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REVIEW PAPER

Key findings of applied research achieved by the Forestry and Game Management Research Institute (Czechia) in the past seventy years

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Abstract
The Forestry and Game Management Research Institute (Czechia) was founded on 31st October 1921 with the establishment of the Forest Protection Department. In the era before and after the World War II, several more institutes were founded, and they underwent a number of reorganizations during the 1950s and finally took the form more or less corresponding with the current one. The institute went through further major changes in the early 1990s. In the 1950s, the forestry research saw dynamic development, partially also caused by a significant increase in the number of experts and finalization of the original concept of the institutional structure which covered almost all fields of forestry. Research focused on topical issues of the forest management, covering forest protection, silviculture, forest ecology, biology ad breeding of forest trees, seed growing, forest economy, forestry mechanization, forest management planning and game management. Results were provided to the forestry practice, and there also were numerous monographs and both scientific and expert articles which helped disseminate new findings. Many of these findings have been applied up to now and others built the basis for further research that has been followed on by the current generation of researchers.

Key words: tree biology and breeding; forest protection and silviculture; forest ecology; forest and game management; forestry economy; forestry mechanization

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1. Introduction

The Forestry and Game Management Research Institute was founded on 31st October 1921 with the establishment of the Forest Protection Department as a response to the necessity to deal with the outbreak of *Lymantria monacha* in Czechia. In the following twenty years, several more institutes were founded based on the concept designed by the ministerial executive Karel Šiman. The World War II brought the implementation of this concept to a halt, but shortly after the war ended, the initial efforts were carried out to a certain extent so that the forestry research could become comprehensive (Zahradník 2016). Up to this era, the number of staff working in individual institutes was very low with the total of approximately forty workers including clerks and the staff at the state experimental stations. There were fewer than thirty researchers, typically from one to three of them for each field (Pfeffer 1937). Many of them worked for universities simultaneously. In the 1950s, there were numerous reorganizations, changes of competencies, separations and merges. Since 1959, the institute has been operating in a form very similar to the current one, although changes after 1989 led to certain restructuring as well as a significant reduction in the number of staff. Nevertheless, the main focus has remained on applied research which was directly or indirectly used in forestry practice. This article mentions key findings of the post-war research with specific impact

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on forestry. Some disciplines which are no longer represented at the institute may be slightly disadvantaged in the historic overview, yet their results were taken into consideration as well.

2. Biology and breeding of forest trees

History of biology and forest trees breeding as a specific field dates back to 1923, but it only developed fully in the post-war period. In this period, research activities of the Biology and Breeding of Forest Trees Division (as well as those of other organizational units at the FGMRI and other fields of forestry as a specific scientific discipline) evolved and were carried out in relation with the increasing needs of the national economy. In the forestry, this mainly applied to the increasing consumption of wood. There were also new requirements on wood qualities: there was a demand for light and durable wood. Requirements of the wood-processing industry focused on high-quality material, and there was a higher demand for healthy wood mass suitable for chemical processing. In the 1950s and 1960s, the forestry looked for ways and methods of increasing and perfecting wood production. In this period, attention was paid to, among others, development of methods to increase production possibilities of the forest soil via melioration interventions and other appropriate forms. The gradual development and use of forest trees breeding can be named among these forms and methods (Vincent 1962). The subdiscipline of forest trees breeding thus began to develop and become increasingly useful, and so it was given corresponding attention. The division (at that time known as the Department of Biology and Breeding of Forest Trees) had a very important role at the FGMRI at that time, similarly to those of forest protection, silviculture etc.

The contents and activities of the Division of Biology and Breeding of Forest Trees were defined and developed in accordance with the progress of this discipline in foreign countries which were highly developed in terms of forestry at that time, such as Germany and Scandinavian countries. Breeding initiatives and concepts which had been verified and implemented in Scandinavian countries were promoted in Czechoslovakia by doc. dr. ing. Gustav Vincent, DrSc., whose scientific work and outcomes were followed on by the Division of Biology and Breeding of Forest Trees in the late 1960s, mainly by Ing. Jiří Šindelář, CSc., who initiated and realized founding tens of research provenance areas intended for long-term verification of forest tree species in this time period and the following ones. Ing. Šindelář focused especially on provenance research of the European larch (*Larix decidua*), Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*) and other deciduous trees, for example alder and bitch (Šindelář 1964, 1974; Šindelář et al. 2008a, 2008b etc.). Along with him, there were also other members of the division who worked on the provenance research, for example Ing. Bohuslav Vinš, CSc. – Norway spruce (*Picea abies*), European silver fir (*Abies alba*) (e.g. Korpeľ & Vinš 1965; Vinš 1966; Vinš & Vančura 1977), Ing. Karel Kaňák, CSc. – especially the provenance research of species of the *Pinus* genus (e.g. Kaňák 1971, 1993), Ing. Antonín Šika, CSc. – various coniferous species of introduced trees (e.g. Šika 1985; Šika & Heger 1971; Šika & Vinš 1971). The provenance research on the national and international level thus became the first and for a long time also the main research activity, and later it was followed by other activities such as research and development of vegetative methods of propagation of forest tree species, hybridization experiments, research and verification of biotechnological methods of forest tree species breeding, including the field of forest tree species introduction. One of the promoters and solvers of research projects in this area was Ing. Zdeněk Zavadil, CSc., who focused on research of vegetative propagation of forest tree species as the main method used for foundation of seed orchards of forest tree species (e.g. Zavadil 1979). Another expert working closely with the Division of Biology and Breeding of Forest Trees was also RNDr. Vladimír Špalek, co-founder of the Forestry and Game Management Research Institute's research station in Kunovice, who focused on fast-growing deciduous tree species from the 1950s to early 1970s (e.g. Vincent & Špalek 1954). In the Baně-Cukrák location at the former Experimental Forest Objects Administration of the FGMRI, he established a complex of long-term verification areas with species of the *Populus* genus. Hybridization experiments carried out mainly with the *Larix* genus were made by Ing. Jiří Šindelář, CSc., who picked up the threads of the scientific work done by doc. G. Vincent (e.g. Šindelář 1987; Šindelář & Frýdl 1993).

