ongoing measurements of micrometeorological parameters, net ecosystem CO_2 exchange and soil respiration will show to which extent the disturbance has affected carbon balance of the studied ecosystem, how the microclimate will change and what will be the impacts of the tree harvest on CO_2 release from the soil. We will assess both the immediate effect of the harvest on the ecosystem carbon balance and gradual changes in CO_2 exchange after the harvest and interpret them in the context of changing micrometeorological drivers. From obtained data we will be also able to predict when the ecosystem will turn to be the carbon sink again.

The relative importance of environmental drivers on the growth of Norway spruce depends on soil types: A case study from Saxony and Thuringia, Germany

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In forest management and science it is important to determine the drivers of tree growth and to quantify their relative importance with regard to forest site characteristics. The growth of individual trees depends on complex interactions between biotic and environmental drivers. Forest management can make use or buffer the effects of biotic drivers, e. g. through thinning strategies. However, large uncertainties emerge from environmental drivers and its effects on tree growth.

The aim of this study is to quantify the relative importance of environmental drivers (climate, soil, and terrain attributes) on the growth of Norway spruce trees (*Picea abies* (L.) Karst.). For that purpose we distinguished three common soil types of Saxony and Thuringia, Germany (Cambisols, Podzols and water-influenced soils, i.e. Gleysol, Planosol, Stagnosol). We used national forest inventory data, regionalized climate data and terrain inferred parameters with a Boosted Regression Tree (BRT) approach. The approach is particularly suitable, since BRT quantify the relative predictor importance, considering non-linearities and interactions among predictors.

The results of this study clearly demonstrate the importance of soil properties on the growth of Norway spruce trees. Terrain attributes and temperature are similarly important for Norway spruce growth on Cambisols and Podzols, whereas spruce growth is mainly influenced by the relative sand content of the soil, the available field capacity and terrain attributes on water-influenced soils. Interactions among environmental drivers are most relevant on Cambisols and Podzols but not on water-influenced soils. Thus, the implementation of the results in growth models of high spatial resolution will support decision making in forest management.

The Kostrzyca Forest Gene Bank

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Rapid environmental changes observed in last decades cause that occurrence of unpredictable disturbances, such as gradation or large-scale fires are more probable to occur. Shifts in forest communities, dieback of certain tree populations are nowadays a real problem, that faces many countries around the world. The Kostrzyca Forest Gene Bank since 1995 has been preserving genetic diversity of polish flora, including gene pool of the most valuable selection objects, the oldest indigenous forest stands, as well as endangered plant species (trees, shrubs and herbaceous plants). Till now 240 plant species including over 2 400 populations and over 6000 individual trees have been conserved in different storage conditions. Those safeguarded resources may play crucial role in forest regeneration in future, especially regarding to negative effects of climate change.

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National Forest Tree Seed Bank

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National Forest Tree Seed Bank was officially established at Kunovice Research Station on 1 July 2014. The main objective of the National Seed Bank is to gradually collect samples of forest tree seeds, specifically orthodox seeds (spruce, pine, larch, birch, alder, etc.). Seed samples (seed lots) are mainly obtained from the highest quality forest stands (selected sources, category A) with a long-term aim to capture the genetic variability of these populations within the Czech Republic (diversity of natural habitats). Seventy-six samples (seed lots) from forest stands and seventeen samples (seed lots) from parents of family have been obtained since the first collections to the seed bank in 2015. Collection of samples is long term process because mast years come irregularly. The rapid onset of calamity in the last two years, for spruce and pine especially, may cause the irreversible loss of many gene sources. Tree seeds in National Forest Tree Seed Bank could play important role for next generations of our forests, especially in the current climate change conditions.

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Current projects related to tree breeding for uncertain futures

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The change of environment due to global warming is leading to more and more uncertain conditions for sustainable forestry as the series of extreme weather events in combination with the mass propagation of bark beetles has shown in the last two years. Since it seems quiet impossible to foresee how the environmental conditions will be in two or more decades in reality, the choice of the right tree species as well as provenance for a given site will be a challenge. On the other hand, several adaptive traits are more or less strictly genetically controlled as has been observed in numerous progeny trials and experiments.

Therefore, SBS started already more than ten years ago the evaluation of phenological, physiological or morphological traits related to stability, resistance and survivability of provenances of various tree species. Additionally, the vegetative propagation of plus trees or of progenies descending from already approved family parents with *in vitro* methods was used to establish clonal material with extraordinary benefits related to yield, quality and stability. Objective of this work is the procurement of forest reproductive material for afforestation and reforestation to create scopes for action for foresters and land users. The presentation will use current projects as examples for the results already achieved and for reproductive material already available.

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Silver birch as a tree species for alternative ways of calamity clearings restoration

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At present in most regions of Czechia spruce stands increasingly frequent are dying due to severe bark beetle calamity. The resulting large clearings are generally characterized by extreme weather conditions so successful recovery is difficult and complicated. Pioneer tree species play an important role in the restoration of these stands, in particular the silver birch. For this reason, the project "Complex solution of forest restoration and silvicultural management in regions with fast large-scale forest decline" pays special attention to this tree species.

