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# TESTING AND IMPLEMENTATION OF TECHNOLOGIES INTO LOGGING DURING A JOINT USE OF SKIDDER, HARVESTER AND FORWARDER IN BULGARIA

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## Abstract

In Eastern Stara planina Mountain, during a 3-year period with some intermittences due to repair works, the following technological schemes have been studied and implemented during practical work: 1) felling of trees using a chain saw, haulage of whole trees by a skidder, felling, delimbing, bucking, cut-to-length (CTL) of full trees by a harvester and assortments transportation by a forwarder; 2) felling and a primary processing of trees by chain saws, haulage of assortments by a skidder and transportation by a forwarder, and 3) felling and primary processing of trees by a harvester and forwarder of assortments. The application of the respective technological scheme depends on the available forest-exploitation conditions. The following machines have been used for the purpose: TK 40 Bolgar and Universal-651 skidders, John Deere 1270D harvester and John Deere 1110D forwarder. The machines John Deere 1270D and John Deere 1110D have been bought second hand (as used machines). The studies have been conducted in Black pine plantations (*Pinus nigra* Arn.) and Scots pine ones (*Pinus silvestris* L.), growing on terrains of a hilly and up to a mountain character. The conditions are as it could be expected after fires, windfalls, snowbreaks, and calamities but appropriate for works which are to be performed by the studied machines. The forestry targets include a clearance of the above mentioned areas, i.e. the clear cuttings. Productivities from 26 up to 68 m3/day have been achieved being its lower limit related to a technology where a chain saw is used while the upper one is related to a completely mechanized technology.As for the harvester and the forwarder, their productivities differ one from another, taking into consideration that the size of the trees exerts greater influence on the work performed by the harvester. Multi-operational machines operators‘ professionalism and experience are significantly important for the implementation of the works and both professionalism and experience are gained by knowledge obtained in the course of a specialized training.

**Key words:** cutting area, productivity, time study, wood harvesting, work-cycle elements.

## Introduction

When harvesters are used, the working time is 71 % of the total shift time (Glöde 1999). The greatest share is taken up by the working hours of 74.8 %, followed by the hours for maintenance of 9.2 %, and the time required for repairing: 5.9 % of the shift time (Dvorak 2010a,b).

On the basis of the available data (Väätäinen et al. 2007), the average productivity of the single-grip harvesters at the stems average volume of 0.3 $m^3$ is of 18 $m^3$ PMH approximately, in clear cuttings. The productivity of the harvester depends upon many factors, as forest stands composition, forest area, character of the surface, relief, operator‘s motivation and habits, character of the tree crown, planned works, trees’ size, number of the assortment species, quantities of the trees in the cutting area, undergrowth density and structural characteristics of the machines (Richardson 1989, Makkonen 1991, Jiroušek et al. 2007, Suchomel et al. 2010).

The productivity obtained in assortment harvesting is of 16.9 $m^3$/productive machine hour (PMH) by Timberjack 1270 harvester and 14.3 $m^3$/PMH by Timberjack 1010 forwarder, at the average stem volume of 0.32 $m^3$ (Gingras 1994), while, according to Gerasimov et al. (2012), with harvester John Deere 1270D, the harvesting operations in forest stands composed of spruce (48 % on average), pine (19 %), birch (22 %), and aspen (11 %), with an average stem volume 0.31 m u.b. of cut-to-length stems by a harvester, are from 4.3 to 14.9 m u.b./(PMH) and 16.0–49.5 m u.b./stem processing machine hour (SMH). The operation of tree processing (0.05–2.00 $m^3$/stem) varies from 62 to 171 s (0.02–0.24 h/$m^3$).

According to Goltsev et al. (2012), the distribution of the harvester work-cycle elements is, as following: 55 % tree processing time, 16 % tree felling time, 4 % for the harvester moving in the stand and 27 % for idle running, while the forwarder work-cycle includes: 73 % for loading time, 16 % for wood transportation, 8 % for movement of the unloaded machine and 3 % for idle running.

At the moment, the manpower, i.e. the operators, which work performance depends upon training and experience, is being taking more and more for a key factor contributing to a high productivity achievement (Dvořák 2010).

The harvester productivity is closely related to the stem volume and the forest stand composition (Richardson 1989, Makkonen 1991, Bulley 1999, Gellerstedt et al. 1999). The time consumption for felling and processing with Valmet Snake is a function of the tree volume and the silvicultural treatment strategy. The locomotion time depends upon the number of trees felled per harvester stop, soil bearing capacity and terrain slope (Stampfer and Steinmüller 2001).

The productivity of the forwarders is highly correlated to the payload volume and the average distance of the haulage, i.e. there is productivity increasing when the payload increases and decreasing with distance increasing (Valenta and Neruda 2004, Bergkvist 2009, Zimbalatti and Proto 2010).

Significant differences exist among the operators and the levels of their training. Regardless of that, if there are good operators, good cares should be taken for them, as such operators can be considered the most precious assets (Purfürst 2007).

In fact the effect exerted by the harvester operator on the productivity of the entire system has been neglected for a long time (Purfürst and Erler 2011). For that reason, 10–15 % of the differences in the operator’s performance are due to the differences in machinery, 20–30 % are explained by a more effective control exerted by the management bodies and 50–55 % result from a better planning and decisions making (Väätäinen et al. 2004).

Besides the above, the general factors, as labour conditions, working time, as well as operators‘ motivation, significantly differ in different countries (Liden 2005). And yet, the differences in achievement of better productivity are still great, even among the experienced operators (Purfürst 2010).

Preplanning and pre-execution shall be obligatorily conducted. And, especially, the harvester drivers' skills are of a particular importance. It is a fact that good operators only feel sure in the cabin. Any ineffective and dangerous operation shall be avoided. The technical capabilities of the devices are really considered as risk factors for the good operator. From our viewpoint, many weeks are needed to find a proper rhythm of work. Over 1000 hours of work are required, as a minimum, to get a command of that machine.

The purpose of this study is on the basis of new logging technologies, developed by us in Bulgaria, the achieved levels of productivity to be shown, for their use in practice when multi-operational forest machines are purchased, and to be implemented into the work performed by these machines.

## Material and Methods

This paper reflects three-year studies (with intervals necessary for the repairing) of the first harvester and forwarder machines, and for the time being, the only ones in Bulgaria, used in logging: John Deere 1270D and John Deere 1110D, respectively, both of them second hand purchased (Fig. 1).

The study has been performed in Black pine plantations (*Pinus nigra* Arn.) and Scots pine ones (*Pinus sylvestris* L.), growing on terrains of a hilly and up to a mountain character. The stands are after fires and calamities but appropriate for operations performed by the above mentioned machines under observation. The forestry objectives include release of the areas for new afforestation by clear cuttings.

The data collection has been separated according to the machine type and each machine has been examined in its proper production environment. In addition, some independent variables have been also collected as related to the above said machines. These variables have included the trees diameter at breast height, the slope and the terrain characteristics. Working time measurement has been taken by chronometer and the measurement of the forwarding distance by a measuring tape.

The harvester cycle includes: moving in cutting area; searching of a tree; harvester head starting; cleaning under tree; inclusion tree, advancing down, cut-

a

b

**Fig. 1. John Deere 1270D harvester (a) and John Deere 1110D forwarder (b) in working process.**

ting tree; summing up the tree to place splitters and advancing the assortments, delimbing, bucking, etc. (max. 4 assortments).

The forwarding includes: travelling empty; moving in cutting area for loading; stacking of the assortments in the cutting area; loading; travelling loaded; unloading and stacking of the assortments in store. The forwarding distances are from 800 to 1000 m.

It has been found in the course of the works that the operator should be familiar with forestry. But it is obvious that great differences exist in productivity among different operators. A skilled and experienced operator is a good observer on the entire system, being able to a prompt and reliable sensory-motor reaction.

The specific requirements of the survey are based on the understanding that an effective operative management requires clear objectives, enough information and a realistic idea of what the process itself means. In this study, we represent the situation as it is in Bulgaria, regarding the utilization of the contemporaneous multi-operational machines. Of course, in comparison with their use in the world practice, as well as with the traditional technologies for forests use, mainly based on the process of forest exploitation, i.e. using motor chain saws and tractors provided with winches. The economics of using the harvester technology depends also upon the forwarder work. The usage factor of the forwarder is compared in complex with the harvester. In our case, while the forwarder is working, the harvester shall be expecting for ready material, because of its frequent repairs. Maybe it is aim oriented to have a ready one and then to forward the material. As in Bulgaria work only these two machines we had to apply this technology.

The data collected during the study have been subjected to a regression analysis to develop regression models relating elemental time to some independent variable. Estimates of total cycle time for harvester and forwarder were then computed for a range of independent.

## Results and Discussion

Table 1 illustrates the taxation characteristics of the stands in the cutting areas (Site A and Site B) where the concrete studies have been performed.

**Table 1. Main characteristics of the harvested stands.**

| Parameter | Value | |
|---|---|---|
| | Site A | Site B |
| Resources, $m^3$/ha | 432 | 407 |
| Cutting area, ha | 2,2 | 3,9 |
| Average terrain slope, % | 40 | 30 |
| Altitude, m | 600 | 650 |
| SFB composition | *Pn* 10 | *Ps* 7, *Pn* 3 |
| DBH, cm | 34 | 26 |
| H, m | 19 | 21 |
| Harvesting method | Combination between CTL | Combination between CTL |
| Sylvicultural system | Clear cuttings (after fires) | Clear cuttings (after windthrow) |

Note: CTL – cut to length.

Table 2 shows the first results achieved from the work performed using John Deere 1270D harvester and John Deere 1110D forwarder. What makes an impression is the scarce productivity of both machines. It is relatively low and highly variable: mainly due to machinery technical state and poorly qualified operators. The difference in productivity between the operators abroad and in Bulgaria is significant, due to our operators‘ insufficient experience, especially with the harvester. That difference consists of a bad positioning of the machine by the Bulgarian operator in the course of works and of his operations performed at low speeds of its working bodies.

The trees shape and size have a direct effect on time for processing related to the effective time in machine hours, and, especially, with the increase of the stems average size. The productivity of the machines could be raised by increasing the time for stems processing instead of improving the methods of work, i.e. if, for example, it is possible to arrive at more than 0.7, the productivity will raise over 100 $m^3$/day.

Besides the above, the observations show that while the harvester was used, the time, required for the processing of one tree with volume of 0.218–0.307 $m^3$/tree, was varying from 115 to 182 s and decreasing by reducing the number of obtained assortments: that is to say, by reducing the size of the trees. The highest share was noted of the bucking and the felling time, as well as of the time for the harvester moving in the cutting area, as of 50 %, 13 % and 13 %, respectively. Using the forwarder, the time was varying from 80 to 117 min/cycle, and the highest share fell to the time of unloading, the times of transportation to and moving in the cutting area: of 33 %, 12 %, 28 % and 13 %, respectively (Fig. 2).

It has been ascertained that no common rule exists for a statistically significant correlation of the single operating costs and time consumption. Such correlation was noted, to a certain extent, in bucking operations when the trees’ diameter was taken into consideration, during the work with the harvester, and in trans-

**Table 2. Share of operative times for harvester John Deere 1270D and forwarder John Deere 1110D.**

| John Deere 1270D Harvester | | John Deere 1110D Forwarder | |
|---|---|---|---|
| **Operation** | **Time, s** | **Operation** | **Time, min** |
| Moving in cutting area | 17–24 | Travelling empty | 8–12 |
| Searching a tree | 5–10 | Moving in cutting area for loading | 10–15 |
| Harvester head starting | 5–10 | Stacking of the assortments in the cutting area | 12–17 |
| Cleaning under tree | 7–12 | Loading | 27–38 |
| Inclusion tree, advancing down, cutting tree | 16–24 | Travelling loaded | 12–16 |
| Summing up the tree to place splitters | 8–10 | Unloading | 11–13 |
| Advancing the 1st assortment, delimbing, bucking, etc. (max. 4 assortments) | 57–92 | Stacking of the assortments in store | 0–6 |
| Total | 115–182 | | 80–117 |

Note: Assortments with diameter in cm: logs at the thin end – 30 cm (15 %) и 18–29 cm (40 %), for beams – 16–18 cm (10 %) and for cellulose.

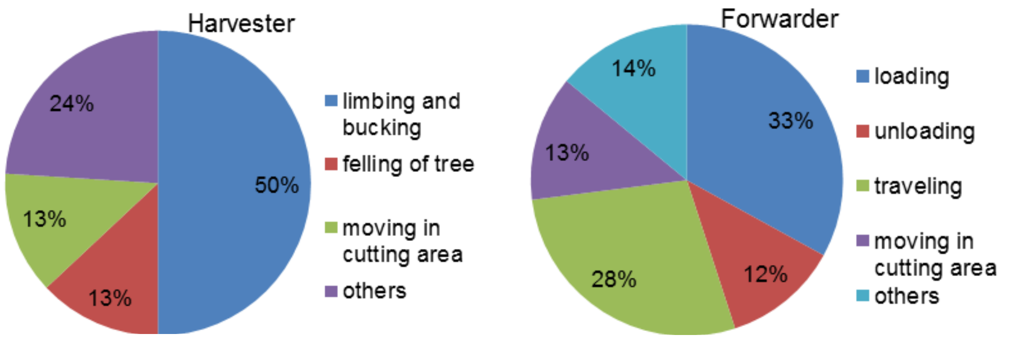


**Fig. 2. Distribution of time for machine work.**

portation, depending upon the forwarding distance, when the forwarder was used but its degree of significance was low. It is due to high variations in the precision of the operations performed by the operators and that is why it was impossible to find out other substantial relations in the examined processes. For this reason, after noting a sufficient experience gained by the operators, the observations went on subsequently.

That is why, about six months later, experimental studies have been conducted on the technologies as follow below:

1) The felling of trees using a chain saw, haulage of whole trees by a skidder, felling, delimbing, bucking, cut-to-length of full trees by John Deere 1270D harvester and assortments transportation by John Deere 1110D forwarder: 33–55 m³/day. The skidder TK 40 Bolgar provided with a winch was used for haulage of full trees cut within the steeper sections of the cutting area. That had also a positive aspect as created a possibility to wood assimilation from the inaccessible part of the cutting area.

2) The felling and the primary processing of trees by a chain saw, haulage of the assortments by a skidder and their forwarding by John Deere 1110D: 26–34 m³/day. The assortments were hauled by Universal-651 skidder where its winch only was used for their drawing out. What really makes an impression is a comparatively higher productivity obtained by applying that kind of 4) technology which is known in Bulgaria as appropriate for skidding by Universal-651 and forwarding away by Bulgarian assortment tractor MSI 100 (28 m³/day). The reason for that is the higher pass ability of John Deere 1110D forwarder which is able to access to the assortments in the cutting area without causing any negative effect on the undergrowth. There should also be pointed out the purpose to follow, as less as possible, the same wheel-track, to contributed the lack of undergrowth.

3) The felling and the primary processing of trees by John Deere 1270D harvester and the forwarding of the assortments by John Deere 1110D forwarder: 46–68 m³/day. As distinct from the first technology, the harvester worked on comparatively even terrain.

The technology (4) which had been used more than 25 years before was given immediately after the technology (2) being the former similar to the latter one, yet, it could not find its application due to some imperfections of MSI 100 assortment tractor.

The results achieved by using the above mentioned technologies are shown on Fig. 3.

It is obvious that the highest productivity has been obtained by the application of the third technology. In comparison with the results indicated in Table 2, it can be clearly seen that thanks to the gained experience, it is quite possible to get a significant raise of productivity. It is realized by exerting the maximum loading of the machines and the maximum pressure on the work performed by the operators thus tending to improve it. When the harvester and the forwarder are used, the logging shall be considered as a production chain which first stage effects on the next one.

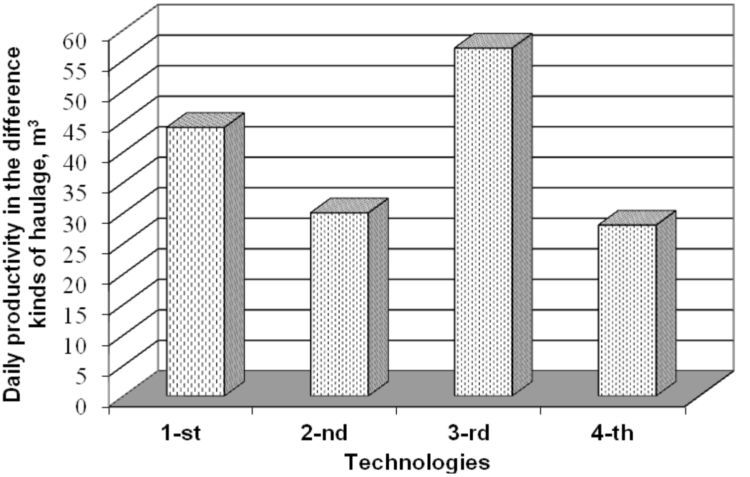


**Fig. 3. Productivity of the examined technologies applicable to logging in Bulgaria.**

The simultaneous running of both processes is important, so that, by making the machines work uninterruptedly, to achieve a raise of their productivity. It is preferable, along with taking into consideration the characteristics of stand, other factors to be taken as well, as the upper soil layer, the relief and such a road network which could enable an easy access of the forwarder. Hence, to optimize the daily loading of the forwarder, the harvester operator can optimize its productivity.

The obtained results shall be used for an effective introduction of machines as the above indicated ones in Bulgaria, taking into account the concrete conditions for that. Any potential user of harvester and forwarder gets a possibility to make his own cost estimates in different conditions and to assess the competitiveness of alternative variants. Especially, in such companies which have been still applying conventional technologies to haulage by tractors and where the cheap manpower is a hindrance to investments for specialized forest machines.

The professionalism and the experience which are gained by the multi-operational machine operators after obtaining knowledge through a specialized training are of a significant importance for the implementation of the assigned tasks. Thus, well trained operators of forest machines will be able to provide higher productivity: 2–3 times greater compared to that which could be reached by the operators working now, whose training is usually conducted inside the enterprise.

There are few differences in the direct operating costs of various machinery systems and for that reason many companies tend to transfer their activities entirely to mechanized technologies. In perspective, it will offer a reduction of operating costs, a raise of productivity and subsequently, an improvement in the financial state of the enterprises.

Regardless of some certain achievements in using of the only harvester and forwarder, it is interesting to make some comparisons with the operating costs sustained by other countries where there are already traditions in using harvesters and forwarders. For example the time for moving of the harvester consists of 3–6 % in other countries (Mäkelä 1986; Kärhä et al. 2006; Väätäinen et al. 2007, 2008; Bergkvist 2009), while it is over 13 % in Bulgaria. The idle time due to reasons of technical, technological and other character is up to 15 %, while in Bulgaria, the time for repairing and maintenance of the harvester is 31 % of the working hours (comprised the idle time for repair in 2013, divided within the examined period). The operating time consists of 63 % of the total working one. A little better are the results about the forwarder where that time is 72 % approximately. As for the machine utilization extent, the results show 61 % for the harvester and 74 % for the forwarder in Bulgaria, while in other significantly experienced countries the indices are over 85–90 %. It depends, to the highest extent, upon the machinery condition and the operators‘ experience. The full costs, the overall expenses for the repair of the machines, the harvester and the forwarded comprised, are of 7 eur/$m^3$ (64 eur/h) and 6 eur/$m^3$ (44 eur/h), respectively. As a whole, the indices are worse, compared to those ones indicated in the publications. The main reasons for such results are the machines' state and the poorly qualified operators, particularly, operators working with a harvester.

The process of assessment of the impact on the environment in the forest proves that any machine, to a different extent, contaminate the soil, especially when the operations are performed on sandy and humid soils. Such damages occur to a greater extent when the forwarder is used and to a lower when operations are done by harvester. However, the use the above mentioned machines causes less damages than works by tractors and trucks which are being actually used in Bulgaria. Higher is the impact by the harvester on the undergrowth and the under forest. In that case, the subjective factor has influence as well. The observations conducted on the ergonomics indices give a reason to establish that the best working conditions in logging, as regards to ergonomics and safety, are when mechanized cutting, processing and transportation by multi-operational machines are used.

## Conclusions

Three kinds of technologies have been elaborated taking into account the forest felling conditions, growing on terrains of a hilly and up to a mountain character and the mechanized means available, as well as the possibilities for the exploitation of multi-operational machines. The productivity obtained from the implementation of the technology into the felling trees with a chain saw, the full trees skidding by tractor TK 40 Bolgar, the delimbing, the bucking, the cut-to-length of full trees by John Deere 1270 harvester and forwarding of the assortments by John Deere 1110 forwarder was 33–55 $m^3$/day. The productivity obtained from the implementation of the technology in the felling and the primary processing of trees by a chain saw, the skidding tractor of the assortments by a Universal-651 skidder and their forwarding was 26–34 $m^3$/day. The productivity obtained from the implementation of the technology into the felling and the primary processing of trees by a harvester and the forwarding of the assortments was 46–68 $m^3$/day. The above mentioned studies have been conducted at an average stem volume of from 0.218 to 0.307 m³ and a haulage distance from 800 to 1000 m.

The productivity is comparatively low and highly variable, mainly due to the poor condition of the harvester and the forwarder and low qualified operators. There is a possibility for raising the productivity and it could be achieved by increasing of tree size, applying a maximum loading on the machines and improving the work of the operators. A number of cases could be adduced when a harvester operator prefers to access closer to the trees instead of having recourse to the maximum range of the manipulator. That way of operating leads to a loss in productivity, due to the frequent moving of the machine. It also reflects on operations performed by the forwarder.

The highest share of the total working hours is that of the operational time – 57.8 % followed by the time for maintenance – 18.0 % and for repairing: 24.2 % of the shift time. The distribution of the harvester working cycle by elements is as following: 50 % – time for trees processing, 13 % – for trees felling, 13 % – for moving in the stand and 24 % – for the remaining time, while the distribution of the forwarder working cycle is: 33 % for the time of loading, 12 % – for unloading, 28 % – for travelling, 13 % – for moving in the cutting area and 14 % – for the remaining time.

In problematic stands, such as calamity ones, the inexperienced operators lose much time to make the right decision for trees processing, especially in the beginning and at the end of the work. The multistage, reiterative and frequent use of the equipment for the same operation is considered a disadvantage.

It has been understood that for the effective functioning of the system harvester – forwarder in Bulgaria, a reserve of 2–3 days for wood material supply between the two phases of cutting and primary processing and transportation shall be taken into account. More time is not necessary because there is also a risk of jamming that may occur and cause major operational delays.

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# EFFECTS OF THINNINGS ON PLANTS AND FUNGI BIODIVERSITY IN A *PINUS NIGRA* PLANTATION: A CASE STUDY IN CENTRAL ITALY

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## Abstract

One of the main consequence of intensive forest exploitation, overgrazing and recurring wildfires over the centuries is the decay of forest cover and soil erosion. In many areas of the Italian Apennines, Black pine (*Pinus nigra* Arn.) plantations were established after the Second World War to improve forest soil quality in marginal and eroded soils. The main aim of these reforestations was to re-establish the pine as a first cover, pioneer species. This was a preparatory step to the reintroduction of broadleaf trees originally living in the same areas, such as oaks and beech trees, and thus to the reestablishment of mixed forests (renaturalisation). Currently in Tuscany, the key functions of these stands are the protection against soil erosion and the hydrological regulation of catchments. In order to guarantee the multifunctional role of these stands, it is necessary to realize silvicultural treatments finalized to the renaturalisation. The present research, carried out in a mountainous area in Tuscany, aims to evaluate the effects of different thinning (selective and traditional) on floristic and mycological diversity. Six experimental plots were established, and different intensity of thinning were applied. Results highlight that the intensity of thinning is directly related to the stability of the stands and also increases the overall biodiversity. In particular, positive effects were evidenced on marketable mushrooms production and on floristic diversity.

**Key words:** floristic diversity, mycological diversity, pine plantations, renaturalisation, silviculture.

## Introduction

Black pine (*Pinus nigra* Arn.) has been one of the most frequently used conifer species for reforestation plantings during the 20$^{th}$ century in Italy, mainly in order to protect land from erosion (Piermattei et al. 2012). However, this species has been commonly used for conservation purposes not only in Italy, but also in Central Europe, in the Balkans and in the other Mediterranean countries (Bussotti 2002).

Pine forests have been considered among the most suitable stands to favour the natural succession toward mixed forests rich of hardwoods (Cantiani et al. 2011). In this framework, the commercial value of the stands was not a priority.

In Central and Southern Apennine, Black pine stands were established during the post 2nd World War period, both to restore forest ecosystems degraded by over-exploitation and to afforest overgrazed pastures during World War I and II.

Black pine is a pioneer species widely planted across Italy due to its low mortality, rapid juvenile growth and low incidence of health issues. Nowadays in Italy Black pine occurs mostly in pure stands of even-aged forests (mean age: 50 years) and covers an area of 236,467 hectares (23 % of national conifers stands) (INFC 2005).

Black pine pure stands were usually planted at a density of 2,500 trees per hectare with a rotation period of approximately 90 years depending on the site characteristics. The common silvicultural management of Black pine even-aged forests consisted of clear cut with artificial regeneration using species with a higher ecological value (Cantiani and Chiavetta 2015). In pure Black pine stands, canopy closure occurs at an early age, therefore pre-commercial thinning around age 30, followed by additional thinning every 15 years, were considered essential for an appropriate management (Cameron 2002, Brüchert and Gardiner 2006).

It is a fact that thinning was rarely carried out in Black pine planted forests mainly because of the low commercial value of the timber assortments in the pre-commercial thinning, which consequently are a cost in the forest management.

Currently, in the majority of the cases, Black pine stands have reached their main objective and they are approaching to the next successional phase. Conforming to the evolution of the forestry theories since the early 1990s, new management strategies were evaluated in order to promote the multifunctional and sustainable role of these stands. In this context, the treatments have been planned to favour stand growth and stability and, at the same time, the ecosystem complexity and biodiversity, with the consequent increase of protective, environmental, economic, and recreational values of the forest (Hartley 2002, Kerr 1999). Thus, the current silvicultural approach is aimed to favour a gradual succession by the establishment of natural regeneration (Nocentini 2013, Mercurio et al. 2009).

Experimental trials recently carried out by Council for Agricultural Research and Economics–Forestry research centre showed an encouraging reaction of Black pine stands to a first delayed heavy thinning (stand age: 30–35 years), which eliminated most of the dominated plants and included also some trees of the dominant layer. During the thinning more than half of the plants were cut in total (intensity >50 %). Black pine is a shade-intolerant pioneer species, and it revealed to be adaptable and reactive to this treatment. Canopy closure occurred very quickly (6–8 year after the thinning) and a strong incremental effect on diameter growth was observed (Cantiani and Piovosi 2009), during the following ten years no mortality resulted in the thinned stands.

On the basis of the positive results obtained by thinning from below of medium-heavy intensity (Bonet et al. 2011, Lindgren et al. 2006, Taki et al. 2010), a new experiment on selective thinning was set up. In selective thinnings, the best trees of the stand are selected according to vigour and stability, and their growth and development is actively promoted by removing competitors in the dominant layer, whereas plants in the dominated layer are harvested only in case of economic convenience.

In this framework, the objective of this study was to compare the selective thinning, the traditional thinning (thinning from below) and no treatment (control) in Black pine stands in Central Italy (in Tuscany). The stands are included in the pilot areas of the project Life13BIO/IT/000282 SelPiBioLife – Innovative silvicultural treatments to enhance soil biodiversity in artificial Black pine stands.

The study was aimed to provide evidence to support the idea that a multifunctional forest management represents a valid alternative to timber production for pine stands. More specifically, the aim was to highlight that selective thinning can be effective not only on stability and growth to enhance wood production, but also on floristic and mycological biodiversity of the forest. The relationship of the stand structure (directly related to the applied treatment) with the following aspects was evaluated: i) floristic diversity; ii) mycological diversity; iii) mushrooms marketable production.

## Material and Methods

### Study area

The study was carried out in Arezzo province (Tuscany, Central Italy), a mountain area where Black pine stands are widely spread (Fig. 1). In Tuscany, the total area of Black pine forests is 20,500 ha and the stands mean age is about 60 years. Pratomagno-Valdarno forest is located in the upper part of pre-Apennine ridge Massiccio del Pratomagno, prevalent South-West and West exposure. It occupies 3,300 ha, 500 of which are covered by Black pine reforestation (86 % are pure Black pine stands). The native geological formation is “Macigno del Chianti”, which is composed of layers of sandstone and


**Fig. 1. Study area.**

**Table 1. Characteristics of the experimental sites.**

| Site | Elevation a.s.l., m | Stand establishment | Geographical coordinates (UTM-WGS84) | Slope, % | Exposition |
|---|---|---|---|---|---|
| La Baita (A) | 880 | 1956 | 43°34'53"N 11°42'47"E | 20 | SW |
| Scoiattolo (B) | 900 | 1950 | 43°36'11"N 11°41'33"E | 15 | W |

layers of siltstone and silt argillites. In such conditions soils are acid and rich in Potassium. The forest is spread over the temperate continental sub-Mediterranean bioclimatic zone according to Rivas Martinez classification (2004).

Rainfall follows the Apennine submontane regime, with a maximum peak in fall and a second peak in spring. Minimum precipitation occurs in July with a dry period between the end of July and the beginning of August. The annual rainfall is 897 mm. The mean annual temperature is 11.6 °C.

The experimental studies were carried out in young high-forest stand of Black pine (aged 56–58 years). The stand was a homogeneous and simplified ecosystem in relation to orography, geological formation and silvicultural treatments. Two sites were included in the experiment: La Baita and Lo Scoiattolo (Table 1).

Sampling was conducted in 2011–2012, during two vegetative seasons after harvesting, and the first one was characterized by an unexpected climate regime in comparison with long term observations. Comparing the thermo-pluviometric regime of the studied period (November 2011 – November 2012) with past long term observations (1995–2010), the total precipitation was lower in 2011 (109 mm vs 315 mm) and the mean temperature was higher (12.7 °C vs 11.5 °C).

## Experimental design

In both sites three permanent experimental plots were set up, where three treatments were applied (one plot for each treatment): two different thinnings (traditional and selective) and one Control (no treatment, Table 2). The traditional thin-

**Table 2. Applied treatment and mensurational parameters per plot.**

| Plot | Treatment | Area, $m^2$ | Age, years | Last harvesting | *N*, $ha^{-1}$ | *BA*, $m^2 \cdot ha^{-1}$ | *V*, $m^3 \cdot ha^{-1}$ | *Dbh*, cm | *H*, m |
|---|---|---|---|---|---|---|---|---|---|
| A1 | Thinning from below | 2000 | 56 | 2009 | 455 | 36.7 | 349 | 32.1 | 24.9 |
| A2 | Selective thinning | 2000 | 56 | 2009 | 405 | 37.2 | 361 | 34.2 | 25.7 |
| A3 | Control | 1400 | 56 | - | 1064 | 67.3 | 625 | 28.4 | 24.0 |
| B1 | Thinning from below | 1250 | 58 | 2009 | 866 | 59.1 | 625 | 29.1 | 24.0 |
| B2 | Selective thinning | 1250 | 58 | 2009 | 624 | 44.2 | 468 | 30.3 | 24.4 |
| B3 | Control | 750 | 58 | - | 1065 | 67.5 | 720 | 28.0 | 20.9 |

Note: *N*, $ha^{-1}$ – number of trees per ha; *BA*, $m^2 \cdot ha^{-1}$ – basal area per ha; *V*, $m^3 \cdot ha^{-1}$ – volume per ha; *Dbh*, cm – quadratic mean diameter; *H*, m – height of mean diameter tree.

ning consisted of a thinning from below, 45 % of the trees were removed, corresponding to 35 % of stand basal area. In the selective thinning, 100 plants in the dominant layer were identified to be favoured and competitors were removed in order to promote stand growth and stability, in this case thinning intensity was 53 %, corresponding to 40 % of stand basal area.

24 permanent sub-plots were identified inside the plots (4 per plot) to study mycological diversity and mushrooms marketable production. Each sub-plot was selected randomly, and the sub-plot surface varied from 300 m$^2$ (minimum threshold) to 364 m$^2$.

In each plot, during spring and summer 2011 and 2012, floristic diversity was sampled according to the Braun-Blanquet (1932) method in a central area of each plot, defined "vegetational sub-plot", in order to avoid edge effect. Plant species were identified and their abundance-dominance was assessed.

**Data collection**

In each plot the main dendrometric parameters of all the trees were measured, and each tree was assigned to a social crown class (3 classes: dominant, co-dominant and dominated) (Pretzsch 2009). On all trees the following variables were also measured: Diameter at breast height (*DBH*), Height (*H*), crown length, single crown cover (according to 4–8 crown radii), and plant coordinates (topographic position). Topographic position (azimuth and horizontal distance from plot centre) was determined with Field Map forest mapping software.

The variables (Table 3) were used to calculate two stand structural indexes (Neumann and Starlinger 2011, Pommerening 2002 and 2006): aggregation index *CE* (Clark and Evans 1954) and Vertical Evenness (Staudhammer and LeMay 2001). Furthermore all gaps inside the plots were identified and measured using software Q Gis. Gap was defined as proportion of openings more than 11 m$^2$ in an area, and is expressed as a percentage (Bottero et al. 2011).

Concerning mycological diversity, measurements on carpophores were taken during fall in 2011 and 2012 and the protocol included:

- weekly harvest of carpophores per sub-plot;
- carpophores species determination;
- α-diversity by Shannon index;
- trophic group distinction (mycorrhiza and saprophytes);
- fresh weight of soil and carpophore (per species);
- drying: soil – 24 hours at 100 °C, carpophores – 24 hours at 50 °C;
- dry weight of carpophores.

Vegetation cover (in total) and, separately, of tree layer and of herbaceous layer were also assessed. Moreover, the phytosociological classes of the species inside the vegetation sub-plots were recorded in order to define the different coenosis from an ecological point of view. Dichotomous-analytical key reported in Flora d'Italia (Pignatti 1982), in Nuova Flora Analitica d'Italia (Fiori 1923–1929), in Flore forestale française (Rameau et al. 1989), and in Flora Europaea (Tutin et al. 1964) were used to help in species identification.

To analyse the data, Braun-Blanquet values were transformed according to the Van der Maarel scale (1979). The Shannon index ($-\sum p_i \cdot \ln p_i$) was calculated to assess *α*-diversity of each vegetation sub-plot ($p_i$ = relative frequency of the

**Table 3. List of the stand structure diversity indices.**

| Index | Equation | Variables | Range values |
|---|---|---|---|
| Aggregation index (*CE*) (Clark and Evans 1954) | $CE = \frac{r_A}{r_E}$ | $r_A = \frac{\sum_{i=1}^{n} HDist_j}{n}$ <br> $r_E = \frac{1}{2}\sqrt{\frac{A}{N}}$ <br> $HDist_{ij}$ = Euclidean distance between *i*-th tree and its nearest neighbor <br> *A* = plot area <br> *N* = plot tree number | min value = 0 <br> max value = 2.1491 <br> *CE* = 1 → completely spatially random distribution <br> *CE* < 1 → spatially clustered distribution <br> *CE* > 1 → spatially regular distribution |
| Vertical Evenness index (*VE*) (Neumann and Starlinger 2001) | $VE = \sum_{i}^{3} (-\log_2 \pi_i) \frac{\pi_i}{\log_2 3}$ | $\pi_i$= is the relative crown area of all trees in the *i*-th heigth layer | *VE* < 1monostoried stands <br> *VE* > 1 multistoried stands <br> *VE* = 1 the vertical distribution of the plants belonging to different classes is homogeneous |

Note: *CE* – Index of aggregation; *VE* – Vertical Eveness index.

species, which in our study corresponded to relative abundance).

### Statistical analysis

The data did not show a normal distribution, consequently non-parametric test were used (U-Mann-Whitney) to highlight statistical differences of the variables related to the mycological study, and the three different silvicultural treatments were considered as source of variation.

Correlation between stand structural indices and parameters related to floristic and mycological biodiversity were performed using the Spearman correlation test.

## Results

Results showed that the last thinning, operated in 2009, influenced stand structure features, as illustrated by the values of the structural indices reported in Table 4 (*CE*, *VE*, Gaps area, and Number of gaps). The plots horizontal structure was random, *CE* is >1 in four plots and the thinning sim-

**Table 4. Values of stand structure diversity indexes after the thinning.**

| Plot | Treatment | CE | VE | Gaps area, m² Mean | min | max | Number of gaps |
|---|---|---|---|---|---|---|---|
| A1 | Thinning from below | 1.46 | 0.37 | 28.6±14 | 12 | 64 | 17 |
| A2 | Selective thinning | 1.33 | 0.39 | 44.1±16 | 24 | 75 | 15 |
| A3 | Control | 1.22 | 0.62 | 35.4±15 | 14 | 61 | 14 |
| B1 | Thinning from below | 0.66 | 0.18 | 23.6±9 | 15 | 47 | 22 |
| B2 | Selective thinning | 1.40 | 0.63 | 28.8±12 | 13 | 53 | 15 |
| B3 | Control | 0.97 | 0.72 | 23.2±15 | 7 | 43 | 12 |

Note: *CE* – Index of aggregation; *VE* – Vertical Evenness index; Gaps area and number of gaps.

plified the vertical structure (*VE* < 1 in all plots). In the selective thinning plots a higher area of gaps was observed in comparison to below and control plots.

Stand structure is a factor strictly linked to eco-physiological parameters, which influence vegetation and carpophores development (light, temperature and soil humidity).