From the late 1950s, the Division of Biology and Breeding of Forest Trees also had the Sofronka Arboretum, which was founded by Ing. Karel Kaňák, CSc., a specialist on the *Pinus* genus breeding, who used this FGMRI remote site for a unique and vast collection of the world assortment of species of the *Pinus* genus. For a long time, the was the country's leading workplace specialized in development of biotechnological methods of forest tree species propagation, in particular *in vitro* methods, suitable for rapid and efficient reproduction of forest tree species and later also for less frequent and hard-to-be reproduced plant species. This was mainly thanks to prof. Ing. Vladimír Chalupa, DrSc. (e.g. Chalupa 1991), whose work was later continued by RNDr. Jana Malá, CSc and her team. Among the outcomes of their work was, for example, creating methodologies for *in vitro* reproduction of more than thirty species of forest tree species and plant species (e.g. Malá et al. 2002, 2005, 2008; Cvrčková et al. 2016). The Division of Biology and Breeding of Forest Trees gave a long-term attention to verification of introduced tree species for the use in Czech forest management. Ing. Antonín Šika, CSc. contributed to this field on the long-term level and achieved signifi-

cant results. One of the modern research areas developed at the division was dendrochronology which included applications of tree-ring analyses and dendrochronological dating methods for production-ecological research of forest ecosystems. At the division, this specialization was pursued by Ing. Bohuslav Vinš, CSc., who was the first to define the term "dendroecology" as a specific branch of classic dendrochronology and dendroclimatology in 1967. Research in the area of production ecology of forests was done on the long-term basis by Ing. Jan Pařez, CSc. (e.g. Pařez 1989) who worked for the FGMRI until 1994. He is currently an external expert at the Institute of Forest Ecosystem Research (IFER). The topic of using computer technology and statistical methods in forestry research was covered at the division by Ing. et Ing. Bohdan Páv from 1960s to 1990s (e.g. Páv et al. 1990).

In the years 1976 – 1986, the division was also joined by prof. Ing. Zdeněk Poleno, DrSc., a leading Czech expert on forest tending, breeding and production (e.g. Poleno 1986). In the 1970s, the division also aimed its attention to research activities connected with the research and protection of the environment. This area was mainly covered by Ing. Věroslav Samek, CSc. (e.g. Samek 1967). In the 1950s and 1960s, another expert active in the division was Dr. Ing. Jaroslav Řehák, CSc., who solved the research task "Research of forest geobiocenosis" concentrating on forest reservations in Mionší, Boubín virgin forest and Žákova hora.

Gradually, the staff of the Division of Biology and Breeding of Forest Trees founded more than 300 long-term research areas where progenies of provenances of both principal and accessory domestic tree species as well as introduced ones are verified. On many research areas, there are also verifications of progeny coming from hybridization experiments which were mainly carried out with the *Larix* genus. Among the research areas founded by the division staff, there are also numerous demonstration objects where variants bred with the use of biotechnological *in vitro* propagation methods are planted and observed.

The work started by the above-mentioned researchers was later continued by, among others, Ing. Karel Vančura, CSc., Ing. Jaroslav Jačka and RNDr. Václav Buriánek who followed on research activities of Ing. Bohuslav Vinš, CSc., while RNDr. Jana Malá, CSc., continued with research of biotechnological propagation methods based on the work by prof. Ing. Vladimír Chalupa, DrSc. Researchres doc. Further, Ing. Vladimír Hynek, CSc. and Ing. Josef Frýdl, CSc., continued with research activities of Ing. Jiří Šindelář, CSc.; and Ing. František Beran continued with research of introduced tree species after Ing. Antonín Šika, CSc. Research activities of Ing. Zdeněk Zavadil, CSc., focusing on vegetative methods of forest tree species cutting and grafting were followed by Ing. Pavel Radosta, CSc. Management of Sofronka Arboretum was taken by Ing. Jan Kaňák, Ph.D., after Ing. Karel Kaňák, CSc., and he currently continues with research and other activities at this site.

As part of measures for saving, preservation and reproduction of genetic resources of forest tree species, the division conducts research focused on application of molecular-genetic analyses in forestry. The results were mainly used for clone identification in seed orchards. There was also genetic screening of partial populations of ten species of forest trees. At first, the isoenzyme analysis was used (Ing. Ondřej Ivanek, CSc.), and later, attention turned to DNA analyses (Ing. Pavlína Máchová, Ph.D., Ing. Helena Cvrčková, Ph.D.).

The division is actively involved in preparations of concept papers for the EUFORGEN programme (Ing. Josef Frýdl, CSc., RNDr. Václav Buriánek) and it also took part in preparations and implementation of the National Programme of Conservation and Reproduction of Forest Tree Species Gene Pool (RNDr. Jana Malá, CSc., Ing. Petr Novotný, Ph.D., Ing. Josef Frýdl, CSc.) as well as establishment and operation of the National bank of Forest Tree Explants (RNDr. Jana Malá, CSc., Ing. Pavlína Máchová, Ph.D., Ing. Helena Cvrčková, Ph.D.) The outcome of current research activities is also the update of rules for transfer of reproduction material for the Douglas fir (*Pseudotsuga menziesii*) and grand fir (*Abies grandis*) from the USA to Canada (Beran et al. 2016a, b).

3. Forest protection

The Forest Protection Institute was founded in 1921 as the first institute of the current research institution. Its head was prof. Julius Komárek. In the post-war era, forest protection on the entomological field was studied by prof. Ing. Dr. Augustin Kalandra, DrSc., who was the head of the institute, and later mainly by the following generation represented by doc. Ing. Vladislav Martinek, CSc. (who was the head of the Forest Protection Division for a long time), Ing. Vladimír Novák, CSc., Ing. Richard Hochmut, CSc., Ing. Jiří Kudler CSc., Ing. Sergej Kolubajiv, CSc., Ing. Miroslav Šrot, CSc., as well as Ing. Milan Švestka, DrSc., as a representative of the younger generation and a number of other young colleagues.