The aim of the project is to verify and optimize the new concept of forest cultivation in areas with rapid large-scale forest dying with efficient use of alternative tree species composition during restoration in order to present exact base for the legislation amendment and at the same time to ensure the long-term safety and success of fulfilling the production and non-production functions of the forest, including the reflection of possible climatic changes. The proposed procedures should primarily ensure the restoration of stable stands and also enable the distribution of restoration period of calamity clearings over a longer time to result in age-differentiated stands.

Therefore, there is an urgent need to develop procedures to ensure a sufficient amount of high-quality forest reproductive material resources with an emphasis on tree species with a pioneering growth strategy. For this purpose, the search for stands of silver birch began in 2019 in the whole territory of Czechia, in which high-quality individuals are selected for approval as a source of qualified reproductive material. So far, a total of 60 high quality silver birch trees have been identified, measured and evaluated. The selection was carried out at localities from the 3rd forest vegetation zone upwards. The maximum height was measured at 38 m, the thickness of the breast-height 56 cm. The quality gene sources should be the basis for establishment of seed orchard. Selected ortets will be sampled for the purpose of genetic characterization by means of DNA analyses using the Simple Sequence Repeats (SSR) method, multilocus genotypes and genetic diversity will be determined. To determine the clonal identity of selected silver birch gene sources 18 suitable high-resolution polymorphic SSR markers were selected and their PCR were optimized.

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Utilization of SSR markers for identification of gene resources of small-leaved linden reproductive material

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Tilia cordata Mill. is historically considered to be a Czech national tree species, which has naturally frequently occurred in past in forest ecosystems and whose extension could again contribute to enhancing biodiversity and increasing the stability of forest ecosystems. This species is appreciated for its high adaptability to climatic factors and is often used for urban greenery. It is a species with suitable soil-improving and soil protection properties. Small-leaved linden stands have a small number of individuals, so the most effective conservation strategies of gene sources are seed orchards and clone banks. To acquire more detailed knowledge of the genetic quality of gene sources of reproductive material and to verify the clonal identity by an objective method, it is possible to use DNA analyses with nuclear microsatellite (SSR) markers. It is widely assumed that populations characterized by narrow genetic diversity could be more sensitive to environmental changes or disease. The SSR method of DNA analyses was used to clonal identification of trees in a model lime (*Tillia cordata* Mill.) seed orchard. Total genomic DNA was extracted by DNA Plant Mini Kit (QIAGEN) from young leaves taken from 377 sampled trees from 38 clones of the model seed orchard. Samples were screened using selected eight polymorphic nuclear microsatellite markers. The obtained data were analysed by statistical programs CERVUS, GenAlEx 6.503. There were detected 79 different alleles at 8 loci in the 377 lime individuals from seed orchard. The obtained results illustrate the utility of the microsatellite loci for assessing spatial patterns of genetic diversity and for individual genotypes identification. 93.6% of the sampled trees could be assigned to the clones represented in the model seed orchard. The identified genetic loci were verified as highly polymorphic and could be further used for clonal identification of lime trees.

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Results of provenance research of Norway spruce in the context of ongoing bark beetle calamity

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There are presented evaluation results of two research plots (Mnichov and Červená Voda) of the international provenance trial with Norway spruce 1972/76–77 at the age of 46 years. Both plots are situated in north of Moravia (Czech Republic) in area infested by extreme bark beetle calamity. On both plots, the identical 64 provenances originated from the Czech Republic, Germany, Austria, Poland, Slovakia, Belarus and Bulgaria are tested. Provenances from four geographical Norway spruce regions according to Rubner (1932) are represented. Dendrometric data (tree height, DBH) were measured and morphological characteristics (stem form, stem damage, defoliation, and health state) were evaluated. Stem volume and growing stock were calculated from measured data. The measurement was performed in 2018 after 3-years long period of extreme summer drought. The results show the highest volume production in both research plots for provenances from Germany, namely 41 Hainsbach (Červená Voda) and 39 Bütterbächel (Mnichov). As for wider geographical provenances origin, two homogeneous groups were clustered (1) Alpine, Rhodopean and Russian-Scandinavian, and (2) Hercynian-Carpathian. The second one represented the best growing provenances, so spruces with this origin may be theoretically recommended for using in regional silviculture in upcoming climatic conditions.

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Fig. 1: Provenance plot Mnichov

Lesy Slovenskej republiky, š.p., Odštepný závod Semenoles Liptovský Hrádok

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LESY SR, state enterprise manages around 884 490 ha of forests, which is approx. 44% of forests in Slovakia.

Beech (*Fagus sylvatica*) accounts for the largest share among the tree species – 33,2%, followed by Spruce (*Picea abies*) – 23,4%, Oak (*Quercus* sp.) - 10,6%. Other coniferous make up – 14,4% and other broadleaved – 18,4%.

There is 17.3 thousands of hectares of forests regenerated annually in Slovakia out of which 7,1 thou. ha (40,6%) is natural regeneration.

State enterprise LESY SR, š.p. provides annualy Forest regeneration on the area of 7,6 thou. ha, out of which 3,5 thou. ha (46,1%) is natural regeneration.