The Shannon index values recorded during 2001 and 2012 in all plots are shown in Figure 2. Both thinning treatments, from below and selective, caused a biodiversity increase in comparison with control plots from a floristic and mycological point of view. The Shannon index mean values were equal to 1.7 and to 1.6, respectively, for thinning from below plots and selective thinning plots, while 1.5 was recorded in control plots. Concerning mycological diversity, higher values of the Shannon index occurred in thinned plots (0.92 for thinning from below plots and 0.87 for selective thinning plots) than in control (0.81).

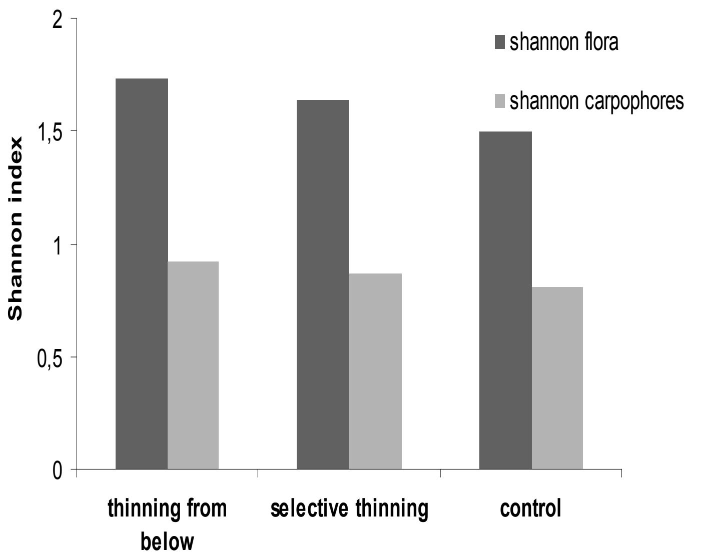



**Fig. 2. The mean Shannon index values for flora and carpophores.**

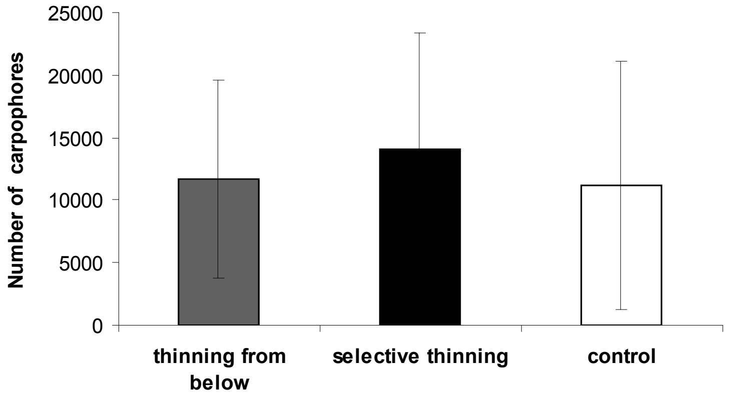



**Fig. 3. Number of carpophores per treatment.**

Both thinning treatments influenced positively fungal production as revealed by carpophores number. During the two studied years (2011 and 2012) carpophores mean number was 14,040 in selective thinning plots, 11,684 in thinning from below plots and 11,218 in control (Fig. 3).

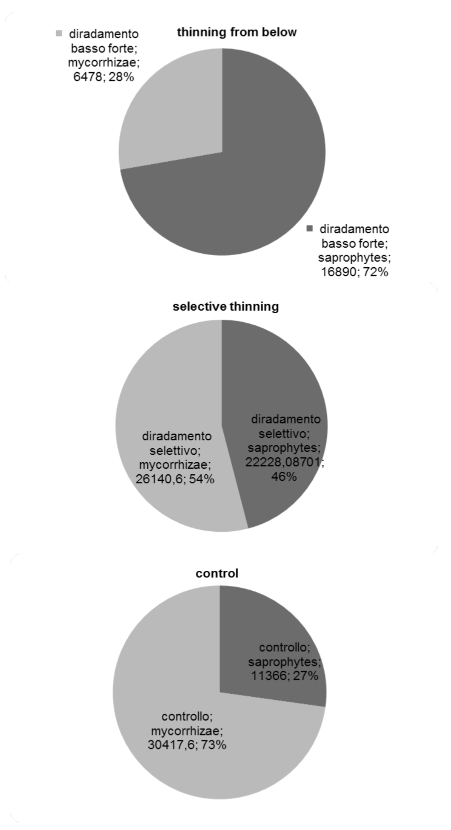
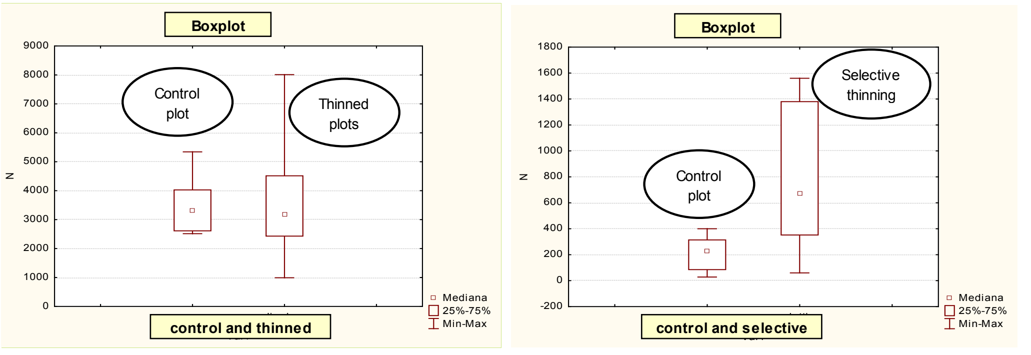



**Fig. 4. Percentage of mycorrhizae and saprophytes per treatment.**

Percentage of fungi species classified in trophic groups can be used as parameter to assess the health status of forest ecosystems. In more detail, the fraction of mycorrhizae species of total macromycetes is considered an effective index of external disturbance factors on a forest ecosystem: the higher is the disturbance level, the lower is the frequency of mycorrhizae. According to our results, the higher disturbance level was observed where thinning from below was applied. However, the studied Black pine stands, which were harvested more recently, are still affected by anthropic disturbance (Fig. 4).

The U-Mann-Whitney test results (Fig. 5a and 5b) showed that the difference in carpophores number between thinned stands (both treatments) and their respective control was significant. Statistical differences were also observed for this variable between selective thinning and control in both experimental sites (Fig. 5b).

The Spearman correlation test (Table 5) highlighted that floristic biodiversity




**5a** **5b**

**Fig. 5. The U-Mann-Whitney test results between thinned plots and control and between selective thinning and control (*p* level < 0.05).**

and species number were significantly related ($p < 0.05$) to horizontal structure diversity index (CE), gap area, basal area (BA), and stand density (N). Concerning fungi, significant correlation ($p < 0.05$) resulted for total production (fungi dry weight) and: mean height (H), vertical stand structure index (VE), basal area (BA) and stand density (N).

Total 86 floristic taxa were totally recorded. More than 40 % of the species are typical for forest ecosystems, while the rest are characteristic to open habitats with plenty of sunlight.

A higher number of species (57) occurred where thinning from below was applied, whereas lower species richness was observed in the plots with the other two treatments (selective thinning 44, control 47).

In control plots higher number of species characteristic to *Querco-Fagetea* and *Quercetea pubescentis* classes was observed. These classes include nemoral species, which are related to mesophyllous conditions of *Querco-Fagetea* and to more thermophyllous conditions of *Quercetea pubescentis*. On the other hand, in thinned plots the present species were characteristic of: sub-thermophile and sunny edges, open environments (perennial herbs), arid meadows (annual herbs) and mesophile meadows. Plots thinned from below resulted to be rich of these groups of species (35), while in the selective thinning plots and in control the number was lower, respectively 21 and 26.

Control plots included characteristic species of forest environments, as trees in juvenile stage and shrubs, and herbs such as *Brachypodium rupestre* (Host) R. et S.

**Table 5. Pair-wise Spearman Rank Correlation Coefficient matrix among calculated indices (only significant correlation at *p* < 0.05 after Bonferroni's correction for multiple comparisons).**

| Index | CE | gap | BA | N |
|---|---|---|---|---|
| Flora species number | 0.005 | 0.003 | 0.004 | 0.002 |
| Shannon on flora | 0.004 | 0.003 | 0.003 | 0.003 |

Note: *CE* – index of aggregation; gap – proportion of total gap area on the total; *BA* – basal area; *N* – number of trees; *VE* – Vertical Evenness index; *H* – height of mean diameter tree.

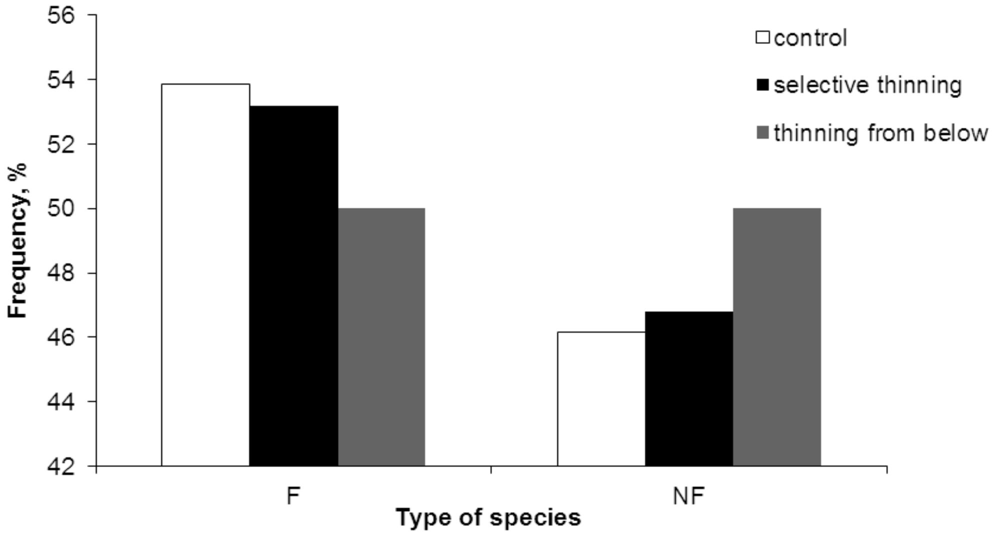



**Fig. 6. Frequency of forest species (F) and non-forest species (NF) separated per treatment.**

In thinned plots (both treatments), species like *Rubus canescens* DC., *Pteridium aquilinum* (L.) Kuhn and *Rumex acetosella* (L.), which are related to plenty of light and disturbance, were mostly found. Moreover high frequency of woody species was observed, as well as Gramineae *Agrostis tenuis* Sibth., which belongs to the *Molinio-Arrhenatheretea* class, characteristic of humid meadows.

Figure 6 shows the frequency (in percentage) in terms of presence/absence of recorded species, “forest” or “non-forest” mean a shrub or a herb characteristic respectively of forest or meadows, in terms both of frequency and abundance. Such kind of categorization is based on both literature (Pignatti 1982, Rameau et al. 1989) and field experience. The graph provides also information about the increase of non-forest species in thinned stands in comparison with control, especially for thinning from below plots. In selective thinning plots, such increase was not equally evident.

## Discussion and Conclusions

According to our results, experimental trials on different kind of thinning in Black pine stands aged 60 provided useful information.

First, results showed that the silvicultural treatments were effective in influencing horizontal and vertical structure of Black pine stands.

It is a fact that thinning influences competition relationships among plants, changing not only stand stability but also ecosystem complexity. Thus it is important to support experiments on different thinning regimes where the objective is to implement the forest multi-functionality (biodiversity, wood production, soil protection) (Jonard et. al 2006, Skovsgaard 2009).

More specifically, further trials should be carried out in Italian Black pine stands, where the traditional routine operations were not applied because they were not financially sound convenient. For these stands, the thinning regime should have included an early pre-commercial thinning and further pre-commercial thinning every 10–15 years. Actually, the common approach consisted of delaying the first thinning (mean age 30 years) and of extending the period between two consecutive operations (Cantiani and Chiavetta 2015).

This experiment was carried out in stands where the previous thinning from below, with intensity 30 % (common standard intensity in Italy), resulted to be not efficient to affect crown competition in the dominant layer and, consequently, it did not favour tree growth.

Our results showed that selective thinning can be efficient in stimulating tree growth and stability. Furthermore, this thinning type influences the crown cover, causing a different light regime (more gaps) and changes water and temperature conditions at soil level. Such reactions have positive effects on general ecosystem biodiversity and complexity, which show an increase, with direct consequences on fungi and flora biodiversity. The positive change of the soil ecological conditions favours the natural process of regeneration, and thus the ecological succession of the Black pine stands. The new stand structure after selective thinning offers a higher management flexibility. The selected individuals, which take advantage of eliminating their competitors, provide more stability to the whole stand even at an older age than that in a usual rotation. Concerning flora, both thinnings caused a rise of the non-forest species in comparison with control during the years after the disturbance operations: shade-intolerance species and, more in general, species characteristic of meadows increased the most. This reaction has been observed where ecological conditions, especially in terms of light and temperature, change and favour annual and no-forest species at the expense of the species characteristic of forest environments (Mattioli et al. 2008, Gondard and Romane 2005). Biodiversity and floristic abundance is mainly related to stand horizontal structure and to the presence of the gaps. A higher area of gaps was observed in selective thinning plots.

Egli et al. (2010) observed a recovery during the fourth year after thinning, with low production during the first 3 years after thinning. These authors suggested that the effect of the temporary site disturbance caused by the intervention could be a possible explanation for these dynamics.

More time is necessary to evaluate whether the thinning effect on biodiversity will last long and to observe whether non-forest species are able to regenerate when the crown cover tends to close (Lust et al. 1998, Götmark et al. 2005). The future different effects on biodiversity of each treatment will also require more time to be assessed. Considering the multi-functionality of the studied stands, it will be possible to plan suitable thinnings aimed to ensure a constant level of biodiversity.

Structure changes have influenced positively fungi presence, in terms of carpophores number and biodiversity, and this is more evident in the thinning which affected more the micro-climate conditions at soil level (Egli et al. 2010). Biodiversity rise and fungi production are actually linked with the parameters of the stands vertical structure which were altered by the thinnings.

Mycorrhizae species percentage on total macromycetes is an effective indicator of external disturbance factors on forest ecosystem: a lower percentage is associated with a higher disturbance level.

Results concerning mycorrhizae species percentage in relation to treatments showed that where no disturbance treatment occurred (control), a higher percentage of mycorrhizae was observed (73 % of carpophores number).

Comparing the two type of thinning, a higher frequency of mycorrhizae resulted where selective thinning was applied (54 % of carpophores number), in relation to the fact that this treatment localizes the disturbance only around the selected plants, while in thinning from below all surface is affected by the harvesting, with a consequent higher impact on the whole stand. A plausible hypothesis for future studies is that the temporal pattern of thinning effect on mushroom yield depends on the thinning intensity, light thinnings leading to immediate positive response, whereas intensive thinning may lead to short-term negative effects after which the mushroom yield may recover and increase.

A limit of this study is that we could observe the treatment effects during two vegetative seasons after harvesting, and the first one was characterized by an unexpected climate regime in comparison with long term observations. More extensive results will be provided thanks to the project Life13BIO/IT/000282 SelPiBioLife – Innovative silvicultural treatments to enhance soilbiodiversity in artificial Black pine stands, which will finance the future development of this study. Thus it will be possible to carry on the monitoring for a longer period post-thinning (4 years), in order to assess more in detail the response in terms of soil biodiversity in Black pine stands in two different zones of Tuscany.

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# TRANSECT SAMPLING METHOD WITH *K*-TREE FIXED NUMBER: A FAST AND ACCURATE METHOD TO ESTIMATE QUANTITATIVE VARIABLES IN OPEN FORESTS

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## Abstract

In this study, we investigated line transect sampling methods with *k*-fixed trees (*k* = 2, 3, 4 and 5) to estimate quantitative variables in Zagros open forests in the west of Iran. Accurate measuring and commercial benefits are two aspects of sampling methods that are important for forest managers. The results of full callipering inventory indicated that density above 12.5 cm DBH, basal area and canopy were 68.04 trees·ha$^{-1}$, 15.16 m$^2$·ha$^{-1}$ and 35.71 % ha$^{-1}$ respectively. Based on ANOVA test, mean of measured variables in the line transect sampling methods with *k* = 2, 3, 4 and 5 were statistical different (*P* = 0.00). The results of study showed that the mean of density, basal area and canopy variables using transect sampling with *k* = 5 trees were closest to actual means derived from full callipering inventory. Our findings showed that line transect sampling method with *k* = 5 fixed trees had reliable results and was statistically reliable, efficient and practical method to estimate of the quantitative characteristics in Zagros open forest area.

**Key words:** forest inventory, line transect sampling, *Quercus brantii* var. *persica*, Zagros forest.

## Introduction

Sampling method is useful to obtain stand information in a large forest area (Bonyad 2015). Line transect sampling method with 2, 3, 4, 5 trees may be applied in forest inventories and ecological surveys in open forests. The best sampling design should provide accurate and representative information about the population, while being geometrically compact and requiring the least amount of field effort. In forest sampling, suitable survey design is a crucial prerequisite for reliable results. In the past studies, in forest inventory researchers have mostly used random and systematic plot sampling methods. These methods were important for forest managers in two aspects: accurate measuring and commercial benefits. Sampling distance method has a survey design engine, with a built-in geographic information system, that allows examining the properties of different proposed designs via simulation, and generating of survey plans (Thomas et al. 2010). The line transects and distance sampling, also known as plot less sampling, has a long history in forest inventory. The line transects and distance sampling are often faster than the fixed-area plot sampling (Hall 1991, Lessard et al. 2002, Sheil et al. 2003, Picard et al. 2005, Kleinn and Vilčko 2006). In the natural populations characterized by an irregular, possibly clustered distribution of trees, the precision of a density estimate from distance sampling can be better than the precision obtained with fixed area plot sampling (Lessard et al. 2002). Some stand elements can be difficult to detect and missed objects will lead to an underestimation of the true density. In order to be sure that all objects in a strip will be detected, the strip width must be small, leading to high variability in estimates. In this situation, line transect sampling can be an alternative to strip surveys (Burnham et al. 1985). Line transect sampling methods have been used since 1930s to estimate the abundance of many biological populations, such as animal, bird, and plant species, and even non-living things. It was used for estimating densities of wildlife populations and can be a useful alternative to the traditional methods (Buckland et al. 1993, Ringvall et al. 2000, Buckland et al. 2001). The study of quantitative variables in forest stands had an important role in evaluation of stand growth and production (Burnham 2002, Zheng and Zhou 2010, Lu et al. 2003). Hermandez (1997) showed that transect sampling method is the best for estimation of density and canopy variables in coniferous forests.

To survey the open forest characteristics required sampling methods with low cost and acceptable accuracy. The open forests are mixtures of trees, shrubs and herbaceous species in which, unlike closed forests, the tree canopies do not form a continuous closed cover (Norvell et al. 2003, Somershoe et al. 2006, Newson et al. 2008, Ronconi and Burger 2009). The open-canopy forests tend to be better coupled to the atmosphere than closed-canopy and the results were differences in climate and conductance of water vapour (Jarvis 1985). Tree cover in open forests is typically more diffuse and variable than in closed forests. The line intersect sampling method for assessing coarse woody debris was tested by using 11 surveyors in four old conifer stands in northern Sweden (Ringvall and Stahl 1999). The study did not indicate any systematic differences between surveyors in their way of performing the inventory, although for the surveyors as a group a negative bias was found. Beasom and Haucke (1975) compared four distance sampling methods: closet individual, nearest neighbours, random pairs, and point centred quarter with 100 % inventory, to obtain density of oak forests in southern Texas. The random pairs and point centred quarter methods were closest to actual density. Sparks and Masters (2002) compared six sampling methods in fixed plots with 3.64 and 5.64 m radii, square plots with a central point, variable plots, transect, and 10 m × 10 m square plots in three forest stands in the southeast regions of Oklahoma. The line transect sampling techniques were useful for obtaining stand information in large open forest area (Krebs 1999, Newton 2007, Sutherland 2008). However, Zagros forest stands were non-timber forests with low density and important for protection purposes. Zagros mountain forests covered 5 million hectares with low density. The natural regeneration virtually did not exist, soil erosion was severe, with exposed bedrock (Marvi-Mohajer 2007). In this study, we investigated line transect sampling method with $k$-fixed trees ($k$ = 2, 3, 4 and 5) to estimate quantitative variables in Zagros open forests.

## Material and Methods

### Study area

This study was carried out at uneven-aged hardwood stands in Zagros open forests in the western part of Iran. Altitudinal range is from 1000 to 3000 m a.s.l. The study area was 37.2 ha located at 46°22´40˝ E and 46°23´30˝ E longitude and 33°42´05˝ and 33°42´40˝ latitude (Fig. 1). Climate in the region of study can be defined as semi-Mediterranean, with mean annual precipitation approximately 600 mm and mean annual temperature 10 °C. Zagros forests provide various non-timber products and services and had multiple socio-economic and ecological functions. They were classified as semi-arid and consist 40 % of Iran's forest areas. The original vegetation of this area consist of uneven-aged mixed forest dominated by *Quercus brantii* Lindl., mixed (*Q. brantii*, *Pistacia atlantica* Desf., *Acer cinerascens* Boiss.), and *Daphne mucronata* Royle, *Amygdalus orientalis* Mill. types. *Q. brantii* var. *persica* is the most abundant tree species in the study area.

### Full callipering inventory (100 % survey)

In full callipering inventory, all trees with diameter at breast height (DBH) > 12.5 cm were measured, and number of trees, canopy, and basal area ($m^2 \cdot ha^{-1}$) were measured and recorded.

### Line transect sampling method

In this study 37 line transect samples were measured. In each line transect sample, first 5 trees were measured in systematic perpendicular lines (Fig. 1), installed with a grid of 100 m × 100 m over the study area. The grid points of perpendicular lines were starting points of line transect samples. Diameter at breast height (DBH), basal area and diameters of crown (large and small diameters of tree crown) of selected trees were measured and recorded. Suunto compass was used to move along the line transect from starting point to fifth tree (Fig. 2). The equations 1 and 2 were used to calculate mean ($\bar{x}$) and variance (S2) of the line transect sampling methods:

$$\bar{x} = \frac{\sum x_i}{n} \quad (1),$$

$$S^2 = \frac{\sum x_i^2 - \frac{\sum (x_i)^2}{n}}{n-1} \quad (2),$$

where: $\bar{x}$ = mean, $S^2$ = variance, $n$ = number of samples and $x_i$ = quantitative value of measured variables in the line transect samples ($i$ = 1, 2, …, 37).

The equations 3, 4 and 5 were used to calculate density of trees per ha (Zobeiri 2007, Bonyad 2015):

$$\bar{a} = \frac{(a_1 + a_2 + ... + a_n)}{d} \quad (3),$$

$$N = \frac{10000}{\bar{a}^2} \quad (4),$$

$$\bar{N} = \frac{\sum N}{n} \quad (5),$$

where: $\bar{a}$ is the mean distance between trees of each transect; $d$ is the number of distance between trees; $n$ is the number of trees per ha at each transect; $\bar{N}$

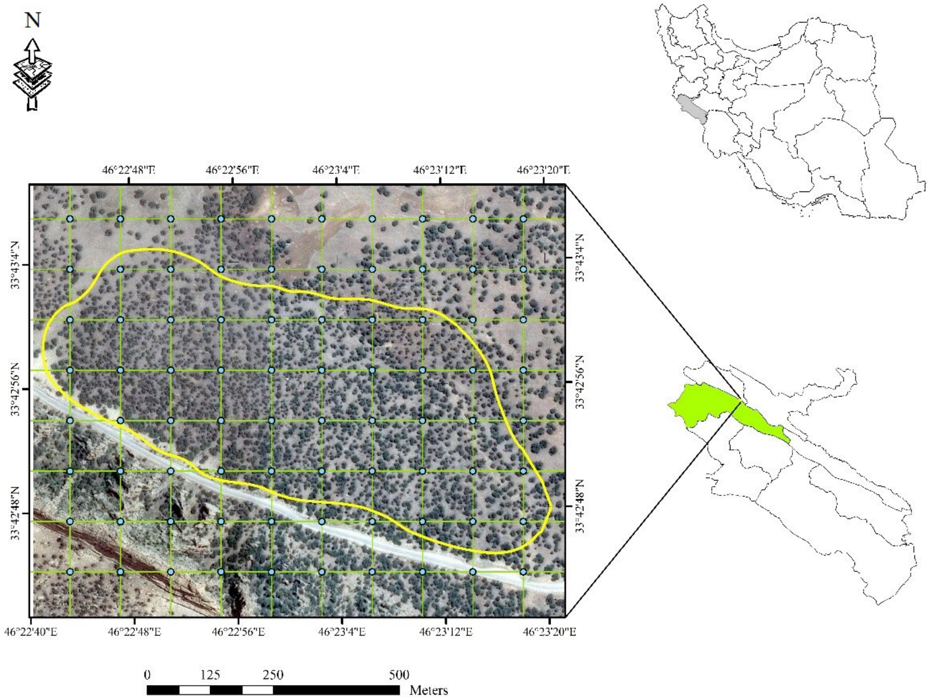


**Fig. 1. Location of study area.**

is the mean number of trees per ha for forest stand and $n$ is the number of transects sampling. The equations 6, 7, 8 and 9 were used to calculate the basal area ($m^2 \cdot ha^{-1}$):

$$g = \frac{\pi}{4} d^2 \quad (6),$$

$$\bar{g} = \frac{\sum g}{n} \quad (7),$$

$$G = \bar{g} \cdot n \quad (8),$$

$$\bar{G} = \frac{\sum G}{n} \quad (9),$$

where: $g$ is the basal area for a tree; $d$ is the diameter at breast height; $\bar{g}$ is the mean of basal area at each transect; $G$ is the basal area per ha, and $\bar{G}$ is the mean of basal area in forest stand. The equations 10, 11 and 12 were used to calculate canopy percent ($ha^{-1}$):

$$\overline{CA} = \frac{\pi \cdot \sum (CD_1 \times CD_2)}{4k} \quad (10),$$

$$CC = \frac{\overline{CA} \times 100}{\bar{a}^2} \quad (11),$$

$$\overline{CC} = \frac{\sum CC}{n} \quad (12),$$

where: $CD_1$ and $CD_2$ are small and large diameter of tree crown in meter; *k* is the number of tree in line transect; $\overline{CA}$ is the mean of tree's crown canopy in each transect; *CC* is the crown canopy of trees at each transect in percent; $\overline{CC}$ is the mean of crown canopy in forest stand in percent.

**Statistical tests**

Levene test was used to variance homogeneity of the line transect sampling methods with *k*-fixed trees (*k* = 2, 3, 4 and 5) in the SPSS. The density and characteristics (DBH, basal area and crown canopy) were compared using t-test and one-way ANOVA. The null hypothesis was that there is no significant difference among the means derived from the sampling methods with *k*-fixed trees. The standard deviation and confidence intervals of measured variables were compared with the ac-

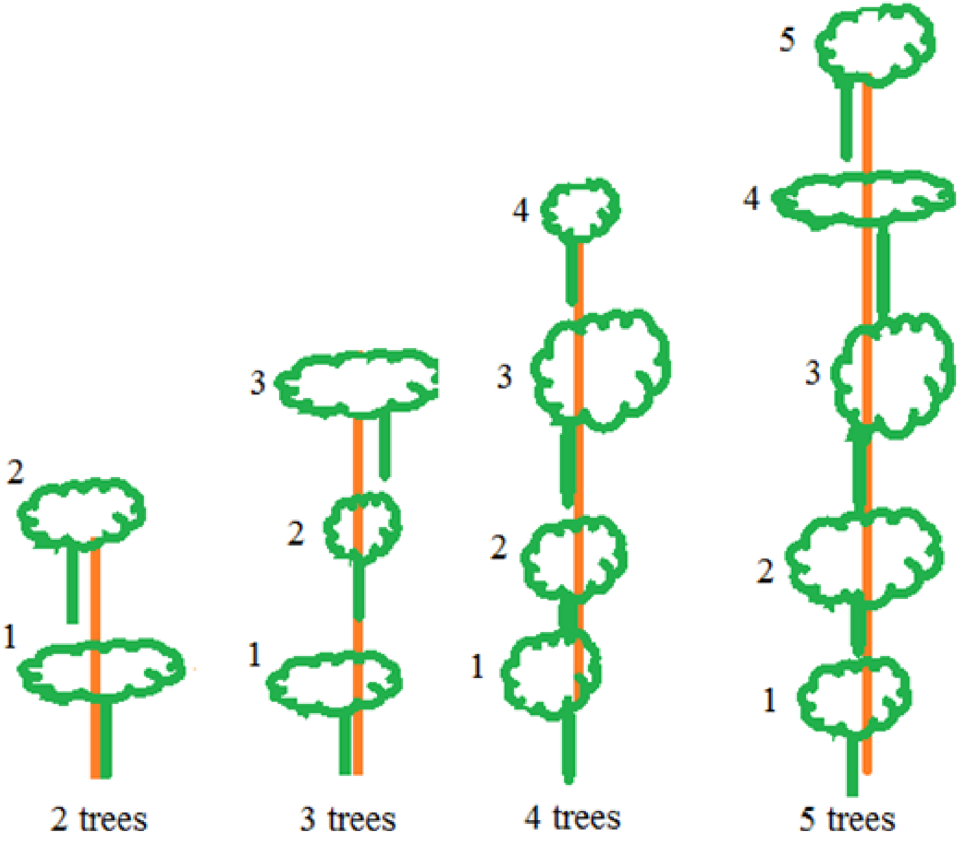


**Fig. 2. Transect sampling method with k-fixed number of trees.**

**Table 1. Results of 100% inventory.**

| Characteristic | Actual mean | *SD* | *CV*, % |
|---|---|---|---|
| Density, ha$^{-1}$ | 68.04 | ±32.87 | 48.30 |
| Basal area, m$^2$·ha$^{-1}$ | 15.16 | ±8.97 | 59.17 |
| Crown canopy, % | 35.71 | ±14.48 | 40.54 |

tual values derived from the full callipering inventory. Pairwise multivariate Hotelling's T$^2$ test was used to test means vectors of measured variables (Tatsouka 1988, Bonyad 2006).

**Table 2. Statistical results for sampling methods.**

| Characteristic | *k*-fixed tree | Actual mean | $\bar{x}$ | *SD* | $S_{\bar{x}}$ | $\bar{x} \pm E$ | *E*, % |
|---|---|---|---|---|---|---|---|
| Density, ha$^{-1}$ | 2 trees | 68.04 | 61.63 | ±46.83 | ±7.70 | 61.63±12.93 | 20.99 |
| | 3 trees | 68.04 | 77.36 | ±33.02 | ±5.43 | 77.36±9.17 | 11.86 |
| | 4 trees | 68.04 | 78.17 | ±40.96 | ±6.73 | 78.17±11.37 | 14.54 |
| | 5 trees | 68.04 | 74.17 | ±7.06 | ±1.16 | 74.17±1.96 | 2.64 |
| Basal area, m$^2$·ha$^{-1}$ | 2 trees | 15.16 | 12.7 | ±14.79 | ±2.43 | 12.7±4.08 | 32.17 |
| | 3 trees | 15.16 | 14.39 | ±7.38 | ±1.21 | 14.39±2.04 | 14.21 |
| | 4 trees | 15.16 | 15.01 | ±10.81 | ±1.77 | 15.01±2.99 | 19.92 |
| | 5 trees | 15.16 | 13.9 | ±2.69 | ±0.44 | 13.9±0.74 | 5.34 |
| Crown canopy, % | 2 trees | 35.71 | 25.17 | ±19.37 | ±3.18 | 25.17±5.35 | 21.26 |
| | 3 trees | 35.71 | 31.46 | ±12.83 | ±2.11 | 31.46±3.56 | 11.33 |
| | 4 trees | 35.71 | 29.02 | ±12.55 | ±2.06 | 29.02±3.48 | 11.99 |
| | 5 trees | 35.71 | 35.25 | ±3.46 | ±0.56 | 35.25±0.94 | 2.68 |

**Table 3. ANOVA test with *k*-fixed trees of line transect sampling methods.**

| Characteristic | Statistic | *df* | Mean Square | *P*-value |
|---|---|---|---|---|
| Density | Between Groups | 3 | 2668182.147 | 0.00* |
| | Within Groups | 144 | 54489.643 | |
| | Total | 147 | | |
| Basal area | Between Groups | 3 | 40142.836 | 0.06 |
| | Within Groups | 144 | 9239.592 | |
| | Total | 147 | | |
| Crown canopy, % | Between Groups | 3 | 116607.667 | 0.00* |
| | Within Groups | 144 | 5213.688 | |
| | Total | 147 | | |

## Results

The results of full callipering inventory indicated that tree density above 12.5 cm DBH, basal area and crown canopy were 68.04 trees (ha$^{-1}$), 15.16 m$^2$·ha$^{-1}$ and 35.71 %, respectively (Table 1).

The results indicated that measured variables including: density of tree/ha, basal area and canopy using transect sampling with $k$ = 5 trees were closest to actual values derived from the full callipering inventory. Also transect sampling with $k$ = 5 trees has less statistical error ($E$, %) than other transect sampling (Table 2).

In ANOVA tests, the equality of variance of measured variables was a prerequisite. The results of variance equality tests indicated that the variance of measured variables in line transect sampling was not equal. Therefore, the results of ANOVA tests would be not robust. However, the analysis of variance was carried out to compare the means of measured variables with $k$-tree fixed ($k$ = 2, 3, 4 and 5), and the results are shown in Table 3.

Based on Hotelling's $T^2$ test, the mean vectors of measured variables derived from transect with 2, 3, 4, 5 trees were compared with actual mean vectors derived from 100 % survey. In statistical terms, there was significant difference and results are shown in Table 4.

**Table 4. Results of pair-wise test using multivariate Hotelling's $T^2$ test.**

| $H_o$ | Num. df. | Den. df. | $F_t$ | $F_c$ | *P*-value |
|---|---|---|---|---|---|
| $\overline{X}^{(T_1)}$ and $\overline{X}^{(T_2)}$ | 3 | 73 | 2.74 | 54.04 | 0.00 |
| $\overline{X}^{(T_1)}$ and $\overline{X}^{(T_3)}$ | 3 | 73 | 2.74 | 7.600 | 0.00 |
| $\overline{X}^{(T_1)}$ and $\overline{X}^{(T_4)}$ | 3 | 73 | 2.74 | 82.61 | 0.00 |
| $\overline{X}^{(T_1)}$ and $\overline{X}^{(T_5)}$ | 3 | 73 | 2.74 | 6.4676 | 0.00 |

## Discussion

Two main peculiarities the sampling methods are important for forest managers: accurate measuring and commercial benefits. The quantitative variables of forest stands had important roles in forest survey and planning. The results of equality of variance tests showed that variances of measured variables derived from different lines transect sampling were not equal. The results of ANOVA test between mean of measured variables with fixed $k$-tree ($k$ = 2, 3, 4 and 5) indicated that density and canopy % of study stands were significantly different ($P$ = 0.00). This study showed that line transect sampling with $k$-5 trees, mean of density per ha, crown canopy and basal area were closest to actual means derived from 100 %. This result is important for forest inventory in the non-timber open forests with low density as Zagros forest area. The standard error and variance of measured variables with different $k$-tree fixed ($k$ = 2, 3, 4 and 5) decreased with increasing number of fixed trees in the line transect sampling. The standard error in all measured variables (density, crown canopy and basal area) with $k$-5 fixed trees was closest to actual means derived from 100 % survey, and the variance of the transect sampling became more homogeneous with increasing the $k$ from 2 to 5 fixed trees (Table 2). However, it should be noted that with increasing of $k$ from 2 to 5 fixed trees requires geometrically compact and higher amount of measuring time, costs and field work. Our results were similar to the results of Buckland et al. (1993) and Ringvall et al. (2000), who reported that the line transect sampling was significant method to estimate densities of wildlife populations and can be a useful alternative to the traditional methods. Findings of our study concord with these obtained by other researchers. Hermandez (1997) showed that transect sampling method was the best for esti mation of density and canopy variables in conifer forests. Lessard et al. (2002) reported that the precision of a density estimate from distance sampling can be better than the precision obtained with fixed area plot sampling. Newson et al. (2008) and Ronconi and Burger (2009) suggested distance sampling method in large forest areas. Findings of our study indicated that line distance sampling method with *k* = 5 fixed trees had reliable result and was efficient sampling method in the open forests with low density as Zagros forests.

## Conclusion

In a large forest area obtaining of stand information derived from full callipering inventory required higher amount of measuring time, costs and field work. Therefore, sampling method was considered useful in such areas. The best sampling design should provide accurate and representative information about the population and should require the least amount of field effort. The line distance sampling method with *k* = 5 fixed trees had reliable results and was efficient to obtain stand information in Zagros open forests. This sampling method with fixed trees was easy, and quick to estimate and monitor the quantitative variables in open forests.