In the 1950s, the role of sister broods of the spruce bark beetle (*Ips typographus*) (L.) was clarified (Martinek 1956a, 1957) as well as its infestation density and natality (Martinek 1956b, 1961). It was proved for the foundation of sister generation that the female can continue laying eggs up to three times with 91%establishing the first sister generation and 38% establishing the second one. This had a significant practical impact on the form of trap trees, in particular in terms of their felling. The scientific contribution of this research still continues to be evaluated very well.

Another important contribution was clarification of the conifer ambrosia beetle (*Xyloterus lineatus* (Ol.)

bionomics. A crucial finding was defining the limitary wood moistness for infestation of wood (especially after windbreaks) with this pest (Novák 1960).

In the 1960s, a lot of attention was given to research of the pine weevil (Hylobius abietis) (Novák 1965), including chemosterilants (Novák 1971). A significant action was the introduction of aggregation and sexual pheromones to forest protection, whether those against spruce bark beetle (*Ips typographus*) (L.) or those against the nun moth (*Lymantria monacha*), the larch tortrix (*Zeiraphera griseana*) and other butterfly pests. Their research was not only done, but in fact also commenced by Czechoslovak researchers from this department as well as other local organizations, such as the Entomological Institute of the Academy of Sciences. After the discovery of the chemical composition of the spruce bark beetle pheromone, Ing. V. Novák, CSc. and his colleagues participated in the development of the new type of pheromone dispensers and pheromone traps. Similarly, in case of butterfly pests, it was primarily Ing. R. Hochmut, CSc. and his team who worked in the development of pheromones for monitoring main butterfly pests – the nun moth (*Lymantria monacha*), larch tortrix (*Zeiraphera griseana*), green oak tortrix (*Tortrix viridana*), winter moth (*Operophtera brumata*) and pine shoot moth (*Rhyacionia buoliana*). Many of these dispensers, traps and methods are still used nowadays (Zahradník et al. 1993).

There have always been achievements in implementation of biological methods of forest protection which were commenced by Ing. Jiří Kudler, CSc. He developed a formula against the European pine sawfly (*Neodiprion sertifer*) on the basis of the *Birdia diprionis* polyhedral virus – from the production process to application (Kudler 1988). Also his work on beneficial insect, predators and parasitoids of forest pests is to be reminded (Kolubajiv 1954). Regarding fungal pathogens, it is necessary to remind leading figures of the post-war era – Ing. Vlastislav Jančařík, CSc., Ing. Branislav Uroševič, CSc. and Ing. Hana Červinková (Jirmanová), CSc., and their successors, especially RNDr. František Soukup, CSc.

A great contribution for forestry can be seen in the explanation of the pined needle-cast fungus (*Lophodermium seditiosum*) bionomics and subsequent defining protective measures against it. This was mainly done by Ing. Vlastislav Jančařík, CSc., who explained its bionomics in local conditions and defined measures for control and direct protection based on repeated preventive fungicide spraying (Jančařík 1977). In the 1980s, he intensively studied large-scale oak dieback connected with tracheomycosis syndromes and suggested methodology of damage monitoring and possible remedies as well as precautions (Jančařík 1990) where he successfully continued with work started by his Slovak colleagues, especially Ing. Roman Leontovyč senior, CSc., who had already collected extensive experience with similar issues in Slovakia. Attention was also paid to biological methods of protection from fungal diseases, especially fungal antagonists of pathogenic wood-destroying fungi (Voroncov & Červinková 1986).

Other activities worth reminding are those related to protection of forest growth against rodents (Ing. Václav Tichý, CSc.) and weed (Ing. Olga Válková, CSc.). Válková summarized long-term results of her research and findings from its application in a publication which was rather unique at that time (Válková 1989).

Last but not least, it is necessary to mention the contribution of the institute staff to development and implementation of control and protection methods against main pest incest species (cephalcia, sawfly, pine weevil, rust, needle-cast fungus etc.). To a certain extent, all employees of the institute participated in solutions of these issues (e.g. Kalandra 1952; Kolubajiv 1952; Kudler 1954; Záruba 1956; Švestka et al. 1998; Zahradník 2014 and others). Based on the research findings, many departmental as well as Czech state (technical) standards were adopted (Knížek 2005; Liška 2005a, b; Zahradník 2005). Another activity of a great importance was the historical overview of forest pest insect in Czechia (Liška et al. 1991).

4. Forest ecology

The Forest Ecology Division had its roots at the Institute of Forestry Biology and Pedology established in 1922 and run by Ing. Dr. Antonín Němec. In the following years, the Institute underwent numerous changes which resulted in the foundation of the Forest Environment Division in 1965, at first run by Ing. Věroslav Samek, CSc. and subsequently by Ing. Jan Materna, CSc. At the end of 1980s, the division split into two units: the Monitoring Division run by Ing. Jan Materna, CSc. and the Forest Environment Division run by Ing. Václav Lochman, CSc. In 1992, its name was changed to the Forest Ecology Division and the subsequent directors were Ing. Hana Uhlířová, CSc. and doc. RNDr. Bohumír Lomský, CSc. Since 1997, doc. Ing. Vít Šrámek, Ph.D. has been the head of the division. Long-term research in forest ecology is focused on evaluation of the forest health and the impact of abiotic and anthropogenic factors, forestry hydrology, bioclimatology and hydropedology, the condition of forest soil and nutrient cycle in relation to the current deposition load and forestry management procedures, research of biological and chemical methods of forest soil revitalization, evaluation of nutrition and water balance of the forest growth and research of processes in forest ecosystem in the context of the climate change.