LESY SR, state enterprise manages more than 72 000 ha of selected sources for collection seeds of forest trees.

„OZ Semenoles“ Liptovský Hrádok is a specialized Forest Enterprise of LESY SR, š.p. OZ Semenoles has a long tradition, since 1923, which provides services in the area of forest seed management, production of forest and ornamental trees and it maintains a seed bank.

Its capacity allows to process around 150 – 200 t of seed raw material a year.

Yearly production of planting material represents approx. 21 mil. of bare-root and 3 mil. of containerised seedlings.

Forest Enterprises „Semenoles“ Liptovský Hrádok provides establishment and management of tree seed orchards on the area of 49 ha for 18 tree species.

Risk assessment of spruce stands using remote sensing and national forest inventory data: A synthesis of the FIRIS project

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In forest management it is important to assess the vulnerability of forest stands against biotic and abiotic disturbances in order to take action beforehand, e.g. through thinning strategies. But reliable information about stand vulnerability is scarce, especially considering the need for consistent management strategies of public and private forests. Therefore, the FIRIS project (Spruce-Risk) seeks to develop methods based on remote sensing and large scale forest inventory data for the mountain ranges of Saxony and Thuringia, Germany.

We developed three distinct methods to identify spruce trees, to quantify the standing stock, and to predict the risk using Sentinel2 – satellite, airborne laser scanning and national forest inventory data, respectively. Based on the information we gained from these three methods, we derived silvicultural management strategies with the overall goal to reduce the risk in the respective forest stands. Here we present how the information can be used as a consistent decision tool for public and private forest management in the scope of forest risk assessment.

Effect of rodents on forest regeneration in clearcuts

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The synergistic effect of drought, bark beetles and forest composition currently creates large-scale clearcuts in forests of Central Europe. The impact of rodents on seedlings increases with the size of a clearcut. We have not been able to fully assess the significance of rodent impact so far. However, we already have some experience in areas affected by air pollution, where not only deciduous tree plantations but sometimes even the spruce was damaged by rodents.

Rodents can damage forest by consuming seeds and seedlings, bark and roots. The most significant damage occurs on seedlings of deciduous trees with thin bark (maple, beech) in winter. The base of a trunk is gnawed by the field vole (*Microtus agrestis*) and the common vole (*Microtus arvalis*), and to a lesser extent by the bank vole (*Myodes glareolus*).

The voles have more suitable conditions: the larger the clearcut; the larger part of the clearcut is overgrown with monocotyledons (especially grasses); the more shelter the clearcut offers.

The most risky period for seedlings is the period until the tree canopy close, or before their bark is too thick for rodents. This can last from several years to several decades.

The damage by rodents is not very high in the Czech Republic; yet it is annual and sometimes significant. Even the total direct tree mortality caused by rodents is not very high; most damaged trees survive. However, we know almost nothing about the consequences of damage to further tree development (increment, stem deformation, infection, wood quality). In beech plantations, more than 50% of trees are damaged at least once by rodents; these “hidden damages” may be much more significant than mortality.

Fig.1: Common vole (*Microtus arvalis*); species causing extensive damage to forest regeneration. (Foto M. Heroldová)

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Rodent summer gnawing of seedlings: a new problem in forest regeneration?

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The damage of seedlings caused by rodents (namely voles of the genera *Microtus* and *Myodes*) was monitored in two localities: in the vicinity of Vítkov (Nízký Jeseník) and in the Drahanská vrchovina Highlands. The number of rodents and their food supply (plant species, biomass amount and nutrient content in biomass) were determined on experimental plots with planting of European beech (*Fagus sylvatica*). In 2018 there was a rich crop of tree seeds, especially oak and beech. In response, last year (2019) populations of all rodents, including voles, grew. In forest plantations it was the common vole (*Microtus arvalis*), the field vole (*Microtus agrestis*), and the bank vole (*Myodes glareolus*) that damage trees by bark gnawing. In the Drahanská vrchovina Highlands, the amount of biomass was lower and contained less nutrients; there was also major damage to seedlings. The lack of rainfall, lower nutrient content in biomass, and higher temperatures in the spring probably force voles to obtain nutrients and especially water from trees even during the vegetation season. We have already observed the same damage to seedlings in Drahanská vrchovina Highlands in 2012. Damage to the seedlings by voles should therefore newly be taken into account even during the vegetation period; lack of precipitation and clearing size are factors that increase the risk of damage.

Fig.1: Young beech damaged by voles during the vegetation period in 2019 (photo: M. Heroldová).

