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EDITORS

Editor-in-Chief

Milko **Milev**

University of Forestry
10 Kliment Ohridski blvd.

1756 Sofia, Bulgaria

Fax: (+ + 359 2) 862 28 54

E-mail: forconf2010@abv.bg

Assistant Editor

Petar **Zhelev**

University of Forestry
10 Kliment Ohridski blvd.

1756 Sofia, Bulgaria

Fax: (+ + 359 2) 862 28 54

E-mail: peter_zhelev@abv.bg

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DEVELOPMENT OF HIGHER FORESTRY EDUCATION IN BULGARIA

Milko Milev, Stefan Yurukov, Kiril Lyubenov, and Petar Zhelev

Faculty of Forestry, University of Forestry, 10, Kliment Ohridski blvd, 1756 Sofia,
Bulgaria. E-mail: m_milev@abv.bg

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Forestry practice, science and education in Bulgaria have been developing according to Bulgarian specific natural and social situation. Forestry is connected with the global policy of the state and its history and socio-economic development. It is influenced by the advanced European practices but it also reflects the regional specific characteristics. Forestry has its own stages of development and is related to the forest practice and science and with the organizational and personnel structure of the forestry sector.

Background information about the development of forestry education was published on occasion of different anniversaries (Iliev et al. 1975, Nickolov et al. 1985, Kolarov and Brezin 1995, Panov 2000, Puchalev and Iliev 2000, Vuchovsky and Dimitrov 2003, Dimitrov et al. 2005, Milev et al. 2006). A comprehensive study of the whole Bulgarian forestry sector was done by V. Stoyanov (1968). For years higher forestry education has served as a basis of the overall forestry education and research, which is making progress today at the Faculty of Forestry (FF) in the University of Forestry (UF).

According to the Czech historian and Minister of Education of Bulgaria Konstantin Jireček and earlier explorers, 80% of the territory of the Balkans was covered with vast and impenetrable forests. During the Middle Ages, mainly between the 14th and the 19th century, most of these forests were destroyed. This was caused by their uprooting in order to get arable land, their burning to release pastures, the use of timber for construction, firewood and coal production, in mining industry, and in shipbuilding for the Ottoman navy. For quite a long time the forests were managed without any plan, knowledge or practical experience, and were additionally damaged during the wars. They were regarded as a freely available renewable resource. Most of the broadleaved forests were cut and were managed as coppice forests. A large amount of wood was used in the reconstruction of towns, villages and economic life after the Liberation from Ottoman rule (1878). The eroded pastures were degrading in quality, stock breeding was in decline and the popula-

tion was impoverished. Natural disasters occurred rather frequently. The destroyed mountain slopes generated occasional floods. Streets, houses, fields and roads were flooded with mud and stones and cattle and people were killed. This happened in Kyustendil, Kazanluk, Koprivshitsa, Karlovo and many other towns at the end of the 19th century and the beginning of the 20th century.

With its specific climate and centuries-old historical development, Bulgaria has preserved woodlands covering more than one third of its entire territory. The climate influence is variable and is modified by the large mountains, especially by the Balkan Mountain Range. Three altitudinal zones are clearly defined: the lowermost zone of the oak forests, the medium zone of the beech and coniferous forests and the sub-alpine zone. The soils are also highly diverse. There are lots of distinct habitats and forest formations including numerous tree species. As a whole, the conditions are favourable for the development of forest vegetation. Most of the stands, however, have deteriorated due to over exploitation, and managed as coppice forests. The forestry data about the 1940^s is quite indicative: only 22% of the area was covered with high broadleaved forests, 10% with coniferous and 2% with mixed ones, whereas 65% was covered with coppice forests (Vuchovsky and Dimitrov 2003). These facts didn't correspond to the natural potential but there was an acute shortage of forestry staff for professional forest management.

The Beginning of Forestry Education

A century ago Bulgaria's forests turned out to be in very poor state but foresters were scarce. Few of them had graduated from secondary and higher forestry schools abroad. Only ten of the forestry employees in 1894 had the necessary training. The first schools for forest-guards were opened in Borovets (1896) and in Velingrad (1911) (Stoyanov 1968, Kolev and Dimitrov 1996). The secondary forestry education started at the Technical school in Sofia, 1919. Among its graduates were the future professors T. Dimitrov, D. Stefanov, A. Biolchev, S. Hristov, I. Dobrinov, D. Velkov and M. Petrov. From 1950 to 1990 the training of forestry technicians was provided by four technical schools located in Velingrad, Bansko, Batak and Berkovitsa. Most of their graduates later studied in the university and are an important part of the forestry community.

Forestry science and education in Europe emerged more than two centuries ago. The basic forestry theories and practices were introduced in Bulgaria at the end of the 19th century mainly from the German, French and Russian schools. In connection with the natural disasters described, there was a growing interest in the European practices in flood control. Afforestation works were started by foresters trained in Germany, France, Austria, the Czech Republic, Russia and Croatia. Stefan Donchev (1855–1930) was the first Bulgarian with an university forestry degree, which was acquired in Croatia and Prussia. Stoyan Brunchev (1864–1940), who graduated forestry in Munich, is the first Bulgarian forester

to take up a higher government position. He has been credited as the Father of Bulgarian forestry.

Attracting foreign specialists to work in Bulgaria was a clever and necessary move. The Czech forester Julius Milde (1861–1942) started work as a deputy-inspector in Sofia in 1890. He contributed to the establishment of Boris's Garden and the afforestation near Sofia. He was the first principal of the Forestry school in Borovets and he founded the first state-owned forest nursery in Belovo (1900). The greatest authority then, however, was Felix Vogeli (1875–1941) who introduced the French practices in flood control. He opened the first Agency for Flood Control and Afforestation in Kazanluk in 1905 and he worked in Bulgaria until 1911. Another smart government move, made in 1904–05, was to send 5 young people to study in France. They graduated in the *École Nationale des Eaux et Forêts* in Nancy and played an important part in the development of Bulgarian forestry research and education. P. Mandzhukov, K. Hristov and T. Dimitrov succeeded each other in heading the Agency established by Vogeli. Later on, their experience was enriched in other flood areas of the country.

The Beginning of Higher Forestry Education

The first articles advocating the need of forestry university graduates were published at the end of the 19th century. This campaign was a reaction of Bulgarian foresters against the destruction of forests. The purposeful action for the protection of Bulgarian forests and the demand for national engineering education became more prominent with the return of our forestry experts trained abroad and their appointment as foresters. The process of introducing higher forestry education was further stimulated by the Laws on Forests adopted at that time. The famous forester K. Baikushev (1867–1932), who graduated in Tarand (1889) published an article in "Svoboda" newspaper in 1892. It was followed by publications by St. Brunchev (1893), Gr. Grozev (1904) and Ts. Donchev (1910). Strong public support was offered by lawyers, teachers, scientists and states people. In 1915 a state commission was set up with the task of exploring the possibility of opening an independent Forestry Faculty at the Sofia University. However, it did not achieve any positive result. In 1919–20 about 100 forestry university graduates were employed in the forestry sector. On the average, each of them was in charge for 30,000 ha of forests, which was 6 or 7 times more than the amount in countries with advanced forestry (Stoyanov 1968). Obviously, the foreign training was not able to meet the needs of experts. In 1921 the establishment of Academy of Forestry was proposed and it was decided to open a Faculty of Forestry at Sofia University. The accomplishment of this idea was postponed once again. However, the issue was considered by the Society of Foresters, as well as by the then Ministry of Agriculture and State Property (MASP) and other forestry experts and nature conservationists.

As a result in 1923 the foundations of the Forestry education were laid down, when the Department of Specific Silviculture was opened within the Faculty of



Prof. Todor Dimitrov – the first Head of Department of Specific Silviculture (1923), Dean of the Faculty of Agronomy and Forestry (1933–34).

Agronomy. Assoc. Prof. Todor Dimitrov was appointed as Head of the Department. Later on, he became a Professor and Dean and was credited as the Father of our higher forestry education. All this was preparing the ground for opening of a Department of Forestry. Professor Yanaky Mollov played an important part in this respect, in his capacity of a Minister of Agriculture and State Property. He contacted the group commissioned by the Sofia University and made up of the Rector and the Deans of the Faculty of Physics and Mathematics and the Faculty of Agronomy. They were offered assistance in providing budget funds for equipment and teaching staff. At his order, in February, 1925 a financial grant was given to the Department of Forestry and the Faculty of Agronomy.

January 28, 1925 is considered to be the birthday of higher forestry education in Bulgaria, since on this day the Academic Council of Sofia University took a decision to open a Department of Silviculture at the Faculty of Agronomy and Forestry (FAF). Prof. Mollov made the following comment on this memorable event: *"The year 1925 shall be remembered and it*

will be written in golden figures in the history of Bulgarian forestry because events of such capital importance seldom take place in the history of a nation".

Dimitar Hristov (1871–1944) was another Minister of Agriculture and State Property who had provided considerable support. Meeting the commitments, MASP notified the Rector of the Sofia University in a letter dated 30th December 1925 that two training and experimental forest ranges had been allocated for the training needs of the students at the Department of Forestry. The first one was situated in the coniferous area of "Yundola" between Rila and the Rhodope Mountains and the second one, called "Petrohan" was situated in the beech forest area in the Balkan Range. The two training and experimental forest ranges today are well-established centres for practical training of the students at UF, as well as for research and recreation. D. Hristov's daughter, Mrs Milka Danadjieva offered her support for forestry education donating the apartment inherited from her father, under the condition that the rent received from it would be used for providing scholarships to the best students in forestry.

First Students and Lecturers

The training of students at the new Department of Forestry started with the summer semester of 1925. Fifty candidates sat up for the entrance examination for the first year and twenty of them were admitted. The first year, students began to study on the basis of a temporary curriculum which was approved on 13th April, 1925. A complete curriculum was approved on 7th May, 1927. It included 16 general, 19 specialized and 8 optional subjects.

The ceremony of granting degrees to the first ten graduate foresters was an important event (13th March, 1929). It was attended by the Rector Prof. D. Shishkov, the Academic Council of Sofia University, representatives of MASP, the Ministry of Education, the Society of Bulgarian Foresters and outstanding citizens of Sofia. A powerful speech was made by the Dean of FAF, Prof. Mollov. The degrees were awarded by the first Professor of Forestry, T. Dimitrov. He expressed his hopes that the young foresters would show *"...competence, perseverance and honesty in their work and preserve the dignity of the forestry institution"*.

The Department of Specific Silviculture was a foundation unit around which the activities of the entire Department of Silviculture were developed. One after another, the following specialized departments emerged: "Forest Management and Forest Inventory", headed by Assoc. Prof. T. Ivanchev (1927); "Forest Use and Forest Technology", headed by Assoc. Prof. V. Stoyanov (1930); "General Silviculture", headed by Assoc. Prof. M. Rouskov (1931). In 1940 one of the lecturers at that time, Iliya Mihailov, continued working in the University of Skopje. There he reached the academic rank of professor and became Head of the Department of Forest Management in the Faculty of Forestry.

Independent Faculties of Silviculture

In 1945, an ordinance-law was adopted for the establishment of a new state university in Plovdiv, including a new Faculty of Agronomy and Forestry. The idea for the establishment of a single centre for training of foresters emerged soon after that. An Independent Faculty of Silviculture at Sofia University was established in compliance with the Law on Higher Education from 1947. The faculty existed only one year.

The Faculties of Agronomy, Forestry, Veterinary Medicine and Zootechnics were separated from the University of Sofia in 1948. These faculties formed the basis of a new higher educational establishment – the Academy of Agriculture with a seat in Sofia. On the following year the Faculty of Silviculture was reorganized into a Faculty of Forestry with two departments, and two years later the total number the departments became four: Department of Forestry; Department of Forest Industry; Department of Forest Use and Transport and Department of Urban Afforestation. Thus, the foundations were laid for the establishment of an independent higher school for training staff in the fields of forestry, forest industry and urban landscape design.

Independent Higher Educational Establishment

In 1953 the Agricultural Academy was replaced by three independent educational establishments and one of them the Higher Institute of Forestry (HIF). The major of "Silviculture" was renamed into "Forestry". The institute was provided with an independent main building. In the autumn of 1955, the foundations of the Institute Park and botanical garden were laid, as suggested by Acad. B. Stefanov. The university training was in the field of five specialties including Forestry and Forest Engineering. During the period between 1925 and 1953 the total number of students admitted was 1583. There were 1014 successful graduates holding a degree in Forestry.

In 1974 two faculties were set up in HIF. The specialty of Forestry belonged to the Faculty of Forestry and Landscape Design (FFLD). Prof. Ivan Dobrinov was as the first Dean of this faculty.

After 1979 another educational reform was took place. A three-stage structure of professional training was introduced. The first educational stage covered widely-based general training, the second stage covered special subjects, and during the third stage students studied highly specialized subjects. Then new curricula were designed which even now form the basis of students' training in forestry.

University Stage

On 27th July, 1995, HIF was given a status of a university by the Parliament of Bulgaria. The celebration of this event was combined with the opening ceremony of the new training and laboratory building.

The University of Forestry is the only higher educational establishment training forestry engineers and specialists in woodworking and furniture production, and in engineering design. It also trains students of Ecology and environmental protection, Business management, Landscape architecture, Veterinary medicine and Agronomy. The training is conducted in three stages – the first and second qualification degrees of Bachelor of Science and Master of Science and the academic degree of Doctor of Philosophy.

In 1999 the National Evaluation and Accreditation Agency (NEAA) granted UF institutional accreditation and the right to train students in the three educational stages. The UF was granted a second positive institutional accreditation in 2006. In May 2007 NEAA finalized the program accreditation for the professional training in Forestry, giving it the highest mark and the right to train PhD students.

Training Description

Higher forestry training all over the world is commonly divided into three stages: Bachelor, Master and PhD. A reform to this effect was carried out in 1997. Since

2002 the term of study for the Bachelor Degree has been reduced from 9 to 8 semesters, and for the Master Degree course 3 semesters have been planned. The academic year is divided into two semesters with 15 study weeks each. All curricula, irrespectively of the period they refer to, have been coordinated with the forestry administration, which is the main employer of forestry staff. Since the academic year 2004/05, training has been provided in compulsory, elective and optional subjects. Credits have been introduced according to the European Credit Transfer System (ECTS). In addition to their degrees, the graduates will be given supplements in English, giving full account of the training received. The training and professional fulfillment of the two degrees of Bachelor and Master are quite independent.

The Bachelor of Science Degree

By tradition and in accordance with the engineering profile of the Forestry, the entrance exam is in mathematics. The Bachelor Degree aims at giving a general idea of the specialty by means of a comprehensive training in general, applied basic and applied specialized subjects. The engineers holding Bachelor's degree in forestry can occupy positions below the rank of managers of forestry enterprises. The well-balanced, widely-based training is carried out in 7 clearly defined series of compulsory subjects:

1) about general comprehension of the natural environment and forest ecosystems: Meteorology and climatology, Forest soil science, Phytocoenology, Ecology and environmental protection;

2) about flora recognition and establishment and management of forests and non-wood resources: Botany, Physiology of woody plants, Dendrology, Forest genetics and tree breeding, Silviculture, Forest plantations, Non-timber forest resources;

3) about forest protection and safety: Forest phytopathology, Forest entomology, Forest and nature conservation legislation, Erosion and flood control, Safety activities and protection of forests;

4) about fauna recognition and management of freshwater aquacultures and game: Zoology, Fisheries, Wildlife management;

5) about the technologies and mechanisation of woodharvesting and other forestry activities: Mechanics and construction, Hauling machines, Mechanization of forestry activities, Forest roads, Forest transport, Technology and mechanization of logging;

6) about the mensuration, inventory taking and management of forests: Geodesy, Forest mensuration, Photogrammetry and remote sensing, Forest management;

7) about the economics, management and planning of forestry activities: Forestry economics, Forestry organisation and planning.

Some of the stated series have been extended with elective subjects providing more specialized knowledge. These subjects include Mushroom and medicinal plants cultivation, Principles of agroforestry; Reclamation of land damaged by

coal-mining, Cynology, Wood and timber, Introduction to woodworking, Structure of protected forests and territories. Foreign language training is carried out in 4th semesters and may be continued in 5th semester.

The optional units belong to different fields of study. They enable students, according to their preferences, to extend their grounding in humanities and economics (Philosophy, General economic theory, Introduction into accounting, Latin). Other optional subjects give students a good grounding in modern telecommunications (Global telecommunication networks) and in modern methodology (Statistical methods and modeling).

The practical training is among its main assets and it has a long-standing tradition. In the 1930^s, the senior students passed through a year-long training ending with an exam. The format of practical trainings has changed in the years. Today a skiing-course has been included and the applied subjects are combined with 8 practical courses lasting 9 weeks each. At the end of their course of study, students pass through a 6-week candidate engineer training, carried out in the respective forestry boards. Since the emergence of the specialty, the bulk of the students' practical trainings have been conducted in the training and experimental forest ranges.

The Master of Science Degree

Since the introduction of the three-stage structure of training in 1997, the Master's Degree programs have undergone some changes. Now the training is in three specializations. The final objective is to train highly qualified specialists by means of theoretical knowledge extension and specialized skills acquisition. Students are prepared to organize, manage, design, control and evaluate activities in the field of forestry, game and fish-farming management, forest use and environmental protection. The term of Master's education is 3 semesters. The final semester is planned for thesis completion and defense. Intensive general training is provided in 5 compulsory units: Forest policy, Multifunctional forest management, Forestry and human resource management, Geographical information systems in forestry, Mathematical methods and models. Specialization is achieved in three main areas. On the basis of their specialization, students choose six elective (Table 1) and one optional subject. They have four practical courses and acquire skills in planning, designing, forest management and doing research. The total number of 12 studied subjects and 4 practical courses brings a minimum of 75 credits, 15 of which come from the thesis.

The students choose one optional subject from other specializations or from following subject, proposed only as optional: Soil microbiology; Structure and managing of water tank for fishing; Agroforestry systems; Basics of scientific research.

The successful graduates are entitled to management positions within the structures of the Ministry of Agriculture and the Ministry of Environmental Protection and Waters. They can also teach at universities, can do scientific research and work at research institutes and in experimental seed-control and forestry ranges.

Table 1. Elective subjects for the three Master's specializations.

Forest Management	Game and Fish-farming Management	Forest Use and Forestry Economics
Forests and forestland evaluation; Biodiversity conservation; Forest tree improvement; Forest growth and yield; Forest protection; Forest plantations; Management of torrent watersheds; Multifunctional forest management; Dendrology of exotic species; World silviculture.	Organization and management of game enterprises; Hunting and fishing tourism; Artificial game breeding and nutrition; Technology and management of fish breeding and aquaculture; Structure and managing of water tank for fishing; Game and fish protection from diseases.	Machine repair and maintenance in forestry; Technology project in silviculture; Technology project in logging; Forests and forest land evaluation; Business planning in forestry.

The exchange of lecturers between UF and universities in Germany, France, Switzerland, Austria, Slovakia, Greece, etc. has greatly contributed to the modernization of the teaching process. We have had a close relationship with the Technical University in Zvolen, Slovakia since the 1970^s when a contract for mutual co-operation was signed. Dr. P. Zhelev had several research visits at the TU in Zvolen, as well as Prof. Iv. Mihov who introduced in Bulgaria Prof. Priesol's distant methods. There have been an impressive number of short-term visits of lecturers and a student exchange has been made. Among the professors who have visited UF on an exchange basis are A. Priesol, Št. Šmelko, L. Šmelkova, M. Šuška, Kl. Hubáč, M. Hladik, L. Paule, K. Gubka, I. Lukačik, etc. In token of our fruitful co-operation with the TU in Zvolen, our Prof. Geno Donchev was awarded the honorary degree Doctor Honoris Causa of this university. In 1996, Prof. Milan Marčok, the then Rector of Zvolen TU was awarded the Honorary Medal of the UF for his contribution to the consolidation of our bilateral cooperation. This cooperation holds a great potential and we should make the most of it.

Comparisons with similar universities have shown from 70 to 90 percent overlapping of the subjects studied there. These similarities are due to the common sources of the different Schools of silviculture. The resemblance between UF in Sofia and the TU in Zvolen is really worth mentioning. There is a 90% correspondence between the subjects studied for the Bachelor degree and 80% correspondence between the subjects offered in the Masters' syllabi. This is a result of our long-term cooperation and it is good evidence of the European subject matter of our education.

University Staff and Equipment

One of the greatest merits of the Bulgarian higher forestry education is the continuity between generations of faculty and the maintenance of its own qualified academic staff. Among the prominent lecturers at the Faculty of Forestry there are

three members of the Bulgarian Academy of Sciences (BAS) – B. Stefanov (1894–1979), P. Petkov (1898–1975) and M. Dakov (1920–2006), two corresponding members – V. Stoyanov (1887–1971) and N. Penev, and many professors and associate professors.

Since the beginning of higher forestry education, the deans of the faculties providing forestry training have been as follows: Prof. T. Dimitrov (1933–34), Acad. B. Stefanov (1947–48), Acad. P. Petkov (1948–51), Prof. Tsv. Hristov (1951–52), Prof. M. Venedikov (1952–53), Prof. Iv. Dobrinov (1974–79), Prof. Hr. Sirakov (1979–84), Prof. G. Ganchev (1984–86), Prof. N. Ninov (1986–88), Assoc. Prof. V. Gagov (1988–93), Prof. D. Kolarov (1993–94), Prof. J. Kuleliev (1994), Assoc. Prof. Iv. Yovkov (1995), Assoc. Prof. K. Lyubenov (1995–2003), Assoc. Prof. St. Yurukov (2003–05), Assoc. Prof. M. Milev (since 2005). Ten professors



The building of the training and experimental forest range, Yundola village.



The building of the Petrohan training and experimental forest range, Barziya village.



Students training in the animal collection of the Department of Wildlife management.

from the Faculty of Forestry were rectors: B. Stefanov (1953–57), D. Stefanov (1957–59), As. Biolchev (1960–66), St. Hristov (1966–68), Hr. Sirakov (1969–72), Al. Iliev (1972–79), N. Botev (1984–89), V. Donov (1989–90), D. Kolarov (1994–2003) and N. Ninov (since 2003).

The Faculty of Forestry nowadays includes six departments – Dendrology, Silviculture, Forest Management, Wildlife

Management, Technology and mechanization of forestry and Soil science. The teaching staff consists of 6 professors, 26 associate professors and 18 assistant-professors. Total 95 teachers provide the education of this speciality.

Both students and faculty have the equipment of UF at their disposal. Specialized laboratories have been set up for each Department. The animal collection is one of our most prized possessions. In the richness of its exhibits it has no parallel among other educational institutions in Europe. Probably, the greatest acquisitions of the University are the two training and experimental forest ranges (TEFR). Education and research quality is further enhanced by the Botanical garden housing more than 750 plant species and the greenhouses. The library containing more than 100,000 volumes and 27,000 periodicals, and the Publishing House aiding the publication of study books and the specialized scientific journal "Forestry Ideas" also contribute to education quality.

The Graduates' Contribution

The Faculty of Forestry at UF is the only Bulgarian institution preparing forestry specialists with higher education. During the years, the total number of the university graduates has amounted to more than 5,500. They form the bulk of the forestry staff and they have been playing an important part in the improvement of forests during the last 65 years. The scale of afforestation in Bulgaria per capita and per unit of area is without parallel. We have 1.2 million ha of plantations, which makes up one third of the existing forests. The plantations have an enormous anti-erosion effect and improve the environment. Millions of decare of wastelands have been reclaimed and erosion near water reservoirs has been put under control. Systems of forest shelter belts (about 13,000 ha) have been established. The afforestations have a favourable effect on many branches of economy such as agriculture and aquaculture, tourism, transport, power engineering and population lifestyle as a whole. The afforested area has increased 1.3 times and has become 3.398 million ha, whereas the whole forest area is 4,063 million ha. Forests make up 33% of the country's territory which makes it the 9th most forested country in Europe. The conditions of forests and forest yield have considerably improved. The growing stock has increased 3 times and amounts total 600 mill.m³ and 163 m³ ha⁻¹ on the average. The total annual forest growth is 14.5 mill.m³ and the average annual growth is 4.04 m³ ha⁻¹. Between 4.8 and 5 mill.m³ of wood are harvested per year with a theoretical potential of 7.1 mill.m³ per year. Bulgarian forests are managed according to modern, environmentally-friendly silvicultural regulations and in correspondence with the leading world practices and European standards, which ensures their sustainable development. Foreign scientists and administrators have declared Bulgaria a leading European country in the fields of forest establishment and cultivation, erosion control activities, environmental reclamation, hunting and game management, etc. From the view point of modern forestry concepts, the conservation of the unique biological diversity here is very important. Forests are hous-

ing the populations of 43 universally endangered species of animals and plants and about 80% of the sites included in the ecological network "Natura 2000". Bulgaria is among the countries having the greatest biodiversity in Europe – 4th place according to some expert evaluations. The conservation of ecological and habitat diversity is an essential point in FF teaching. The technologies studied are based on the principles of nature- friendly forestry and practical activities. The theories for multifunctional management and sustainable development are the key issues for conserving biodiversity, productivity, renewable capacity, viability and potential, so that forests will be able to continue performing their ecological, economic and social functions in the future.

All these achievements of our graduates show the important and all-embracing mission of the forestry specialty, whose 85-year history underlines its uniqueness and the traditions of our higher education.

Perspectives

We have sound Bachelor's degree education because of the long-term development of the subjects included in it. The complex university training, ordering subjects chronologically and proceeding from basic to applied disciplines combined with practical courses, requires a sufficient amount of time for the whole educational process. So, it would be rather reckless to reduce the Bachelor's Degree term of training to 3 years. The concept of the 4-year Bachelor's Degree education doesn't interfere with the Bologna concept. Europe respects national identity, especially in the sphere of education. The regional character of forestry makes the blind standardization of curricula even counterproductive. It is quite normal, though, to keep in touch with the subject development, subject matter choice and the methodology of related universities in order to borrow what is useful and applicable. At the same time, however, it is important to do research in connection to the local and practical business problems. The newly introduced system of credit transfer is bound to ensure student and teacher mobility based on common modules. It will be fully developed when the stipulated commitments are met and supplied with adequate mechanisms of control. Mobility enables communication and the creation of a common European educational ground.

Another important task for the future is the improvement of Master's Degree education. Being still new to our conditions, it is in its nascent stage and obviously has a number of weaknesses. The curricula need updating and expansion. More new subjects should be introduced reflecting the nature of this qualification stage. Such is the subject Forest pedagogy, taught at many European universities. It is in essence PR in Forestry and it is gaining increasing importance in the context of the multifunctional forest management. The improvement of communication with the public and NGOs, actually, will be of great benefit to many foresters.

Together with the tendency towards environmentally friendly forest management, there is a growing interest in the renewable sources of energy. The concern

about the global climatic changes is also obvious. Because of these trends, afforestation, our traditional priority, has now been given additional emphasis. Forest plantations have good perspectives. They have the task to provide resources for the ever-increasing market of wood and non-wood products at a time when protected forest areas are being expanded. The interest in this kind of forestry is due to the existence of at least 250 thousand ha of wastelands unfit for farming. Forest Plantations is a subject taught in our Master's course but it should be enriched with a study of the integration of its economic, ecological and social objectives.

Academic science is of particular importance to Master's degree education. What it still has to achieve is to develop more research directly involved with practical problems; to be more active in applying for international projects and to attract more students to the research. What can help in this respect are foreign contacts, information on forthcoming competitions, training in application procedures and availability of experimental materials. We have signed new agreements with many universities and research institutions. FF lecturers are taking part in the cooperation between the National Forestry Board (NFB) and EU forestry structures.

The development of distance learning is yet another perspective for our education. The online presentation of the necessary teaching materials is expected soon in order to improve the overall learning process.

FF management focuses towards a more sustainable quality of learning. The results up to now show a transition from a system according to which all of the admitted students graduate to a more natural pyramid-like structure. Our objective is better preparation of graduates, intensifying work with motivated students. In order to achieve this, the completion of the following tasks is necessary: increasing the variety of person-to-person instruction, starting thesis development well on time, presenting the best theses at students' conferences and international forums. Another challenge facing the graduates is the implementation of the innovative forestry strategy and the National strategy for rural regional development in the context of our European membership. It will be a demanding task to become a competent expert and to manage to come up to the great public expectations.

Our time has made the forester's concern for nature a vital priority for the future of the humanity. Therefore, our profession is increasing in popularity and responsibility. Its basic formula now is the sustainable development of natural resources, especially forests, which means meeting our needs today without impairing the chances of future generations. As Professor T. Dimitrov said in the past *"The forest is a bridge connecting the past, present and future. It enables us to lend a hand to our posterity"*. There can hardly be a greater insight into the meaning of sustainable development.

Finally, it is worth quoting the Bard of the Bulgarian forest, Acad. Nickolay Haitov, a famous Bulgarian writer who graduated and worked as a forester: *"Seeing around the creative work of Bulgarian foresters, I feel proud to have been a part of this noble and manly profession and to be still spiritually bound to it"*. Today we can rightfully be proud of the efforts of all teachers who have contributed to the development of Bulgarian higher forestry education and we have to work with con-

cern for its successful future. That future will be shared with related departments in Europe. It is our honor and recognition that the Faculty of Forestry in Sofia UF, namely in this anniversary in 2010, joined the newly established Conference of the Deans and Directors of European Forestry Faculties and Schools (ConDDEFFS).

References

- Dimitrov S.**, Stenin G., Bogdanov B. 2005. Bulgarian Forestry Figures and Scientists. NAF-NBF. Sofia, 360 p. (in Bulgarian).
- Iliev A.**, Nickolov S., Dobrinov I. 1975. Home Silviculture. Zemizdat. Sofia, 239 p. (in Bulgarian).
- Kolarov D.**, Brezin V. 1995. Seventy Years of Forestry Education in Bulgaria. HIF, Sofia, 146 p. (in Bulgarian).
- Kolev N.**, Dimitrov S. 1996. A Hundred Years of Forestry Education in Bulgaria. Committee of Forests. Sofia, 68 p. (in Bulgarian).
- Milev M.**, Tepeliev J., Yurukov S. 2006. A Handbook for Students of Forestry. UF Publishing House, 90 p. (in Bulgarian).
- Nickolov S.**, Dobrinov I., Karadochev P. 1985. Sixty Years of HIF. Sofia, 95 p.
- Panov P.** 2000. The Tamed Floods of Bulgaria. MAF-NBF. Sofia, 291 p. (in Bulgarian).
- Puchalev V.**, Iliev I. 2000. The University of Forestry 1925–2000. Sofia, 176 p. (in Bulgarian and English).
- Stoyanov V.** 1968. History of Bulgarian Forestry. Part I. IF-BAS. Sofia, 273 p.
- Vuchovsky H.**, Dimitrov S. 2003. Bulgarian Forests and Forestry in the 20th century. MAF-NBF. Soifa, 352 p. (in Bulgarian).

DIAMETER DISTRIBUTION MODEL FOR SCOTS PINE PLANTATIONS IN BULGARIA

Tatiana Stankova^{1,2} and Ulises Diéguez-Aranda¹

¹Department of Agroforestry Engineering, Higher Polytechnic School,
University of Santiago de Compostela, 27002 Lugo, Spain.

E-mail: tatianastankova@yahoo.com

²Forest Research Institute – BAS, 132 Kliment Ohridski Blvd.,
1756 Sofia, Bulgaria.

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Abstract

The main objective of this study is to derive a diameter distribution model for Scots pine (*Pinus sylvestris* L.) plantations in Bulgaria, which predicts with high confidence the allocation pattern of the tree diameters from stand level variables. As the investigated stands showed predominantly unimodal distribution pattern, their diameter distributions were characterized by 2-parameter Weibull function. Six methods for its parameter estimation were examined: two methods for parameter recovery through moments (PRM_L and PRM_S), a method for parameter recovery through the stand basal area (PRM_B), two parameter prediction methods (PPM_NLS and PPM_MLE), and a modified parameter prediction method based on a mixed-effect model (PPM_Mixed). An empirical percentile model, not connected to a predefined functional form of the distribution, was fitted for comparison. The choice of the best performing model involved estimation of ranks based on Kolmogorov-Smirnov test and Error Index values for goodness of fit evaluation, against a fit and a validation data sets. Two of the parameter recovery methods (PRM_L and PRM_S) and one of the parameter prediction methods (PPM_NLS) performed best, PRM_S being the overall outperformer and PRM_L being the simplest for application. The empirical percentile model ranked fourth and was not advantageous for representing diameter distributions of Scots pine plantations. The two best models derived (PRM_L and PRM_S) describe well the diameter allocation pattern of the Scots pine plantations in Bulgaria and can be applied to estimate the diameter distributions from stand level variables in a simple and reliable way.

Key words: distribution moments, empirical percentile model, parameter prediction method, parameter recovery method, *Pinus sylvestris*, Weibull distribution function.

Introduction

The diameter distribution models are of particular importance for evaluation of the results from the forest management activities, but they are not always available in the forest inventories and often

are not predictable by the whole-stand growth and yield tables, as in Bulgaria. To overcome the shortage of information, diameter distribution models are being developed to predict the pattern of tree diameter distribution from stand level variables. Numerous functional relationships

have been examined, the Weibull frequency distribution function being most commonly preferred in fitting unimodal distributions, because of its flexibility in fitting a variety of shapes and degrees of skewness, and relative simplicity of estimating its parameters. The parameter recovery approach, which relates percentiles or moments of the distribution, used to recover the Weibull parameters, to stand level variables, and the parameter prediction approach, which connects the function parameters directly to the stand parameters, are the two main methodological groups applied for estimation of the coefficients of the Weibull distribution function. Different modifications and techniques, characteristic to both groups as well as combinations of the estimation approaches have been proposed, revealing the advantages and the limitations of the different methods (Bailey and Dell 1973, Cao 2004, Liu et al. 2004, Merganič and Sterba 2006, Siipilehto 2009). The main objective of the present study is to derive a diameter distribution model for Scots pine (*Pinus sylvestris* L.) plantations in Bulgaria, which predicts with high confidence the allocation pattern of the tree diameters from stand level variables.

Material and Methods

All plots used for data collection are situated in the mountains of Bulgaria and cover the variety of sites, densities and growth stages of the Scots pine plantations. The data set used for model parameterization is composed of two subsets (Table 1). The first subset consists of 153 diameter frequency distributions obtained by temporary sample plots established in 2002–2005. The second subset includes 83 di-

ameter distributions from published data sources (Krastanov et al. 1980, Marinov 2002, Marinov et al. 1997) of permanent sample plots measured one or more times by 2 to 6-year intervals. The validation data set consists of 166 diameter distributions and includes data recorded in a provenance test plantation in 2007 and published data from the forest inventory plots and other permanent sample plots (Efremov 2006) measured once or more times by 10-year intervals. Beside the diameter distribution data, the stand level variables density (ha^{-1}), basal area ($\text{m}^2 \cdot \text{ha}^{-1}$), dominant height (m), quadratic mean diameter (cm), age (years), and site index were also used in the analyses (Table 1). The stand dominant height, where absent, was estimated through its relationship to the mean height established by Stankova et al. (2006), and the site indices of all plots were determined by the site quality tables for Scots pine stands by growth mode (Mihov 1986) for the third type of growth mode (slowing down growth).

Most of the diameter distributions in the modeling data set exhibited unimodal pattern; for this reason, the 2-parameter Weibull frequency distribution function was employed to characterize the diameter distribution pattern of the Scots pine plantations sampled:

$$f(x) = \left(\frac{c}{b}\right) \left(\frac{x}{b}\right)^{c-1} e^{-\left(\frac{x}{b}\right)^c} \quad (\text{Eq. 1}),$$

where x stands for diameter at breast height and b and c are the scale and the shape parameters, respectively. The model coefficients were estimated in 6 different ways (Table 2). The first two methods apply the parameter recovery approach through the first raw (m_1) and the second central (m_2) moments of the

Table 1. Stand and tree characteristics of the modeling and the validation data sets for modeling the diameter distributions of Scots pine plantations in Bulgaria.

	Variable	Modeling data set (P = 193) N = 236, n = 44942						Validation data set (P = 73) N = 166, n = 23889		
		Subset 1 (P = 153) N = 153, n = 9372			Subset 2 (P = 40) N = 83, n = 35570					
		Mean	min	max	Mean	min	max	Mean	min	max
Stand variables	QMD, cm	15.2	3.6	35.3	14.7	5.7	23.2	19.8	6.5	34.7
	Density, ha ⁻¹	3164	498	12200	3298	679	9305	1706	393	8640
	Age, years	35	10	78	34	14	50	43	15	80
	Dominant height, m	15.9	3.6	32.6	14.5	6.3	23.2	18.4	6.4	32.5
	Basal area, m ² .ha ⁻¹	41.17	5.54	72.27	44.73	15.72	104.41	42.80	10.12	67.84
	Site index	31	22	38	29	22	38	31	22	38
	Plot size, m ²	270	85	1269	1658	148	2960	954	386	1989
Tree variable	dbh, cm	13.7	2	36	12.3	1	47	16.9	2	52

QMD – quadratic mean diameter; dbh – diameter at breast height; P – number of plots;
N – number of distributions; n – number of trees.

distribution (Table 2, Eqs. 2 and 3). In the first method (PRM_L) the raw moment m_1 , which is the arithmetic mean diameter, was estimated by linear regression on the quadratic mean diameter (Stankova et al. 2002) (Table 2, Eq. 4). In the second method (PRM_S) the arithmetic mean diameter was evaluated by a relationship (Table 2, Eq. 5) on the quadratic mean diameter and other stand level variables (Diéguez-Aranda et al. 2006). The second central moment m_2 , which is the variance of the distribution, is estimated in both methods by the arithmetic and the qua-

dratic mean diameters (Table 2, Eq. 6). The third method for model parameterization (PRM_B) was adapted from Cao et al. (1982) and employs the measured value of the stand basal area per hectare to recover the parameters iteratively (Table 2, Eq. 7), while expressing parameter b through c by Eq. 2. In the parameter calculation the fitted basal area was allowed to deviate from the experimental one (Eq. 7) by no more than 5%. Two parameter prediction methods (PPM_NLS and PPM_ML) and one modified parameter prediction method (PPM_Mixed) for coef-

Table 2. Main formulae and estimated regressions for the examined methods for diameter distribution modeling.

Method*	Formulae for estimation of function parameters		Estimated final regressions
PRM_L	(Eq. 2) $b = \frac{m_1}{\Gamma\left(1 + \frac{1}{c}\right)}$	(Eq. 3) $m_2 = \frac{m_1^2}{\Gamma^2\left(1 + \frac{1}{c}\right)} \left(\Gamma\left(1 + \frac{2}{c}\right) - \Gamma^2\left(1 + \frac{1}{c}\right) \right)$	$m_1 = 0.9974 \overline{QMD} - 0.3700$ ($R^2 = 0.9993$; RMSE = 0.1622)
PRM_S		(Eq. 4) $m_1 = a + b \overline{QMD}$	
PRM_B		(Eq. 5) $m_1 = \overline{QMD} - \exp(-0.0079A - 0.0143SI - 0.8488N)$ ($R^2 = 0.8488$; RMSE = 0.4092)	
PPM_NLS		(Eq. 6) $m_2 = \overline{QMD}^2 - m_1^2$	The coefficients b and c are iteratively calculated
PPM_ML		(Eq. 7) $BA = \frac{N\pi}{40000} \sum_{i=1}^n db h_i w_i \left(\frac{c}{b} \right) \left(\frac{db h_i}{b} \right)^{c-1} e^{-\left(\frac{db h_i}{b}\right)^c}$	$b = 1.0295 \overline{QMD} - 4.0285/A - 0.0001N$ ($R^2 = 0.9993$; RMSE = 1.00)
PPM_Mixed		(Eq. 1) $f(x) = \left(\frac{c}{b_f + b_r} \right) \left(\frac{x}{b_f} \right)^{c-1} e^{-\left(\frac{x}{b_f}\right)^c}$	$c = 0.1189 \overline{QMD} + 0.0580Hd + 0.0471SI + 0.0001N$ $b = 0.9405 \overline{QMD} - 32.7534/A + 0.1116Hd - 0.0540BA$ ($R^2 = 0.9742$; RMSE = 1.00)
		(Eq. 8) $f(x) = \left(\frac{c}{b_f + b_r} \right) \left(\frac{x}{b_f + b_r} \right)^{c-1} e^{-\left(\frac{x}{b_f + b_r}\right)^c}$	$c = 0.0900 \overline{QMD} + 26.6279/A + 0.1145Hd + 0.0105BA$ $b_f = 0.5774$; $c = 3.3466$; $b_r = 0.0051 \overline{QMD} + 0.0054Hd - 0.000011N - 0.0014A$ ($R^2 = 0.6706$; RMSE = 0.0764)
Empirical Percentile Model	(Eq. 9) $N_k = \left[\frac{P_j - D_k^L}{P_j - P_{j-1}} (t_j - t_{j-1}) + (t_j - t_i) + (t_{j+1} - t_j) \frac{D_k^U - P_j}{P_{j+1} - P_j} \right] N_r$ $P_{j-1} < D_k^L < P_j$ $P_j < D_k^U < P_{j+1}$		$P_0 = 0.6250 \overline{QMD} - 39.1850/A - 0.0540Hd$ $P_5 = 0.8037 \overline{QMD} - 40.0203/A - 0.1118Hd + 0.0001N$ $P_{15} = 0.8407 \overline{QMD} - 26.8200/A - 0.067807Hd + 0.3582$ $P_{25} = 0.8552 \overline{QMD} - 16.1550/A - 0.00003N$ $P_{35} = 0.9055 \overline{QMD} - 8.75380/A - 0.00005N$ $P_{45} = 0.9382 \overline{QMD} - 5.9976/A + 0.0164Hd - 0.00005N$ $P_{55} = 1.0057 \overline{QMD} - 0.00005N$ $P_{65} = 1.038 \overline{QMD} + 8.821/A + 0.047Hd + 0.00003N - 0.9062$ $P_{85} = 1.1105 \overline{QMD} + 10.1768/A + 0.0644Hd + 0.00002N$ $P_{95} = 1.1859 \overline{QMD} - 5.6796/A + 2.5322$ $P_{100} = 1.3417 \overline{QMD} - 46.7059/A - 0.2009Hd + 7.8921$ ($R^2 = 0.9822$; RMSE = 0.9938)

* Method abbreviations are as defined in the text; Γ - Gamma function; m_1 - first raw moment; m_2 - second central moment; $\mathbf{X}$ - vector of the stand variables; $\boldsymbol{\beta}$ - vector of parameters; BA - stand basal area (m^2/ha); N - stand density ($1/\text{ha}$); n - number of diameter classes; w - width of the diameter class; $db h_i$ - diameter class; b_f , b_r - fixed and random parts of the coefficient b in the mixed-effect model, respectively; N_T - total number of trees; N_k - number of trees in the K -th size class; D_K^L and D_K^U - lower and upper limits of the K -th diameter size class, respectively; P_k - k -th percentile; t_k - the proportion of the trees with diameter less than P_k ; $k(0, 5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 100)$; $\{i, i-1, j, j+1\} \in k$; SI - site index; A - stand age (years); $\overline{QMD}$ - quadratic mean diameter (cm); Hd - dominant height (m); R^2 - coefficient of determination; RMSE - root mean square error.

ficient estimation were also tested. The first two follow three main steps of application: (i) parameter estimation by plots, (ii) parameter prediction through stepwise multiple regressions on the stand level variables, and (iii) simultaneous refitting of the selected regressions for b and c through seemingly unrelated regression (Table 2). PPM_NLS and PPM_ML differ in the first step of the estimation procedure, because while PPM_NLS applies the ordinary non-linear least squares technique, PPM_ML utilizes the maximum likelihood estimation. The PPM_Mixed method employed a non-linear mixed-effect model, in which the Weibull function parameters were considered mixed, i.e. composed of a fixed part (common for all distributions) and a random part specific for each plot (Table 2, Eq. 8). After estimation of the mixed-model parameters, the random parts of the parameters were predicted through regressions on the stand level variables.

A modification without driver percentile of the empirical, percentile-based model introduced by Borders et al. (1987), which is not connected to a predefined functional form of the distribution, was also fitted for comparison. This method defines an empirical probability density function with 12 ordered percentiles (Table 2, Eq. 9), and the principle percentiles are further predicted from the stand level variables by stepwise multiple regressions followed by a seemingly unrelated regression.

Kolmogorov-Smirnov (K-S) test was applied to compare the experimental distributions with the predicted ones by each of the proposed models (Little 1983, Liu et al. 2004). To allow comparison of the distribution shapes, their mean value was subtracted prior to the analysis (Stankova and Zlatanov 2010). The Error Index (EI) was estimated for each diameter distribution as the sum of the absolute differences between predicted and

Table 3. Mean values of the comparison test statistics (K-S and EI) and method ranking according to the results of the Wilcoxon rank-sign test*.

Method	Modelling data set				Validation data set				Rank sum		
	K-S		EI		K-S		EI		K-S	EI	Total
	Mean value	Rank	Mean value	Rank	Mean value	Rank	Mean value	Rank			
PRM_L	0.2680	4	119	1	0.1636	1	60	1	5	2	7
PRM_S	0.1942	1	123	2	0.1649	1	62	2	2	4	6
PRM_B	0.2484	3	141	4	0.2642	5	76	3	8	7	15
PPM_NLS	0.2020	1	136	3	0.1728	2	62	2	3	5	8
PPM_ML	0.3479	5	308	6	0.2240	4	136	5	9	11	20
PPM_Mixed	0.2774	4	153	5	0.3238	6	89	4	10	9	19
Empirical Percentile Model	0.2284	2	138	4	0.1922	3	72	3	5	7	12

* Abbreviations are as introduced in the text.

observed number of trees per 1000 m² within each diameter class (Reynolds et al. 1988, Liu et al. 2004), and indicates the typical misfit of a model, because the EI will be small only when the model predicts well for all diameter classes. Kolmogorov-Smirnov and EI test statistics were determined for both the modeling and the validation data sets, and further compared by Wilcoxon signed-ranks test in order to find statistically significant differences between the examined modeling approaches, regarding their goodness of fit. Different ranks were assigned to the methods distinguished as significantly different by the Wilcoxon test, for each test statistic and data set separately, and the overall method ranking was based on the rank totals summed from the 4 respective groups.

Results and Discussion

The final regressions required for application of the different modeling methods, their coefficients of determination (R^2), and their Root Mean Square Errors (RMSE) are presented in Table 2. In the PPM_Mixed method, both regression coefficients were initially represented by a fixed and a random part, but the random part of the shape parameter could not be regressed satisfactorily on the stand level variables and for this reason the model was reformulated with a mixed-scale and fixed-shape parameter (Table 2, Eq. 8). Two of the examined methods for parameter estimation (PRM_S and PPM_NLS) modeled successfully the pattern of all distributions in both the modeling and the validation data sets, which was revealed by the K-S test.