Since the very beginning, the division focused on research of air pollution damage of forest ecosystems and revitalization of pollution affected areas. Although air pollution damage of forests was recognized as early as at the beginning of the 20th century (Stoklasa 1923), it was only in the 1970s and 1980s when it reached the extent which meant one of the most serious disasters in

the forestry history. Air pollution damage led to deforestation of crest areas in predominant parts of the Ore Mountains (Krušné hory) and Jizera Mountains (Jizerské hory). Clearcuts induced by air pollution and considerable decrease of health conditions were also recorded in other locations – the Krkonoše Mountains, Orlické Mountains, Hrubý Jeseník and Moravian-Silesian Beskids. The overall area of clearcuts induced by air pollution exceeded 100 thousand ha. The issue of air pollution damage was covered by a significant part of the research capacity both at the Forestry and Game Management Research Institute (Němec 1958; Kučera & Jirgle 1974; Materna 1988) and forestry faculties. One of the leading figures was Ing. Jan Materna, CSc. and his team including Ing. Rudolf Kohout, CSc., Ing. Lída Ryšková, Ing. Jiří Jirgle, CSc., Ing. Jiří Kučera, Ing. Jindřich Tichý, CSc., Ing. Eliška Semorádová and others, who mainly focused on the mechanism of SO_2 impact on tree species, evaluation and prediction of forest growth health and damage of soil environment in polluted areas (Kohout 1982; Jirgle et al. 1983; Materna 1984; Lomský et al 2002). As a result of these research projects, a classification of damage degrees and zones endangered by air pollution was introduced for forest areas and it has been used up to the present time (Materna 1973; Kučera & Jirgle 1974). The increasing trend of defoliation in the early 1990s and its subsequent decrease led to the new definition of forest zones endangered by the influence of air pollution and the emergence of the Decree of the Ministry of Agriculture of the Czech Republic No 78/1996 Coll. on designation of forest zones endangered by the influence of emissions. The new designation was also based on results of the Forest Condition Monitoring as part of the ICP Forests programme, level I, which was initiated in 1987. In 1996, a network of intensive monitoring was established as part of the ICP Forests programme which also included, in partnership with the Czech Hydrometeorological Institute, the establishment of a network of stations measuring concentration of sulphur dioxide and hydrogen fluoride in the air (Šrámek 1998). Results of this monitoring in the years 1984-2003 were also summarized (Fabiánek 2004).

Prediction of progressing damage related to the air pollution load was one of the key sources for the Plan of Forest Regeneration in Polluted Areas (Kubelka et al. 1993). After the decrease of the air pollution level in the 1990s, research activities focused mainly on revitalization of the areas in question. They significantly contributed to explanation of the causes of damage on spruce stands in 1996 and birch stands in 1997 (Lomský & Šrámek 2004). A large team of authors worked on up-to-date instructions for forestry methods in the most heavily damaged part of the Ore Mountains (Slodičák et al. 2008; Šrámek et al. 2008) which was subsequently updated as part of the Ore Mountains Revitalization Plan as adopted by the Government of the Czech Republic in November 2016.

A specific activity for revitalization of areas affected by air pollution is liming of forest soil. It has been done intensively since 1970s (Kubelka 1988). Based on extensive research of soil properties, forest stands nutrition and forest health, clearly defined procedures for selection of the given area, control of liming application and long-term monitoring of its efficacy (Šrámek et al. 2014) were elaborated at the turn of the century and they are still adhered to.

As early as in 1950s, hydrological measurements in small forest catchments were introduced. The Moravian-Silesian Beskids, as an area with high precipitation and nearby industrial centres, were always seen as an important source of potable water. On the other hand, local streams have always had unstable water regimes, and steep hillsides with flysch substratum suffered from considerable erosion due to concentrated overland flow. In 1954, a nationally important water-supply region was declared in the Beskids. It had the area of 909 km^2 and more than 60% were covered with forests. In 1978, the Beskids were declared a water supply preserve. In the 1960s, two impounding reservoirs – Šance and Morávka – were built as well as other multipurpose reservoirs.

The Hydrology Division in Beskids was founded in 1951 in Hnojník under the Peat Research Institute, but as early as 1952, it became a part of the Forestry and Game Management Research Institute. After two years, in 1954, it became a part of the Melioration Research Institute. Since 1980, the division has been a permanent part of the Forestry and Game Management Research Institute (Chlebek & Jařabáč 1995). Significant researchers contributing to hydrology of the Beskids catchment areas were, primarily, Ing. Václav Zelený, CSc., Ing. Milan Jařabáč, CSc. and Ing. Alois Chlebek.

After initial researches of precipitation intensity in 45 stations in the Beskids, measurements in the forest catchments of Červík and Malá Ráztoka were commenced in 1953. From the beginning, the research here was focused on the impact of renewal and transformation of forest stands, precipitation and run-off regime, forest soil erosion and durability and quality of forest resources. Until 1965, the catchments underwent the "calibration" period when interventions in forest stands were basically stopped. On the Červík basement, there was only one case of felling as a consequence of a gale disaster (on the area of approx. 4 000 m^3). From 1966, an accelerated regeneration of stands through strip felling was introduced, and it was planned for the following 20 years. The time schedule, however, was not followed for several reasons, such as the air pollution disaster in the late 1970s which required more pressing issues to be solved. In spite of this, forest stands were regenerated in Malá Ráztoka on approximately 70% of the area, and in 95% of the Červík subcatchment area respectively. Surprisingly, measurements in these catchments found no significant changes in precipitation and run-off relations, although Malá Ráztoka saw a slight increase in water content during the

1980s (Jařabáč & Chlebek 1989). In the late 1980s, it was proved that building of the road network and the use of inappropriate logging and hauling machinery led to increased erosion (Jařabáč & Chlebek 1987). Nevertheless, on the whole, interventions resulted in no negative changes. Despite these results, data from experimental catchment areas were never used as a support for large-scale logging. On the contrary, research reports, especially after 1990, point out the need of sensitive management in forest ecosystems. The results from the Beskids catchment areas have continued to be in practical use – among others, in evaluations of the hydric function of forests on clear-felled areas and in stands with a tree layer decline (Šach et al. 2018).