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Natural regeneration in the area after bark beetle calamity in the Beskidy Mountains (Poland)

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At the turn of the 20th and 21st centuries large-scale decline of Norway spruce artificial stands occurred in the Western Beskidy Mountains, mainly caused by bark beetle outbreak. This area is located mainly in the lower montane zone, and in the highest elevations it is the upper montane zone. Natural regeneration predominates in open areas. Investigations carried out in years 2013-2016 in deforested areas showed a large amount of pioneer species (silver birch *Betula pendula* Roth, European rowan *Sorbus aucuparia* L. Emend), or an expansive Norway spruce *Picea abies* (L.) H. Karst. regeneration. Their species composition is usually different from the target one, appropriate for forest site's diversity. The advantage of natural regeneration is limiting the expansion of weeds covering the soil (reed grass *Calamagrostis arundinacea* (L.) Roth, bilberry *Vaccinium myrtillus* L.), and creation of conditions suitable for planting target trees species, mainly European beech *Fagus sylvatica* L. and silver fir *Abies alba* Mill. It is necessary to control the species composition of regeneration, to shape stands more resistant to stress and stable, adapted to the site conditions. Silvicultural treatments applied in these areas should fulfill a number of specific requirements, among other such as: maintaining forest cover protective function, supporting target species, shaping spatial structure of regeneration, building resistance of trees to damaging agents (mainly atmospheric factors), adjusting interactions between tree species. Under these conditions, achieving target species compositions of high stability stands is a multi-stage and long-term task.

Above-ground biomass accumulation and cycle of naturally regenerated birch stands on large clear cut

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The above-ground biomass of birch nurse stand was investigated on the large-scale clear cut of the research area Nemojov (East Bohemia, altitude 460 m, *Fagetum illimerosum acidophilum,* former spruce stand damaged by Kyrril 2007, dense birch stand from natural regeneration). The above-ground biomass of the stand was calculated from annual plot inventory data analyses, biomass equations were parameterized from repeated destructive analyses of sample trees. Litter-fall was investigated quantitatively by collectors.

Stand density culminated at the stand age of 7 years (average 1.9 pcs/m^2), DBH of birch trees reached 3.1 cm in 10 years. BA increased from 1.9 m^2/ha (5 years) to 12.8 m^2/ha (10 years). Above-ground biomass dry matter (DM) was 27 t/ha at the age of 10 years. The proportion of the stem to the total biomass increased with stand age and varied between 75% and 91%. Litterfall DM of young birch stand varied from 2.4 to 4.4 t/ha/y with average 3.3 DM t/ha/y. The amount did not change with growing stand age. In the litterfall, share of the leaves was about 94% before canopy closing, afterwards natural thinning and debranching increased the amount of branches in litterfall. Amount of leaf litterfall varied in time depending on the weather conditions of every season. Leaf litterfall started in July (6-10% of total amount), most of the leaves fell in September and October. Annual litterfall returns about 45 kg of N back to the soil (2 kg of P, 13 kg of K, 32 kg of Ca and 7 kg of Mg).

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Are underplantings a proper way for beech reintroduction?

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European beech (*Fagus sylvatica* L.) represents the tree species most common in the Central European natural forests, including Czech Republic. It occupied *cca* more then 40% of the forest area, from 3rd to 7th forest altitudinal zones. Its proportion was drastically lowered due to forest exploitation during Medieval centuries, the forest lands were reforested by mostly Norway spruce (*Picea abies* /L./ Karst) and Scots pine (*Pinus silvestris* L.) in the 18th and 19th century later. The even-age (class age) silviculture of monospecific stands (monocultures) was introduced and dominated the forestry in the Central Europe, with many management and economic benefits, on the contrary with lower stability of these forests. During this process, the original sites occupied by broad-leaved and mixed forests were converted into spruce (and pine) monocultures, in European conditions decreased the share of broadleaves from 2/3 to 1/3 only, resulting in 6 – 7 mil. ha of spruce growing at non-native sites in Europe. Last decades, re-introduction of beech is supported as well as the increasing of share of broad-laved species in general to increase forest stability. This trend is similar also in the neighboring countries, despite many problems connected with this approach, having even greater importance in the context of climate change. Beech is also considered as one of the main site improving and stabilizing species, accordingly to Czech legislation for forest regeneration. Its reintroduction and coniferous stand conversion can be assured through planting, direct seeding or natural regeneration of broadleaves following clear-cutting or planting under conifer shelterwoods.

The presented study documents the growth, quality of growth and vitality of plantations of beech in two positions at the same site (580 m. a.s.l., forest habitat type 5K8 acid fir-beech site, soil type Cambisol): underplantings at 50% of light intensity of open space and clear-cut. Plantations were established in 1994 by bare-root plantings in the same day of April, in the 1 x1 m spacing, shelter at the underplanted locality was removed 2010. The plots were measured regularly in the period 1994 – 2003, later 2017 and 2019. In 2017, the plantations showed very different character (underplanting/ clear-cut position): density 5900/3750 pcs.ha^{-1}, mean DBH 6.8/7.0, mean height 8.7/6.9, basal area 21.41/14.42 m^2.ha^{-1}. Underplanting was documented as very proper way of re-introduction of beech in the species composition of Czech forests. The reintroduction of beech at the newly originated clearcuts should be done with the use of ecological shelter of preparatory or climax species.

It can be concluded, that underplantings represent a proper way for re-introduction and regeneration of beech in comparable conditions, i.e. in 5th vegetation altitudinal zone. The mortality and damages are much lower comparing to plantations on clear-cuts. Also, the height growth is faster and the necessity of protection against weed competition and game damages is considerable lower. The quality of young individuals is much better and undeplantings seem to be the best method for beech regeneration. In higher altitudes, the problems can arise due to more harsh conditions and less favorable micro-ecological conditions in underplantings, in lower vegetation altitudinal zones on the contrary the lack of soil moisture and competition of overtopping stand for water can be decisive. These sites need strongly further research.