The Empirical Percentile Model and the PRM_L method failed to model 2 and 3 of the 402 distributions, respectively. The PRM_B and PPM_Mixed methods, which modeled acceptably the distributions of the modeling data set (failed in 3 and 7 cases, respectively), showed poor predictive ability for the validation data set (failed in 18 and 39 cases, respectively). The results from the comparison of the examined methods are shown in Table 3. The total sums of the ranks varied between 6 and 20 and the methods of best diameter distribution modeling potential were the two parameter recovery methods through moments (PRM_S and PRM_L) and the parameter prediction method by non-linear least squares estimation at the first step of its application (PPM_NLS).

The parameter recovery methods have generally proved better to the parameter prediction ones in estimation of the Weibull frequency distribution function (Liu et al. 2004). The function relating the quadratic mean to the arithmetic mean diameter used in PRM_S (Eq. 5) is theoretically preferred, because it ensures that the predicted values for the arithmetic mean diameter will not exceed the quadratic mean and takes into account the influence of the stand variables. On the other hand, the simple linear regression in the method PRM_L estimated in the present study intrinsically overcomes the problem of higher arithmetic mean diameter (Table 2) and allows modeling the diameter distribution only through the value of the quadratic mean diameter. The parameter prediction approach PPM_NLS also showed very good results in the present study, which can be largely accounted to the very strong relationships of the function parameters

to the stand level variables. PPM_NLS appeared much better than PPM_MLE, although the maximum-likelihood estimation (MLE) has been preferred as the one providing unequivocally the best possible distribution. The advantage, however, of the MLE is more pronounced when the primary purpose of its application is the distribution estimation itself and is recommended for large samples. Cao et al. (2004), on the other hand, examined different ways for estimating the 3 parameters of the Weibull function involving different prediction methods and combinations with recovery approaches. The study suggested that the limitations of the parameter prediction approaches can be successfully overcome by reformulating the optimization criterion for parameter estimation in two ways: maximizing the sum of the log-likelihood values or minimizing the error sum of squares of the cumulative distribution functions from all plots. The parameter recovery method (PRM_B) proposed by Cao et al. (1982) has been designed to practically utilize the information about the stand basal area per hectare, easily obtained through relascope sample plots. Fitting Eq. 7, however, requires exhaustive, often difficult to converge calculations. In spite of the theoretically logical derivation of this method, its poor goodness of fit and estimation efforts make it disadvantageous in comparison to the other tested parameter recovery methods. Mixed-effect models, which have been successfully developed and applied as an alternative to the purely deterministic models, are preferable mainly when calibration through supplementary observations of the dependent variable is involved. Such calibration in the diameter distribution modeling is barely justified

because an additional determination of the frequency of even a single diameter size class requires many additional measurements, which makes such approach meaningless. Prediction of the random parameters through the stand level variables was attempted in this study, but the simplified mixed-model technique proposed here did not produce satisfactory results. The poor predictability of the PPM_Mixed for the validation data set and the lack of significant relationship of the random component of the shape parameter to the stand level variables suggest that this approach has to be abandoned in modeling diameter distributions. A case study on *Pinus taeda* plantations (Borders and Patterson 1990) showed that an empirical percentile function can exceed the goodness of fit of the Weibull frequency function mainly because of better modeling of the non-unimodal distributions. This method did not show here superiority to the Weibull function estimated by the parameter recovery through moments. Although not connected to a particular known function, the percentile model outlines through its 12 percentiles a specific distribution pattern, which should be characteristic to the investigated type of stands. Thus, the distribution pattern estimated by this method did not represent the diameter distributions of the Scots pine plantations better than the Weibull frequency distribution function.

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References

- Bailey R.L., Dell T.R.** 1973. Quantifying diameter distributions with the Weibull function. *Forest Science* 19: 97–104.
- Borders B.E., Patterson W.D.** 1990. Projecting Stand Tables: A Comparison of the Weibull Diameter Distribution Method, a Percentile-Based Projection Method, and a Basal Area Growth Projection Method. *Forest Science* 36: 413–424.
- Borders B.E., Souter R.A., Bailey R.L., Ware K.D.** 1987. Percentile-Based Distributions Characterize Forest Stand Tables. *Forest Science* 33: 570–576.
- Cao Q.V.** 2004. Predicting parameters of a Weibull function for modeling diameter distribution. *Forest Science* 50: 682–685.
- Cao Q.V., Burkhart H.E., Lemin R.C.** 1982. Diameter distributions and yields of thinned loblolly pine plantations. School of Forestry and Wildlife Resources Publication No FWS-1-82, Virginia Polytechnic Institute and State University Blacksburg, Virginia 24061. 62 p.
- Diéguez-Aranda U., Castedo-Dorado F., Álvarez-González J.G., Rodríguez-Soalleiro R.** 2006. Dynamic growth model for Scots pine (*Pinus sylvestris* L.) plantations in Galicia (north-western Spain). *Ecological Modeling* 191: 225–242.
- Efremov R.** 2006. Effect of selection and linear-selection thinnings on the diameter growth of *Pinus sylvestris* L. plantations. Sofia. *Forest Science* 3: 47–61. (in Bulgarian).
- Krastanov K., Belyakov P., Shikov K.** 1980. Dependencies in the structure, growth and productivity of the Scots pine plantations and thinning activities in them. Research report. Forest Research Institute of BAS, Sofia (in Bulgarian).
- Little S.N.** 1983. Weibull diameter distributions for mixed stands of western conifers. *Canadian Journal of Forest Research* 13: 85–88.
- Liu C., Zhang S.Y., Lei Y., Newton P.F., Zhang L.** 2004. Evaluation of three methods for predicting diameter distributions of black spruce (*Picea mariana*) plantations in central Canada. *Canadian Journal of Forest Research* 34: 2424–2432.
- Marinov I.** 2002. Stationary studies of hydrological and erosion processes in forest ecosystems. Research report for the period 2000–2002, Forest Research Institute of BAS, Sofia (in Bulgarian).
- Marinov I., Mandev A., Grozeva M., Timousheva S., Markov I., Genov K.** 1997. Investigation on the hydrological effectiveness against erosion of the coniferous plantations in western Bulgaria. Report on a project with National forestry board. Forest Research Institute of BAS, Sofia (in Bulgarian).
- Merganič J., Sterba H.** 2006. Characterization of diameter distribution using the Weibull function: method of moments. *European Journal of Forest Research* 125: 427–439.
- Mihov I.V.** 1986. A method for determination of the type of growth of forest stands and its application to site index determination of Scots pine stands, DSc thesis, University of Forestry, Sofia (in Bulgarian).
- Reynolds M.R., Burk T.E., Huang W.-C.** 1988. Goodness-of fit tests and model selection procedures for diameter distribution models. *Forest Science* 34 (2): 373–399.
- Siipilehto J.** 2009. Modelling stand structure in young Scots pine dominated stands. *Forest Ecology and Management*, 257 (1): 223–232.
- Stankova T., Zlatanov Tz.** 2010. Modeling diameter distribution of Austrian black pine (*Pinus nigra* Arn.) plantations: a comparison of the Weibull frequency distribution function and percentile-based projection methods. *European Journal of Forest Research*, 129 (6): 1169–1179.
- Stankova T., Shibuya M., Hagihara A.** 2002. A method for density control of forest plantations. Sofia, *Forest Science* 2: 27–38.
- Stankova T., Stankov H., Shibuya M.** 2006. Mean-dominant height relationships for Scotch pine and Austrian black pine plantations Bulgaria. *Ecological Engineering and Environmental Protection* 2: 59–66.

COMPARATIVE RISK ASSESSMENT STUDIES OF HEAVY METAL POLLUTIONS IN BEECH FORESTS

Nadka Ignatova and Sonya Damyanova

Department of Plant Pathology and Chemistry, Faculty of Ecology and Landscape Architecture, University of Forestry, Sofia, 10 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria. E-mail: nadia_ignatova@abv.bg

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Abstract

Beech forests in the Western part of Bulgaria have been monitored in order to assess the risk of harmful effects of lead (Pb) and cadmium (Cd) pollution by means of Critical Loads calculations and their exceedances by real deposition. Critical loads of Pb and Cd for two sites (Vitinya and Petrohan) have been determined using the "Steady State Mass Balance" method based on the heavy metal uptake by the biomass and the leaching of the metals in the root zone. Real deposition of Pb and Cd was measured every two weeks during a one-year period by collecting the throughfall in plastic collectors (6 for each site). All samples have been analysed for their Pb and Cd content using atomic emission spectroscopy. The same method has been applied for measuring the content of Pb and Cd in the wood of beech trees. Fluxes of leaching water were measured in grid cells of 10 x 10 km for the entire country. The results obtained show that the critical loads of both Pb and Cd are lower for the Vitinya site demonstrating the higher sensitivity of beech to the pollution of heavy metals in comparison with the Petrohan site. In addition the real deposition of Pb and Cd has been higher at the Vitinya site. Although there were no exceedances of critical loads of Pb for both sites, additional deposition in the future will lead to a sooner exceedance of the critical load at the Vitinya site as compared to the Petrohan site. We conclude that the beech forest at the Vitinya site is at risk of damages by Cd pollution whereas the beech forest at the Petrohan site is more tolerant to heavy metal pollution due to its higher critical loads.

Key words: atmospheric deposition, cadmium, critical loads, exceedances, lead, throughfall.

Introduction

There is ample awareness of interactions at the starting point of the source-receptor chain with respect to sources and emissions of heavy metals and their adverse effects as air pollutants on ecosystems and various services these ecosystems provide, such as a sustainable

biodiversity (Metzger et al. 2005). Since forest ecosystems are associated with many ecosystem functions related to biodiversity, provision of forest products, water protection and carbon sequestration, it is crucial to know the amount of pollutant deposition above which these ecosystems would be damaged. Critical loads have been defined as quantita-

tive estimates of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge (Nilsson and Grennfelt 1988). The Bulgarian focal center has contributed to the calculation and mapping of critical loads of acidifying pollutants and heavy metals mostly for forest and aquatic ecosystems (Ignatova 2007; Ignatova et al. 1998, 2002, 2005; Ignatova and Damyanova 2006; Slootweg et al. 2007).

Critical loads for different receptors can be used to determine the sensitivity of a given receptor. When the value of the critical load is high, the receptor is more tolerant and less sensitive to the pollutant of concern. In this case the receptor can withstand large amounts of pollutant deposition without showing harmful effects. The risk of damage can be assessed by means of exceedances of critical loads of current deposition rates of the pollutant of interest. This approach is very effective because it can inform regional emission control policies. This study proposes modelling methodologies that have the capability of providing effect-based support to policies that are aimed at mitigating air pollution and the change of biodiversity and climate in an integrated manner.

The aim of this study was to carry out comparative investigations on the sensitivity and risk of damage of heavy metal pollution in beech forests in the Western Balkan Mountain by means of critical load calculations and their exceedances. From this point of view the following tasks have been taken into account:

1. Determination of Pb and Cd deposition rates in the precipitation of beech

forests in two regions of the Western Balkan Mountain differing in air pollution levels.

2. Collection of measured data needed for the calculation of local critical loads of Pb and Cd for beech forest in order to assess their sensitivity to heavy metal pollution.

3. Assessing the risk of harmful effects and damages to beech forests by computing the exceedances of critical loads of Pb and Cd.

Material and Methods

Collectors for throughfall under beech crowns have been installed at two sites of the Western Balkan Mountain: Petrohan and Vitinya (Fig. 1). The collectors were located at 3 positions (Fig. 2) following the forest: 1 – close to the beech stem; 2 – In the middle of the crown projection; 3 – between two trees.

The throughfall has been collected with 18 plastic funnels (1 m above the ground) per site with a collecting surface of 314 cm² in polyethylene bottles (Fig. 3) stored in the upper soil layer to minimize biological activity in the collected solution due to darkness and lower temperatures. Individual water samples have been collected fortnightly after measuring the water volume and analysing the samples for their Pb and Cd content by atomic emission spectrometry.

Pb and Cd uptake by the biomass has been derived by multiplying the content of these metals in the beech stem and branches, measured by atomic emission spectrometry, with the annual growth determined after cutting the representative trees.

The runoff of water under the root zone has been measured and mapped as mean annual values for a period of 20 years in grid cells of 10 x 10 km for the entire country (Kehayov 1986). The method is based on a splitting of river hydrographs, hydrogeological parameters of the underground water bodies, measurements of the mineral runoff between neighbouring hydrometric sites, infiltration of the water source etc.

There is agreement that the effect of heavy metals on forests is in better correlation with the metal concentration in the soil solution than in the soil itself (Crommentuijn et al. 1997, Lamersdorf et al. 1991, Tyler 1992, Wilkens 1995). From this point of view the leaching of heavy metals has been obtained by multiplying the runoff of water under the root zone with the critical concentration of the heavy metals in the soil solution (UBA, 2004).

The effect-based steady-state mass balance model was used to calculate the critical loads of Pb and Cd. The model implies that the critical load equals the net uptake by the forest growth plus an acceptable metal leaching rate, according to the follow equation:

$$CL(M) = \mu + Mle(crit)$$

where: $CL(M)$ = critical load of a heavy metal M (Pb or Cd), $g \cdot ha^{-1} \cdot yr^{-1}$;

μ = Metal net uptake in the harvestable parts of plants under critical load conditions, $g \cdot ha^{-1} \cdot yr^{-1}$;

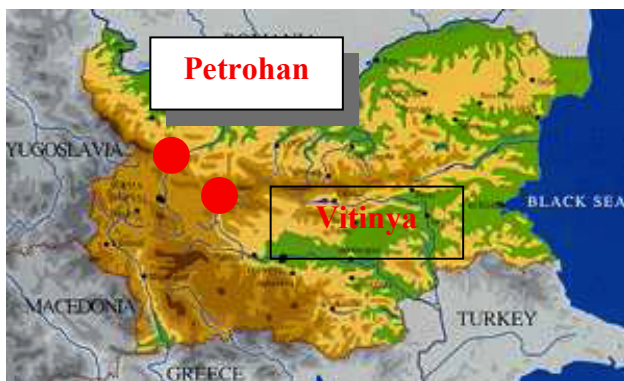


Fig. 1. Two monitoring sites in a beech forest of the Western Balkan Mountain in Bulgaria (Petrohan and Vitinya).

$Mle(crit)$ = Critical leaching of a metal M from the considered soil layer, $g \cdot ha^{-1} \cdot yr^{-1}$.

The **metal net uptake** of harvestable parts of plants was calculated by multiplying the annual yield by the fraction of metal net uptake within the considered soil depth and the metal content of the harvestable parts of the plants as follow:

$$\mu = f \mu Y_{ha} [M]_{ha},$$

where: μ = Metal uptake in harvestable parts of plants, $g \cdot ha^{-1} \cdot yr^{-1}$;

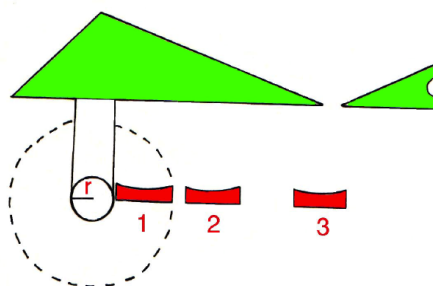


Fig. 2. Distribution of collectors for the deposition of heavy metals under beech crowns: 1 – close to the stem; 2 – under the half of the crown projection; 3 – between two trees.



Fig. 3. Permanently open collectors for the deposition of heavy metals.

Pb and Cd by present atmospheric depositions as **exceedances of critical loads** were calculated by the following equation:

$$CL(M)_{ex} = PL(M) - CL(M),$$

where: $PL(M)$ = Present deposition of Pb or Cd, $g \cdot ha^{-1} \cdot yr^{-1}$;
 $CL(M)$ = Critical load for Pb and Cd, $g \cdot ha^{-1} \cdot yr^{-1}$.

Results and Discussion

fMu = Fraction of metal net uptake within the considered soil depth, accounting also for the metal uptake due to deposition on vegetated surfaces (the fraction of metal net uptake within the considered soil depth has been set to 1);

Y_{ha} = Yield of harvestable biomass (dry weight), $kg \cdot ha^{-1} \cdot yr^{-1}$;

$[M]_{ha}$ = Metal content of the harvestable parts of the plants, $g \cdot kg^{-1} dw$.

The **critical leaching flux** of heavy metals from the topsoil was calculated according to the follow equation:

$$Mle(crit) = cle \cdot Qle \cdot [M]_{ss(crit)},$$

where: $Mle(crit)$ = Critical leaching flux of heavy metal from the topsoil, $g \cdot ha^{-1} \cdot yr^{-1}$;

Qle = Flux of drainage water leached from the regarded soil layer, $m \cdot yr^{-1}$;

$[M]_{ss(crit)}$ = Critical limit for the total concentration of heavy metal in the soil solution ($10 \text{ mg} \cdot m^{-3}$ for Pb and $3 \text{ mg} \cdot m^{-3}$ for Cd) (UBA 2004);

$cle = 10$; this is a factor for appropriate conversion of flux units from $mg \cdot m^{-2} \cdot yr^{-1}$ to $g \cdot ha^{-1} \cdot yr^{-1}$.

The differences between the monitored and the critical possible loads of

Given that the amount of the throughfall in the beech forest at the Petrohan site was higher (898 mm) than at the Vitinya site (807 mm), it was necessary to determine the acidity and heavy metal concentrations in order to calculate the real HM deposition at these sites. The mean annual acidity of the throughfall under the crowns of the beech forest in Petrohan was 5.88 pH compared to 5.69 in Vitinya, showing that the precipitation entering the soil was in general not acidic and that the difference between the pH values was not significant. Under these conditions both the heavy metal concentration levels and the deposition rates have been higher in Vitinya as compared to Petrohan. The mean concentration of Pb for the study period was $0.8 \mu g \cdot dm^{-3}$ in Vitinya whereas in Petrohan it reached $0.6 \mu g \cdot dm^{-3}$. The concentration of Cd was two times higher in Vitinya ($0.2 \mu g \cdot dm^{-3}$) than in Petrohan ($0.1 \mu g \cdot dm^{-3}$) (Fig. 4). Although the amount of throughfall was higher in Petrohan, the deposition of both Pb and Cd was lower in comparison with the Vitinya site. The Pb deposited in Vitinya was $5.76 \text{ g} \cdot ha^{-1} \cdot yr^{-1}$ and $4.98 \text{ g} \cdot ha^{-1} \cdot yr^{-1}$ in Petrohan. The respective val-

ues for Cd deposition were $1.47 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (Vitinya) and $0.90 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (Petrohan) (Fig. 5).

In general, critical loads of pollutants can be used for the assessment of the sensitivity of receptors to a given pollutant. Higher values of critical loads indicate higher tolerance and lower sensitivity of receptors to pollutants. From a practical point of view it is common to compare the critical load with the real deposition of pollutants.

Using this comparison, the real risk of damage and disturbance of the sustainable development of a beech forest can be assessed. As mentioned above, the deposition of both Pb and Cd was higher in Vitinya than in Petrohan, but these deposition rates are not suitable for assessing the risk of harmful effects of these pollutants to forest ecosystems, because their critical loads have been lower in Vitinya as compared to Petrohan.

When comparing the variables used for the determination of critical loads of Pb at the two experimental sites, it can be seen that both Pb uptake by the harvestable part of the biomass and its leaching by the water runoff under the root zone were much higher in Petrohan than in Vitinya. On one hand this can be related to the higher concentration of Pb in the beech stems and branches in

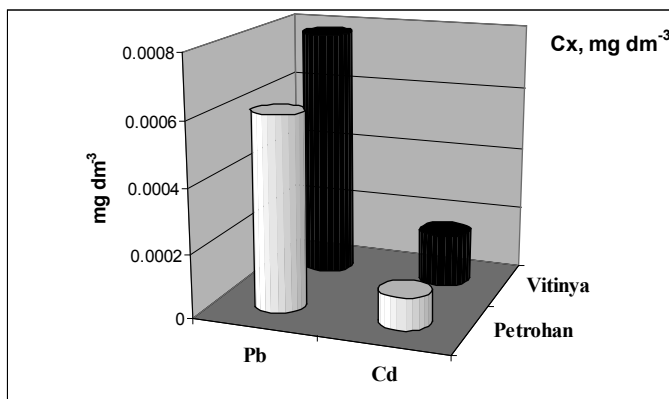


Fig. 4. Mean annual concentration of Pb and Cd in the throughfall of beech forests in Petrohan and Vitinya.

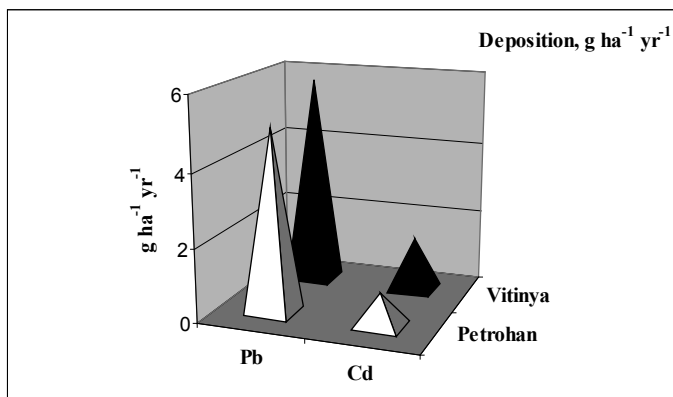


Fig. 5. Annual deposition of Pb and Cd in the throughfall of beech forests in Petrohan and Vitinya.

Petrohan ($0.0014 \text{ g} \cdot \text{kg}^{-1}$) than in Vitinya ($0.0004 \text{ g} \cdot \text{kg}^{-1}$), leading to a biomass uptake of Pb of $10.24 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ in Petrohan as compared to $2.79 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ in Vitinya. On the other hand the leaching of Pb by the water runoff in Petrohan was higher ($10.63 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) than in Vitinya ($3.63 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). In this case the value of the critical load of Pb at the Petrohan site was 3 times higher ($20.87 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) than in Vitinya ($6.42 \text{ g} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). The obtained

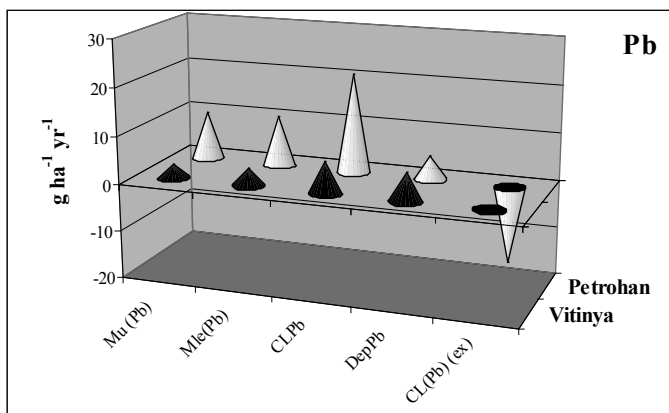


Fig. 6. Annual biomass uptake (MuPb), leaching (MlePb), critical load (CLPb), deposition (DepPb) and exceedance of critical load (CLPbex) of Pb in beech forests in Petrohan and Vitinya.

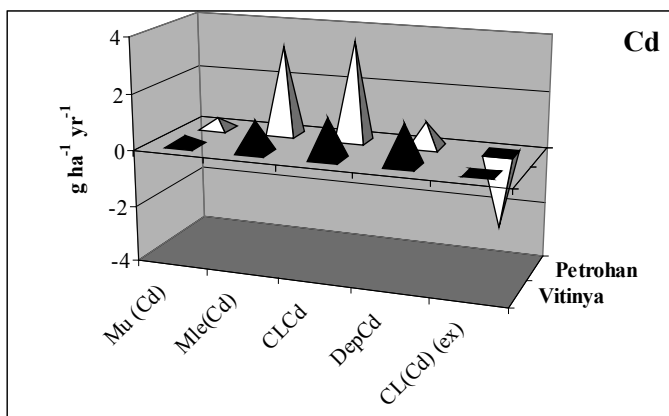


Fig. 7. Annual biomass uptake (MuCd), leaching (MleCd), critical load (CLCd), deposition (DepCd) and exceedance of critical load (CLCdex) of Cd in beech forests in Petrohan and Vitinya.

values of critical loads have demonstrated that the beech forest in Petrohan was more tolerant to the Pb deposition than the beech forest at the Vitinya site. A comparison of the critical loads with the real deposition rates revealed that there were no exceedances of critical loads at both sites for the entire study period,

hence the beech forests were not at risk of damages due to Pb deposition. The negative values of the exceedances at the Petrohan site suggest that the beech forest there could withstand much more additional deposition of Pb ($15.89 \text{ g ha}^{-1} \text{yr}^{-1}$) before reaching the critical load value as compared to the Vitinya site, where the critical load value would be already exceeded after an additional Pb deposition of only $0.66 \text{ g ha}^{-1} \text{yr}^{-1}$ (Fig. 6). Therefore, the risk of harmful effects and damages after a low increase in Pb deposition is higher in Vitinya than in Petrohan.

Similar results have been found for Cd (Fig. 7). Despite higher Cd deposition rates in Vitinya, the critical load was higher in Petrohan ($3.55 \text{ g ha}^{-1} \text{yr}^{-1}$) than in Vitinya ($1.44 \text{ g ha}^{-1} \text{yr}^{-1}$). However, the most significant difference found is that the critical load of Cd was not exceeded in Petrohan ($-2.65 \text{ g ha}^{-1} \text{yr}^{-1}$), whereas it was exceeded in Vitinya

($0.03 \text{ g ha}^{-1} \text{yr}^{-1}$) which increases the risk of damage at the latter site.

Human health effects of deteriorating forest ecosystem services through HM deposition – represented here as a change in the quality of drinking water – has been taken into account in our study. Critical

loads of Pb and Cd for ecotoxicological effects on terrestrial ecosystems were calculated for Bulgarian Forests by the Coordination Centre and were compared to the human health- drinking water values (Slootweg et al. 2005). It was found that both values for the entire forested area of Bulgaria were between 4 and 6 g.ha⁻¹yr⁻¹. Later critical loads of Pb and Cd for Bulgarian forests based on eco-toxicological effects on soil organisms were published in the CCE Status Report 2008 (Hettelingh et al. 2008). The values were between 1 and 4 g.ha⁻¹yr⁻¹ and between 10 and 30 g.ha⁻¹yr⁻¹ for Cd and Pb, respectively. In this study, the use of the human health effects- drinking water approach led to Pb critical load values of 20.87 g.ha⁻¹yr⁻¹ and 6.42 g.ha⁻¹yr⁻¹ for the Petrohan and Vitinya site, respectively. Similar differences were found for Cd: The critical load of Cd was higher in Petrohan (3.55 g.ha⁻¹yr⁻¹) than in Vitinya (1.44 g.ha⁻¹yr⁻¹). This means that the values of critical loads for both Pb and Cd were similar despite the existence of different critical limits and the use of different approaches.

Conclusions

The risk of damage to Bulgarian beech forests due to the deposition of Pb and Cd cannot thoroughly be assessed by the calculation of the deposition rate of these pollutants only. Additional calculations of critical loads are needed to determine the tolerance of these beech forests to heavy metal pollution. Of the two sites examined, the beech forest in Petrohan can accept higher deposition rates of Pb and Cd before any damages to the forest would be expected as compared to the forest in Vitinya.

The real risk of damage can be assessed through the calculation of the exceedances of critical loads of Lead and Cadmium using measured deposition data. The results obtained in this study have shown that critical loads of Pb have not been exceeded for the beech forests at two Bulgarian sites. However, the possibility to accept additional deposition of Pb before reaching the critical load was lower for the Vitinya site in comparison with the Petrohan site. Special attention has to be paid to Cd whose critical load was exceeded in Vitinya, which increases the potential risk of forest damage at that site.

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References

- Crommentuijn T., Polder M.D., Van de Plassche E.J. 1997. Maximum permissible concentration and negligible concentrations for metals, taking background concentrations into account. RIVM report No 601501001.
- Hettelingh J.-P., Posch M., Slootweg J. (eds.) 2008. Critical load, dynamic modelling and impact assessment in Europe: CCE Status Report 2008, Coordination Centre for Effects. www.pbl.nl/cce.

- Ignatova N.** 2007. Developments in calculation and mapping critical loads of acidifying pollutants and heavy metals for terrestrial and aquatic ecosystems in Bulgaria. Proc. Effect-Oriented Activities in the Europe. Baia Mare, Romania: 106–123.
- Ignatova N., Jorova K., Grozeva M., Trendafilov K., Tintchev G., Petkova T.** 1998. Manual on Methodologies for calculation and mapping of critical loads for acidity, sulfur and nitrogen for soils in Bulgaria. Sofia, Iriss, 49 p. (in Bulgarian).
- Ignatova N., Jorova K., Grozeva M., Fikova R.** 2002. Preliminary Modelling and Mapping of Critical loads for Cadmium and Lead in Bulgaria. In: Hettelingh J.-P., J. Slootweg, M. Posch (eds): 69–75.
- Ignatova N., Jorova K., Velizarova E., Fikova R., Broshtilova M.** 2005. Modelling and mapping of critical loads for cadmium and lead in Europe. Bulgaria. CCE Progress Report (J. P. Hettelingh, J. Slootweg, M. Posch Eds.), RIVM, Bilthoven, Netherlands: 69–75.
- Ignatova N., Damyanova S.** 2006. Modelling approach and data base needed for calculating critical loads of heavy metals for surface water. Scien. Articl. Ecology: 186–200.
- Kehayov T.** 1986. Underground waters in Bulgaria, mapping in 1:2000000, vol. V: 304–307, S., BAS.
- Lamersdorf N.P., Godbold D.L., Knoche D.** 1991. Risk assessment of some heavy metals for the growth of Norway Spruce. Dordrecht. Water, Air, Soil Pollution: 57–68.
- Metzger M., Leemans R., Schroter D.** 2005. A multidisciplinary multi-scale framework for assessing vulnerabilities to global change. International. Journal of Applied Earth Observation and Geoinformation 7 (4): 253–267.
- Nilsson J., Grennfelt P.** 1988. Critical Loads for Sulfur and Nitrogen Miljörappport North 1988:97. Nordic Council of Ministers, Copenhagen, Denmark, 418 p.
- Slootweg J., Posch M., Hettelingh J.-P.** 2007. Critical loads of Nitrogen and Dynamic modeling. Bulgaria. CCE Progress Report, RIVM, Bilthoven, 201 p.
- Tyler G.** 1992. Critical concentrations of heavy metals in the mor horizon of Swedish forests. Solna, Sweden, Swedish Environmental Protection Agency, Report 4078, 38 p.
- UBA** 2004. Manual on Methodologies and Criteria for Mapping critical Loads and Levels and air pollution effects, risks and trends. available: www.icpmapping.org.
- Wilkens B.J.** 1995. Evidence for ground-water contamination by heavy metals through soil passage under acidifying conditions. PhD thesis, University of Utrecht, 146 p.

THE USEFULNESS OF TIME SERIES ANGLE-COUNT FOREST INVENTORY DATA IN ASSESSING FOREST GROWTH MODEL ACCURACY

Chris Stuart Eastaugh and Hubert Hasenauer

Universität für Bodenkultur (BOKU) Institute of Silviculture. Peter Jordan Strasse 82, A-1190 Vienna, Austria. E-mail: cseastaugh@yahoo.com.au

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Abstract

Forest policy and forest carbon accounting systems must be underpinned by appropriately accurate information, yet such information is often difficult and expensive to collect. This has led to the promotion of more cost-efficient forest sampling methodologies, and to the rise of modeling as a means to predict or interpolate changes to forest conditions in response to various stimuli. The accuracy of such modeling is usually determined through comparison with field data, often collected at a relatively limited number of sites.

Large bodies of relevant forest data are collected in National Forest Inventories, but there are inherent methodological problems in using this NFI data for model validation, particularly if such data is collected using angle-count sampling. Angle-count sampling has the advantage of being a relatively fast and cheap method of collecting forest data, but it is generally considered that at least four samples should be taken at a site for the results to be usefully precise. Some NFIs however take only a single angle-count sample at each fixed sampling point. Although at a broad scale these results may give useful figures, their usefulness at the plot scale is severely limited, especially if the intent is to judge plot timber volume increments or prepare forest carbon budgets. The availability of a time series does however allow for some statistical correction to single angle-count estimations. This study demonstrates the statistical uncertainties in using angle-count time series, and develops a method of reducing such 0 to a level that angle-count NFI data may be usefully used for comparisons with forest models.

Key words: carbon accounting, carbon budgets, sampling, statistics.

Introduction

Rising interest in forest carbon accounting has led to a renewed interest in forest inventories and forest process modelling as a means to accurately assess carbon stocks, both as presently existing and under a range of future

scenarios. Although process modelling shows great promise in being able to track changes to ecosystem carbon stocks and fluxes in response to various stimuli, there is always a need for modelling to be properly validated against field data to give confidence in results. Model validation often relies on

a relatively small number of experimental plots.

Large bodies of forest growth data are available in many countries, through the various National Forest Inventories (Tomppo et al. 2010). Inventories however are designed to aggregate samples taken at many points to give accurate information at large scales, whereas process modelling aims to accurately simulate single stands based on point-specific input information. Although at the large scale aggregated results found with either method should be similar, this is not adequate for validating model performance as model errors in some areas may be masked by opposing errors elsewhere in the aggregated dataset. This problem is compounded in the case of inventories that use more sophisticated sampling techniques such as angle-count sampling.

Angle count sampling for efficiently estimating forest stocks was developed in Austria by Bitterlich (1947, 1984), and popularised in North America by Grosenbaugh (1952). The method is now well known to practicing foresters across most of the world, and if properly performed has been proven to give unbiased estimates of stand basal areas in timber cruising operations (Palley and Horwitz 1961). Recently however angle-count sampling has also become an integral part of some National Forest Inventories (i.e. Austria (Gabler and Schadauer 2006) and Germany (Kändler 2006)). Since the late 1950s three methods have been developed for calculating increments from successive angle count samples: the Difference method, the Starting Value method and the End Value method (Shieler 1997). These were attributed by Hradetzky (1995) to Van Deusen et al. (1986), Grosenbaugh (1958) and Roesch et al.

(1989). In the case of Austria, a single angle-count sample is taken at each corner of a 200 m square, with these squares located on a systematic grid of 3.889 km resolution over all forested land.

The volume (V) of a single tree is a function of basal area (g). Common allometrics such as those of Pollanschütz (1974) multiply g by height (h) and a shape-dependant form factor (f).

$$V^{TREE} = g * h * f \quad \text{Equation 1}$$

In order to determine volume per hectare, the number of trees per hectare must be estimated. Angle-count methodology relies on the fact that each tree counted in the sample may be taken to represent a fixed number of trees per hectare ($nrep$). The $nrep$ for each tree sampled is estimated as the basal area factor (K) used in the sampling divided by the basal area of the tree.

$$nrep_i = \frac{K}{g_i} \quad \text{Equation 2}$$

The volume per hectare is then:

$$V^{PLOT} = \sum_{i=all_trees_sampled} V_i * nrep_i \quad \text{Equation 3}$$

Difference method

Using the Difference method to calculate increment, the growth between time 1 ($t1$) and time 2 ($t2$) is simply the difference between the volumes at the two periods plus any removals due to harvesting or mortality.

$$Growth = V_{t2}^{PLOT} - V_{t1}^{PLOT} + removals \quad \text{Equation 4}$$

The shortcoming of the Difference method is apparent from an examination of equations 2 and 3. As trees grow g increases, but this increase in growth (which should contribute to an increase in V^{PLOT}) is offset by an equivalent fall

in $nrep$. Observed growth with the difference method can only come from increases in h , or increases in i (that is, when new trees are added to the sample between $t1$ and $t2$). If no new trees are added to the sample then the calculated increment will be an underestimation, whereas if many new trees are added (due to the random physical location of the trees in the plot), then the method may considerably overestimate growth.

Starting value method

The Starting Value method avoids the problem of new trees introducing high variance into increment calculations by keeping $nrep_i$ constant between time periods, and ignoring any increases in i . Thus:

$$nrep_{i,t2} = nrep_{i,t1} = \frac{BAF}{g_{i,t1}} \quad \text{Equation 5}$$

New trees in the second sample period may be either ingrowth (I) or non-growth, depending on whether they were under or over a particular dbh threshold in the first period. Ingrowth are trees that are newly present in the sample at $t2$ that were effectively not present in the stand at $t1$. If the dbh threshold is greater than zero then ingrowth must be further differentiated into ingrowth or ongrowth (cf Martin 1982), but this complication is not relevant to our discussion here.

$$Growth = \sum_{i=trees_present_in_both_samples} (V_{i,t2}^{TREE} - V_{i,t1}^{TREE}) * nrep_i + removals + \sum I \quad \text{Equation 6}$$

With this method, $V_{t2}^{PLOT} \neq V_{t1}^{PLOT} + Growth + removals$. Because $nrep_i$ is constant between measurements, any random variation in g is greatly ampli-

fied when upscaling to the per hectare values.

End value method

The End Value method also keeps $nrep_i$ constant between time periods, but uses the $nrep_i$ values from the second time period:

$$nrep_{i,t2} = nrep_{i,t1} = \frac{BAF}{g_{i,t2}} \quad \text{Equation 7}$$

$$Growth = \sum_{i=trees_present_in_the_second_sample} (V_{i,t2}^{TREE} - V_{i,t1}^{TREE}) * nrep_i + removals + \sum I \quad \text{Equation 8}$$

This method also results in an increment estimate that is not necessarily equal to the change in estimated volume. There are some theoretical improvements in variance because of the larger number of trees used to estimate $nrep$, but to some extent this is offset by the need to estimate the $t1$ basal area of trees that only entered the sample in $t2$.

Either of the latter two of these methods are currently preferred, due to a lower variance in increment results (Hradetzky 1995). Recent work however (Eastaugh and Hasenauer 2011) points to possible bias in results from the Starting Value and End Value methods, hence our efforts will focus on the Difference method.

We use a case study example to investigate the range of error in timber growth increments estimated by applying the Difference method to time-series of single angle-count samples, and develop a correction method that significantly reduces the variance on single points. Our purpose is to demonstrate that the errors in Difference method in-

crement calculations applied to single points are not completely random, but are correlated with the number of new trees that enter the sample at the subsequent inventory. By estimating this systemic error we are able to apply a simple correction to increment results, achieving substantially reduced variance than the original. As an example of the benefits of the improvement, we show how the corrected results may be

used to better test the accuracy of a forest growth model.

Data and Methods

23 fixed-area research plots were established in a spruce/pine forest at Litschau (northern Austria) in 1977, and have been remeasured each 5th year since that time. This study uses plot number 10, which

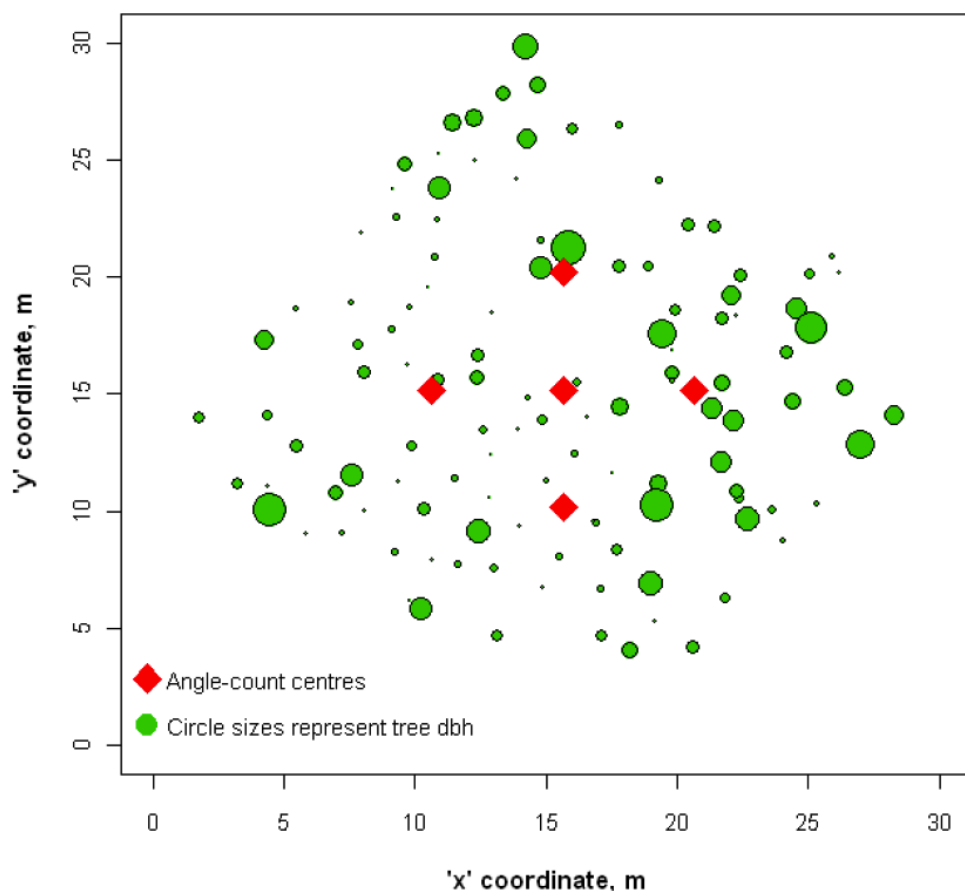


Fig. 1. Permanent research plot No 10 at Litschau, in 1977. Green circles are an exaggerated representation of tree diameter (1.3 to 32.1 cm), red diamonds show the centre-points of the 5 simulated angle-count samples.

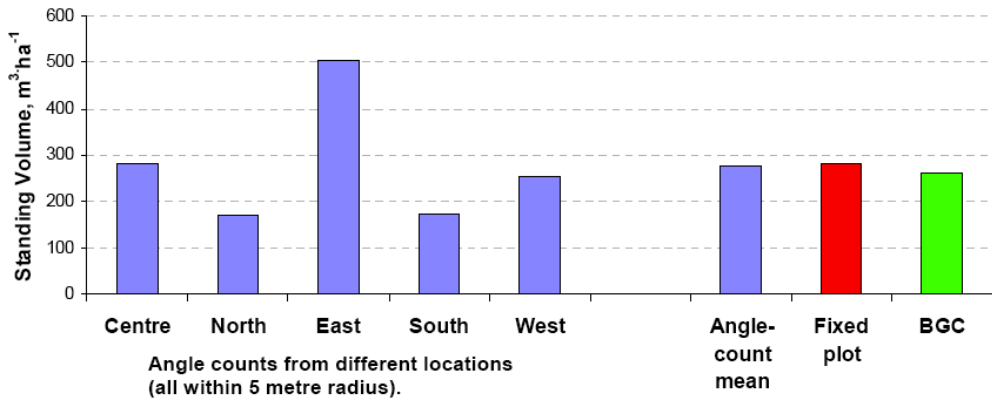


Fig. 2. Individual angle counts are poor estimates of stand volume. Aggregation of angle-counts is necessary to produce a reasonable estimate of stand volume.

is predominantly spruce and formed part of the validation dataset for the biogeochemical process model BIOME BGC (Pietsch et al. 2005). The plot is 486 m², and in 1977 consisted of a range of tree sizes up to 32.1 cm (Fig. 1).

In each measurement period, all trees on the plot are measured for height and diameter at breast height (dbh), and their location coordinates recorded. This allows us to reconstruct the stand as it appeared in each measurement period, and determine what an angle count sample from any point would have measured, if such a sample had been made. As shown in figure 1, we simulate an angle-count sample at the geometric centre of the plot, and five metres in each cardinal direction from that centre. Given the range of tree sizes on the plot, none of these samples (in any time period) overlaps the fixed-area plot boundary. Tree volumes are calculated based on dbh, height and a form factor according to parameters determined by Pollanschütz (1974).

Process modelling with BIOME BGC (Thornton 1998) is performed using in-

put criteria from internal plot documentation, species parameters from Pietsch et al. (2005) and interpolated DAYMET daily climate data (Petritsch 2002). The model gives results in terms of kilograms of stem carbon per square metre, which are then converted to timber volume according to biomass expansion factors from Pietsch et al. (2005).

Standing volume estimates for 1977 taken from the fixed-area plot data, simulated angle-count sampling and modelling are shown in figure 2.

An indicative range of the estimate variability from the Difference method (derived from the Litschau plot 10 data) is shown in figure 3. More formal discussions of Difference method variance may be found in Palley and Horwitz (1961), Van Deusen (1986) and Hradetzky (1995).

Correction method

The Correction method developed here relies on the fact that the error in the Difference method is due mainly to the

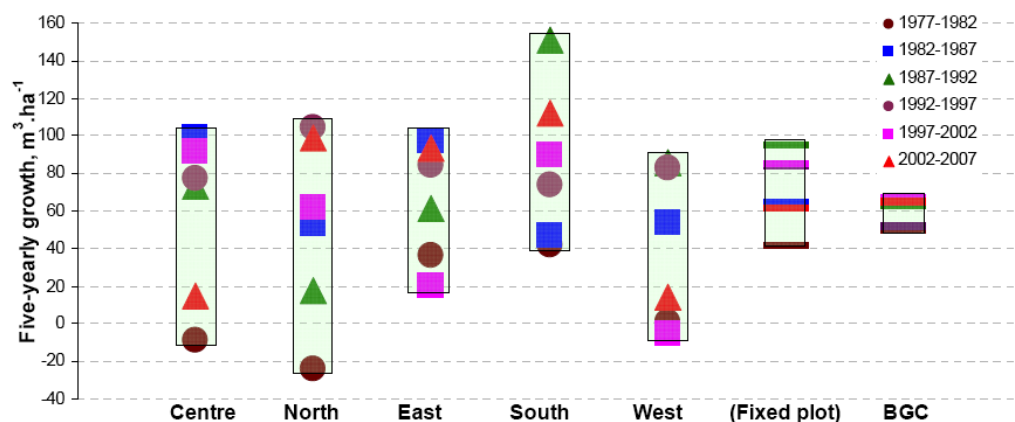


Fig. 3. Range of variation in increments calculated according to the Difference method.

(largely random) chance of new trees entering the sample in t_2 . This information is extractable from standard angle-count records, and so the component of the error that is due to this chance is to some extent correctable.

The error in Difference method estimates is strongly correlated to the number of new trees entering the sample in the subsequent measurement period (Fig. 5). Although the function of the regression in figure 4 is drawn from empirical data, it is possible to estimate this function through determining the 'x' intercept and the slope directly from measured data at any individual angle-count point.

The 'x' intercept of the error function in figure 5 represents the point where the Difference method will accurately estimate the stand growth (error = 0). This represents the point where the number of trees entering a sample between measurement periods is equal to the true growth increment of the stand. As angle-counts are an unbiased estimate of stand volume, this point

may be approximated by the mean number of new trees entering a stand, averaged over either time or space (assuming that we average within a reasonably homogenous space). The slope of the error function matches the mean volume per hectare represented by a new tree added to the sample. Correcting the Difference method values involves adding or subtracting the estimated error derived from the error function, according to the number of new trees added.