Besides hydrological parameters, also quality of water running off from forest ecosystems has been monitored since the mid 1970s. This topic was covered mainly by the team led by Ing. Václav Lochman that monitored not only catchments in the Beskids, but also those of the Pekelský brook in the area of the Švihov reservoir on the Želivka river, in the Moldava location in the Ore Mountains and in microcatchments in other locations in the Czech Republic. In individual monitored locations, the attention was given to evaluation of depositions to forest ecosystems (chemistry of precipitation in open areas and under the plant stand), chemistry of soil water and chemical composition of water in small forest streams as well as changes in chemical parameters in forest soil. The results showed that despite air pollution being enormous in some locations – such as Moldava in the Ore Mountains (Lochman et al. 2008a) – forest ecosystems had considerable buffering capacity and water in monitored streams complied with most chemical parameters for potable water, i.e. there was not a huge increase in the amount of sulphates, nitrates or heavy metals (Vícha & Lochman 2012). After an immense reduction of air pollution in the 1990s, the increase in pH was observed, but there was also a higher run-off of sulphates from forest catchments (Vícha et al. 2013). Imissions and acid depositions had a considerably negative effect on the condition of forest soils where significant decrease in contents of alkali cations was observed (Lochman et al. 2008b).

5. Silviculture

The Silviculture Institute was founded in 1923 in Brno. The research station in Opočno where it concentrated its activity was first established as a sector research institute of the Czechoslovak State Forests in 1951 and run by Ing. Jiří Mottl, CSc. Subsequently, the department was led by doc. Ing. Vladimír Peřina, CSc. for a long time, and later on by doc. Ing. Antonín Jurásek, CSc. The post-war development in silviculture research is mainly connected with the names of researchers including Hugo Konias, doc. Ing. Vladimír Peřina, CSc., Ing. Luděk Chroust, CSc., Ing. Vratislav Dušek, CSc., Ing. Theodor Lokvenc, CSc. and Ing. Vladimír Zakopal, CSc., while the younger generation is represented by doc. Ing. Antonín Jurásek, CSc., doc. Ing. Marian Slodičák, CSc., Ing. František Šach, CSc., Ing. Vratislav Balcar, CSc. and many other colleagues. It should also be noted that many future professors at forestry faculties started their career at this institute – to name at least a few, this applies to prof. Ing. Vladimír Tesař, CSc., prof. Ing. Petr Kantor, CSc. a prof. Ing. Vilém Podrázský, CSc.

One of the main contributions in this area was the research and implementation of ecology principles of tending felling. In the traditional European forestry, the stand tending was always connected with targeted selection in which a less suitable stand component was intentionally removed in favour of the desirable component. This ensured sufficient production of wood and maximized the quality of the target production.

Long-term experiments with tending of spruce, pine and oak stands which were carried out from 1960s to 1980s at the FGMRI research station in Opočno resulted in defining another aspect of tending felling: their impact on the stand conditions, mainly on the stand's water balance, radiation regime and other climatic elements influencing growth of trees after an intervention.
It was discovered that after tending interventions, the interception decreases and more precipitation reaches the forest soil. Precipitation in combination with a higher temperature support decomposition processes in the forest soil and thus improve the nutrition cycle in the ecosystem.

Findings about ecological effects of tending felling currently help form the foundation of suggested cultivation methods in forests affected by anthropogenic activity as well as locations endangered with drought.

Forestry in areas affected by air pollution, for example in the Ore Mountains, was also problematic. In 2005, the Grant Service of the Lesy ČR ("Forests of the Czech Republic") state enterprise commissioned the project "Forest Management in the Ore Mountains" with the objective to get a comprehensive evaluation of the condition and development of stands of substitute tree species in air pollution affected areas of the Ore Mountains based on all existing research results and forestry experience in this region, including elaboration of comprehensive and variant recommendations of measures to be taken here.

The project included all aspects relevant for defining forestry measures ranging from evaluation of the condition of the environment, forest soils, substitute tree species stands including their lifetime period and evaluation of the game influence on the forest, up to recommendations of potential and realistic measures leading to improved soil quality and stands' nutrition, decreased pressure on the forest caused by the game, transformation of substitute tree species stands, cultivation and renewal of stands, recommendations of the use of planting stock, chemical and biological melioration etc. Forestry methods were also assessed in terms of

their economic aspects, including their cost-efficiency. Based on the assignment, nine realization outputs were suggested for individual areas of forestry activities as well as the concluding synthesis of findings with respect to long-term safeguarding of all forest functions, including the production function (Slodičák et al. 2008).

The research helped to collect data on the current condition and development of forest soils and their damage, and it identified the health of substitute tree species stands differentiated by specific locations and stand structures. It also gathered data on the impact of game on forest ecosystems including the economic evaluations and suggestions for minimizing damage. There was a variant suggestion of cultivation methods including parameters of the planting stock, forest regeneration, adjustment of rotation, adjustment of the species structure, improvement principles and methods of transforming substitute tree species stands. At the same time, cost-efficiency of individual versions of cultivation methods was assessed. Similarly, suggested forestry principles were also elaborated for the Jizerské Mountains area (Slodičák & Novák 2009).

Another important output provided by this division was defining stabilization measures for forest stands with a spruce dominance. Based on the results of long-term experiments in 1980s and evaluations carried out after 2000, methodology for spruce stands or forest stands with a spruce dominance was suggested in respect to increased occurrence of extreme climatic conditions and disturbed soil environment. In accordance with the research results, it is recommended to start tending in spruce stands with the initial density of 3 – 4 thousand seedlings per 1 ha no later than with the upper height of 5 metres (i.e. before the age of 20 years) with selective treatment from below, after which there should be left approximately 1 300 – 1 500 individual plants of the best quality in regular spacing. During this intervention, also the necessary sorting of the stand should be carried out. With all such interventions, admixture of deciduous trees is supported, especially a beech. Additional tending interventions with the upper height of 10, 20 and 25 metres are milder with a decreasing intensity of intervention and prolonged cultivation period. From the second tending intervention on, it is possible to combine the negative selection below with the positive selection above while selecting and marking 300 – 400 high-quality target trees, typically dominant and co-dominant ones, in regular spacing to be freed from competing trees. It is advisable to do the pruning to the height of 4 – 5 m focusing on dry branches. In spruce stands cultivated according to this model, there is sufficient space for the development of crowns and root systems at the young age as well as for development of a trunk resistant to a possible break caused by snow (which is the main harmful phenomenon in these stands in the first half of the rotation period). The lower tending intensity in the second half of the rotation period aims to maintain the closed canopy and combine internal and external stabilization of the stand as a protection against wind damage.