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Adaptive forest management in Slovenian spruce forests

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Spruce is among five most abundant tree species in the Slovenian forests with almost 33% share in total living stock. Despite its potential abundance in the country the latest extreme weather events in 2014 and 2017/2018 confirm its increasing vulnerability and consequent exposition to bark beetle infestation/ calamities.

Several aspects relevant for the future development and perspective of the species are highlighted:

- responses of young natural and planted spruces compared on extreme sites with large post-disturbance canopy openings;
- light response in damaged and undamaged stands for predominant species;
- abundance of regeneration (primary, secondary spruce sites and spruce growing on primary beech and fir sites) in different elevation categories;
- growth response of spruce on different sites and elevations and
- future-prediction scenarios.

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V4-1820 Causes and effect of December 2017 windthrow on further development of European beech and Silver fir stands in Slovenian Forests

V4-1614 Adaptive management in spruce forests in Slovenia

Forest restoration following small-scale disturbances and reforestation after large-scale functional breakdowns in spruce and pine forests on the foundation of forest typology and landscape ecology

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Storms, wet snow, drought periods and bark beetle calamities led to a cascade of breakdown in spruce and pine forests, resulting in a wide variety of consequences from small scale disturbances with ecosystem structuring potential to large-scale functional losses within entire forest systems. Large forested areas are potentially endangered by these breakdowns, e.g. spruce forests covering between 110,000 – 130,000 ha in mountain ranges and loess-hill regions as well as approximately 10,000 ha of pine forests within the Pleistocene lowlands, ca. 20 – 25% of the hole Saxony forest area.

To counteract the high-risk potential, conversion of spruce and pine forests are getting continuously and intensively since 30 years with the goal to create forests that are well adapted to the change of regional and local site conditions. The continuous conversion of spruce and pine forests at a large area resulted in a second layer of young trees that already shape forest systems after the cascade of breakdown through biotic and abiotic factors. But despite the described efforts, the efficiency of forest management will be influenced by mid- to long-term reforestation strategies. Thus it is of utmost importance to use the combined potential of secondary succession and managed forest restoration in a way to efficiently reach local forest developmental goals. However, in order to account for the functionality of the cultural landscape it is crucial for forest management to include all available information and details about forest typology, the available resources of forest enterprises and the potential urgency to restore ecosystem services in the process of forest restoration and reforestation.

The summary of principal approaches to forest stands renewal on salvage clear cuts in the Czech Republic

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It is necessary to use all the naturally-regenerated tree species present on the site; other tree species should be planted so as to get an appropriately mixed stands. Decision about which species is needed is taken into account for future juvenile stand tending. The principal aim is an establishment of mixed, fine-structured mixtures with broad spectrum of tree species providing expected services of forest. The principal approach consists in use of at least three dominant species sharing the mixture nearly equally on the same site where are also other accompanying species are desirable to increase diversity.

Four principal approaches to salvage clear cuts renewal are recommended; combinations of the four are also possible

Direct planting of tree species mixtures according to recommended species composition. Both main target species only and/or mixed with main pioneer species are allowed to be established. Prefer use of the target species on rich sites such as nutrient-rich, loamy and enriched-colluvial ones in accessible-terrain conditions.

Gradual planting (prolonged two-phase renewal) consisting in planting of intolerant, well-performing species in open conditions first – both pioneer and target species such as larch, spruce, sessile oak, alder, aspen and birch which are interplanted using other more tolerant species after 2 – 5 years; these are capable of taking advantage of ecological effects provided by the preceding plantation. It can be preferred on nutrient-rich and gleyic nutrient-medium sites in accessible-terrain conditions.

Two-phase renewal when first phase consists in artificial regeneration mainly – preparatory stands can be established using both planting and seeding. Many tree species can be used; there are also allowed lower planting densities per hectare because next phase consists in interplanting of other species. This approach is recommended in large salvage clear cuts particularly. If natural regeneration is not satisfactory, it is necessary to add plantation using planting stock capable of well performance on the site.

Two-phase renewal when first phase consists in natural regeneration mainly – the second phase can be realized via both natural regeneration and interplanting (underplanting) by tree species that need specific microclimate conditions. There is an essential prerequisite of its applicability; parent trees present and weed development on the site.

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Adequate silviculture management of newly established stands on clear cuts

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According to ongoing bark-beetle outbreak, majority of the forest management activities are concentrated on the renewal of clear cuts. However, successive management of young newly established stands will be of great importance in the next decade. It can be assumed (and also recommended), that foresters will use a set of renewal treatments such as direct planting or seeding, natural regeneration, using preparatory tree species, etc. that help establish a wide spectrum of young stands on the clear cuts. There is, however, a lack of experience in forest tending of diversified forest stands on large open areas, especially of preparatory stands or of mixed ones.