Results

Applying the Correction method based only on information available from one point retains the mean for that point, but allows the variation around the mean for that point to be considerably reduced (Fig 5, compare with Fig. 3).

If, as in this example, all points may validly be aggregated in space, then less (but still some) improvement is gained over aggregating results from



Fig. 4. Estimation error (the increment estimated through successive angle counts using the difference method) is strongly correlated to the number of new trees present in the second sample. Data points represent estimate error for each sample point, in each measurement period ($n = 30$).

the Difference method (Fig. 6). Such aggregation however does not reduce the variance of single point values as is possible with the Correction method. For a 90% probability of falling with a confidence interval of 10%, the reduction in variance equates to a reduction in the number of plots needing to

be aggregated from 19 down to 7. At the scale of the Austrian National Forest Inventory, if the variance between points was similar to that in this case study, the size of aggregated sample units would decrease from around 71 square kilometres to 26 square kilometres.

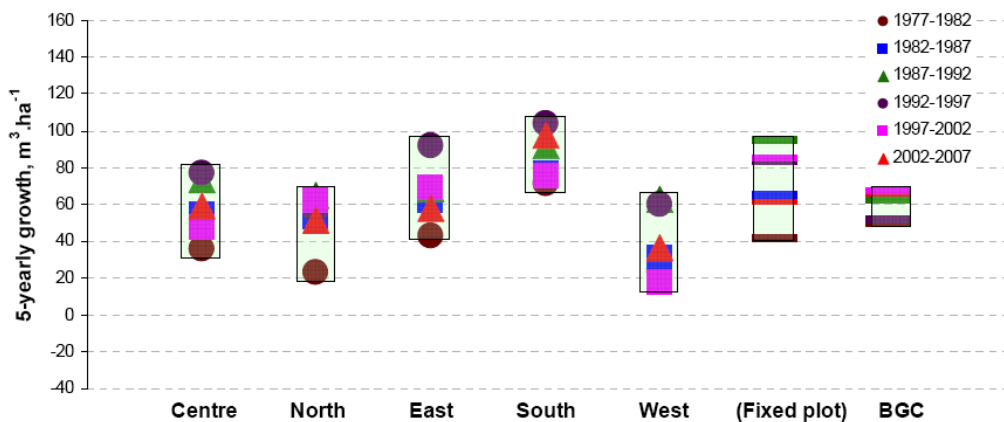


Fig. 5. The correction method retains the mean increment of the data points used to estimate the mean n , while reducing the variance around that mean.

Discussion

Although the example here used only a small number of points, the relationship between the estimate error of increments derived from the Difference method with the number of new trees entering a sample is clear, and may be seen in larger datasets (in development).

The error behaviour of the Difference method is a well-known problem, and most forest agencies avoid it by using either the Starting Value method or the End Value method. Van Deusen et al. (1986) demonstrated that each of these three methods are theoretically unbiased estimators of volume increment but did not account for the errors that are inevitably part of any forest inventory. Recent work on large datasets (Eastaugh and Hasenauer 2011) has shown that the Starting Value and End Value methods introduce a positive bias into increment estimates due to the propagation of measurement errors. The Difference method is more resistant to these biases.

The Correction method outlined here relies on the spatial and temporal autocorrelation that will be present among groups of sample points. In the simple example presented here spatial and temporal autocorrelations are weighted equally (through deriving the slope and intercept of the error function using all available samples), but greater improvement could perhaps be obtained through applying different weights to the spatial and temporal components, depending on the variance present in their respective dimensions.

Determining the population from which to derive the mean number of new trees added is a question of homogeneity. In the example above the 5 sample points are clearly drawn from the same stand (being all within a 5 metre radius), but some caution must be taken if the parameters of the correction function were to be drawn from a more diverse sample set. As the 'x' intercept represents the mean basal area increment of the stand divided by the basal

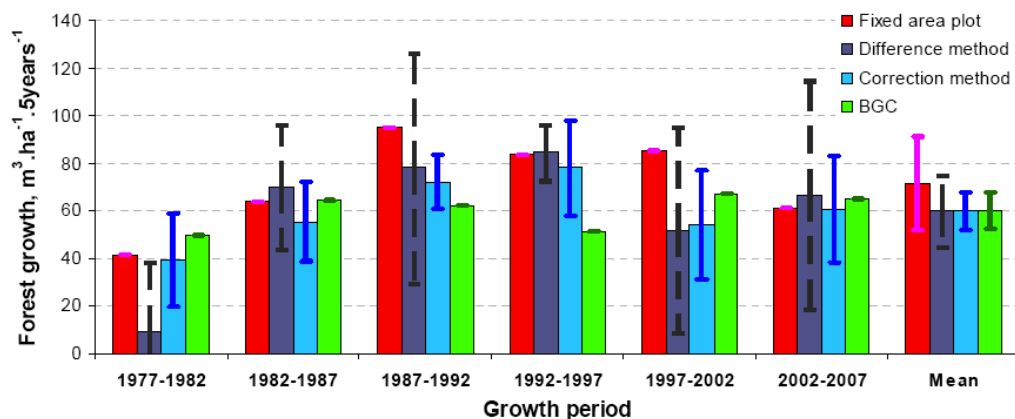


Fig. 6. Forest growth averaged across five sample sites within a 5 metre radius, in each measurement period. Error bars show one standard deviation above and below the mean for each period.

area factor, the mean number of trees should be drawn from sample populations that could be expected to show similar growth characteristics. These are however the same issues that must be faced when determining the appropriate level of stratification and aggregation of uncorrected samples.

Conclusions

Errors arising from the difference method are largely systemic rather than fully random, and are thus partly correctable. The correction method developed here retains the same mean as groups of estimates made with the difference method, but removes the systemic error component. Random error will of course still be apparent in results, but the reduction in variance allows for smaller scale aggregations of angle count data to meet particular precision requirements.

Although this paper is not intended to be a formal proof of the general applicability of our proposed increment correction procedure, we believe that the corrected difference method will provide more precise estimates of increment from time-series of angle-count data than the uncorrected Difference method, without the biasing effects of currently used alternatives. An unbiased method with reduced variance will be a better basis for comparisons with process model results.

References

- Bitterlich** W. 1947. Die Winkelzahlmessung (Measurement of basal area per hectare by means of angle measurement). Allgemeine Forst- und Holzwirtschaftliche Zeitung 58: 94–96.
- Bitterlich** W. 1984. The Relascope Idea: Relative Measurements in Forestry. Commonwealth Agricultural Bureau: Slough, England.
- Eastaugh** C.S., Hasenauer H. 2011. Bias in volume increment estimates derived from successive angle-count sampling. (submitted).
- Gabler** K., Schadauer K. 2006. Methoden der Österreichischen Waldinventur 2000/02. Grundlagen, Entwicklung, Design, Daten, Modelle, Auswertung und Fehlerrechnung. BFW-Berichte 135: 1–6.
- Grosenbaugh** L.R. 1952. Plotless Timber Estimates-New, Fast, Easy. Journal of Forestry 50: 32–37.
- Grosenbaugh** L.R. 1958. Point-sampling and line-sampling: probability theory, geometric implications, synthesis. USDA Forest Service South Forest Experimental Station Occasional Paper 160, 34 p.
- Hradetzky** J. 1995. Concerning the precision of growth estimation using permanent horizontal point samples. Forest Ecology and Management 71: 203–210.
- Kändler** G. 2006. The Design of the Second German National Forest Inventory. In: McRoberts, Ronald E.; Reams, Gregory A.; Van Deusen, Paul C.; McWilliams, William H., eds. 2009. Proceedings of the eighth annual forest inventory and analysis symposium, 2006. October 16–19; Monterey, CA. Gen. Tech. Report WO-79. Washington, DC: U.S. Department of Agriculture, Forest Service, 408 p.
- Martin** G.L. 1982. A method for estimating ingrowth on permanent horizontal sample points. Forest Science, 28: 110–114.
- Palley** M.N., Horwitz L.G. 1961. Properties of some random and systematic point sampling estimators. Forest Science 5 (1): 53–65.
- Petritsch** R. 2002. Anwendung und Validierung des Klimainterpolationsmodells DAYMET in Österreich. Diploma thesis, University of Natural Resources and Applied Life Sciences Vienna.

- Pietsch** S.A., Hasenauer H., Thornton P.E. 2005. BGC-model parameters for tree species growing in central European forests. *Forest Ecology and Management* 211: 264–295.
- Pollanschütz** J. 1974. Formzahlfunktionen der Hauptbaumarten Österreichs. *Allgemeine Forstzeitung* 85: 341–343.
- Roesch** F.A., Green E.J., Scott C.T. 1989. New compatible basal area and number of tree estimators from remeasured horizontal point samples. *Forest Science* 35: 281–293.
- Schieler** K. 1997. Methode der Zuwachsberechnung der Österreichischen Waldinventur. Dissertation, University of Natural Resources and Applied Life Sciences Vienna.
- Thornton** P.E. 1998. Description of a numerical simulation model for predicting the dynamics of energy, water carbon and nitrogen in a terrestrial ecosystem. PhD thesis, University of Montana, Missoula.
- Tomppo** E., Gschwantner T., Lawrence M., McRoberts R.E. 2010. (eds) *National Forest Inventories: Pathways for common reporting*. Springer, Berlin.
- Van Deusen** P., Dell T.R., Thomas C.E. 1986. Volume growth estimation from permanent horizontal plots. *Forest Science* 32 (2): 415–432.

ANALYSIS OF ENERGY WOOD CHIPS PRODUCTION IN SLOVAKIA

Valéria Messingerová^{1*}, Miroslav Stanovský^{1**}, Stanimir Stoilov²,
and Michal Ferencík^{1***}

¹Department of Forest Exploitation and Mechanization, Technical University in Zvolen, Faculty of Forestry, 24 T. G. Masaryka St., 960 53 Zvolen, Slovakia.

*E-mail: messin@vsld.tuzvo.sk; **E-mail: stanov@vsld.tuzvo.sk;

***E-mail: ferencik@vsld.tuzvo.sk

²Department of Technologies and Mechanization of Forestry, University of Forestry, 10 St. Kliment Ohridski Blvd., 1756 Sofia, Bulgaria.

E-mail: stoilovs@ltu.bg

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Abstract

The aim of this study is to evaluate the wood chips production as fuel for energy sector in the State Forests Enterprise of Slovak Republic logging conditions. Working operations of primary transport are analyzed – ground-based skidding systems that drag or carry logs from stump to landing, transportation of energy wood chips in containers. The main result of the research is the possibility to optimize the energy wood chips transportation methods from environmental and economical point of view. The paper deals with the knowledge and experience of increasing the value of less valuable wood from thinnings.

Key words: energy wood chips, wood chipper, primary transport, transportation, thinning.

Introduction

Biomass means dendro-, phyto- and zoo-material suitable for industrial and energy utilization. Biomass means also residue and by-products from silviculture biomass and its processing as well as usable part of household organic residue. Biomass, as one of the sustainable energy carrier, is being the resource with the highest potential in Slovakia.

The forest land area in Slovakia continually increases. Since 1950 the forest land area has increased with about

234,840 ha (11.8%). The area of forest land for regeneration has also increased with about 168,993 ha (9.6%) since 1950. The area usable for wood production is nowadays 1,751,200 ha, which is 90.7% from the whole forest land area. The biomass as raw material for the energy sector is supplied from forest stands as fire wood or chips. At present we are using more wood due to the higher energy consumption. Since 2007 the forest land area has increased with about 840 ha and the forest land area for regeneration with about 649 ha

and has reached 1,946 thousand hectares (Ministry... 2009).

The need of biomass increased in 1980s and forestry practice was oriented especially towards processing of crown parts throughout the whole-tree cutting method. The development of suitable machines was closely connected with these trends. Produced wood chips were used for production of wood pulp, agglomerated materials and in metallurgy. In the second half of 1980s processing started with leftovers after delimbing of coniferous trees using multipurpose machines at landings. The result was a complex utilization of the biomass, where green parts of trees were used for animal feeding and wooden part for energy purposes.

Nowadays, there is a visible increase of interest in the utilisation of less valuable wood, logging residue from final cuts and thinnings for energy production in Slovakia. There is a specialized forest enterprise, which produces biomass for energy purposes in Slovakia. Its name is Forest Enterprise "Biomasa" in Levice, and it belongs directly to the State Enterprise Forests of the Slovak Republic in Banská Bystrica. It has been working since 2004. It produced 120,000 tons of wood chips in 2008 and 122,000 tons in 2009. This enterprise with seven regional centres covers 90% of the Slovak energy demands.

In 2004 only one regional project really was working for supplying SES Tlmače with energy wood chips. A project for heating the Nová Dubnica town with energy wood chips was prepared for the end of the same year. The project was prepared and realized by the Forest Enterprises in Považská Bystrica and Trenčín. Later on in 2005 some

other permanent customers have been established in the towns Handlová, Kysucké Nové Mesto, together with some foreign customers.

On the 1st of January 2005 a "Biomasa" Centre was established consisting of the regional centres Levice, Rimavská Sobota, Trenčín, Revúca, Čadca, Palárikovo, Vranov nad Topľou. The Regional centre Rimavská Sobota was divided into Beňuš and Revúca in 2008. In the same year 2005 the "Biomasa" Forest Enterprise (OZ Biomasa) was established (Olajec 2005).

Material and Methods

Basic information comes from foreign and Slovak literature, Green Reports – data from the internet and from unpublished materials from the State Enterprise Forests of the Slovak Republic in Banská Bystrica (Riško 2009). Original data has also been obtained from the Levice "Biomasa" Forest Enterprise and from field measurements in Regional centre Levice. The data obtained has been processed, analysed and presented in the following chapter.

Results

Technology for preparing the wood for chipping

Storage of material for chipping is space demanding, because a work with whole trees, or with their crown parts is necessary. The whole tree method is to be used – from the place of cutting up to landing place. Nowadays it has become a common practice to forward crown

parts from the forest stands to the landing site. Skyline systems, adapted tractors, skidders and harvesters are mostly used for preparation of wood for biomass using forwarders for transportation of topwood and wood with diameter under 7 cm (Slugeň 2009). For a successful production of energy chips the good synchronization is important between their production and their transportation.

If there are trees with stumps of better quality at the landing, it is necessary to pick them up and to store them at special landing sites. The chips from chipper are loaded directly into containers on trucks and thus the following turns out to be effective:

- to use a truck with load capacity of 10–12 tons for transportation of the chips up to 50 km;
- to use a truck with a trailer with load capacity of 20–25 tonnes for transportation of the chips on distances over 50 km.

Amounts of the chips produced at OZ Biomasa in 7 regional centres

As it was mentioned above, there are seven regional biomass centres in Slovakia: Levice, Trenčín, Revúca, Palárikovo, Beňuš, Vranov and Čadca. Each of them produces biomass on the area of assigned Forest Enterprises. The amounts of biomass produced for each Regional “Biomasa” Centre are presented in Table 1.

The table shows that the highest volume of wood chips was produced in 2007, followed by 2008 and 2009. It is necessary to state, that the differences are not significant.

Costs, prices, sales

The costs for production of 1 t of wood chips are as follows:

- 10–12 €·t⁻¹ – fuels, wages of workers;

Table 1. Production of energy wood chips in the regional centres in the period 2007–2009.

Activity	Centre	Amount of biomass produced, t		
		2007	2008	2009
Biomass production	RC Levice	20,731.38	17,659.78	17,156.50
	RC Trenčín	15,145.76	14,921.29	16,545.74
	RC Beňuš	19,153.79	20,378.90	17,540.44
	RC Revúca	21,484.71	20,378.05	18,002.13
	RC Vranov	16,378.90	16,507.53	20,340.87
	RC Čadca	20,228.20	14,151.88	17,664.34
	RC Palárikovo	17,166.18	18,211.81	15,765.52
	Total	130,288.92	122,209.34	123,015.64

- 5 €.t⁻¹ – overhead costs (wages of the managers);
- 18 €.t⁻¹ – average price for purchasing wood for chipping.

Transportation costs:

- up to 50 km, the costs are 0.22 €.km⁻¹.t⁻¹ (usually Tatra 6x6 chiptruck, with capacity 10 t of chips);
- over 50 km, the costs are 0.084 €.km⁻¹.t⁻¹ (transportation with trucks equipped with chiptrailers, 20–25 t of chips).

Average costs for production of 1 t of wood chips are about 35–40 €, according to conditions.

Raw wood for chipping is purchased from the State Forest Enterprise, based in Banská Bystrica (98% of volume), and from the private sector (2%). The price of the chips depends on their state, moisture content (dry wood biomass, warm wood biomass and partially dried) and on their quality (the amount of smallwood in the prepared wood).

The chips of the best quality are produced from wood biomass with smallwood content up to 40% and they have also the best prices on the market. If the smallwood content is between 41–60%, the produced chips are of medium quality and finally, the chips from wood with smallwood content over 61% are of the worst quality and they have the lowest price on the market. A summary of the total revenues and costs in OZ Biomasa can be seen in Fig. 1.

Perspectives of development and processing of the biomass

Wood biomass is a valuable raw material of environmental friendly energy. The biomass energy comes from the sun and the world production is around 2.10^{14} kg, what represent 90 TW of energy. Biomass means mainly wood, but also hedgeways and energy plantations. Biomass has been used as a

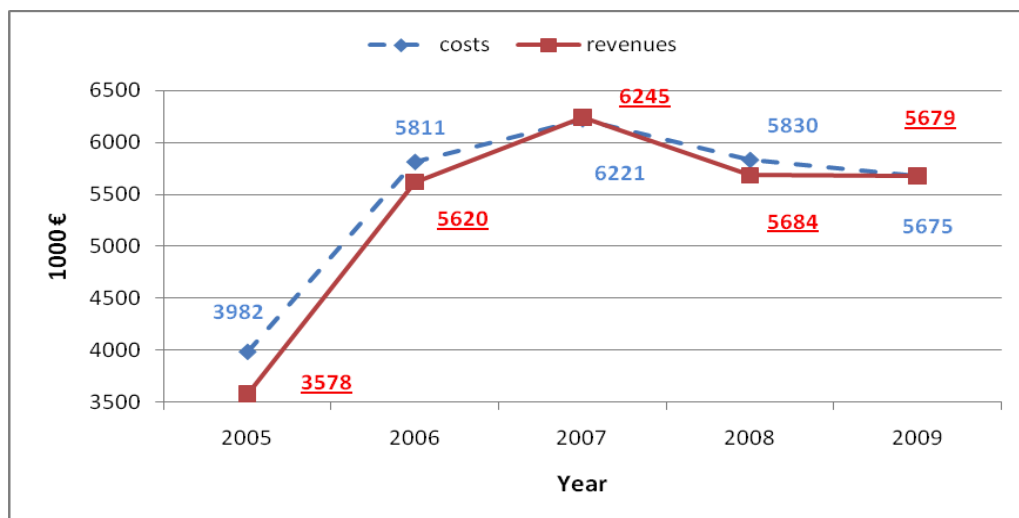


Fig. 1. Development of the total revenues and costs in the branch Company "OZ Biomasa" in the period 2005–2009 (Riško 2009).

fuel for thousands of years worldwide. However, present technologies allow us to use biomass a lot more effectively and in larger volumes.

The utilization of wood biomass is perspective in Slovakia because in many cases (e.g. the woody debris) is used as an energy raw material, which would otherwise be valueless. There are hectares of useless and abandoned agricultural land, where a local carrier of energy could be grown. This resource does not pollute the air or increase the global warming and its transportation would be cheaper, because this source is local.

Strengths and weaknesses of biomass utilization:

- a local source of energy: does not require inefficient transport, the price does not depend on the supplier monopoly, the international market trends and it is easier predictable;
- money stays at the regional level and this means a local economy stimulation, creating new work opportunities (in general rural development);
- it is a sustainable carrier of energy;
- forest debris utilization;
- biomass decreases CO₂ production;
- biomass utilization contributes to a decentralization.

Biomass utilization has also some weaknesses, for example the energy plantations (short-rotation forests), which could be established as monocultures, could have negative impact to the environment. From an economical point of view, an analysis has to be made whether the outputs are higher than the inputs in Slovakia.

Biomass is a valuable substitution of fossil fuels. Dried wood is compara-

ble to the calorific value of brown coal, which has been the basic energy carrier source in Slovakia but it is sulphur free.

Biogas contains approximately 70% natural gas energy.

Biomass is a key sustainable energy carrier for both small and large technological units. Nowadays 14% of the world energy requirements are covered by biomass energy. However, for three quarters of the world population, which is primary from the third world countries, biomass is the main fuel source. On average, the percentage of biomass energy consumption is about 38% (in some countries 90%). Therefore we can suppose the world population will increase and the fossil fuel reserves will decrease, the significance of biomass will become more important and demanded (Chovan 2010).

Biomass is also a valuable energy carrier in the developed countries. In Sweden (27%), Latvia (26%), Finland (25%) or Austria the percentage of biomass energy consumption is more than 15%, in Slovakia is less than 10% (European... 2010). There are plans to marginally increase the percentage of biomass utilization in Sweden in order to substitute nuclear energy. In USA the percentage of biomass utilization as a primary energy source is about 4% (the same as for the nuclear energy). The biomass which would be produced on agricultural land could substitute nuclear energy in the future, without consequences for the price of agricultural plants. The biomass used for ethanol production could substitute 50% of the imported oil.

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References

Chovan M. 2010. Analýza činnosti Lesy SR Banská Bystrica [Analysis of forest management in State Enterprise Lesy SR Banská Bystrica], š. p. OZ Biomasa Levice za obdobie posledných rokov, DP, Technical University in Zvolen, 60 p. (in Slovak).

European Biomass Statistics 2009. Bioenergy statistics. November 2009. Available: <http://www.aebiom.org/?p=319>

Ministry of Agriculture of Slovak Republic 2009. Správa o lesnom hospodárstve v Slovenskej republike [Green Report 2009]. Ministerstvo pôdohospodárstva SR, Bratislava, 168 p. (in Slovak).

Olajec I. 2005. Strategické zámery Lesov SR, š. p. v produkcii lesnej palivovej biomasy [Strategic Objectives of Lesy SR, State Enterprise production in forest biomass fuel]. (in Slovak).

Riško A. 2009. Lesná štiepka – perspektívny zdroj energie [Forest chips – prospective energy source] (PowerPoint presentations), State enterprise Forests of the Slovak Republic in Banská Bystrica. (in Slovak).

Slugeň J. 2009. Environmentálne aspekty práce harvesteru Timberjack 1270 D a forwardera Timberjack 1110 D vo výrobnotechnických podmienkach OZ Slovenská Ľupča [Environmental aspects of the work of Timberjack 1270 D harvester and Timberjack 1110 D forwarder in a productive-technical conditions of OZ Slovak Ľupča]. In: Acta Facultatis Forestalis Zvolen, Slovakia, Technická univerzita vo Zvolene, ISSN 0231-5785. Vol. 51, No 2: 97–108. (in Slovak).

ENVIRONMENTAL ESTIMATION OF MECHANIZED TECHNOLOGIES FOR REGENERATIVE CUTS IN MOUNTAINOUS CONDITIONS

Dimitar Georgiev and Stanimir Stoilov

Department of Technologies and Mechanization of Forestry, University of Forestry, 10, Kliment Ohridski blvd, 1756 Sofia, Bulgaria. E-mail: dimitarg@itu.bg

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Abstract

An environmental estimation is made of regenerative cuts in mountain beech (*Fagus sylvatica* L.) stands, based on a motormanual prime processing and transportation by wheel cable skidders. After the mechanized regenerative cuts, about one-third of the residual trees are damaged, fortunately most of them superficially. Predominantly the tree roots and stems are damaged. Inside the stands, the number of damaged trees is smaller, whereas around the skid roads almost half of the trees are damaged. In the first case, the residual trees are damaged by the felled trees (mainly higher than the first 1 m of the stem). In the second case the damages are caused by the skidded stems. The results show that the percentage of damaged understorey is about 16.89%, including 80% of it recoverable. To reduce tree damages along the skid roads and especially those along the curves, it is advisable to use some protective devices for prevention. To minimize the damages on the understorey it is necessary to use protective X-devices, diverting rollers and cones on the front of the logs. It is advisable to improve the professional skills of the loggers and to introduce effective stimulations for environmentally-sound logging operations.

Key words: regenerative cuts, motormanual prime processing, wheel skidder, damages, residual stand.

Introduction

The negative impact of regenerative motormanual cuts on forests is focused on 3 directions: damages on the residual trees, damages on the understorey, and forest soil compaction. For our forests the effects mentioned above are extremely unfavorable, because of the protective function and mountainous location of the major part of the Bulgarian forests. The number and size

of damages caused by logging operations depend on the tree species, age, season, type and cutting intensity, location, logging technology and system of machines. The timber harvested in Bulgaria is extracted predominantly by wheel tractors. The choice of proper logging technology according to certain natural and productive conditions is made by comparative analysis based on economic as well as environmental criteria.

The aim of the present study is to make an environmental estimation of mechanized logging technologies for regenerative cuts in order to find out the reasons for damages and the ways to reduce their impact on wood quality.

Background

Despite the increased understanding of environmentally-sound logging, the number of studies in this field is limited. The problems are discussed not very carefully and studies cited are from countries with different logging technologies (Baev et al. 1985, Mateev et al. 1986). According to many authors cited by Schütz (1990), 33% of the residual stands have damages greater than 10 cm² after thinnings in Switzerland and that leads to a danger of wood destruction. The Scandinavian authors (Saarilahti 1999, 2000, 2003; Wästerlund 1994) report mainly about the damages caused by the interaction between tractor wheels and forest soils during cut-to-length (CTL) logging operations. The share of damaged trees in Czech Republic using CTL technologies and system of machines ranges between 1.50 and 2.38% (Dvořák 2005). According to Ferencik et al. (2008) the negative effect of the CTL technology in Slovakia is expressed as tree damages (not higher than 1 m) of 25% of the residual stands on the average. A comparative study between motormanual and fully mechanized logging concerning the size of residual stand damages, made by Košir (2008), shows that in the first case the number of damaged trees is greater and later on these damages make the stand structure worse.

In Bulgaria Dinev (2003) studied the effect of different thinning technologies on the damages of residual stands. To reduce stand damages and facilitate timber extraction, proper felling directions must be kept, consistent with skid roads. On areas with high tree stand density, a crosscutting of stems into stem sections is recommended, although that the technology is being modified. The skid roads must be with proper width and suitable curves, consistent with the stem length. The use of protective devices for residual trees along the road curves is recommended for reducing the damages (Georgiev and Stoilov 2007).

We could conclude that the effect of different logging technologies and machines on residual stands in the modern logging practice in Bulgaria is a live question.

Objects and Methods

Damages were classified by their depth (superficial and deep), as well as by their location on the stems (root, stem or both root and stem) (Meng 1978). The aim was to find out the cause of damages – fallen trees, skidder equipment or tree load, as well as unsuitable curves or width of skid roads. The understorey damages were classified as bended, raw and broken (i.e. irretrievable damages).

In the Petrohan Training and Experimental Forestry Enterprise at the University of Forestry, located in the West Balkan Mountains, six test areas (TA) in two compartments were marked. The skidding operations were made by means of a LKT-81T double drum wheel cable skidder.

TA1 (compartment No 94, area 0.4875 ha) and TA2 (subcompartment No 19b, area 0.1407 ha) were intended for estimating the damages inside the residual stands. TA3 (compartment No 94, length of 130 m) and TA4 (subcompartment No 19b, 65 m long) were strips of the trees located at 1 m spacing along the skid roads (the latter 4 m wide) intended to specify damages caused by skidding. TA5 and TA6 with areas of 24 m² and 14 m² respectively, were located in compartment No 94 and were intended for determining understorey damages. In subcompartment No 19b no natural regeneration was observed.

Results and Discussion

The data analysis of test areas shows that 93 out of 305 remaining trees (i.e. 30.49%) were damaged during the regenerative cuts (see Fig. 1). The injuries

of 28 damaged trees (30.11%) were deep (under bark). On TA2 two of the damaged trees were broken at a height of 5 m and 6 m respectively, and a third tree was partly uprooted and bent. The most damaged trees were at 1 m distance along the skid roads: on TA3 that were 63.33% of all the trees, and on TA4 – 35.14%.

Root damages

The share of trees with damaged roots in the residual stands of the studied test areas is large – 34.41%. The dimensions of tree damages in cm² are shown in Fig. 2. On TA1 root damages with areas over 100 cm² (46.15%) were prevailing. Damages with areas smaller than 10 cm² were not found. The damages were caused by trees extracted by the skidder winch as well as by other skidder equipment. All root damages on TA2 were with areas over 100 cm² and were also caused by ex-

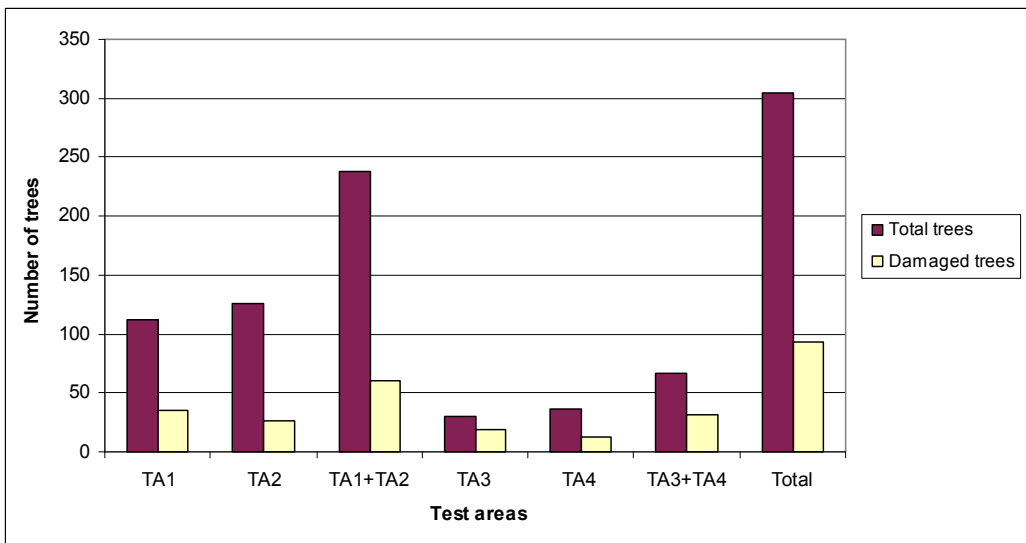


Fig. 1. Total number of trees and number of the damaged ones.

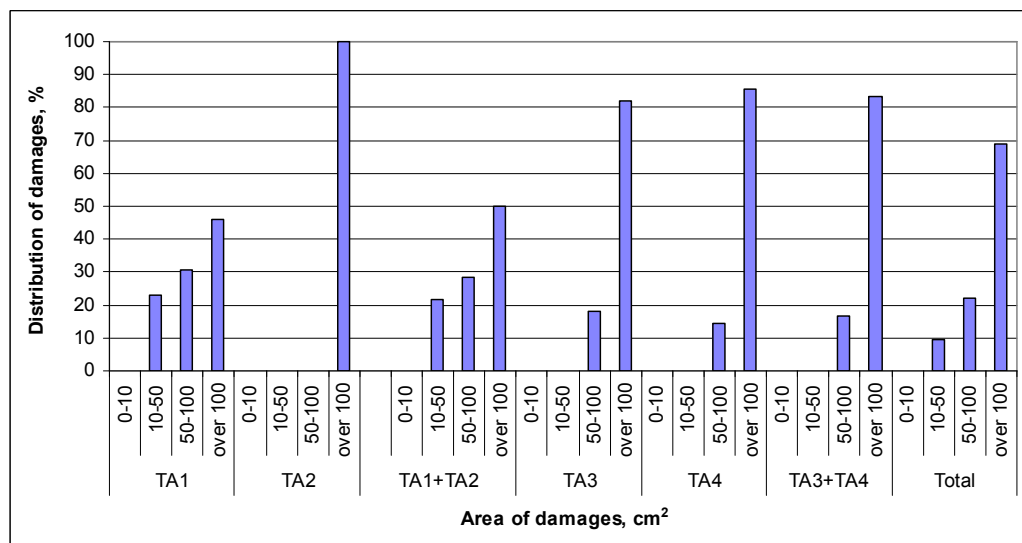


Fig. 2. Distribution of root damages by area.

tracted trees and the skidder equipment. Generally, inside the stands (TA1 and TA2) large size damages prevailed.

The share of root damages along the skid roads was very large: on TA3 and TA4 the damages with areas over 100 cm² (83.33%) were prevailing. Here the root damages were caused by the skidded long stems, especially along the curves.

The summary for both of the studied stands shows that the percentage of root damages of the residual trees over 100 cm² is the largest – 68.75%. In both of the stands the roots of 32 out of 305 residual trees (10.49%) were damaged, i.e. every tenth tree.

Stem damages

The distribution of stem damages by height is shown in Fig. 3. If damages are caused by the skidder equipment during the bunching of wood materials we could assume that they were up to 1 m above the ground surface, where-

as the damages higher than 1 m were caused by the trees felled nearby.

On TA1 nearly 2/3 of the stem damages were located up to a height of 1 m, therefore they were caused by the arch and the cable winch, as well as by the extracted stem sections. All the rest of the damages were caused by wrong felling directions, respectively by the thick branches and stems of felled trees in that case. Inside both of the stands (i.e. on TA1 and TA2) on the average 46.35% of stem damages lower than 1 m were caused by stem sections extracted to the skidder and the skidder equipment, whereas 53.65% of the damages were caused by the felled trees.

The distribution of stem damages by area is shown in Fig. 4. If we classify the damages into two groups – up to 500 cm² and over 500 cm², the first group includes 87.5% of the damages on TA1 and only 36% of these on TA2. Therefore, the damages on the residual trees on TA2 were more serious and the stand was

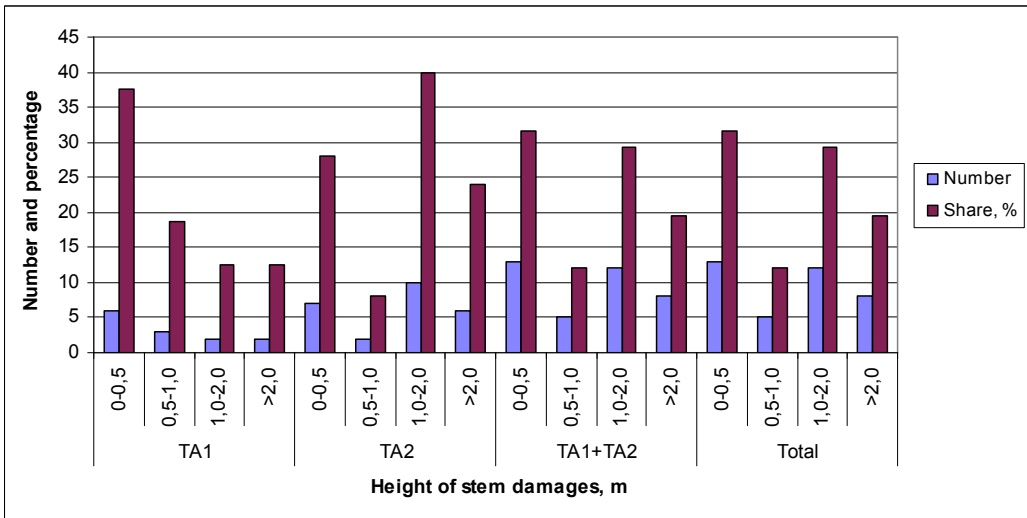


Fig. 3. Distribution of stem damages by height.

in danger. Generally, the areas of damages on TA1 and TA2 were approximately equally distributed in the ranges 0–100 cm², 100–500 cm² and 500–1000 cm², whereas the damages with areas over 1000 cm² were not numerous – 17.07%.

Concurrent root and stem damages

The distribution of that type of damages is illustrated in Fig. 5. On TA2 there were no concurrent root and stem damages.

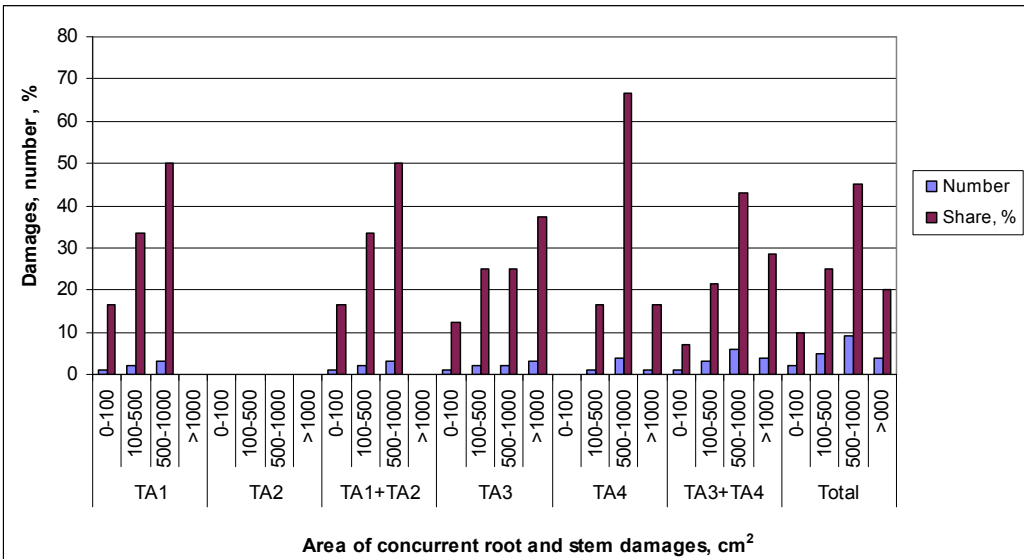


Fig. 4. Distribution of stem damages by area.

On TA1 66.67% of the damages at a height lower than 1 m were caused by the skidder equipment and the bunched stem sections, whereas 16.67% of them were caused by the felled trees. The most numerous concurrent root and stem damages of the residual stands on TA3 and TA4 were at a height of 0.5–1.0 m – 60%, whereas these at heights of 0–0.5 m and 1–2 m were relatively equally distributed – 20% each group. The damages were entirely caused by the skidded stem sections.

It is seen from Fig. 6, that large damages prevail, therefore the health of trees is in danger. On TA1 50% of the damages were with areas of 500–1000 cm² and there were no damages larger than 1000 cm². On TA2 no concurrent root and stem damages were found. Along the skid roads, damages with areas of 500–1000 cm² dominated (42.86%), followed by these over 1000 cm² (28.57%).

Understorey damages

Results show that on TA5 and TA6 16.89% of the understorey was damaged. Fortunately, the greatest part of the damaged understorey (80%) was raw, i.e. recoverable, while the rest was broken (see Fig. 7). As mentioned previously, in subcompartment 19b there was no natural regeneration and test areas were not placed there.

Conclusions

After the regenerative cuts in the studied stands 30.49% of the residual stands were damaged, fortunately 69.89% of them – injured superficially. The damaged residual trees in both of the stands were distributed by parts of tree as follows: root damages – 34.41%, stems damages – 44.09%, and concurrent root and stem damages – 21.5%. Inside

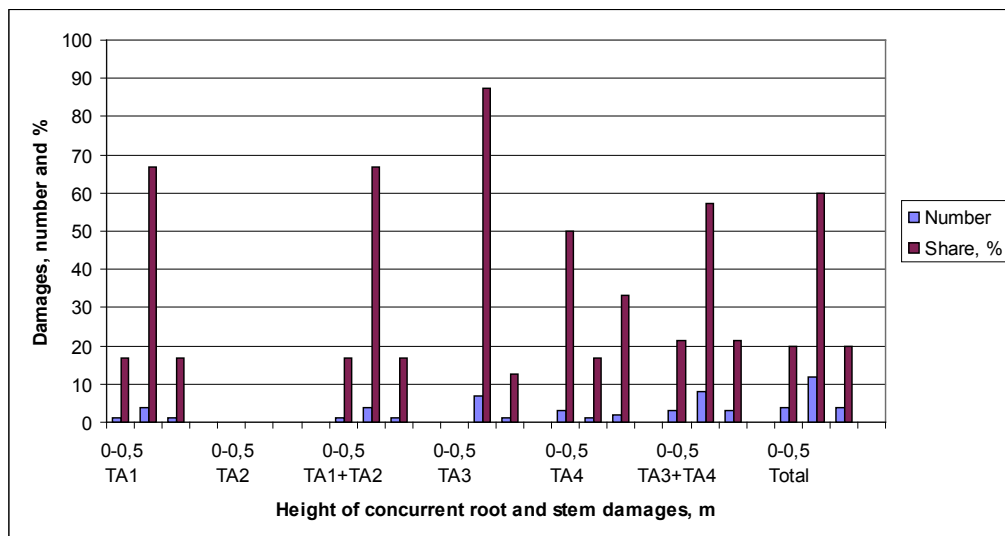


Fig. 5. Distribution of concurrent root and stem damages by height.

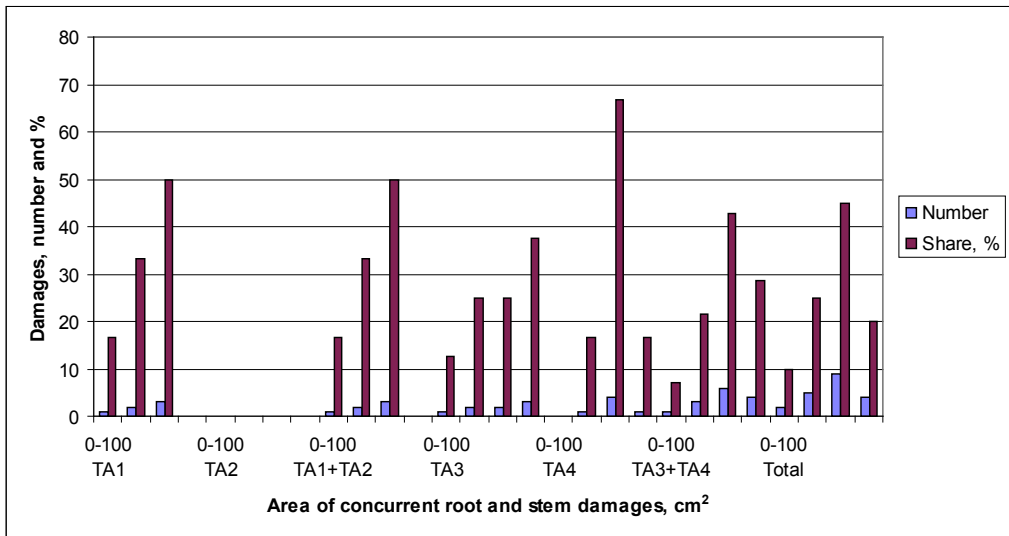


Fig. 6. Distribution of concurrent root and stem damages by area.

the stands the damaged trees were 25.94%, 75.60% out of which – superficially.

The most numerous damages were the stem damages – 70.93%, followed

by the root damages – 20.5% and the concurrent root and stem damages – 8.57%.

During the transportation the semi-suspended stem sections injured almost

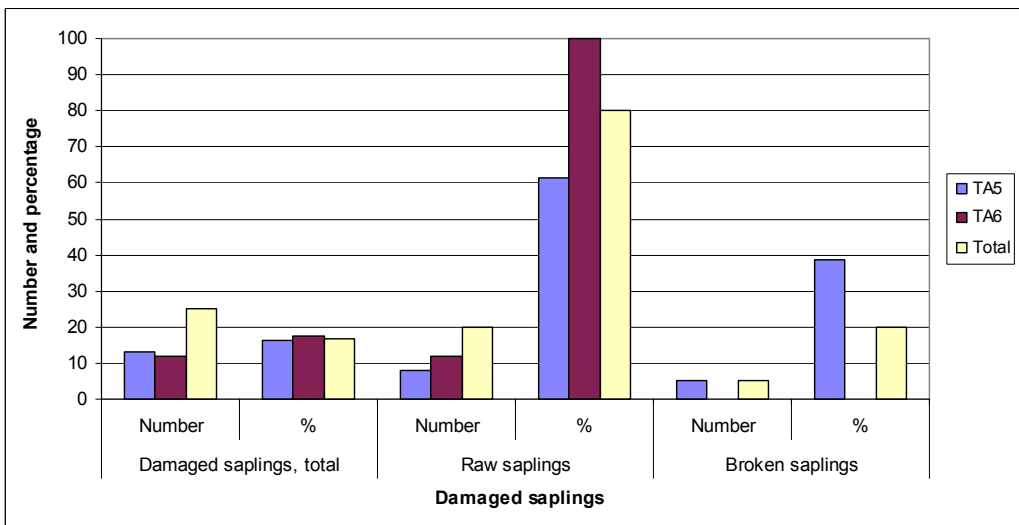


Fig. 7. Distribution of the understory damages.

half of residual trees along the skid roads (47.76%), 59.38% of them – superficially and 40.63% – deeply. The damages were predominately root damages (56.25%), the rest (43.75%) were concurrent root and stem damages.

Inside the stands, 50% of the root damages were with areas over 100 cm², whereas along the skid roads – 83.33% were larger than 100 cm². In the first case the damages were caused by the stem sections during the bunching, in the second case – by the load during the skidding to the landing. The tree stem damages were mainly at a height over 1 m (53.66%) and with areas over 1000 cm² (56.10%). These damages were located only inside the stands and they were caused by improperly directed felled trees which interlaced with the residual trees. This additionally increased the tree stem damages within the final prostration of the trees and lead to critical situations concerning the logger safety.

The concurrent root and stem damages inside the stands were predominately with areas of 500–1000 cm² (50%) and at a height of 0.5–1 m (66.67%), whereas along the skid roads damages of over 500 cm² (71.43%) and at a height up to 1 m (78.67%) were prevailing. In the first case as mentioned above the damages were caused by the bunching and in the second case – by the skidded loads.

The damaged understorey saplings were 16.89% of the total, 20% of which being broken and the rest – recoverable.

Therefore, significant damages on the residual trees and the understorey in the studied stands were caused by the skidded stems. To reduce stand damages, an adequate felling direction is

required, consistent with the skid roads and a proper bunching direction as well. In high density stands some cutting of the long stems is recommended that means certain changes of the logging technology. To reduce tree damages along the skid roads and especially those along the curves it is advisable to use some protective devices for prevention. To reduce the understorey and soil damages it is necessary to use protective cones on the front part of the logs.