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# GROWTH AND PERFORMANCE OF MACEDONIAN PINE (*PINUS PEUCE* GRISEB.) IN BAVARIA AGAINST THE BACKDROP OF CLIMATE CHANGE

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## Abstract

One strategy for mitigating the effects of climate change on forests in an uncertain future is the allocation of risk across a portfolio of different tree species. Since the beginning of 2009, a project of the Bavarian State Institute of Forestry (LWF) has sought to identify warm- and drought-tolerant exotic tree species suited to conditions expected in Bavaria under climate change. As an outcome of this process, six potential non-native tree species were selected for the establishment of species trials in Germany (Bavaria and Thuringia), Austria and southern Switzerland. Parallel to the creation of young trial plantations, one species – *Pinus peuce* – was analyzed in detail in 67- to 105-year-old planted stands in Bavaria to obtain complementary information. This effort sought to quantify growth and performance of this species and compare these results with those of other tree species already grown successfully in Central European forests, e.g. Norway spruce, Scots pine, Eastern white pine, and Douglas fir. Measurements in four small planted stands in the Grafrath Experimental Forest showed mean DBHs from 26.8 to 43.8 cm and average heights from 24.1 to 28.4 m, with single tree volumes ranging from 0.7 to 1.8 m³. Due to drought conditions, particularly during a period of increased temperatures, the radial growth rate of *P. peuce* was considerably reduced in 1976 and 2003 and beyond, after which the species recovered only moderately. As a consequence of decreasing precipitation and more frequent late spring frosts, *P. peuce* exhibited strong negative reactions in annual ring growth. In general, these trees reacted positively to increasing mean annual temperature. Despite high volume production, the results revealed several uncertainties about the suitability of *P. peuce* for southern Bavaria under conditions of climate change. Based on the assumption of further decreases in precipitation in the near future, *P. peuce* can be expected to suffer increasingly from drought stress and to demonstrate decreased annual increment. Nevertheless, the species seems to be appropriate for afforestation in montane areas because of its proven resistance to wind throw and snow break.

**Key words:** *Pinus peuce***,** climate change, forest transformation, tree species selection, growth trials, Bavaria

## Introduction

Foresters worldwide are confronted with the question of how to react properly to the implicit dynamics of climate change. Decision making should be based on critical scientific analyses.

One of the first and most important steps in silviculture is species selection for afforestation and reforestation purposes.

This has far-reaching implications for silvicultural practice against the background of the rapidly changing conditions for forestry.

Growth and performance of forests is influenced not only by the specific site requirements of tree species, but also by current and future climatic conditions. According to the Intergovernmental Panel on Climate Change (IPCC) report of 2007 (IPCC 2007), forests worldwide will be endangered because of water shortages, heavy precipitation events and increased temperatures. In Europe, even well-established native tree species like Norway spruce, Scots pine and European larch will be threatened by increases in temperature and lack of precipitation, which in turn can lead to enhanced susceptibility to forest pests (Kölling and Zimmermann 2007).

One strategy for mitigating the effects of climate change on forests in an uncertain future is the allocation of risk across a portfolio of different tree species. Since the beginning of 2009, a project of the Bavarian State Institute of Forestry (LWF) has sought to identify warm- and drought-tolerant exotic tree species suited to conditions expected in Bavaria under climate change. The selection of these species was done by applying three filters. The first filter was created by obtaining a geographic information system (GIS) layer containing climate data worldwide with focus on areas where the climatic conditions are similar to those currently existing in Bavaria or those expected under climate change. This layer was then overlaid with information on natural distributions of tree species occurring in these areas which resulted in a set of potential tree species. Two additional filters were then applied – a utility value filter created through a utility value analysis in which ecological and socio-economic parameters were evaluated; and finally, a growth filter containing existing knowledge on tree growth of each selected species. Based on the outcome of this process, six potential non-native tree species were chosen for the establishment of species trials in Bavaria (Schmiedinger et al. 2009) and later in Austria, southern Switzerland and Thuringia. These species include Bornmüller fir (*Abies bornmülleriana* Mattf.), Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Lebanon cedar (*Cedrus libani* A.Rich.), Oriental beech (*Fagus orientalis* Lipsky), Silver linden (*Tilia tomentosa* Moench) and Macedonian pine (*Pinus peuce* Griseb.).

For quite a long time, Eastern white pine (*Pinus strobus* L.) was favored by the wood industry because of its potential for rapid growth on nutrient-limited forest sites in Central Europe. Unfortunately, the species' susceptibility to white pine blister rust (*Cronartium ribicola* J.C.Fisch.) resulted in the dieback of vast areas of white pine stands. As an alternative, Macedonian pine was planted in several locations in Germany (Alexandrov 1998).

During the planning period of the above described project, some older plantings of *Pinus peuce* (67- to 105-year-old planted stands) were identified in Upper Bavaria and Upper Palatinate and analyzed in detail to obtain complementary information. This effort sought to quantify previous growth and performance of *P. peuce* in Germany and compare these results with those of other tree species, e.g. Norway spruce, Scots pine, Eastern white pine, and Douglas fir. The focus of this analysis was the quantification of individual tree and stand growth of *P. peuce* under recent climatic conditions on several Bavarian sites.

## Material and Methods

### Study site locations

### Experimental Forest Area Grafrath

The Grafrath Experimental Forest comprises 34 ha and is located 40 km west of Munich, Germany (latitude 48°11’67”N, longitude 11°16’67”E) at an elevation of approximately 580 m a.s.l. The average temperature recorded at the site between 1961 and 2010 was 8.1° C·year$^{-1}$, and the average precipitation between 1963 and 1980 was 977 mm·year$^{-1}$. Soils range from calcareous sandy-loamy gravel to gravelly-sandy loams.

There are four stands containing *Pinus peuce* at the site, some of which are growing in mixture with other species. Details regarding the age and size of these four *P. peuce* stands (from hereon referred to as G1, G2, G3 and G4) are shown in Table 1 (along with information about one additional stand – stand BW – at another location which is described below).

The Grafrath Experimental Forest was established in 1881 by Prof. Dr. Robert Hartig for the purpose of conducting experiments with exotic species which remain active today (LWF Bayern 2015). In 1970, Rohmeder (1970) published the first reports regarding two of the *Pinus peuce* stands described above. However, even in this publication, no information is provided about the origin and provenance of the seeds used to establish these stands. According to him, these two stands were allowed to remain very dense, and thinning activities were marginal and occurred relatively late. This accounts for the dense stocking which persists to this day. Rohmeder provided no detailed information about any pre-commercial and commercial thinning from these stands. In the period subsequent to Rhomeder’s investigation – 1970 to 2011 – damages and self-thinning events in these stands were also very limited.

### Bodenwöhr

A fifth mixed forest stand consisting of 58 % *Pinus peuce*, 39 % *Pinus sylvestris* L. and 3 % *Picea abies* (L.) Karst. is located near Bodenwöhr (BW), Germany which lies about 160 km north of Munich (latitude 49°17’46”N, longitude 12°20’138”E). The elevation at this site is 378 m a.s.l., the average temperature is 8.5° C·year$^{-1}$ and the average precipitation is 677 mm·year$^{-1}$. The area is 0.13 ha in size, and the soils are secondary podsols.

The most recent thinning measures – applied in 1997 – were focused mainly on *Pinus strobus,* and thus, only single specimens of *P. peuce* were harvested. The vitality of *P. peuce* at this site is good, and here too, damages are very rare.

## Methods

Initially, key parameters of forest growth (e.g. DBH and height growth as well as calculated growth indicators like basal area, volume, and stocking of the stands) were collected. Tree and crown heights were measured with a Vertex IV instrument and DBH was determined using a circumference tape. Height-diameter relations and a stand height curve were derived on the basis of measurements from at least 30 individual trees in each stand. Crown length was calculated from tree and crown height to be used as an indicator of vitality. Form factor was determined with a Criterion RD 100 instrument which was applied to ten trees per stand.

Derived data for each of the five stands was compared with yield tables for Norway spruce and Scots pine, and with data gathered from other non-native conifers, i.e. *Pinus strobus* and *Pseudotsuga menziesii* (Mirb.) Franco grown in Grafrath and Bodenwöhr. To this end, increment cores were sampled, and the deviation of annual radial growth increment from average radial increment for several periods between 1950 and 2008 was analyzed.

To conduct growth ring analyses, samples were taken in Bodenwöhr at 1.1 m above surface. Two samples per tree were taken from a total of 20 trees from the dominant collective. In Grafrath, five increment cores per stand were sampled. All cores at both locations were gathered with a Pressler's borer (Ø: 5 mm). Subsequent analyses took place in the lab of the Chair of Forest Growth and Yield Science with the help of a Digital Positiometer (after Johann 1977).

These data were initially analyzed using the software Lignometer.exe, and further analyses were conducted with the help of the statistic functions in both Microsoft Office Excel 2007 and R. Measured data series were synchronized with the help of climatic pointer years. Two dry years – 1976 and 2003 – were particularly important in this procedure.

## Statistical procedures

The different aged stands were chosen to allow for an evaluation of growth series and were thus, ranked according to their stand age (in 2011). The age of the stand in Bodenwöhr (BW) was 67 years, Grafrath stand G2 – 74, G4 – 77, G1 – 97 and G3 – 105 years.

To calculate the diameter-height curve, the statistic program R (Version 2.10.0, R Development Core Team 2009) with the function $h = 1.3 + [d/(a + b \cdot d)]^3$ after Petterson (1955) was used, where: $a$ and $b$ are regression coefficients, $d$ is the DBH and $h$ represents the height.

Form factor was calculated using the formula $f_{1.3} = V/W_{1.3} \Rightarrow V/(g_{1.3} \cdot h)$, where: $V$ is the volume and $W$ is the reference cylinder with $d$ as DBH and $h$ as height (see Kramer and Akça 2008 for details).

Growing stock is the cumulative volume of the stand from the point of establishment until 2011, including both intermediate felling volumes and volume stock in 2011. The unit used is m³/ha standing gross volume over bark. Again, it should be noted that, because of the lack of information about the amount of intermediate fellings from Grafrath, the cumulative volume of the stands at this site is likely to be underestimated.

For the growth ring analysis, age trends were first eliminated using a second-degree polynomial, and the ratio of the expected value from this smoothed curve and the actual measured radial increment was then calculated. The resulting index curve makes it possible to show the percentage and normalized deviation of the growth increment (Pretzsch 2003). The correlation between the trend-adjusted annual growth ring increments and climatic variables like precipitation, temperature and other variables was done with the help of the statistics program R (Version 2.10.0, R Development Core Team 2009) and Microsoft Office Excel 2007 was used for the graphical presentation.

## Results

In the following section, the basic results of the studies on growth and yield in stands of Macedonian pine in Bavaria are summarized (Table 1).

**Table 1. Characteristics of existing Macedonian pine stands in Grafrath and Bodenwöhr, Germany.**

| Indicator \ Location | Bodenwöhr BW | Grafrath G2 | Grafrath G4 | Grafrath G1 | Grafrath G3 |
|---|---|---|---|---|---|
| Age, years | 67 | 74 | 77 | 97 | 105 |
| Mixture, % | MPi 58, SPi 39, NSp 3 | MPi 83, Be 12 | MPi 95, others 5 | MPi 99 | MPi 77, Be 15, others 8 |
| Area, ha | 0.113 | 0.063 | 0.061 | 0.036 | 0.058 |
| Density (N), trees/ha | 932 | 741 | 659 | 632 | 310 |
| Mean DBH, cm | 21.1 | 28.6 | 38.5 | 41.5 | 43.8 |
| $DBH_{Top100,}$ cm | 41.2 | 53.1 | 47.9 | 47.8 | 55.4 |
| Mean Ht, m | 22.8 | 18.9 | 28.5 | 27.4 | 21.9 |
| $Ht_{Top100}$, m | 28.9 | 31.0 | 29.5 | 29.5 | 31.3 |
| Crown length, m | 14.4 | 11.0 | 9.4 | 7.4 | 14.8 |
| Basal area, $m^2$/ha | 32.50 | 61.51 | 77.43 | 85.16 | 46.47 |
| Growing stock, $m^3$/ha | 326 | 721 | 906 | 1,015 | 534 |
| MAI, $m^3$/ha/a | 4.9 | 9.7 | 11.8 | 10.5 | 5.1 |
| $SDI_{Reineke}$ | 710 | 919 | 1,319 | 1,423 | 763 |
| $H_{100}/d_{100}$-ratio | 70 | 58 | 62 | 62 | 57 |

Abbreviations: MPi – Macedonian pine, SPi – Scots pine, NSp – Norway spruce, Be – European beech, DBH – diameter at breast height, Ht – height, MAI – mean annual increment, SDI – stand density index.

## Height growth

Figure 1 shows the stand height curves for Macedonian pine in Grafrath and Bodenwöhr. The dots and curves represent the analysis of the current state of the existing and fitted diameter/height relations of the surveyed stands in 2011.

The height data measured in the four stands in Grafrath (G1-G4) were combined to construct one diameter/height curve which is defined by the regression parameters $a$ = 2.45294 and $b$ = 0.278907. The data from the Bodenwöhr stand were used to form a curve defined by the parameters $a$ = 1.802837 and $b$ = 0.287547. The coefficient of determination for the Grafrath curve is $R^2$ = 0.9473 and that for the Bodenwöhr curve $R^2$ = 0.8991. Thus, both show a quite strong diameter/height relationship. Figure 1 demonstrates that the Bodenwöhr curve (red) initially goes steeper than the Grafrath curve (blue). Both curves show a slow but steady increase and end at a height of 30–31 m. Over the entire range of diameters, the Bodenwöhr curve shows growth superior to that demonstrated by the Grafrath curve.

The mean tree height in Bodenwöhr is 22.8 m, and in the Grafrath stands G2,

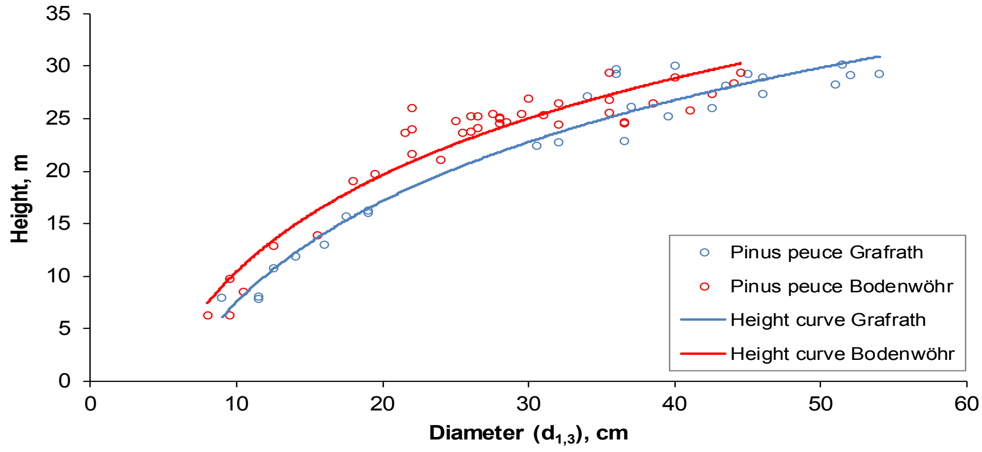


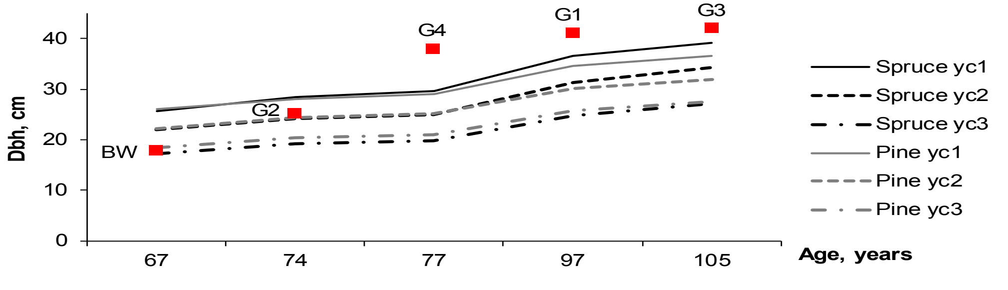

**Fig. 1. Diameter/height relations and stand height curves (after Petterson) for Macedonian pine in Grafrath and Bodenwöhr, Germany.**

G4, G1, G3 is 18.9 m, 28.5 m, 27.4 m and 21.9 m respectively. The mean height of the top100 trees in Bodenwöhr is 28.9 m, and in the Grafrath stands is as follows: G2 – 31.0 m, G4 – 29.5 m, G1 – 29.5 m, and G3 – 31.3 m (Table 1).

The height where tree crowns commence in the four stands in Grafrath is on average 11.5 m and in Bodenwöhr 8.5 m. Crown length is a valuable indicator for vitality and stability of individual trees as well as of stands. In addition, this parameter gives an indication of stand density and competition. Table 1 shows that the trees in Bodenwöhr have very long crowns with an average crown length of 14.4 m. In Grafrath, the trees in stand G3 have the longest crowns with an average of 14.8 m, followed by those in stand G2 with a mean crown length of 11 m.

## Diameter growth

Figure 2 shows a comparison of the diameters of the mean basal area trees of the measured stands of Macedonian




Note: yc – yield class.

**Fig. 2. Age-based comparison of mean DBH values of Macedonian pine (red boxes) in each of the measured stands in Grafrath and Bodenwöhr, Germany with values from Norway spruce and Scots pine taken from Wiedemann-yield tables.**

pine with yield tables for *Picea abies* and *Pinus sylvestris* (after Wiedemann 1936/42 and 1943). The data displayed from the Wiedemann tables are for yield classes 1 to 3. Interpretations of this kind must be done with care in this case, because yield tables are usually based on the assumption of a consequent thinning regime and schedule and, as previously mentioned, the Macedonian pine stands in this study (with the exception of the Bodenwöhr (BW) stand) never underwent thinnings. The mean diameter of the BW stand (age 67, poor site) is very similar to that found in the growth curve for a stand of spruce/pine in yield class 3. With increased stand age (Grafrath stands), the mean diameters for G4, G1, and G3 exceed spruce/pine in yield class 1.

## Stand density

The largest number of *Pinus peuce* trees in Grafrath are found in the nearly pure stand, G1. Other stands dominated by *P. peuce* are G4 and G2. Using the data gathered to calculate Reineke's Stand Density Index (SDI) yielded a value of 1,423 trees per ha for G1, 1,319 for G4, 919 for G2, 763 for G3, and 710 for BW. Sterba (1991) referred to reference values between 600 and 750 trees per ha for *P. sylvestris*. Thus, the calculated SDI values for the Grafrath stands clearly exceed this benchmark, while the SDI for BW meets it nicely. Normally indications of self-thinning are found in very dense stands. In Grafrath, however, this is true only in G2, while the others are still very densely stocked.

## Stand basal area

Stand G1 has the highest basal area with 85.16 m²/ha for *Pinus peuce* and 1.23 m²/ha for all other species. G4 has a basal area of 77.43 m²/ha for *P. peuce*, while the other remaining species combined have a basal area of 3.71 m²/ha. In G2, *P. peuce* basal area is 61.51 m²/ha, 8.85 m²/ha for all other species combined and 3.59 m²/ha for standing *P. peuce* deadwood. In the oldest stand (G3), *P. peuce* has a basal area of only 46.47 m²/ha and 13.93 m²/ha of basal area are formed from other species. In the Bodenwöhr stand (BW), *P. peuce* has a basal area of 32.50 m²/ha, while *P. sylvestris* and *Picea abies* together have a combined basal area of 23.40 m²/ha (Fig. 3).

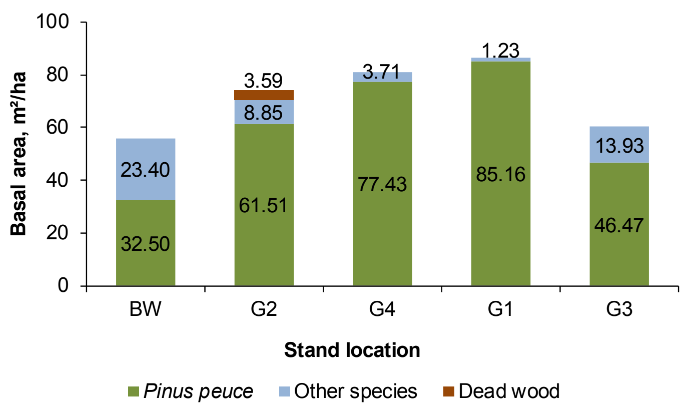
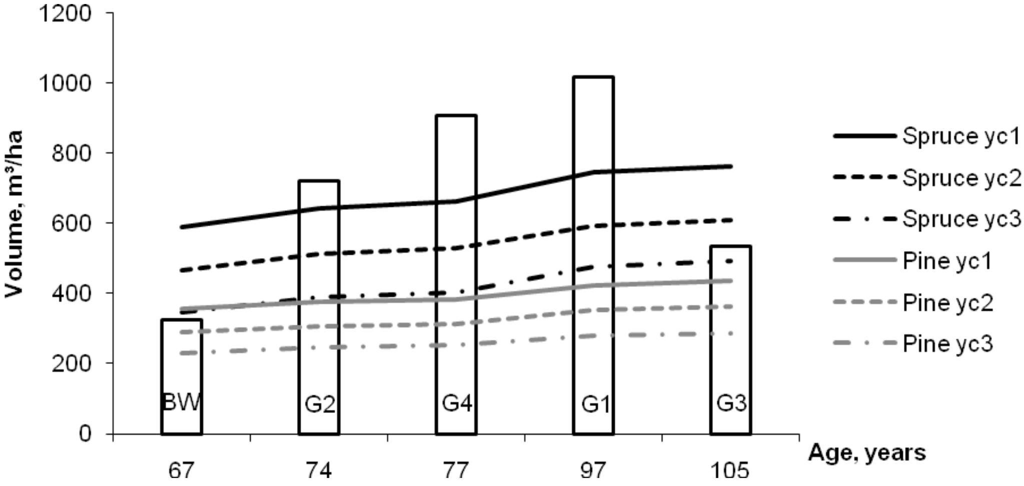



**Fig. 3. Basal area of Macedonian pine stands in Grafrath and Bodenwöhr, Germany.**




Note: yc – yield class.

**Fig. 4. Comparison of growing stock of Macedonian pine in Grafrath and Bodenwöhr, Germany with yield table values (Wiedemann) for Norway spruce and Scots pine.**

## Growing stock and yield

The highest total standing growing stock can be found in stand G1 with a calculated amount of 1.015 m³/ha (Table 1). Stand G4 carries the second highest stock with 906 m³/ha, G2 has 721 m³/ha, and G3 has the lowest stock of the Grafrath stands with 534 m³/ha. Growing stock in Bodenwöhr (BW) was calculated to be 326 m³/ha.

In comparing the total volume of growing stock of Macedonian pine with the yield table values for Norway spruce (after Wiedemann 1936/42, Fig. 4, black lines) and Scots pine (after Wiedemann 1943, Fig. 4, gray lines), it becomes obvious that the volume of *Pinus peuce* (age 67) is very similar to that of *P. sylvestris,* yield class 1. Volume growth of Macedonian pines in the stands of age 74, 77 and 97 greatly exceeds that from the yield tables for *Picea abies*, yield class 1. However, in the oldest stand (105 years) *Pinus peuce* falls behind *Picea abies*, yield class 2, but is still superior to *Pinus sylvestris,* yield class 1.

## Mean annual increment

The largest mean annual increment (MAI) was produced in stand G4 with 11.8 m³/ha/year (Table 1), followed by G1 with 10.5 m³/ha/year and G2 with 9.7 m³/ha/year. In the oldest stand, G3, the MAI was only 5.1 m³/ha/year. This is very close to the result from Bodenwöhr (BW) of 4.9 m³/ha/year.

## Slenderness-ratio

The height100/DBH 100-ratios of *Pinus peuce* for the four stands in Grafrath and the single stand in Bodenwöhr were calculated, as these ratios are an indicator of the support matrix of a forest stand and thus, of resistance against storm damage. All the values calculated range between 70 and 57, which shows a high level of stability against wind and storms.

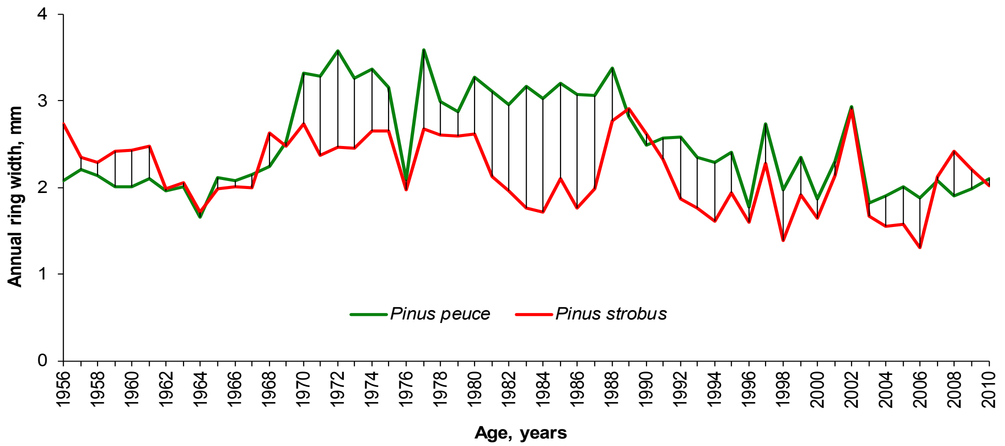



**Fig. 5. Comparison of annual ring width between Macedonian pine and white pine in Bodenwöhr, Germany between 1956 and 2010.**

## Dendrochronological investigations

With only a few exceptions (1968, 1990, 2008, 2009) dendrochronological studies of the annual ring width in Bodenwöhr demonstrate that *Pinus peuce* exceeds the average radial increment of *P. strobus* (Fig. 5).

## Factors influencing the annual ring width of *Pinus peuce*

Figure 6 gives an overview of the annual ring width chronology of *Pinus peuce* derived from wood cores taken from all four stands in Grafrath and the one stand in Bodenwöhr.

In the two dry pointer years, 1976 and 2003, *Pinus peuce* demonstrated a possible drought response with a decrease in annual ring width; while in the two wet pointer years, 1965 and 2002, this tree species showed an increase in growth ring width.

The deviations (in %) from the average radial increment are shown in Figure 7. The

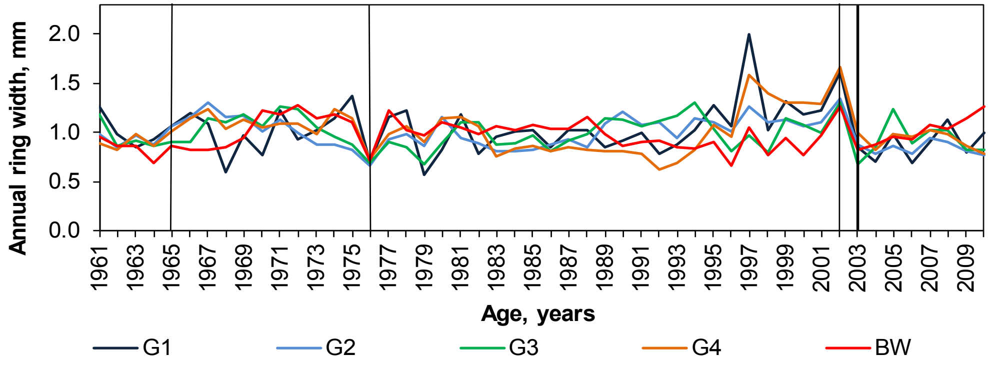



**Fig. 6. Dendrochronology (annual growth ring width data) of Macedonian pine in Grafrath and Bodenwöhr, Germany over a time span of 50 years.**

Note: Climatic pointer years – 1965 (wet year), 1976 (dry year), 2002 (wet year), and 2003 (dry year) – are marked by vertical lines).

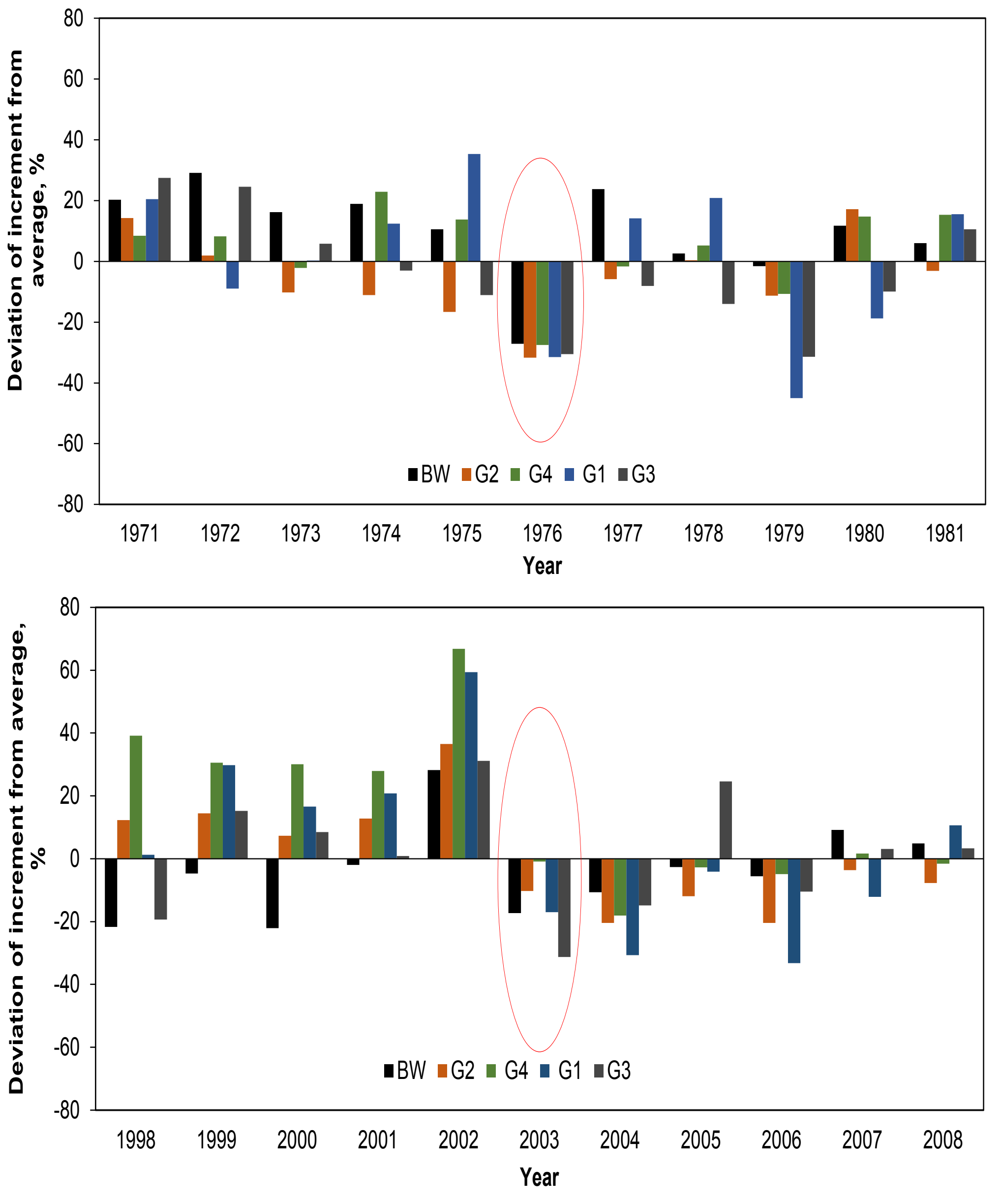



**Fig. 7. Deviation of annual radial growth increment (in %) from average radial increment in Grafrath and Bodenwöhr, Germany for the period from 1971–1981 (above) – pointer year 1976 (red oval), and for the period from 1998–2008 (below) – pointer year 2003 (red oval).**

dry spells of 1976 and 2003 were marked by a decrease of up to 40 % in radial increment. These losses are very similar to those seen in *Pinus strobus* and *Pseudotsuga menziesii* during the same period (data not shown).

## Discussion

When Rohmeder (1970) provided early results for the growth of Macedonian pine in Bavaria, he could not have been aware of the upcoming problem of climate change. His brief publication was hardly noticed by forest scientists and forestry professionals. Four decades later, a new Bavarian initiative (project KLIP 18) has searched worldwide for species that are presumably well adapted to drought conditions and the dynamics of climate change. *Pinus peuce* was found to be a promising candidate. This was one starting point for this study aimed at obtaining additional information and data from planting trials with this species in Bavaria. Existing plantations of *P. peuce* were located in one stand in Bodenwöhr and four stands in Grafrath, where a survey and measuring campaign of growth, yield and performance was begun. A comprehensive study was carried out and issued by Rommel (2012).

In this paper, some of the key results of the study are presented and compared with yield table data for Norway spruce and Scots pine. It should be noted that a comparison of this kind may be of limited value, because model stands for yield tables of Norway spruce and Scots pine have undergone well-defined thinning schedules, while the *Pinus peuce* stands investigated here did not. Thus, although the calculated growing stock and basal area figures, as well as the stand density indices presented here demonstrate remarkably high productivity and yield reliability, these results should be treated with caution.

In the initial years in the life history of the *Pinus peuce* stands investigated, growth was very slow. The expected culmination of the diameter increment in this species has been estimated to be between ages 30 and 80 (Lines 1985, Alexandrov 1998). On the other hand, it is well known that *P. peuce* can continue producing high diameter increments for a relatively long time period (Holzer 1972). In comprehensive studies on the structure and productivity of natural *P. peuce* forests in the North Pirin Mt., Tsakov (2001) was able to demonstrate the good condition, very good growth and productivity of the stands.

A closer look at the five particular Bavarian samples presented here shows a slow growth pattern during the early juvenile growth phase with increasing increments in subsequent growth stages. With increasing stand age, diameter increment slows down and eventually, decreases. According to Holzer (1972), the slow growth of *P. peuce* during the early juvenile phase is genetically determined and cannot be improved by transplanting of the species to more temperate conditions.

Factors determining growth and yield of forest species are, inter alia, site factors like soil, exposition, topography, and altitude; but also, factors intrinsic to the stand itself, like stand density, vitality, and crown length. A very important and complex group of factors are climatic factors.

The dendrochronological data shown here seem to exhibit visible signs of drought and support the assumption that *Pinus peuce* may suffer from dry spells and periods of high temperature – phenomena which are very similar to that which have been found true for Norway spruce and Scots pine. This situation suggests that *P. peuce* may not be much better adapted to drought than conifer species that are native to the study area or other, previously introduced species like Douglas fir. The dry pointer years – 1976 and 2003 – seemed to act in a very negative way on the growth of *P. peuce*, while in the wet pointer years – 1965 and 2002 – a distinct increase in growth increment was detected. It is assumed that *P. peuce* suffers from dry spells as well as other tree species. High temperatures during the growing season in 2003 could have made the situation even worse. On the basis of the Bavarian data and the climate data, the documented losses in increment can nicely be explained. These results indicate that precipitation has an important and significant influence on annual growth ring width. This is in accordance with the findings of Panayotov and Yurukov (2007) and Panayotov et al. (2010) in the Pirin Mountain in Bulgaria where *P. peuce* had small annual rings in years with low annual or seasonal (summer) precipitation levels. The data are also supported by the recently presented results of Ivanova et al. (2015) who found that the capacity for stomatal control of photosynthesis in saplings of Macedonian pine decreased with drought in summer. This can be interpreted as a signal of imbalance in physiological processes.

Interestingly, an increase in growing season temperature in Grafrath had a positive effect on annual growth ring increment, while the opposite reaction was found in Bodenwöhr.

Seen against the backdrop of climate change, the results of this study suggest that *Pinus peuce* may suffer from declining precipitation during the vegetation period and possibly also from increased temperatures.

*Pinus peuce* is a very cold-tolerant species and dehardened more slowly - in comparison to other temperate tree species – in the period from mid-winter to early spring (Kreyling et al. 2015). The data do not allow for conclusions to be drawn as to whether this characteristic may allow *P. peuce* to escape from late spring frost damage on new needles after bud break.

Overall, the Macedonian pine in the studied stands appears to be in good condition and has successfully withstood the heavy windstorms that occurred in Bavaria 1990 and 1999 without any damage.

Alexandrov and Andonovski (2011) give a short overview of pests and diseases of *Pinus peuce*. One of the most serious pathogens of five-needle pines is white pine blister rust (*Cronartium ribicola*). A few signs of this pathogen (i.e. resin flow, yellow spots on needles and single dead branches) were found in the stands in Grafrath and Bodenwöhr. Nevertheless, there were no typical signs like aecia or pycnia. Rohmeder (1970) mentioned sporadic outbreaks of blister rust disease in Grafrath, but those were concentrated on *P. strobus*, which grew in close vicinity to *P. peuce*, and the latter did not suffer from this significantly. Damages from wood-rotting found in natural stands of *P. peuce* in Bulgaria were mostly caused by the fungi *Phaeolus schweinitzii* (Fr.) Pat., while wood-rotting in plantations of *Pinus peuce* mainly resulted from infection with *Heterobasidion annosum* (Fr.) Bref. (Rossnev 1985). Wood-rotting caused by infections with the above mentioned pathogens in *Pinus peuce* stands in Bavaria was never highlighted as a problem.

## Conclusions

Despite high volume production, the results of this investigation reveal several uncertainties about the suitability of *Pinus peuce* for Bavaria under future climatic conditions. Based on the assumption of further decreases in precipitation in the near future in Bavaria, the species will most likely suffer increasingly from drought stress and show decreases in annual increment.

Nevertheless, it seems appropriate for afforestation in montane areas because of its demonstrated resistance to windthrow and snowbreak.