Therefore, current silviculture research focuses on definition and practical testing of adequate measures to get both stable and all desired services providing new stands after salvage clear-cutting. Besides the knowledge and practical experience from "classical" young stands (common forestry), we have experiments established after former calamities, e.g. wind calamity Kyrril in 2007. Dissemination of new knowledge and experiences is of the utmost importance, because neglected thinning of young stands would lead to loss of stability and undesirable shifts in species composition, quality and overall functionality of the forest ecosystems.

Fig.1: Young stands on calamity clear cuts need adequate measures to support their stability and mixture maintenance

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How to reforest large clear-cut areas after bark beetle calamity

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The ongoing bark beetle calamity results in large clear-cut disaster areas. These areas should be reforested as soon as possible to prevent soil degradation and weed infestation that would result in expensive soil preparation for forest regeneration. Artificial regeneration (by planting or sowing) is and will be the main method of reforestation as natural regeneration has some specific limits and natural succession is unpredictable, often too slow and we cannot rely on it.

It is necessary to provide access to the stands the first. Many areas become waterlogged after harvesting and need to be drained. At large open clear-cut areas, it is necessary to reduce the speed of wind. We can leave strips of standing trees, we can form mechanical barriers (i.e. from brushwood), we can use weeds as a barrier (to cut weeds only in strips) or we can plant belts of fast growing species there. Site preparation is suitable and beneficial at these localities. We can remove brushwood from the site, but it is also possible to crush it or to form rows after chemical treatment to eliminate the negative effect of fast wind. Leaving the brushwood at the reforested area has some advantages, but on the other hand, it complicates self-regeneration and care of the plantation.

Choosing the right species composition is crucial for forest future. We have to establish stable stands with respect to the changing climate conditions. We can use some target species at most of the areas immediately after harvesting, or we can always use the preparatory species. Creating mixtures of species is recommended as well as alternation of stands with different woody composition resulting in a sequential regeneration and species conversion to age-structured mixed stands. It is necessary to respect the site conditions, size of the area to be reforested and its side protection. In Central Europe, we can recommend *Quercus robur, Quercis petrea, Pinus sylvestris, Larix decidua and Carpinus betulus*, eventually elms and *Fraxinus excelsior* from the target species at large open areas; limes, however, often go dry and therefore cannot be recommended. Climax species like *Fagus sylvatica*, *Abies alba* or *Pseudotsuga menziesii* are suitable for planting in the second phase of regeneration under the cover of the preparatory stands; they can also be planted in the cover of the neighbouring stands or (pre)planted fast growing species. Natural regeneration of target species (*Acer pseudoplatanus, Acer platanoides, Larix decidua, Fraxinus excelsior*) is hardly ever successful as there are only few maternal trees in the surroundings and/or they are too far away and also due to heavy weed infestation. As the preparatory species we can use *Betula pendula, Sorbus aucuparia, Populus tremula*, *Alnus glutinosa* and *Alnus incana* by natural as well as by artificial regeneration with sowing or planting. Soil scarification is often necessary to enable natural regeneration due to weed infestation. We can also use *Picea abies* as a preparatory species because of good growth of its young stands but we need to perform species conversion in time.

It is necessary to use good-quality planting stock for planting. Plants of lower height, with thicker root collar and with large root systems full of mycorrhiza are suitable. We can use both containerized and bare-rooted plants, however, use of bare-rooted seedlings and large-sized plants is risky. Due to often droughts in the vegetation season in the last few years it is recommended to plan the planting for the autumn, to sink bare-rooted plants in soil, to cover the root balls of containerized plants with soil and to use hydroabsorbents. Weed and pest infestation and game damage should be minimized. These are some main recommendations and rules for managing reforestation works in the current situation to achieve stable stands of a good quality in future.

Cluster planting in TFE Křtiny - knowledge, experience and recommendation

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Cluster planting is a regeneration method, where trees are artificially planted in patches (evenly) which are distributed within cleaning or under old stand (conservation process). Spaces between artificially regenerated patches are usually left for natural processes. In the second half of the 20th century, this method was rediscovered by the Soviet and Polish silviculturists – Tarasenko, and Szymanski. This method was also used for the regeneration of mountain forests. Large calamity events in the second half of 20th century led to the establishment of several experiments of this method in Western Europe. Regarding present knowledge two types of cluster planting are distinguished – group and nest planting. Nest planting consists of seedlings planted in high density on small patches (nest). In contrast, group planting uses larger patches (groups) where around 15-25 trees are planted in traditional density. The distances between nests vary usually from 3 to 7 m and between two groups from 10 to 12 m depending on tree species. Three experiments (*Tipeček* – *Soběšice* – *Vranov*) of cluster planting in the TFE Křtiny were established during 2013 – 2015. In the *Vranov* plot, nine beeches were planted into small groups (5,3 m^2) in 2011. In the *Soběšice* plot, seventeen maple seedlings were planted into groups of size 7,1 m^2 in 2013. The *Tipeček* plot consist of groups 20,25 m^2 large, where 16 maple seedlings were planted in 2015. Whereas *Vranov* and *Soběšice* experiments were established in a clearing, maple seedlings in *Tipeček* were planted up to about 4 m high birch pioneer stand. Distances between groups were 10 m for *Vranov* and *Tipeček* plots and 9 m for *Soběšice plot*. Firsts results showed that the perspective of the tested methods in TFE Křtiny is limited by appropriate game management.