The recommended procedure also respects requirements on wood production. Possible production losses after the first, very intense, intervention are quickly compensated by increased increment of the preserved trees, and the production quality is ensured both by the selection of target trees and their pruning, and also by development in closed canopy in the second half of the rotation period.

An important issue addressed in the past was the systemic solution of the quality of forest tree species planting stock. The quality of forest tree species planting stock is significant for successful forest regeneration, and so the FGMRI's applied silvicultural research paid extraordinary attention to it. An important impulse for the new concept of the planting stock quality came with the year 1989, when production of the planting stock became a business activity and the research results had to be processed for the forestry practice in the form of technical standards and groundwork for legislation. In 1998, the FGMRI in partnership with the Mendel University in Brno published the Czech Technical Standard No. 482115 ("Forest Tree Planting Stock") and the most important quality parameters as stated by the research were used for the legislative updates (the Implementing Decree to the Act no. 149/2003 Coll.). Research of the planting stock quality continued to bring additional important findings even after the above mentioned standard, and so it was completely revised in 2012 (Jurásek et al. 2012).

On the long-term level, the FGMRI also focused on optimizing methods of container planting of forest tree species. This mainly applies to using suitable types of containers which prevent root deformation. This applied research resulted in introduction of verified methodology "Use of Forest Nursery Planting Stock from Biologically Verified Containers for Reforestation" (Jurásek & Nárovcová 2012). Its practical output is the "Catalogue of Biologically Tested Containers of Planting Stock for Forest Tree Species Growing" which gets continuously updated and is available for expert on the FGMRI website. This material is extensively used in the forestry practice and its authors were given the Award of the Minister of Agriculture for the Best Realized Research and Experimental Development Result in 2014. The aggregate information of nursery practice was published Dušek (1997).

The silvicultural research also focused on observation of the species structure and its impact on run-off conditions in forest stand. It was studied in cases of young stands of the Serbian spruce (*Picea omorika*) and European white birch (*Betula pendula*) on the foothills of the Krkonoše Mountains (Šach et al. 1994), young stands of the Norway spruce (*Picea abies*), young mixed coniferous stands (spruce 50, larch 35, pine 15, birch, beech) and adult spruce stands on the foothills of the Orlické Mountains (Šach & Černohous 2010). In the Orlické Moun-

tains, the run-off was observed with both adult and young spruce stands and both adult and young beech stands (Kantor 1994). It was measured as vertical lysimetric run-off, and on slopes, there were also measurements of surface and lateral run-off through soil profiles (units of % only). The run-off was double in forest stands in theextra-vegetative period (73%) as compared to vegetative period (37% of precipitation in open areas). A double amount of run-off (70% of precipitation) was also generated due to higher precipitation and lower temperatures and thus also lower interception and evapotranspiration (IET) from the 6th forest vegetation zone, while the 5th forest vegetation zone with its lower precipitation and higher temperatures and thus also higher IET had lower run-off (35% of precipitation).

Within one forest vegetation zone, the run-off in a hydrological year was higher from deciduous stands in comparison with the coniferous ones. Coniferous, especially spruce stands can suffer from droughts in lower forest vegetation zones (no. 5 and lower). However, run-off from coniferous stands was steadier over time. This means that more frequent and higher flood run-offs with higher culminations will probably be handled in a better way by coniferous stands than the deciduous ones. Hydric qualities on the level of fully stocked forest stands get stabilized during the 2nd (for lower forest vegetation zones) or the 3rd (for higher vegetation zones) age class.

The level of run-off depends not only on the tree species, but also on the growth stage of the stand and the forest vegetation zone. Practical results were reflected in the Guidelines on Management of Forests with Water Management Functions (Šach et al. 2007) and Method Procedure Using Optimization of Water Regime through Arrangement of Mixed Culture in Landscape (Švihla et al. 2014).

6. Forest management and planning

The Forestry and Game Management Research Institute never had a specialized department of forest management planning and this area was addressed in various institutes and organizational units. Since the late 1960s, Czechoslovak research work started to focus on growth charts. The research was scheduled for a longer time period with the objective to collect a sufficiently large set of data from research areas situated in Czechoslovakia and with the objective to collect data from repeated measurements so that the real growth of individual tree species over time could be monitored. The main researchers were the two research institutes in Strnady and Zvolen, but basically all forestry organizations and both forestry faculties were involved.

At that time, German growth charts by various authors were still in use, although they did not always fully meet the domestic needs. The partnership with the two Forest Management Institutes in Brandýs nad Labem and Zvolen was of a great importance as they were able to establish hundreds of research areas in stands of main tree species in all age classes, and as a result, a sufficiently large database considering the growth and development of the main local tree species could be made. Both the methodological and practical work with growth charts was managed by the Commission for Czechoslovak Growth Charts where all participating organizations were represented. The commission's staff changed over time. The first edition of growth charts was published in 1979 under the editorial team of prof. Ing. Ján Halaj, DrSc. and Dr. Ing. Jaroslav Řehák, CSc. Gradually, three editions were published with different methodologies applied. I was impossible to reach a unified application for both parts of Czechoslovakia. The reason was that there were different growth conditions in the Hercynian and Carpathian region and neither of the parties was satisfied with the accuracy. The FGMRI Zbraslav-Strnady was represented by prof. Ing. Zdeněk Poleno, DrSc., prof. Ing. Ivo Kupka, CSc., Ing. Jan Pařez, CSc. and Ing. Martin Černý, CSc.