Unfortunately, there is still little information from provenance studies beyond its natural range in other parts of Europe. Genetic characterization of *Pinus peuce* was carried out through analyses of the composition of needle oils by Hagman (1989), Dobrev (1992), and Nikolić et al. (2008, 2014), and of allozyme markers by Zhelev et al. (2002) and Zhelev and Tzarska (2009). The information obtained from these studies may offer an instrument for studying population genetics. An overview of genetic research in five-needle pines (*Pinus* subgenus *Strobus*) in Europe was given by Blada and Popescu (2004a). Genetic research with a focus on conservation efforts of *P. peuce* in Bulgaria was presented by Alexandrov et al. (2004), Dobrev (2007) and Alexandrov and Dobrev (2012, 2015). Hence, up to now no molecular genetic markers for the identification of unknown provenances like the ones in the Bavarian study have been developed.

Another interesting aspect already suggested by researchers in the 1970s deals with the idea of breeding hybrids of *Pinus peuce* × *P. strobus.* The products of such crosses are expected to combine the high productivity of *P. strobus* with the low susceptibility of *P. peuce* to blister rust and snowbreak (Rohmeder 1970, Grossmann 1974, Lattke et al. 1987, Popnikola et al. 1978, Alexandrov 1998). Subsequent experiments have already shown the feasibility of creating such hybrids (Blada 1989, Blada and Popescu 2004b).

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# EFFECT OF CANOPY GAPS ON THE CONDITIONS FOR NATURAL REGENERATION IN MOUNTAINOUS BEECH FORESTS OF NORTHERN IRAN

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## Abstract

This study investigates the effect of canopy gaps created by single-tree selection cutting on regeneration density and diversity in Oriental beech (*Fagus orientalis* Lipsky) forests of Northern Iran. Five gaps within each of three different size classes (small (100–200 $m^2$), medium (200–300 $m^2$), and large (300–400 $m^2$)), together with 15 control areas located in the undisturbed forest surrounding each gap were randomly selected. Abundance of tree regeneration was measured in 4-$m^2$ quadrates established within each gap and control area. The percent cover of herbaceous species and litter depth was also quantified. Shannon diversity, Smith-Wilson evenness and Margalef richness indices were then computed for each quadrate. Results indicated that percent cover of herbaceous species increased significantly with increasing gap size while the opposite was observed for litter depth. Species richness and Shannon diversity index values were higher in gaps than in control areas, but significant differences were only detected between medium size gaps and control areas. With the exception of large gaps, regeneration density was higher in gaps than in control areas. These results indicate that natural tree regeneration in beech forests of Northern Iran tends to be maximized at intermediate levels of canopy gap size, which also correspond to intermediate levels of litter depth and percent cover of herbaceous species.

**Key words:** artificial gap, beech forests, herb-layer diversity, Hyrcanian region, regeneration.

## Introduction

Forests are dynamic systems subjected to continuous changes (Stanciou and O'Hara 2005) induced by natural (e.g. fire or flood) or anthropogenic (e.g. harvesting) disturbances. These disturbances may markedly affect forest ecosystems (Legout et al. 2009) through, for example, the periodic formation of canopy gaps of different sizes that can produce different mosaic patterns at the forest scale (Yamamoto et al. 2011). In turn, these gaps generally promote the establishment and development of tree seedlings that are important for forest sustainability and that can lead to significant changes in forest composition, structure and functions (Millington et al. 2012).

The effects of canopy gaps on tree regeneration have been studied by many authors (Denslow 1995, Mountford et al.

2006, d'Oliveira 2009, Sefidi et al. 2011, Diaci et al. 2012, Schwartz et al. 2013, Mallik et al. 2014). Several studies indicated that gaps can be a key factor in regeneration establishment and further seedling growth of many plant species (Runkle 1982, Sapkota et al. 2009, Muscolo et al. 2010, Schliemann and Bockheim 2011). For example, the density and diversity of woody plant regeneration were higher in gaps created by partial harvesting than in an adjacent undisturbed boreal forest stand (Mallik et al. 2014). Indeed, canopy gaps can cause changes in light, soil moisture, nutrient availability, litter depth and other factors that affect tree regeneration and long-term forest structure and composition (van Dam 2001, Dupuy and Chazdon 2008). In other words, canopy gaps can increase resource availability for plant regeneration and provide various niches for the establishment of tree species of different life traits, which can help maintain tree density and diversity (Nascimento et al. 2012).

On the other hand, canopy gaps were sometimes reported to have little influence on seedling establishment and growth (D'Oliveira and Ribas 2011) because many species, particularly shade-tolerant species, could be established before gap formation (Nagel et al. 2010). These contrasting results could be explained by differences in studied regions (Runkle 1985) as well as in gap features such as size, shape (Li et al. 2005), age (Clinton et al. 1994) and orientation (Duguid et al. 2013). In particular, gap size was reported to play an important role for the establishment, survival and growth of different tree species (Denslow 1987).

In many beech forests of Northern Iran, canopy gaps of different sizes, directly or indirectly created by human activities, are the dominant source of regeneration in *F. orientalis* forests in northern Iran (Sagheb-Talebi et al. 2005, Sefidi et al. 2011). These authors reported that canopy gaps are generally well regenerated due to their particular environmental conditions. Northern Iranian forests, which are also known as Hyrcanian forests, have been established since over 1 million years and are considered one of the oldest forest ecosystems of the world. In the past, these forests covered 5 million ha but today, overexploitation reduced this area to about 1.8 million ha of which only 1.2 million ha are considered high quality commercial forests. This highlights not only the importance of protecting Northern Iranian forests, but also the necessity to help establish tree regeneration by creating canopy gaps through the application of selection cutting systems (Marvie-Mohadjer 2011).

To promote sustainability of these forests and pursue efficient forest harvesting, it is important to document the effects of canopy gaps on tree regeneration establishment. Therefore, the main objectives of this study are: 1) to determine the effects of canopy gaps created by selection cutting on tree regeneration density; 2) to compare tree species diversity between gaps of different sizes and adjacent forest areas; and 3) to explore the role of the percent cover of herbaceous species and leaf litter depth on the density and diversity of tree regeneration in different size gaps and forest areas.

## Material and Methods

### Study area

This study was conducted in an 82-ha forest area of Asalem region in the west of

Guilan province in Northern Iran. This area is located between latitudes 37°32'38" N and 37°35'56" N and longitudes 48°42'27" E and 48°47'55" E. The north aspect dominates the landscape whereas elevation varies from 900 to 2000 m a.s.l. According to the nearest meteorological station (Pylambara), mean annual temperature and precipitation are 15 °C and 1440 mm, respectively. Based on Domarten classification, the regional climate is considered very humid. Common forest soils are slightly acidic with a pH varying from 5.2 to 5.9. Types of parent material include tuff, shill and calcareous with minor traces of basalt and schist. The general soil type is forest brown (Dystric-Eutric Cambisols), with a texture from medium to slightly heavy and a maximum depth of 80 cm. This uneven-aged forest is of natural origin and is dominated by Oriental beech (*Fagus orientalis*). Dominant height is 32 m while mean stand density is 308 trees per hectare with many individuals observed in diameter classes 25 to 35 cm. The forest composition is completed by other deciduous broadleaved species, mainly Cappadocian maple (*Acer cappadocicum* Gled.), Common hornbeam (*Carpinus betulus* L.), Wild service tree (*Sorbus torminalis* (L.) Crantz), Wych elm (*Ulmus glabra* Huds.), Caucasian alder (*Alnus subcordata* C.A.Mey.), and Wild cherry (*Cerasus avium* (L.) Moench) (Anonymous 2003).

## Treatments and data collection

Canopy gaps in the studied forest were created by single-tree selection system applied in 2006 while all measurements were conducted during July 2013. Canopy gaps were all located on a northern aspect with a slope varying from 30 to 35 %. At the beginning of the study, 35 artificial gaps were identified according to the presence of cut tree stumps. Because most of these gaps were elliptically shaped, gap area was estimated using Runkle's ellipsoid method (Runkle 1982):

$$A = \frac{\Pi \cdot L \cdot W}{4},$$

where *A* is the gap area, *L* is the ellipse length (long diameter), and *W* is the ellipse width (short diameter). After determining the area, gaps were divided into three categories: small (100–200 m$^2$), medium (200–300 m$^2$), and large (300–400 m$^2$) (Table 1). Then, five gaps were randomly selected in each category for a total of 15 gaps (Berg and Van Lear 2004).

**Table 1. Characteristics of gaps created by single-tree selection system (Berg and Van Lear 2004).**

| Gaps | Area, m$^2$ | Number of identified gaps | Number of selected gaps |
|---|---|---|---|
| Small | 100–200 | 17 | 5 |
| Medium | 200–300 | 8 | 5 |
| Large | 300–400 | 10 | 5 |

To compare regeneration density and diversity observed in canopy gaps with those observed under closed canopy, control areas were identified in the undisturbed forest surrounding each gap. These control areas were selected to have topographical characteristics similar to those of adjacent gaps and were located at least 15 m from gap edges (Wang and Liu 2011). Control areas were as numerous as gaps, i.e. 5 control areas for each size class, for a total of 15 control areas. To determine the regeneration density (number of tree seedlings/m$^2$) within each gap, 2×2 m quadrates were systematically established 1 m apart along the two diameters of the ellipsoidal gaps (Brockway and Outcalt 1998). Their number established in each gap thus depended on the gap size and varied from 8 to 15. The establishment of quadrates in control areas followed exactly that of the corresponding gaps and their number thus also varied from 8 to 15 in each control area. Within each of these 4-m$^2$ quadrates, the number of tree seedlings shorter than 130 cm was determined (Abrari Vajari et al. 2011) as well the percent cover of herbaceous species using Domin's criterion (Mueller and Ellenberg 1989). In addition, the litter thickness was measured with a ruler in the center of each quadrate.

### Data analysis

To calculate diversity, evenness, and richness of regeneration species in the gaps and control areas, the following indices were used:

– Shannon-Wiener diversity index,

$$H' = -\sum_{i=1}^{S} p_i \ln p_i ,$$

– Smith-Wilson evenness index

$$E_{\mathrm{var}} = \frac{2}{\pi \arctan\left\{ \sum_{i=1}^{s} \left( \log_e(n_i) - \sum_{j=1}^{s} \log_e(n_j)/s \right)^2 \Big/ S \right\}} ,$$

– Margalef's richness index

$$D_{mg} = \frac{S-1}{\ln N} ,$$

where: $p_i$ is the relative frequency of the $i^{th}$ species, $n_i$ is the number of individuals of the $i^{th}$ species, $n_j$ is the number of individual of the $j^{th}$ species, $S$ is the total number of species (richness), and $N$ is the total number of individuals. These indices were calculated using the Ecological Methodology software (Krebs 1999).

Kolmogorov-Smirnov test was used to evaluate the normality of data and Levene's test was used to investigate the homogeneity of variances. After securing data normality, paired *t*-tests were used to compare tree regeneration density and diversity between canopy gaps and control areas. Regression analyses were used to examine the relationships between gap area and both litter depth and percent cover of herbaceous species by giving a gap area of 0 m to each control area. All statistical analyses were performed using the SPSS 16.0 software.

## Results

### Effect of canopy gaps on tree regeneration density and diversity

Regeneration densities were higher in small and medium size canopy gaps compared to control areas, but no significant differences were found between them (Table 2).

Diversity and richness index values were greater in all size gaps compared to control areas. Shannon-Wiener ($H'$) and Margalef ($D_{mg}$)

**Table 2. Mean (±SE) density of tree seedlings (N/m$^2$) in gaps and corresponding control areas (CA).**

| Study areas | Density, N/m$^2$ | *p* |
|---|---|---|
| Small gap | 47±5.5 | |
| CA | 46±10.6 | 0.864 $^{ns}$ |
| Medium gap | 122±25.7 | |
| CA | 93±24.7 | 0.227 $^{ns}$ |
| Large gap | 83±18.7 | |
| CA | 143±49.9 | 0.417 $^{ns}$ |

Note: ns is no significance.

index values were significantly higher in the medium size gaps than in the control areas (α < 0.5), while Smith-Wilson evenness index was lower in gaps than in control areas even though differences were not significant (Table 3).

**Table 3. Mean (±SE) of diversity indices in gaps and corresponding control areas (CA).**

| Study areas | Diversity indices | | |
|---|---|---|---|
| | *H'* | $E_{var}$ | $D_{mg}$ |
| Small gap | 1.22±0.2 | 0.545±0.1 | 3.137±0.2 |
| CA | 1.2±0.1 | 0.719±0.1 | 2.926±0.3 |
| Medium gap | 1.28±0.1* | 0.379±0.1 | 3.187±0.4* |
| CA | 0.84±0.7* | 0.745±0.05 | 1.967±0.2* |
| Large gap | 1.49±0.09 | 0.588±0.1 | 3.365±0.4 |
| CA | 1.03±0.1 | 0.605±0.1 | 2.99±0.5 |

Note: * indicate a significant difference at $P < 0.05$ between gaps and control areas. *H'* – Shannon-Wiener diversity index; $E_{var}$ – Smith-Wilson evenness index; $D_{mg}$ – Margalef's richness index.

### Effect of canopy gaps on percent cover of herbaceous species and litter depth

The percent cover of herbaceous species significantly increased with increasing gap size (Fig. 1a), while the opposite was observed for litter depth (Fig. 1b).

Regression analysis calculated between litter depth and tree seedling densities are presented in Figure 2. Within both canopy gaps and control areas, tree seedling density was negatively and significantly related to litter depth, with a steeper slope associated with control areas compared to canopy gaps (Fig. 2).

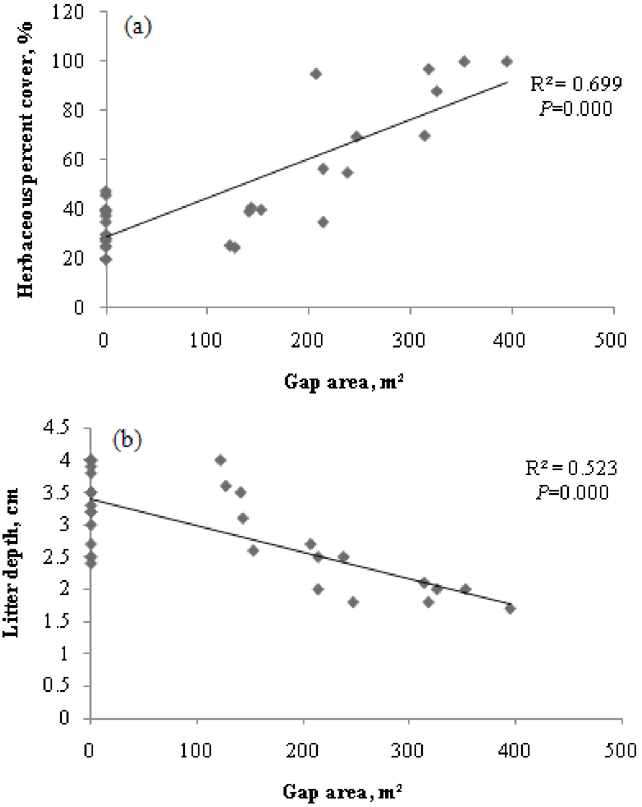


**Fig. 1. Relationship between gap area and herbaceous percent cover (a), and litter depth (b) in different canopy gap sizes. Gap size under closed canopy was considered as 0.**

## Discussion

In general, higher values of both Margalef's richness and Shannon diversity indices were observed in gaps of various sizes compared to control areas in accordance

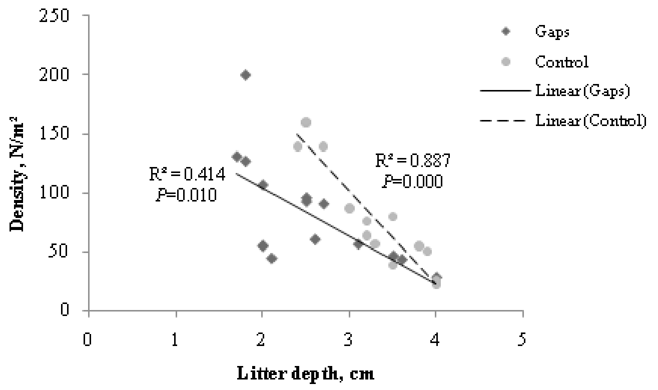


**Fig. 2. Relationship between litter depth and seedling density in gaps (solid line), and under closed canopy (dotted line).**

with the results of Naaf and Wulf (2007) and Wang and Liu (2011). Forest gaps cre ated by partial harvesting generate ecological niches for various species regeneration as a result of micro-environmental heterogeneity (Li et al. 2005). Moreover, gaps generally increase available resources, particularly light (Denslow 1987, Romell et al. 2008) and soil moisture (Griffiths et al. 2010). Therefore, competition for obtaining these resources is lower in canopy gaps (Cahill and Casper 2002) within which seedling growth and diversity are higher than in control areas.

Species diversity and richness in medium size gaps were significantly greater than in control areas because gaps promote the establishment of shade intolerant species before crown closure (Wang and Liu 2011). Results from Albanesi et al. (2005) obtained in fir forests and those of Pourbabaei et al. (2013) in beech forests also showed that a gap range of 200–300 m² was the most suitable size for establishing and diversifying tree regeneration.

In small canopy gaps, species diversity and richness were only slightly higher than in closed canopy likely because of very small differences in environmental conditions such as light and nutrient availability (Fahey and Puettmann 2007). Small differences in percent herbaceous cover were also observed between small gaps and control areas (Fig. 1a). These small differences were likely related to the effect of surrounding trees which substantially shade the gap perimeter and even the gap center (Gagnon et al. 2004). Therefore, small canopy gaps were not associated with changes in forest floor plant communities which can thus be considered as relatively stable (Promis et al. 2012). The small differences between small canopy gaps and control areas can even disappear over a short period of time because of canopy closure which would likely prevent the development of many species, especially the shade intolerant ones (Franklin et al. 2002). Hence, these gaps will be mostly filled by shade-tolerant tree species, which can lead to a decline in regeneration diversity and richness (Anderson and Leopold 2002).

Species diversity and richness were not significantly different between large canopy gaps and control areas. This result is likely related to the larger exposition to full sunlight and high temperatures in large canopy gaps, conditions that promotes the growth of herbaceous species which, in turn, limit the establishment and development of tree seedlings. This is supported by significant positive relationship between the percent cover of herbaceous species and gap size (Fig. 1a). Therefore, the germination, establishment and spatial arrangement of regeneration in large gaps may be influenced by the presence of abundant herbaceous species, which compete for light, water and nutrients (George and Bazzaz 2003, Page and Cameron 2006, Hagemann et al. 2012). The presence of herbaceous species can negatively affect seed germination conditions and thus reduce the abundance of seedlings (Frochot et al. 1996, Grant et al. 2003, Godefroid et al. 2005). Our results also indicated that species richness in small, medium, and large gaps were greater than that of control areas in accordance with the results of other studies (Runkle 1982, Denslow 1995, Busing and White 1997, Li et al. 2005, Sapkota et al. 2009).

Overall, regeneration density between gaps and control areas were similar in agreement with results of Nagel et al. (2010) observed in forests of Bosnia and Herzegovina. Accordingly, in Amazonian forests, no significant differences were observed in seedling densities between artificial gaps and closed canopy, 12 years after gap formation (d'Oliveira and Ribas 2011).

The establishment, growth, survival and density of tree seedlings can also be affected by litter cover (Molofsky and Augspurger 1992). Indeed, litter cover can directly or indirectly influence plant establishment by modifying soil temperature and moisture, water and nutrient availability, herbivory, and plant competition (Ganade and Brown 2002, Dupuy and Chazdon 2008). In addition, litter can act as a mechanical barrier against seed germination and seedling establishment (Hutchinson et al. 2005). Accordingly, we found significant negative relationship between litter depth and tree seedling density both in canopy gaps and under closed canopy (Fig. 2). However, litter in large gaps was significantly shallower than in small gaps as already observed by Mountford et al. (2006) and Griffiths et al. (2010). Although the shallower litter and the canopy openness associated with large gaps can positively affect seed germination and regeneration establishment (Dupuy and Chazdon 2008), too large gaps can have the opposite effect by reducing seedling density through increasing competition by herbaceous, shade-intolerant species (Albanesi et al. 2005, Mihok et al. 2005). Our results clearly show that litter depth affected tree seedling density, and that these effects depended on gap size such that increasing litter depth reduced seedling density in both gaps and control areas.

## Conclusion

The application of selection cutting resulted in the formation of canopy gaps of different sizes. These gaps, together with small-scale natural disturbances, create a mosaic of habitat conditions that diversify the forest (Mallik et al. 2014). Canopy gaps provide suitable conditions for the establishment of seedlings and are a major driver of beech-dominated forest dynamics of Northern Iran.

Canopy gap creation through selection cuttings must be prioritized to maintain the ecological stability of these beech-dominated forests while allowing sustainable production. This silvicultural treatment should help preserve the natural uneven-aged structure of these forests, which promotes environmental heterogeneity and tree species diversity. According to our results, medium-sized gaps were associated with maximum regeneration density while maintaining suitable herbaceous cover, litter depth and seedling diversity. For future application of the selection cutting system in these forests, it is thus recommended to create canopy gaps ranging from 200 to 300 m$^2$. If possible, this silvicultural system should be accompanied by the timely removal of herbaceous species to reduce competition with newly established seedlings.

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# INVESTIGATION OF HERBACEOUS SPECIES DIVERSITY IN FOREST, ECOTONE AND PASTURE AREAS OF UPLAND IN THE NORTH OF IRAN

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## Abstract

Biodiversity of ecosystems is determined to a considerable extent by the diversity of herbaceous species. The aim of this study was to examine and compare diversity of herbaceous species in the forest, ecotone, and pasture located in upland areas in Shirud, Mazandaran Province, Iran. In each area, eight 100 m$^2$ circular sampling plots were established along a transect using random-systematic method, and coverage of herbaceous species was recorded in each plot. There were significant differences in diversity, evenness and richness among the forest, ecotone and pasture areas. The results of ANOVA and Duncan's tests indicated that the forest and pasture sites had higher diversity compared to ecotone. Jaccard and Sørensen's similarity coefficients also confirmed the better growing conditions for herbaceous species in the forest and pasture sites in comparison to the ecotone. This paper presents evidence that species diversity is closely linked to grazing intensity.

**Key words:** herbaceous diversity, grazing, forest, ecotone, pasture, Mazandaran.

## Introduction

Plant diversity plays an ecological key role in forest ecosystems, including in succession and nutrient cycles (Gilliam 2007, Hart and Chen 2008, Nilsson and Wardle 2005). Thus, vegetation studies are important to assess the current state of forest ecosystems and to project it in the near future (Oxbrough et al. 2014). In the last few decades, especially after the Rio Conference, loss of biodiversity associated with human activities became a main source of concern for forest ecologists (UNCED 1992). Maintaining biological diversity is a key aim of global forest policy, which promotes ecosystem health in the face of changing land use and climate. Sustainable management of forest ecosystems is essential to the society and economic by services that forests provide. It is an important component of the environmental policies at national level and is a specific focus of the Conventional on Biological Diversity (Oxbrough et al. 2014). Therefore, it is essential to estimate the plant diversity of forest ecosystems. Such estimation can assist the forest managers to identify endangered species and to reveal the population trends. Moreover, quantifying plant diversity allows comparison of different sites and regions (Gotelliand and Colwell 2001).

Natural heterogeneity in a geographical area reflects habitat diversity. Ecotones are one of the major factors that cause such diversity. Pioneer American plant ecologist, Frederic Clements (1905) defined an ecotone as a “junction zone between two communities, where the processes of exchange or competition between neighboring formations might be readily observed”. The main features of these areas are vegetation transition (Schumann et al. 2003, Suzuki et al. 2006) and species diversity (Junyan et al. 2014). Flora and fauna diversity in ecotones are often richer than in the neighboring ecosystems; however, overexploitation could pose a serious threat to their ecological diversity (Sharma et al. 2014).

Pasture is a natural ecosystem that contains vast genetic resources, plant and animal diversity. The biological diversity of pastures is determined mostly by their plant diversity that ensures stability of the ecosystems against changing environmental factors (McCann 2000). Protection of pasture ecosystems entails management and conservation of their ecological complexity and this can only be achieved by studying and measuring species diversity. With the advance of science related to natural resources and necessity for maintaining biodiversity and managing valuable natural resources, there is a growing interest in examining ecological diversity through different diversity indices (Ghazoul and Sheil 2010, Newton 2007).

Measurement of biodiversity in an ecosystem is essential for biological control and conservation of genetic resources (Ninan 2012). Species composition, dominance, evenness, and the number of species are important parameters used in evaluating the ecological conditions of ecosystems (Orwin et al. 2014). These parameters show the diversity, richness, and status of these resources and help adopting an appropriate management plan. The present study examines the herbaceous species diversity of the forest, ecotone, and pasture located in upland areas in Shirud of Mazandaran Province, and provides insights into the way that will help to restore and manage these ecosystems.

## Materials and Methods

### Study area

Shirud area is located in southern Tonekabon city in Mazandaran province from 36°41′05″ to 36°45′40″N and from 50°46′0″ to 50°50′10″ E. It is bordered by private farmlands from the north, by Chalakrud watershed basin from the west, and by Tiromrud watershed basin from the east and south. Minimum and maximum altitudes are 100 and 3520 m a.s.l., respectively. The total area of Tiromrud basin is 20287 ha. The average annual temperature of the region is 16 °C, the average annual rainfall is 1100 mm, and the maximum and minimum monthly rainfalls are 269.6 mm and 38 mm, respectively (Ramsar Synoptic Weather Station 2012). The forest soils are acidic with a pH varying between 5.5 and 6.5. The present study was carried out in the forest with slope of 50 %, ecotone with slope of 25 % and pasture with slope of 40 %. According to the general overview of study area and local experts` view, the forests, grassland and ecotone are affected by grazing intensity. For this reason, we considered the average grazing intensity of the forest and the pasture, and high intensity grazing in the ecotone site. Criterion for selecting ecotone was low slope since grazing intensity (especially sheep) was high there. The forest type is beech community (*Fagetum-oreintalea*) and the predominant tree species in the forest are *Fagus orientalis* following by *Carpinus betulus*, *Alnus subcordata*, *Parrotia persica*, *Acer velutinum*, *Quercus castaneifolia* and *Fraxinus excelsior.*

## Data collection

First, the sampling range was selected in the forest with tree, shrub and herbaceous species, the ecotone with shrub and herbaceous species, and the pasture sites with herbaceous species at altitude of 1754 to 2275 m a.s.l. using a map of the area. Systematic sampling was done along a transect at 50, 100 and 150 m intervals across the forest, ecotone and pasture sites with different grazing intensity. We selected two areas in which grazing intensity were medium (i.e., forest) and high (i.e., ecotone) in order to assess the grazing effect. To determine the grazing intensity of Shirud area, we used restrictions on water resources, slope, distance from the village and the camp livestock. Nested plot method was used to sample herbaceous species and the minimal area curve was plotted (100 $m^2$ was obtained in this study) (Houeto et al. 2013). Overall, eight plots were established in each area, where the coverage of herbaceous species was estimated.

## Data analysis

The diversity indices were calculated using Ecological Methodology software, and the results were further analyzed by SPSS 16. Kolmogorov-Smirnov test was used to examine the normality of data. Given the normal distribution of data, one-way ANOVA was used to compare the three sites, and Duncan's test was applied for multiple comparisons of means.

The diversity, evenness, and richness of each area were calculated using the software mentioned above (McArt et al. 2012, Robbins et al. 2006, Oldeland et al. 2010):

- Shannon-Wiener index (Hamilton 2005): This index has higher sensitivity to rare species. It is a suitable method for comparing diversity in different areas (Pena et al. 2010, Jongsma et al. 2014).
- Simpson index: Simpson index is the probability that two individuals taken at random belong to the same species (Leps et al. 2006).
- Smith and Wilson's evenness index: This index is based on the variance in abundance of species. According to Smith et al. (2008) this is the best evenness, because it is independent of species richness and is sensitive to both rare and abundant species in a sample or a community (Garibaldi et al. 2013, Han et al. 2014).
- Richness index: The simplest and most common measurement of species richness is the number of species (Garibaldi et al. 2013).

Similarity among the three studied sites was examined by Jaccard and Sørensen coefficients (Table 1).

**Table 1. Jaccard and Sørensen's similarity coefficients.**

| Similarity index | Description |
|---|---|
| Jaccard<br>$S_J = \dfrac{a}{a+b+c}$ | *a* = number of species in common for both sites.<br><br>*b* = number of species in the first sample or community. |
| Sørensen<br>$S_S = \dfrac{2a}{2a+b+c}$ | *c* = number of species in the second sample or community. |

## Results

The list of herbaceous species in the forest, the ecotone and the pasture sites are shown in Table 2. Totally 71 species belonging to 39 families were identified (33 species and 23 families in the forest, 26 species and 21 families in the ecotone,

**Table 2. List of the herbaceous species in studied areas.**

| Species | Family | Mean percent cover | | | Relative frequency | | |
|---|---|---|---|---|---|---|---|
| | | Forest | Ecotone | Pasture | Forest | Ecotone | Pasture |
| *Achillealanulosa* Nutt. | Asteraceae | - | - | 5 | - | - | 0.13 |
| *Agrostis stolonifera* L. | Poaceae | 7 | - | 7 | 0.13 | - | 0.5 |
| *Alchemilla vulgaris* L. | Rosaceae | - | 5.38 | 5.5 | - | 1 | 0.5 |
| *Allium sativum* L. | Alliaceae | 6 | - | - | 0.13 | - | - |
| *Alyssum iranicum* Hausskn ex Baumg. | Brassicaceae | - | - | 3.38 | - | - | 0.25 |
| *Alyssum maritimum* (L.) Lam. | Brassicaceae | 4.8 | - | - | 0.63 | - | - |
| *Arctium lappa* L. | Asteraceae | 6 | - | - | 0.13 | - | - |
| *Artemisia annua* L. | Asteraceae | 6.5 | - | - | 0.75 | - | - |
| *Asperula odorata* L. | Rubiaceae | 20.29 | - | - | 0.88 | - | - |
| *Atriplex tatarica* L. | Chenopodiaceae | - | - | 4 | - | - | 0.25 |
| *Capsella bursa-pastoris* L. | Brassicaceae | - | - | 3.5 | - | - | 0.25 |
| *Carex hirta* L. | Cyperaceae | 7.5 | - | 6 | 0.25 | - | 0.5 |
| *Carex sylvatica* L. | Cyperaceae | 8.5 | - | - | 0.5 | - | - |
| *Centaurea iberica* Trevir. &Spreng. | Asteraceae | - | - | 5 | - | - | 0.13 |
| *Centaurium pulchellum* (SW.) Druce | Gentianaceae | - | - | 1 | - | - | 0.13 |
| *Chelidonium majus* L. | Papaveraceae | - | - | 2 | - | - | 0.25 |
| *Cichorium intybus* L. | Asteraceae | - | 4.88 | 5 | - | 1 | 0.5 |
| *Cirsium spectabilis* DC. | Asteraceae | 2.5 | 19.25 | 6 | 0.13 | 1 | 1 |
| *Colchicum kotschyi* Boiss. | Liliaceae | - | 2 | - | - | 0.13 | - |
| *Conyza bonariensis* L. | Asteraceae | - | - | 2 | - | - | 0.25 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Crocus caspius* Fisch. &C.A.Mey. ex Hohen | Iridaceae | 4.5 | 15.38 | 5.83 | 0.25 | 1 | 0.75 |
| *Cuscuta campestris* L. | Cuscutaceae | - | - | 5 | - | - | 0.13 |
| *Cynoglossum creticum* Mill. | Boraginaceae | - | 3 | - | - | 0.13 | - |
| *Digitalis purpurea* L. | Scrophulariaceae | 6.67 | 4 | - | 0.38 | 0.13 | - |
| *Eryngium caucasicum* Trautv. | Apiaceae | - | - | 4 | - | - | 0.25 |
| *Euphorbia amygdaloides* L. | Euphorbiaceae | 6.25 | - | - | 0.5 | - | - |
| *Filago vulgaris* Lam. | Asteraceae | - | - | 5 | - | - | 0.13 |
| *Fragaria vesca* L. | Rosaceae | 5.6 | - | - | 0.63 | - | - |
| *Galium ghilanicum* Stapf | Rubiaceae | - | - | 6.5 | - | - | 0.25 |
| *Geranium maculatum* L. | Geraniaceae | 6.2 | - | 5.75 | 0.63 | - | 1 |
| *Geranium molle* L. | Geraniaceae | - | - | 5 | - | - | 0.25 |
| *Geum urbanum* L. | Rosaceae | - | - | 3 | - | - | 0.25 |
| *Heracleum persicum* Desf. exFisch. | Apiaceae | 4 | 5 | - | 0.13 | 0.13 | - |
| *Hypericum androsaemum* L. | Hypericaceae | 5.75 | - | - | 0.5 | - | - |
| *Juncus fontanesii* J.Gay | Juncaceae | - | 5 | - | - | 0.13 | - |
| *Lamium album* L. | Lamiaceae | 5.4 | - | 4.67 | 0.63 | - | 0.38 |
| *Malva parviflora* L. | Malvaceae | - | 2 | - | - | 0.13 | - |
| *Medicago sativa* L. | Papilionaceae | - | 5 | 4 | - | 1 | 0.5 |
| *Mentha pulegium* L. | Lamiaceae | - | 8 | - | - | 0.25 | - |
| *Mercurialis perennis* L. | Euphorbiaceae | 5 | - | - | 0.25 | - | - |
| *Nasturtium officinale* W.T. Aiton | Brassicaceae | - | 3.25 | - | - | 0.13 | - |
| *Phlomis bruguieri* Desf. | Lamiaceae | 7 | 2 | 4 | 0.13 | 0.25 | 0.37 |
| *Phyllitis scolopendrium* L. | Aspleniaceae | 6.5 | - | - | 0.25 | - | - |
| *Plantago major* L. | Plantaginaceae | - | - | 3 | - | - | 0.13 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Plantago ciliata* Desf. | Plantaginaceae | - | 5.88 | 8.25 | - | 1 | 0.5 |
| *Polygonatum orientale* Desf. | Asparagaceae | 7 | 2 | - | 0.25 | 0.13 | - |
| *Polygonum convolvulus* L. | Polygonaceae | - | - | 2 | - | - | 0.13 |
| *Primula heterochroma* Stapf. | Primulaceae | 7 | - | 4.2 | 0.5 | - | 0.63 |
| *Pteridium aquilinum* (L.) Kuhn | Hypolepidaceae | 6 | 5 | 19 | 0.25 | 0.25 | 0.4 |
| *Ranunculus arvensis* L. | Ranunculaceae | - | 4.25 | 6.4 | - | 1 | 0.63 |
| *Rosa canina* L. | Rosaceae | 8 | - | - | 0.13 | - | - |
| *Rubus fruticosus* L. | Rosaceae | 16 | 15 | - | 0.25 | 1 | - |
| *Rumex* sp. | Polygonaceae | - | 21.63 | 8 | - | 1 | 0.5 |
| *Salvia officinalis* L. | Lamiaceae | 7 | - | - | 0.38 | - | - |
| *Sambucus ebulus* L. | Caprifoliaceae | 7 | 6 | - | 0.38 | 0.13 | - |
| *Sedum hispanicum* L. | Crassulaceae | - | - | 2 | - | - | 0.13 |
| *Senecio vernalis* Waldst. & Kit. | Asteraceae | - | 2 | - | - | 0.13 | - |
| *Silene conica* L. | Caryophyllaceae | - | - | 4.75 | - | - | 0.25 |
| *Silene gallica* L. | Caryophyllaceae | - | - | 5.75 | - | - | 0.25 |
| *Solanum melongena* L. | Solanaceae | 7.75 | - | - | 0.5 | - | - |
| *Taraxacum* sp. | Asteraceae | - | - | 4 | - | - | 0.13 |
| *Teucrium hyrcanicum* L. | Lamiaceae | - | - | 3 | - | - | 0.13 |
| *Thymus carnosus* Boiss. | Lamiaceae | - | - | 3 | - | - | 0.13 |
| *Trifolium resupinatum* L. | Papilionaceae | 6 | - | 9.29 | 0.38 | - | 0.88 |
| *Urtica dioica* L. | Urticaceae | 11.88 | 15 | 5.67 | 0.5 | 0.13 | 0.38 |
| *Veronica persica* Poiret. | Scrophulariaceae | - | - | 5 | - | - | 0.13 |
| *Viola sylvestris* Lam. | Violaceae | 5.2 | 2.88 | 4.25 | 0.63 | 1 | 0.5 |

and 40 species with 27 families in the pasture).

In the ecotone, the highest cover percentage belonged to *Cirsium spectabile* (19.25 %), followed by *Crocus caspius* (15.38 %), *Rumex* sp. (21.63 %), *Urtica dioica* (15 %), in the forest, *Rubus fruticosus* (15 %), *Asperula odorata* (20.29 %) and in the pasture, *Pteridium aquilinum* (19 %) had the maximum percent cover (Table 2).

As shown in Figures 1 and 2 (Jaccard and Sørensen similarity coefficients), the highest similarity was found between the forest and pasture sites and the lowest one – between the ecotone and pasture sites.

A comparison of the studied sites in terms of evenness, richness and diversity (using one-way ANOVA and Duncan's multiple range tests) are given in Table 3.

Duncan's test revealed that there was a significant difference between the forest and the ecotone sites, and between the ecotone and the pasture sites in Simpson and Shannon-Wiener indices (α = 1 %). However, no significant difference was found between the forest and pasture sites. There was also significant difference between the forest and pasture sites in the Smith-Wilson index (α = 5 %), and between the studied sites in species richness, which was higher in the forest and pasture in comparison to the ecotone (Table 3).