References

- Baev A., Mateev A., Rosnev B., Garetkov D., Bachvarov D., Radkov D., Tabakov D., Vasileva E., Naumov Z., Vasilev Z., Raev I., Kostadinov K., Shikov K., Kaludin K., Krastanov K., Marinov M., Belyakov P., Petkov P., Dragoev P., Gateva R., Zlatanov S., Bozhinov H.** 1985. Mountainous forest ecosystems. Zemizdat, Sofia. 320 p.
- Dinev D.** 2003. Research and results from thinnings in the forests of Bulgaria. Publishing House of University of Forestry, Sofia. 262 p.
- Dvořák J.** 2005. Analysis of forest stands damages caused by usage of harvester technologies in mountain areas. Electronic Journal of Polish Agricultural Universities, Forestry, Volume 8, Issue 2. 10 p.
- Ferenčík M., Messingerová V., Stanovský M.** 2008. Analýza dopadu harvesterovej technológie na lesné porasty vo flyšovom pásme Hornej Oravy. In: Proc. of Int. Scientific Conference "Integrated Logging Technologies", Brezovica, Slovakia, 2008: 33–42.
- Georgiev D., Stoilov S.** 2007. Evaluation of environmental impact of wheel skidder in selection silvicultural system. In: Proc. of International Symposium "Sustainable forestry – problems and challenges", Ohrid, FYR of Macedonia, 24–26.10.2007: 66–69.

Košir B. 2008. Modelling stand damages and comparison of two harvesting methods. *Croatian Journal of Forest Engineering*, vol. 29 (1): 5–14.

Mateev A., Marinov T., Shipkovenski D., Kushlev D., Zhelyazkov P., Antov B. 1986. Environmental problems of forest utilization. Zemizdat, Sofia. 192 p.

Meng W. 1978. Baumverletzungen durch Transportvorlänge bei der Holzernte – Ausmaß und Verteilung. Folgeschäden am Holz und Versuch ihrer Bewertung. Schriftenreihe der LFB Baden-Württemberg, Band 53, 159 p.

Saarilahti M. 2003. Soil Interaction Model. Project Deliverable D2 (Work Package No 1) of the Development of Protocol for

Ecoefficient Wood Harvesting on Sensitive Sites (ECOWOOD) No QLK5-1999-00991 (1999–2002), Helsinki, 87 p.

Saarilahti M., Anttila T. 1999. Ruth Depth Model for Timber Transport on Moraine Soils. In: Proc. of 9th International Conference of the ISTVS, Munich: 29–37.

Saarilahti M., Mulari J., Rantala M. 2000. Multicycle Rut Depth in Forwarding. ECOWOOD-Project, University of Helsinki, Helsinki: 29–37.

Schütz J.-P. 1990. Sylviculture. Presses Polytechniques et Universitaires Romandes. Wästerlund I. 1994. Environmental Aspects of Machine Traffic. *Journal of Terramechanics*, vol. 31, issue 5: 265–277.

FRICITION COEFFICIENTS SEEDS ANALYSIS OF SOME CONIFEROUS TREE SPECIES

Konstantin Marinov and Kiril Lyubenov

Department of Technology and Mechanisation of Forestry, Faculty of Forestry,
University of Forestry, 10 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria. E-mail:
kmarinov_ltu@abv.bg

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Abstract

In this paper an experimental study is exposed which has been conducted for determining the angles and the friction coefficients of seeds of some coniferous tree species. These parameters are used in the design and construction stages of forest planters and seeding machinery. These parameters can also be applied in the technological research of many forestry processes such as: dewinging, cleaning, sorting, seeds sowing etc. The object of research are seeds of some of the main coniferous tree species which are a subject of economic activity in our country – Scots pine (*Pinus sylvestris* L.), Black pine (*Pinus nigra* Arn.), Norway spruce (*Picea abies* Karst.) and Macedonian pine (*Pinus peuce* Griseb.). As a result of this study, the angle parameters and the friction coefficients of the studied seeds have been established. Results can be used in the design of forestry machinery and in the research of technological processes connected to the movement and processing of seeds.

Key words: friction coefficients, *Pinus sylvestris*, *Pinus nigra*, *Picea abies*, seeds.

Introduction

The technological properties of forest seeds and their mixtures are the basis for design of seed production and forestry machines. The production of conifer tree seeds requires a longer production process, in which specialized machinery is used. This requires knowledge of the characteristics and properties of the seed material obtained in Bulgaria.

During the process of movement of seeds and mixtures friction occurs in the working bodies of the machinery. The amount of friction depends on the friction properties of these materials. The objec-

tive indicators to measure this friction are the angle of friction on the machinery surface and the angle of repose. The friction coefficients for determining the structural and technological parameters of the machinery and processes are a function of these indicators. The friction coefficients on the machinery surface are used to determine the parameters of hopper-, feeder- and transporting equipment, for calculating the resistance and productivity of the process etc. The coefficients of internal friction of the seed materials, expressed by the angle of repose, serve to determine the type of sowing devices, the filling devices' parameters, the forces

of friction between seeds in the process of their treatment etc.

In our country there are studies on the technological properties of seed materials from the main coniferous species (Vasilev 1964; Marinov 1996, 2007). In regard to the friction coefficients these studies lack information or this information is insufficient. Results, regarding the friction coefficients of forest seeds on various surfaces, referring to local tree species, are known to us from foreign sources (Sviridov 1987).

It can be deduced from the literature and analysis reference, that the study of angle and friction coefficients of seeds and mixtures of the major part of our country's coniferous species, presents a particular interest with a scientific and practical character.

The aim of this work is to study and determine the friction coefficients of seeds and mixtures of the main conifers in Bulgaria.

Tasks of the study. The following main tasks must be solved in order to achieve the target:

1. Determining the friction angle of seeds and mixtures on a smooth steel surface;

2. Determining the angles of repose and the coefficients of internal friction of the seed materials.

The object of the study are seed materials from Scots pine, black pine, Norway spruce and Macedonian pine from the region of the Western Rhodopes, Rila, Pirin and Osogovo mountains.

The subject of the study is the angles of friction of seeds with wings, pure seeds and technological seed mixtures,

pounded wings and impurities in dewinging machines.

Material and Methods

The test materials are provided by the state forestry seed stations in the towns of Razlog and Samokov. The study has been conducted at the laboratory "Forestry machines" at the Department of Technology and Mechanization in Forestry at the University of Forestry in Sofia. The study materials are derived from seed crops and seed production orchards in the Western Rhodopes, Rila, Pirin and Osogovo mountains. The Scots pine and the Norway spruce are from the territory of the state forestry stations in the towns of Razlog, Blagoevgrad, Garmen, Mesta, Samokov and Yakoruda, the black pine – from Osogovo, Simitli, Razlog and Katuntsi and the Macedonian pine is from Razlog, Gotse Delchev and Yakoruda.

The humidity of seeds during the testing is maintained between 8–10%, same as in the machinery rooms and the seed storage rooms. The studied samples are compiled through the separation of samples from different lots, in accordance with the methods and means, provided by the state standard and international regulations (BSS 1999, EN ISO 8402 1996, ISO 3534-1 1996). The humidity is determined by an analytical method using a thermostatic desiccator (BSS 1999). The tests are conducted with winged and dewinged seeds, technological mixtures and impurities in the dewingers.

The friction coefficients on a metal surface are defined by the friction angle of the test materials on an inclined

surface (Nartov et al. 1981, Sviridov 1987). A special device with a mobile arm, with an attached steel plate, has been used for this purpose. The test samples are being placed on that plate and thus, the elevation angle of the arm, where the particles at rest begin to move, is being determined. The friction angle of the test samples on a metal surface is determined by the size of this angle. The friction coefficient is expressed by the formula:

$$f = \operatorname{tg} \alpha \quad (1),$$

where α is the friction angle.

The angles and coefficients of internal friction of the test materials are defined by their angle of repose with the horizontal surface. In order to determine this angle of repose, one of the accepted practice devices is used (Nartov et al. 1981). A funnel, which is mounted on a stand, is used for this purpose. The test materials are poured into the funnel on a horizontal plane. Thus a bulk figure is formed which has the shape of a cone, the forming wall of which concludes with the horizontal plane an angle, equal to the angle of repose. The angle of repose is determined with stilts. The coefficient of internal friction is expressed by the formula:

$$\mu = \operatorname{tg} \varphi \quad (2),$$

where φ is the angle of repose.

The friction angles and the repose are determined by an optical universal octant „Carl Zeiss Jena“ with an accuracy of 0.5 degrees.

Results and Discussion

Between 150 and 220 samples from each of the 22 studied groups are used in the tests. Results from the measurements are processed by the Descriptive Statistics methods. Calculations are made using the computer program „Statistika 7“ from StatSoft. The results are subjected to a statistical verification and analysis in accordance with the mathematical models and modus (Tasev 2010). The more important numerical characteristics are presented in a tabular form. With respect to the angle of repose of seeds and technological mixtures, these characteristics are presented in Table 1 and 2 and the characteristics of the angle of friction on a metal surface of winged and de-winged seeds and technological mixtures of seeds and impurities – in Table 3.

Histograms and curves of distribution of the random variables are drawn based on the obtained data. They are presented in a graphic form on Fig. 1–7.

Table 1. Angle of repose of pure (dewinged) seeds.

Seeds	Mean X	Med. Me	Mode Mo	Min X _{min}	Max X _{max}	Std. Dev. S	Coef. Var. V, %	Skewness Ka	Kurtosis Ke
Scots pine, φ	29.70	29.50	29.50	27.00	32.00	0.8783	2.9569	-0.2440	0.6006
Norway spruce, φ	33.15	33.00	33.00	30.50	35.50	1.0245	3.0906	-0.1149	-0.4025
Black pine, φ	26.48	26.50	26.5	24.00	29.00	0.9799	3.7008	-0.0955	-0.2221
Macedonian pine, φ	28.04	28.00	28.00	25.50	30.50	0.9539	3.4017	-0.0110	-0.1978

Table 2. Angle of repose of technological seed mixture in dewinger.

Technological seed mixture	Mean X	Med. Me	Mode Mo	Min X _{min}	Max X _{max}	Std. Dev. S	Coef. Var. V, %	Skewness Ka	Kurtosis Ke
Scots pine, φ	42.95	43.00	Multiple	38.00	49.00	1.8938	4.4093	0.5605	0.1776
Norway spruce, φ	48.43	48.00	48.00	44.00	53.00	1.4654	3.0255	-0.0071	0.1724
Black pine, φ	37.32	37.25	37.00	32.00	43.00	1.7704	4.7443	0.2319	0.3841
Macedonian pine, φ	41.52	41.50	41.50	37.50	46.00	1.4548	3.5040	0.2891	0.5759
Impurities, φ	56.74	56.50	56.50	54.00	60.00	1.0688	1.8840	0.3002	0.2059

Table 3. Angle of friction on steel surface of seeds with wings, pure (dewinged) seeds and technological seed mixture and impurities in dewingers.

Seed materials	Mean X	Med. Me	Mode Mo	min X _{min}	max X _{max}	Std. Dev. S	Coef. Var. V, %	Skewness Ka	Kurtosis Ke
Scots pine – seeds with wings, α	29.65	29.50	30.00	27.00	32.00	0.8920	3.0080	-0.1352	0.3931
Scots pine – pure seeds, α	24.65	24.50	24.50	22.00	27.50	0.9070	3.6799	0.0276	0.8046
Scots pine – tech. seed mixture, α	27.57	28.00	28.00	24.00	31.00	1.2994	4.7137	-0.1417	0.0529
Norway spruce – seeds with wings, α	36.11	36.00	36.00	33.50	38.50	0.8723	2.4154	-0.1996	0.3628
Norway spruce – pure seeds, α	30.61	30.50	30.50	28.00	33.00	0.8835	2.8858	-0.0940	0.5205
Norway spruce – tech. seed mixture, α	33.50	33.00	33.00	30.00	37.00	1.3357	3.9867	0.1255	0.2477
Black pine – seeds with wings, α	28.02	28.00	28.00	25.50	30.50	0.8419	3.0052	-0.1777	0.4007
Black pine – pure seeds, α	22.58	22.50	22.50	20.00	25.00	0.8040	3.5608	-0.3038	0.9157
Black pine – tech. seed mixture, α	26.42	26.00	27.00	23.00	30.00	1.3858	5.2453	-0.1199	-0.1531
Macedonian pine – seeds with wings, α	25.70	25.50	25.50	23.00	28.50	0.8340	3.2452	-0.1195	1.2742
Macedonian pine – pure seeds, α	20.65	20.50	21.00	18.00	23.00	0.7770	3.7623	-0.3502	1.1780
Macedonian pine – tech. seed mixture, α	24.39	24.00	24.00	21.00	28.00	1.3314	5.4581	-0.1024	0.0119
Impurities, α	34.61	35.00	35.00	31.00	38.00	1.2430	3.5907	0.0211	0.0719

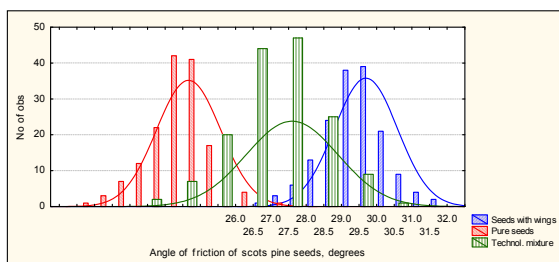


Fig. 1. Histograms of angle of friction of Scots pine (*Pinus sylvestris*) seeds.

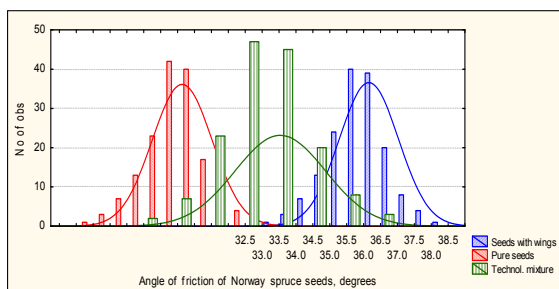


Fig. 2. Histograms of angle of friction of Norway spruce (*Picea abies*) seeds.

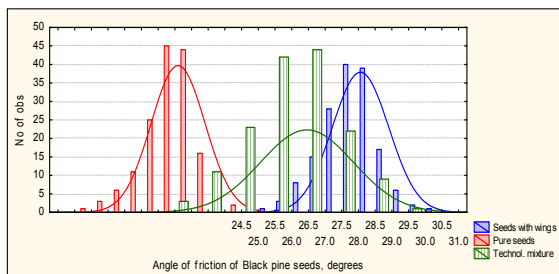


Fig. 3. Histograms of angle of friction of Black pine (*Pinus nigra*) seeds.

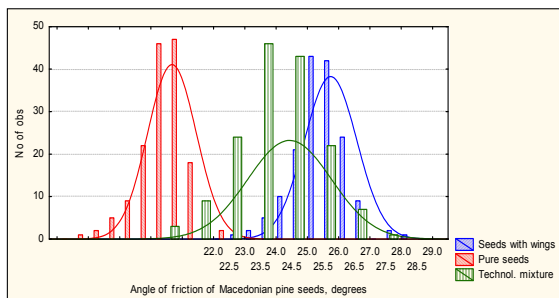


Fig. 4. Histograms of angle of friction of Macedonian pine (*Pinus peuce*) seeds.

The friction angles and the repose are indicated on the X-axis and the number of the objects (samples) is indicated on the Y-axis. The respective curve of the normal distribution is drawn for each of the studied groups. Using the graphical-analytical method, different levels can be determined by these graphs, when there are some set restrictive conditions.

A verification has been made for determining the type of distribution of the angles of friction in accordance with the known laws of distribution of random variables. The verification showed that for all studied cases, the estimated coefficients of variation with respect to Table 1, 2 and 3, are less than 0.3 or $V < 30\%$. This gives us grounds to assume that the studied variables have a normal (Gaussian) distribution (Tasev 2010). From the obtained average values of friction angles, in accordance with formulas (1) and (2), the average values of respective coefficients of friction of the studied seed materials have been also defined. The coefficients of friction on a steel surface are presented in Table 4 and the coefficients of internal friction – in Table 5.

In determining the geometrical parameters of the hopper – and feeder devices of the machinery it is appropriate to use the maximum values of the angles of friction and repose, X_{max} from Table 1, 2 and 3. This will ensure the full fluxion of the materials into the devices with gravitational power.

The angle of repose of the seeds with wings for all the four tree species is greater than 70° , which assigns them to the group of non-fluxion (plastic) bulk materials. When working with such seeds it is necessary the hopper devices of the machines to be fitted with a mechanism for coercive filling.

The technological mixtures in the dewingers include mainly seeds from the processed lots that are between 65–75% of the total weight, pounded wings – about 20–30% and needles and cone scales – less than 5%. To determine the geometrical parameters of these machines, the average values of friction angles are used and for determining the parameters of the process their friction coefficients are mainly used.

The angles of repose and friction of the pure seeds are used for the design of hopper devices, sowing devices and seed tubes for forest seeders. The friction coefficients, obtained as average values of these angles, are used for determining the technological and production parameters of the sowing process.

The group of impurities is formed by the technological mixture in the dewingers while the pure seeds are separated, i.e. this group includes pounded wings, needles and cone particles. Because of the fact that the differences in the angular

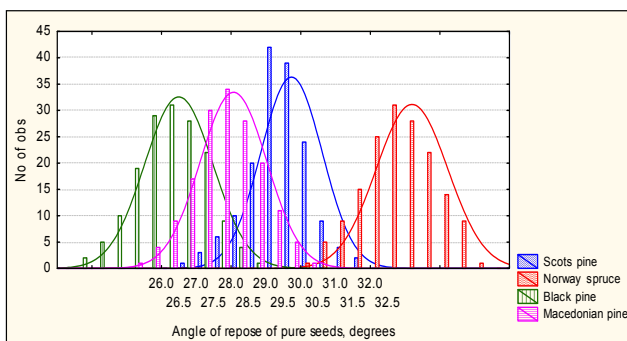


Fig. 5. Histograms of angle of repose of pure (dewinged) seeds.

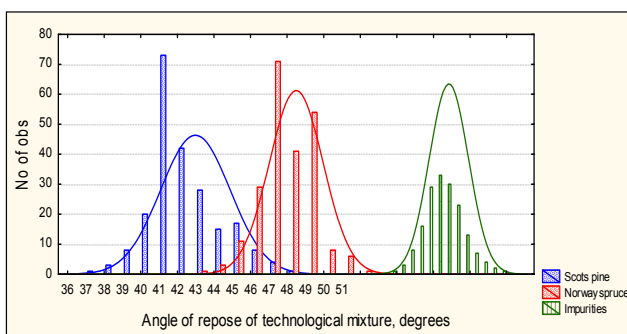


Fig. 6. Histograms of angle of repose of technological seed mixture and impurities.

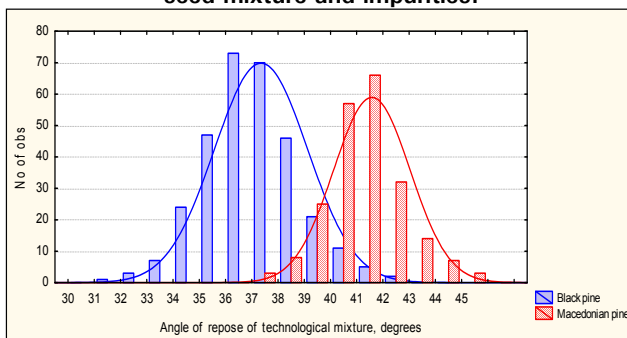


Fig. 7. Histograms of angle of repose of technological seed mixture.

parameters are very small for the different tree species, the tables show their average values. The friction coefficients of this group are mainly used in the cal-

Table 4. Friction coefficients of seed materials on steel surface.

Seed materials	Scots pine	Norway spruce	Black pine	Maced. pine	Impurities
Seeds with wings, f	0.5692	0.7295	0.5322	0.4813	–
Dewinging seeds, f	0.4589	0.5916	0.4159	0.6769	–
Technol. seed mixture, f	0.5221	0.6620	0.4968	0.4534	0.6901

Table 5. Coefficients of internal friction of seed materials.

Seed materials	Scots pine	Norway spruce	Black pine	Maced. pine	Impurities
Dewinging seeds, μ	0.5704	0.6531	0.4981	0.5326	–
Technol. seed mixture, μ	0.9309	1.1275	0.7623	0.8853	1.5247

culation and design of some seed cleaning machines and pneumatic transport systems.

Conclusions

This study has a scientific and a practical character. Thanks to this study the existing knowledge on the physical-mechanical and technological properties of seed materials from our main coniferous species have been enriched and further developed. The following main results of this study can be pointed out:

1. The friction angles and coefficients of the studied seed materials on a smooth steel surface are determined;
2. The angles of repose and coefficients of internal friction of pure seeds and technological mixtures in the dewingers are determined;
3. The type of distribution and the numerical characteristics of the angular parameters of the studied seed materials as random variables with a normal distribution law are determined.

The results are intended for research in the field of forest seed production and the sowing process. Seed cleaning machines, dewingers, transporting and sowing machines can be designed and constructed with the help of these results. They also define some technological parameters of the processes in the respective area of application.

References

- BSS** (Bulgarian State Standard) 1953:99 1999. Seeds of forest trees. Rules for sampling and testing methods. (in Bulgarian).
- EN** ISO 8402 and ISO 3534-1 1996. International Rules for Seed Testing (IRST) 1996.
- Marinov K.** 1996. Technological properties of seeds of Scots Pine, Black Pine and Norway Spruce used in their separation. Proceedings of the International Symposium "Second Balkan Conference on study, protection and use of forest resources", Sofia, 3–5 June 1996: 212–217. (in Bulgarian).
- Marinov K.** 2007. Study on the influence of basic technological parameters on dewing-

ing process of seeds from conifer tree species. Proceedings of the International Symposium "60 Years Faculty of Forestry", October 24th – 26th 2007, Ohrid, Macedonia: 120–125.

Nartov P., Poluparnev Y., Sviridov L. 1981. Mechanization of work to determine seed quality of forest seeds. Mechanization and automation of forestry production. Overview. Moscow, 32 p. (in Russian).

Sviridov L. 1987. Coefficient of friction forest seeds. Forest Journal No 3: 21–26. (in Russian).

Tasev G. 2010. Mathematical models and methods. Sofia, 73 p. (in Bulgarian).

Vasilev V. 1964. Physics-mechanical properties of some coniferous seed and technology for their mechanical cleaning and sorting. Forestry science, year 1, No 6: 65–83. (in Bulgarian).

**CONTRIBUTION TO THE IDENTIFICATION
OF DOUGLAS FIR (*PSEUDOTSUGA MENZIESII* (MIRB.)
FRANCO) PROVENANCES PROMISING
FOR AFORESTATION PRACTICE**

Emil Popov

Forest Research Institute – BAS, 132 “St. Kliment Ohridski” blvd., Sofia 1756,
Bulgaria. E-mail: emilpopov99@hotmail.com

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Abstract

Rapid growth is one of the most valuable characteristics of Douglas fir. In order to make the best use of this feature of its, it is necessary to investigate the growth characteristics of this tree species at level population. The objective of this research is to contribute in identifying promising provenances of Douglas fir in the experimental plantation in Konyavska Mountain. In order to attain the above objective methodologies for establishment and assessment of provenance experiments, early tests and statistics were applied. The average values for height of the trees for a period of five consecutive years: 5, 6, 7, 8 and nine as well as the current height increment for four years for each provenance in the trial plantation established with provenances from the states of Oregon, Washington, Arizona and New Mexico in State Forest Service Kyustendil were estimated. Based on data about the sums of precipitation and air temperature, drought and semi-drought periods were determined for corresponding years. The provenances are determined as promising if they meet the following two conditions: to be at the top of classification according to reached height and current increment in height, and to be of current increment in height influenced by the duration of dry and semi-dry periods to the least extent.

Key words: provenance experiment, height growth, current increment, drought resistance.

Introduction

Rapid growth is one of the most valuable characteristics of Douglas fir. In order to make the best use of this feature of its, it is necessary to investigate the growth characteristics of this fir at level population.

Experiments for testing different Douglas fir provenances began in the native land of this species as early as in 1912

(Morris 1934), and these go on even today in all countries it has been introduced in (Kleinschmit and Bastien 1992).

This article reveals the investigated main quantitative growth characteristics of Douglas fir, namely: heights of 5-, 6-, 7-, 8- and nine-year-old seedlings and current increment in height of 6-, 7-, 8- and nine-year-old seedlings.

The two main objectives of this work are as follows:

1. Assessing the provenances in terms of their growth and current increment in height;

2. Determining the provenances whose current increment in height has been affected to the least extent by the duration of dry and semi-dry periods.

Materials and Methods

The trial provenance plantation established in Kyustendil State Forestry in the spring of 1990 is the object of the present investigation. The plantation contains provenances from 20 seed zones in the states of Oregon, Washington, Arizona and New Mexico. Detailed data on the latitudes, and longitudes of the provenances, as well as their altitudes, were published in 1990 (Popov 1990). The provenance trials were in accordance with the methods that Lines developed in 1967.

The plantation was established while using square spacing of 2-metre intervals between each two seedlings. The trial was in two replications. Each experiment plot had sizes of 16 to 16 meters. The height of each seedling was measured with precision of 2 cm for five consecutive years. Thirty-six seedlings were measured as an average for each replication. Methods of descriptive statistics and one-way analysis of variances were used for finding the seedling height and the current increment in height. The reliability of the group comparison methods by Fisher, Bonferroni, Scheffe, Duncan and Tukey (Dowdy and Wearden 1983) was checked in view of determining the significance of the differences between the average values of seedling heights and current

increment in heights. Rank correlation analysis was used for finding the stability of the seedling current growth in height. Graph analysis and rank correlation analysis were used for finding the relationships between the current increment in seedling height and the duration of the dry and semi-dry periods.

The mean monthly and annual temperatures of the air were taken from the reference book of Moralyiski (1986), and the monthly and annual sums of precipitation – from the book of Koleva and Peneva (1990) about the meteorological stations in Bulgaria; I have used the data about Kyustendil Meteorological Station, as it is the nearest to the trial plantation.

Walter's (1972) methods were used for determining the duration of the dry and semi-dry periods. I have used two curves expressing the rates of monthly precipitation sums. These sums are presented for Curve 1 on the right ordinate scale in such a way that 20 mm of precipitation correspond to 10°C on the left ordinate scale. For Curve 2, the monthly precipitation sums are presented in bold also on the right ordinate scale in such a way that 30 mm of precipitation correspond to 10°C on the left ordinate scale. The duration of dry periods, when there were such, is presented graphically in the diagrams, (Walter has called them 'ecological diagrams'.) Dry are the periods, presented on the abscise scale. For these periods, the curve that expresses the rates of the mean monthly temperatures passes above Curve 1. Semi-dry are the periods presented on the abscise scale, and the curve that expresses the rates of the mean monthly temperatures passes above Curve 2.

Results and Discussion

Growth in height is one of the main quantitative characteristics that are used for finding the productivity and often viability of plants while testing various tree species, provenances and progenies. For the heights and current increments of seedlings of all the investigated provenances, the following values were found in cm: arithmetic mean ($\bar{X}$), standard deviation (σ), and standard error (α). The check of the precision of all mean values met the precision criterion of such investigations $p \leq 5\%$. The generalized results are presented in Figures 1 and 2. Analyses of variances were made for the reached heights and current increment in height of the trees.

Group comparisons in which Fisher test (after Dowdy and Wearden) was used made it possible to determine 14 good provenances as follows: No 4 Newhalem, No 31 Idanha, No 5 Newhalem, No 20 Parkdale, No 7 Darrington, No 8 Darrington, No 11 Bremerton, No 6 Darrington, No 9 Monroe, No 34 Toledo, No 29 Idanha, No 43 Oakridge, No 12 Moclips и No 10 Bremerton. These provenances were subdivided according to Fisher's test into four homogenous groups. The average height of each of these provenances exceeds by 10% the average for the whole trial plantation, i.e. $(\bar{X} + 10\% = 254.2 \text{ cm})$. Four of these 14 provenances have average heights each exceeding average height for the plantation by 20%, i.e. $(\bar{X} + 20\% = 277.3 \text{ cm})$. Ac-

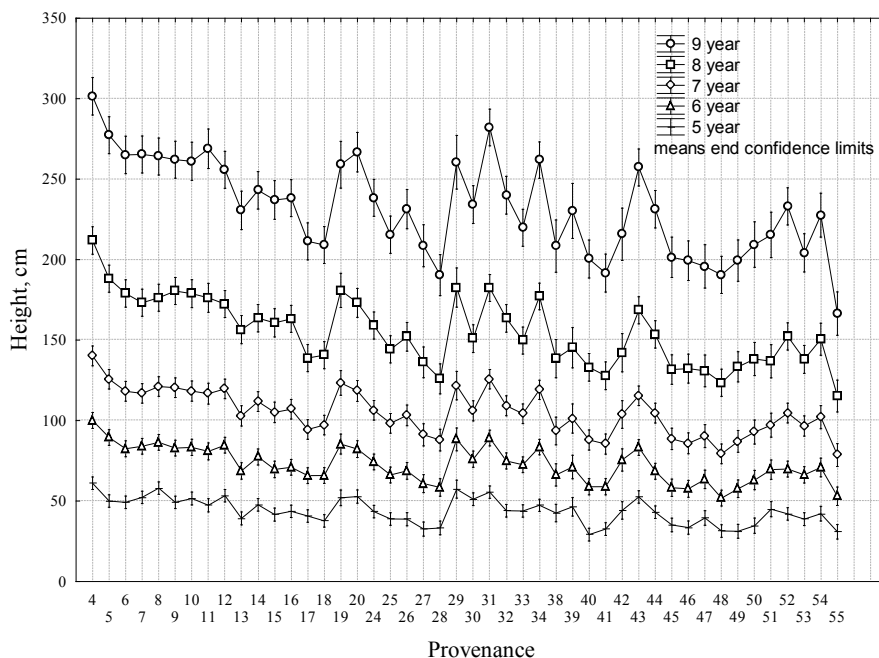


Fig. 1. Height growth of Douglas fir provenances in the age interval of 5 to 9 years.

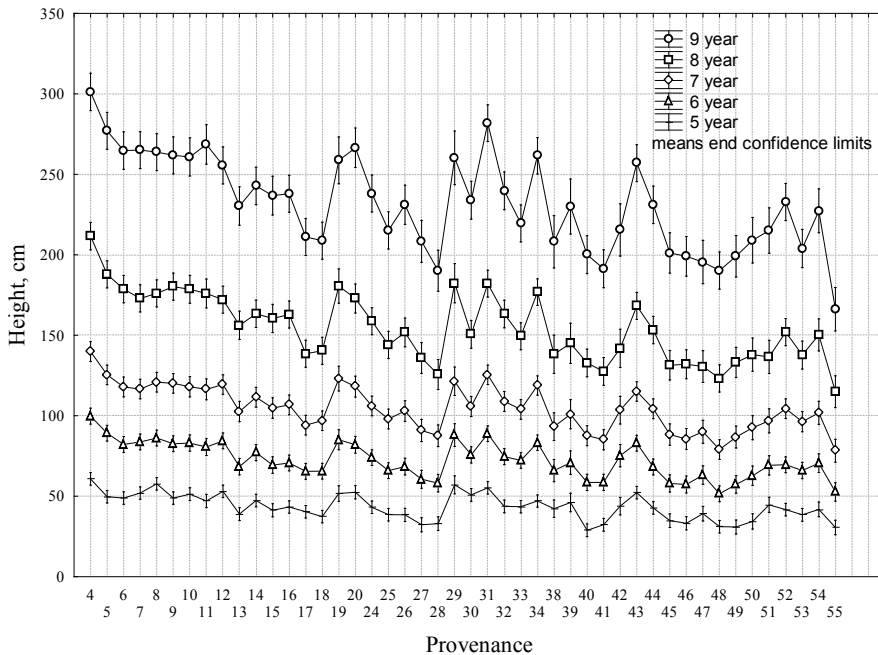


Fig. 2. Current height increment of Douglas fir provenances in the age interval of 6 to 9 years.

cording to the test these 4 provenances were subdivided into two homogenous groups.

The results obtained were compared with results pertaining to the set of provenance trials of IUFRO, which includes 182 provenances tested on the territories of 22 European countries (Kleinschmit and Bastien 1992).

These trials clearly show that provenances from the provinces in the Coastal Regions, the western part of the Cascade Mountains in the State of Washington, and the western part of the Cascade Mountains in the state of Oregon have good adaptiveness and growth in the most of the regions of testing. It must be pointed out here that these are regions of extremely great differences

in climate. Be speaking of the countries Denmark, Belgium, France, Italy, Great Britain, Turkey, the Canadian province of British Columbia and Germany.

The rank correlation analyses showed very great positive relationships between the average heights and increments. The results obtained show a distinct stability of the changes in the average heights and increments of the trees according to provenances. This makes it possible to carry out early testing and assess the growth in height of the provenances tested.

Plant organisms need particular environmental conditions for the normal occurrence of their growth and development. High temperatures and droughts are among the most unfavorable cli-

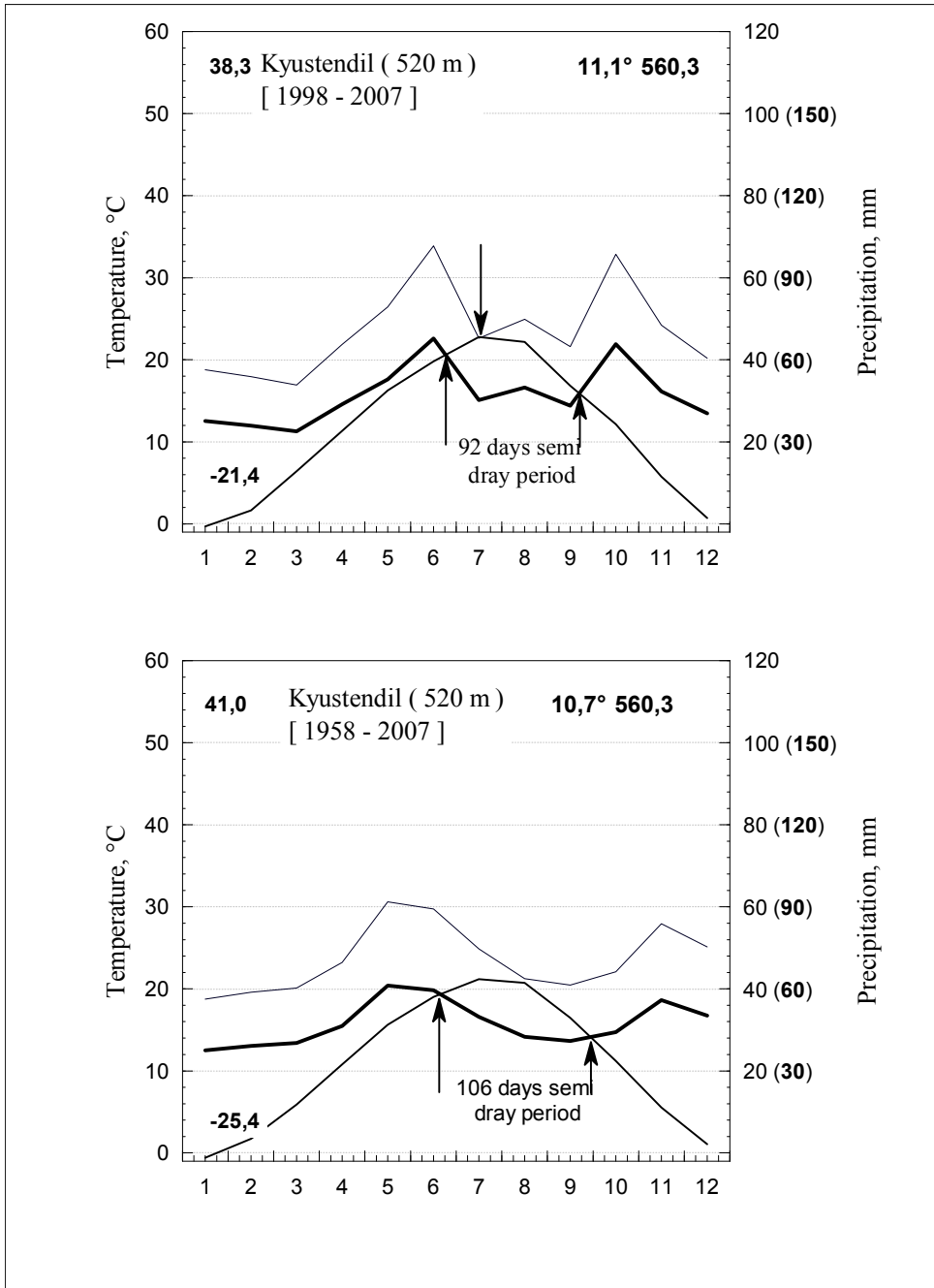


Fig. 3. Ecological diagrams 1.

matic conditions. In the Temperate Climatic Zone, the duration of hot and dry period affects negatively the current increment of trees.

Ecological climatograms have been made in accordance with Walter's methods. These are presented on Figures 3 and 4. The main climatic characteristics taken into consideration were the air temperature and precipitation sums for the last decade, the whole period that there is available information about, and the period when average values were found for the current increment in height of the trees of the provenances tested in the trial plantation in Kyustendil State Forestry. These climatograms provide particular visual information about the climatic conditions and their changes during the above mentioned periods of time.

The semi-dry periods determined for the years 1958–2007, 1998–2007 and 1991–1995 were respectively 106, 92 and 102 days. During the last interval of time the current increment of trees was determined, the availability was found of not only a semi-dry period but also of a dry one lasting 26 days.

This circumstance shows aggravation of the average values of temperature and precipitation during the growing season within the time interval that is of interest in connection with this investigation, and it provided the reason for more detailed analyses.

Climatograms have also been prepared for each particular year when current increment was found; based on these the availability and durations of the semi-dry and dry periods were determined with precision of 1 day. The values obtained are as follows: dry periods in 1995 – a total of 13 days, in

1994 – a total of 90 days, in 1993 – a total of 94 days, in 1992 – a total of 76 days and semi-dry period in 1995 – a total of 31 days, in 1994 – a total of 188 days, in 1993 – a total of 187 days, in 1992 – a total of 126 days.

The duration of the dry and semi-dry periods was compared with the current increment in height of the seedlings of all the provenances investigated. It was found out that the current increment diminished as dry period duration increased.

The correlation coefficients expressing the relationship between dry period duration and the current increment of the seedling in height, for all the provenances in trial had negative values as they varied from $R = -0.95$, for Provenance 42 Oakridge (OR) to $R = -0.70$ for Provenance 29 Idanha (OR). The low values of the correlation coefficients in this trial show lower dependence of current increment in height on the unfavorable conditions expressed as availability and duration of dry and semi-dry periods in each particular year.

Conclusion

Provenances 4 Newhalem, No 29 Idanha and No 10 Bremerton have been determined as promising. They meet the following requirements: to be at the top of classification according to reached height and current increment in height, and to be of current increment in height influenced by the duration of dry and semi-dry periods to the least extent. We consider the methodological approach used genuine and therefore, deserving greater attention while assessing tree species and provenances in trial plantations.

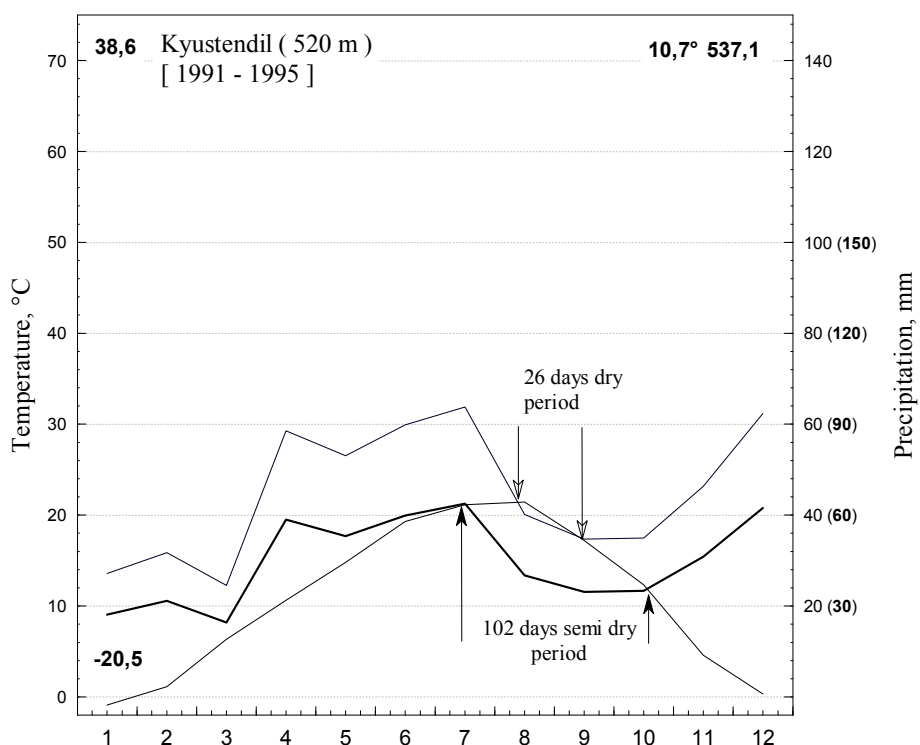


Fig. 4. Ecological diagrams 2.

References

- Dowdy S., Wearden S.** 1983. Statistics for Research, Wiley Series in Probability and Mathematical statistics, Applied Probability and Statistic Section, John Wiley and Sons, New York, 537 p.
- Kleinschmit J., Bastien J.C.** 1992. IUFRO's role in Douglas-Fir (*Pseudotsuga menziesii* (Mirb. Franco) tree improvement. – *Silvae genetica*, vol. 41 (3): 161–173.
- Koleva E., Peneva R.** 1990. Climatic Reference book, Precipitation in Bulgaria, Publishing House of BAS, Sofia. (In Bulgarian)
- Lines R.** 1967. Standardization of Methods for Provenance Research and Testing XIV IUFRO – Congress, Munchen, vol. III: 672–718.
- Moralyiski E.** 1986. Climatic Reference book for PRB, Air temperature in Bulgaria, Science and Art, Sofia. (In Bulgarian)
- Morris W.G.** 1934. Hereditary Test of Douglas Fir Seeds and their Application to Forest Management. *Journal of Forestry*, 1934, vol. 32: 11–17.
- Popov E.** 1990. The influence of Douglas-Fir (*Pseudotsuga menziesii* (Mirb.) Franco) seed provenances on the growth in the height, terminal but formation and the frost resistance of one year old seedlings. – *Nauka za gorata* (Forest science), 3: 3–17. (In Bulgarian)
- Walter H.** 1972. Vegetation of the Earth and Ecological System of the Geo-biosphere. Verlag Eugen Ulmer, Stuttgart: 25–27.

DYNAMIC GROWTH MODEL FOR BIRCH STANDS IN NORTHWESTERN SPAIN

Esteban Gómez-García, Felipe Crecente-Campo, Tatiana Stankova, Alberto Rojo, and Ulises Diéguez-Aranda*

Department of Agroforestry Engineering, University of Santiago de Compostela. Escuela Politécnica Superior, R/ Benigno Ledo, Campus universitario, 27002 Lugo, Spain. *E-mail: ulises.dieguez@usc.es

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Abstract

A dynamic whole-stand growth model for birch (*Betula pubescens* Ehrh.) stands in Northwestern Spain is presented. In this model, the initial stand conditions at any point in time are defined by three state variables (number of trees per hectare, stand basal area and dominant height), and are used to estimate total or merchantable stand volume for a given projection age. The model uses three transition functions expressed as algebraic difference equations to project the corresponding stand state variables at any particular time. In addition, the model incorporates a function for predicting initial stand basal area, which can be used to establish the starting point for the simulation. Once the state variables are known for a specific moment, a distribution function is used to estimate the number of trees in each diameter class by recovering the parameters of the Weibull function, using the moments of first and second order of the distribution. By using a generalized height diameter function to estimate the height of the average tree in each diameter class, combined with a taper function that uses the above predicted diameter and height, it is then possible to estimate total or merchantable stand volume.

Key words: *Betula pubescens* Ehrh., even-aged stands, whole-stand growth model, generalized algebraic difference approach, basal area disaggregation, Galicia.

Introduction

The *Betula* genus is distributed throughout most of Europe, where it is mainly represented by two stand-forming tree species, *Betula pubescens* Ehrh. and *Betula pendula* Roth. In the Iberian Peninsula, these two taxa are freely hybridized, and their taxonomy is somewhat confused, with each possessing a number of different nomenclatural iden-

titles (Castroviejo et al. 1990). Of the two taxa, *Betula pubescens* is the more oceanic, westerly distributed taxon, while *Betula pendula* is rarer and occupies more easterly and southerly, high altitude, mesic locations (Stevenson 2000). In Galicia (north-western Spain) Downy birch (*Betula pubescens*) grows at 0–1700 m above sea level, although it is more abundant in the north-eastern area of this region at altitudes above

400–500 m. This species requires high moisture all year round and may be considered a fast-growing pioneer tree, which readily colonises open ground originated by human activity (burning, cutting or grazing) or natural disturbances. In Galicia there are currently 32,000 ha of stands that include birch as the main tree species (Xunta de Galicia 2001). However, it is much less common than it could be in Galicia as an integral part of the climax vegetation in the area, as a potentially useful species for colonising part of the approximately 635,000 ha (almost one third of the forest area in Galicia) that is at present unproductive or is colonised by scrub. Despite this, there is a notorious lack of reference information regarding silviculture, growth and yield of this species.

Considering that growth and yield models are of primary concern in making forest management decisions, the objective of this study was to develop a management-oriented dynamic whole-stand model for simulating the growth of even-aged birch stands in Galicia.

Material and Methods

The data used to develop the model were obtained from three different sources. Initially, in the winter of 1998–1999 a network of 137 permanent plots was established in even-aged, birch-dominated stands (85% or more of the standing basal area consisting of birch). The plots were located throughout the area of distribution of this species in Galicia, and were subjectively selected to represent the existing range of ages, stand densities and sites. The plot size ranged

from 200 m² to 1000 m², depending on stand density, in order to achieve a minimum of 30 trees per plot. All the trees in each sample plot were labelled with a number. The diameter at breast height (1.3 m above ground level) of each tree was measured with calliper twice (perpendicular to each other) to the nearest 0.1 cm and the arithmetic mean of the two measurements was calculated. Total height was measured to the nearest 0.5 m with a hypsometer in a randomized sample of 30 trees, and in an additional sample including the dominant trees. Descriptive variables of each tree were also recorded, e.g., if they were alive or dead.

Taking into account that some plots had disappeared because of forest fires or clear-cutting, a subset of 54 of the initially established plots was re-measured in the winter of 2008–2009. These plots were selected for some of the dynamic components of the model. The interval between the measurements was considered sufficient to absorb the short-term effects of abnormal climatic extremes (von Gadow and Hui 1999). The first two sources of data were the two inventories carried out in 1998–1999 and 2008–2009.