This commission had to deal with numerous methodological issues as extensive data sets from different locations with different conditions, such as different levels of relative density of fully stocked stands, the question of dominant and subsidiary stands in various stages of tending with a lack of precise data on tending interventions carried out (Pařez 1987a, b).

7. Forestry economy

The Forest Economy Institute was founded by prof. Dr. Ing. Rudolf Haša in 1923. In the post-war era, it dealt with issues such as the lack of forest workers, improvement of forest work processes, improvement of forestry equipment, creation of performance standards, research of social and health conditions of forest workers and issues of work hygiene and safety in forestry.

In the 1950s, activities were focused on solving problems connected with mechanization development and optimization of work processes and management. The emphasis was put on technical and economic analyses of methods for logging with the use of a one-man power saw, skidding, planting standards, forestation in various natural conditions and the application of punched card computer technology in state-owned forests administration.

The economic research in 1960s addressed economic standardization and typization of main production activities enabling their easier management (developing laboriousness indicators of individual production activities and their management on the level of internal organizational units, the use of operational research methods in economic transport analyses and placement of central manipulation storehouses, elaborating methodology for raw timber pricing, optimization of work technology with a one-man power saw in terms of hygiene, organizational

rules for team work etc.). An important figure in the area of forest economy at that time was Ing. Jaroslav Mervart.

In the 1970s, the Forest Economy Division run by doc. Ing. Zdeněk Bluďovský, DrSc. solved tasks connected with management issues in organizational units in state-owned forests, work productivity measurements in the context of introduction of new technology into the production process, labour and working conditions evaluation, remuneration of managers etc. In the early 1970s, the independent Automated Management Systems Unit was established and doc. Ing. Milan Novotný, CSc. became its director. Existing economic topics were thus supplemented with the issues of computer technology as a support for management activities (e.g. optimization of timber transportation within the organization, projects focused on automated weights calculations and logging resources assortmentation, sales register processing on the organization's level, application of critical methods for logging activity on the forest district level etc.). These tasks were addressed by, among others, Ing. Miloň Pohořelý, CSc. and Ing. Záviš Pexidr, CSc. An important role in solving research problems was also played by the Mathematics and Statistics Lab run by Ing. Božena Temmlová.

In the 1980s, forest economy research focused on company and sector economy (e.g. costs of production processes, wood chips production, weight reception of timber, efficiency standards etc.). These projects were worked on by Ing. Jiří Skýpala, Ing. Jiří Bozděch, Ing. Miloš Klouda and others. With the introduction of personal computers (Olivetti, Redifon) to forestry in 1986, the division started to design automated management systems for the organization and use economic-mathematical methods such as optimization and modelling.

In 1991, the research institute underwent organizational transformation and three divisions – Forest Economy Division, Automated Management Systems Division, and Production and Management Division – were dissolved. Later, also the technical standardization (Ing. Miroslav Michalec, Ing. Vlasta Vančurová) and prognostication activities (Ing. Václav Novotný) were discontinued.

In the 1990s, the research team of Ing. Jiří Matějíček, CSc., Ing. Jiří Skoblík, CSc. and Ing. Jan David in the newly established Division of Forestry Policies managed to renew the "Forest Appreciation" discipline after 40 years with the use of newly developed appreciation models for forest estates, forest stands and forest damages which led to preparation of data for the respective legislation.

8. Forestry mechanization

The Křtiny Research Station was founded in 1951. Its founder and first director was Ing. Václav Štaud, CSc., an outstanding researcher in forestry and its technicization (Neruda, 2000). The station was opened as a subdivision of the Forestry Mechanization Research Institute in Oravský Podzámok with the task to address mechanization for wood logging and skidding as well as forest regeneration. These initial tasks were later expanded to other fields of forestry. After the forest research reorganization in 1957, the Křtiny Research Station became a part of the Forestry and Game Management Research Institute in Jíloviště – Strnady (FGMRI). It continued its operationas this research institute's organizational unit until the end of 1990 when it was transferred to the Training Forest Enterprise in Křtiny as part of the then Brno University of Agriculture (currently the Mendel University in Brno).

After this reorganization, the research station turned to production of its own specialized portfolio of research solutions for technical and technological development in forestry. These activities currently include forest transport cableways equipment, machinery for preparation of soil for forest regeneration, forestation machinery etc.

During its existence, the Křtiny Research Station has had a number of leading experts focusing on forest technology who devoted all their efforts to their profession. We should primarily name Ing. Václav Štaud, CSc., who was in charge of the station at the very beginning when he had to find compensation for horses in forests and introduce tractors. He also came up with inventive solutions in technological preparation of units which were directly linked with the forest management development (in which he closely cooperated with another leading expert, prof. Ing. Bohumil Doležal, DrSc. from the Forestry Faculty of the Brno University of Agriculture). He was personally involved in creating the design and solution of wood skidding with the use of forestry cableways technologies and so on. It was also thanks to this division that the Research Station has achieved and maintained its top international reputation. In the era when the technological development of planting activities lagged behind wood logging and skidding (i.e. in the 1970s), Ing. Václav Štaud, CSc. also took charge of tasks oriented on forest nurseries and forest regeneration. Probably the most famous output of this era was (and continues to be) the genius furrow tree planter RZS-1 machine, whose construction principles inspired planting machines manufactured abroad as well.