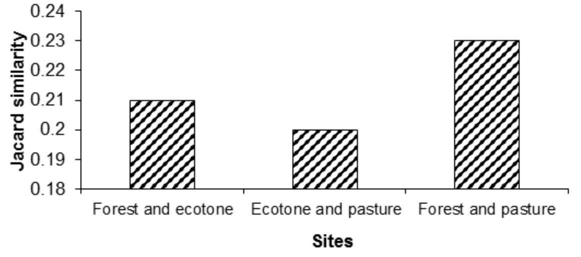


**Fig. 1. The values of Jaccard's similarity coefficient in the studied sites.**

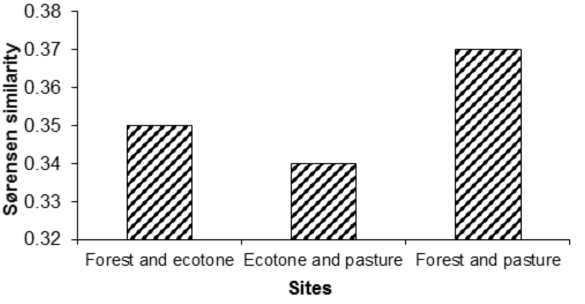


**Fig. 2. The values of Sørensen's similarity coefficients in the studied sites.**

**Table 3. The values of diversity indices in studied sites.**

| Index | Site | Mean±*SD* | *P*-value |
|---|---|---|---|
| Simpson | Forest<br>Ecotone<br>Pasture | 0.04±0.72<br>0.17±0.68<br>0.04±0.90 | 0.001** |
| Shannon-Wiener | Forest<br>Ecotone<br>Pasture | 0.56±3.39<br>1.07±2.12<br>0.45±3.59 | 0.001** |
| Smith and Wilson | Forest<br>Ecotone<br>Pasture | 0.06±0.84<br>0.14±0.63<br>0.16±0.79 | 0.009** |
| Richness | Forest<br>Ecotone<br>Pasture | 12.5±4.69<br>0.14±0.63<br>3.92±16.13 | 0.00* |

**Note: *SD* – standard deviation; *P* – level of significance; * indicate significant difference at the 0.05 level; ** indicate significant difference at the 0.01 level.**

## Discussion

Understanding the effect of biological stress on an ecosystem is an important issue because each stress tends to cause area destruction and reduced diversity. This study revealed that the grazing has decreased the diversity, evenness and richness of species in the studied sites. The results indicated that there is a significant difference among the ecotone, forest and pasture sites in species abundance and diversity. Jaccard and Sørensen's similarity coefficients showed high similarity between the forest and pasture, and low similarity between the ecotone and pasture sites. This states that herbaceous species in the forest and the pasture sites have been less exploited. In contrast, they have experienced severe biological stress caused by anthropogenic pressure by people and livestock and this has led to decrease of species diversity and richness. Grazing causes changes in the pattern of species dominance (Aikens et al. 2007, Rasingamet al. 2009). *Cirsium spectabilis*, *Crocus caspius*, *Rumex* sp., *Urtica dioica, Rubus fruticosus, Asperula odorata*, *Pteridium aquilinum* were dominant and indicator species in the forest, ecotone and pasture areas, respectively (McEvayetet al. 2006, Ebrahimi et al. 2014).

In addition, the results indicate that diversity of herbaceous species is higher in the forest and pasture than in the ecotone. There was higher species richness in the forest and the pasture in compared to the ecotone, and clearly grazing is one factor that reduces the richness and abundance of species. This subject is supported by the results of Bouahim et al. (2011). Reduced species richness due to cattle grazing has been reported in various studies (Altesor et al. 2006, Loydi et al. 2012, Pykälä 2005, Roberts and Zhu 2002, Schumann et al. 2003). In the studied sites cattle grazing affected more the evenness of herbaceous species than the richness. Evenness plays more significant role in maintaining diversity than richness. This is consistent with the results of Anderson and Hoffman (2007), Arévalo et al. (2007), Casado et al. (2004), and Fernández-Lugo et al. (2009). It is associated with abundance, and maximum values are obtained when all species are equally represented (Hayek and Buzas 2013). Species evenness was higher in the forest and pasture sites than in the ecotone, where grazing pressure has decreased the coverage of species, thus reducing evenness and diversity (Ebrahimi et al. 2014). Overgrazing reduces species evenness and can disturb an ecosystem (Navarro et al. 2006), but moderate grazing has a positive effect on plant stability (Klimek et al. 2007, Van der Walt et al. 2014, Sun et al. 2008).

Comparison of species diversity indicated that diversity indices were significantly higher in sites subjected to moderate grazing compare to the sites with overgrazing ($\alpha$ = 1 %). Our results support the Mligo's study (2006), which showed that grass cover was negatively correlated with grazing intensity, and moderate grazing ensures annual regeneration of species. Like Hendricks et al. (2005), we found that diversity is lowest in areas around cattle pens where grazing pressure was the highest. This is consistent with the results of Austrheim and Eriksson (2001), McIntyre and Lavorel (2001), Pykälä (2005), Weiss et al. (2014), Zhao et al. (2007), Mligo (2006), Guo et al. (2010), Tárrega et al. (2006) and Barger et al. (2004).

Our results support the reports that high intensity grazing leads to decreased species diversity. Significantly lower diversity and evenness in a high-intensity grazing site indicates that the community faces difficult conditions and destruction of the area causes loss of certain critical plant species. On the other hand, moderate grazing increases species diversity and has a positive effect on the grass cover of the region. Our findings showed that the level and quality of biodiversity in the region is closely linked to destructive grazing and conservation of herbaceous species that can play an effective role in maintaining and increasing plant diversity. The forest and the pasture are in more favorable conditions than the ecotone, although the forest had lower diversity in comparison with the pasture site. This can be attributed to tree canopy cover in the forest that leads to lower replacement of grass cover. The results of this research are consistent with the findings of Parr et al. (2012).

## Conclusions

Species diversity is closely linked to grazing intensity. Therefore, the planning should be based on local participation and should promote proper exploitation methods that help the conservation of natural resources and biodiversity. Based on the present findings, we recommend that exploitation of plants by local people should be limited when cattle is herded to unprotected areas. It is necessary to evaluate species diversity in these ecosystems continually in order to restore them to their initial phase.

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# COMPARATIVE STUDY ON CROWN LEACHING COMPOSITION OF BLACK PINE, ATLAS CEDAR, COMMON OAK AND BLACK LOCUST

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## Abstract

The rainfall amount and its chemical composition were studied in the period 2009–2013 in the Pismenovo arboretum, situated close to Black Sea coast (Tsarevo State Forest Service). The objective of the proposed work comprises conducting of prolonged studies on N, $P_2O_5$, $K_2O$, Ca and Mg content and the highlighting of the particularities in the seasonal dynamics of the above mentioned elements in the leaves of some tree species. The purpose of this work comprises a conducting of longer comparative research on the dynamics of the chemical composition of atmospheric precipitations under the canopy of different forest-tree plantations. The results showed that Black pine (*Pinus nigra* Arn.) crowns capture 29.2 % of the total rainfall amount at open field. The same percentage in Atlas cedar (*Cedrus atlantica* Manetti) was 34.4 %, in Common oak (Q*uercus robur* L.) – 6.5 %, in Black locust (*Robinia pseudoacacia* L.) – 23.3 % and the throughfall in the 75-year-old coppice oak forest was 15.8 %. A difference in the chemical composition of throughfall has been determined, depending on age and species (coniferous or deciduous). The pH value of the throughfall and that of rain water at open field had acid to slightly acid reaction, and the acidity increased during the winter. The lowest values of pH were measured in the water passed through Black pine crowns, and the highest ones – in the water passed through the crown of Black locust. Most nitrate ions were registered in the throughfall fluxes of Black pine. Most ammonium ions were detected in the throughfall fluxes of the 75-year old coppice oak forest, and chloride ions – in the throughfall of Atlas cedar. The content of calcium and magnesium in the throughfall also increases in comparison to that one measured in open field fluxes. The highest content of these two elements was recorded in the throughfall of Black locust.

**Key words:** ammonium ions, canopy, chlorides, nitrate ions, pH, forest, open field precipitation, throughfall.

## Introduction

The throughfall fluxes of the tree species cause changes in their chemical composition and evidence many times higher mineralization. The amount of the elements washed away by rain water depends on tree species composition, age, phase of development etc. As referenced, a great attention is paid to research works focusing on the washing away of the biogenic elements by rain water from the tree vegetation crowns (Kolodyazhnaya 1963; Smit 1985; Ignatova 1986, 1987, 1992; Karpachevsky et al. 1988; Fikova and Ignatova 2003; Alenas and Skarby 1988; Hansen et al. 1994; Lindberg et al. 1990; Likens and Bormann 1995). This is because these research works are significantly important both for the examination of the cycling of the substances related to nutritional regimen of tree species and of the hydrothermal regimen of river basins in forest ecosystems (Bahmani et al. 2012, Ziegler et al. 2009). Dry deposition of base cations, nitrate, as well as particulate ammonium, and sulphate in coniferous forests was measured by Ferm et al. (2000). According to studies by Reinap (2011), dry deposition models are insufficient due to a lack of semi-empirical data and because of difficulties in parameterization of the efficiency (E) with which leaves capture aerosols.

The purpose of this work comprises a conducting of longer comparative researches on the dynamics of the chemical composition of the atmospheric precipitations passed under the canopy of different forest-tree plantations.

## Objects and Methods

The rainfall amount and chemical composition has been measured for more than 10 years on the territory of Pismenovo arboretum, Tsarevo State Forest Enterprise, sector $12^5$, in the peripheral sub-region of Strandzha mountain. The results, obtained within the period 2009–2013, are indicated in the study (Broshtilova 2009).

The rainfall quantity is collected into plastic collectors after the throughfall fluxes of the 20–25-year-old trees, as following: Black pine, Black locust, Common oak (plantations), 75-year-old *Quercus frainetto* Ten. coppice plantation, and the rainfalls at open field. Water samples are taken from each single throughfall flux where pH is potentiometrically determined, the ammonia and nitrate ions – by a direct distillation using the Parnas-Wagner apparatus, the contents of sulphates, calcium and magnesium – by the complex-metric method; while the content of chlorides is argentometrically detected using Mohr`s method.

## Results and Discussion

Of the total annual amount of throughfalls at the open field, 29.2 % throughfall fluxes are captured by Black pine crowns, 34.4 % by Atlas cedar ones, 6.5 % by Common oak, 23.3 % by Black locust and 15.8 % by the old oak forest, compared to the rainfall at open field (Table 1). The coniferous plantations capture in their crowns about 2 times more of rainfalls, as compared to the coppice oak forest, and approximately 5 times more in comparison with the Common oak plantation.

**Table 1. Detained rainfall of wood crowns, mean values (% of the total rainfall amount at open field).**

| Species\year | 2009 | 2010 | 2011 | 2012 | 2013 | Average |
|---|---|---|---|---|---|---|
| *Pinus nigra* Arn. | 35.0 | 29.4 | 20.5 | 30.4 | 30.8 | 29.2 |
| *Cedrus atlantica* Manetti | - | 32.5 | 39.0 | 30.2 | 35.7 | 34.4 |
| *Robinia pseudoacacia* L. | 14.0 | 27.1 | 32.9 | 24.0 | 18.5 | 23.3 |
| Q*uercus robur* L. | 5.0 | 8.5 | 3.9 | 6.1 | 6.1 | 6.5 |
| 75-year old coppice oak forest | 14.0 | 15.3 | 13.3 | 19.5 | 16.7 | 15.8 |

The reaction (pH) of the rain water at open filed and the throughfall fluxes under the canopy of the studied species in Pismenovo arboretum varies from slightly acid to acid (Fig. 1). The highest acidity is detected in the rainfalls in 2012 when a pH value of 4.78 in the throughfall fluxes of the old oak forest is measured in February (Fig. 2): probably, that is due to a higher degree of the atmospheric air pollution in the above mentioned region, within the respective period. During the whole period of study, pH values, measured in all of the species, are lower in the winter months. The average results, obtained within the period 2009–2013, show that the most acid rainfalls are in February, with the exception of the throughfalls of Common oak, having the highest acidity in January. As a hypothetical reason for such lower values of pH in that period, the predominance of snowfalls could be considered.

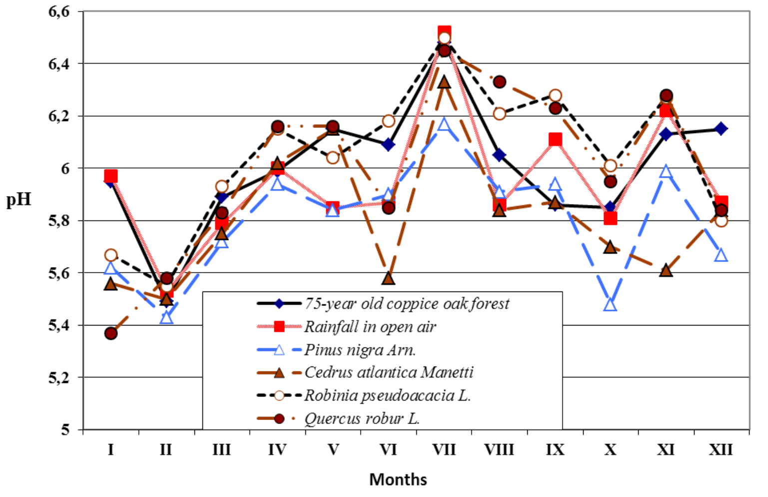


**Fig. 1. The dynamics pH value of the rainfall for the period 2009–2013 (mean values).**

The average concentration of the ammonia ions in the rainfalls is significantly lower, compared to that one of the nitrate ions (Table 2). The greatest difference exists in the throughfall fluxes of Black pine, as of 3.8 times, while the smallest one is

Most acid are the throughfalls fluxes of Black pine followed by Atlas cedar ones while the highest value of pH is measured in the throughfalls of Black locust (Table 2, Fig. 1 and 2).

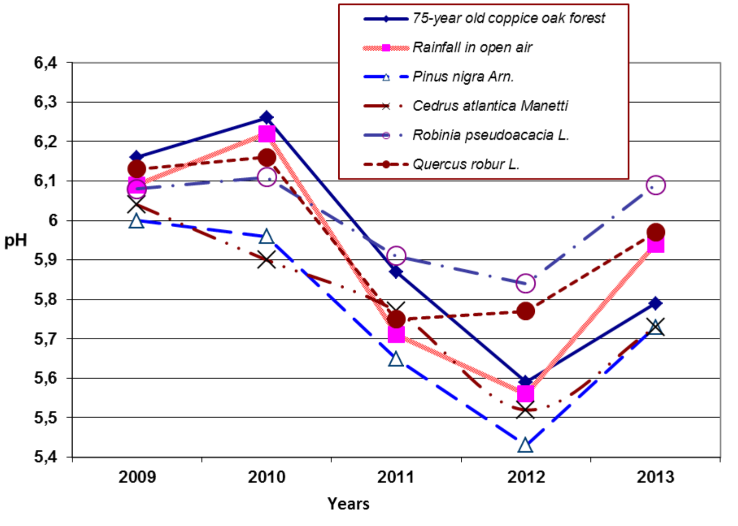


**Fig. 2. Mean annual acidity of open field precipitation and forest throughfall for the period 2009–2013 (mean values).**

**Table 2. Average concentrations chemical ingredients in rainfall in open air and under the crowns (period 2009–2013).**

| Variant | pH | $NH_4^+$ | $NO_3^-$ | $Cl^-$ | $SO_4^{2-}$ | $Ca^{2+}$ | $Mg^{2+}$ |
|---|---|---|---|---|---|---|---|
| | | mg/l | | | | | |
| Rainfall in open air | 5.90 | 1.46 | 4.63 | 4.47 | 0.46 | 6.30 | 1.31 |
| *Pinus nigra* Arn. | 5.75 | 2.20 | 8.48 | 8.41 | 0.38 | 8.04 | 2.21 |
| *Cedrus atlantica* Manetti | 5.79 | 3.67 | 7.46 | 13.26 | 0.11 | 10.11 | 3.56 |
| *Robinia pseudoacacia* L. | 6.01 | 2.17 | 4.76 | 10.45 | 0.12 | 13.15 | 4.40 |
| *Quercus robur* L. | 5.96 | 2.55 | 4.61 | 5.26 | 0.42 | 7.21 | 1.94 |
| 75-year-old coppice oak forest | 5.93 | 4.80 | 7.02 | 8.33 | 0.12 | 11.3 | 2.84 |

registered in the throughfall fluxes of the old oak forest: 1.5 times.

The content of the ammonia ions is the lowest in the rainfalls at open field while in the throughfall fluxes of the old oak forest there is a difference of more than 3 times. The concentration of the ammonia ions in the throughfall fluxes of Atlas cedar is 2.5 times higher, as compared to that one in the rainfalls at open field. Within the period from April to June, the content of the ammonia ions, detected in the throughfall fluxes of the old oak forest and Common oak is significantly higher in comparison with that one in the rest months (Fig. 3). So, the obtained results have shown that more intensive washing away of biogenic elements from the tree leaves is evidenced when the leaves are younger, intensively growing during the above mentioned months.

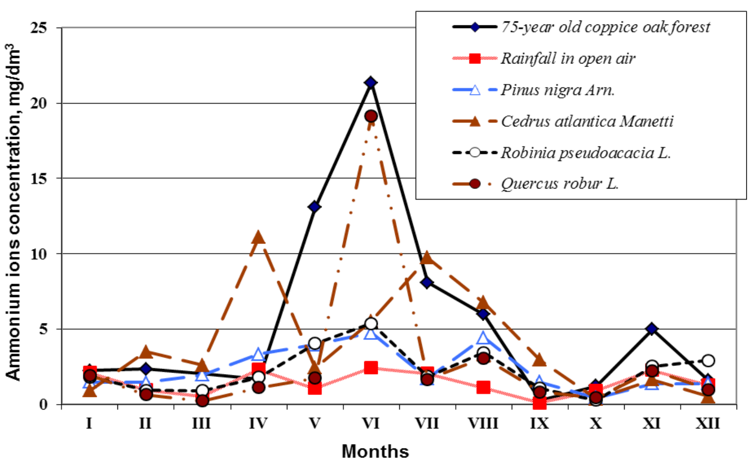


**Fig. 3. Ammonium ions concentrations in the rainfall (period 2009–2013, mean values).**

The concentration of the nitrate ions is the highest in the throughfall fluxes of Black pine: about 2 times higher than in the rainfalls at open filed and throughfalls of Common oak. About 1.7 times more nitrates are washed away from the Black pine crown by rainfalls in comparison with the nitrates washed out from the crowns of Common oak and Black locust (Table 2). The content of the nitrate ions in throughfalls of coniferous species within the period March-June is significantly higher compared to that one in the rest months (Fig. 4).

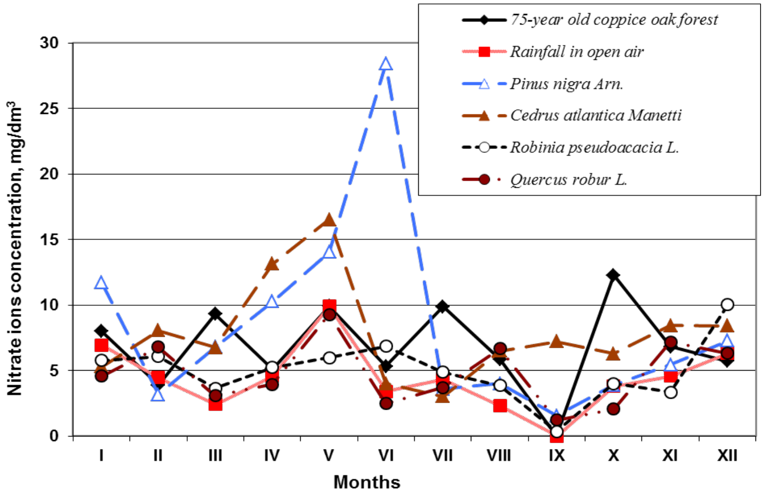


**Fig. 4. Nitrate ions concentrations in the rainfall (period 2009–2013, mean values).**

The content of chlorides is higher during the second half of the year, especially in the throughfalls of Black locust and Atlas cedar (Fig. 5). When the rainfalls pass through the crowns of the tree species, the concentration of chlorides in the throughfalls undergoes a significant change. The highest is the concentration of chlorides in the throughfall fluxes of Atlas cedar: about 3 times higher. It is 2.3 times higher in the throughfall fluxes of Black locust, 1.9 times higher in the throughfalls of the old oak forest and 1.2 times higher in the throughfalls under the Common oak canopy, compared to that one in the rainfalls at open field (Table 2).

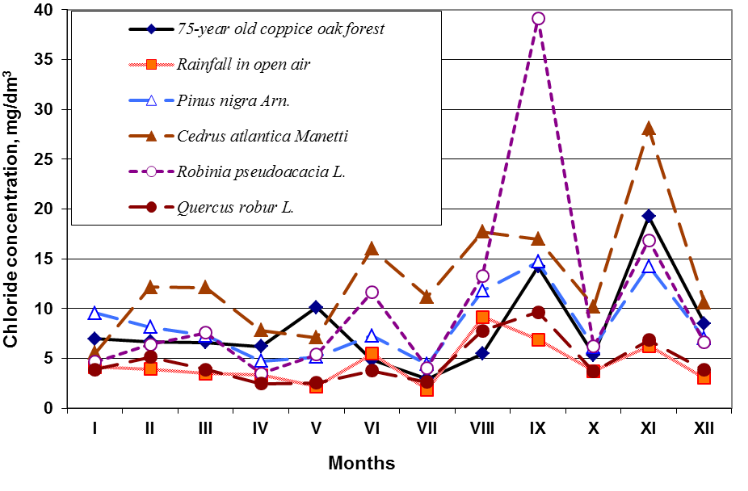


**Fig. 5. Chloride concentrations in the rainfall (period 2009–2013, mean values).**

There is also an increase of Ca and Mg content in the throughfall fluxes of the trees, in comparison with that one in the rainfalls at open field: the content of calcium ions is 2 times greater and that one of magnesium ions: 3 times greater (Table 2). The average results, obtained within the period (Fig. 6 and 7), have shown that the greatest amounts of calcium and magnesium ions are washed away by rainfalls from the crowns of Black locust trees. One of the reasons for more intensive washing away from the crown of Black locust is the significantly higher Ca and Mg content in its leaves.

Such comparatively high annual average concentrations of calcium and magnesium in the rain waters, registered in all of the variants, can be explained by the proximity of the examined sites to the sea (Likens and Bormann 1995).

As about sulphates, certain amounts of them are detected in the rain waters only in some years (when the study was conducted), and, mainly, in January, February and March. In contrast to the other studied elements, the content of sulphates in the rain water at open field is greater than in the throughfall fluxes of the examined tree species (Table 2).

Confronting the annual dynamics of sulphates (Table 3), it is evident that their content corresponds to the highest acidity of the precipitation: a fact which proves an existing relationship between the acidification of the atmospheric precipitations and the content of pollutants of industrial origin (Fikova and Ignatova 2003).

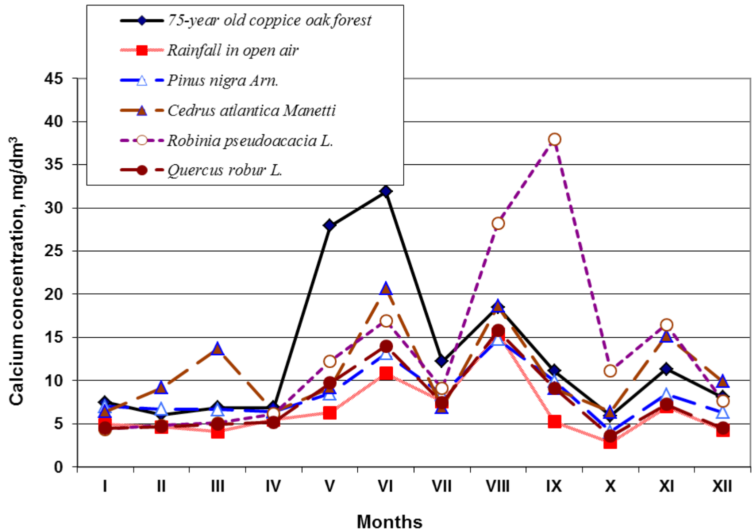


**Fig. 6. Calcium concentrations in the rainfall (period 2009–2013, mean values).**

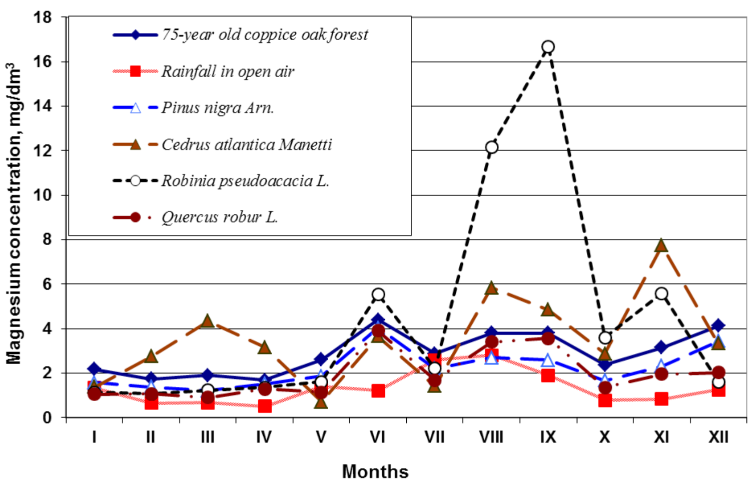


**Fig. 7. Magnesium concentrations in the rainfall (period 2009–2013, mean values).**

**Table 3. Sulfates content in rainfall, mean values (mg/dm³).**

| Variant\years | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| Rainfall in open air | 0 | 0.35 | 1.33 | 0.60 | 0 |
| *Pinus nigra* Arn. | 0 | 0.35 | 1.15 | 0.40 | 0 |
| *Cedrus atlantica* Manetti | 0 | 0.35 | 0 | 0.21 | 0 |
| *Robinia pseudoacacia* L. | 0 | 0 | 0 | 0.58 | 0 |
| Q*uercus robur* L. | 0 | 0.17 | 0.77 | 1.15 | 0 |
| 75-year old coppice oak forest | 0 | 0 | 0 | 0.58 | 0 |

## Conclusions

Black pine crowns capture 29.2 % of the total rainfall amount at open field. The same percentage in Atlas cedar was 34.4 %, in Common oak – 6.5 %, in Black locust – 23.3 % and the throughfall in the 75-year-old coppice oak forest was 15.8 %.

A difference in the chemical composition of throughfall has been determined, depending on age and species (coniferous or deciduous).

The pH value of the throughfall and that of rain water at open field had acid to slightly acid reaction, and the acidity increased during the winter. The lowest values of pH were measured in the water passed through Black pine crowns, and the highest ones – in the water passed through the crown of Black locust.

Most nitrate ions were registered in the throughfall fluxes of Black pine. Most ammonium ions were detected in the throughfall fluxes of the 75-year-old coppice oak forest, and chloride ions – in the throughfall of Atlas cedar.

The content of calcium and magnesium in the throughfall also increases in comparison to that one measured in open field fluxes. The highest content of these two elements was recorded in the throughfall of Black locust.

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# DYNAMICS OF MACROELEMENTS IN THE LEAVES OF TREE SPECIES GROWING IN PISMENOVO ARBORETUM DURING THE GROWING SEASON

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## Abstract

The study took place in the period 2008–2012 in Pismenovo arboretum, situated in the peripheral sub-region of Strandzha Mountain (South-Eastern Bulgaria). Nitrogen and macroelement contents were examined in the leaves of 21–25-year-old specimen belonging to the following species: *Pinus nigra* Arn. ssp. *austriaca* Höss, *Pinus nigra* Arn. ssp. *laricio* Poiret, *Cedrus deodara* Loud., *C. atlantica* Manetti, *C. libani* A. Rich., *Cupressus sempervirens* L., *Quercus petraea* (Matt.) Liebl. (3 provenances), *Q. robur* L. (4 provenances), *Q. pubescens* Willd., *Q. rubra* L., *Q. suber* L., *Q. harwissiana* Stev., *Q. frainetto* Ten., *Fagus sylvatica* L., *F. orientalis* Lipsky and *Tilia tomentosa* Moench. Nitrogen content in the leaves of most deciduous species was the highest in May, maintaining comparatively high values in June and gradually lowering in the next months until the end of growing period. $P_2O_5$ content had its maximum value in the summer months, keeping relatively high values until the end of the growing period. K concentration in the leaves of most species was highest in August. Ca and Mg content gradually increased from the beginning to end of the growing period. N, P and K content in the coniferous species was significantly lower as compared to the one in the leaves of the deciduous species, which makes the latter ones more tolerant to soil fertility. Of conifers, the lowest concentration of these substances was recorded in the needles of the Atlas cedar. In deciduous species the highest content was measured in *Tilia tomentosa* and *Quercus hartwissiana* and the lowest one – in the leaves of the Cork oak. There were also differences among the provenances within a species. In Cedar needles, Ca and Mg concentration is 2 times higher, compared to that one in the needles of Black pine and *Pinus nigra* Arn. spp. *laricio*. It is obviously a characteristic biological particularity. The differences should be considered when modelling nutrient circulation in forest stands and when evaluating the long-term sustainability of forest management.

**Key words:** calcium, coniferous species, deciduous species, magnesium, nitrogen, phosphate, potassium.

## Introduction

Nitrogen and other macroelements content and dynamics in the leaves of the tree species are of a great importance for the highlighting of the elements cycling in the forest ecosystems where the purpose is to optimize their productivity, sustainability, conservation and regeneration of species diversity.

The seasonal dynamics of the concentration of macroelements in the leaves of tree species varies as it is dependent on their accessibility in the soil, climatic factors, age of the leaves and trees, phase of development during the growing season etc. (Bauer et al. 1997, Lukina 1996, Lukina et al. 2000, Lukyanets 1980, Yurukova and Bondev 1990). It is also known that the chemical composition of the plants is influenced by genetic factors, as well; and the plasticity of nitrogen, phosphorus and potassium content in the photosynthetic organs can be utilized in the selection of genotypes of desired characteristics (Bridgen 1988). Some authors clarify the relationship between air pollution and concentration of elements in needles and leaves of the tree species (Mankovská et al. 2004, Szaro et al. 2002).

The objective of the proposed work comprises the conducting of prolonged studies on N, P, K, Ca and Mg content and the highlighting of the particularities in the seasonal dynamics of the above mentioned elements in the leaves of some tree species.

## Objects and Methods

That examination of macroelements content and dynamics in the leaves has been going on for more than 10 years (Broshtilova and Broshtilov 2009). The study points to the results obtained within the period 2008–2012. Pismenovo arboretum is located in the peripheral sub-region of Strandzha Mountain, on the territory of the State Forestry Tsarevo (Sector $12^5$). Each of the species is planted on an area of 500 $m^2$, 25 × 20 m size, with separating paths of 4 m each. The saplings are planted in rows at the inter-distance of 2 m and intra-distance of 1 m.

The arboretum is situated on a slight slope terrain (1–2 °) at 70 m a.s.l., at north exposure. The soil is cinnamon-coloured, very deep, consolidated by an average to heavy sand-clay soil texture, gleying in its lower levels, due to winter over-moisturing. Considering its potential water resources, that kind of soil is characterized as fresh to humid. It has average stocks of humus and assimilable potassium and poor to average stocks of total nitrogen; there is a low acidic reaction in its root-inhabited layer. The assimilable phosphorus content is very low.

The content of macroelements is examined in the leaves of 20–25-year-old trees, as follows: Black pine (*Pinus nigra* var. *austriaca* Poiret), *Pinus nigra* Arn ssp. *laricio* Poiret), Deodar cedar (*Cedrus deodara* Loud.), *Atlas cedar* (*Cedrus atlantica* Manetti), Lebanon cedar (*Cedrus libani* Laws.), Common cypress (*Cupressus semepervirens* L.), Durmast oak (*Quercus petraea* Liebl.) – 3 provenances („Tsarevo", „Varbitsa" and „Varshets"), Common oak (*Quercus robur* L.) – 4 provenances („Vardim Island", „Village of Yulievo", district of Kazanlak, „Sofia" and "Slovenia"), Pubescens oak (*Quercus pubescens* Willd.), Red oak (*Quercus rubra* L.), Cork oak (*Quercus suber L.*), *Quercus hartwissiana* Stev., *Quercus frainetto* Ten., Common beech (*Fagus sylvatica* L.), Oriental beech (*Fagus orientalis* Lipsky), ansd Silver linden (*Tilia tomentosa* Moench).

Leaves of 6–7 model trees of average height and degree of development, from the light exposed side of the crown, are collected for analysis in the middle of each month, during the growing season (May-September). 2-year-old needles of the coniferous species are analyzed in that period. Samples are taken annually each month from May to September. The results presented are the average of five years. Nitrogen content in the needles is determined using Kjeldahl`s method, while the content of phosphorus was spectrophotometrically detected, potassium – by the emission method and magnesium – by the complex metric one.

## Results and Discussion

The coniferous species are of a significantly lower N concentration in their needles compared to that one in the leaves of the deciduous species (Fig. 1a,b). The average results, obtained within the examination period of N content in the coniferous species, show approximately 2 times lower N content therein, compared to that one in the broadleaved species. Similar data are reported about the differences in N concentration in Black pine needles and Oak leaves in the region of Strandzha Mountain (Pavlova et. al. 1995, 2000). Data about significantly lower N content in the needles of conifers compared to that in the leaves of deciduous is designated by other authors (Bauer et al. 1997, Hagen et al. 2004).

The highest N concentration is detected in Black pine needles, being by 7.4 % higher compared to that one in *Pinus nigra* Arn. ssp. *laricio*, and by 20.3 % higher, in comparison with that one in Atlas cedar leaves. There are no significant differences among the three Cedar species.

In the deciduous species, the highest N content is detected in the leaves of *Q. harwissiana*, followed by that one in Red oak and Silver linden leaves. The lowest is the concentration in Cork oak leaves (27 % lower, compared to that one in the leaves of *Q. hartwissiana*).

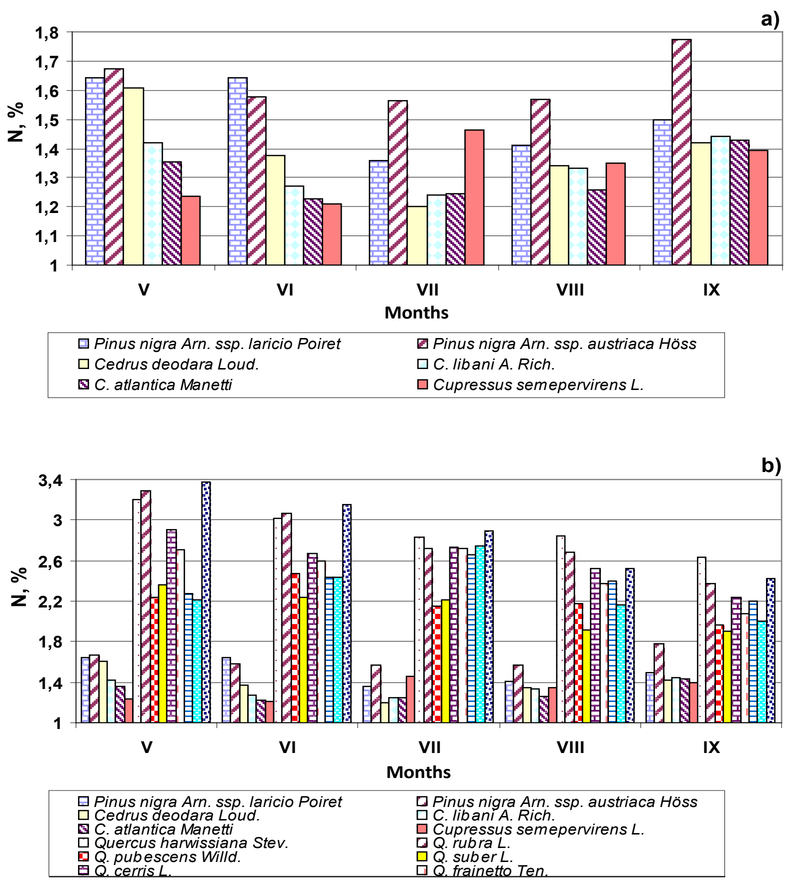


**Fig. 1. Dynamics of nitrogen in the leaves of coniferous (a) and deciduous (b) species during the growing periods 2008–2012 (mean values).**

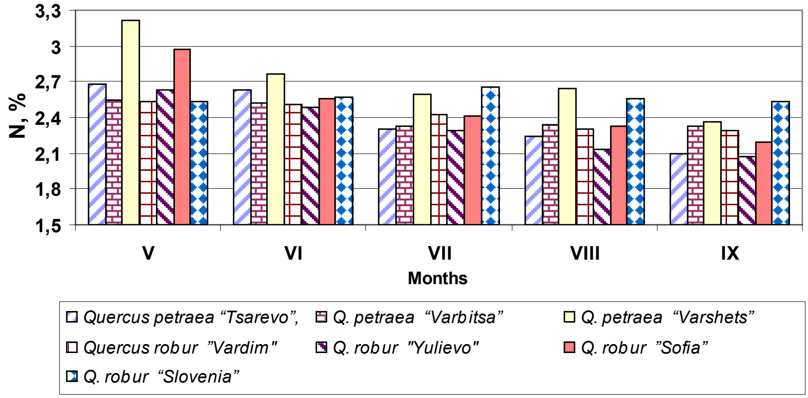


**Fig. 2. Dynamics of nitrogen in the leaves of Durmast oak and Common oak provenances during the growing periods 2008–2012 (mean values).**

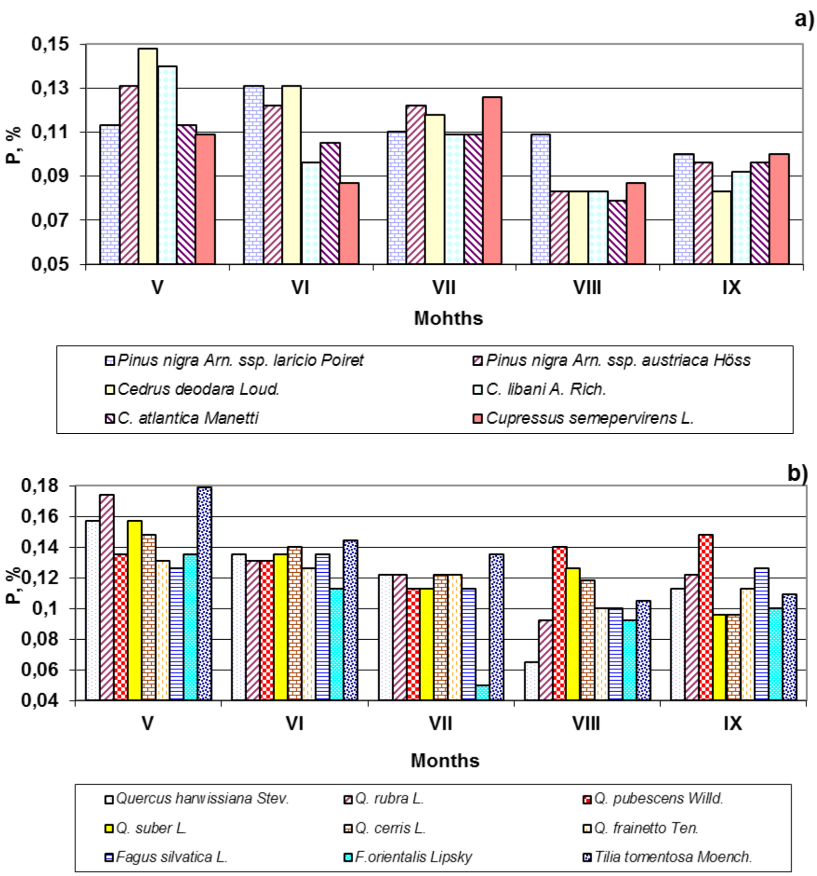


**Fig. 3. Dynamics of P in the leaves of coniferous (a) and deciduous (b) species during the growing periods 2008–2012 (mean values).**

There are differences among the single provenances within the species of Common and Sessile oak (Fig. 2). The average results within the period show that N content in the leaves of Common oak ("Yulievo" provenance) is lower by10 %, compared to that one in the leaves of the trees of "Slovenia" provenance. N content in the leaves of Durmast oak trees ("Tsarevo" provenance) is by 22 % lower, compared to that one in the leaves of the trees of „Varshets" provenance. According to some authors, a higher N content can be considered as an indicator of a better growth, vitality and adaptability of the trees from the respective origin (Lukyanets 1980, Patlai and Boiko 1978).