Apart from these inventories, where possible, two undamaged dominant trees were destructively sampled in the winter of 1998–1999, constituting a final sample of 214 trees. They were selected as the first two trees found outside the plots but in the same stands within $\pm 5\%$ of the mean diameter at 1.3 m above ground level and mean height of the dominant trees. The trees were felled leaving stumps of average height 0.16 m; total bole length was measured

to the nearest 0.01 m. The logs were cut at approximately 1 m intervals until the diameter was 7 cm and at 2 m intervals thereafter. The number of rings was counted at each cross sectioned point and then converted to stump age. Additionally, 90 non-dominant trees were felled outside 23 locations in the winter of 2008-2009 to ensure representative distribution by diameter and height classes for taper function development. Log volumes (stem parts with merchantable size) were calculated by Smalian's formula. The top of the tree was considered as a cone. Tree volume above stump height was aggregated from the corresponding log volumes and the volume of the top of the tree. The third source of data corresponds to the 304 trees felled. Summary statistics of the stand and tree variables used in model development are shown in Table 1.

Model structure

The model is similar in structure to those developed by Diéguez-Aranda et al. (2006a) and Castedo-Dorado et al. (2007), and is based on the state-space approach (García 1994). It can be classified as a variable-density whole stand model in which stand volume is aggregated from mathematically generated diameter classes. A two-stage process that first predicts future stand density and then uses this information to estimate future stand volume allows predicting growth by subtraction (Davis et al. 2001).

Three state variables (dominant height, number of trees and basal area) define the initial stand conditions at any point in time in the model. These variables are used to estimate stand volume, classified by timber assortments, for a given projection age. Three transition

Table 1. Summarised data corresponding to the sample of plots and trees used for model development.

Variable	1 st inventory (137 plots)				2 nd inventory (54 plots)			
	mean	min	max	S. D.	mean	min	max	S. D.
<i>A</i> , years	30.3	12.0	70.0	10.1	38.9	22.0	56.0	10.0
<i>H</i> , m	15.3	7.2	24.4	3.6	18.3	11.0	24.5	3.0
<i>N</i> , trees ha ⁻¹	1750	390	6000	1099	1433	350	4480	836
<i>B</i> , m ² ha ⁻¹	24.0	3.3	66.5	10.3	30.6	9.2	71.8	11.1
304 trees								
<i>d</i> , cm	20.0	7.3	39.2	5.97				
<i>h</i> , m	14.5	6.2	24.4	3.42				
<i>h_{st}</i> , m	0.16	0.0	0.5	0.08				

Note: *A* = stand age; *H* = dominant height, defined as the mean height of the 100 largest-diameter trees per hectare; *N* = number of trees per hectare; *B* = stand basal area (only live trees were included in the calculations for *N* and *B*); *d* = diameter at breast height over bark; *h* = total tree height; *h_{st}* = stump height.

functions, expressed as algebraic difference equations, are used to project the corresponding stand state variables at any particular time. In addition, the model incorporates a function for predicting initial stand basal area, which can be used to establish the starting point for the simulation. A distribution function is used to estimate the number of trees in each diameter class, once the state variables are known for a specific age, by recovering the parameters of the Weibull function, using the distribution first- and second-order moments (arithmetic mean diameter and variance, respectively). Finally, it is possible to estimate total or merchantable stand volume (which depends on specified log dimensions) by using a generalized height-diameter function, to estimate the height of the average tree in each diameter class, combined with a taper function that uses the above predicted diameter and height.

The following sections describe how each of the three transition functions and the disaggregation system were developed.

Development and fitting of transition functions

The site quality equation, which combines compatible site index and dominant height growth models in one common equation, was developed by Diéguez-Aranda et al. (2006b) using data from stem analysis of the 214 dominant trees. The model was derived using the generalized algebraic difference approach (GADA, Cieszewski and Bailey 2000) on the basis of the model proposed by Cieszewski (2002). The fitting was done in one stage using the base-age-invariant dummy variables

method (Cieszewski et al. 2000), expanding the error term with a second-order continuous-time autoregressive error structure to correct the inherent autocorrelation of the longitudinal data set used. This method was programmed using the SAS/EST® MODEL procedure (SAS Institute Inc. 2004a).

A dynamic equation was developed for predicting the reduction in tree number due to density-dependent mortality, which is mainly caused by competition for light, water and soil nutrients within a stand. Among the different models reported in the literature for modelling regular mortality, those included in Diéguez-Aranda et al. (2005b) were evaluated. They are equations in algebraic difference form, which were fitted to the data of the 54 plots measured twice by ordinary least squares using the SAS/STAT® NLIN procedure (SAS Institute Inc., 2004b).

The stand basal area growth of an even-aged forest depends on stand age, stand density (defined as number of trees per hectare or basal area), and site productivity (Murphy and Farrar 1988). Nevertheless, not all the equations which have been used for projecting stand basal area include these three variables. In developing the transition function for stand basal area, the equations reported in Diéguez-Aranda et al. (2005a) were evaluated. The equations were fitted to the data of the 54 plots measured twice by ordinary least squares using the SAS/STAT® NLIN procedure (SAS Institute Inc. 2004b).

Disaggregation system

The two-parameter Weibull function (Equation 1) was used to model the

diameter distribution of the 137 birch plots from the first inventory and of the 54 plots re-measured:

$$f(x) = \left(\frac{c}{b}\right) \left(\frac{x}{b}\right)^{c-1} e^{-\left(\frac{x}{b}\right)^c} \quad (1)$$

where x is the random variable, b the scale parameter of the function, and c the shape parameter that controls the skewness.

Several methods for parameter estimation were preliminary tested and compared for their goodness of fit. A parameter recovery method through moments and a parameter prediction method based on least squares difference estimation techniques proved best, but considering that the moments method warrants that the sum of the disaggregated basal area obtained by the Weibull function equals the stand basal area provided by an explicit growth function of this variable, the moments method was selected for application in the present study. The function parameters were recovered from the first raw moment, which is the arithmetic mean diameter $\bar{d}$, and the second central moment, which is the variance of the distribution (var), estimated by the arithmetic and the quadratic mean diam-

eters ($\text{var} = d_g^2 - \bar{d}^2$) (Diéguez-Aranda et al. 2006a), using the following expressions:

$$\text{var} = \frac{\bar{d}^2}{\Gamma^2\left(1+\frac{1}{c}\right)} \left[\Gamma\left(1+\frac{2}{c}\right) - \Gamma^2\left(1+\frac{1}{c}\right) \right] \quad (2)$$

$$b = \frac{\bar{d}}{\Gamma\left(1+\frac{1}{c}\right)} \quad (3)$$

where Γ is the Gamma function.

The arithmetic mean diameter was the only variable to be modeled through a relationship on the quadratic mean diameter and other stand level variables

by the function $\bar{d} = d_g - \exp(\mathbf{X}\boldsymbol{\beta})$, where $\mathbf{X}$ is a vector of stand variables and $\boldsymbol{\beta}$ is a vector of parameters to be estimated. This equation was fitted to the data by ordinary least squares using the SAS/STAT® NLIN procedure (SAS Institute Inc. 2004b).

A generalized height-diameter relationship was developed to estimate the height of the average tree in each diameter class. Several models that predict the dominant height of the stand when the diameter at breast height of the subject tree equals the dominant diameter of the stand were evaluated (Crecente-Campo et al. 2010). They were fitted to the data of the 137 plots from the first inventory and of the 54 plots re-measured by ordinary least squares using the SAS/STAT® NLIN procedure (SAS Institute Inc. 2004b).

In order to obtain total- and merchantable-tree volume from the average tree-diameter of each class and its estimated height, a modification of the Kozak's (2004) variable exponent taper function was fitted to data of diameter outside bark and height of the 304 destructively sampled trees. For this purpose, a mixed-model was used and fitted using the SAS macro %NLINMIX (SAS Institute Inc. 2004b).

Selection of the best equation in each module and overall evaluation of the model

The comparison of the estimates of the different models fitted in each module

was based on numerical (coefficient of determination $-R^2$ – and root mean square error –RMSE) and graphical (plots of studentized residuals against the estimated values, and graphs of the fitted curves overlaid on the trajectories of different variables) analyses.

For the overall evaluation of the model, observed state variables from the first inventory of the 54 plots measured twice were used to estimate total stand volume at the age of the second inventory. Total stand volume was selected as the principal objective variable because it is the critical output of the whole model, its estimation involves all the functions included in it and is closely related to economical assessments. Estimations of this variable and of the state variables were evaluated in terms of the critical error (Huang et al. 2003).

Results and Discussion

Table 2 summarizes the equations selected for each sub-model. All parameter estimates were significant at a 5% level. The estimated Weibull functions modeled successfully all but 4 of the 191 examined diameter distributions, based on the Kolmogorov-Smirnov test. Figures 1–3 show the transition functions fitted curves overlaid on the observed trajectories.

It can be observed that the fitted equations follow the observed growth trajectories well, especially in the case of the stand survival function. The accuracy of this function over a wide range of ages and other stand conditions ensures that the projections of the final output variables of the whole model (e.g., stand or merchantable vol-

ume) are realistic. This equation is especially important when light thinnings are carried out (Avila and Burkhart 1992), as was the case in some of the studied stands. After heavy thinning operations it seems reasonable to assume that mortality is negligible (Castedo-Dorado et al. 2007).

As regards the stand basal area projection equation, initial basal area and initial age do not seem to provide enough information about the future trajectory of the basal area of the stand, regardless its thinning history, thus number of stems is also included as an explanatory variable. The stand basal area model has an asymptote of $74.4 \text{ m}^2 \text{ ha}^{-1}$, which corresponds to biological expectations, at least for the stand conditions analysed in this study (Table 1). The basal area initialization equation will work well in unthinned or lightly thinned stands, although the fitting statistics showed worse results than other sub-models. Because the number of trees per hectare varies over time, the initialization and the projection functions are not compatible. However, this is not a major problem because the initialization function would only be used to provide an initial value of stand basal area when no inventory data are available (Amateis et al. 1995).

Explanatory variables of the components of the disaggregation system can be easily obtained at any point in time from dominant height, number of trees and basal area transition functions. The only exception is dominant diameter of the generalized h - d relationship, which is a variable that is difficult to project (Lappi 1997) and must, therefore, be estimated from the diameter distribution.

Table 2. Equations selected for each sub-model and goodness of fit statistics.

Transition functions	Dominant height growth/Site index	R^2	RMSE
	$H_2 = \frac{19.80 + X_0}{1 + 758.0/X_0 A_2^{-1.398}},$ $\text{with } X_0 = \frac{H_1 - 19.80 + \sqrt{(19.80 - H_1)^2 + 3032H_1 t_1^{-1.398}}}{2}$	0.989	0.505 m
	Number of trees per hectare reduction	0.978	120 trees ha ⁻¹
	$N_2 = \left(N_1^{-1/1.577} + 0.01255 \left(\left(\frac{A_2}{100} \right)^{1.577} - \left(\frac{A_1}{100} \right)^{1.577} \right) \right)^{-1.577}$		
Auxiliary relationships	Stand basal area growth	0.950	2.50 m ² ha ⁻¹
	$G_2 = G_1^{A_1/A_2} \exp(2.290(1 - A_1/A_2) + 0.2521(\ln N_2 - A_1/A_2 \ln N_1))$		
	Stand basal area initialization	0.760	5.44 m ² ha ⁻¹
	$G = -77.14 + 0.1189A + 1.894H + 9.559 \log N$		
	Disaggregation (arithmetic mean diameter)	0.929	0.27 cm
	$\bar{d} = d_g - \exp(-1.418 + 0.0884H - 0.0395S)$		
	Generalized height-diameter relationship	0.778	1.78 m
	$h = 1.3 + (H - 1.3) \exp((-0.3834H + 0.5139N/1000)(1/d - 1/d_0))$		
	Taper equation	0.950	1.56 cm
	$d_i = 0.9652d^{0.9421}h^{0.08482}x^{4.094-0.3939q^4-0.4112(l/e^{d/h})-4.153x^{0.1}+2.813(l/d)+0.05345h''+0.3332x}$ $\text{with } x = w/(1 - (1.3/H)^{1/3}), w = 1 - q^{1/3}, q = h_i/h$		

Note: H_1 , H_2 , N_1 , N_2 , B_1 , B_2 = dominant height (m, defined as the mean height of the 100 largest-diameter trees per hectare), number of trees per hectare, and stand basal area (m² ha⁻¹) at initial A_1 and

final A_2 stand projection ages (years), respectively; log = natural logarithm; $\bar{d}$ = arithmetic mean diameter (cm); S = site index (m, at a reference age of 20 years); h = total tree height (m); d = diameter at breast height (cm, 1.3 m above ground level); d_0 = dominant diameter (cm, average value of the 100 largest-diameter trees per hectare); d_i = top diameter over bark at height h_i (cm); h_i = height above the ground to top diameter d_i (m). Total- and merchantable-tree volumes must be computed numerically. Stand volumes are aggregated from mathematically generated diameter classes.

Total stand volume was selected in the present study as the critical output variable for the whole-stand growth model, although other stand variables can be assessed on the basis of this model (e. g., biomass, carbon pools). A critical error of 20% was obtained when projecting total stand volume from the first to the second inventory; critical errors of 14–15% were obtained for

dominant height, number of trees per hectare, and stand basal area. In this step, 84% of the examined diameter distributions passed the Kolmogorov-Smirnov test ($\alpha=5\%$). Considering the required accuracy in forest growth modelling, where a mean prediction error of the observed mean at 95% confidence intervals within ± 10 –20% is generally realistic and reasonable as a

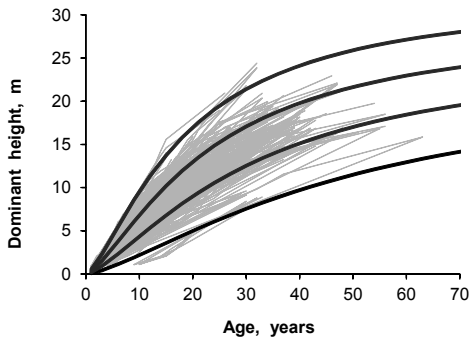


Fig. 1. Curves for site indices of 5, 9, 13 and 17 m at a reference age of 20 years overlaid on the profile plots of the data set.

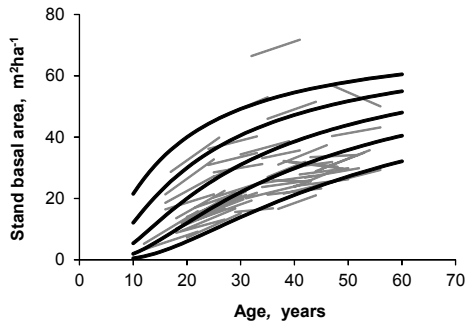


Fig. 3. Stand basal area growth curves for stand basal areas of 6, 12, 20, 30 and 40 m² ha⁻¹ at 20 years overlaid on the trajectories of observed values over time.

limit for the actual choice of the acceptance and rejection levels (Huang et al. 2003), we can state, on the basis of the critical error statistics obtained, that the model provides satisfactory predictions.

As the model was based primarily on data from stands of ages greater than 12 years old, predictions of site index for younger stands should be made with caution, because at young ages erratic height growth may lead to erroneous site classifications. Apart

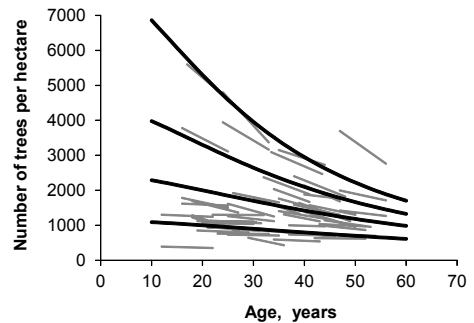


Fig. 2. Trajectories of observed and predicted tree number per hectare over time. Model projections for spacing conditions of 1000, 2000, 3300 and 5300 trees per hectare at 20 years.

from this exception, the model may be used over the expected rotation of the species in the region of study (~ 60–70 years).

The most important limitation of the model is that it does not consider the later effect of thinning and pruning before the trees fully occupy the additional space that has been made available to them. However, this effect does not seem to be important in our case since very heavy thinning treatments were not considered (García 1990).

The relatively simple structure of the stand growth model makes it suitable for embedding into landscape-level planning models and other decision support systems that enable forest managers to generate optimal management strategies. Nevertheless, because of the large number of calculations needed to obtain outputs (especially those involving use of the disaggregation system), the model will be implemented into the GesMO[®] 2009 forest growth simulator (Diéguez-Aranda et al. 2009) to facilitate its use by forest managers.

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References

- Amateis** R.L., Radtke P.J., Burkhart H.E. 1995. TAUyield: A stand-level growth and yield model for thinned and unthinned loblolly pine plantations. School of Forestry and Wildlife Resources. Virginia Polytechnic Institute and State University, Report No 82, 38 p.
- Avila** O.B., Burkhart H.E. 1992. Modeling survival of loblolly pine trees in thinned and unthinned plantations. Canadian Journal of Forest Research 22: 1878–1882.
- Castedo-Dorado** F., Diéguez-Aranda U., Álvarez González J.G. 2007. A growth model for *Pinus radiata* D. Don stands in north-western Spain. Annals of Forest Science 64 (4): 453–465.
- Castroviejo** S., Lainz M., López González G., Montserrat P., Muñoz Gardeménia F., Paiva J., Villar L. 1990. Flora Ibérica: Plantas vasculares de la Península Ibérica e Islas Baleares. Volumen II: Platanaceae-Plumbaginaceae (partim.). Madrid: RJB (CSIC).
- Cieszewski** C.J. 2002. Comparing fixed- and variable-base-age site equations having single versus multiple asymptotes. Forest Science 48: 7–23.
- Cieszewski** C.J., Bailey R.L. 2000. Generalized Algebraic Difference Approach: Theory based derivation of dynamic site equations with polymorphism and variable asymptotes. Forest Science 46: 116–126.
- Cieszewski** C.J., Harrison M., Martin S.W. 2000. Practical methods for estimating non-biased parameters in self-referencing growth and yield models. University of Georgia PMRC-TR 2000-7.
- Crecente-Campo** F., Tomé M., Soares P., Diéguez-Aranda U. 2010. A generalized nonlinear mixed-effects height-diameter model for *Eucalyptus globulus* L. in northwestern Spain. Forest Ecology and Management 259: 943–952.
- Davis** L.S., Johnson K.N., Bettinger P.S., Howard T.E. 2001. Forest Management: To Sustain Ecological, Economic, and Social Values. McGraw-Hill, New York, 804 p.
- Diéguez-Aranda** U., Castedo Dorado F., Álvarez González J.G. 2005a. Funciones de crecimiento en área basimétrica para masas de *Pinus sylvestris* L. procedentes de repoblación en Galicia. Investigación Agraria, Sistemas y Recursos Forestales 14 (2): 253–266.
- Diéguez-Aranda** U., Castedo Dorado F., Álvarez González J.G., Rodríguez Soalleiro R. 2005b. Modelling mortality of Scots pine (*Pinus sylvestris* L.) plantations in the northwest of Spain. European Journal of Forest Research 124: 143–153.
- Diéguez-Aranda** U., Castedo-Dorado F., Álvarez-González J.G., Rodríguez-Soalleiro R. 2006a. Dynamic growth model for Scots pine (*Pinus sylvestris* L.) plantations in Galicia (north-western Spain). Ecological Modelling 191: 225–242.
- Diéguez-Aranda** U., Grandas-Arias J.A., Álvarez-González J.G., Gadow K.V. 2006b. Site quality curves for birch stands in North-Western Spain. Silva Fennica 40: 631–644.
- Diéguez-Aranda** U., Rojo Alboreca A., Castedo-Dorado F., Álvarez González J.G., Barrio-Anta M., Crecente-Campo F., González González J.M., Pérez-Cruzado C., Rodríguez Soalleiro R., López-Sánchez C.A., Balboa-Murias M.A., Gorgoso Varela J.J., Sánchez Rodríguez F. 2009. Herramientas selvícolas para la gestión forestal sostenible en Galicia. Xunta de Galicia.

García O. 1990. Growth of thinned and pruned stands, in: James R. N., Tarlton G. L. (Eds.), *Proceedings of a IUFRO Symposium on New Approaches to Spacing and Thinning in Plantation Forestry*. Rotorua, New Zealand, Ministry of Forestry, FRI Bulletin No 151: 84–97.

García O. 1994. The state-space approach in growth modelling, *Canadian Journal of Forest Research* 24: 1894–1903.

Huang S., Yang Y., Wang Y. 2003. A critical look at procedures for validating growth and yield models. In: Amaro A., Reed D., Soares P. (Eds.), *Modelling Forest Systems*. CAB International, Wallingford, Oxfordshire, UK: 271–293.

Kozak A. 2004. My last words on taper functions. *Forestry Chronicle* 80: 507–515.

Lappi J. 1997. A longitudinal analysis of

height/diameter curves. *Forest Science* 43: 555–570.

Murphy P.A., Farrar R.M. 1988. Basal area projection equations for thinned natural even-aged forest stands. *Canadian Journal of Forest Research* 18: 827–832.

SAS Institute Inc. 2004a. SAS/ETS® 9.1 User's Guide. Cary, NC: SAS Institute Inc.

SAS Institute Inc. 2004b. SAS/STAT® 9.1 User's Guide. Cary, NC: SAS Institute Inc.

Stevenson A.C. 2000. The Holocene forest history of the Montes Universales, Teruel, Spain. *The Holocene* 10: 603–610.

von Gadow K., Hui G.Y. 1999. *Modelling forest development*. Kluwer Academic Publishers, Dordrecht, 213 p.

Xunta de Galicia 2001. O monte galego en cifras. Dirección Xeral de Montes e Medio Ambiente Natural. Consellería de Medio Ambiente. Santiago de Compostela.

DENSITY AND BIOMASS OF THE WILD TROUT IN SOME BULGARIAN RIVERS

Vasil Kolev

Department of Wildlife Management, University of Forestry, 1756, 10 St. Kl.
Ohridski Blvd., 1756 Sofia, Bulgaria. E-mail: vassilie@abv.bg

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Abstract

The wild trout biomass density in four tributary streams of the Maritza river (Topolnitsa, Stryama, Yadenitsa and Chepinska) was investigated by electrofishing. The study was carried out in 100 m long closed test areas, from mid summer to autumn 2008. The theoretical density for two consecutive catches was calculated. It was found that the areas of populations of wild trout in the Topolnitsa and Stryama creeks are fragmented and with a very low-rate density. The theoretical density of wild trout estimated is as follows: for the Chepinska stream – 446 ha⁻¹ and for the Yadenitsa stream – 608 ha⁻¹. The theoretical number of wild trout with a length of 23 cm and more was calculated for the Stryama stream – 15 ha⁻¹, for the Yadenitsa stream – 12 ha⁻¹, and for the Chepinska stream – 4 ha⁻¹ respectively. Within the four studied creeks the highest rate of wild trout theoretical biomass was found to be that of the Yadenitsa stream – 26.27 kg.ha⁻¹, followed by stream Chepinska with 20.43 kg.ha⁻¹. The quantity of fish allowed for fishing, with a length of 23 cm and more, according to the Law (Anonymous 2006), was very low in all the four creeks that were studied.

Key words: electro-fishing, specimens allowed to catch, streams, theoretical biomass of population, theoretical density of population, wild trout.

Introduction

The stock and the biomass of wild trout were examined by many authors in connection with managing of trout streams as well as in order to estimate the influence of some factors on trout populations. For example in the Pyrenees (France) many studies were conducted on trout populations and the results are as follows: in the river Pique et Ger Lim et al. (1993) estimated the mean number of brown trout to be 2469 ha⁻¹ and the biomass – 278 kg.ha⁻¹. Baran et al. (1993) reported an mean density

of wild trout in the river Neste d'Aure between 5 and 126 trout per 100 m² and the mean biomass between 183 and 3242 kg per 100 m². Lagarrigue et al. (2001) studying river Neste d'Ouie estimated the number of wild trout to range between 2201 and 11,516 ha⁻¹ and the biomass between 94.6 and 212.5 kg.ha⁻¹. A study of the river Luz made by the Federation of Fishermen in Hautes Pyrenées (Fédération ... 2007) showed the following mean density of brown trout – 60.1 trout per 100 m² and the mean biomass turned to be 1.32 kg per 100 m² and the number of

brown trout longer than 18 cm was 4.2 trout per 100 m².

The investigation of the Federation of fishermen in Friburg (Fédération ... 2004) of the river Petite Sarine (Switzerland) showed an mean density of wild trout of 1445 ha⁻¹ in 2000, 1147 ha⁻¹ in 2003 and 1808 ha⁻¹ in 2003.

In the river Lima (Portugal) Maia and Valente (1999) studying the population of brown trout estimated the mean density to be between 10 and 20 trout per 100 m² and the mean biomass – 285.5 kg per 100 m².

Bergstedt et al. (2005) explored the impact of mining and reclamation efforts from 1999 up to 2004 on the population of brown trout in the Arkansas River (Colorado, USA). From their results can be estimated that in the unpolluted part of the river the mean number of brown trout for the six years was approximately 1500 ha⁻¹ and the mean biomass was approximately 102 kg.ha⁻¹.

The most extensive study of wild trout in the Danube catchment and in the Aegean catchment, in Bulgaria, was conducted in the doctorate thesis of Yankov (1988), an ichthyologist from the Union of hunters and fishermen in Bulgaria. Yankov explored the catch areas of the rivers Iskar and Vit as well as in the Aegean catchment – the catch areas of the rivers Mesta, Vucha, Chaya and Struma. Yankov also examined the dynamics of wild trout population, the state of wild trout stocking, the rates of growth of wild trout, the sexual maturity and fertility of wild trout. For all studied rivers Yankov (1988) calculated an mean density of trout population of 1123 ha⁻¹ and an mean biomass of 52.81 kg.ha⁻¹.

Another detailed study of wild trout was made by Karapetkova et al. (2000),

an ichthyologist from the Bulgarian Academy of Sciences (whose works are dedicated to fish systematics) and by Dikov and Yochev (2000), ichthyologists from the Complex experimental station of Fishery of the Union of hunters and fishermen in Bulgaria, both working on some problems of the dynamics of fish populations, density and biomass of the populations of some fish species in Bulgaria. Karapetkova et al. (2000), Dikov and Yochev (2000) studied the density, the biomass, and the dynamics of wild trout populations in the creeks of Veleka, Mladezhka and Aydere, belonging to the Black see catchment. These authors found that the mean density of trout population was between 48 and 656 ha⁻¹ and the mean biomass varied between 5.071 and 56.531 kg.ha⁻¹.

A study of wild trout population was made by Dikov and Yankov (1985) for some streams in the Rila Mountains, namely the Rilska, Iliina, Bela Mesta and Cherna Mesta, all belonging to the Aegean catchment,. The authors studied the growth rate of wild trout in the streams mentioned above. Yankov (1985) made an investigation of trout stocks in the streams Rilska, Iliina, Bela Mesta and Cherna Mesta. The author indicated that in the fourth of the studied streams the mean density of trout population varied between 33 and 192 da⁻¹ and the mean biomass – between 1.08 and 7.61 kg.da⁻¹.

Materials and Methods

Study area

The study area (Fig. 1) includes four tributaries of the Maritza river

– Chepinska, Yadenitsa, both in the Rhodope Mountains, as well as Stryama and Topolnitsa, located in the Sredna gora Mountains. All the studied creeks belong to the Aegean cathment.

The creek Topolnitsa, a left tributary of the river Maritza, is 100 km long. The trout zone of this stream ranges from the spring to the Dushantsi dam and it is 25 km long.

The creek Stryama is another left tributary of the river Maritza with a length of 110 km, 9 km of which are a trout habitat.

The creek Yadenitsa, a right tributary of the stream Maritza, is 16 km long; two-thirds of which is a trout zone.

The creek Chepinska (70 km long) is also a right tributary of the river Maritza. Wild trout inhabit 35 km of this creek, upstream from the city of Velingrad.

All of the studied streams had local populations of trout in the past. After the 50^s of the 20th century, stocking started everywhere with young trout of different origins. In 2008 in the fourth of the investigated streams a stoking was made with young trout with provenance from the aquaculture “Toshkov chark” in the Rhodope Mountains (an unpublished report of the National Agency for Fishing and Aquaculture – NAFA).

Equipment, methods and layout

The study material was caught by electrofishing, according to Seber and Le Cren removal method (1967) by two catching passes. This method is reliable when during the first pass a minimum of 50% of the individuals in the catching area are eliminated. This method, as the



Fig. 1. Location of studied streams.

most suitable one for studies of inner Bulgarian creeks, is recommended by Yankov (1988).

The electrofishing was conducted by direct current (DC) at two upstream passes. We used the backpack electrofisher SAMUS 725G – (Samus special electronics, Poland), powered by a 12 V accumulator battery with a capacity of 75 Ah.

The electrofisher converter provides DC impulses with a frequency ranging between 5 and 100 Hz, duration 0.03–3 ms and a maximum power of 650 W. The electrofisher is suitable for water resistance from 25 to 1000 Ω . The amperage in load condition is from 5 to 65 A.

The catch areas are 100 m long, blocked off at the upper and the lower borders by 5 mm square mesh nets.

Four catch areas were put in each creek, and 5 – in the Yadenitsa stream.

The catch was carried out by two persons, each with a fishing keep net, passing along together into the catch areas upstream. One of the nets was a single 28 cm hoop anode. The cable cathode was immersed into the creek some meters ahead.

The fish length was measured by a ruler with an accuracy of 1 mm and the weight – with an electronic portable scale with an accuracy of 1 g. The caught fish were kept alive in a wire basket and a plastic pail and after the measurement were released back.

The fish species identification was made according to Kottelat and Frayhof (2007).

The estimation of fish abundance was made according to Seber and Le Cren (1967) formulas for two catching passes. The theoretical number of fish is determined as follows:

$$N_e = \frac{C_1^2}{C_2 - C_1} \quad (1),$$

where C_1 and C_2 are, respectively, the number of fish from the first and from the second catch passes.

The variation of the real number of fish N_e is defined by the following equation:

$$Var[N_e] = \frac{N_e \cdot \bar{q} \cdot (1 + \bar{q})}{p^3} \quad (2),$$

where $\bar{q}$ is the mean catchability for

each removal pass, $\bar{q} = \frac{C_2}{C_1}$; $\bar{p} = 1 - \bar{q}$.

The study results are reliable if

$$N_e \cdot p^3 > 16q^2 \cdot (1 + \bar{q}) \quad (3).$$

The biomass B is calculated as a sum of individual weights of all the wild trout individuals located in each of the catch areas.

The theoretical biomass B_e calculates according to Mahon et al. (1979),

$$B_e = \frac{B \cdot N_e}{N} \quad (4).$$

where B_e is theoretical biomass, B – biomass of catch individuals; N – number of catch individuals.

The parameters of all the 17 studied catch areas satisfied the requirements of the formula.

The classifying of the studied streams was made by the classification of Yankov (1988) for Bulgarian trout streams (according Sherbowsky's method).

- streams with very high-rated trout abundance, where trout abundance is more than 1500 ha⁻¹, respectively biomass is more than 65 kg.ha⁻¹;

- streams with very small-rated trout abundance, where trout abundance is less than 300 ha⁻¹, respectively biomass is less than 15 kg.ha⁻¹.

- Wild trout (Salmonidae);
- Maritza barbel (Cyprinidae);
- Minnow (Cyprinidae);

The migration of wild trout in the Topolnitsa creek is interrupted because of the polluted part of the water course. Probably the number of wild trout in this

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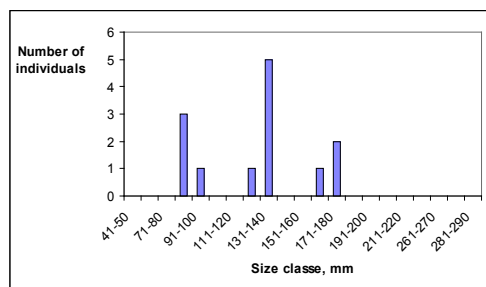


Fig. 2. Size composition of the catch of the wild trout from stream Topolnitsa.

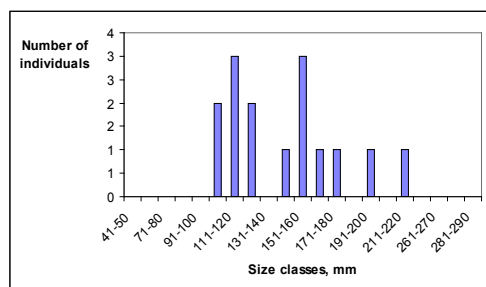


Fig. 3. Size composition of the catch of the wild trout from stream Stryama.

stream fills up only by young fish stocking. This assumption could be confirmed by the grouping of catches – several groups of similar length were distinguished. Wild trout individuals in the Topolnitsa creek were grouped in 6 size classes, corresponding to 3 age classes (Dikov and Yankov 1985, Yankov 1988), probably a result of young fish stocking in 3 successive years. The wild trout individuals seem to be introduced as follows:

- from size classes of 81–90 mm and 91–100 mm in 2008;
- from size classes of 121–130 mm and 131–140 mm in 2007;
- from size classes of 161–170 mm and 171–180 mm probably in 2006.

The catch composition from the Stryama stream is similar, but the size

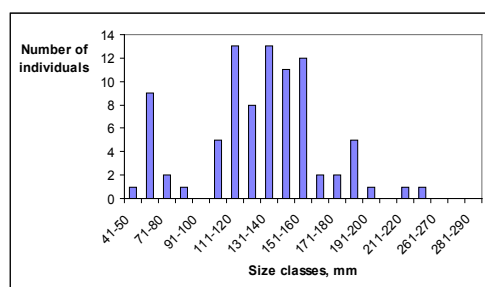


Fig. 4. Size composition of the catch of the wild trout from stream Yadenica.

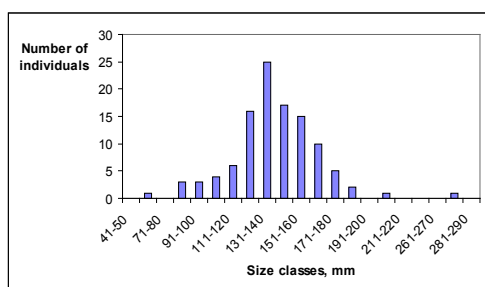


Fig. 5. Size composition of the catch of the wild trout from stream Chepinska.

classes are more. Most of the wild trout in this stream belong to two classes of length: 101–130 mm and 141–180 mm. Wild trout, permitted to catch according to the Law for fishing and aquaculture (LFA), were caught only in the Stryama creek.

The prevailing length of the wild trout individuals caught in the Yadenitsa and Chepinska streams ranged between 121 mm and 160 mm – 52% of them (Figures 4 and 5). The individuals longer than 160 mm in both of the rivers weren't numerous – 17%. In these watercourses a few individuals from lower size classes were also caught – 11%. The peak of the size composition of individuals in the Yadenitsa creek plotted in Fig. 4 is 71–80 mm is due to an im-

ported young wild trout stocking within 2008 (an unpublished report of National Agency for Fishing and Aquaculture – NAFA).

According to Yankov (1988), the size of mature wild trout in Bulgarian rivers is 140-250 mm. In the Yadenitsa and Chepinska creeks young immature individuals prevailed. The irregular structure of the catch in the Yadenitsa and Chepinska creeks as well as the small number of individuals from large size groups shows a high-rate of mature individuals mortality (in these watercourses only 3 wild trout individuals were permitted for fishing according to LFA, 2 individuals in the Yadenitsa stream and 1 in the Chepinska). There is a significant difference between the numbers for middle and upper age classes of wild trout in both of the mentioned streams. Probably, the annual rate of fishing in the Yadenitsa and Chepinska streams exceeds the annual production and it injures size and age structure of fish population (Pravdin 1966).

Theoretical abundance and theoretical biomass of wild trout population in the studied streams

The calculated abundance of wild trout in the Topolnitsa and the Stryama, tributaries of the Maritza river is far less than the abundance estimated for the streams Yadenitsa and Chepinska as shown in Table 2. In the Stryama creek the number of individuals is smaller due to the narrower width of

the water course. The number per ha and the biomass per ha in the Stryama creek are larger than in the Topolnitsa stream.

Both – theoretical abundance and theoretical biomass of streams of Yadenitsa and Chepinska exceed those of the water courses in the Sredna gora Mountains. Due to stream Yadenitsa is relatively narrower than Chepinska, there is less wild trout per 100 m of the water course, but biomass and density per hectare, respectively, are more.

Wild trout abundance and biomass in the four studied streams are smaller than the mean values estimated by Yankov (1988) for Bulgaria – 1123 ha⁻¹ and 52.81 kg.ha⁻¹ respectively.

The wild trout number and the biomass for the Yadenitsa creek were smaller than the smallest stock in the water courses in the Rhodope Mountains, calculated by Yankov (1988) for stream Chaya (mean number 531 ha⁻¹ and mean biomass 28.17 kg.ha⁻¹). The stock of the Yadenitsa stream is similar to those of the Aydere and Mladezhka creeks (Karapetkova et al. 2000) with a mean number ranging between 48 and 656 ha⁻¹ and a mean biomass 5.071–56.531 kg.ha⁻¹.

Table 2. Mean theoretical density (N_e) and mean theoretical biomass (B_e) of the wild trout in the streams Topolnitsa, Stryama, Yadenica and Chepinska.

Stream	N_e , pieces	N_e , ha ⁻¹	N_e , km ⁻¹	B_e , kg	B_e , kg.ha ⁻¹	B_e , kg.km ⁻¹
Topolnitsa	6	108	56	0.14	2.77	1.44
Stryama	4	112	40	0.12	3.41	1.23
Yadenica	18	608	178	0.79	26.27	7.86
Chepinska	27	446	271	1.25	20.43	12.54

In the pure trout zone of the Yadenica stream the stock of wild trout is relatively large – a mean of 908 ha⁻¹, whereas in the the mixed barbell-trout zone the mean is 157 ha⁻¹. The mean biomass of trout in the pure trout zone of the creek is 33.61 kg.ha⁻¹.

In the first blocked off section in the mixed barbel-trout zone of the Yaden-

Table 3. Mean theoretical density (N_e) and mean theoretical biomass (B_e) of the wild trout with length of 23 cm and more in the streams Topolnitsa, Stryama, Yadenica and Chepinska.

Stream	N_e , pieces	N_e , ha ⁻¹	N_e , km ⁻¹	B_e , kg	B_e , kg.ha ⁻¹	B_e , kg.km ⁻¹
Topolnitsa	6	108	56	0.14	2.77	1.44
Stryama	4	112	40	0.12	3.41	1.23
Yadenica	18	608	178	0.79	26.27	7.86
Chepinska	27	446	271	1.25	20.43	12.54

itsa stream only one, but the biggest individual, was caught. Probably this is an old individual who has driven out off the territory the other trouts.

The wild trout population in the Chepinska stream has lower number and biomass than stream Chaya (Yankov 1988).

The trout stock of the Topolnitsa and Stryama creeks is much smaller than the smallest one estimated by Yankov (1988) for the catchment of the Iskar river (a mean density of 270 ha⁻¹ and mean biomass 7.62 kg.ha⁻¹).

According to Yankov's classification (1988) the density of wild trout population in Yadenitsa creek is rated as a medium one and so is the biomass. The density of wild trout population in the Chepinska stream is rated as low and so is the biomass. Wild trout populations in the streams Topolnitsa and Stryama are characterized with very low rate of density as well as of biomass.

The amount of wild trout individuals permitted for fishing according to LFA, in the streams Stryama, Yadenitsa and Chepinska is very limited (see table 3). In the Topolnitsa creek no individual was caught with a length equal or over the permitted size.

Yankov (1988) recommended a stop of fishing if the number of wild trout permitted for fishing is under 120 ha⁻¹, according to LFA, or the total biomass is under 30 kg.ha⁻¹ until restoration of the normal stocks.

In the studied streams – Topolnitsa, Stryama and Chepinska, the total biomass doesn't exceed 30 kg.ha⁻¹. The number of wild trout with a length over 23 cm (permitted legally for fishing) in none of studied rivers reaches 120 individuals per hectare.

Environmental problems found in the Topolnitsa stream

In the trout zone of the Topolnitsa creek a municipally polluted sector was found. It caused a fragmentation of the population and made the migration of wild trout upstream impossible.

Conclusions

Wild trout stocks in the studied streams are smaller than the medium stocks determined for Bulgaria.

The number of permitted for fishing wild trout individuals according to LFA,

in the streams Stryama, Topolnitsa, Yadenitsa and Chepinska is very limited.

Recommendations

The pollution of the Topolnitsa stream by the town of Koprivstitsa must be stopped by the Ministry of Environment and Waters of Bulgaria.

A stop of fishing is recommended for the four studied creeks until the number of trout with a length of and over 23 cm reaches at least 120 ha⁻¹.

References

- Anonymous** 2006. Normative documents. Ministry of agriculture and forestry, Executive agency of aquaculture, 301 p.
- Baran P.**, Delacoste M., Lascaux J.M., Belaud A. 1993. Relations entre les caractéristiques de l'habitat et les populations de truites communes (*Salmo trutta* L.) de la vallée de la Neste d'Aure, Bulletin Français de la Pêche et de la Pisciculture 331: 321–340.
- Bergstedt L.**, Chadwick J., Conklin D.Jr., Canton S. 2005. Improvements in brown trout and invertebrate populations in the Arkansas River during reclamation efforts on California Gulch, National Meeting of American society of Mining Reclamation, ASMR, 3134 Montavesta Rd, Lexington, KY 40502: 52–68.
- Dikov Ts.**, Yankov Y. 1985. Growth rate of the river trout in four rivers in the Rila Mountains. International symposium: "The game and environment", Sofia: 517–526.
- Fédération** des Hautes Pyrénées pour la pêche et la protection des milieux aquatiques (FDAPPMA 65) 2007. Etude du peuplement piscicole du Luz, 9 p.
- Fédération** Fribourgeoise des Sociétés de Pêche (FFSP) 2004. Etude de la Petite-Sarine, Rapport final, Projet partiel No 00/24, Fribourg, 9 p.
- Karapetkova M.**, Yochev S., Dikov Ts. 2000. The state of fish abundance in Veleka rivers and its tributaries. Report to the Ministry of environment and waters, 43 p.
- Kottelat M.**, Frayhof J. 2007. Handbook of European freshwater fishes. Edition Kottelat, 646 p.
- Lagarrigue T.**, Baran P., Lascaux J.M., Belaud A. 2001. Analyse de la variabilité de la croissance d'une population de truite commune (*Salmo trutta* L.) dans une torrent Pyrénéen. Bulletin Français de la Pêche et de la Pisciculture 375/360: 573–594.
- Lim P.**, Segura G., Belaud A., Sabaton C. 1993. Étude de l'habitat de la truite fario (*Salmo trutta fario*). Rôle des cahées artificielles et naturelles dans les rivières aménagées. Bulletin Français de la Pêche et de la Pisciculture 331: 373–396.
- Maia C.**, Valente A. 1999. The brown trout *Salmo trutta* L. populations in the river Lima catchment. Asociación Española de Limnología, Madrid Spain, Limnetica 17: 119–126.
- Pravdin I.** 1966. Manual for fish study. Edible industry, Moscow, 338 p.
- Yankov Y.** 1985. Number and biomass of the river trout in four rivers in Bulgaria. International symposium: "The game and environment", Sofia: 508–517.
- Yankov Y.** 1988. The dynamic of populations of river trout (*Salmo trutta fario* L.) in the major trout rivers in Bulgaria. PhD thesis. Bulgarian academy of sciences, Institute of zoology, 157 p.

VISUAL LANDSCAPE RESOURCE DESIGN

Genoveva Tzolova

Department of Park and Landscape Design, Faculty of Ecology and Landscape Architecture, University of Forestry, 10 Kliment Ochridski Blvd., 1756 Sofia, Bulgaria. E-mail: gevivtz@gmail.com

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Abstract

There are numerous design techniques that can be used to reduce the reduce impacts from surface-disturbing projects. The techniques described should be used in conjunction with visual resource contrast rating process wherein both the existing landscape and the proposed development or activity are analyzed for their basic elements of form, line, color, and texture. This discussion of design techniques is broken down into two categories: design fundamentals and design strategies. **Design fundamentals** are general design principles that can be used for all forms of activity or development, regardless of the resource value being addressed. Applying these three fundamentals will help solve most visual design problems: proper siting or location, reducing unnecessary disturbance, repeating the elements of form, line, color, and texture. **Design strategies** are more specific activities that can be applied to address visual design problems. Not all of these strategies will be applicable to every proposed project or activity: color selection, earthwork, vegetative manipulation, reclamation/restoration, linear alignment design considerations. The fundamentals and strategies are all interrelated, and when used together, can help resolve visual impacts from proposed activities or developments. The techniques presented are only a portion of the many design techniques available to help reduce the visual impacts resulting from surface-disturbing activities or projects. Further research into planning and design references and/or consultation with professional designers and engineers will help to further reduce the visual impacts of any development.

Key words: visual impact, surface disturbing, landscape design.

Introduction

The public lands in our country contain many outstanding scenic landscapes. While these lands provide a place to escape and enjoy the beauty of nature, they are also used for a multitude of other activities. Any activities that occur on these lands, such as recreation, mining, timber harvesting, grazing, road development etc., have the potential to disturb

the surface of the landscape and impact scenic values (Kress and Van Leeuwen 2006). Visual resource assessment and management is a system for minimizing the visual impacts of surface-disturbing activities and maintaining scenic values for the future (Crowe 1966, Forestry Commission 1994, Lyle 1999, Zube et al. 1982). The authorities should be committed to sound management of the scenic values on public lands in order to

ensure that these benefits are realized and the scenic values are protected.

In order to meet the responsibility to maintain the scenic values of the public lands, has been developed a Visual resource assessment and management system (BLM 2007) that addresses the following:

Development of an area with high scenic value might be focused on preserving the existing character of the landscape, and management of an area with little scenic value might allow for major modifications to the landscape.

Assessing scenic values and determining visual impacts can be a subjective process. Objectivity and consistency can be greatly increased by using the basic design elements of form, line, color, and texture, which have often been used to describe and evaluate landscapes, to also describe proposed projects. Projects that repeat these design elements are usually in harmony with their surroundings and those that don't create contrast. By adjusting project designs so that the elements are repeated, visual impacts can be minimized.

The visual resource assessment and management system provides a way to identify and evaluate the scenic values of landscape. It also provides a way to analyze potential visual impacts and apply visual design techniques to ensure that surface-disturbing activities are in harmony with their surroundings.

Method and Design Techniques

A site assessment is taken for granted in ascertaining soil and climatic conditions. The visual assessment is less straightforward, but equally important, if landscape

values are to be conserved. A landscape analysis should cover both the general type of regional landscape and the character of an individual site (Forestry Commission 1994; Bell 1993, 2004).

The landscape analysis method involves determining whether the potential visual impacts from proposed surface-disturbing activities or developments will meet the management objectives established for the area, or whether design adjustments will be required. A visual contrast rating process is used for this analysis, which involves comparing the project features with the major features in the existing landscape using the basic design elements of form, line, color, and texture. The analysis can then be used as a guide for resolving visual impacts. Once every attempt is made to reduce visual impacts, professionals can decide whether to accept or deny project proposals. They also have the option of attaching additional mitigation stipulations to bring the proposal into compliance.