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Mixed native species with monoculture of *Acacia mangium* improves forest stability and adaptability in South China

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Plantation of nitrogen-fixing trees used to be an effective way to rehabilitate degenerated land, while simple species composition and insufficient forest regeneration imply forest susceptibility. To address the advantages of mixed plantation, especially with the introduction of native species, for afforestation, we monitored dynamics of plant community structure, tree growth, soil nutrient elements in pure *Acacia mangium* forest plantation in about 40 years after afforestation. Native species planted with 15-year of pure *A. mangium* forest was managed to compare its efficiency in forest restoration with the monoculture of *A. mangium*. Differences in the regenerated species, soil physiochemistry properties, and soil microbial community in the two plantation strategies were investigated to evaluate the advantages of mixed- species plantation. Although monoculture of *A. mangium* indicated higher efficiency of soil organic carbon and total nitrogen pools accumulation, mixed plantation forest with native species improved new species recruitment and sustained more stabilized plant community structure. Higher heterogeneity in mixed forest could compromise the lower increment in soil nutrition, thus maintain the comparable soil microbial community to pure *A. mangium* plantation forest in the long-term of forest recovery. We conclude that improving the pure *Acacia* forest by introducing native tree species is an effective way for sustaining forest stability and improving adaptability for future climate change.

Coppicing ability and biomass production of birch (*Betula pendula*)

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Coppicing is an old and traditional form of sustainable forest management which is regarded as a cultural heritage. Present return towards coppicing has many reasons (biodiversity support, rapid biomass production and profit, system is suitable and economical also for small forest owners). Young birch stands can be suitable for coppice system (native species, rapid growth on wide range of natural conditions). Coppice was tested on locality Nemojov (East Bohemia, 460 m asl., *Fagetum illimerosum acidophilum*), birch stand originated from natural regeneration on clear-cut after Kyrril (2007). Dense birch stand (age 7 years, density 18 000 pcs/ha) was cut in 3 terms (March, May, July) and 2 replications in year 2014, sprouts were annually evaluated.

Nearly all stumps regenerate immediately in the year of cutting (96%). Most of sprouts originated 0–5 cm above the ground level. Number of sprouts and their growth depended on stump dimensions and term of cutting. Number of sprouts on stump increased with growing stump diameter and decreased with stump height. Stumps from later cutting terms had higher number of sprouts, but their growth was lower compared to sprouts from winter or spring terms. Differences among plots were evident still 4 years after cutting. Number of sprouts on stump gradually decreased with age, Sprout annually mortality was 4-11%. Dominant sprouts had DBH above 5 cm and height over 5 m (5 years old), above-growth biomass production (20 t/ha of dry mass) was higher than comparative stand from generative regeneration.

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Bark beetles: Actual strategies and management during mass attacks in Switzerland

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At present, the second highest infestation of bark beetles ever recorded occurs in Switzerland. This poses a great challenge for forest services and forest owners. The situation is aggravated by the fact that not all of the attacked timber can be harvested and sold.

The government's strategy is to intervene mainly in protection forests, pursuing a traditional forest protection. These activities are financially supported by public funds. If the owners do not act in time, substitute measures can be taken in critical cases. Outside protection forests, the strategy is delegated and determined by the cantons, usually in cooperation with the forest owners. There are less regulations for these stands, and mainly only recommendations are made. Their implementation and the activities taken vary considerably and often depend on the structure of forest ownership and the financial and technical resources available to it.

The following points are of primary importance when authorities define strategies for measures and recommendations:

a) Safety for forest visitors, forest workers, buildings, traffic routes and power lines.
b) Priority setting in space and time according to the main forest functions and harvest and sales opportunities of damaged timber.
c) Structure and condition of existing forest stands and risk of bark beetle infestation spreading over a large area.
d) Prospects of success of potential measures.

The Swiss Federal Research Institute WSL consults the authorities on demand. The national „storm damge" handbook (see reference) will be revised and adapted to the actual damage by climate change and bark beetles.

New for Switzerland is the temporary storage of infested timber in bark outside forests. To this end, individual cantons are making financial contributions and coordinate the provision of storage sites. But dispite all efforts, under the actual conditions more bark beetle infested trees will regionally remain in stands and will not be harvested, even in production forests, this at the owners economical risk and loss.

Reference

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The impact of the bark beetle calamity on the economic potential of forestry in the Czech Republic

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The analysis informs about the impact of the bark beetle calamity on the development of raw timber prices and of the economic potential of forestry in the Czech Republic. The methodological approach to the analysis is based on the following inputs: potentially optimal species composition of forest stands and recommended rotation periods by the basic spatial units, i.e. groups of forest habitat types. This input is in accordance with the principles of the Czech typological system and meets the requirements of the applicable legislation; optimal economic measures of silvicultural and logging operations; the real amount of raw timber costs and prices valid in particular variants examined. The key synthetic assessment criterion is the gross profit of forestry production (HZLV), defined as the difference between the sales of raw timber and full costs.