N content in the leaves of most deciduous species is the highest in May, keeping relatively high values in June and gradually dropping later on, during the vegetation period and maintaining relatively high values even in September (Fig. 1b). In Pubescens oak leaves, the maximum concentration of N is detected in June, while in Common oak leaves ("Slovenia" provenance) and Common and Oriental beech its maximum is in July.

No outlined seasonal dynamics is observed in the coniferous species during the growing season, regardless of a certain trend to N concentration increase from May to June and to its drop in October (Fig. 1a).

In most of the species, the content of P is the maximum in the beginning of the growing season and its high values are being also kept in June and July (Fig. 3a,b). According to Yanovich (1965), the concentration of phosphorus in the leaves is uneven during the growing period and it reaches its maximum in summer months: probably, that is due to a higher energy need in the same period characterized by the soil moisture exhaustion (Yanovich 1965).

No substantial differences are found out in Black pine and *Pinus nigra* Arn. ssp. *laricio* regards to the average concentrations of P in the needles. The concentration of P in Deodar cedar needles is slightly higher, compared to that one of the

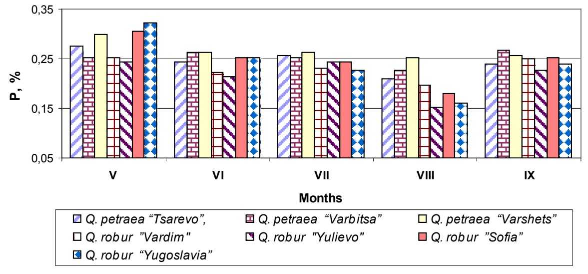


**Fig. 4. Dynamics of P in the leaves of Durmast oak and Common oak provenances during the growing periods 2008–2012 (mean values).**

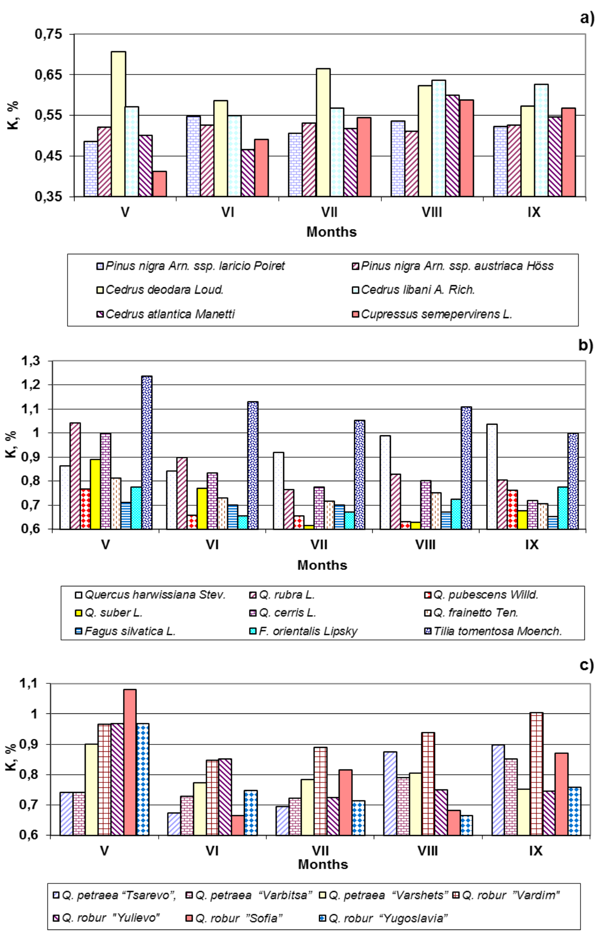


**Fig. 5. Dynamics of K the leaves of coniferous (a) and deciduous (b) species and oak provenances (c) during the growing periods 2008–2012 (mean values).**

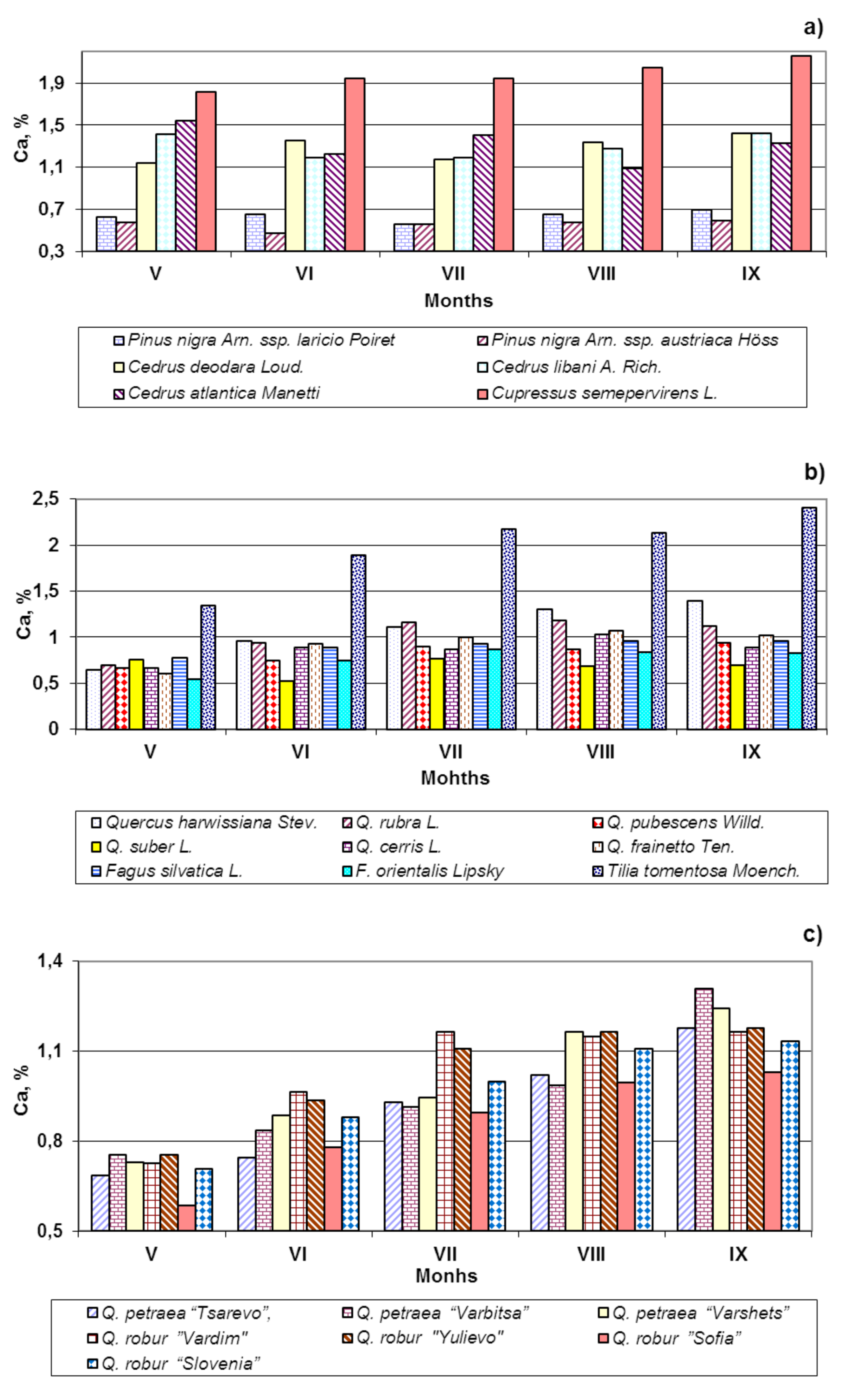


**Fig. 6. Dynamics of Ca in the leaves of coniferous (a) and deciduous (b) species and oak provenances (c) during the growing periods 2008–2012 (mean values).**

other two Cedar species. The lowest P concentration is detected in Common cypress leaves.

The highest P concentration is detected in Silver linden leaves and in Durmast oak ones ("Varshets" provenance), while the lowest P concentration is in Common oak ("Yulievo" provenance) leaves and Oriental beech ones (Fig. 4).

The differences in P concentration are not great among the single species and origins. According to Pavlova et al. (1995, 2000), there are similar average P concentrations in Sessile oak leaves within the same region.

K concentration in the needles of the coniferous species evidences a slight increase from May to June, with the exception of K concentration in Deodar cedar needles, which is the highest in the beginning of the growing season (Fig. 5a).

In most of the deciduous species, K concentration in the leaves is the highest in the beginning of the growing period, dropping in June and keeping the same values up to the end of the growing season (Fig. 5b).

During that same period, as previously mentioned, regarding N and P content, the average results, obtained in the deciduous species, show that the highest concentration of K is detected in Silver linden leaves, while the lowest one is in Cork oak and Common beech ones. There is a difference of 37.6 %.

In the coniferous species, the lowest K content is detected in Atlas cedar needles: by 17.1 % lower, compared to that one in Deodar cedar leaves. No significant difference exists between Black pine and *Pinus nigra* Arn. spp. *laricio* regarding K concentration in their needles (Fig. 5a).

The differences in K concentration are not great among the origins (Fig. 5c).

Ca and Mg contents in the growing season is characterized by a flu-

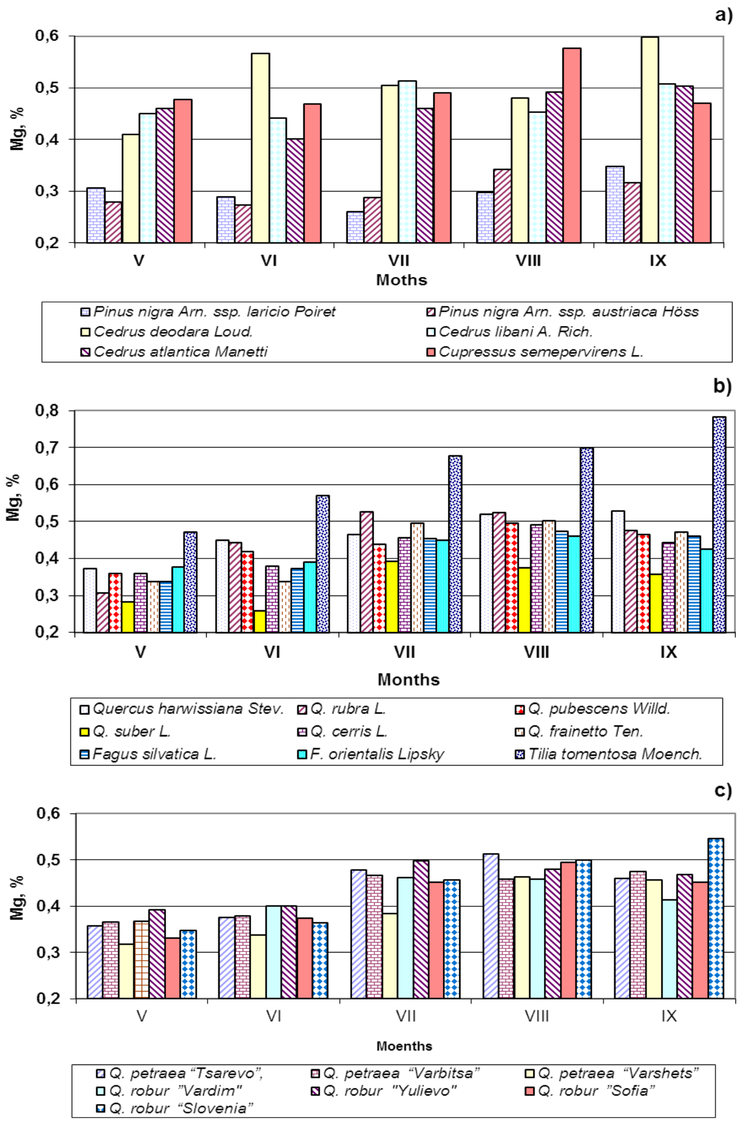


**Fig. 7. Dynamics of Mg in the leaves of coniferous (a) and deciduous (b) species and oak provenances (c) during the growing periods 2008–2012 (mean values).**

ent increase from the beginning up to the end, more evidently outlined in the deciduous species (Fig. 6a,b,c and 7a,b,c).

The average results show that a very high Ca concentration in Cedars and Common cypress leaves is characteristic in that same season, nearly 2 times higher, compared to that one in Black pine needles (Fig. 6a). It is obviously a characteristic biological particularity.

Ca concentration in silver linden leaves is significantly high er in comparison with that one of the other species, nearly 3 times higher than the concentration in Cork oak leaves (Fig. 6b).

In Cedar needles, Ca and Mg concentration is 1.7 times higher, compared to that one in the needles of Black pine and *Pinus nigra* Arn. spp. *laricio*.

In the deciduous species, Mg concentration is the highest again in Silver linden leaves and the lowest in Cork oak leaves (Fig. 7b).

No significant differences exist in Ca and Mg concentration among the single provenances (Fig. 7c).

## Conclusions

Nitrogen content in the leaves of most deciduous species was the highest in May, maintaining comparatively high values in June and gradually lowering in the next months until the end of growing period. P content had its maximum value in the summer months, keeping relatively high values until the end of the growing period. K concentration in the leaves of most species was the highest in August. Ca and Mg content gradually increased from the beginning to the end of the growing period.

N, P and K content in the coniferous species was significantly lower as compared to the one in the leaves of the deciduous species, which makes the latter ones more tolerant to soil fertility.

Of conifers, the lowest concentration of these elements was recorded in the needles of the Atlas cedar. In deciduous species the highest content was measured in *Tilia tomentosa* and *Quercus hartwissiana* and the lowest one – in the leaves of the Cork oak. There were also differences among the provenances within a species.

In Cedar needles, Ca and Mg concentration is 2 times higher, compared to that one in the needles of Black pine and *Pinus nigra* Arn. spp. *laricio*. It is obviously a characteristic biological particularity.

The differences should be considered when modelling nutrient circulation in forest stands and when evaluating the long-term sustainability of forest management.

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# VARIATION OF THE ACID-BASE PROPERTIES OF FOREST SOIL AND LITTER UNDER DIFFERENT TREE SPECIES AFFECTED BY FOREST FIRES IN SOUTH-EASTERN BULGARIA

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## Abstract

Acid-base properties in cinnamonic forest soils (Chromic Luvisols) and forest litter under different fire-affected stands of tree species have been studied. The samples were taken immediately after fire, 1 month, 3 months and 1 year after it from affected and from unaffected (control) areas. The depth at which soil sampling was performed was from 0 cm to 5 cm and from 5 cm to 20 cm. Soil and litter acidity (pH) was measured potentiometrically in an aqueous extract. The most pronounced changes in pH values in comparison with the control variants was established in soil samples, taken from influenced by a surface fire broadleaf stand of *Quercus pubescens* Willd. The pH changes in the samples from forest litter were more pronounced than the changes registered in soil samples. A trend of a soil acidity increase was established till one year after fire influence for Austrian pine plantations and oak stands.

**Key words:** cinnamonic forest soil, forest litter, soil acidity, *Pinus nigra* Arn., *Pinus sylvestris* L., *Quercus pubescens* Willd.

## Introduction

Fire is a dynamic process that influences composition, structure, and patterns of a vegetation community and soil (Boerner 1982). Soil properties could be influenced by short-term, long-term or permanent fire-induced changes, depending primarily on types, severity and frequency of fires, and post-fire climatic conditions. Fire could cause alterations of soil biogeochemical cycles, destroying/burning soil organic matter that increased soil pH for short duration, and change availability of nutrients in soil (Prieto-Fernandez et al. 1993, González-Pérez et al. 2004, Neill et al. 2007, Nguyen 2011).

Soil pH is one of the most important index, influencing directly and indirectly availability of soil nutrients (DeBano et al. 1998, Úbeda et al. 2005). According to Pritchett and Fisher (1987) the magnitude and duration of soil pH changes depends on the amount of ash formed, and also on the soil texture and pre-fire content of soil organic matter. Nutrient cations – Ca, Mg, and K, released by combustion of organic matter tend to move downward into the soil's profile, and result in elevation of sub-surface soil pH (Dikici and Yilmax 2006, Murphy et al. 2006). In many studies was found that the soil pH increases immediately after forest fire (Kutiel and Shaviv 1990, Velizarova et al. 2001, Velizarova et al. 2002, Boerner et al. 2009, Tufekcioglu et al. 2010, Aref et al. 2011, Bogdanov 2013, Pereira et al. 2014). The results of pH changes in fire influenced soils under Austrian pine plantations show that its increasing depends on fire intensity (Velizarova et al. 2010). According to Kutiel and Naveh (1987) the pH values showed significant increase immediately after the fire and then decreased rapidly to the levels of unburned soil. This trend is presumably due to the increase of soluble cations from the formed ash (DeBano et al. 1977). Khanna et al. (1994) assessed that capacity of ash to neutralize soil acidity was well correlated with sum of concentrations of K, Ca, and Mg in ash itself. Forest fires lead to quick increase in soil pH, resulting from combustions of soil organic matter (SOM) and plant residues, and denaturation of organic acids in soils. The numerous authors suppose that increment of pH only occurs when temperature during fire is greater than 450° and organic matter is absolutely burned, and ash is formed (Macadam 1987, Arocena and Opio 2003, Qian et al. 2009). Kutiel et al. (1990) found that soil pH decreased to pre-fire conditions eight months after a low intensity fire in a pine forest in Israel, while following a high intensity fire was found that soil pH values remained significantly higher in burned plots for at least two years (Litton and Santelices 2003). Higher soil acidity (lower pH values) in fire influenced soil in comparison with not affected was established five years after fire occurrence in deciduous forests (Ilinkin et al. 2013). Increasing of the soluble forms of calcium, magnesium, potassium and sodium are the reason for soil acidity decrease immediately after forest fire (Bogdanov 2014). Ulery et al. (1993) found that the topsoil pH could increase as much as 3 units immediately after fire. This rise was essentially due to formation of K and Na oxides, hydroxides, and carbonates in result of fire. In contrast, the fire-induced changes of soil pH are negligible in calcareous soils which have a high buffer capacity (Motavalli et al. 1995). All reviewed data show that the impact of forest fire on soil and forest litter pH depends on tree species composition, type and intensity of fire, buffer capacity of soils and require detail studies for separate area, affected by forest fire.

The purpose of the study was to establish the time-dependence changes in pH of cinnamonic forest soils (Chromic Luvisols) and forest litter under different tree species form South-eastern part of Bulgaria.

## Material and Methods

The sampling was performed in Cinnamonic forest soils – Chromic Luvisols (LVha) (WRBSR 2014) impacted by crown and surface forest fires occurred in summer 2013 in South-eastern part of Bulgaria (Fig. 1).

Object 1 was representative for crown and surface fire affected area in Mineralni bani Municipality region. The main tree species is Austrian pine (*Pinus nigra* Arn.) plantation assigned as ’*PN*‘ impacted by crown and surface fire occurred in August 2013. Soil samples were collected in three replications from fire-influenced soil, assigned as C1, C2, C3 (crown fire) and from undisturbed soil – U1, U2 and U3 (control variants) (Fig. 1, Table 1).

Within Svilengrad Municipality region two objects have been established. The studied area is located in southern part of Sakar Mountain referring to Southern edge of border of forest vegetation region (Zahariev et al. 1979). In Object 2 the mixed coppice stand with dominant tree species Downy oak (*Quercus pubescens* Willd.) assigned as follows – S1, S2, S3 was affected by surface fire. In Object 3, the main tree species, affected by surface fire in August 2013 was Scots pine plantation (*Pinus sylvestris* L.) – '*PS*'. Sampling plots were assigned as S4, S5 and S6 respectively. Close to the affected area undisturbed sites for control plots were established – U4, U5, U6, U7, U8 and U9 (Table 1).

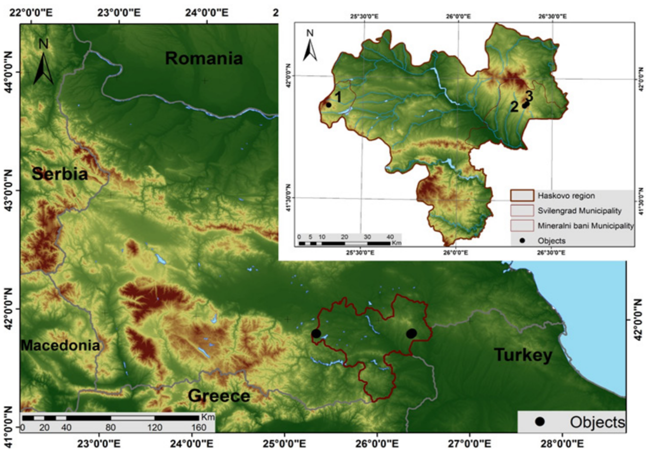


**Fig. 1. Location of the studied area: Object 1 – Mineralni bani Municipality region; Object 2 and Object 3 – Svilengrad Municipality region.**

**Table 1. Study area characteristics.**

| Studied objects | Variants | Fire type | Dominant tree species | Altitude, m | Stand age | Area, ha | Geographic coordinates |
|---|---|---|---|---|---|---|---|
| | | | Mineralni bani Municipality | | | | |
| | C1 | | | | | | 41°52'54.9" N 25°19'8.1" E |
| | C2 | Crown and surface fire | | | | | 41°52'55.5" N 25°19'9.6" E |
| 1 | C3 | | *Pinus nigra* (*PN*) | 473 | 40 | 7.0 | 41°52'55.3" N 25°19'9.9" E |
| | U1 | | | | | | 41°52'57.6" N 25°19'5.9" E |
| | U2 | Undisturbed | | | | | 41°52'57.3" N 25°19'5.8" E |
| | U3 | | | | | | 41°52'57.5" N 25°19'5.9" E |
| | | | Svilengrad Municipality | | | | |
| | S1 | | | | | | 41°53'18.9"N 26°21'15.1"E |
| | S2 | Surface fire | | | 50 | 5.8 | 41°53'18.7"N 26°21'15.1"E |
| 2 | S3 | | *Quercus pubescens* (*Q*) | 462 | | | 41°53'18.9"N 26°21'15.5"E |
| | U4 | | | | | | 41°53'18.9"N 26°21'14.2"E |
| | U5 | Undisturbed | | | 35 | 6.7 | 41°53'19.2"N 26°21'13.9"E |
| | U6 | | | | | | 41°53'18.7"N 26°21'13.6"E |
| | S4 | | | | | | 41°53'50.8"N 26°22'4.2"E |
| | S5 | Surface fire | | 378 | | | 41°53'50.6"N 26°22'4.3"E |
| | S6 | | | | | | 41°53'50.6"N 26°22'4.0"E |
| 3 | U7 | | *Pinus sylvestris* (*PS*) | | 45 | 1.2 | 41°53'51.5"N 26°22'4.4"E |
| | U8 | Undisturbed | | 377 | | | 41°53'51.3"N 26°22'4.7"E |
| | U9 | | | | | | 41°53'51.6"N 26°22'5.1"E |

The changes in soil pH were studied in dynamic. For this purpose, the sampling was performed immediately after fire, 1 month, 3 months and one year after fire marked as I, II, III and IV (sampling) respectively. The soil samples for analysis were taken in 3 replications from a depth: 0–5 cm and 5–20 cm. Sampling was performed from forest litter at each variant for soil sampling. Forest litter samples were collected using sampling frame with size 25 × 25 cm. Forest litter samples were analysed for pH, using a 1:2 ratio (mass forest litter /volume $H_2O$) solution. Soil pH was determined in suspension soil to water in ratio 1:5. Measurement was performed potentiometrically by pH meter (HANNA HI 2211).

## Results and Discussion

In Fig. 2, the results of pH values of forest litter from different tree species, affected by forest fire in studied periods are presented.

A considerable increase of pH in forest litter, collected from *PN* plantation affected by fire was observed, as the highest value 7.9 was recorded for the period immediately after the fire occurrence. During next three periods of investigation a decrease of pH was observed (Fig. 2). The similar trend was observed for two other tree species affected by forest fire in Object 2 and Object 3. However the most pronounced changes of pH between control variants and fire affected forest litter were observed for *PN* and *PS*, which is most probably in result of the organic acids denaturation (Certini 2005) and due to increase of soluble cations from the formed ash (DeBano et al. 1977).

Parzych and Sobisz (2012) established that in the needles of *Pinus nigra* a notably higher accumulation of P, K, Ca, Mg and Mn was observed than that in the needles of *Pinus sylvestris* which could be the reason for higher differences in pH of *PN* forest litter between control and fire affected samples. Less increase in pH values for all studied periods in the forest litter under coppice oak stand (*Q*) influenced by surface fire was found as results of investigations. The highest values were recorded in the period immediately after the fire – pH = 8.2.

The trend in pH changes through the next studied periods was slightly downward (Fig. 2, Object 2). The results of forest litter pH from the *PS* sampling sites show the highest values of the pH – 8.3 immediately after fire occurrence. The difference in pH of the fire affected forest litter and control one is the highest immediately after forest fire and decreased to values from the control sampling sites one year after forest fire. The pH increment is with about 3 units, while in ash formed as a result of the fire affected oak litter, it is with about 1.5 units. Pereira et al. (2011) also found higher pH in ash of conifers species in comparison with broadleaf (oak) species and explain the increasing of pH in ash with formation of more $CaCO_3$. Similar results were obtained by Pereira et al. (2014) and Blank and Zamudio (1998), who found that pH values were higher in ash extracted from fire affected forest litter under *Pinus pinaster* Ait. and *Salix scouleriana* Barratt ex Hook. respectively than from unburned one. Our results for time-relation changes of pH in forest litter after fire are in agreement with that established by Smith (1969) who found that the pH values of fire influenced L-H sub-horizons remained higher than ones of uninfluenced litter for a year after the fire occurrence. One year after fire, due to the felling of Austrian pine forest stands no ash on the surface of mineral soil was found (Fig. 2, Object 1).

Additionally, the newly formed needle fall was found just before the second period of sampling, which could also provoke slightly underestimation of forest litter pH (Fig. 2, Object 3). In Fig. 3 the results of pH values in both soil layers are presented. Soil pH in layer from 0 to 5 cm under *PN* affected by surface and crown fire show negligible changes in comparison with control variants during all studied periods (Fig. 3).

However slightly increased pH could be mentioned at the end of the period – about one year after forest fire. The combustion of forest litter, in result of which sum of concentrations of K, Ca, and Mg in ash itself increase reduced fire intensity and heat transfer to the mineral soil.

On the other hand, the dissolution of this ash and subsequent effects upon surface soil chemistry depends, to a great extent, on the nutrient status of the soil prior to fire and the mass of ash-derived nutrients that are added as a consequence of fire (Boerner 1982). Similar trend was observed for Chromic Luvisols under *PN* plantations, affected by surface and crown fire 20 months after it (Velizarova et al. 2011). In studies of Glogov and Bogdanov (2003) and Bogdanov (2013) in Chromic Luvisols under coniferous forests affected by surface and crown fire also observed increasing of pH values one year after it.

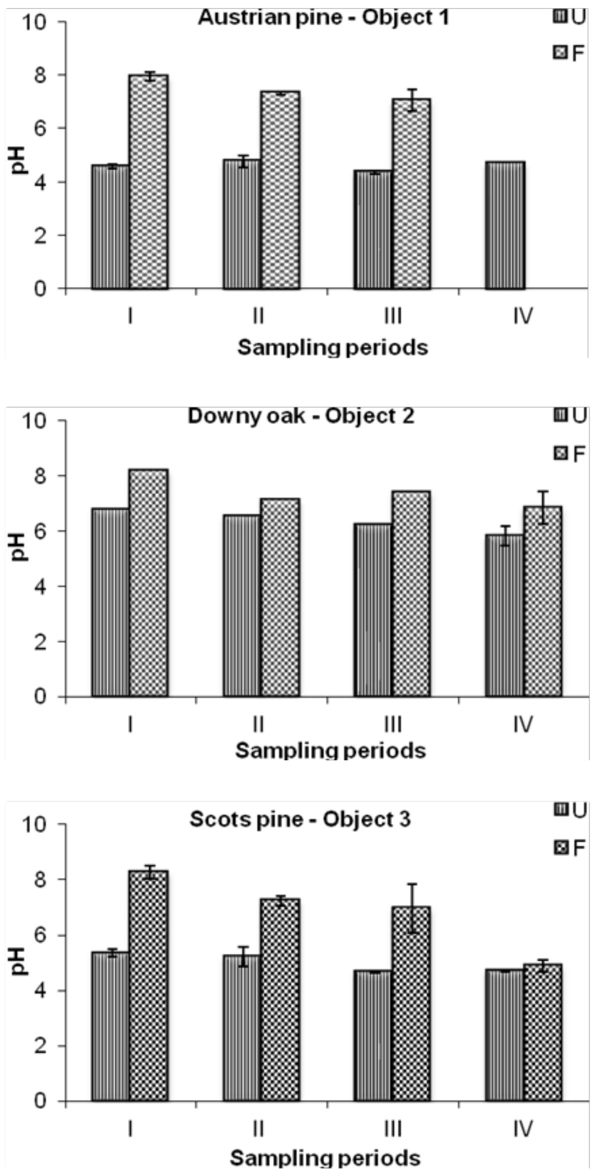


**Fig. 2. Time-related changes of pH (mean ±SD) in the forest litter under Austrian pine plantation – Object 1, Downy oak stand – Object 2 and Scots pine plantation – Object 3.**

Note: U – unburned sampling sites; F – fire affected sampling sites.

Soil pH in variant with *PS* plantation affected by surface fire, was changed

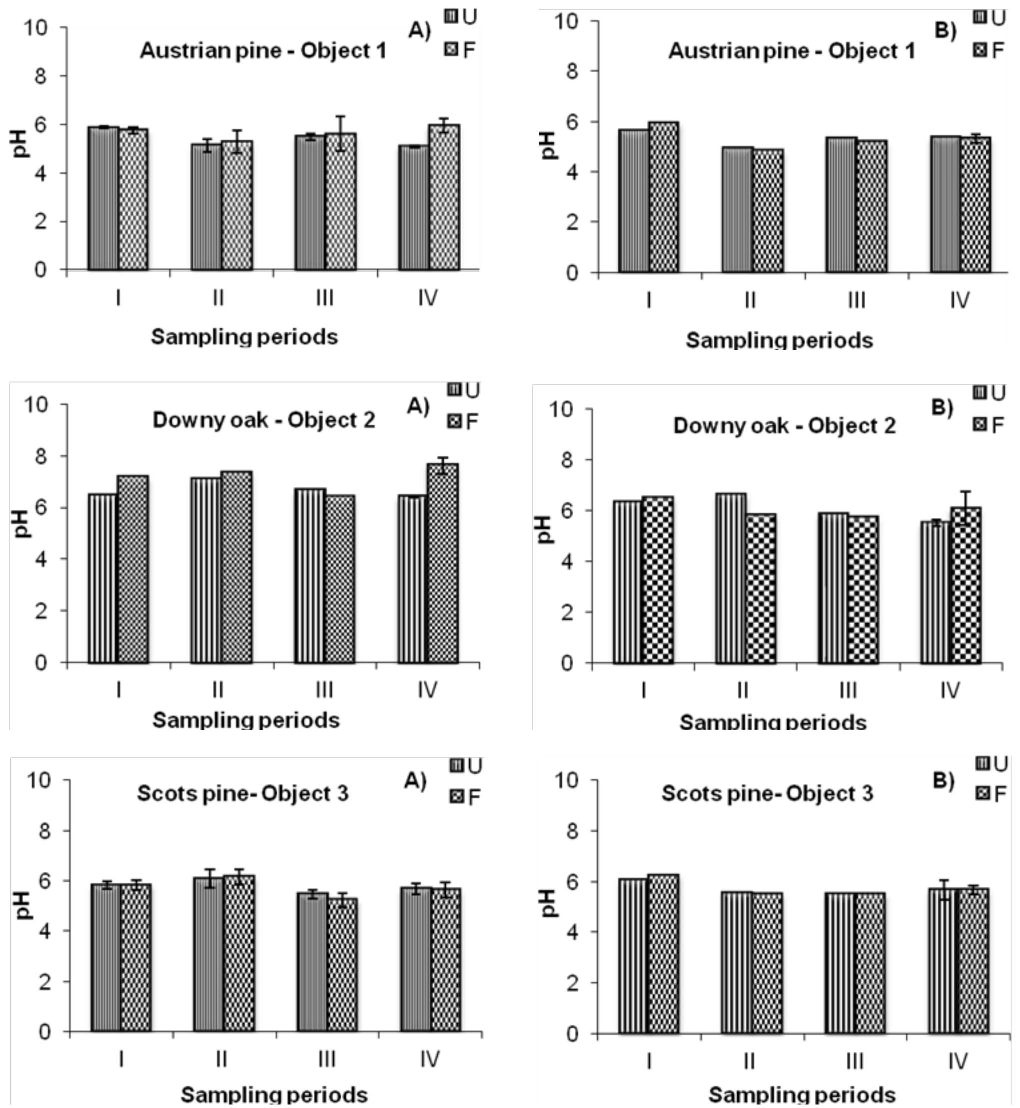


**Fig. 3. Time-related changes of soil pH (mean ±SD) under *P. nigra* plantation – Object 1, *Q. pubescens* stand – Object 2 and *P. sylvestris* plantation – Object 3.**
Note: A) 0–5 cm soil layer; B) 5–20 cm soil layer, U – unburned sampling sites, F – fire affected sampling sites.

negligibly for both layers for all studied periods. The increase in soil pH, however, is usually temporarily and depends on the initial soil pH, amount of ash released, chemical composition of the ash, and wetness of the climate (Wells et al. 1979). Also, the fire has different effect on soil pH depending on a reached temperature. The decrease in soil pH at lower temperature was established as well as increasing of soil pH at the higher temperature (Fernandez et al. 1997).

The increasing of pH in soil a year after fire in variants *Q* and *PN* is presumably due to leaching of soluble components from surface mineral soil layer to soil depths (Grier 1975). The same increasing of the pH values in cinnamonic forest soils under Austrian pine plantation a year after forest fire occurrence was also established (Bogdanov 2013). Tryon (1948) found that the hardwood ash is more effective in increasing of pH values of the soil than the conifer ash. Our results show that soil pH increases more pronouncedly in the surface 0–5 cm of soil affected by fire under oak stand. If we take into account the statement that magnitude and duration of pH changes in mineral soil depends on the amount of ash formed due to forest litter burning, the relatively high pH values in forest litter (formed ash) after fire occurrence could be the reason for this results (Tryon 1948). Knighton (1977) studied the burning effects on an oak-hickory forest and found that the availability of Ca and Mg were considerably higher in the soil solution from the burned sites than the control, but with no indication of a cumulative effect over time. Soil pH in the layer of 0 to 5 cm in the variant of oak stand affected by fire is increased immediately after it. The soil pH under oak stand changed negligibly in result of fire influence in the next two periods, but at the end of the studied period increase in comparison with control variants is mentioned (Fig. 3, Object 2).