The Research Station was lucky enough to have employed many other outstanding and enthusiastic scientists and researchers, designers and machinery workers. Achieved results were enabled not only by their expertise, but also by their efficient and active collaboration. To name a few, there was for example Ing. Jaroslav Popelka, a visionary and excellent designer of many forestry mechanization devices (e.g. cableways, logging machinery and also the first prototype of the forestry wheeled skidder – a predecessor of the later well-known LKT machines), Ing. Zdeněk Réman and Ing. Mirko Dressler, CSc. (cableways, logging machinery including their legendary branch trimmer), Ing. Ivo Adámek, CSc. and Ing. Václav

Jahoda, CSc. (building forest roads, traction winch machinery), Ing. Vladimír Liška and Ing. Jaroslav Drochytka (forest nursery technology and forest regeneration), Ing. Přemysl Horek, CSc. and Ing. Lubomír Novák, CSc. (forestry cableways, dendromass wood chipping) and others. Last but not least, Ing. Alois Švenda, CSc. ran the Research Station after Ing. V. Štaud, CSc. Ing. A. Švenda, CSc. focused on the use of fragile wood, segmentation of stand and in the 1980s, he continued with the issues including mechanized technology for forest nursery large-scale production and technologies for the use of tree mass. A significant output of his research activity in the mid 1980s – and he was well ahead his time – was the technology replacing classic nursery technologies with production of small and medium-sized container planting using firm seedling trays. Ten years later, this technology won recognition in Northern Europe for PLUG+ seedlings production.

Tradition of above mentioned mechanization devices which the Research Station developed decades ago and continued to improve and modify is built upon up to the present time, with some current products made here. We will only mention a few of all of those products whose significance and application in the forestry operation have endured. The most important ones are the TPF-1 disc cutter, the above mentioned furrow tree planter manufactured in the original RZS-1 version and in several modification, forest cableways (the LARIX line), and there has also been a revived demand for the APOS branch trimming machine.

9. Game management

The history of game management research began with the establishment of the Game Management Division in 1931 under the leadership of Ing. Jiří Sekera. In 1935, this division was merged with the Forest Protection Institute. The game management research in the post-war era was represented mainly by RNDr. Miroslav Bouchner, CSc., Ing. Bohuslav Fanta, CSc., Ing. Zdeněk Fišer, CSc., Ing. Václav Hanuš, CSc., RNDr. Jiří Janda, CSc., Ing. Alois Kotrlý, CSc., Ing. Josef Lochman, CSc., RNDr. Stanislav Mottl, CSc., MVDr. Jaromír Páv, Ing. Miloslav Říbal, CSc., Ing. Bohumil Volf, CSc. and their followers Ing. František Husák, CSc., Ing. František Havránek, CSc. and many others.

Research focused on small game, both feathered and fur-bearing game, as well as hoofed game. Researchers addressed issues such as introduction, breeding, nutrition, health and also sensibility to various substances and pesticide doses.

In the post-war period, a generation of researchers was involved in game management research, which profoundly profiled each of its fields. MVDr. Jaromír Páv, CSc. substantially developed parasitology of the game (Páv 1972), and his results are still a valuable source of information. Similarly, Ing. Václav Hanuš, CSc. and Ing. Zdenek Fišer, CSc. contributed to the development of intensive breeding of small game by forming of the first compound feed for pheasant game and the principles of breeding this important game species, including environmental adjustments. An important achievement of the team Ing. Václav Hanuš, CSc., Ing. Zdeněk Fišer, CSc. and RNDr. Miroslav Bouchner, CSc. was the inventory of the presence of grouse in the Czech Republic. This, nowadays historical material, fully documents the occurrence of forest fowls, nowadays endangered species, and contributes to the possibility of their salvage. Lastly named is a well-known ornithologist who has dealt with game species, especially water birds, his pubic book on wildlife (Bouchner 1986) has been published in a number of countries. The issue of cloven-hoofed game was solved mainly by Ing. Josef Lochman, CSc., which significantly contributed to the development of the use of game preserves for spend the winter in the Czech Republic or to the mouflon breeding. The problems of forest protection and testing of the plant protection products (repelents) were solved by Ing. Miloslav Říbal, CSc. and testing of the impact of other plant protection products on deer followed up RNDr. Jiří Janda, CSc.; this activity was discontinued soon. In recent decades, the monitoring of state of health of game according to the quality of the environmen was developed by doc. MVDr. Karel Bukovjan, CSc. Mehods of management of game populations were developed through regulations of Ministry of Agriculture and various methodologies by Ing. František Havránek, CSc.

Many monograph publications were written as a result of the research, providing comprehensive data on various species. These publications include, for example, monographs on the Cavicornia (Lochman et al. 1979), the mouflon (Mottl 1980), the red deer (Lochman 1985) and the fallow deer, sika deer and whitetail deer (Husák et al. 1986). The study of the hare was covered by Semizorová & Švarc (1982). Attention was also paid to efforts to make the research on game more popularized. As a result, there was, for example, a publication on animal tracks (Bouchner 2003).

10. Conclusions

This overview cannot be a complete and exhaustive summary of everything that has been discovered and provided for practical forestry use during the almost 100-year history of the Research Institute. Intentionally, there was no focus on pre-war and war period, although many important and serviceable achievements were made at that time – to mention at least one, we can remind the reason for establishment of the Forest Protection Division (later an Institute, which was a predecessor of the current Research Institute in this field) due to the need to deal with the nun moth disaster.

The whole system of research institutes was built based on the initial concept by Ing. Dr. Karel Šiman pre-

sented in 1919 – 1923. Its establishment was completed in the late 1940s and finally it was largely transformed in the 1950s. Only then, also because of the significant increase in the number of researchers (in the early 1990s, for example, the number of employees was approximately 500 and some three fourths of them participated directly in research), did the institute fully focused on the needs of practical forestry. Many results of the research done from the 1950s have become outdated. However, they played an important role in their era. And what is even more important, following researchers built on these findings and shifted the amount of know-how even further and made it accessible for practical application. It may sometimes seem this progress was rather moderate in the year-on-year perspective, yet seen from the distance of several decades, it is clearly evident. Also for this reason, this overview lists current findings as well because they follow on and draw from the work of the predecessors. This shows how appreciated older research outputs are, as they built the foundation for the present-day results, not to mention the fact that these experienced forerunning researchers contributed to the education and scientific growth of the subsequent generation.

The overview as presented here is thus not only a look back to the past, but also a reminder of the active contribution of the research for the contemporary practice as well as an outlook for both close and far future.

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