The economic potential of forests of the Czech Republic was investigated in the following time horizons: year 2012, representing rather a long-term level of raw timber prices, year 2016, which can be described as the beginning of bark beetle calamity impact, year 2018, where the last comprehensive set of relevant data comes from, and the year 2070.

Development of the potential gross profit of forestry production HZLV (mil. €) is presented in Table 1:

Year	2012	2016	2018	2070
HZLV	318	285	210	203

Development of average prices of selected assortments of spruce raw timber in the Czech Republic (€/m^3):

Assortments/ Year	3rd A/B quality grade logs	5th quality grade logs – wood pulp	6th quality grade logs – fuelwood
2012	84	34	29
2016	81	31	31
2018	73	26	29
2019*	58	19	17

Source: Czech Statistical Office of the Czech Republic

* In the case of a positive evaluation of the analysis, the full data set for 2019 will already be available and supplied.

A further dramatic decline in HZLV occurred in 2019, as can be seen from the price development of spruce raw timber prices (at present, prices of spruce raw timber for only three quarters of 2019 are available).

From a long-term perspective, it is possible to outline a number of scenarios for the development of the potential annual effect of forestry. One of the possible scenarios is given in Table 1 for the 2070 horizon. It assumes that raw timber prices will return to 2016 levels and that the share of spruce in the species composition will decline from the current ca. 51% to 32.8%. Forests with this currently implemented species composition, i.e. reduced proportion of spruce, will enter the production process. The impact of this change in the species composition to the disadvantage of spruce means a reduction in HZLV by € 82 million compared to 2016.

Salvage logging, including bark beetle calamities, has always had an economic impact on the forestry industry. However, as Kupčák (2019) states, given the current scale and dynamism, they are beyond the scope of the current and especially the future resources of most forest owners. It is probably only about the beginning of a possible deep “turn” in the Czech forestry industry as a branch, including forest-political and national economic aspects.

Economic impacts of bark beetle calamity on non-state forest owners

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V důsledku dlouhodobého vlivu klimatických změn a přírodních kalamit došlo v roce 2015 v severovýchodní části České republiky k přemnožení lýkožrouta smrkového ve smrkových porostech oslabených dlouhými periodami sucha a vysokých teplot v době vegetačního období. Nepříznivé klimatické podmínky pokračovaly a oblast katastrofického rozsahu kůrovcové kalamity v současné době pokrývá významnou část smrkových porostů České republiky. Vlivem snížené hladiny spodní vody začínají odumírat suchem a hmyzími a houbovými škůdci jsou napadány i ostatní dřeviny, zejména borovice, dub a buk.

Ekonomický dopad na vlastníky lesa je obrovský. Na majetcích, kde v roce 2015 kalamita začala, jsou nyní vytěženy veškeré prosty s většinovým zastoupením smrku, napadány jsou i porosty ve věku 20–50 let. U středních a větších majetků holiny a zalesněné plochy po kalamitě představují až 30% rozlohy. Porosty na menších majetky kalamita zlikvidovala zcela.

V současné době rozsah napadeného dříví vysoce překračuje disponibilní zpracovatelské i odbytové kapacity, enormně rostou náklady, ceny dříví u souší a ve slabých porostech klesají pod výrobní náklady. Malí vlastníci nejsou v této situaci schopni zpracování kalamitního dříví řešit.

Stát poskytuje dotační podporu na zalesnění a pěstební práce. Na částečné pokrytí újmy při zpracování kůrovcové nahodilé těžby za rok 2018 vypsal samostatný dotační titul. Dotace však pokrývají cca ¼ skutečných nákladů a skutečné újmy, jsou však vypláceny s velkou časovou prodlevou (½ -2 roky) a vlastníci nemají prostředky na překlenutí tohoto období.

Po zpracování kalamity se vlastníci dostanou do situace, že objemy těžeb na několik desetiletí výrazně poklesnou a nebudou moci zajistit ze svých prostředků dostatečnou péči v rozsahu, který potřebným způsobem zajistí ekosystémové služby (půdoochranné, retenční, vodohospodářské, klimatické, rekreační) přístupnost lesa pro veřejnost, zachování a ochranu biodiverzity založených porostů (ochrana proti zvěři).

Situaci dokumentují údaje za vybrané lesní majetky postižené kalamitou.

Effective strategic decisions: bark beetle disturbances and implications in planning forest management

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Throughout the last years, the loss of forest areas caused by bark beetle outbreaks has steadily risen. Many methods of decision making have been found to deal with a variety of spatial and temporal scale, from one stand to a very large and national level. The main purpose of this research is to define the possible high potential disturbed sites, and to focus on the investigation powers there. We described an effective and accurate approaches for Czech forest practitioners through modeling to optimize all available resources and to prevent further spread of bark beetle. The proposed solutions are to refrain the cutting down dead trees. Further, concentrate all human and financial capacities to protect the healthy standing forest lands.

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International association WoodEMA, i.a. for Economics and Management in the forest based sector is non-profitable and open association. It was founded in 2007. Association's goal is to promote results of scientific and professional work of its members, mutual scientific co-operation in the field of forestry and wood processing. The goal of the presentation is to give information about association´s goals, activities and possibilities of cooperation.

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