The data for pH of soil layer from 5 to 20 cm also are presented in Fig. 3 (B). Our results show that changes were negligible in all studied variants, except in case of the stands of oak, influenced by forest fire (Object 2). The difference between pH of fire influenced soil for all studied periods in surface soil layer of oak stand (Object 2) is higher in comparison with pH of surface soil layer under *PS* and *PN*. This affect is long-term, as high pH values were kept during all studied period (Fig. 3, Fig. 4). According to the results obtained by Ulery et al. (1993), Henig-Sever et al. (2001) and

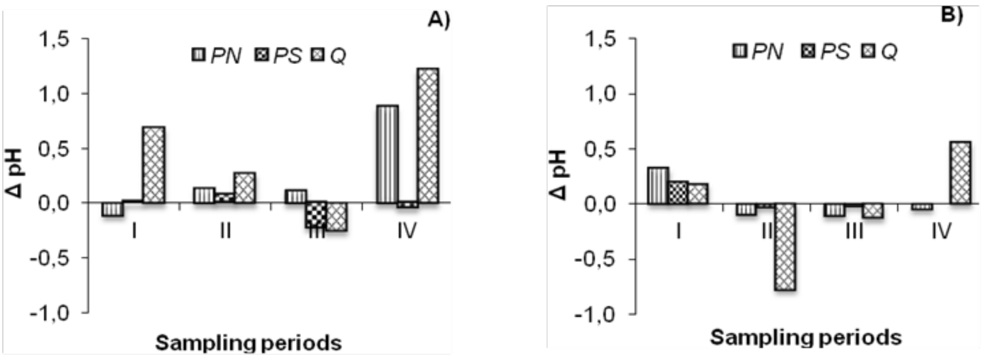


**Fig. 4. Time-related soil pH differences (Δ pH) in soil layers: A) from 0 to 5 cm; B) from 5 to 20 cm of studied variants and time periods.**

Note: *PN* – *Pinus nigra*; *PS* – *Pinus sylvestris* and *Q* – *Quercus pubescens*.

**Fig. 5. Studied sampling sites immediately after fire occurrence:**
**A) Object 1 – *P. nigra* plantation, influenced by crown and surface fire, the forest litter after fire is black coloured;**
**B) Object 2 – *Q. pubescens* stand, influenced by surface fire, the forest litter after fire is grey-white coloured;**
**C) Object 3 – *P. sylvestris* plantation, influenced by surface fire, the forest litter after fire is black coloured.**

Goforth et al. (2005) the pH values of the ash, sampled after forest fire increased with fire severity increase. Neary et al. (1999) and Dūdaitė et al. (2011) found that during high intensity fires (~500ºC) a light grey or white ash is produced, composed mainly of alkaline (Ca, K, Mg). The elements such as Ca, K, Mg were the most abundant in white ashes, produced from combusted leaf litter (Goforth et al. 2005) which over time, could increase pH of the soil. Most probably, the newly formed light-grey coloured ash layer, on the soil surface under downy oak stand, is the reason for more sizable changes of the soil pH values than in *PN* and in *PS* plantations. At the end of the studied period $\Delta$ pH = 1.22 in the 0–5 cm soil layer (Fig. 4, A). Only in the variant with *PS* significant changes in soil pH have not been registered as immediately after fire and one year after. Similar results were obtained by Velizarova and Tashev (2008) studied changes in soil pH one year after fire influenced mixed plantations of *Pinus sylvestris* and *Pinus nigra*.

## Conclusions

The values of pH increased significantly in fire affected forest litter of *Pinus nigra*, *Quercus pubescens* and *Pinus sylvestris* immediately after forest fire occurrence. In long-term scale – one year after fire these values are still higher than control variants.

The results for soil pH changes showed more pronounced increases in the surface 0–5 cm of soil affected by surface fire under oak stand. This trend was kept for the layer below. Slightly increase in soil pH was observed at the first year of observations.

During all studied periods, the results show negligible changes in soils affected by surface and crown fires under *Pinus nigra* in both layers compared to control variants. At the end of the period, the pH increase of fire-influenced soil in the surface 0–5 cm soil layer was observed.

Soil pH changes for both soil layers in variant with *Pinus sylvestris* plantation are negligible for all researched periods.

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# HEIGHT STRUCTURE OF SCOTS PINE STANDS

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## Abstract

The present study has been carried out to reveal the structure according to height of relatively even-aged - mature and middle-aged Scots pine dendrocoenoses in Rila and the Rhodopes Mountains and Sakar Mountain. A total of 111 sample plots have been established, 68 of these being in mature, natural Scots pine forests and 43 in young and middle-aged ones. Study has been aimed at analysing the structure according to height of natural Scots pine dendrocoenoses with a view to model their volume and their assortment structure. The height curves for both age groups of stands have been investigated. Yurdan Douhovnikov's method of natural indicators (MNIs) has been applied. Three groups of curves have been found out according to their levels of declivity, namely: slightly inclined curves, characteristic of the stands of zero natural indicator (ZNI) $SH_0 \geq 1.1$, semi-steep curves with $0.86 \leq SH_0 \leq 1.09$, and steep curves with $SH_0 \leq 0.85$. The distribution according to types of declivity has been investigated in two scenarios – separately and as a whole. This investigation has resulted in finding distributions of close values in both scenarios for the particular age groups, especially the general distribution. That gives reasons for investigating the stands as a whole in terms of their height structure through the method of natural indicators regardless of age. It was found that the average relative curves of the heights (or average curves of normal numbers) surveyed dendrocoenoses of Scots pine and United average curve of the relative heights of Turin are too close on his course. Since an average curve of Turin has been established for all species, this proximity proves the possibility of establishing common average diluted curves of the heights of Scots pine along with other tree species.

**Key words:** construction height, declivity of curves, natural indicators, Scots pine dendrocoenoses.

## Introduction

It is important to permanently perfect the main standards and references pertaining to forests, as well as the models and tables of assessing the timber volume and the respective assortments. This is why increasing and improving the knowledge of the regularities in the growth and structures of forest dendrocoenoses (stands) remains an important scientific task.

Scots pine stands occupy a comparatively large area of the forests in Bulgaria. They comprise 51.7 % of the coniferous forests and are among the most highly productive lasting natural stands. These forests are important both for harvesting timber and for recreation, health care and amenity because they thrive under the conditions of mountains and hills. Scots pine laterally products, such as resin and lightwood, are valuable raw materials for colophony, turpentine and other products necessary for a number of industrial branches.

A number of authors have carried out studies of the structures of forest stands (Tyurin 1938; Tretyakov 1927, 1952; Sirakov 1947; Nedyalkov 1964, 1967; Dimitrov 1978, 2003; Mihov 1991; Mihov et al. 1993; Mihov 2005; Tonchev 2007). The most important inferences the above and other authors have made from their studies of stand structure according to height are as follows:

Tretyakov (1927) established that forest structure always has a constant nature, regardless of the relative stocking, age, tree species and growth conditions, even though these might pertain as to normal stands so to complex mixed ones. Thus he formulated the Law about the Unity of Stand Structure.

Tyurin (1938) found out that the height curves for homogenous, pure, even-aged growing stocks resembled one another in their forms and were not influenced by tree species and site conditions; only age and economic activity were found to have some influence. This gave him the reason for calculating an average general curve of relative heights for all tree species.

Dimitrov (2003) has pointed out that the relative heights, alias reduction numbers, in Tyurin's general curve of relative heights need to be specified.

Mihov (2005) shows the necessity of equalising the height curves by means of a parabola equation while using a polynomial function of some degree, or a logarithmic function. This equalisation has successfully been applied into the present study.

Tonchev (2007) comparing the average curve of relative heights for coppice Common beech growing stocks with Tyurin's average general curve has found differences indicative for a specificity proceeding from the tree species and the origin of dendrocoenoses.

We have carried out research concerning the structure in height of natural beech dendrocenosis (Petrin et al. 2014). With the usage of natural points method the steepness of the heights' curves was found out that the dendrocenosis built height does not depend on age and it is possible to create common curves of heights for more than one tree species.

The studies of the above and other authors have been used as a methodical background for our studies.

### Aim of Study

The aim of study is to analyze the height structure of the natural Scots pine dendrocoenoses depending on their age. To carry out a comparison between the mean curves of the normal numbers concerning the height structure of Scots pine which occur, the mean curves of the normal numbers with the Unified Mean Curve were found for all tree species of Tyurin (1938).

## Objects and Methods

### Objects

The present investigation pertains to natural Scots pine stands in Rila Mountains (the regions of Samokov, Belovo and Yundola), the Rhodopes Mountains (the regions of Satovcha, Devin, Velingrad and Ardino) and Sakar Mountain (the region of Svilengrad). A total of 111 sample plots (SP) have been laid out, 68 of these being in mature and 43 in young or middle-aged natural Scots pine forests.

## Methods

The main method assumed for this investigation is the one that uses natural indicators – Method of natural indicators (MNIs), invented by Yurdan Douhovnikov (1966). It enables to judge about the curve's form by only one number – the zero natural indicator ($SH_0$) of the structure according to height. For each sample plot, the natural levels of thickness (NLT) have been calculated after Tyurin (1938) by dividing the absolute levels of thickness by the average diameter and are received relatively not round degrees of thickness or relative diameters for example: 0.56; 0.67; 0.76; … 1.43. The curves of the heights are further equalised graphically and for round relative degrees of thickness, called Natural degrees of thickness, and are registered the absolute heights by choosing the real interval of research of the curve – in our research it is from 0.6 to 1.4.

The absolute values of the heights are converted into relative heights through the division by height of natural degree of thickness 1.4 which is adopted for final right. The curves of the relative heights in this type are called, in the method used, normal numbers or quality points. From the curves of the normal numbers is calculated the mean curve of the normal numbers ($qx_{av}$) for separate accumulations of curves depending on the age. Further each and every curve of the normal numbers ($qx_i$) is divided into the mean ($qx_{av}$) and the natural numbers straight lines are obtained $y = a{\cdot}x+b$. Their coefficients are calculated by the methods of the smallest squares through composition and solution of a system of two equations with two unknown values and those coefficients are namely Natural points the angle *a* and the zero *b*. Between both coefficients from their side there exists a direct connection which could be found out eventually. But for the aims of our study is used only the zero natural point – the coefficient *b* which is written as $SH_{0,n}$, where *S* is build (structure), *H* is height to point zero (0) and natural (n).

We have distributed the zero natural indicators (ZNIs) of the structure according to height ($SH_0$) on the basis of their values into three groups, namely: $SH_0 \leq 0.85$, $0.86 \leq SH_0 \leq 1.09$, and $SH_0 \geq 1.1$. Then, the influence of age upon the distribution according to types of declivity of the investigated height curves has been studied. The investigated Scots pine stands have been distributed according to types of declivity on the basis of the zero natural indicators values. This has been done separately for the mature, on the one hand, and the middle-aged or young dendrocoenoses, on the other, as well as totally, when they have all been considered as an aggregate. For this purpose, we obtained the average curves of the quality indicators ($qx_{av}$) separately – first, for the mature, and, second, for the young or middle-aged stands. In addition, an average general curve was calculated, regardless of age.

## Results and Discussion

### Types of structure according to height depending on the slope (declivity) of height curves

Height-curves' forms have been investigated by means of the characteristic called curve's declivity towards the abscissa. The less acute the angle of the slope is, the steeper the curve is, and here we have introduced the notion declivity of curve (curve's declivity).

Curves' declivity reveals the difference in the heights for two or more levels of thickness, and the steeper these curves are, the bigger this difference is. The steeper curve suggests higher increment in height and vice versa – lower increments correspond with less inclined curves.

The steeper curve talks about a higher mean height increase on average height between two degrees of thickness in the frame of dendrocoenoses or height increase and the opposite the more slant curves less increase. Therefore, in equal conditions in the bigger supply of dendrocoenoses in this case moves towards the thicker and the taller trees and more good quality sorts. Such dendrocoenoses give better supplies and a better quality sorts.

**Table 1. Values of zero natural indicators ($SH_0$) of the structure according to height for Scots pine stands according to sample plots, depending on the average curve (separate or general) of the quality indicators, and according to age groups.**

| No | Separate | Ge-neral | No | Separate | General | No | Separate | General | No | Separate | General | No | Separate | General | No | Separate | General |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mature stands | | | | | | | | | | | | | | | | | |
| 1 | 1.26 | 1.31 | 13 | 0.87 | 0.91 | 25 | 1.38 | 1.44 | 37 | 0.84 | 0.88 | 49 | 1.09 | 1.14 | 61 | 1.24 | 1.29 |
| 2 | 1.31 | 1.37 | 14 | 0.98 | 1.03 | 26 | 1.63 | 1.69 | 38 | 0.80 | 0.84 | 50 | 1.08 | 1.13 | 62 | 1.07 | 1.12 |
| 3 | 0.97 | 1.02 | 15 | 2.15 | 2.22 | 27 | 1.15 | 1.20 | 39 | 0.79 | 0.83 | 51 | 1.01 | 1.05 | 63 | 0.82 | 0.87 |
| 4 | 1.24 | 1.29 | 16 | 1.09 | 1.14 | 28 | 0.79 | 0.83 | 40 | 0.84 | 0.88 | 52 | 0.89 | 0.93 | 64 | 1.00 | 1.05 |
| 5 | 1.11 | 1.16 | 17 | 0.95 | 1.00 | 29 | 0.8 | 0.84 | 41 | 0.78 | 0.83 | 53 | 0.96 | 1.01 | 65 | 0.92 | 0.96 |
| 6 | 0.99 | 1.03 | 18 | 1.08 | 1.13 | 30 | 0.71 | 0.75 | 42 | 0.78 | 0.82 | 54 | 1.08 | 1.13 | 66 | 0.79 | 0.83 |
| 7 | 1.10 | 1.15 | 19 | 1.24 | 1.29 | 31 | 0.80 | 0.84 | 43 | 0.84 | 0.88 | 55 | 1.11 | 1.16 | 67 | 0.85 | 0.89 |
| 8 | 1.10 | 1.15 | 20 | 1.24 | 1.29 | 32 | 0.81 | 0.85 | 44 | 0.82 | 0.86 | 56 | 0.84 | 0.88 | 68 | 0.90 | 0.95 |
| 9 | 1.02 | 1.06 | 21 | 1.18 | 1.23 | 33 | 0.82 | 0.86 | 45 | 0.88 | 0.93 | 57 | 0.83 | 0.88 | | | |
| 10 | 1.31 | 1.36 | 22 | 0.95 | 0.99 | 34 | 0.86 | 0.90 | 46 | 0.78 | 0.82 | 58 | 0.86 | 0.90 | | | |
| 11 | 0.88 | 0.93 | 23 | 1.39 | 1.44 | 35 | 0.81 | 0.85 | 47 | 0.92 | 0.97 | 59 | 0.94 | 0.99 | | | |
| 12 | 1.14 | 1.19 | 24 | 0.88 | 0.92 | 36 | 0.82 | 0.86 | 48 | 1.03 | 1.07 | 60 | 0.88 | 0.92 | | | |
| Middle-aged and young stands | | | | | | | | | | | | | | | | | |
| 1 | 1.01 | 0.96 | 9 | 0.72 | 0.68 | 17 | 0.75 | 0.71 | 25 | 1.21 | 1.15 | 33 | 0.9 | 0.85 | 41 | 0.93 | 0.88 |
| 2 | 2.05 | 1.98 | 10 | 1.02 | 0.97 | 18 | 0.41 | 0.37 | 26 | 0.89 | 0.84 | 34 | 0.86 | 0.81 | 42 | 1.12 | 1.07 |
| 3 | 0.97 | 0.92 | 11 | 0.72 | 0.68 | 19 | 0.48 | 0.45 | 27 | 0.74 | 0.7 | 35 | 0.93 | 0.88 | 43 | 0.7 | 0.66 |
| 4 | 1.52 | 1.46 | 12 | 1.07 | 1.02 | 20 | 0.56 | 0.52 | 28 | 1.12 | 1.07 | 36 | 0.97 | 0.93 | | | |
| 5 | 1.16 | 1.11 | 13 | 0.79 | 0.75 | 21 | 0.47 | 0.44 | 29 | 2.26 | 2.18 | 37 | 0.86 | 0.82 | | | |
| 6 | 1.13 | 1.08 | 14 | 1.18 | 1.12 | 22 | 0.51 | 0.47 | 30 | 1.11 | 1.06 | 38 | 0.81 | 0.77 | | | |
| 7 | 1.02 | 0.98 | 15 | 1.48 | 1.42 | 23 | 1.8 | 1.73 | 31 | 1.11 | 1.05 | 39 | 0.94 | 0.89 | | | |
| 8 | 0.95 | 90 | 16 | 0.87 | 0.83 | 24 | 1 | 0.96 | 32 | 0.95 | 0.91 | 40 | 0.96 | 0.91 | | | |

The above method has enabled us to find for the sample plots investigated the zero natural indicators used for characterising the height-structure curves (or height curves) of natural Scots pine dendrocoenoses, and these have been presented in Table 1.

As it is seen from Table 1, the values of zero natural indicators vary for the whole aggregate, regardless of age groups, within the range from 0.37 to 2.26. It was found the precise correspondence of the natural indicators' values with the declivities of height curves, namely: low natural indicators correspond with steep curves, and high indicators – with curves. According to the differentiated ranges, there are three types of height curves – steep, semi-steep and slightly inclined. These three types of curves and their corresponding values of zero natural indicators ($SH_0$) can be seen in Fig. 1.

Fig. 1 reveals that low values of $SH_0$ correspond with a steep curve, the high ones – with a slightly inclined one, and the natural indicators, whose values are about 1, with a semi-steep curve. The steeper the curve is, the higher the difference between two levels of thickness, or height increment between two degrees of thickness is. Therefore, stands of steeper height-structure curves are supposed to have higher volumes of timber and better assortment structures. This inference coincides with the better interpretation of the thickness-structure curves, as these curves correspond with the low values of zero natural indicators of thickness structure ($SN_0$), which have a right-hand-side asymmetry and are also supposed to have higher volumes (Petrin et al. 2013).

Based on the above-differentiated ranges for different types of height curves, according to their declivity, their distributions have been obtained with both scenarios of investigation – separately and generally, and these are presented in Table 1.

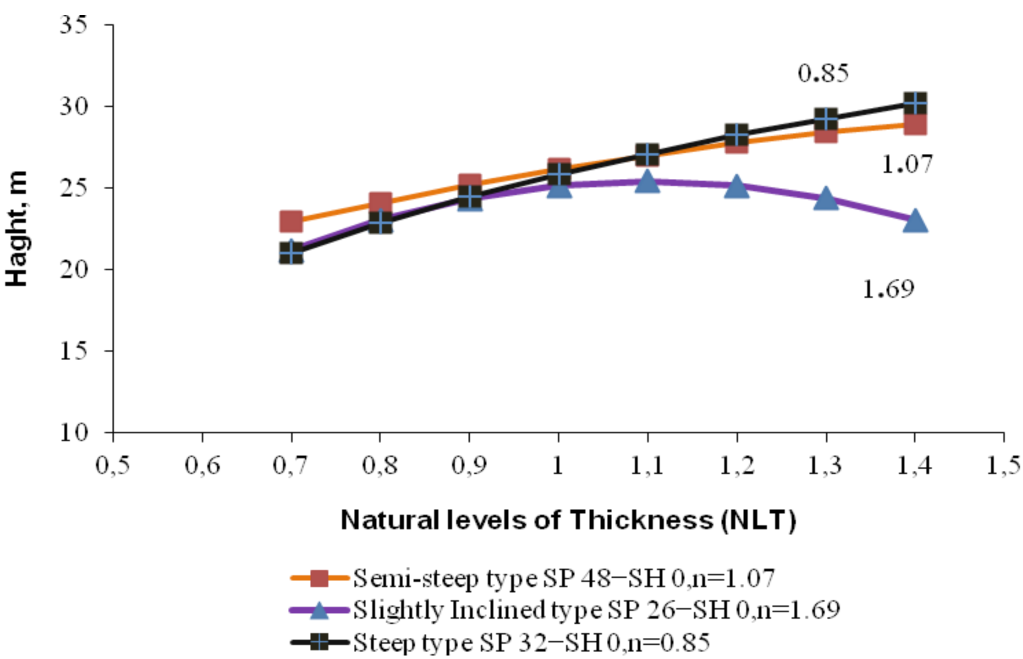


**Fig. 1. Three types of height-structure curves depending on natural indicators $SH_0$.**

**Table 2. Distribution of sample plots according to height curves declivity for different aggregates with both scenarios of investigation.**

| Curves' declivity | Investigating separately | | Total sample plots, number | Share of sample plots, % | Investigating generally | | Total sample plots, number | Share of sample plots, % |
|---|---|---|---|---|---|---|---|---|
| | Mature, number | Middle-aged or young, number | | | Mature, number | Middle-aged or young, number | | |
| Slightly inclined | 19 | 13 | 32 | 28.8 | 23 | 8 | 31 | 27.9 |
| Semi-steep | 27 | 18 | 45 | 40.5 | 33 | 18 | 51 | 45.9 |
| Steep | 22 | 12 | 34 | 30.6 | 12 | 17 | 29 | 26.1 |
| Total | 68 | 43 | 111 | 100 | 68 | 43 | 111 | 100 |

In Table 2 one can see that for both age groups (mature, middle-aged or young), with the two kinds of investigation – in separate aggregates and in only one – almost one and the same distribution of the sample plots according to type of declivity is observed. In both scenarios semi-steep curves prevail. And after that, steep curves prevail with mature, separately investigated stands, and slightly inclined curves prevail with the stands considered as a whole. With young or middle-aged stands, when considered as a whole, steep curves prevail. The smaller number of sample plots under mature dendrocoenoses with steep curves, when they are investigated as a whole, together with the young or middle-aged ones, suggests a certain reduction of their timber volumes, which is explicable. It is just the opposite with the young or middle-aged ones – the prevalence of steep sample plots, when the stands are considered as a whole, reveals a certain increase in the volumes with a possible general model. These differences compensate one another with the distribution as a whole in both cases, and it is characterised by apparent prevalence of the semi-steep type and with the even distribution of steep and semi-steep curves. If we consider the general distribution of all plots, we see that 40.5 % of the stands are on semi-steep plots, when they are considered separately, and 45.9 % when they are considered as a whole. These results reveal that it is possible to model, generally and averagely, the structure according to height for all aggregates of height curves regardless of declivity type and age, which simplifies modelling, the simplification being an advantage.

## Comparing the average relative-height curves (the curves of quality indicators) for natural Scots pine stands with Tyurin's general curve of heights

In Table 3, are presented the comparisons of our average relative-height curves (quality indicators' curves) and Tyurin's average general relative-height curve pertaining to all tree species.

**Table 3. Average curves of quality indicators as compared with Tyurin's average general curve of quality indicators.**

| Curves's belonging | Natural levels of thickness | | | | | | | | | Indicators for accuracy | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 1.3 | 1.4 | Correlation coefficient | Standard deviation | Variation coefficient | Error in aritmetic means, m |
| Mature stands | 0.75 | 0.81 | 0.85 | 0.89 | 0.93 | 0.95 | 0.97 | 0.99 | 1 | 0.995 | 0.01 | 1.36 | 0.004 |
| Middle-aged stands | 0.7 | 0.76 | 0.82 | 0.86 | 0.9 | 0.94 | 0.96 | 0.98 | 1 | 0.998 | 0.03 | 3.69 | 0.010 |
| Average general curve of quality indicators | 0.73 | 0.79 | 0.84 | 0.88 | 0.92 | 0.95 | 0.97 | 0.99 | 1 | 0.996 | 0.02 | 1.96 | 0.005 |
| Tyurin's average curve | 0.77 | 0.81 | 0.85 | 0.88 | 0.91 | 0.94 | 0.96 | 0.98 | 1 | - | - | - | - |

As it is seen from Table 3, our average curves are very close to Tyurin's one (1938), designed for all species, which also show calculated statistical indicators suggesting a greater correlation between the curves. The magnitude of the correlation indicator is very close to 1 besides, apparent is the great closeness of the particular values of the quality indicators of the particular natural levels of thickness, as and in the Fig. 2.

This inference is very important for providing the possibility of assuming an average general curve of relative heights for more than one tree species. We have concluded this same about Common beech during an analogous study of natural beech and natural Scots pine stands (Petrin 2014, Petrin et al. 2014). Height-order curves are known to provide the basis of timber-volume measurement and assortment-volume distribution. Therefore, it is possible

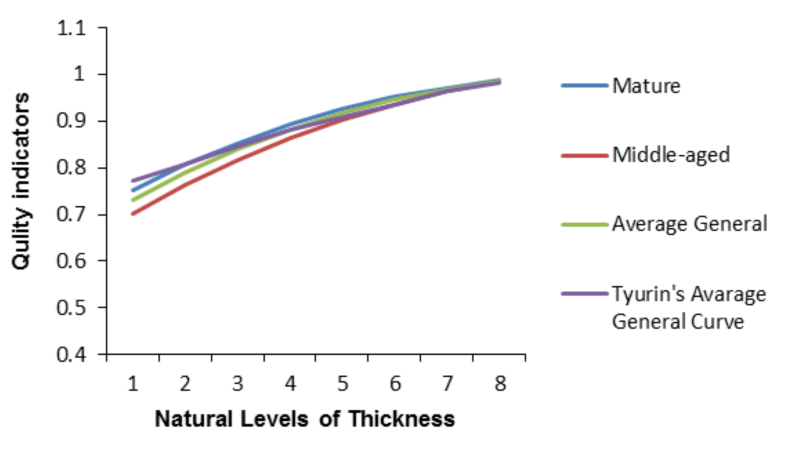


**Fig. 2. Average curves of quality indicators.**

to develop general models of the structure according to height (general height-order curves) for natural Scots pine and Common beech dendrocoenoses.

## Conclusion

The main inferences from the investigation are the following:

Three types of height-structure curves have been found while investigating the young, middle-aged and mature natural Scots pine stands: steep curves, semi-steep curves and slightly inclined curves. Steep curves are related to low values of zero natural indicators – $SN_0 \leq 0.85$, semi-steep ones – to ZNIs' average values, within the range $0.86 \leq SH_0 \leq 1.09$, and the slightly inclined ones – to the high values of ZNIs – $SH_0 \geq 1.1$.

The apparently prevailing stands are those of the semi-steep height curves, and this gives the reason for considering the height curves of the investigated stands with a view to forming these curves' general and average models.

The similar distribution of the investigated stands according to their height-structure curves' declivity, when these are considered separately according to age groups and as one general aggregate, suggests the inference that stands' structure according to height does not depend significantly on age, so the stands can be studied together.

The average relative curves of heights (or the average curves of quality indicators) and Tyurin's average general curve of relative heights are very close in their development.

The results obtained prove the possibility of creating average general height-order curves for more than one tree species, as well as of developing general models of timber volumes and their assortment structure.

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# NUTRIENTS AND HEAVY METALS CONCENTRATIONS IN NEEDLES OF *PINUS BRUTIA* TEN. IN THESSALONIKI, GREECE

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## Abstract

The present study is based on the differential concentrations of nutrients and heavy metals observed in *Pinus brutia* Ten. needles resulting from the influence of various factors, such as traffic and topographical conditions in four sites in urban and periurban areas of Thessaloniki, Greece. The results showed that there were significant differences in nutrient and heavy metal concentrations in the needles collected in the four sites. In particular, the samples from the periurban forest exhibited significantly higher concentrations of Mg and Ca than the samples collected in the sites near the centre of the city. *The s*ignificantly higher concentrations of K observed in the samples collected from two sites in the city, are possibly attributed to the fertilization of the parks. The high concentrations of Na found in the samples collected in sites of the periurban forest, are due to topographical conditions and aerial deposition. However, the highest level of Mn and Zn observed in the samples collected in the site of the periurban forest located far away from the busy ring road, is mainly attributed to soil type. High levels of Cu, Pb, Ni and Cr concentrations were found in the needles collected from the sites close to the busy traffic roads of Thessaloniki. No significant differences in the levels of Fe and Cd among the samples of the four sites were found. However, the concentrations of elements measured in *P. brutia* needles collected in the urban and periurban areas of Thessaloniki are below the normal level and as a result they do not constitute an alarming pollution agent in the city.

**Key words**: periurban forest, pollution, trace elements, traffic, urban environment.

## Introduction

Nutrients and heavy metals released from anthropogenic sources have entered the environment and have followed normal biogeochemical cycles. Although they are natural components and some are essential in plant nutrient (micronutrients), they are accumulated in the soil and air in increasing amounts, as a result of the increased urbanization and expansion of industrial activities, causing a serious risk to human health (Kabata-Pendias 1992, Voutsa et al. 1996, Baslar et al. 2005).

In this context, Thessaloniki, which is the second biggest city in Greece, was chosen for the investigation particularly with regard to airborne particles daily released from vehicular traffic (Ward et al. 2004, Oliva and Espinosa 2007, Vlacho-


**Fig. 1. Sites 1 and 2 (located near the busy traffic centre of the city), site 3 (located in the periurban forest besides the ring road) and site 4 (located in the periurban forest far away from the busy ring road).**

kostas et al. 2012). An important feature of large urban centers, such as the city of Thessaloniki, is that the intense emission of pollutants and heat are trapped within the city because of the high-density housing, resulting in changes in the balance of temperatures and increased dispersion of pollution (Namdeo et al. 1999).

Analyses of plant sample trace elements have been a fundamental feature of ecological research for a long time. It is now well accepted that trees in urban and suburban areas have been used to detect the deposition, accumulation and distribution of trace metals in the ecosystems, because they first accept the negative effects of large concentrations of air pollutants and then provide the cheapest and simplest method by analyzing their tissues, leaves, twigs or their shanks, to assess the effects of the increased concentration of pollutant substances (Baslar et al. 2009, Kula et al. 2010). In the extant literature, there are many studies focusing on using bark and needles of pine species. Thus, Yilmaz and Zengin (2004) used the needles of Scots pine, Pyatt (1999) – of Corsican pines and Baslar et al. (2003) and Dogan et al. (2010) – of Turkish red pine to monitor heavy metal pollution.

The objective of the present study was to indicate the differential concentrations of nutrients and heavy metals in *Pinus brutia* Ten. needles, in terms of the influence of traffic and topographical conditions in the area of Thessaloniki.

## Materials and methods

Two sites (1 and 2) located near the busy traffic centre of the city and two other sites located in the periurban forest, one besides the ring road (site 3) and the other one far away from the busy ring road (site 4) were selected for the investigation (Fig. 1). In all sites, the age of *P. brutia* trees ranged from 50 to 60 years as they were planted during a reforestation program which basically started in the 1950s.

In each site, needles were collected from 20 randomly selected *P. brutia* trees.

From each tree, a significant amount of needles was collected from four sides (west, east, south and north) in the middle of the crown length. Sampling was carried out after a prolonged rainless period in mid September 2012. Each collected sample was stored in clean sealing plastic bags and transported to the laboratory for further processing, after they had been labeled. The total number of samples was 80. In the laboratory, the samples were placed unwashed in an oven and dried at 70 °C for about 48 hrs to remove all moisture. Subsamples of needles were then ground in a Willey mill to pass through a 40 mesh stainless steel sieve before being analyzed. An amount of 0.35 to 0.45 g was taken from each sample and was digested in a mixture of $HNO_3$, $HClO_4$ and $H_2SO_4$ (5:1:1) following the method of Allen et al. (1986). The elements Ca, Mg, K, Na, Mn, Fe, Cu, Zn were determined by means of the atomic absorption spectroscopy (Perkin-Elmer AAnalyst 300), whereas the concentrations of the elements Pb, Cd, Cr and Ni were determined by an atomic absorption spectrometer with flame and graphite furnace modes.

## Statistical analysis

For each site, the concentration of each element in *P. brutia* needles was calculated as the average of the 20 samples. For each element, one-way analyses of variance (ANOVA) were performed to determine whether there are any significant differences among the four different sites in urban and periurban areas of Thessaloniki. Duncan and Dunnett's T3 tests were used for the comparison of means. For the statistical analysis the statistical software SPSS 20.0 was used.

## Results

According to Table 1 in both sites located near the busy traffic centre of the city, the needles of *P. brutia* exhibited the lowest ($p < 0.05$) Mg and Ca concentrations. The highest ($p < 0.05$) Mg concentration was observed in the needles of site 4 in the periurban forest far away from the busy ring-road, whereas no significant difference ($p > 0.05$) in Ca concentration of *P. brutia* needles was observed between the sites in the periurban area. In both sites located in the periurban forest, the needles of *P. brutia* exhibited the lowest K concentration, whereas the highest concentration was observed in the needles of site 1. The collected needles of *P. brutia* in site 3 showed higher ($p < 0.05$) Na concentration than those which were collected in sites 1 and 2. In the needles collected in site 4, the highest ($p < 0.05$) Zn, Mn concentrations were observed and the lowest ($p < 0.05$) Cu, Ni concentrations. No significant differences ($p > 0.05$) in Cu, and Ni concentrations were observed among the other three sites. In both sites located in the urban area, the needles of *P. brutia* exhibited the lowest ($p < 0.05$) Mn concentration, whereas the lowest ($p < 0.05$) concentration of Zn was observed only in site 2. The results of the statistical analysis showed no significant differences ($p > 0.05$) in Fe, and Ni concentrations among the four sites. In *P. brutia* needles collected in site 1 and 3, the highest ($p > 0.05$) Pb concentration was observed. No significant difference ($p > 0.05$) was observed between the other two sites. In the collected needles from site 4 the lowest Ni concentration was observed, whereas no significant differences ($p > 0.05$) were observed among the other three sites. In both sites located near the busy traffic centre of the city, the needles of *P. brutia* exhibited the highest ($p < 0.05$)

**Table 1. Nutrients and heavy metal concentrations in the needles of *Pinus brutia*.**

| Element | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| | | Concentrations ($mg \cdot g^{-1} \pm$ S.D.) | | |
| Mg | 1.76[1] c[2] ± 0.41 | 1.92 c ± 0.25 | 2.37 b ± 0.38 | 2.72 a ± 0.33 |
| K | 7.16 a ± 1.49 | 5.48 b ± 0.99 | 3.24 c ± 0.80 | 2.65 c ± 0.67 |
| Ca | 5.37 b ± 1.84 | 6.03 b ± 1.58 | 7.33 a ± 1.93 | 7.89 a ± 1.57 |
| Na | 0.91 c ± 0.19 | 1.13 bc ± 0.88 | 1.95 a ± 1.03 | 1.50 ab ± 0.77 |
| | | Concentrations ($\mu g \cdot g^{-1} \pm$ S.D.) | | |
| Cu | 6.59 a ± 0.75 | 6.80 a ± 0.77 | 7.29 a ± 1.10 | 5.98 b ± 0.66 |
| Fe | 120.08 a ± 28.03 | 110.69 a ± 37.98 | 120.91 a ± 36.90 | 115.15 a ± 27.18 |
| Zn | 23.66 c ± 3.67 | 20.60 d ± 3.85 | 26.53 b ± 4.31 | 32.94 a ± 4.05 |
| Mn | 25.53 c ± 8.57 | 38.93 c ± 20.05 | 73.42 b ± 22.17 | 178.90 a ± 53.27 |
| Pb | 0.971 a ± 0.27 | 0.602 b ± 0.10 | 0.818 a ± 0.14 | 0.606 b ± 0.10 |
| Cd | 0.086 a ± 0.03 | 0.074 a ± 0.03 | 0.081 a ± 0.02 | 0.096 a ± 0.02 |
| Ni | 1.311 a ± 0.45 | 0.954 a ± 0.66 | 1.028 a ± 0.21 | 0.351 b ± 0.12 |
| Cr | 0.924 a ± 0.74 | 0.925 a ± 0.87 | 0.298 b ± 0.39 | 0.060 b ± 0.00 |

Note: [1] – mean concentration of 20 samples; [2] – in a row, the means are statistically different at $p < 0.05$ when they do not share a common letter. The comparisons of K, Na, Cu, Mn, Pb, Ni and Cr concentrations were made using Dunnett T3 test. The comparisons of Mg, Ca and Zn concentrations were made using Duncan test.

Cr concentrations. No significant difference ($p < 0.05$) in Cr concentration was observed between the sites both in the researched periurban and urban areas of the city.

## Discussion

It is now well accepted that plants can be effectively used for monitoring environmental pollution in urban areas. There are many studies focusing on using the bark and leaves of tree species to provide valuable information about the quantity and quality of pollutants in the atmosphere (Ceburnis and Steinnes 2000, Migaszewski et al. 2002, Kaya and Yaman 2008, Sawidis et al. 2011). The present study was focused on the differential concentrations of nutrients and heavy metals in *P. brutia* needles in four sites in the urban and periurban area of the city in order to determine if they resulted from the influence of various factors, such as traffic and topographical conditions, and might be related to heavy metal pollution in urban environments. Mg and Ca concentrations were higher in the needles collected from the sites located in the periurban forest (sites 3 and 4) than those collected from the sites located near the busy traffic centre of the city, which may be due to the region bedrock. According to Papaioannou (1993), Ca and Mg have common sources, which could be attributed to the region bedrock and the territories full of bases.