The design techniques used are in conjunction with the visual resource assessment process where both the existing landscape and the proposed development or activity are analyzed for their basic elements of form, line, color and texture.

Discussion

This discussion of design techniques is broken down into two categories: design fundamentals and design strategies.

Design fundamentals

There are three design fundamentals which are general design principles that can be used for all forms of activity or

development, regardless of the resource value being addressed. Applying these three fundamentals helps to solve most visual design problems:

Proper Location

Choosing the proper location for a proposed project is one of the easiest design techniques to understand and apply, and one that will normally yield the most dramatic results.

Which are the considerations when choosing a project location? Design projects should be located as far away from prominent viewing locations as possible – visual contrasts or impacts decrease as the distance between the viewer and the proposed development increases, so:

- Topographic features and vegetation should be used to screen proposed development (Fig. 1a).
- Projects should not be located on or near prominent topographic features (Fig. 1b).
- The shape and placement of projects should be designed to blend with topographic forms and existing vegetation patterns (Fig. 1c).

Reducing Unnecessary Disturbance

Reducing the amount of land disturbed during the construction of a project

reduces the extent of visual impact. Techniques that help reduce surface disturbance include:

- Placing underground utilities either along the edge or under the surface of an existing road;
- Establishing limits of disturbance that reflect the minimum area required for construction;
- Requiring restoration of disturbed areas no longer required after construction has been completed (Fig. 2a);
- Planning projects so that they utilize existing infrastructure whenever possible;
- Consolidation of communications facilities reduces the amount of visual sprawl (Fig. 2b);
- Maximizing slope when it is aesthetically and technically appropriate;
- Locating construction staging and administrative areas in less visually sensitive areas.

Repeating the Elements of Form, Line, Color, and Texture

Every landscape has the basic elements of form, line, color, and texture. Repeating these elements reduces contrasts between the landscape and the proposed activity or development and results in less of a visual impact.

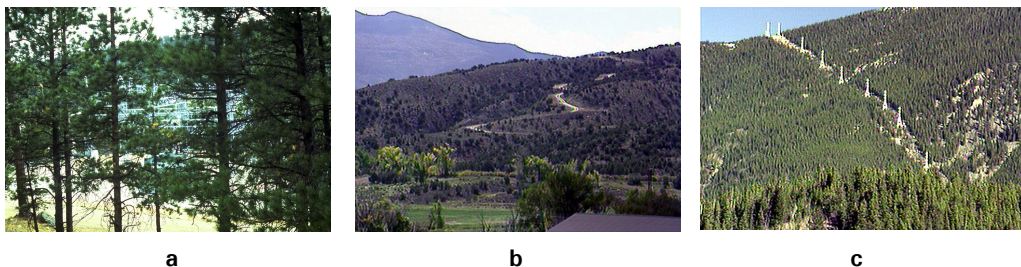


Fig. 1. Examples of location: a) Vegetation can be used to screen development; b) Road alignment repeats the forms in the landscape and it fits easily on the natural terrain; c) Locating this electrical line in heavily wooded area causes strong contrast.

Another way of looking at this is to use the existing landforms, vegetation patterns, natural lines in the landscape, etc., to reinforce the design of the proposed activity or development. By “playing off” of these naturally occurring elements, the design of the proposed development will be in closer harmony with the natural landscape.

Examples of the proper use of form (Fig. 3a, c), line (Fig. 3b), color and texture (Fig. 3d).

Design strategies

The strategies are more specific activities that can be applied to address visual design problems. Not all of these strategies are applicable to every proposed project or activity:

Color Selection

Color selection has the greatest impact on the visual success or failure of our projects. Strong contrasts in color (Fig. 4b) create easily recognizable visual conflicts in the landscape.

Making color selections, designers should consider the following:

- The color selection for all structures should be made to achieve the best blending with the surrounding landscape in both summer and winter (Fig. 4a);

- Paints should be used to help reduce glare.



Fig. 2. Unnecessary disturbance and reduction of unnecessary disturbance: a) Clearcutting on this prominent feature creates strong contrasts and attracts attention from this critical viewing point; b) Consolidation of communications facilities reduces the amount of visual sprawl.

It is almost impossible to remove all sun glare;

- Surface disturbance of mineralized soils can result in strong color contrasts. In many situations, this suggests that

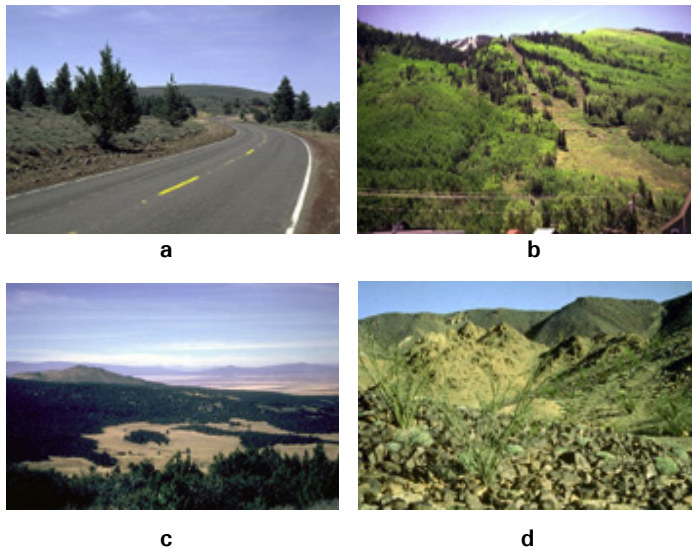


Fig. 3. Examples of the proper use of form, line, color and texture: a) The road alignment repeats the forms of the landscape; b) The clearing of this hillside works well with the existing lines and vegetative patterns found in this landscape; c) The vegetative clearing in the photo repeats the natural forms and shapes in the landscape; d) Replacement of rock on this exploratory drilling site repeats the texture of this landscape.

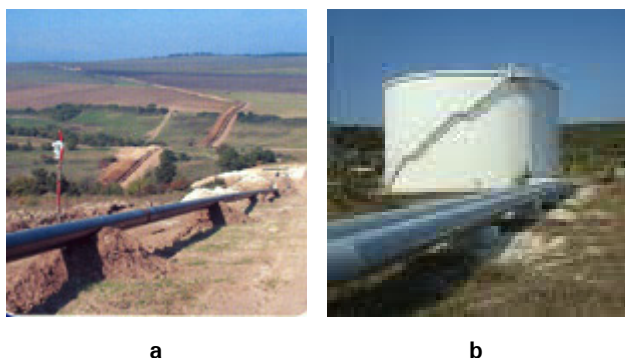


Fig. 4. Proper and improper color section: a) The color selected for this facility blends with the color in this landscape; b) The color selected for this tank strongly contrasts with the colors of this landscape.

the area should be avoided as a location for the proposed development, or that color selections for the manmade facilities or disturbance might need to reflect the lighter colored soil revealed by the disturbance;

- Colors should be selected from a distance that permits viewing of the entire landscape surrounding the proposed development;

- Colors that blend with or are in harmony with the existing colors of the earth, rocks, and vegetation are usually more visually pleasing and attract less attention than colors that are chosen to be in contrast (Fig. 4b).

Earthwork

The scars left by excessive cut and fill activities during construction in landscapes often leave long-lasting negative visual impacts. This is especially true of activities that disturb the highly mineralized soils of the arid west. Once the dark surface soil layer is disturbed, exposing the much lighter color of the

subsurface soil, a strong contrast is created that may take many years to recover.

There are a number of ways to reduce the contrasts created by earthwork construction. Proper location and alignment are probably the most important factors. Fitting the proposed development to the existing landforms in a manner that minimizes the size of cuts and fills will greatly reduce visual impacts from earthwork. Other earthwork design techniques, such as balancing cut and fill or constructing with all fill or all cut

should be considered, are appropriate as methods to reduce strong visual impacts.

Other strategies may include:

- Rounding and/or warping slopes (shaping cuts and fills to appear as natural forms) (Fig. 5a).

- Bending slopes to match existing landforms;

- Retaining existing rock formations, vegetation, drainage, etc., whenever possible;

- Split-face rock blasting (cutting rock areas so that the resulting rock forms are irregular in shape, as opposed to making uniform “highway” rock cuts) (Fig. 5b);

- Toning down freshly broken rock faces through the use of asphalt emulsions, rock stains, etc.;

- Using retaining walls to reduce the amount and extent of earthwork;

- Retaining existing vegetation by using retaining walls, reducing surface disturbance, and protecting roots from damage during excavations.

- Avoiding construction types that will generate strong contrasts with

the surrounding landscape (Fig. 5 c, d);

- Prohibiting dumping of excess earth/rock on downhill slopes.

Vegetative manipulation

Effective method of reducing the visual impact is to retain as much of the existing vegetation as possible, and where practical, to use the existing vegetation to screen the development from public viewing areas.

Some other techniques include:

- Designing vegetative openings to repeat natural openings in the landscape. Straight line edges should be avoided (Fig. 6a).
- Minimizing the impact on existing vegetation by:
 - Partial clearing of the limits of construction rather than clearing the entire area – leaving islands of vegetation results in a more natural look;
 - Using irregular clearing shapes (Fig. 6c);
 - Feathering/thinning the edges of the cleared areas (Fig. 6b). Feathering edges reduces strong lines of contrast. To create a more natural look along an edge, a good mix of tree/shrub species and sizes should be retained.

Structures

The visual impact from new structures placed on the existing landscape can be reduced by:

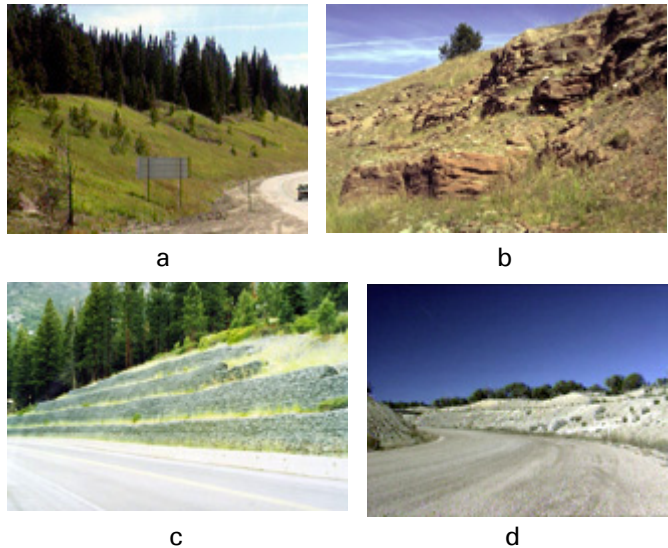


Fig. 5. Proper and improper earthwork construction: a) Rounding the top and bottom of the slope and also undulating the face of the slope create a more natural-looking landscape; b) The split-face rock blasting technique used on this project creates a more natural-looking rock face; c) The rock gabion treatment of this hillside creates strong contrasts in line and color; d) This typical highway construction side slope treatment creates an unnatural form in the landscape.

- Repeating form, line, color, and texture (Fig. 7a);
- Minimizing the number of structures and combining different activities in one structure wherever possible;
 - Using earth-tone paints and stains;
 - Using self-weathering metals;
 - Chemically treating wood so that it can be allowed to self-weather;
 - Using natural stone in wall surfaces (Fig. 7b);
- Burying all or part of the structure;
- Selecting paint finishes with low levels of reflectivity;
- Using rustic designs and native building materials;

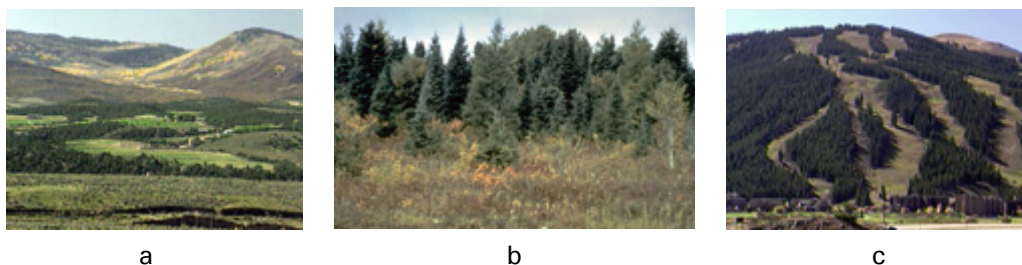


Fig. 6. Examples of proper vegetative manipulation: a) Vegetative clearings of an irregular shape blend well with the existing landscape; b) This feathered edge treatment creates a natural progression from grasses to mature trees; c) The design of this ski slope incorporates irregular shapes, but the hard, unthinned edges create a strong visual contrast.

- Using natural-appearing forms to complement landscape character, not the opposite (Fig. 7d);

- Screening the structure from view through the use of natural landforms and vegetation (Fig. 7c).

Restoration/reclamation

Strategies for restoration and reclamation are very much akin to the design strategies for earthwork, as well as the design fundamentals of repeating form,



a



b



c



d

Fig. 7. Some examples of proper and improper use of structure design: a) This structure repeats the line, color, and texture of this landscape; b) The use of native materials in this early structure; c) This structure is well-screened from the critical viewing area; d) These structures, in addition to creating strong color contrast, are not in scale with the human environment.

line, color, and texture and reducing unnecessary disturbance. The objectives of restoration and reclamation include reducing long-term visual impacts by decreasing the amount of disturbed area and blending the disturbed area into the natural environment while still providing for project operations.

Though restoration and reclamation are a separate part of project design, they should not be forgotten or ignored. All areas of disturbance that are not needed for operation and maintenance should be restored as closely as possible to previous conditions.

Several strategies that can enhance any restoration or reclamation effort include:



Fig. 8. Examples of successful restoration or reclamation efforts: a) and b) Successful restoration leaves little or no visual scarring; c) The replacement of the large rocks in this pipeline right-of-way creates a natural-looking environment.

- Striping, saving, and replacing top-soil layer on disturbed earth surfaces;
- Enhancing vegetation by:
 - Mulching cleared areas;
 - Furrowing slopes;
 - Using planting holes on cut/fill slopes to retain water;
 - Choosing native plant species;
 - Fertilizing, mulching, and watering vegetation;
 - Replacing soil, brush, rocks, forest debris, etc., over disturbed earth surfaces (Fig. 8c) when appropriate, thus allowing for natural regeneration (Fig. 8a, b) rather than introducing an unnatural looking grass cover;
- Minimizing the number of structures and combining different activities in one structure wherever possible.

Linear alignment

Projects and activities associated with linear alignments include roads, trails, pipeline developments, and underground and overhead utility lines. Proper location can often contribute significantly to the reduction of line and color impacts (Fig. 9a, b), making other measures either unnecessary or less costly and easier to accomplish.

There are several major considerations for determining an alignment:

- Topography is a crucial element in alignment selection. Visually, it can be used to subordinate or hide manmade changes in the landscape. Projects located at breaks in topography or behind existing tree groupings are usually of much less visual impact than projects located on steep side slopes. By taking advantage of natural topographic features, cut and fill slopes can be greatly minimized;
- Soils are especially important when selecting an alignment. They should be analyzed for stability and fertility and a revegetation program should be planned;
- Hydrological conditions can strongly affect the visual impact of buried and surface construction. The risks of surface and subsurface erosion within the corridor should be analyzed and evaluated;
- Crossings with other linear features or structures should be designed to minimize their visual impact:
 - When possible, crossings should be made at a right angle;
 - Structures should be set as far back from the crossing as possible;
 - In areas with tree and shrub cover, the rights-of-way and structures should be screened from the crossing area.



a



b

Fig. 9. Proper linear project alignments: a) and b) Linear alignments repeat the forms and lines of the landscapes thus minimizing the visual conflict.

Determining the engineering design, landscape design, and visual considerations for a linear alignment must be accomplished together to ensure that all three are addressed and included in the final design solution.

Conclusion

The fundamentals and strategies are all interrelated, and when used together, can help resolve visual impacts from proposed activities or developments.

The techniques presented here are only a portion of the many design techniques available to help reduce the visual impacts resulting from surface-disturbing activities or projects. Further research into planning and design references and/or consultation with professional design-

ers and engineers will help to further reduce the visual impacts of any development.

References

- Bell S.** 1993. Elements of Visual Design in the Landscape. E & F N Spon. London.
- Bell S.** 2004. Elements of Visual Design in the Landscape. E & F N Spon. London, 196 p.
- BLM** 2007. Bureau of Land Management. Washington Office – Recreation Group. April 30, 2007. Available: <http://www.blm.gov/nstc/VRM/index.html>
- Crowe S.** 1966. Forestry in the Landscape. Forestry Commission Booklet No 18. HMSO, London, 47 p.
- Forestry** Commission 1994. Forest Landscape Design. Guidelines, HMSO, London, 28 p.
- Kress G.R., Van Leeuwen T.** 2006. Reading images: the grammar of visual design. Routledge, 291 p.
- Lyle J.T.** 1999. Design for human ecosystems: landscape, land use, and natural resources. Island Press, 279 p.
- Zube E.H., Sell J.L., Taylor J.G.** 1982. Landscape perception: Research, application and theory. Landscape Planning, Volume 9, Issue 1, July 1982: 1–33.

HEIGHT STRUCTURE ANALYSIS OF PURE *JUNIPERUS EXCELSA* M. BIEB. STANDS IN PRESPA NATIONAL PARK IN GREECE

Athanasios Stampoulidis and Elias Milios*

Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Pantazidou 193, 682 00 Orestiada, Greece. *E-mail: emilios@fmenr.duth.gr

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Abstract

The aim of this study was to analyze height structure of pure *Juniperus excelsa* stands in Prespa National Park in Greece. Since many trees in these stands are multi-stemmed, the height structure based on the tallest stem in each tree was chosen as a representative measure of stand structure. During the summer of 2009, a plot of 100 m x 100 m, which was divided in four subplots of 50 m x 50 m, was established in a medium site quality stand, while a plot of 50 m x 50 m was established in a good site quality stand. Moreover, 90 plots of 25 m x 20 m were established in juniper stands and groups having different canopy cover percentage and forms of *J. excelsa* trees in good and medium site quality areas. In all plots the height of the tallest stem of each tree was measured. In most stands, in both sites, the height class of 5 m dominates in height structure. However, in some cases the class of 3 m dominates in medium site qualities and the class of 7 m in good site qualities. The highest trees found in medium and good site qualities were 12 m and 14 m respectively. The density of *J. excelsa* groups and stands ranged from 80 to 580 *J. excelsa* trees per ha. The rather low tree-height of Juniper trees in Prespa National Park as well as the height structure and density of *J. excelsa* stands are the result of anthropogenic disturbances. The results of this study will contribute to the knowledge and protection of this rare ecosystem in Greece.

Key words: disturbances, protected area, site insensitive species, site quality.

Introduction

Juniperus excelsa M. Bieb. is a species of central and southern Balkans which is also found in Anatolia, Crimea, central and southwest Asia and east Africa (Athanasiadis 1986, Boratynski et al. 1992, Christensen 1997). *Juniperus excelsa* is a site insensitive species, which is able to adapt from full light to dense shade and to show growth increase if the growth conditions are

ameliorated (Milios et al. 2007, Milios et al. 2009). These traits contribute to the survival of *J. excelsa* in intensely disturbed and severe environments (Milios et al. 2009). In Greece, in most cases, small groups of *J. excelsa* trees are formed or trees appear as scattered individuals in open forests in degraded ecosystems. In very few cases *J. excelsa* is observed in larger units of pure and mixed stands (Milios et al. 2007).

The aim of this study was to analyze the height structure of pure *J. excelsa* stands in Prespa National Park in Greece. Prespa National Park is one of the very few places where the species forms pure stands in extended areas. The results of this study will contribute to the knowledge and protection of this rare ecosystem in Greece.

Study Area

The study was carried out in the western part of Prespa National Park in Greece. Prespa National Park is situated in the northern-western part of Greece close to the Albanian and F.Y.R.O.M. borders. The *J. excelsa* stands and groups (mixed and pure) appear in an area of approximately 2732 ha within altitudinal range from 840 to 1360 m. The substratum consists of limestones and dolomitic limestones and the soils are clay to clay silt (Pavlidis 1985). The soils are rather shallow and surface appearances of parent material are observed in many cases (Pavlidis 1985). On average the annual precipitation in Nestorio, which is one of the closest meteorological stations, is 817 mm and the mean annual temperature is 10.8°C.

In the pure *J. excelsa* stands species such as *Quercus macedonica*, *Juniperus oxycedrus*, *Quercus pubescens*, *Pyrus amygdaliformis*, *Carpinus orientalis*, *Acer monspessulanum* and *Juniperus foetidissima* occur. Their density is low and they do not influence the physiognomy of stands.

Research Method

Juniperus excelsa stands appear in two site types. Site type A represents the

more or less productive sites (good site qualities) of the area, whereas site type B represents the less productive sites (medium site qualities). For characterizing sites, the soil depth was determined through soil profiles. In site type A the soil depth ranged approximately from 26–30 to 50 cm and in site type B from 5 to 20–25 cm. The vast majority of *J. excelsa* stands is found in site type B.

In each site, there are dense and sparse *J. excelsa* stands and groups. In the dense formations the canopy cover percentage (canopy cover area $\times$ 100/total area of *J. excelsa* formations) ranges from 60 to 80% while in the sparse ones the canopy cover percentage ranges from 30 to 40%. Regardless of the density of the stands and groups, the *J. excelsa* trees appear as scattered individuals or in small aggregations.

Another characteristic that differentiates the Juniper formations regardless of their density is the height where the living foliage (branches having living needles) appears. In almost all areas of site type B the living foliage of trees appears at ground level. All the trees are multi-stemmed, which results in the formation of an impenetrable hemispherical or spherical crown. This type of tree form characterizes, by far, the most *J. excelsa* stands and groups. On the other hand, in all areas of site type A and in a very small proportion of areas in site type B in a significant number of trees the living foliage appears at a height of 50–60 cm above the ground.

Therefore, as a result six structural types were recognized: 1) dense (DAH) and 2) sparse (SAH) groups or stands in site type A where in a significant number of trees the living foliage ap-

pears at a height of 50–60 cm above the ground, 3) dense (DBH) and 4) sparse (SBH) groups or stands in site type B where in a significant number of trees the living foliage appears at a height of 50–60 cm above the ground, 5) dense (DBG) and 6) sparse (SBG) groups or stands in site type B where the living foliage of trees appears at ground level.

During the summer of 2009, in each structural type 15 plots of 500 m² (20 m x 25 m) were established with the use of the stratified random sampling method. Moreover, in order to have a representative view of *J. excelsa* stand height structure in extended areas, a plot of 100 m x 100 m, (EB) which was divided in four subplots of 50 m x 50 m, (EB1, EB2, EB3 and EB4) was established in a site type B area, whereas a plot of 50 m x 50 m (EA) was established in a site type A area, since in all cases the pure *J. excelsa* formations in site type A appear in areas lower than 0.7 ha.

In each plot the height of the tallest stem of each tree having height over 1.3 m was measured as a representative measure of stand structure, since most of the trees in site type B are multi-stemmed and the presentation of all heights or of diameters in figures could have created a confusion.

Results

In almost all structural types and in the EB plot (100 m x 100 m) the height class of 5 m dominates (Fig. 1, Fig. 2). In the SBG structural type the height class of 3 m dominates. In the good site qualities in the EA plot (50 m x 50

m) the greater number of trees fall in the height class of 7 m. The highest tree found in medium and good site qualities was 12 m (DBH, DBG) and 14 m (DAH), respectively (Table 1).

The highest mean density of *J. excelsa* trees was found in DBG structural type, while the absolute highest density was found in DAH structural type. The SBG structural type exhibits the lowest mean and the absolute lowest density of *J. excelsa* trees (Table 1).

In the EB plot the height structure appears to be more or less stable concerning the three plots (EB1, EB1 + EB2 and EB) shown in the Figure 2, starting from the plot of 50 m x 50 m (EB1) and moving on to larger plots (e.g. 50 m x 100 m, 100 m x 100 m).

Discussion

The density of *J. excelsa* trees in Prespa National Park is lower than the density of junipers in the mixed stands of the central part of Nestos Valley situated in the north-east of Greece as well as the corresponding density in *J. excelsa* stands of Isparta – Sutculer in Turkey (Milios et al. 2007, Carus 2004). The maximum height of the juniper trees in Prespa National Park is higher than that of Nestos Valley, and more or less the same as the height of the highest trees in Isparta – Sutculer in Turkey and is lower than that of *J. excelsa* stands in Balouchistan (Milios et al. 2007, Carus 2004, Ahmed et. al. 1990). Moreover it is lower than the maximum tree height in *J. excelsa* formations in the valley of Hayl Juwary in Oman (Fisher and Gardner 1995).

In the overall area of the species distribution the height structure of *J.*

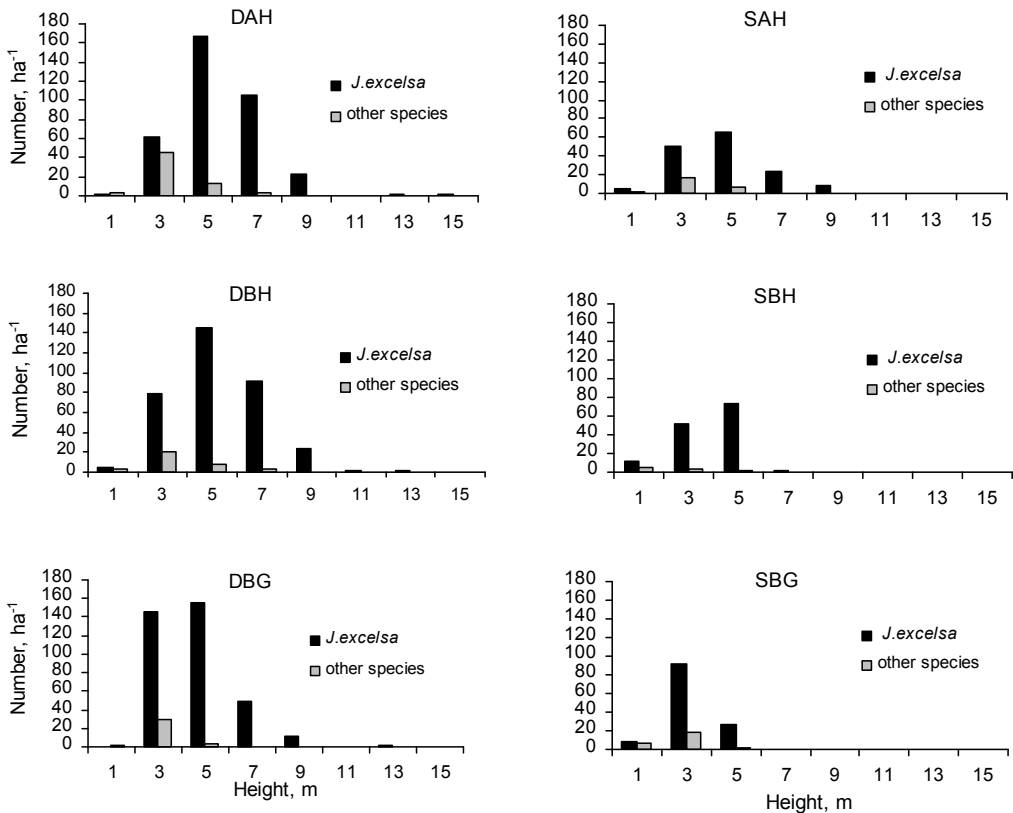


Fig. 1. Distribution of heights in the six structural types.

excelsa formations varies. The height classes that dominate in the *J. excelsa* stands found in four site types in the central part of Nestos Valley, range from 4 to 8 m (Milios et al. 2007). Moreover, the lower height classes (2–8 m) show the highest density of trees in the height structure of *J. excelsa* stands in Balouchistan, however, it has been remarked that height classes ranging from 6 to 9 m dominate in the *J. excelsa* formations in the valley of Hayl Juwary in Oman. (Ahmed et. al. 1990, Fisher and Gardner 1995).

As it can be concluded from the height structure of all structural types,

the pure *J. excelsa* stands in the study area are uneven aged. The height and age structure as well as the density of *J. excelsa* stands in Prespa National Park have been strongly affected by anthropogenic disturbances. In 1917 and during the World War II in some locations of site type B all the *J. excelsa* trees were cut by the army (Pavlidis 1985). Moreover, even today illegal cuttings have been observed (personal observation).

Another disturbance, which influenced the growth rates and the heights of trees was the cutting of the Juniper branches by the local residents in the

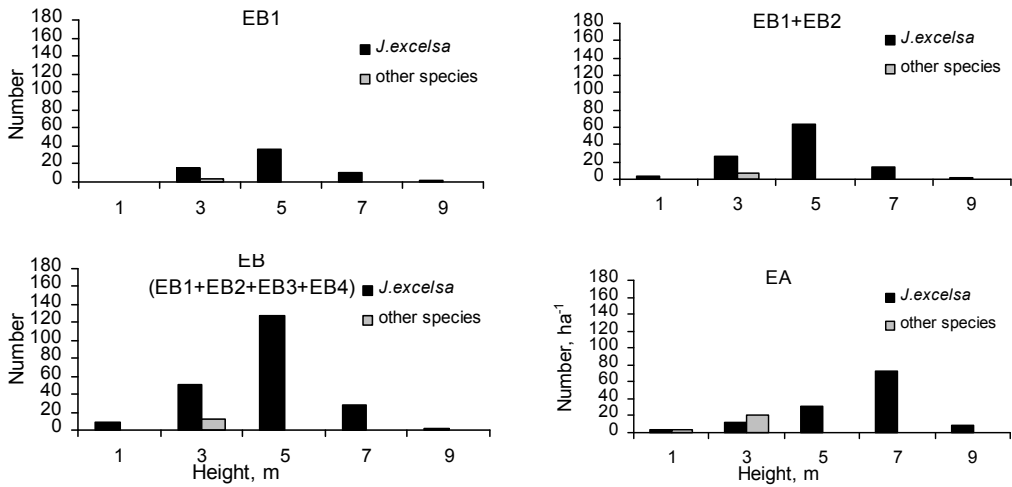


Fig. 2. Distribution of heights in EB1, EB1 + EB2, EB and EA plots.
(in the EB1, EB1 + EB2 and EB plots, Number is the actual number of trees
in each plot while in the EA plot the number of trees per hectare is given)

Table 1. Structural characteristics of pure *J. excelsa* stands and groups.

Structural types	Density of <i>Juniperus excelsa</i> , ha ⁻¹		Density of all species, ha ⁻¹	
	X ± SD	Range	X ± SD	Range
DAH	360 ± 67	300–580	424 ± 53	360–580
SAH	155 ± 19	120–180	180 ± 25	120–220
DBH	347 ± 51	260–420	380 ± 57	280–480
SBH	136 ± 26	100–200	147 ± 36	100–220
DBG	361 ± 46	300–460	396 ± 51	300–480
SBG	127 ± 28	80–180	151 ± 32	100–200
	Height of <i>Juniperus excelsa</i> trees, m		Height of other species trees, m	
	X ± SD	max	X ± SD	max
DAH	5.07 ± 1.762	14	3.03 ± 1.142	7
SAH	4.21 ± 1.746	9	2.92 ± 0.946	5
DBH	4.76 ± 1.750	12	3.07 ± 1.258	6
SBH	3.54 ± 1.000	6	2.40 ± 1.228	5
DBG	4.06 ± 1.542	12	2.67 ± 0.799	5
SBG	2.93 ± 0.827	5	2.79 ± 0.588	4

X ± SD = Mean ± Standard Deviation

past. The locals used these branches to make traps for the fish in Prespa Lakes (Catsadorakis 1995). Grazing is another disturbance factor in the area. Even though grazed *J. excelsa* seedlings or sapling were not found, trampling of regeneration might have affected the density of stands.

In the future, more research is needed regarding the regeneration and dynamics of the *J. excelsa* stands in Prespa National Park in order to be properly protected and managed.

Conclusions

The *J. excelsa* stands in Prespa National Park in Greece are differentiated by their density and the height where the living foliage of trees (branches having living needles) appears. In most stands, in both sites, the height class of 5 m dominates in height structure. However, in some cases the class of 3 m dominates in medium site qualities and the class of 7 m in good site qualities. The highest trees found in medium and good site qualities were 12 m and 14 m respectively. The height and age structure as well as the density of *J. excelsa* stands in Prespa National Park have been strongly affected by anthropogenic disturbances.

Acknowledgments

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References

- Ahmed M., Shaukat S.S., Buzdar A.H. 1990. Population structure and dynamics of *Juniperus excelsa* in Balouchistan, Pakistan. *Journal of Vegetation Science* 1: 271–276.
- Athanasiadis N. 1986. Forest botany (in Greek), Part II, Thessaloniki (in Greek).
- Boratynski A., Browicz K., Zielinski J. 1992. Chorology of trees and shrubs in Greece, Kornik, Poznan. 286 p.
- Carus S. 2004. Increment and growth in Crimean Juniper (*Juniperus excelsa* Bieb.) stands in Isparta–Sütçüler region of Turkey. *Journal of Biological Sciences* 4: 173–179.
- Catsadorakis G. 1995. The texts of information center of Prespa (in Greek).
- Christensen K.I. 1997. Cupressaceae. In: Strid A. and Tan K. (Ed.), *Flora Hellenica*. Koeltz Scientific Books: 9–14.
- Fisher M., Gardner A.S. 1995. The status and ecology of a *Juniperus excelsa* subsp. *polycarpus* woodlands in the northern mountains of Oman. *Vegetatio* 119: 33–51.
- Milios E., Pipinis E., Petrou P., Akritidou S., Smiris P., Aslanidou M. 2007. Structure and regeneration patterns of the *Juniperus excelsa* Bieb. stands in the central part of the Nestos valley in the northeast of Greece, in the context of anthropogenic disturbances and plant facilitation. *Ecological Research* 22: 713–723.
- Milios E., Smiris P., Pipinis E., Petrou P. 2009. The growth ecology of *Juniperus excelsa* Bieb. trees in the central part of the Nestos valley (NE Greece) in the context of anthropogenic disturbances. *Journal of Biological Research* 11: 83–94.
- Pavlidis G. 1985. Geobotanical Study of the National Park of Lakes Prespa (NW Greece) Part A' Ecology, Flora, Phytogeography, Vegetation Thessaloniki, 308 p. (in Greek).

THE CONTROL OF OAK MILDEW BY BIOFUNGICIDE

Snežana Rajković*, Mara Tabaković-Tošić,
and Vesna Golubović-Čurguz

Institute of Forestry, Kneza Visislava 3, Belgrade, Serbia.

*E-mail: srajkovic1@gmail.com

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Abstract

Microsphaera alphitoides Griff. et Maubl. is the most widespread and frequent disease in oak forests. The fungus is primary pathogene attacking plants in all developmental stages. Since it causes the greatest harms on young stands of pedunculate oak, when attacks are strong, chemical protection (treatment by fungicides) is applied. In Serbia fungicides for control of pathogenes in forest ecosystems are not registered. Therefore, it is necessary to select ecotoxicologically favourable fungicides registered in this region and obey FSC policy in application of pesticides. Biofungicides are used for biological control of fungi causing plant diseases. This paper studies the independent influence of biofungicide AQ10 in concentrations 0.03 g, 0.05 g, and 0.07 g on agent of oak mildew. Preliminary studies of effect of biofungicide AQ10 are conducted by standard OEPP method PP1/69(2) (OEPP/EPPO, 1997) in pedunculate oak nurseries subject to infection potential of parasitic fungus *M. alphitoides*. Leaf infection was estimated by EPPO method (Guideline for efficacy evaluation of fungicides *Podosphaera leucotricha*) PP1/69(2); infection intensity was determined by Towsend-Heuberger's method, and efficiency by Abbott's.

Key words: biofungicide – AQ10, efficiency, *Microsphaera alphitoides*.

Introduction

Serbia is considered as secondary forest land. According to the latest data of Forest Inventory of National Republic of Serbia from the 2009th year, the forest is 29.1% (of which 37.6% is in the middle part of Serbia and 7.1% in Vojvodina) of the total area of the territory of Serbia. In relation to the global aspect, the forested area of Serbia is closer to the world, which is 30% and was significantly lower than European, which reaches 46%.

The total area of forests in Serbia is 2,252,400 ha, and the most important species of oak is on the surface – 720,800 ha. Since then, forest of *Q. cerris* L. stretch of 345,200 ha, *Q. petraea* (Matt.) Liebl. forest the 173,200 ha, forest *Q. frainetto* Ten. on 159,600 ha, of *Q. robur* L. forests and 32,400 ha, of forest *Q. pubescens* Willd. to 10,400 ha.

Several species of powdery mildew are known to infect oaks. These include *Erysiphe abbreviata* (syn. *Microsphaera abbreviata*), *E. alphitoides* (syn. *M. alphitoides*), *E. calocladophora* (syn. *M. calo-*

cladophora), *E. extensa* (syn. *M. extensa*), and *E. hypophylla* (syn. *M. hypophylla*) (Braun 1987, Braun and Takamatsu 2000, Braun et al. 2003).

E. alphitoides is common, widespread in Asia and Europe on numerous species of the genus *Quercus*, and has been introduced in various other parts of the world (Braun 1987, Butin 1995, Bunkina 1991). In Europe, it is morphologically rather uniform (Braun 1995), whereas in Asia, above all in China, Japan and Korea, its chasmothecia are more variable (Homma 1937, Nef and Perrin 1999, Otani 1988, Rajkovic and Tabakovic-Tosic 2008).

Because of the desire for reducing the negative consequences of applying chemicals, and the possibility of resistance, biological control is becoming increasingly important. For biological control of plant disease causing fungi used biofungicides. Efficiency of biofungicides improves by adding the polymer during its application.

The biofungicide AQ10 (Ecogen Inc., Langhorne, PA) is a pelleted formulation of conidia of *Ampelomyces quisqualis* Ces. ex Schlechtend., a fungus that parasitizes powdery mildew colonies. It is intended for use as part of an integrated management program; therefore, information is needed on its compatibility with conventional chemical fungicides (Rajkovic et al. 2009).

Material and Methods

The experiments were made in the nursery „Rogut“ which is located in Batocina, near Kragujevac, at altitude 115 m. The investigations were carried out on the oak seedlings *Q. robur*

L., aged 6 years, seed origin. The seeds from which seedlings produced comes from recognized seed stands oak, reg. No C 02.11.01.01, which borders with the nursery. Height of seedlings are from 0.30 cm to 1.70 m (mostly about 1.20 m), because the part of seedlings were cating in the first and second vegetation period. Seedlings were planted densely in rows length of about 60 m (8 rows in total, an average of 6 seedlings per m²), with space between the row around 40 cm. For the experiment were used two rows. The control was estimate in the second row.

Biofungicide – AQ10 is a new biofungicide that contains fungal spores of for the control of powdery mildew by parasiting and killing the fungal organisms that cause the disease. It is approved for the efficient and biotical use of Powdery Mildew. For its activation it needs 60% of air humidity therefore application should be made in the early morning or late evening when the humidity is at its highest, with the addition of some wetting agent. When spores of *A. quisqualis* penetrate into Powdery Mildew mycelia (2–4 hours) their efficacy is depending on external influences not any more. This biofungicide is mostly preventive product but it acts also “eradicatively” and is efficient also against mycelia which passed the winter. Initial application should begin before the appearance of the symptoms and at the latest when three spots on 100 leaves have been observed. AQ10 has very short pre-harvest interval, only 24 hours, so it can be applied up to and including the day of harvest.

Fungicide Sulphur SC (a. i. Elementary sulphur 810.50 g.l⁻¹) in use 0.5% (Galenika-Phytopharmacy a.d. Belgrade-Zemun).

The appearance and development of powdery mildews is followed by the first appearance to the development of disease in control in the degree when it is possible to establish clear differences between control and variations where biofungicides were used. The trials were set by the instructions of methods PP 1/152 (2) (EPPO 1997b) and the plan is fully randomized block design. The experiment was conducted in four repetitions. The basic plot consisted of 8 trees (1x3 m apart) 25 m². Estimation on leaves by secondary infection of powdery mildew: 15 well-developed leaves were selected on shoot from the outer zones of branched part of each tree. Recommendations are to avoid the shoots with primary infection of powdery mildews and shoots completely infected by powdery mildews and shoots that arise from the interior foliage.

Amount of water per unit surface: Application of fungicides was performed using the backstroke sprayer "Solo"; with the consumption of 1000 l.ha⁻¹ of water. Time of application of biofungicide and its combination with polymers: 07.07.2010. FF: Shoots are 15–20 cm length. The intensity of disease assessed by the method of EPPO, 1997a: Guideline for the efficacy evaluation of fungicides – *Podosphaera leucotricha*, No PP 1/69 (2) in Guideline for the efficacy evaluation of Plant Protection Products (EPPO 1997a: 100–102). Time of estimation: 11.07.2009. Phytotoxicity is estimated by instructions of PP methods (1/135 (2) (OEPP, 1997d). Weather conditions: during the treatments there were more favorable conditions for the application of biofungicide: the wind was below 1 m.s⁻¹, and the temperature 18.8–26.4°C, with sunny intervals of 2–3 hours after treatment. Before treatment there was no rain

48 h, and after 6–8 hours of treatment there was no rainfall, while the relative humidity was 80%, because the nursery is protected with old forest plantations in surrounding. Data of land: in the oak nursery soil is poorly processed. Weeds were repressed by hand mower. Irrigation was not applied. Type of land at the tested locality was vertisol, wet, deep 80 to 120 cm. Other measures in the experimental field: Treatments by insecticides and bioinsecticides were done in 07.05.2009. For the suppression of gypsy moths in the variants where the product AQ10 is applied in all used concentrations, used a biological product Forey (0.3 l.ha⁻¹). In variants where AQ10 combined with Nu film 17 in the lower and higher doses were used applying insecticides Avaunt 15SC (200 ml.ha⁻¹). The variant where the AQ10 was applied in combination with Nu P film was used Coragen 20 SC (200 ml.ha⁻¹). On the control variants there was no application of any pesticides or biopesticides.

Statistics

Data processing was performed using standard statistical methods (intensity of infection by Townsend-Heuberger (Townsend and Heuberger 1943), the efficiency of the Abbott (Abbott 1925), analysis of variance and Duncan test (Duncan 1955) and methods PP/181 (2) (EPPO 1997c). Differences of intensity of disease were evaluated by analysis of variance and LSD-test.

Results

We are presented the data of realized powdery mildews infestation on the oak

Table 1. Intensity of attacks *M. alpitoides* on oak leaves and efficiency of biofungicide AQ10 in the locality Batočina – Kragujevac.

No	Fungicide	Doses/Conc.	Infection, %	Efficacy, %	Standard, %
1	AQ10	0.03 kg.ha ⁻¹	15.35 bc	21.68	28.33
2	AQ10	0.05 kg.ha ⁻¹	2.15 ab	63.52	83.00
3	AQ10	0.07 kg.ha ⁻¹	6.15 a	68.62	89.67
4	Sumpor SC	0.5 %	4.60 a	76.53	100.00
5	Untreated	–	19.60 c	0.00	0.00
	Isd 005		6.65		
	Isd 001		9.33		

leaves in the Table 1. Biofungicide was applied in three doses, at the lowest application dose (30 g) percentage of infection was 15.35%, in the middle dose 7.15% and in the highest dose was 6.15%. This results of investigations shows that if this application of biofungicide in two higher doses had successfully control.

There are no statistically differences between the highest dose of application of biofungicide AQ10 and fungicide Sulfur. Fungicide Sulfur SC showed the efficiency of 84.43% which is low efficiency for chemical fungicides but still satisfactory for practice. Infection on control variant was 19.75% which means that the presence of pathogens was significant that could be carried out this experimental essay and to properly assess the effectiveness of the investigated preparations.

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References

- Abbott** W.S. 1925. A method for computing the effectiveness of an insecticide. *JEcon Entomology* 18: 265–267.
- Braun** U. 1987. A monograph of the Erysiphales (powdery mildews). *Beihefte zur Nova Hedwigia* 89: 1–700.
- Braun** U. 1995. The powdery mildews (Erysiphales) of Europe. *Gustav Fischer Verlag, Jena*, 337 p.
- Braun** U., Cunningham J.H., Brielmaier-Liebetanz U., Ale-Agha N., Heluta V. 2003. Miscellaneous notes on some powdery mildew fungi. *Schlechtendalia* 10: 91–95.
- Braun** U., Takamatsu S. 2000. Phylogeny of Erysiphe, Microsphaera, Uncinula (Erysiphaceae) and Cystotheca, Podosphaera, Sphaerotheca (Cystothecaceae) inferred from rDNA ITS sequences and some taxonomic consequences. *Schlechtendalia* 4: 1–33.

Butin H. 1995. Tree diseases and disorders. Causes, biology and control in forest amenity trees. Oxford University Press, Oxford, 252 p.

Bunkina I.A. 1991. Porjadok Erysiphales Gwinne-Vaughan. In: Azbukina ZM (ed.), Nizshie rastenija, griby i mohoobraznye Sovetskogo Dal'nego Vostoka, Griby, Vol. 2. Askomicety, Erizifal'nye, Klavicipital'nye, Gelocial'nye. Nauka, Leningrad: 11–142.

Duncan D.B. 1955. Multiple-range and multiple F test. Biometrics, 11: 1–42.

EPPO 1997a. Guideline for the efficacy evaluation of fungicides – *Podosphaera leucotricha*, No PP 1/69 (2) in Guideline for the efficacy evaluation of Plant Protection Products, 1997: 100–102.

EPPO 1997b. Guidelines for the efficacy evaluation of plant protection products: Design and analysis of efficacy evaluation trials – PP 1/152 (2), in EPPO Standards: Guidelines for the efficacy evaluation of plant protection products, 1, EPPO, Paris: 37–51.

EPPO 1997c. Guidelines for the efficacy evaluation of plant protection products: Conduct and reporting of efficacy evaluation trials PP 1/181 (2), in EPPO Standards: Guidelines for the efficacy evaluation of plant protection products, 1, EPPO, Paris: 52–58.

EPPO 1997d. Guidelines for the efficacy evaluation of plant protection products: Phytotoxicity assessment – PP 1/135 (2), in

EPPO Standards: Guidelines for the efficacy evaluation of plant protection products, 1, EPPO, Paris: 31–36.

Homma Y. 1937. Erysiphaceae of Japan. Journal of the Faculty of Agriculture, Hokkaido Imperial University 38: 183–461.

National forest inventory of the Republic of Serbia, Forest Fund of the Republic of Serbia 2009. Monograph, 1 edition, Ministry of Agriculture, Forestry and Water Management, Department of Forests, Planeta print, Belgrade.

Nef L., Perrin R. 1999. Damaging agents in European forest nurseries. Practical handbook. European Communities, Italy.

Otani Y. 1988. S. Ito's Mycological Flora of Japan Vol. III. In: Ascomycotina, No 2. Yokendo, Tokyo. Roll-Hansen F, 1961. *Microsphaera hypophylla* Nevodovskij (*M. silvatica* Vlasov) an oak powdery mildew fungus. Reports of the Norwegian Forest Research Institute 17: 38–54.

Rajkovic S., Tabakovic-Tosic M. 2008. Controlling measures of Powdery mildew. Forest Science No 4, 64 p.

Rajkovic S., Tabakovic-Tosic M., Golubovic-Curguz V. 2009. AQ10 – new preventive biolofungicide. Information Bulletin EPRS IOBS, No 9, Kiev: 175–177.

Towsend G. R., Heuberger J. W. 1943. Methods for estimating losses by diseases in fungicide experiments. Plant Disease Reporter 24: 340–343.

EXCHANGES OF CO₂ THROUGH THE SOIL-ATMOSPHERE INTERPHASE IN BROADLEAF AUTOCHTHONOUS FORESTS FROM THE NW OF SPAIN (*QUERCUS ROBUR* L. OR *BETULA ALBA* L.): INTRA-ANNUAL VARIATIONS

Irene Fernandez, Beatriz Carrasco, and Ana Cabaneiro

Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia, Consejo Superior de Investigaciones Científicas (CSIC), Apartado 122, E-15780 Santiago de Compostela, Spain. E-mail: ifernandez@iiaj.csic.es

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Abstract

It is widely accepted that increasing concentrations of “greenhouse gases” will raise the temperatures of the Earth’s atmosphere and oceans. By acting as C sinks, forest ecosystems can store significant amounts of CO₂. There is, therefore, a growing need to evaluate the C cycle in forest ecosystems. Quantification of the C stored in forests, both in plants and soils (global balance between CO₂ fixation and CO₂ emission), and the knowledge of the main factors affecting net C fluxes in these ecosystems are basic and essential tools to control this environmental problem. This research work encompasses the study of the seasonal variations of the CO₂ emissions from soils of two different types of deciduous forests of the temperate-humid zone (*Quercus robur* L. or *Betula alba* L.) located in Galicia (Northwestern Spain). With this objective, permanent forest plots were established and *in situ* determinations of soil CO₂ effluxes were assessed using a portable infrared gas analyser. The determinations of the exchanges of this gas through the soil-atmosphere interphase were periodically carried out during a whole year (winter, spring, summer and autumn) in order to quantify the seasonal variations of these soil emissions. The significance of the seasonal variations observed for both types of forests and the implications of the results obtained in the global warming mitigation strategies, as well as the relation of these CO₂ effluxes with soil temperature, are discussed.

Key words: *Betula alba*, greenhouse gases, *Quercus robur*, seasonal fluctuations, soil CO₂ effluxes, soil organic matter, terrestrial C cycle.

Introduction

Deciduous forests are part of the European cultural heritage and are a key component of Galician landscapes. By amplifying parent material alteration with the development of fine and coarse tree roots, these kinds of ecosystems

contribute to soil depth increase, to preserve fertility, productivity as well as C fixation and to prevent soil erosion. Since both the biosphere and the edaphosphere of these forests are important organic matter reservoirs, their degradation could generate considerable emissions of greenhouse gases (GHG)

due to biomass decomposition and soil organic matter mineralization. For this reason, adequate silvicultural managements are necessary to keep their C retention capacity and to avoid the conversion of these forests into a possible source of CO₂ that could contribute to global warming.

It has been reported that the CO₂ concentration in the air is responsible for more than 70% of the greenhouse effect (Lashof and Ahuja 1990) and some authors predict that CO₂ emissions to the atmosphere could increase from 7.4 GtC.year⁻¹ in 1997 to approximately 26 GtC.year⁻¹ in 2100 (Houghton et al. 1996). Nowadays, considering absorptions by natural sinks and emissions by CO₂ sources, the net balance of total emissions towards the atmosphere amounts to 3 GtC.year⁻¹. As a result of this excess of CO₂, the greenhouse effect have been increased, raising the mean temperature of the atmosphere by 0.7°C since the industrial period commencement. Although the effects of elevated CO₂ concentration in the ecosystem functioning are uncertain, many scientist state that doubling CO₂ atmospheric concentrations could produce serious environmental consequences (Lindzen 1994, Adams et al. 1999), with biological, economical and edaphic negative effects.

Although some authors indicate that the soil respiration rate is scarcely sensitive to the environmental temperature, it is widely accepted that a global increase of the temperature can cause soil C losses if the soil have enough moisture (Leirós et al. 1999, Gallardo and Merino 2007). For this reason, the evaluation of the C effluxes and the knowledge of the main factors affecting their inten-

sity could be basic and essential tools to control this environmental problem.

Therefore, the aim of this research is to quantify the CO₂ exchanges in the soil-atmosphere interphase in *Quercus robur* L. or *Betula alba* L. ecosystems located in Galicia (Northwestern Spain). This research work also encompasses the study of the seasonal variations of the soil CO₂ emissions during a whole year, in order to enhance the knowledge of the C cycle in these types of broad-leaf autochthonous ecosystems.

Methods and Study Area

Deciduous species such as oak and birch are the natural forests in the NW of Spain (Galicia). This geographic area is located in the temperate-humid climate zone and the main meteorological records corresponding to the period of study (temperature and rainfall values during the year 2009) are included in Fig. 1. The forest plots studied were located throughout this region and were selected to represent the whole range of stand densities, undergrowth types and growing conditions in Galician forests for these two tree species. None or scarce silvicultural treatments were applied to the forests selected for this study and the spatial distribution of the different plots is represented on the regional map included in Fig. 1.

To monitor soil CO₂ effluxes, 12 oak and 12 birch permanent forest plots (around 1000 m²) were established, in order to determine the intra-annual variation of the CO₂ exchanges through the soil-atmosphere interphase in this type of broadleaf autochthonous ecosystems. In all permanent plots, *in situ*

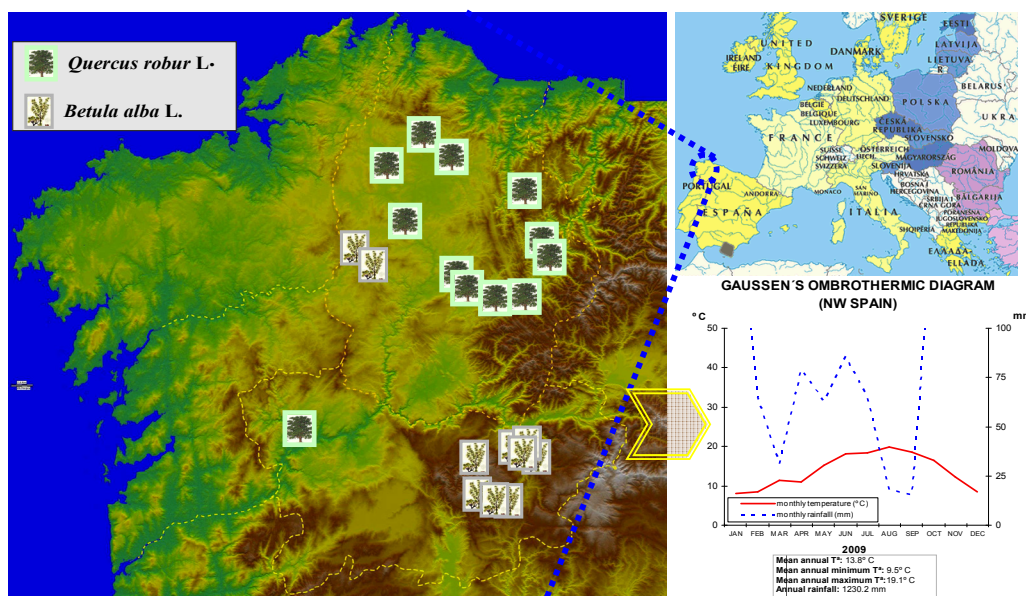


Fig. 1. Geographic distribution of the selected oak and birch forest plots and general climatic conditions of the Galician region during the studied period.

measurements of soil C effluxes were assessed using a portable infrared gas analyser (EGM-4, PP Systems) and expressed as $\text{g CO}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$. For each forest plot a squared pattern (4 rows and 6 columns) was established and 24 punctual determinations of the soil CO_2 emissions were periodically carried out during the 4 seasons of the year (winter, spring, summer and autumn'2009) in order to quantify the seasonal variations of the edaphic releases to the atmosphere. Simultaneously in each measurement point, a 10 cm probe was introduced into the forest floor to register the subsurface soil temperature.

After the removal of the litter and the duff, a representative soil sample (composed by mixing 24 subsamples regularly taken following the previously indicated squared pattern) from the upper layer of the A horizon (0–15 cm)

were collected in winter to determine the main soil characteristics. The soil pH was measured using a 1:2.5 soil:water ratio. Organic C was determined by dry combustion in a Carmograph 12 (Whostoff, Germany), with primary and secondary ovens at 90°C and 400°C, respectively. Total soil C content, expressed as $\text{kg C} \cdot \text{m}^{-2}$, was estimated by considering only the 0–15 cm depth layer and a soil density of $1000 \text{ kg} \cdot \text{m}^{-3}$. Statistical analyses were performed using the computer software SPSS 15.0 (2006). ANOVA test was applied to analyse the possible variations between oak and birch soils.

Results and Discussion

For both types of ecosystems, all the selected forest plots exhibited acidic

and highly organic soils, with soil pH values around 4.5 and averaged soil C contents always surpassing the 6.5% for *Betula alba* L. and the 8.5% for *Quercus robur* L. Thus, within this temperate-humid zone, oak forests seem to exhibit a significantly higher soil C content ($P < 0.05$) than birch plantations. The values found in these soils are in agreement with the results obtained for different types of forest soils of this region (Sánchez-Rodríguez et al. 2002; Fernandez et al. 2004; Diaz-Maroto et al. 2005, 2007; Fernandez et al. 2006) and also with soils from other countries of similar latitudes (Mansson and Falkengren-Grerup 2003).

Annual soil CO₂ emissions to the atmosphere from oak forests were slightly lower than effluxes from birch plantations (Table 1). The annual mean value of the soil CO₂ emissions exhibited a significant negative correlation with the total soil C content (Fig. 2a) and, despite the scarce variability of the soil pH, a significant positive correlation with this edaphic parameter (Fig. 2b) and, due to this, the quantity of C released to the atmosphere was

lower for more organic and acidic soils.

The values of the averaged annual soil CO₂ emissions found for these broadleaf autochthonous tree species are slightly higher than the results found for coniferous forests from the same area (Carrasco 2008).

When the results obtained for each season of the year were considered, a similar trend in both types of ecosystems was observed along the whole studied period, clear seasonal variations being revealed. Although intra- and interspecific differences were found, minimum values of the mean soil CO₂ emissions to the atmosphere were always observed during the winter season for both birch and oak ecosystems, these values differing significantly (ANOVA, $P < 0.05$, $n = 12$) from spring, summer and autumn emissions (Fig. 3). In all cases, maximum values of the mean soil CO₂ emissions were measured in the hotter seasons, particularly in the summer with values surpassing twice the soil C emissions observed during the winter (Table 1).

Furthermore, a very similar pattern was observed when values of the sub-

Table 1. Averaged values (mean $\pm$ standard deviation) of some edaphic parameters related to the soil C cycle for oak and birch forest ecosystems.

Parameters		<i>Quercus robur</i> L. n = 12	<i>Betula alba</i> L. n = 12
pH		4.65 $\pm$ 0.36	4.56 $\pm$ 0.29
Soil organic carbon (0-15 cm depth), kg C.m ⁻²		13.02 $\pm$ 3.35	9.89 $\pm$ 3.79
Soil CO ₂ emissions (annual mean), g CO ₂ .m ⁻² h ⁻¹		1.11 $\pm$ 0.25	1.24 $\pm$ 0.31
Seasonal soil CO ₂ emissions, g CO ₂ .m ⁻² h ⁻¹	WINTER	0.67 $\pm$ 0.27	0.61 $\pm$ 0.19
	SPRING	1.30 $\pm$ 0.34	1.46 $\pm$ 0.49
	SUMMER	1.39 $\pm$ 0.44	1.72 $\pm$ 0.55
	AUTUMN	1.07 $\pm$ 0.42	1.18 $\pm$ 0.62

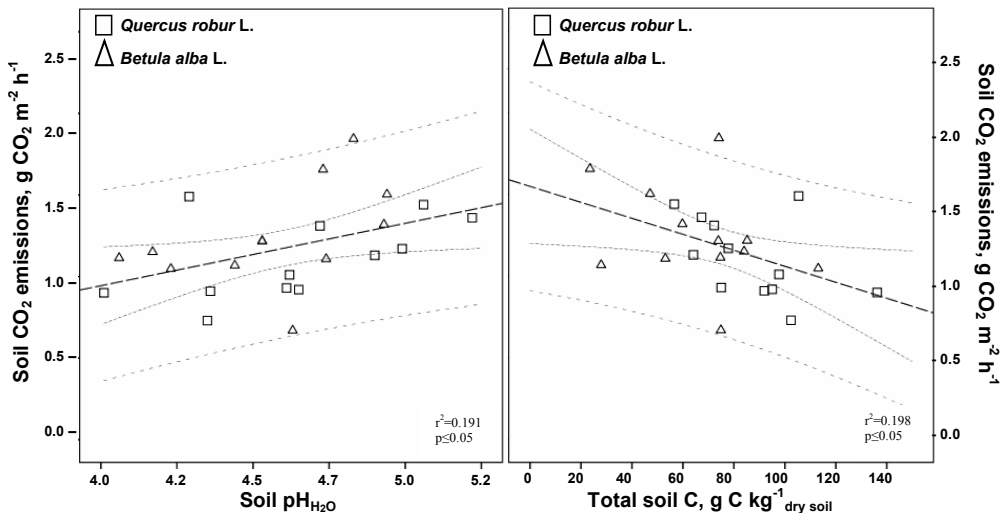


Fig. 2. Relationship between the annual averaged soil CO₂ emission rates and some edaphic characteristics.

surface edaphic temperature were analysed (Fig. 4), since soil CO₂ emission rates significantly correlated with this instant edaphic temperature, for both *Betula alba* or *Quercus robur* ecosystems (Fig. 5), this correlation being even slightly stronger in *B. alba* plots. Other authors also found a similar relation between these two parameters, the soil temperature and CO₂ exchange rates (Asensio et al. 2007, Shi et al. 2009).

Conclusions

Based on the experimental results obtained in this study, the following conclusions can be drawn:

- The tree species determines the total soil C content, oak forests normally exhibiting more organic soils than birch ecosystems.
- Significant seasonal variations of soil CO₂ emission rates were observed in both types of deciduous ecosystems.

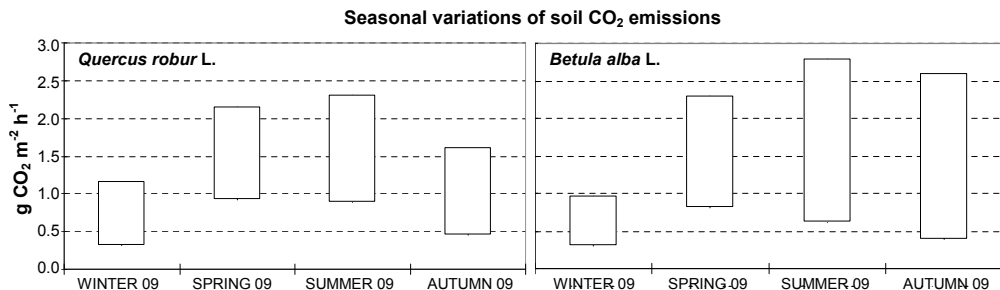


Fig. 3. Range of the soil CO₂ emissions in oak and birch ecosystems for the different seasons of the year.

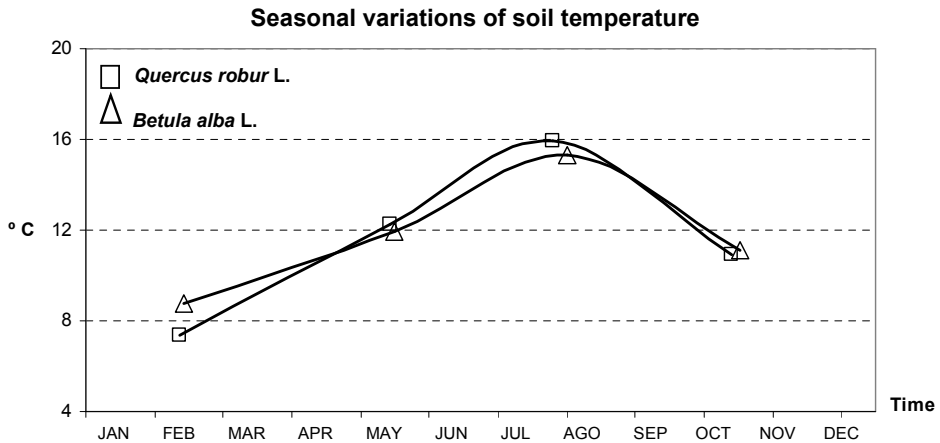


Fig. 4. Averaged subsurface edaphic temperature (°C) in oak and birch forests obtained simultaneously to the determination of the seasonal soil CO₂ emission rates.

- Edaphic emissions were slightly lower in oak woodlands as compared with birch forests and in both tree species the soil pH have a significant influence on the edaphic C effluxes.
- A significant correlation between the soil CO₂ emission rate and the

edaphic temperature were observed in the two types of ecosystems considered.

- These results can be used as a tool for forest management and they can contribute not only to quantify the total CO₂ released to the atmosphere in the

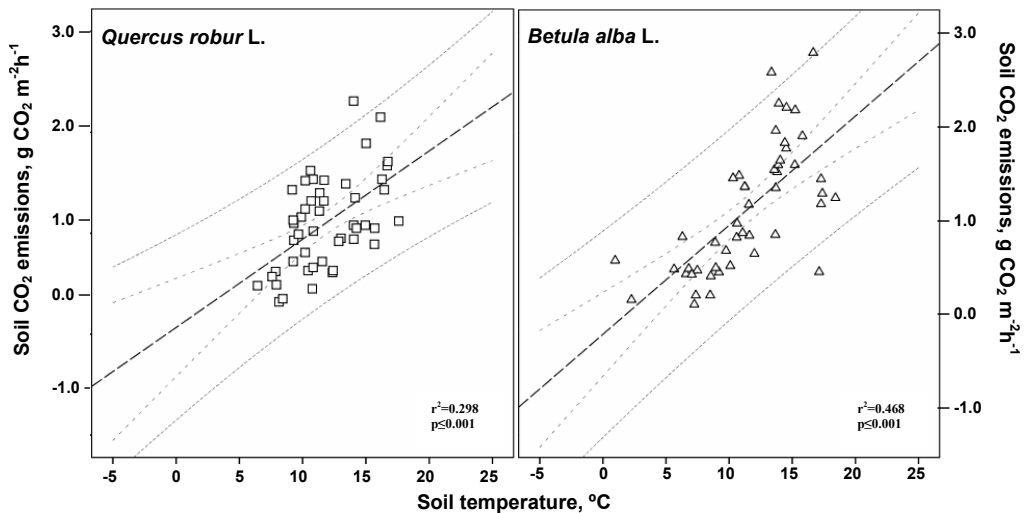


Fig. 5. Relationship between the averaged soil CO₂ emission rate and the subsurface soil temperature seasonally determined in oak and birch forests.

contemporary climatic conditions but also to evaluate the role of these deciduous forests in the global terrestrial C cycle.

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References

- Adams R.M.**, Hurd B.H., Reilly J. 1999. Agriculture and global climate change: A Review of Impacts to U.S. Agricultural Resources. The Pew Center on Global Climate Change, Arlington, VA.
- Asensio D.**, Peñuelas J., Ogaya R., Llusià J. 2007. Seasonal soil and leaf CO₂ exchange rates in a Mediterranean holm oak forest and their response to drought conditions. *Atmospheric Environment* 41: 2447–2455.
- Carrasco B.** 2008. Efecto del tratamiento silvícola sobre la dinámica de la materia orgánica edáfica. Implicaciones en el cambio global. Dissertation Degree, University of Santiago de Compostela, 113 p.
- Díaz-Maroto I.J.**, Vila-Lameiro P., Silvapando F.J. 2005. Autoécologie des chênaies de *Quercus robur* L. en Galice (Espagne). *Annals of Forest Science* 62: 737–749.
- Díaz-Maroto I.J.**, Fernández-Parajes J., Vila-Lameiro P. 2007. Chemical Properties and Edaphic Nutrients Content in Natural Stands of *Quercus pyrenaica* Will in Galicia, Spain. *Eurasian Soil Science* 40: 522–531.
- Fernandez I.**, Cabaneiro A., González-Prieto S. 2004. The use of isotopic tracer (¹³C) to monitor soil organic matter transformations caused by heating. *Rapid communications in Mass Spectrometry* 18: 435–442.
- Fernandez I.**, Cabaneiro A., González-Prieto S. 2006. Partitioning CO₂ Effluxes from an Atlantic Pine Forest Soil between Endogenous Soil Organic Matter and Recently Incorporated ¹³C-Enriched Plant Material. *Environmental Science & Technology* 40: 2552–2558.
- Gallardo J.F.**, Merino A. 2007. El ciclo del carbono y la dinámica de los sistemas forestales. In: El papel de los bosques españoles en la mitigación del cambio climático (Bravo F., Ed.). Fundación Gas Natural, Spain.
- Houghton J.T.**, Meira Filho L.G., Callander B.A., Harris N., Kattenberg A., Maskell K. 1996. Climate change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.
- Lashof D.A.**, Ahuja D.R. 1990. Relative Contribution of Greenhouse Emissions to Global Warming. *Nature* 344: 529–531.
- Leirós M.C.**, Trasar-Cepeda C., Seone S., Gil-Sotres F. 1999. Dependence of mineralization of soil organic matter on temperature and moisture. *Soil Biology and Biochemistry* 31: 327–335.
- Lindzen R.S.** 1994. On the scientific basis for global warming scenarios. *Environmental Pollution* 83: 125–134.
- Mansson K.F.**, Falkengren-Grerup U. 2003. The effect of nitrogen deposition on

nitrification, C and nitrogen mineralization and litter C:N ratios in oak (*Q. robur*) forests. Forest Ecology and Management 179: 455–467.

Sánchez-Rodríguez F., López C., Rodríguez-Soalleiro R., Español E., Merino A. 2002. Influence of edaphic factors on the productivity of *Pinus radiata* D. Don

plantations in NW Spain. Forest Ecology and Management 171: 181–189.

Shi A., Li Y., Wang S., Wang G., Ruan H., He R., Tang Y., Zhang Z. 2009. Accelerated soil CO₂ efflux after conversion from secondary oak forest to pine plantation in southeastern China. Ecological Research 24 (6): 1257–1265.

COMPARING THE POTENTIAL CARBON MINERALIZATION ACTIVITY OF THE SOIL ORGANIC MATTER UNDER TWO BROADLEAF AUTOCHTHONOUS TREE SPECIES FROM THE NW OF SPAIN (*QUERCUS ROBUR* L., *BETULA ALBA* L.)

Irene Fernandez, Beatriz Carrasco, and Ana Cabaneiro

Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia, Consejo Superior de Investigaciones Científicas (CSIC), Apartado 122, E-15780 Santiago de Compostela, Spain. E-mail: ifernandez@iiaag.csic.es

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Abstract

The importance of the soil organic matter pool on the terrestrial carbon (C) cycle is clearly reflected by the fact that every year around 10% of the atmospheric C circulates throughout the biomass and the soil. Not only the size of this pool but also the composition and lability of the organic compartments have a notable influence on the soil CO₂ emissions, since its nature determines the resident times and persistence of the different C compounds into the soil. Therefore, two different types of deciduous forests of the temperate-humid zone (*Quercus robur* L. or *Betula alba* L.) were studied in order to evaluate the biodegradative processes of their soil organic matter. In Galicia (Northwestern Spain), 24 permanent forest plots were established to determine their potential C mineralization activity using long term incubation experiments that were carried out under laboratory controlled conditions. The cumulative data of the potential soil CO₂ effluxes were fit to a double exponential kinetic model that considers two C pools of different lability and different instantaneous mineralization rates in order to estimate the labile and recalcitrant C pools in these soils. Differences on the total soil C content as well as on the soil organic matter mineralization kinetics between both forest types were found and the implications of the results obtained in the global warming mitigation strategies are discussed. The results obtained are useful not only to evaluate the quantity of CO₂ released to the atmosphere from these Atlantic forests but also to contribute to a better prediction of the C balance in a global warming scenario.

Key words: *Betula alba*, carbon mineralization kinetics, CO₂ release, global warming, labile and recalcitrant carbon pools, *Quercus robur*, terrestrial carbon cycle.

Introduction

The Earth's carbon (C) budget is distributed among the different biogeochemical compartments, with permanent

flux exchanges between them. Within terrestrial ecosystems, forests play an important role in sequestering and storing C (Sampson 1995) and deciduous forests from the mild temperate zone

of the Northern Hemisphere are one the major terrestrial biomes.

In the NW of Spain (Galicia), located within the temperate-humid zone, both coniferous and deciduous forest types are found. However, the typical Galician forest is formed by different species of deciduous trees, like oaks and birches, these broadleaf forests being valuable natural resources. Pedunculate oak (*Quercus robur* L.) is the third most abundant tree species in Galicia (Xunta de Galicia 2001), with annual harvest volume of 74,500 m³ in the period 1995-2001. Oak forests cover 188,000 ha in this region (Xunta de Galicia 2001) and are mainly derived from natural regeneration (Gorgoso-Varela et al. 2008). Birch (*Betula alba* L.) stands currently cover 32,000 ha and birch is the fifth most abundant species in terms of number of trees in Galicia, after *Eucalyptus globulus*, *Pinus pinaster*, *Quercus robur* and *Quercus pyrenaica*.

Soils have a great importance on the global C cycle due to their long term capacity to retain C (several centuries for the more recalcitrant compounds) as well as due to the magnitude of the C fluxes involved, since every year around 10% of the atmospheric C circulates throughout the biomass and the soil (Oades 1989). In particular, soil C pool is a major component of the global C cycle (Lal and Follett 2009) and it is the key factor in stabilization, accumulation, and dynamics of terrestrial organic C (Andreux 1996). It also strongly influences sustainability, fertility, and productivity of forest ecosystems (Schoenholtz et al. 2000, Wander and Drinkwater 2000), particularly in acidic and sandy soils where fertility is mainly determined by soil organic mat-

ter content and quality (Fernandez et al. 2006). Thus, understanding soil organic matter dynamics and the contributions of different organic pools to the total CO₂ effluxes from forest soils as well as the mechanisms involved in soil organic matter mineralization kinetics is important since it influences main forest and environmental processes from a climate change perspective.

Therefore, the aim of this research is to study the soil C dynamics in two different types of deciduous forests (*Quercus robur* L. or *Betula alba* L. ecosystems) located in Galicia (Northwestern Spain) in order to determine the potential C mineralization activity and to compare the soil organic matter quality under these two types of temperate ecosystems.

Methods and Study Area

The oak and birch forest ecosystems studied, developed over acidic (granite or schists) parent material (Fig. 1) and located in the NW of Spain, were selected to represent the whole range of stand densities, undergrowth types and growing conditions in Galician forests for these two tree species. None or scarce silvicultural treatments were applied to the forests selected and the spatial distribution of the different plots accompanied by the main meteorological records corresponding to the period of study (temperature and rainfall values during the year 2009) are described by Fernandez et al. (2010).

After the removal of the litter and the duff, a representative soil sample (composed by mixing 24 subsamples regularly taken following a squared



Fig. 1. Soil profiles developed over acidic parent material: oak forest over granite (a), oak forest over schists (b) and birch forest over schists (c).

pattern) from the upper layer of the A horizon (0–15 cm) were collected in winter to determine the main soil char-

acteristics. The soil pH was measured using a 1:2.5 soil:water ratio. The field capacity was assessed at 10 kPa in a



Fig. 2. Respirometric system used to perform the soil incubation experiments.

Richard's membrane-plate extractor. Total organic C was determined by dry combustion in a Carmograph 12 (Whostoff, Germany), with primary and secondary ovens at 90°C and 40°C, respectively. Total organic N was determined by Kjeldahl digestion using the method developed by Bremner (1965).

For each forest plot, a long term incubation of representative soil samples was carried out under controlled conditions

(28°C and 75% field capacity). During 3 months, the C mineralized was periodically determined by measuring the CO₂ produced during the biodegradative process (Fig. 2). The cumulative data of the potential soil CO₂ effluxes were fit to a double exponential kinetic model (Eq.1) that considers two C pools of different lability and different instantaneous mineralization rates in order to estimate the labile and recalcitrant C pools in these soils.

$$\text{Eq.1: } C_t = C_0(1-e^{-kt}) + (C-C_0)(1-e^{-ht})$$

Ct: cumulative C (g.kg⁻¹) released after time t (d), C₀: potentially mineralizable C in a labile pool with an instantaneous mineralization rate k (d⁻¹), C: total amount of C (g.kg⁻¹) present in the soil sample, (C-C₀): amount of C (g.kg⁻¹) in a recalcitrant pool with an instantaneous mineralization rate h (d⁻¹).

Statistical analyses were performed using the computer software SPSS

15.0 (2006). ANOVA test was applied to analyse the possible variations between oak and birch soils.

Results and Discussion

Soils from the selected forest plots, all with acidic parent materials, exhibited pH values between 4.0 and 5.2 (Table 1). Despite the high variability of the soil organic matter content of the different forest ecosystems, the mean C content of soils from oak plantations (87 g C.kg⁻¹ d.s.) was significantly higher (ANOVA, p<0.05, n=24) than the mean C content from birch forests (66 g C.kg⁻¹ d.s.). The values found in these soils are in agreement with the results obtained for different types of forest soils of this region (Sánchez-Rodríguez et al. 2002; Fernandez et al. 2004; Diaz-Maroto et al. 2005,

Table 1. Range of values of some edaphic parameters related to the soil C cycle for oak and birch forest ecosystems.

Parameters	<i>Quercus robur</i> L.		<i>Betula alba</i> L.	
	Granite	Schists	Granite	Schists
Soil pH	4.0–5.2	4.3–4.9	4.1–4.9	4.4–4.9
Total soil C, g C.kg ⁻¹ d.s.	56.6–136.2	64.1–105.4	47.1–113.1	27.9–85.2
Total soil N, g N.kg ⁻¹ d.s.	3.3–6.8	4.2–6.7	3.3–7.7	2.7–5.7
C-to-N ratio	14–20	13–18	14–16	13–17
C mineralized, g C.kg ⁻¹ d.s.	1.51–3.72	2.08–3.55	1.33–3.07	1.17–2.65
C mineralization coefficient, %	1.98–3.20	2.73–3.38	2.25–3.15	2.77–5.65
Soil labile C, %	0.62–1.36	0.65–1.02	0.33–1.15	0.96–1.28

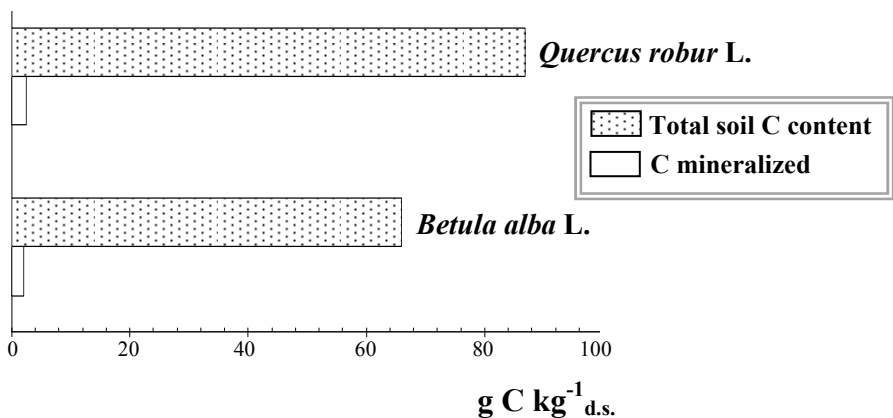


Fig. 3. Total soil C content and quantity of C mineralized at the end of the incubation.

2007; Fernandez et al. 2006) and with soils from other countries of similar latitudes (Mansson and Falkengren-Grerup 2003). Also, differences on the soil organic matter quality between both tree species were observed, oak ecosystems showing, in general, more elevated values of the C-to-N ratio (mean C-to-N ratio = 18 ± 2) as compared with birch forests (mean C-to-N ratio = 15 ± 2). Thus, the organic matter of both types of ecosystems could be considered, according to the classification of temperate forest humus (Duchaufour 1977), an intermediate type between *moder* and *mull*.

The averaged quantity of $\text{CO}_2\text{-C}$ evolved from oak soils at the end of the incubation ($2.4 \text{ g C kg}^{-1} \text{ d.s.}$) was slightly

higher than the amount released by birch ($2.1 \text{ g C kg}^{-1} \text{ d.s.}$) soils (Fig. 3).

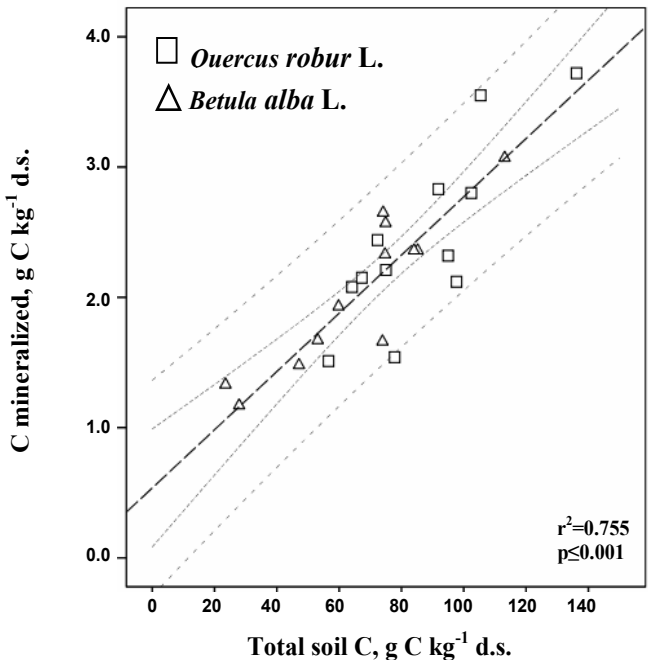


Fig. 4. Relationship between the quantity of C mineralized and the total soil C content in oak and birch forests.

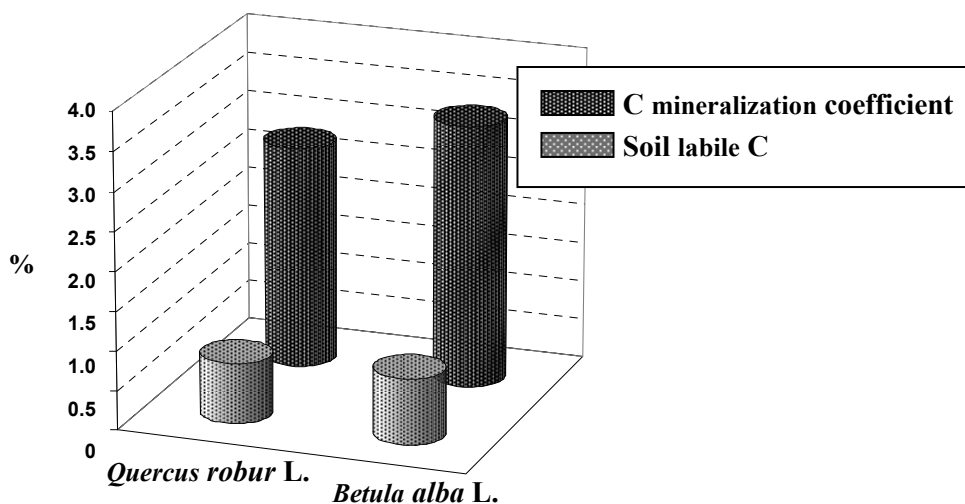


Fig. 5. C mineralization coefficient and percentage of labile C for oak and birch forests.

A significant correlation between the C mineralized by the soil during the incubation period and the total soil C content was found ($P < 0.001$) in both type of forests (Fig. 4).

On the other hand, the mean soil C mineralization coefficient was slightly higher for birch (3.3%) ecosystems as compared with oak (2.8%) forests (Fig. 5), this activity index being positively correlated with the proportion of labile C in the soil ($r^2 = 0.202$, $P < 0.05$).

Also, the C mineralization coefficient statistically correlated with the total soil C content in birch forests but no significant correlation was observed in oak ecosystems (Fig. 6). In general, the values of this activity index can be considered as relatively low, but typical for acid soils from the same area (Fernandez et al. 2006). Although differences on the soil organic matter characteristics between oak and birch ecosystems were found, differences on the C mineralization kinetics were not significant, maybe due to the intraespecif-

ic variability derived from the high number of factors taken into account.

Conclusions

Based on these experimental results, the following conclusions can be drawn:

- Within this temperate-humid zone, oak forests exhibited a significantly higher soil C content than birch plantations.
- In general, for both tree species, a relationship between the total soil C content and the quantity of C mineralized during the 12 weeks of incubation was found, highly organic soils potentially releasing more C effluxes than less organic ones.
- The soil C mineralization coefficient strongly correlated with the soil organic matter content for birch forests, but not for oak plantations.
- These results show the potential quantity of CO_2 that can be released to the atmosphere from these Atlantic

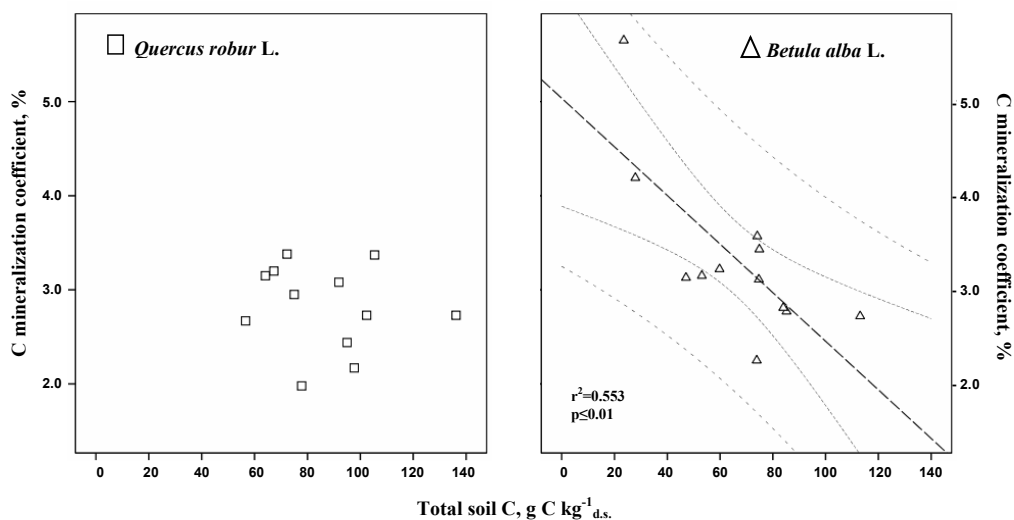


Fig. 6. Relationship between the total soil C content and the C mineralization coefficient in oak and birch forests.

forests and can contribute to a better prediction of the C balance in a global warming scenario since:

i) The success of a sustainable silviculture seems to be related with both mineralization indices: with the C mineralization coefficient in *B. alba* forests and with the total quantity of C mineralized in *Q. robur* plantations.

ii) In comparison with birch forests, oak ecosystems seems to show a higher soil C retention capacity due to a higher resistance to biodegradation of the recalcitrant C pool of their soil organic matter.

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References

- Andreux F. 1996. Humus in world soils. In: Pico, A. (Ed.) Humic Substances in Terrestrial Ecosystems. Elsevier Science, Amsterdam: 45–100.
- Bremner J.M. 1965. Organic forms of nitrogen. In: Methods of soil analysis. Vol II. Chemical and microbiological properties,

ASA, Madison, Wisconsin: 1238–1255.

Díaz-Maroto I.J., Vila-Lameiro P., Silva-Pando F.J. 2005. Autoécologie des chênaies de *Quercus robur* L. en Galice (Espagne). *Annals of Forest Science* 62: 737–749.

Díaz-Maroto I.J., Fernández-Parajes J., Vila-Lameiro P. 2007. Chemical Properties and Edaphic Nutrients Content in Natural Stands of *Quercus pyrenaica* Will in Galicia, Spain. *Eurasian Soil Science* 40: 522–531.

Duchaufour P. 1977. Atlas ecológico de los suelos del mundo. Toray-Masson. Barcelona.

Fernandez I., Cabaneiro A., González-Prieto S. 2004. The use of isotopic tracer (^{13}C) to monitor soil organic matter transformations caused by heating. *Rapid communications in Mass Spectrometry* 18: 435–442.

Fernandez I., Cabaneiro A., González-Prieto S. 2006. Partitioning CO_2 Effluxes from an Atlantic Pine Forest Soil between Endogenous Soil Organic Matter and Recently Incorporated ^{13}C -Enriched Plant Material. *Environmental Science & Technology* 40: 2552–2558.

Fernandez I., Carrasco B., Cabaneiro A. 2010. Exchange of CO_2 through the soil-atmosphere interphase in bradleaf autochthonous forests from the NW of Spain (*Quercus robur* L. or *Betula alba* L.): intra-annual variations. *Forestry Ideas* No 2: 250–257.

Gorgoso-Varela J.J., Rojo-Alboreca A., Afif-Khouri E., Barrio-Anta M. 2008. Modelling diameter distributions of birch (*Betula alba* L.) and pedunculate oak (*Quercus robur* L.) stands in northwest Spain with the beta distribution. *Investigación*

Agraria: Sistemas y Recursos Forestales 17: 271–281.

Lal R., Follett R.F. 2009. Soil carbon sequestration and the greenhouse effect. Ed. SSSA, USA, 452 p.

Mansson K.F., Falkengren-Grerup U. 2003. The effect of nitrogen deposition on nitrification, C and nitrogen mineralization and litter C:N ratios in oak (*Q. robur*) forests. *Forest Ecology and Management* 179: 455–467.

Oades J.M. 1989. An introduction to organic matter in mineral soils. In *Minerals in Soil Environments*. SSSA Book Series 1: 89–159.

Schoenholtz S.H., VanMiegroet H., Burger J.A. 2000. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. *Forest Ecology and Management* 138: 335–356.

Sampson R.N. 1995. Designing forestry projects for climate action plan implementation. *Interciencia* 20: 373.

Sánchez-Rodríguez F., López C., Rodríguez-Soalleiro R., Español E., Merino A. 2002. Influence of edaphic factors on the productivity of *Pinus radiata* D. Don plantations in NW Spain. *Forest Ecology and Management* 171: 181–189.

Wander M.M., Drinkwater, L.E. 2000. Fostering soil stewardship through soil quality assessment. *Applied Soil Ecology* 15: 61–73.

Xunta de Galicia 2001. O monte galego en cifras. Consellería de Medio Ambiente. Dirección Xeral de Montes e Medio Ambiente Natural, 226 p.

INITIAL RESULTS OF PLANTATIONS OF *LARIX EUROPAEA* L. ESTABLISHED FOR RECULTIVATION

Dragana Dražić, Milorad Veselinović, Biljana Nikolić, Branislava Batos,
Nevena Čule, Vesna Golubović-Ćurguz*, Suzana Mitrović

Institute of Forestry, Kneza Viseslava 3, Belgrade, Serbia.

*E-mail: vesnacurguz@gmail.com

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Abstract

The aim of the present study was to study success and development of coniferous trees for the needs of intensive plantations for biomass production, used in the recultivation process of mine-spoilt banks of opencast mines in the Kolubara basin. For this purpose, an experiment with European larch seedlings, aged 2+0, which lasted for four years in plots with seven repetitions was set. The distance between the rows with the seedlings was 1 m, and 2.5 m between the plants in a row. Out of the initial 1,000 seedlings 90.5% and 77.4 % survived in the first and second year after planting, respectively. At the later stages, the decay of the plants almost stagnated (up to 74.8%). From autumn 2007 to spring 2010 total height increment of seedlings was 1.17 m. Total root collar diameter increment was nearly 1.9 cm. The highest increment was reported during the last vegetation of seedlings (in spring 2010): diameter increment was about 1.2 cm and height increment was about 0.9 m.

Differences between seedlings from sludge treated and untreated, control deposols (measured in spring 2010), were significant. Treated seedlings showed better results in mean root collar diameter as well as in mean height of seedlings (2.5 cm and 1.7 m, respectively) in comparing with untreated (control) ones (1.9 cm and 1.0 m, respectively). The results obtained justify the future more intensive establishment of plantations of this fast-growing conifer species. European larch also appears to be suitable for growing on mechanically damaged substratum.

Key words: European larch, survival of seedlings, growth, increment, recultivation.

Introduction

The European larch (*Larix europaea* Lam. et DC.) is a conifer naturally prevalent in disjunct areas in the high mountain massifs of Central Europe. The mode of distribution promotes the existence of a number of geographic races, subspecies and varieties (Vidaković 1982). Larch

is a pioneer-species. The formation of heartwood begins at a very early age, and therefore, it has a large proportion of heartwood even at a relatively young age. This makes it usable for purposes where chemically treated wood was used earlier (Bergstedt and Lyck 2007).

Due to its rapid growth and height increment, as well as resistance to air pollu-

tion and tolerance to different soil types, the European larch is widely prevalent beyond its areal, in artificially established plantations at different altitudes (in forest plantations, parks, forest parks, etc.).

The provenances from Poland and Sudetes Mountains showed the best results, as well as the second generation of Danish sources (Brandt 1977 and Bornebusch 1948, ex Bergstedt and Lyck 2007). Since the first experiments conducted at waste dump sites of opencast mines in Indiana, USA (cited in Dražić 2002), European larch has performed successfully in many other forest plantations. It was due to the improvement of soil characteristics resulting from rapid accumulation of leaf litter, for instance in Germany and Pennsylvania, as well as in height and width increment, for instance in Denmark (Medvick 1973, Illner et al. 1967, Miles et al. 1973 and Schlatzer 1973, respectively, all cited in Dražić 2002), Bulgaria (Milev et al. 2004) and Serbia (Dražić 2002, Šmit et al. 1997, etc.). Apart from the European larch, other *Larix* species were also used for afforestation (Lukkarinen et al. 2009) with variable success among provenances.

Sludge is frequently used to improve the characteristics of sandy (Gál 1984), and degraded soils (Dželetović et al. 2009, and references therein), since it simultaneously influences both physical and chemical characteristics of soil, combined with fast plant growth (Hall and Coker 1983). The distribution and availability of heavy metals presents an open issue (Tsadilas et al. 1995). But there was no evidence that toxic materials and heavy metals would accumulate in the trees at higher quantities of sludge (Gál 1984). The effects of heavy-metal-containing sewage sludge on the soil microbial community were also ex-

amined (Bååth et al. 1998). Community tolerance to specific metals increased the most when the same metal was added to the soil. There were also indications of co-tolerance to metals whose concentration had not been elevated by the sludge treatment. Therefore, it is expected that the sludge treatment will have positive impact not only on the growth of larch seedlings, but also on other flora on degraded soil, as well as chemical and physical characteristics of deposol.

The aim of the study was to investigate the success of the development of the larch trees for the needs of the short-rotation intensive plantations for biomass production in the recultivation process of mine-spoilt banks of opencast mines.

Material and Methods

The experiment was set in the Kolubara basin, Baroševac locality, with European larch seedlings, aged 2 + 0. It lasted for four years. The distance between rows with seedlings was 1 m, and 2.5 m between the plants in a row, in seven replications (plots, 6 x 25 seedlings in one plot). The distance between the seedlings enabled the mechanical processing during the cycle of the plantation establishment. The care measures were regularly applied in the seedlings, including supplementary fertilization.

The plantations were established on a soil substratum belonging to the sandy loam class, with slight acid reaction (pH = 4.9) and low humus concentration (0.94%). C/N ratio was low (2.62), concentration of phosphorus was also low

(< 1 mg.g⁻¹ of substratum), but concentration of potassium was medium (13.2 mg per 100 g of substratum). In the spring of the first year after planting, the initial nourishment was carried out with 30 g of NPK mineral fertiliser per seedling in order to ensure the highest planting rate and initial growth. The nourishment of one part of seedlings was carried out with sludge, which, according to its texture composition, comes under a loam class. It was characterised by a mild alkaline reaction of soil solution. The pH of sludge was 7.3, while substitution pH was 6.6. The concentration of total humus was exceptionally high (73.48%), the concentration of total nitrogen was low (0.64%), the C/N ratio was high (66.6) and the concentration of phosphorus (5.5 mg per 100 g of substratum) and potassium (8.6 mg per 100 g of substratum) were within

the low limits. Determining the success of development of European larch seedlings on the sample plot was done by using literature sources on the same and other fast-growing conifers, established on similar and different substrata.

Results

Out of the initial about 1,000 seedlings, 90.5% and 77.4 % survived in the first and second year after the transplation, respectively. At the later stages, the decay of the plants almost stagnated (74.8%, Table 1). Total height increment of seedlings (from autumn 2007 to spring 2010) was 1.17 m. Total root collar diameter increment of seedlings was 1.86 cm. During the first two years after the transplation (2007 and 2008) the

Table 1. Survival, growth and increment of larch seedlings (2007–2010).

Parameters	Spring 2007	Autumn 2007	Autumn 2008	Spring* 2009	Spring 2010	Total Increment 2007–2010
Total number of seedlings	1009	913	781	781	755	
Survival, %	100	90.5	77.4	77.4	74.8	
Height, m ($\bar{X} \pm S_x$)		0.34 ± 0.40	0.38 ± 0.50	0.58 ± 1.14	1.51 ± 2.56	
Height increment, m			0.04	0.20	0.93	1.17
Root collar diameter, cm ($\bar{X} \pm S_x$)		0.51 ± 0.05	0.87 ± 0.12	1.22 ± 0.18	2.37 ± 0.32	
Root collar diameter increment, cm			0.36	0.35	1.15	1.86

* Measurements in 2009 were done after the beginning of vegetation period.

average root collar diameter and its increment were quite low. The highest increment was reported during the last vegetation of seedlings (in spring 2010): diameter increment was about 1.2 cm and height increment was about 0.9 m.

Differences between seedlings from sludge treated and untreated, control deposols (measured in spring 2010), were significant (Table 2). Treated seedlings showed better results in mean root collar diameter as well as in mean height of seedlings (2.51 cm and 1.68 m, respectively) in comparing with untreated (control) ones (1.94 cm and 0.97 m, respectively). Furthermore, height of seedling showed several times greater variability than root collar diameter, both in treated and control seedlings (expressed by the standard deviation, Table 2).

Discussion and Conclusion

The obtained results of height and width growth and increment were compared to the previously analysed increment of larch plantations also planted on deposols of opencast mines in the

Kolubara basin, plot D (Dražić 2002). The dynamics of diameter development of larch seedlings in this sample plot was approximately the same as the development dynamics of an average stand stem in a larch plantation planted on deposol of heavier mechanical composition, but significantly lower than those planted on deposol of lighter mechanical composition. These differences obviously depend on the mechanical and chemical properties of deposols. In terms of height and height increment, larch seedlings had lower height and height increment in comparison to the previously planted larch plantations, regardless of mechanical composition of deposol. However, it should be considered that these larch plantations were planted more thickly and have not been thinned.

The average larch height increment (up to the 16th year) on deposols of opencast mines in the Kolubara basin was 0.88 m and volume increment $4\text{--}10.37\text{ m}^3\cdot\text{ha}^{-1}$ (Šmit and Veselinović 1996). Larch has also shown the largest average volume increment, as compared to *Pinus nigra* and *Pinus sylvestris*, as well to numerous broadleaves. Having in mind these data, along with the fact

Table 2. Differences between sludge treated and untreated (control) larch seedlings (2010).

Measured properties	Root collar diameter, cm		Height, m	
Treated / Control	Treated	Control	Treated	Control
No of seedlings	571	183	571	183
Minimum value	0.90	0.70	0.12	0.29
Maximum value	5.90	4.20	3.80	3.20
X ± Sx	2.51 ± 0.35	1.94 ± 0.34	1.68 ± 2.66	0.97 ± 2.63
S ± Ss	8.34 ± 0.25	8.20 ± 0.24	63.45 ± 1.88	62.90 ± 1.86

X – mean; **Sx** – standard error of the mean;

S – standard deviation; **Ss** – standard error of the deviation.

stated by Dražić (2002) that the larch, in period between the 6th and 13th year, shows relatively consistent ascending development, and that the medium stand tree experiences abrupt growth between fifth and ninth year, it could be assumed that the larch trees analysed in this study will continue their intensive growth and development, in particular the ones treated with sludge. When studying the impact of sludge quantity on development of *Larix laricina* seedlings Couillard and Grenier (1989) did not found whether the different sludge quantity influenced the seedling growth, but they concluded that there was a significant, positive correlation between the growth of seedlings and the phosphorus and nitrogen content of their tissues, as well as that these elements originated from the wastewater sludge. The obtained results in this study justify the future more intensive establishment of plantations of this fast-growing conifer species. European larch also appears to be suitable for growing on mechanically damaged substratum.

References

- Bååth E., Díaz-Raviña M., Frostegård A., Campbell C.D. 1998. Effect of metal-rich sludge amendments on the soil microbial community. *Applied Environmental Microbiology* 64: 1238–1245.
- Bergstedt A., Lyck C. 2007. Larch wood – a literature review (eds.). *Forest & Landscape Working Papers* 23, Forest & Landscape Denmark, 115 p.
- Brandt K. 1977. Hybridlærk i hedeskovbruget. *Hedeselskabets tidsskrift* 98 (7/8): 155–160.
- Couillard D., Grenier Y. 1989. Effect of applications of sewage sludge on N, P, K, Ca, Mg and trace element contents of plant tissues. *Science of the Total Environment* 80 (2–3): 113–125.
- Dželetović Z.S., Filipović R.M., Stojanović D.Dj., Lazarević M.M. 2009. Impact of lignite washery sludge on mine soil quality and poplar trees growth. *Land Degradation & Development* 20 (2): 145–155.
- Dražić D. 2002. Multifunkcionalna valorizacija predela i ekosistema stvorenih rekultivacijom odlagališta površinskih kopova Kolubarskog basena. Monograph, Savezni Sekretarijat za rad, zdravstvo i socijalno osiguranje – Sektor za životnu sredinu, Beograd, 261 p.
- Gál J. 1984. Sludge utilization by trees in Hungary. *Waste management and research* 2 (4): 359–367.
- Hall J.E., Coker E.G. 1983. Some effects of sewage sludge on soil physical conditions and plant growth. In: G. Catroux et al. (eds.) *The influence of sewage sludge application on physical and biological properties of soil*. D. Reidel, Dordrecht, Holland: 43–61.
- Lukkarinen A.J., Ruotsalainen S., Nikkanen T., Peltola H. 2009. The growth rhythm and height growth of seedlings of Siberian (*Larix sibirica* Ledeb.) and Dahurian (*Larix gmelinii* Rupr.) larch provenances in greenhouse conditions. *Silva Fennica* 43(1): 5–20.
- Milev M., Kitin P., Takata K., Iliev I., Nakada R. 2004. The introduction of *Larix* in Bulgaria – adaptation, growth and utilization. *IUFRO International Symposium Larix 2004. IUFRO Working Party S2.02-07 Larch Breeding and Genetic Resources, 2004, Kyoto & Nagano, Japan. Abstracts*: 50.
- Šmit S., Veselinović N. 1996. Rekultivacija pošumljavanjem odlagališta površinskih kopova rudnika lignita "Kolubara". Monograph, Institute of Forestry, Belgrade, 111 p.
- Šmit S., Veselinović N., Popović J., Minić D., Miletić Z., Marković D., Dražić D., Veselinović M., Vuletić D., Vučković B., Ratknić M. 1997. Recultivation by afforestation of minespoil banks of opencast

lignite mine "Kolubara". Monograph, Institute of Forestry, Belgrade, 147 p.

Tsadiras C.D., **Matsi** T., **Barbayiannis** N., **Dimoyiannis** D. 1995. The influence of sewage sludge application on soil properties and on the distribution and availability of

heavy metal fractions. Communications in Soil Science and Plant Analysis 26 (15–16): 2603–2619.

Vidaković M. 1982. Četinjače. Morfoloģija i varijabilnost. Monograph, JAZU i Sveučilišna naklada Liber, Zagreb, 710 p.

USE AND ASSORTMENT OF ORNAMENTAL EPIPHYTES SUITABLE FOR VERTICAL GARDENS IN THE INTERIOR

Mariela Shahanova

University of Forestry, 10 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria.

E-mail: m_shahanova@abv.bg

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Abstract

Vertical gardens are a special type of interior phytodesign, getting more and more popular in the world landscape practice. They are specific arrangements of ornamental plants created in the exterior as well as in the in-door spaces, forming a self-maintaining system. In the interior the most appropriate and commonly used are the epiphytes. Principles of nutrition and their requirements to the environmental conditions are prerequisites for a successful use in the vertical gardens. In specialized collections and sales network in our country, that offer a variety of ornamental epiphytes, the plants are used and often treated as terrestrial plants. This article presents an analysis of the species composition of epiphytes in real world models of vertical gardens and the assortment of such species kept in collections or commercially available in our country. A survey on the diversity of imported and grown epiphytes carried out in June-September 2009 is presented. Totally 10 sites are audited (9 commercial garden centres and also the greenhouses of the Institute of Ornamental plants – Negovan).

Key words: indoor vertical gardens, species variety of the vertical gardens, assortment of ornamental epiphytes.

Introduction

The construction of vertical gardens in the interior is connected exclusively with the usage of epiphyte and hemi-epiphyte tropical species. The use of representatives from the terrestrial species is restricted or admissible in vertical green constructions in the exterior. The use of epiphytes is recommended because of the vertical positioning of green plates, the specific fabric that substitutes the soil substrate and the method of attachment

of roots in it, as well as the specific nutrition of plants.

The description of the epiphytic flora from the end of the 19-th century till today has passed through different stages. (Lüttge 1989). About 28,000 epiphyte species from 65 families and 850 genera. (e.g. nearly 10% of the vascular flora) are defined.

The numerous studies in recent years require the supplementing and updating of the list of epiphytes. These changes concern mainly genera and families from Araceae, Asteraceae, Bromeliaceae,

Clusiaceae, Cactaceae, Cyclanthaceae, Ericaceae, Marccgraviceae, Melastomataceae, Onagraceae, Orchidaceae, Rubiaceae, Scrophulariaceae, Solanaceae. A contemporary research of De Guzman et al. (1998) enlarged the spectrum of epiphyte species from the genus *Peperomia* Ruitz. et Pav. On the basis of detailed field experiments Zotz and Schultz (2008) suggested some taxonomic changes.

The analysis (ex Lüttge 1989) shows that there are no epiphytes in Gymnosperms. Among all higher plants 23,466 species are epiphytes, included in 879 genera (7% of all higher plants genera). Most of the epiphytes belong to the angiosperms and they are mostly used as a source of *ornamental plants* (20,863 species or 89% of all epiphytes of the higher flora). The fern group follows (29% of the species variety in that group are epiphytes). Unfortunately the big variety of taxa among ferns hasn't been broadly used for ornamental purposes. At the same time about 90% of ferns cultivated as interior species are epiphytes or facultative epiphytes: members of *Nephrolepis*, *Davalia*, *Platynerium*, *Asplenium*, *Phlebodium* etc.

Monocots are the richest group of epiphytes among the angiosperms, being 67% of the epiphytes (522 genera) and 80% from the epiphyte species (16,610 species).

The richest in epiphytes is *Orchidaceae* with 440 genera (50% of all genera including epiphytes) and 13 951 species (67% of all epiphytes among the angiosperms). Unfortunately, a small part of the epiphyte forms of orchids are introduced as ornamentals and the introduced ones usually participate as parental forms of modern cultivated hybrids.

Families of higher plants containing less than 5 epiphytes are 45% of all plant families and 18% of the families contain only one epiphyte. As a whole, 52% of the epiphyte genera (454) include less than 5 epiphytes and 218 (25%) – just one.

The epiphytes is a group, often cultivated for ornamental purposes. In our country the richest collection of epiphytes belongs to the Botanical Garden of the Bulgarian Academy of Sciences. The extremely wide variety of taxa does not allow us to summarize them in this paper. Only two of the collections of representatives of the richest and most commonly used (in vertical gardens) families numbers as follows: 133 specimens of 121 taxa of Bromeliaceae Juss (Petrova 1995) and 67 samples from 51 taxa of Begoniaceae C. A. Agardh (Stoeva 1995). In addition to their rich assortment, these collections are valuable, because more epiphytes are grown for years and are adapted to conditions of high intensity of light. The collections of the University Botanical Gardens with its branch in Balchik are also rich. According to some reports from 2010 the collection of the richest in epiphytes families contains as follows (Sofia and Balchik): Bromeliaceae – 10 genera and 13 species (Sofia); 16 genera and 43 species (Balchik); Orchidaceae – 19 genera and 32 species (Sofia); 19 genera and 34 species (Balchik); Araceae – 4 genera.

Kabatliyska (2001) offers an analysis of the possible use and classification based on aesthetic features of one of the richest group of epiphytes (bromeliads).

The first steps in building a vertical garden in our country has made land.arh. Kamen Popov (from the 'Mr. Green'company). His recently built inte-

rior vertical garden covers 60 m² and includes representatives of over 15 taxa.

However, in flower production the great ornamental potential and variety of epiphytes is still partially studied. The peculiarities of epiphytes as an unique group from physiological point of view (Benzing 1990, 2000; Griffiths et al. 1986; Zotz and Schultz 2008) are still neglected in the technologies of ornamental plant production and breeding.

Aim and tasks

The aim of the present study is to describe the epiphyte species variety in real vertical gardens from the world practice as well as a survey on the assortment of ornamental epiphytes offered by commercial greenhouses in our country.

The following tasks are set:

1. A study of the plant diversity in the world famous vertical gardens and the deployment of plants according to their morphological peculiarities and ecological requirements;

2. Analysis of the taxa variety of epiphytes, imported and grown commercially in our country.

Methods and objects

The diversity of plants in vertical gardens (Patrick Blanc's projects and associates) has been defined by sketches and illustrative material. An analysis of the full sets of species used in 5 implemented projects is made, from which 3 in interior and 2 in exterior (for warm and moderate climate respectively). The predominant taxa were identified in 43 projects implemented by the same author (Blanc 2008). The deter-

mination of taxa to a different taxonomic level is in accordance with the available information and opportunities for identification.

The study of the greenhouses in the country was made in June-September 2009. The following greenhouses were studied: 3 in Sofia: the Flora Center Drujba, the Plantava Company and the L2-company; 4 in the Varna region: the "Mimosa" garden center, the "Exotic" garden center, the "Erica Co" garden center and the Flower shop "The Jungle"; 2 in the Burgas region: the "Burgastsvet" greenhouses and the Ravda village garden center "Kozarevi". Some ancillary data for the collections was received from the University Botanical Garden (Sofia) with branch in Balchik, and the Institute of Ornamental plants (Negovan).

Discussions

In general, the number of successful examples of vertical gardens is growing larger. Many companies engage themselves in technological development, improvement and maintenance of this definitely new type of interior landscaping.

1. Species composition of the vertical gardens.

Results of the plant diversity analyses of the studied objects are summarized in Table 1.

The analyses shows that in *interior panels* the ratio between the different growing types – epiphyte species (including facultative epiphytes too) to the terrestrial species is as follows: In **Project No 1** – epiphytes/terrestrials – 39:10;

Table 1. Species variety and characteristics based on the types of epiphytism.

No	Place	Total number of genus used	Total number of species used	E	N	N:E	E:N	He	Predominant genus
1	Interior, Cite de'espace Toulouse, France	37	56	32	10	4	3	5	<i>Ficus, Aechynanthus, Peperomia, Philodendron, Aechmea, Asparagus, Pilea, Rhipsalis, Rhoeo.</i>
2	Interior, Lexington, Great Britain	15	17	10	6	1	0	0	<i>Asparagus, Schefflera.</i>
3	Interior, French embassy New Delhi, India	15	29	15	7	0	1	6	<i>Aglaonema, Dracena, Ficus, Philodendron, Pilea, Schefflera.</i>
4	Exterior, Mall in Seoul, South Korea (tropical climate)	7	7	2	2	3	0	0	<i>Euonymus, Heloniopsis, Heuchera, Liriope, Mukdenia Pachysandra, Saxifraga.</i>
5	Exterior, Hotel Persing hall, Paris France	88	90	12	68	5	0	0	<i>Abutilon, Iris + hygrophytes (5 species).</i>

Legend: E – epiphytes; N – terrestrials; N:E – terrestrials as facultative (or occasional epiphytes); E:N – epiphytes as facultative terrestrials; He – hemi epiphytes.

epiphytes/semi epiphytes – 32:5; epiphytes/ facultative epiphytes – 32:7; In **Project No 2** – epiphyte/terrestrials – 11:6; no semi epiphytes or facultative epiphytes are found out. In **Project No 3** – epiphyte/terrestrials – 16:7; epiphytes:semi epiphytes – 15:6 and epiphytes/facultative epiphytes – 15:1.

The average percentage distribution of species is 57% for the epiphytes (no facultative epiphytes included) and 18% for the terrestrials. The representatives

of genera: *Ficus, Aechynanthus, Peperomia, Philodendron, Aechmea, Asparagus, Pilea, Rhipsalis, Rhoeo, Schefflera, Aglaonema, Dracaena* are prevailing.

As a whole *in the exterior* panels the epiphytes are neglected. This can be explained by the higher intensity of light and direct sunshine and the fact that most of them are built in temperate climate zones. The increasing presence of epiphytes in the lower part of the panels should be explained with the decreasing light and creation of warmer micro-

climate, permitting the inclusion of even more tender-frost representatives. Here the ratio between the epiphytes and terrestrials is as following: from 1:29 at the top to 10:14 at the basis of the panels, where the group of the shadow tolerant plants and hygrophytes species also increases. Among the species for the exterior terrestrial forms are dominating together with representatives of blossoming or foliage shrubs. In the indoor panels representatives are identified of 83 epiphyte species from 59 genera, 19 facultative epiphytes from 14 genera and 11 semi epiphytes from the genus *Ficus*.

In the interior vertical gardens the epiphyte species predominate, most of them being herbaceous plants, followed by the bushy climbers, the shrubs and the trees. Shrubs occupy the top whereas climbers take up elongated diagonal spots. In all panels the presence of ferns is obligatory, as well as the presence of aroids (situated always in the middle and in the lower part of the panels) and representatives of genus *Ficus* (situated always on the top part of the panels). The preferences are towards broad-leaved species mostly climbers. A certain rhythm is observed in the designed spots and pasting of certain patterns.

In the exterior vertical gardens an exclusive variety of life forms is observed – perennials and annuals. Blossoming plants, including some weeds are prevailing. Having in mind the frost resistance, more tender-frost species are used in contrast with the case of traditional horizontal flower compositions. The most tender frost species are situated on a sheltered position in the panel's base, such species being traditionally used in a warm interior. Some grass species are used including hygrophytes. Species

with tiny leaves are predominating and the spots are considerably smaller than those created in the interior.

2. Species variety in commercial greenhouses in our country.

As a result of the study, representatives of 80 genera from 32 families have been recorded. Species diversity is presented in Table 2, including species in mass production or sale, imported and produced in larger quantities. Single individuals or such with collector's value are not included.

Results of the present study can be summarized as follows:

- Out of all 80 genera described, representatives of 10 are found in 80 to 100% of the surveyed greenhouses, representatives of 13 – in 60 to 80%; representatives of 17 – in 40 to 60%, representatives of 22 – in 20 to 40%. Representatives of 18 genera are found occasionally (in less than 20% of surveyed sites).

- The most commonly available species and varieties are from the following genera: *Anthurium*, *Syngonium*, *Hedera*, *Begonia*, *Guzmania*, *Tillandsia*, *Calathea*, *Marantha*, *Nephrolepis* and *Pilea*.

- The highest species diversity is found in the following genera: *Peperomia*, *Begonia*, *Anthurium*, *Philodendron*, *Nephrolepis*, *Hedera*, *Guzmania*, *Neporegia*, *Tillandsia*, *Vriesea*, *Calathea*, *Ficus*, *Fittonia*, *Hypoestes*.

- Excluding the richest collections of the Botanical garden at the BASci, the University Botanical garden and it's branch in Balchik, in 2009 the greatest diversity of

Table 2. Species of commercial interest imported and grown in greenhouses

No	Family	Genus	Total number of species and cultivars in the sites of observation	Sites of observation*
1.	Acanthaceae Juss.	<i>Fittonia</i> Coem.	26	3, 4, 6, 7, 8, 9, 10
2.	Acanthaceae Juss.	<i>Hypoestes</i> Sol. ex R. Br.	25	1, 2, 3, 4, 5, 10
3.	Acanthaceae Juss.	<i>Pachystachus</i> Nees.	3	1, 10
4.	Araceae Juss.	<i>Aglonema</i> Schott.	21	2, 7, 8, 9, 10
5.	Araceae Juss.	<i>Alocasia</i> (Schott.) G. Don	12	2, 5, 6, 7, 8, 9, 10
6.	Araceae Juss.	<i>Anthurium</i> Schott.	49	2, 3, 4, 5, 6, 8, 9, 10
7.	Araceae Juss.	<i>Dieffenbachia</i> Schott.	17	2, 3, 7, 8, 9, 10
8.	Araceae Juss.	<i>Epipremnum</i> Schott.	2	7, 9,
9.	Araceae Juss.	<i>Monstera</i> Adans.	6	2, 7
10.	Araceae Juss.	<i>Philodendron</i> Schott.	40	2, 5, 7, 8, 10
11.	Araceae Juss.	<i>Scindapsus</i> Schott.	14	2, 3, 4, 7, 8
12.	Araceae Juss.	<i>Spathiphyllum</i> Schott.	13	2, 6, 7, 8, 9, 10
13.	Araceae Juss.	<i>Syngonium</i> Schott.	27	1, 2, 3, 4, 5, 7, 9, 10
14.	Araliaceae Juss.	<i>Hedera</i> L.	40	1, 2, 3, 4, 7, 8, 9, 10
15.	Araliaceae Juss.	<i>Schefflera</i> Forst.	10	1, 2, 8
16.	Asclepiadaceae R. Br.	<i>Dischidia</i> R. Br.	3	10
17.	Asclepiadaceae R. Br.	<i>Hoya</i> R. Br.	21	4, 7, 8
18.	Asparagaceae Juss.	<i>Asparagus</i> L.	20	3, 4, 6, 7, 9
19.	Antericaceae J. G Agardh.	<i>Chlorophytum</i> Ker.Gawl.	9	2, 5, 6, 9
20.	Begoniaceae C. A. Agardh	<i>Begonia</i> L.	91	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
21.	Bromeliaceae Juss.	<i>Aechmea</i> Ruiz. et Pav.	18	2, 3, 4, 5, 6, 8, 9
22.	Bromeliaceae Juss.	<i>Ananas</i> Mill	5	2, 5
23.	Bromeliaceae Juss.	<i>Billbergia</i> Thunb.	7	2, 5
24.	Bromeliaceae Juss.	<i>Bromelia</i> LAdans.	4	5, 10
25.	Bromeliaceae Juss.	<i>Cryptanthus</i> Otto & Dietr.	8	2, 5
26.	Bromeliaceae Juss.	<i>x Cryptbergia</i> Hort.	3	10
27.	Bromeliaceae Juss.	<i>Dyckia</i> Schult.f.	2	10

No	Family	Genus	Total number of species and cultivars in the sites of observation	Sites of observation*
28.	Bromeliaceae Juss.	<i>Guzmania</i> Ruiz. et Pav.	28	2, 3, 4, 5, 6, 7, 8, 10
29.	Bromeliaceae Juss.	<i>Neoregelia</i> L. B. Sm.	25	2, 3, 4, 5, 6, 9
30.	Bromeliaceae Juss.	<i>Nidularum</i> Lem.	7	2, 8, 10
31.	Bromeliaceae Juss.	<i>Orthophytum</i> Beer.	2	5
32.	Bromeliaceae Juss.	<i>Tillandsia</i> L.	33	2, 3, 4, 5, 6, 7, 9, 10
33.	Bromeliaceae Juss.	<i>Puya</i> Molina	8	10
34.	Bromeliaceae Juss.	<i>Vriesea</i> Lindl.	24	2, 3, 4, 6, 9, 10
35.	Cactaceae Juss.	<i>Rhipsalis</i> Gaertn.	13	2, 3, 5, 6, 9
36.	Cactaceae Juss.	<i>Hatiora</i> Britton & Rose	3	10
37.	Cactaceae Juss.	<i>Schlumbergera</i> Lem	9	2, 3
38.	Cactaceae Juss.	<i>Callisia</i> Loefl.	6	3, 4, 8, 10
39.	Clusiaceae Lindl.	<i>Clusia</i> L.	2	2 **
40.	Commelinaceae R. Br.	<i>Setcreasea</i> K.Schum & Sydow	3	6, 10
41.	Commelinaceae R. Br.	<i>Tradescantia</i> L.	17	1, 2, 3, 10
42.	Eriocaulaceae Desv.	<i>Syngonanthus</i> Ruhland	1	2 **
43.	Gesneriaceae Dum.	<i>Aeschyananthus</i> Jack	6	1, 2, 3,
44.	Gesneriaceae Dum.	<i>Columna</i> L.	5	3, 7, 10
45.	Gesneriaceae Dum.	<i>Gloxinia</i> L'Her	16	2, 3, 4, 10
46.	Gesneriaceae Dum.	<i>Kohleria</i> Regel	2	10
47.	Gesneriaceae Dum.	<i>Saintpaulia</i> H.Wendl.	4	2, 3, 4
48.	Maranthaceae Petersen	<i>Calathea</i> G.Mey	36	1, 2, 3, 4, 5, 7, 8, 9, 10
49.	Maranthaceae Petersen	<i>Ctenanthe</i> Eichler	15	2, 3, 4, 6, 7, 9, 10
50.	Maranthaceae Petersen	<i>Maranta</i> L.	14	1, 2, 4, 6, 7, 3, 9, 10
51.	Maranthaceae Petersen	<i>Stromanthe</i> Sond.	9	2, 3, 4, 9, 10
52.	Melastomataceae Juss.	<i>Medinilla</i> Gaudich	1	10

No	Family	Genus	Total number of species and cultivars in the sites of observation	Sites of observation*
53.	Moraceae Link	<i>Ficus</i> L.	22	2, 3, 4, 6, 9
54.	Nepenthaceae Dum.	<i>Nepenthes</i> L.	2	2
55.	Orchidaceae Juss.	x <i>Vuystekeara</i> Hort.	4	2, 3, 4
56.	Orchidaceae Juss.	<i>Cattleya</i> Lindl.	2	2
57.	Orchidaceae Juss.	<i>Cymbidium</i> Sw.	11	2, 3, 4, 9
58.	Orchidaceae Juss.	<i>Dendrobium</i>	11	2, 4
59.	Orchidaceae Juss.	<i>Ludisia</i> A. Rich.	6	2, 5, 6, 9
60.	Orchidaceae Juss.	<i>Miltonia</i> Lindl.	6	2, 4
61.	Orchidaceae Juss.	<i>Oncidium</i> Sw.	2	2
62.	Orchidaceae Juss.	<i>Phalenopsis</i> Blume	17	2, 3, 4, 6
63.	Orchidaceae Juss.	<i>Vanda</i> Jones ex R. Br.	4	2, 8
	Polypodiophyta:			
64.	Adiantaceae Newm.	<i>Adiantum</i> Burm. f	22	1, 2, 4, 6, 9, 3
65.	Adiantaceae Newm.	<i>Pellaea</i> Link.	5	1, 2, 3,
66.	Aspleniaceae Newm.	<i>Asplenium</i> L.	7	1, 2, 3, 6, 9
67.	Blechnaceae (C. Prel) Copel.	<i>Blechnum</i> L.	1	2
68.	Davalliaceae (Gaud.)M.R.Schob.	<i>Davallia</i> Sm.	12	2, 3, 4, 7, 8, 9,
69.	Dryopteridaceae Ching	<i>Didymochlaena</i> Desvaux	1	6
70.	Dryopteridaceae Ching	<i>Dryopteris</i> Adans	1	2
71.	Oleandraceae Ching ex Pic.Serm.	<i>Nephrolepis</i> Schott	28	1, 2, 3, 4, 5, 6, 7, 8, 9
72.	Polypodiaceae Bercht. & J. Presl	<i>Platyserium</i> Desvaux	9	2, 3, 5, 7, 8, 9
73.	Polypodiaceae Bercht. & J. Presl	<i>Polypodium</i> L.	13	2, 3, 4, 6
74.	Pteridaceae Ching	<i>Pteris</i> L.	3	2, 7, 8

No	Family	Genus	Total number of species and cultivars in the sites of observation	Sites of observation*
75.	Woodsiaceae (Diesl) Herter	<i>Athyrium</i> Roth	1	2
76.	Piperaceae C. A. Agardh	<i>Peperomia</i> Ruitz & Pav.	43	2, 3, 4, 6, 7, 8, 9
77.	Piperaceae C. A. Agardh	<i>Piper</i> L.	3	8
78.	Selaginellaceae P. B.	<i>Selaginella</i> P. Beauv.	15	1, 2, 3, 4, 6, 9
79.	Saxifragaceae Juss.	<i>Saxifraga</i> L.	6	1, 2, 5
80.	Urticaceae Juss.	<i>Pilea</i> Lindl.	23	1, 2, 3, 4, 5, 6, 9, 10

***Sites of observations:** 1. Institute of ornamental plants – Negovan, Sofia; 2. Flora Center – Drujba, Sofia; 3. L2-company – Sofia; 4. Plantava Company – Sofia; 5. Ravda village “Kozarevi” Garden centre; 6. “Burgastsvet” greenhouses – Burgass; 7. Garden centre “Erica Co” – Varna; 8. Flower shop “The Jungle” – Varna; 9. Garden centre “Exotic” – Varna; 10 Garden centre “Mimosa” – Varna.

** representatives of the following genera are rarely imported.

taxa for commercial use was found in the “Flora Centre”, Sofia (57 taxa).

- The observations show that the greater part of the plants from the taxa described above are grown as a traditional soil crop not regarding their specificity as epiphytes. This results in deterioration of their condition and ornamental qualities, atypical appearance and vulnerability to diseases and pests.

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References

Benzing D.H. 1990. Vascular Epiphytes General Biology and Related Biota. Series: Cambridge Tropical Biology Series, Cambridge University press, 530 p. (e-books).

Benzing D.H. 2000. Bromeliaceae – profile of an adaptive radiation. Cambridge University press, 530 p. (e-books).

Blanc P. 2008. The Vertical Garden. From Nature to the city Preface by Jean Nouvel W.W.Norton & Company. New York, London, 192 p.

Griffiths H., Lüttge U., Stimmel K-H., Crook C.E., Griffiths N.M., Smith JAC 1986. Comparative ecophysiology of CAM and C₃ bromeliads. III. Environmental influences on CO₂ assimilation and transpiration. Plant Cell Environ, 9: 385–393.

De Guzman C.C., Quintana E.G., Mayuga I.C. 1998. Epiphytes in genus. *Peperomia* Ruiz. Et Pav. Annual Scientific Conference of the Federation of Crop Science Societies of the Philippines, Cebu City (Philippines), 19–24 April 1998.

Kabatliyska Z. 2001. Morphological and biological specialities of representatives from fam. *Bromeliaceae* Juss. according to their use in different plant compositions. Conference '50 Years 'Landscape architecture' – Evksinograd, May: 55–61.

Lüttge U. 1989 (editor). Vascular Plants as epiphytes. Evolution and Ecophysiology.

Ecological studies 76. Springer Verlag, 270 p.

Petrova A. 1995. Bromelias collection of BAS Botanical Garden. '70 Years Forestry Education in Bulgaria', Sofia, University of Forestry, volume 3: 436–442.

Stoeva K. 1995. Collection of Begonia gender of BAS Botanical Garden. '70 Years Forestry Education in Bulgaria', Sofia, University of Forestry, volume 3: 443–446.

Zotz G., Schultz S. 2008 The vascular epiphytes of a lowland forest in Panama – species composition and spatial structure *Plant Ecology*, 195 (1): 131–141.

FIRE BEHAVIOR IN BLACK PINE (*PINUS NIGRA* ARN.) PLANTATIONS IN SOUTHERN BULGARIA: A SIMULATION STUDY

Konstantinos Koukoulomatis¹ and Ioannis Mitsopoulos²

¹University of Forestry, 10 Kliment Ohridski Blvd., Sofia, Bulgaria. E-mail: bombardier415@yahoo.gr

²Faculty of Forestry and Natural Environment, Aristotle University of Thessaloniki, P.O. Box 228, 54124, Thessaloniki, Greece.

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Abstract

Surface and canopy fuel characteristics that influence the initiation and spread of wildland fires were measured in representative Black pine (*Pinus nigra*) plantations in Southern Bulgaria. Potential fire behavior (type of fire, probability of crown fire initiation, crown fire type, rate of spread, fire line intensity and flame length) in Black pine plantations was simulated with the most updated fire behavior models. The probability of crown fire initiation was high even under moderate burning conditions, mainly due to the low canopy base height and the heavy surface fuel load. Assessment of surface and canopy fuel characteristics and potential fire behavior can be useful in fuel management and fire suppression planning.

Key words: surface and canopy fuels, fire behavior, rate of spread, fire line intensity, flame length.

Introduction

Wildland fires are the most destructive disturbance of the natural lands. Natural landscapes have always been subjected to fire in southern Europe and thus, burning became part of their dynamic natural equilibrium (Moreno and Oechel 1994). Recent changes in land-use patterns have caused the reduction or abandonment of traditional activities, such as extensive grazing or wood harvesting. This resulted in increase of the amount of fuel available for burning (Perez et al. 2003).

Fire behavior models implemented in fire management decision support sys-

tems require accurate descriptions of fuel complex characteristics. Until recently, fuel complex characterization has been limited to surface fuel beds (Anderson 1982, Dimitrakopoulos 2002), due to the restricted applicability of fire behavior simulation models only to surface fuels (Andrews 1986). The development of fire behavior models and systems designed to predict fire behavior (Van Wagner 1977, 1989; Scott and Reinhardt 2001; Cruz et al. 2004, 2005) made necessary the measurement of surface and canopy fuel data.

Crown fire modelling depends on two basic procedures: the analysis of surface

to crown fire transition and the study of crown fire rate of spread. An extensive review of the existing crown fire models can be found in Pastor et al. (2003).

The objective of this study was to assess the potential fire behavior in Black pine plantations in Southern Bulgaria by using simulations with the most recent fire behavior models.

Material and Methods

Study area

The study area was located in the eastern part of Ivaylovgrad region (26°06'N, 41°31'W) and Harmanli region (25°97'N, 41°55'W) in Southern Bulgaria. The altitude ranged from 50 m to 840 m a.s.l. and the climate is of sub-mediterranean type, with cold winters and dry hot summers. The mean annual rainfall is 775 mm and the mean annual air temperature is 13°C. In the past, numerous fires have burned different parts of the forest. The forest comprises of even-aged stands, often with a sparse understorey of herbaceous vegetation and a substantial layer of pine needles litter. The forest site was characterized by a mean tree height of 18 m and a mean stem density of 750 stem ha⁻¹. Slopes ranged from 20 to 50%.

Modelling fuel and fire behavior

In one representative sample plot (25 m x 20 m), surface and crown fuel parameters were measured according to Koukoulomatis and Mitsopoulos (2007) study. Surface fuel parameters were measured in ten 1 m² sampling plots. The clip and weight method was used for the

determination of all fuel loads by size category (Brown et al. 1982). Crown fuel biomass was estimated by using site-specific crown fuel allometric equations (Koukoulomatis and Mitsopoulos 2007), while canopy fuel vertical profiles were developed using Scott and Reinhardt (2001) method.

Potential crown fire behavior was simulated using Cruz et al. (2004, 2005) crown fire initiation and spread models, with input data the canopy and surface fuel load values of the sample plot. These models have been tested and evaluated in high intensity experimental crown fires in pine plantations with satisfactory results, while other crown fire models (Rothermel's surface and crown rate of fire spread models with Van Wagner's crown fire transition) have shown to have significant underprediction bias when used in assessing potential crown fire behavior in conifer forests and plantations (Stocks et al. 2004, Cruz and Alexander 2010). The type of fire (active crown fire or passive crown fire) was assessed by Van Wagner's (1977) criterion for active crown fire spread. Available surface fuel loads are required to run the crown fire initiation model (Cruz et al. 2004). For this, the surface fuel model, typical of the understory vegetation of Black pine forest was used as surface fuelbed during the fire simulation (Koukoulomatis and Mitsopoulos 2007). Low burning conditions were set to fine fuel moisture of 14% and 10 km.h⁻¹ windspeed, moderate burning conditions to fine fuel moisture of 10% and 20 km.h⁻¹ windspeed, while extreme burning conditions were set to fine fuel moisture of 6% and 30 km.h⁻¹ windspeed. All the wind values refer to 10 m open windspeeds. Fire-

line intensity was estimated by Byram's (1959) equation. Crown fire intensity was calculated by adding the available canopy fuel load to the available surface fuel load. The litter, the live foliage and the live and dead branches with diameter less than 2.5 cm were considered as available surface fuel load. Surface fuel consumption by the fire was adjusted to 90%, 60% and 30% of the total load, representing extreme, moderate and low burning conditions, respectively. Heat content values for all simulations were obtained from Dimitrakopoulos and Panov (2001). Crown fire flame length was estimated according to Thomas' (1963) flame length equation. Surface fire behavior was modeled using Rothermel's rate of spread model (Rothermel 1972). All crown fire behavior predictions refer to level terrain and are valid only for active crown fires.

Results and Discussion

Table 1 presents surface and canopy fuel characteristics that were measured at the sample plot. Table 2 presents surface and active crown fire behavior potential that should be expected in the plot according to the fire behavior models simulation. Crown fireline intensity and flame length reached up to 91 500 kW.m⁻¹ and 53 m, respectively. Simulations with wind speeds greater than 20 km.h⁻¹ always lead to crown fire initiation regardless of the canopy and surface fuel characteristics. All simulations under extreme burning conditions resulted in crown fire initiation, as it is often reported in field observations (Alexander 1998). Under moderate burning conditions both crown and surface fires were observed, depending mainly on the fuel characteristics (CBH, surface fuel bed height, CBD)

Table 1. Surface and canopy fuel characteristics at the sampled plot.

Fuel model	Surface fuel load, t.ha ⁻¹	Litter depth, cm	Litter weight, t.ha ⁻¹	Canopy fuel load, kg.m ⁻²	Canopy bulk density, kg.m ⁻³	Canopy base height, m
Litter layer of Black pine forest	3.1	0.8	6.2	1.2	0.13	3.8

Table 2. Potential fire behavior of Black pine plantations.

	Rate of spread, m.min ⁻¹			Fireline intensity, kW.m ⁻¹			Flame length, m		
	Burning conditions								
	Low	Moderate	Extreme	Low	Moderate	Extreme	Low	Moderate	Extreme
Black pine plantation fuel complex	6.3 ^a	22.8 ^b	61.5 ^b	3,123 ^a	24,771 ^b	91,459 ^b	1.9 ^a	22 ^b	53 ^b

^a Surface fire resulted

^b Crown fire resulted

of the stand. Under low burning conditions, in all cases fire spread was limited to surface fuels. Active crown fire rate of spread in Black pine plantations ranged from 22.8 to 61.5 m.min⁻¹. In most cases, crown fire behavior simulations indicated that crown fire transition and spread is a common feature in Black pine plantations. The low fuel strata gap, the heavy available surface fuel load and the substantial height of the surface fuel bed that characterize Black pine fuel complexes increase dramatically the likelihood of crown fire initiation. Active crown fire rate of spread, fireline intensity and flame length in Black pine stands were found similar to values reported in typical active crown fires in the International Crown Fire Modelling Experiment, where the rate of crown fire spread ranged from 15.8 to 69.8 m.min⁻¹, the fire intensity from 20,000 to 100,000 kW.m⁻¹ and the flame front was 2–3 times the mean stand height (Stocks et al. 2004). Under extreme burning conditions, active crown fire rate of spread was even observed in Black pine plantations with CBD lower than Agee's (1996) threshold value (0.10 kg.m⁻³), as the simulation results indicated.

Surface fire predictions, crown fire initiation and rate of spread models used in this simulation are empirical. Nevertheless, they have been tested in high intensity experimental wildland fires with satisfactory results (Stocks et al. 2004). Furthermore, the variability in fuel complex characteristics used during model conception and the physical fuel (CBD, fuel strata gap, surface fuel consumption) and weather (wind speed, fine fuel moisture content) parameters, should make them applicable to other conifer fuel complexes as well. Additionally, wind speed

is the variable that has the most influence in crown fire behavior. Wind speed is the dominant factor that affects fire behavior in wildland forests (Dimitrakopoulos and Dritsa 2003). Passive crown fire characteristics were not simulated due to the lack of a validated model that predicts passive crown fire behavior.

Conclusion

This study simulated the initiation and spread of wildland fire in representative Black pine (*Pinus nigra*) plantations in Southern Bulgaria. Potential fire behavior (type of fire, probability of crown fire initiation, crown fire type, rate of spread, fireline intensity and flame length) in Black pine plantations assessed with the most updated fire behavior models.

Fire behavior prediction in Black pine plantations can be useful in fire management, fire prevention planning or in decision making during actual fire suppression. The current fire behavior simulations are just a supplement to the efforts for fire prevention and active suppression tactics and their accuracy must be validated with real observations from wildfires burning in the field.

References

- Agee J. 1996. The influence of forest structure on fire behavior. In: Proceedings of the 17th Annual Forest Vegetation Management Conference, January 16–18, Redding, California: 52–68.
- Alexander M.E. 1998. Crown fire thresholds in exotic pine plantations in Australasia. Ph.D. Thesis, Australian National University, Canberra, Australia, 228 p.

- Anderson** H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA, Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-122, Ogden, Utah, 22 p.
- Andrews** P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system-BURN subsystem part I. USDA, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report. INT-260, Ogden, Utah, 130 p.
- Brown** J.K., Oberheu R.D., Johnston C.M. 1982. Handbook for inventorying surface fuels and biomass in the interior west. USDA Forest Service General Technical Report INT-129. Ogden, Utah, 48 p.
- Byram** G.M. 1959. Combustion of forest fuels. In: Davis K.P. (ed.), *Forest Fire: control and use*, New York, McGraw Hill Book Co: 61–89.
- Cruz** M.G., Alexander M.E., Wakimoto R.H. 2004. Modeling the likelihood of crown fire occurrence in conifer forest stands. *Forest Science* 50: 640–658.
- Cruz** M.G., Alexander M.E., Wakimoto R.H. 2005. Development and testing of models for predicting crown fire rate of spread in conifer forest stands. *Canadian Journal of Forest Research* 35: 1626–1639.
- Cruz** M.G., Alexander M.E. 2010. Assessing crown fire potential in coniferous forests of western North America: a critique of current approaches and recent simulation studies. *International Journal of Wildland Fire* 19: 377–398.
- Dimitrakopoulos** A.P. 2002. Mediterranean fuel models and potential fire behavior in Greece. *International Journal of Wildland Fire* 11: 127–130.
- Dimitrakopoulos** A.P., Panov P.I. 2001. Pyric properties of some dominant Mediterranean vegetation species. *International Journal of Wildland Fire* 10: 23–27.
- Dimitrakopoulos** A.P., Dritsa S. 2003. Novel nomographs for fire behavior prediction in Mediterranean and submediterranean vegetation types. *Forestry* 76: 479–490.
- Koukoulomatis** K.D., Mitsopoulos I.D. 2007. Crown fuel weight estimation of Black pine (*Pinus nigra*) plantations in Southern Bulgaria, *Silva Balcanica* 12: 57–65.
- Moreno** J.M., Oechel W.C. 1994. The role of fire in Mediterranean-type ecosystems. Springer-Verlag, New York, NY.
- Pastor** E., Zarate L., Planas E., Arnaldos J. 2003. Mathematical models and calculation systems for the study of wildland fire behavior, *Progress Energy and Combustion Science* 29: 139–153.
- Perez** B., Cruz A., Fernandes-Gonzales F., Moreno J.M. 2003. Effects of the recent land-use history on the postfire vegetation of an uplands in Central Spain. *Forest Ecology and Management* 182: 273–283.
- Rothermel** R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA, Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-115, Ogden, Utah, 40 p.
- Scott** J.H., Reinhardt E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire potential. USDA, Forest Service, Rocky Mountain Research Station, Research Paper RMRS-29, Fort Collins, USA, 59 p.
- Stocks** B.J., Alexander M.E., Wotton B.M., Steffner C.N., Flannigan M.D., Taylor S.W., Lavoie N., Mason J.A., Hartley G.R., Maffey M.E., Dalrymple G.N., Blake T.W., Cruz M.G., Lanoville R.A. 2004. Crown fire behavior in a northern jack pine – black spruce forest. *Canadian Journal of Forest Research* 34: 1548–1560.
- Thomas** P.H. 1963. The size of flames from natural fires. In: *Proceedings of 9th International Symposium on Combustion Processes*. Academic Press, New York: 844–859.
- Van Wagner** C.E. 1977. Conditions of the start and spread of crown fires. *Canadian Journal of Forest Research* 7: 23–34.
- Van Wagner** C.E. 1989. Prediction of crown fire behavior in conifer stands. In: MacIver D.C., Auld H., Whitewood R., (eds.) *Proceedings at the 10th Conference on Fire and Forest Meteorology*. Ottawa, Canada: 207–212.