The highest concentration of K observed in the needles of site 1, was possibly originated from the fertilizers used in the herbaceous and shrubby plants of the park. Large amounts of Na ions can cause toxicity and other problems if they overcome the permitted concentration limit which is 0.5 $mmol{\cdot}l^{-1}$ (Venter 2010). Its high concentration observed in the needles collected in the periurban area is due to the combination of site location and upward movements of the winds coming from the sea (Papaioannou 2015).

Cu is essential for plant nutrition and it mainly originates from the metal industry, mining, coal-fired plants, traffic, copper-containing fungicides and fertilizers used in agriculture (Ruhling and Steinnes 1988, Otvos et al. 2003). Its penetration into the leaves depends upon the plant species (Siedlecks et al. 2001). In addition, Greger (1999) states that Cu can be directly taken up by leaves from the air due to direct atmospheric pollution. Its concentration in the needles of sites 1, 2 and 3, affected by traffic, was higher than that of site 4, which is located in the periurban forest far away from the busy ring road. According to Alifragis and Papamichos (1994), Cu concentrations up to 20 ppm will become toxic whereas values less than 4 ppm will lead to deficiency in plants. The results of the present study showed that Cu concentrations are close to the minimum limit proposed by Alifragis and Papamichos (1994). This proved that there is no Cu pollution in the investigated area. Similar results were also given by Sawidis et al. (1995) in their study of air pollution with heavy metals in Thessaloniki using trees as biological indicators. Dogan et al. (2010) found the concentrations of Cu in the needles of *P. brutia* collected from suburban and roadside areas equal to 3.10 and 5.30 $\mu g{\cdot}g^{-1}$, respectively.

The wear of tyres and of brake pads, and the combustion of fuel and oil/lubricants are recognized as major sources of Zn and Cd alongside roadways within the Thessaloniki area (Ewen et al. 2009). Bowen (1979) mentioned that the concentration of Zn in plants ranges from 20 to 400 $\mu g{\cdot}g^{-1}$, dry weight. Thus, the concentrations of Zn (which are close to minimum limit proposed by Bowen (1979) in *P. brutia* needles in all researched area) do not constitute an alarming pollution agent in the city of Thessaloniki. This is due, firstly, to the small industrial activity in the urban and periurban area and, secondly, to the winds prevailing in this area which blow northerly and, as a result, clean the atmosphere.

Fe is one of the principal elements in the Earth's crust (Baslar et al. 2005) and is considered to be geogenic but can also be emitted by industries. The main emission sources of iron can be the steel industry, coal burning and intensive traffic (Ruhling and Steinnes 1988). For plants, the concentration of Fe required for growth is considered to be 100 $mg{\cdot}kg^{-1}$ (Galatis et al. 2003). The results showed no significant differences in its concentrations among the four sites. The concentrations in the needles collected from the sites located near the busy traffic centre as well as in site 3 located in the periurban forest, besides the ring road, were as high as the concentration in the needles collected from site 4 located in the periurban forest, far away from the busy ring road. In contrast, Dogan et al. (2010) found that Fe concentration in the needles of *P. brutia* collected from industrial and roadside areas (595.50 and 500.90 μg·g$^{-1}$, respectively) was much higher than in the needles collected from the control area. Thus, the concentrations of Fe in *P. brutia* needles (in the investigated area) do not constitute an alarming pollution agent in the city of Thessaloniki.

Mn is found in nature and its concentration in the soil is determined by the nature of the parent rock (Aubert and Pinta 1977). As it comes from human activities, such as industry or fossil fuel combustions, Mn concentrations are emitted in the atmosphere and they enrich the ground or surface water and groundwater (Metentzoglou 2009*).* Its concentration, which is considered to be essential for plants, is 50 mg·kg$^{-1}$ (Galatis et al. 2003). The highest concentration in site 4 is attributed to the type of the parent rock. The low concentrations measured in *P. brutia* needles in sites near the busy traffic centre do not constitute an alarming pollution agent in the city.

Pb tends to accumulate heavily in the ground due to its low solubility and desegregation by soil microorganisms and is distinguished by its long residence time in the environment (Mitsios 2004). Leaded fuel is a main source of Pb pollution as well as waste incineration, metal production and mining activities (Dogan et al. 2010). The highest concentrations were found in the needles collected from sites 1 and 3. Possibly, the traffic on the roads close to these sites is denser than the roads close to site 2. Ewen et al. (2009) report that the traffic flow patterns have an impact on Pb concentrations, rather than traffic density and they found the highest concentrations in sites which are road junctions in Thessaloniki. The normal concentration in plants ranges from 0.1 to 10 mg·kg$^{-1}$ (Bhanu Prakash et al. 2007), whereas, according to Malik et al (2010), the normal concentration is considered 5 mg·kg$^{-1}$ dry weight. Therefore, the concentrations of Pb measured in *P. brutia* needles in the investigated area were below the normal level.

Ni is mainly considered to be an essential micronutrient and originates mainly from oil and coal burning, the steel industry and smelters (Otvos et al. 2003). Higher concentrations were observed in the needles collected from both sites located near the busy traffic centre of the city as well as from the site besides the ring road than in the needles collected from the site far away from the busy ring road. The normal Ni concentration in plants is reported to be between 1 and 10 ppm (Rebafka et al. 1990) and toxic symptoms to plants occur at concentrations above 50 mg·kg$^{-1}$ (Bhanu Prakash et al. 2007, Chen et al. 2009). Therefore, there is no critical Ni pollution in the researched areas as the concentrations in *P. brutia* needles were found to be at normal levels.

Among heavy metals, Cd is one of the elements concentrating the greatest environmental concern (Dogan et al. 2007). Pb and Cd do not have any known physiological function in plants and can be toxic. The industrial uses of Cd are the largest sources of environmentally hazardous amounts of cadmium as well as coal burning and the incineration of wastes containing it. According to the results of the present study, the concentrations in the needles collected from the sites located near the busy traffic centre of the city as well as in the site besides the ring road were as high as the concentration in the needles collected from the site lacated far away from the busy ring road. Furthermore, Kabata-Pendias and Pendias (1984) reported that the concentration of Cd in contaminated plants ranges between 5 and 30 mg·kg$^{-1}$. Therefore, the concentration in *P. brutia* needles collected in the investigated area was within normal levels.

Cr is mainly emitted by the iron and steel processing industry and from coal combustion (Cucu–Man et al. 2004), whereas heavy traffic, and especially transportation near the intercity road, is an additional emission source (Ruhling and Steinnes 1988). According to Bowen (1979) and Cary (1982) the normal Cr concentration in plants that does not cause toxic reactions is 0.23 mg·kg$^{-1}$, and generally below 1 mg·kg$^{-1}$. In the present study, Cr concentrations were higher in the needles collected in the urban area of Thessaloniki than in the needles collected in the periurban forest. However, its concentrations were not toxic to plants as they were found to be lower than 1 mg·kg$^{-1}$.

## Conclusions

The results of the present study demonstrate that the concentrations of heavy metals Cu, Pb, Ni and Cr in *P. brutia* needles collected from the sites located near the busy traffic centre of Thessaloniki city or besides the ring road are higher than those of the needles collected from the site located far away from traffic roads. In contrast, the traffic on the roads has no impact on Fe and Cd concentrations in *P. brutia* needles. However, the highest Mn concentration in the site located in the periurban forest far away from the busy ring road is attributed to the type of the parent rock. As far as the concentrations of nutrients are concerned, the concentrations of Mg and Ca observed in the needles collected from the sites located in the periurban forest, which are higher than the concentrations in the needles collected from the sites located in urban areas of the city, may be due to the region bedrock. The high Na concentration in the needles collected in the periurban area is attributed to the combination of the site location and upward movements of the winds which come from the sea. The highest concentration of K observed in sites of the urban area is possibly originated from the fertilizers used in the herbaceous and shrubby plants of the park. However, the concentrations of elements measured in *P. brutia* needles collected in the urban and periurban areas of Thessaloniki are below the normal level and as a result they do not constitute an alarming pollution agent in the city.

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# PHENOTYPIC VARIABILITY OF DOUGLAS FIR (*PSEUDOTSUGA MENZIESII* (MIRB.) FRANCO) IN BELARUS PLANTINGS

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## Abstract

Finding ways to assess the productivity of exotic species under the new climatic conditions is an important part of the successful introduction of silvicultural practices. The purpose of this research is assessment of intra-population polymorphism in Douglas fir stands in terms of seasonal development, color of female strobili and anthers, and bark texture (structure). Concerning the seasonal development and phenology, the following phenotypes were distinguished: very early, early, middle, late and very late; according to the color of female strobili – green, greenish-brown and purple; according to the color of anthers – yellow, orange, purple and brown; and according to bark texture (structure) – deep fissured cork (coarse bark), middle fissured cork (transitional) and shallow fissured cork (plane bark) phenotype. Each of the plants was characterized by a highly individual phenotypic spectrum. The most informative and accessible for practical use were phenotypes on of bark structure: coarse bark phenotype – bark cork, light, in the form of massive plates of thickness greater than 5 cm with cavities, divided by deep fissures. At the age of 70–75 years the bark in the butt-log part gradually peels off and falls to a height of 2–3 m. A new bark is formed actively instead of the fallen one. Transitional phenotype – bark is relatively dense, thickness up to 4–5 cm, shaked, moderately deep fissures. There is a detachment of the bark at the root collar to a height of 0.7–1.0 m. Plane bark phenotype – bark is dense, thin, thickness up to 2–3 cm, small plates, cloven by shallow fissures, not exfoliate. Morphological polymorphism of Douglas fir under bark texture (structure), clearly expressed in the form of introduction populations, notably characterized by growth index. Trees of deep fissured cork (coarse bark) phenotype are considered as the most productive. At the age of 71, their average height is 30.8 m, average diameter – 42.7 cm. Trees of middle fissured cork (transitional) demonstrated lower height by 8 % and diameter by 20 %. Both phenotypes had a small degree of tapering and a well-developed crown. Trees of shallow fissured cork (plane bark) phenotype ranked below in height by 25 % and by 42 % in diameter and are characterized by higher values of variation coefficients. They form a canopy in the second planting as a regrowth. Thus, deep fissured cork (coarse bark) and middle fissured cork (transitional) phenotypes are the most promising for planting.

**Key words:** bark type, phenotype, productivity.

## Introduction

Plant interpopulation and intrapopulation variability is the subject of numerous modern research reports (Leiblein-Wild and Tackenberg 2014, Sattarian et al. 2011). Special attention is given to polymorphism in coniferous species populations

(Martinez-Meier et al. 2011, Agundez et al. 1992, Turna and Güney 2009, Urbaniak et al. 2003, O'Reilly and Farmer 1991, Jianxun et al. 2003 Putenikhin et al. 2004, Kuzmina 2004, Vidyakin 2007, Barchenkov 2010). Experimental studies important for identifying stable diagnostic features, gaining new information about the species taxonomy and intraspecific diversity, revealing of the adaptive potential, as well as for the purpose of breeding and afforestation. Not only studies on natural populations, but also on plantations of introduced species, developing in new edaphic and climatic conditions in complete isolation from the mainland and under the influence of anthropogenic factors are particularly important.

Intraspecific variation of *Pseudotsuga menziesii* (Mirb.) Franco in forest plantations in Western Europe has been studied since the first half of 20$^{th}$ (Göhre 1958, Rohmeder and Schönbach 1959). Different forms of intraspecific variation of *Pseudotsuga menziesii* (Mirb.) Franco were identified in Russia by Schepotiev (1982), in Latvia by Pirags (1979), and in forest plantations in Ukraine by Kholyavko (1981). In Belarus, Shkutko (1970) was the first who drew the attention to polymorphic species, and later on Fedoruk (1980) performed a study on the cultivated dendroflora of the region.

The aim of the present research was to study phenotypic variability of *Pseudotsuga menziesii* in populations introduced to Belarus, to identify the most informative and accessible features allowing to assess the productivity of plantations.

## Materials and Methods

Objects of study were pure and mixed plantations with on the participipation of *Pseudotsuga menziesii* (Table 1).

Continuous inventory of the stand was carried outin the area of plantations. Collection of materials was performed according to procedures generally accepted in forestry and forest inventory. Age of trees was estimated on refined wood cores, obtained with an increment borer. The study of phenotypic variability of traits in plantations was based on the method of phenes. Phenes are considered as discrete alternative variations of traits and were studied using methodological approaches of Zhivotovsky (1982) and Egorov (1997, 2001).

The most informative and clearly expressed trait in the introduced populations

**Table 1. Characteristics of experimental plantationgs of *Pseudotsuga menziesii*.**

| Habitat (plantation composition) | Age, years | Average height, m | Average diameter, cm | Site index | Number of trunks, ha$^{-1}$ | Standing timber volume, m$^3$/ha |
|---|---|---|---|---|---|---|
| State forest reserve (SFR) "Priluksky" sq. 66 alloc. 2; N53.79, E27.37 (70 % Douglas-fir; 20 % Larch; 10 % Spruce) | 71 | 30.1 | 34.7 | Ia | 488 (total 677) | 630 (total 820) |
| State Scientific Institution (SSI) "Central Botanical Garden of NAS of Belarus", the sector of North America sq. 91; N53.91, E27.62 (100 % Douglas-fir) | 73 | 24.1 | 42.4 | I | 405 | 710 |

a b c

**Fig. 1. Phenotypes of *Pseudotsuga menziesii* in bark structure.**
Legend: a) coarse bark; b) transitional; c) plane bark.

was the morphological polymorphism in bark texture (structure). On this basis the trees in plantations were represented by three phenotypes: deep fissured cork (coarse bark), middle fissured cork (transitional) and shallow fissured cork (plane bark) (Fig. 1).

The coarse bark phenotype included bark cork, light, in the form of massive plates of thickness greater than 5 cm with cavities (Fig. 2), divided by deep fissures. At the age of 70–75 years the bark in the butt-log portion gradually peels off and falls to a height of 2–3 m. Replacing the fallen bark actively forms the new one (Fig. 3).

In the transitional phenotype, the bark is relatively dense, with a thickness up to 4–5 cm, shaked, with moderately deep fissures (Fig. 1b). There is a detachment of the bark at the root collar to a height of 0.7–1.0 m.

In the plane bark phenotype, the bark is dense, thin, with thickness up to 2–3 cm, small plates, cloven by shallow fissures, not exfoliate (Fig. 1c).

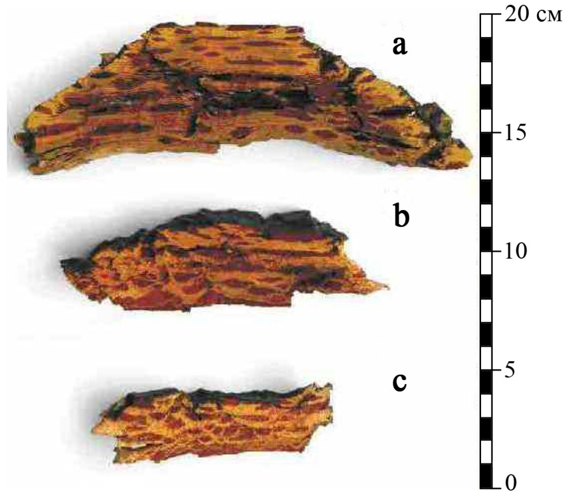


**Fig. 2. Cross-section cut of bark plates of *Pseudotsuga menziesii* phenotypes.**
Legend: a) coarse bark; b) transitional; c) plane bark.

a b

**Fig. 3. Type of trunk with coarse bark phenotype of *Pseudotsuga menziesii* before falling (a) and after falling (b) of the bark.**

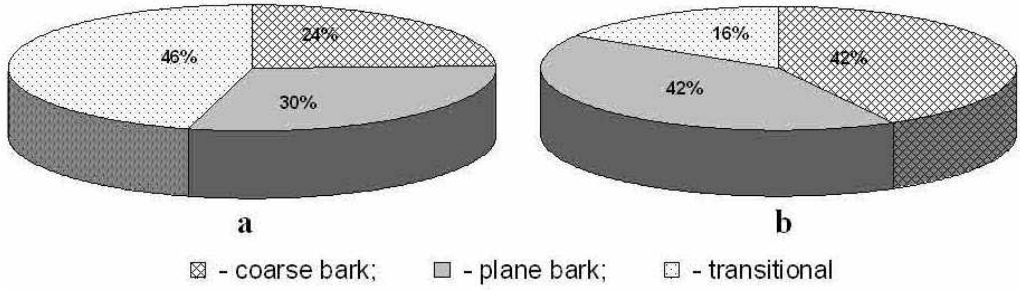


**Fig. 4. Frequency of bark structure phtnotypes in the plantations *Pseudotsuga menziesii* .**
Note: a) SFR "Priluksky"; b) SSI "Central Botanical Garden of NAS of Belarus".

Processing of experimental data was performed using ANOVA and standard methods of descriptive statistics. Significance of differences between samples was determined using U-Mann-Whitney test.

## Results and Discussion

The results showed that intra-population polymorphism of *Pseudotsuga menziesii* was well expressed mostly in the seasonal development (distinguished very early, early, middle, late and very late), color of female strobili (green, greenish-brown and purple), color of anthers (yellow, orange, purple and brown), and bark texture (structure). There were other differences, but it wa's often quite difficult to take them into account due to the high density of plantations, making the assessment of their phenotypic structure difficult.

The frequency of the studied phenotypes in bark structure differed in the two studied plantations. In the mixed forest plantations in SFR "Priluksky" the middle fissured cork (transitional) phenotype prevaileds (46 %). In the pure plantation in SSI "Central Botanical Garden of NAS of Belarus" the deep fissured cork (coarse bark) and shallow fissured cork (plane bark) had the same frequency (42 %). Significant differences in frequency were observed also between the other phenotypes (Fig. 4).

According to Rohmeder and Schönbach 1959) the tree phenotype with deeply fissured bark is more susceptible to pathogenic fungus *Polyporus schweinitzii* Fr., causing stem rot. However, in studied plantations no infected trees were identified. At the same time, due to the development of a thick bark, this phenotype is more fire resistant and winter hardy (Kohnle et al. 2012). Plane bark *Pseudotsuga menziesii* differeds from the others in developing thinner branches, thus having better wood quality and being less prone to fungal diseases (Schepotiev 1982).

Identified morphological polymorphisms in bark texture (structure) was significantly related to the growth index of height and diameter (Table 2).

In accordance with the data, trees of deep fissured cork phenotype (coarse bark) are considered as the most productive. At the age of 71, their average height is up to 30.8 m, and average diameter of 42.7 cm. Trees of middle fissured cork (transitional) are second to the first one in average inventory indices: height by 8 % and diameter by 20 %. Overall, however, it is also a very promising, fast-growing, phenotype. Some of its individuals are among the highest in the plantation, reaching at the age of 71 38.5–39.5 m. in height. Both phenotypes have a small degree of tapering and a well-developed crown.

Trees of the shallow, fissured cork phenotype (plane bark) expressed significantly lower values of height (by 25 %) and diameter (by 42 %) in comparison to deep fissured cork (coarse bark) phenotype. They were characterized by higher values of variation coefficients. These plants formed the second layer of the stands.

The relationship between the *Pseudotsuga menziesii* phenotypes in bark structure and height and diameter of the trees was confirmed by the results of variance analysis (Table 3).

**Table 2. Variation in growth traits of *Pseudotsuga menziesii* bark phenotypes.**

| Phenotype | Age, years | Height, m | | Diameter, cm | |
|---|---|---|---|---|---|
| | | *M* ±*m* | min – max | *M* ± *m* | min – max |
| SFR “Priluksky” | | | | | |
| Coarse bark | 71 | 30.8 ± 0.7 a | 14.8 – 39.8 | 42.7 ± 1.5 a | 16.4 – 67.0 |
| Transitional | | 28.5 ± 0.7 a | 12.1 – 39.5 | 35.6 ± 1.1 b | 14.3 – 64.4 |
| Plane bark | | 23.2 ± 0.8 b | 11.4 – 38.2 | 24.7 ± 1.0 c | 13.4 – 57.6 |
| SSI “Central Botanical Garden of NAS of Belarus” | | | | | |
| Coarse bark | 73 | 24.5 ± 0.2 a | 20.7 – 27.0 | 45.0 ± 1.0 a | 32.9 – 60.1 |
| Transitional | | 23.6 ± 0.4 a | 21.7 – 25.6 | 43.9 ± 1.7 a | 32.7 – 52.7 |
| Plane bark | | 24.0 ± 0.3 a | 18.4 – 26.6 | 39.0 ± 1.1 b | 22.1 – 49.8 |

Note: *M* – mean value, ±*m* – error of the mean; Means followed by the same letter within a column don’t differ significantly at $P < 0.05$.

**Table 3. Analysis of variance for testing the relationship between bark structure phenotypes and growth and traits of *Pseudotsuga menziesii***

| Growth variable | Dispersion | *SS* | *df* | *MS* | *F* | *p*-level |
|---|---|---|---|---|---|---|
| Height | variants | 1352.60 | 1 | 1352.60 | 35.35 | $7.3\times10^{-9}$ |
| | balance | 12014.47 | 314 | 38.26 | | ($p < 0,05$) |
| | total | 13367.08 | | | | |
| Diameter | variants | 10159.64 | 1 | 10159.64 | 88.52 | $1.1\times10^{-18}$ |
| | balance | 36038.85 | 314 | 114.77 | | ($p < 0,05$) |
| | total | 46198.49 | | | | |

Legend: *SS* – sum of squares, *df* – degrees of freedom, *MS* – mean square, *F*-value, *p*-value.

The calculation of power of influence factor ($\eta^2$) on studied characteristics of a tree trunk showed that for the height it amounts to $\eta^2_H = 0.101$ and for the diameter – $\eta^2_D = 0.220$. The significance of the corresponding values was confirmed by the calculated values of criterion $\chi^2_H = 31.92$ and $\chi^2_D = 69.52$ ($p \le 0.05$).

Phenotypic variability of morphological characters in *Pseudotsuga menziesii*, taken with its various economically valuable characteristics can be used for breeding purposes (Cruz-Nicolás et al. 2011). In particular, the bark type may be an additional indicator for plus tree selection.

## Conclusion

Plantations of *Pseudotsuga menziesii* remain highly polymorphic when cultivated in conditions of the Republic of Belarus. The most informative and accessible are bark structure phenotypes, which include deep fissured cork (coarse bark), middle fissured cork (transitional) and shallow fissured cork (plane bark). Each of the plants is characterized by highly individual phenotypic spectrum.

Phenotypes of *Pseudotsuga menziesii* in bark texture (structure) crust differ in productivity, which allows to conclude that two of them (deep fissured cork (coarse bark) and moderately fissured cork (transitional) are the most promising for the establishment of forest plantations. Type of bark can also be a used as a marker in plus tree selection.

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# AGE, GROWTH RATE AND CONDITION FACTOR OF THE CHUB (*SQUALIUS ORPHEUS* KOTTELAT & ECONOMIS, 2006) IN THE STRYAMA RIVER

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## Abstract

A study of the Maritsa chub in the Stryama River, a left tributary of the Maritsa River was carried out. The research was conducted in autumn in the period 2006–2011. A total of 458 specimens of Maritsa chub were caught by electrofishing. The size-age composition was simple. The population was represented by five age groups. The chub's population in the Stryama River was dominated by young and middle size groups. The relationship between the average values of $L$ (standard length) and $S$ (scale radius) was described by the equation: $L = 17228+2.1934 \cdot S$; correlation $r = 0.9979$. The length growth of the chub in the Stryama River is relatively fast. The relation between the fish weight ($W$) and length of the population was represented by the equation: $W = 0.000009 \cdot L^{3.1154}$; $r = 0.9996$. The condition factor of the chub in the Stryama River is one of the lowest in comparison with the other water courses in the Aegean catchment area.

**Key words:** length growth, size-age composition, Squalius orpheus, weight growth.

## Introduction

The Maritsa chub (*Squalius orpheus* Kottelat & Economis, 2006) is an endemic species for the Balkan Peninsula. It was recently identified as a separate species by Kottelat and Economidis (2006). Apostolou and Dobrovolov (1999) assume that the chub from Aegean basin is a separate species as well. The species occurs in the water courses of the Aegean watershed from the Maritsa River to the Struma River (Kottelat and Economidis 2006, Kottelat and Freihof 2007). This is one of the most numerous fish species in the middle zone of the Maritsa River tributaries in Bulgaria and also one of the favorite sport fish in these water courses.

The first detailed study of the Maritsa chub along the whole Bulgarian water course of the Struma River was conducted by Michajlova (1964). The author published the data for the length and weight growth of the chub in the Struma River. A study of the age structure and the increase of the chub population in the Batak dam, situated in the watershed of the Maritsa River, was carried out by Zivkov (1973). He reported detailed data on the growth rate of the chub in this dam. The length and weight growth rate of the Maritsa chub in the Dzerman River, a left tributary of the Struma River, was studied by Dikov and Zivkov (1985). In his PhD

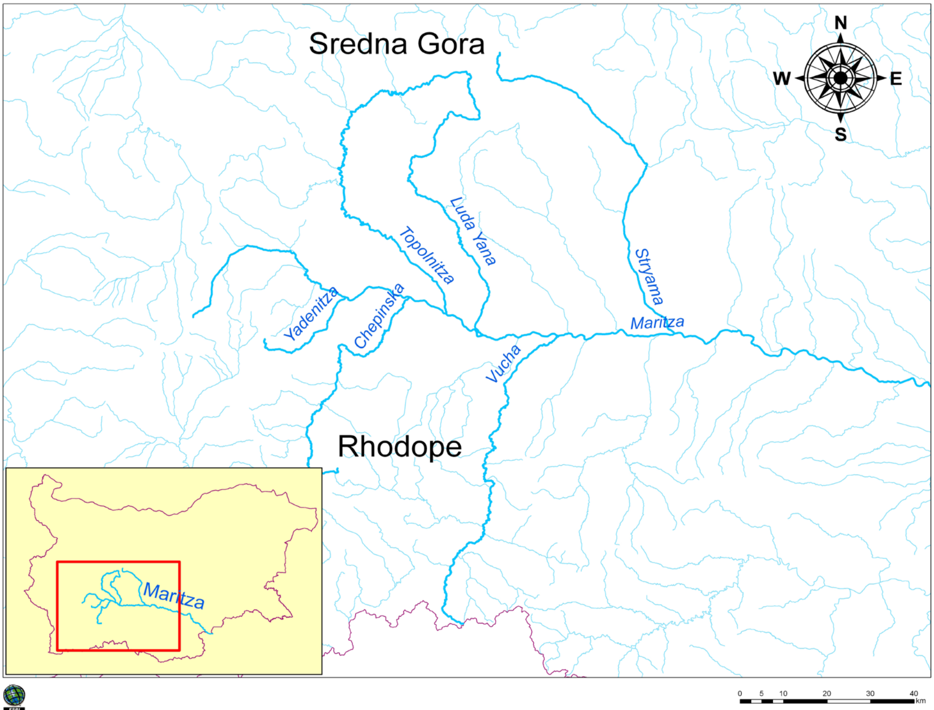


**Fig. 1. Location of the Sryama River, Arc Map 10.0 (ESRI – ArcGIS 2013).**

thesis Marinov (1986) reported information about the length growth of the chub in the Chepinska River, a right tributary of the Marisa River. Dikov et al. (1994) published the results of a survey of the fish stocks in the inland rivers of Bulgaria. They reported data on the length growth of the chub in the rivers Struma and Mesta and also in the Arda River, a right tributary of the lower course of the Maritsa River.

The aim of the study was to compare the growth rate and the condition factor of the chub in the Stryama River with the results obtained for other rivers.

### Study area

The study area includes the Stryama River, a left tributary of the Maritsa River coming from the Sredna Gora Mountains. The Stryama River springs east of the peak Vezhen in the Middle Balkan Mountains and flows between the Balkan and the Sredna Gora mountains (Fig. 1). Its length is 110 km with a catchment area of 1,789 km$^2$. The river flows into the Maritsa River near the village of Manole. Most of the Stryama River is in the Upper Thracian Valley. The river is characterized by small slope, although its average altitude is high.

## Materials and Methods

The aim of the study was to establish the age structure, the length growth and the condition factor of the chub in the Stryama River and also to compare them with these

**Table 1. Sampling areas in the Stryama River.**

| No | Location | Geographic coordinates | | Altitude, m a.s.l. | Date of sampling |
|---|---|---|---|---|---|
| | | N | E | | |
| 1 | Near the bridge of the road Plovdiv-Rakovski | 42°15'07.29'' | 24°50'21.05'' | 174 | 16.11.2006 |
| 2 | Near the bridge of the road Plovdiv-Banya | 42°32'18.12'' | 24°49'22.78'' | 283 | 17.11.2006<br>17.04.2011 |
| 3 | Near the town of Banya next to the fish farm. | 42°33'39.11'' | 24°47'45.81'' | 302 | 17.11.2006<br>19.11.2006<br>19.10.2011<br>20.11.2011<br>16.12.2011 |
| 4 | Near the village of Rozino next to the bridge on the Stryama River | 42°41'29.46'' | 23°34'00.57'' | 478 | 26.10.2008 |

features of the chub in the other water courses in the Aegean catchment area.

In the period 2006–2011 458 pieces of Maritsa chub were collected from the Stryama River by electrofishing. A SAMUS 725G converter was used, providing up to 640 V direct current (DC), frequency 50 Hz and output power reaching up to 200 W. The catch was performed according to the EN 14011:2004 instruction (Water quality – Sampling of fish with electricity).

Fish for this study were caught mainly in autumn. In order to collect the material for the study four sampling areas were used (Table 1). The standard length (*L*) of the fish with a precision of 1 mm and weight (*W*) with a precision of 1 g were measured. The age was determined by measuring the fish scales. For this purpose a microscope Olympus CX 31 at a 40× magnification was used.

The identification of the species was made according to Kottelat and Freyhof (2007).

An estimation was made of the growth rate of the Maritsa chub in different water bodies, comparing the average lengths of equal age specimens (Raikova-Petrova and Zivkov 1993, Zivkov 1999). The weight calculated for the specimens of fixed lengths (50, 100, 150, 200, 250, etc., mm) were used as condition factors of the different populations of Maritsa chub (Zivkov 1999).

Survival ($S = e^{-z}$) and annual mortality rate ($A = 1–S$) were calculated using the equation describing the relationship between the number of fish in the catch and their age (Raikova-Petrova and Zivkov 1993, Zivkov 1999).

## Results and Discussion

The relation between the fish length (*L*) and the scale radius (*S*) is:

$L = 17228+2.1934 \cdot S$; $r = 0.9979$.

The decrease of mean logarithmic values of chub's abundance in the Stryama River is well described by the slope regression:

$\text{Ln } N\% = 4.9353–0.851 \cdot t$; $r = 0.8526$; $n = 458$.

### Age composition

The second age group dominates in the catch (Fig. 2). The dominant size is between 121 and 130 mm (Fig. 3). The big-

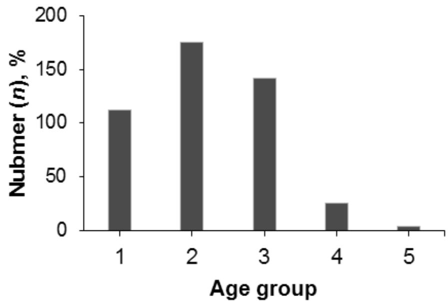


**Fig. 2. Age structure of the population of Maritsa chub in the Stryama River.**

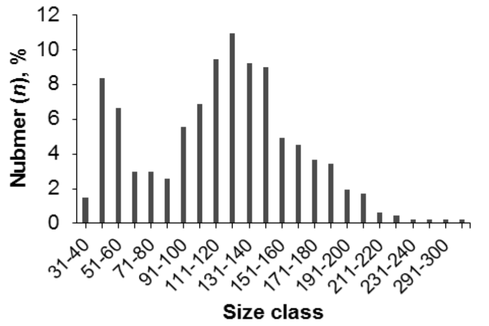


**Fig. 3. Size class of the population of Maritsa chub in the Stryama River.**

gest specimen is 322 mm long and weighs 607 g. The full length of the body of this specimen is 368 mm, and the total weight is 698 g. It has been caught in 2006 and it is not the oldest specimen (its age was four years) (Table 2). The oldest specimen has been caught in 2010. It is five years old and measures 295 mm and 428 g.

The population is dominated by young and middle-sized fish respectively 40–50 mm and 100–150 mm long. The greatest is the mortality rate of the Maritsa chub in the Stryama River in the forth and the fifth age groups (Fig. 2 and Fig. 3). The population of chub in the Sryama River is characterized by relatively low survival rate ($S$ = 42.7 %) and a higher annual mortality rate ($A$ = 57 %). The number of specimens over 200 mm long in the sample is very small, which shows a great elimination of fish of larger sizes due to angling (Pravdin 1966). Confirmation of this hypothesis is the higher annual mortality rate and the fact that the oldest caught specimen in the sample is only five years old. Michajlova (1964) has found six age groups of the Maritsa chub in the Struma River, Dikov et al. (1994) has indicated seven age groups of the chub in the Struma River and Zivkov (1973) has established eleven age groups of the Maritsa chub in the Batak dam. Obviously in the Struma River and in the Batak dam the Maritsa chub lives many years more and reach larger size.

## Growth rate

The length and the weight growth of the Maritsa chub are shown in Tables 2 and 3. The Maritsa chub has the greatest length growth in the first year of its life. This is due to the fact that in their first year fish are not yet sexually mature and use their reserves only for growth. In the subsequent year, length growth is significantly reduced. It is very likely that this growth reduction is related to sexual maturation of some of the chub at that age (Nikolsky 1965). From the third year on, the linear growth rate slightly increases and remains at a constant level until their fifth year (Table 2).

Both the length and the weight growth increase steadily but relatively slowly from the first to the fifth year (Table 3). The annual values of length and weight reached by the chub in the Stryama River are one of the smallest for the Maritsa chub in the Aegean watershed on the territory of Bulgaria (Table 4). The growth of chub in the Stryama River approximates that of chub in the Arda River. As shown

**Table 2. Back calculated body length of the Maritsa chub in the Stryama River.**

| Generation | Age group | Body length ($L$, mm) at the end of each year of thelife, calculated from scales radius ($S$) | | | | | Number |
|---|---|---|---|---|---|---|---|
| | | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | |
| 2011 | I | 76 | | | | | 12 |
| 2010 | II | 50 | 94 | | | | 35 |
| 2009 | III | 63 | 72 | 134 | | | 86 |
| 2008 | IV | 54 | 80 | 127 | 173 | | 63 |
| 2007 | IV | 57 | 83 | 127 | 186 | | 22 |
| 2006 | V | 50 | 81 | 100 | 125 | 175 | 86 |
| 2005 | II | 41 | 81 | | | | 34 |
| 2004 | III | 55 | 74 | 123 | | | 86 |
| 2003 | IV | 61 | 81 | 124 | 173 | | 31 |
| 2002 | V | 76 | 104 | 114 | 151 | 210 | 3 |
| Average body length ($L_{av}$), mm | | 58 | 83 | 121 | 162 | 192 | |
| Real length ($L_r$), mm | | 49 | 84 | 122 | 166 | 181 | |
| Growth length ($t'$), mm | | 58 | 25 | 38 | 41 | 31 | |

in Table 4 the chub in the dams Batak and Pyasachnik has registered the fastest growth of the Maritsa chub, faster than the chub growth in all investigated rivers

**Table 3. Back calculated body weight of the Maritsa chub in the Stryama River.**

| Generation | Age group | Back calculated body weight ($W$, g) of the Maritsa chub at the end of each year of the calculated life, from body length ($L$, mm) | | | | | Number |
|---|---|---|---|---|---|---|---|
| | | $W_1$ | $W_2$ | $W_3$ | $W_4$ | $W_5$ | |
| 2011 | I | 6.6 | | | | | 12 |
| 2010 | II | 1.8 | 12.6 | | | | 35 |
| 2009 | III | 3.7 | 5.5 | 37.6 | | | 86 |
| 2008 | IV | 2.3 | 7.5 | 32.0 | 84.4 | | 63 |
| 2007 | IV | 2.6 | 8.6 | 32.2 | 106 | | 22 |
| 2006 | V | 1.8 | 7.9 | 15.1 | 30.5 | 87.1 | 86 |
| 2005 | II | 0.9 | 7.9 | | | | 34 |
| 2004 | III | 2.4 | 6.1 | 29.3 | | | 86 |
| 2003 | IV | 3.3 | 7.9 | 29.6 | 84.4 | | 31 |
| 2002 | V | 6.6 | 17.5 | 22.9 | 55.3 | 155.1 | 3 |
| Average body weight ($W_{av}$), g | | 3.2 | 9.1 | 28.4 | 72.1 | 121.1 | |
| Real weight ($W_r$), g | | 1.8 | 8.6 | 26.9 | 74.3 | 108.2 | |
| Weight growth – ($t'$), g | | 3.2 | 5.9 | 19.3 | 43.7 | 49.0 | |

**Table 4. Comparison of average lengths of equal age Maritsa chub in different water bodies from its habitat.**

| Author/s and year | River Dam | Body length ($L$, mm) of Maritsa chub at the end of each year of life, calculated from scales radius ($S$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | $L_7$ | $L_8$ | $L_9$ | $L_{10}$ | $L_{11}$ |
| Dikov et al. 1994 | Arda River | 58 | 104 | 137 | 159 | | | | | | | |
| Our data 2015 | Stryama River | 58 | 83 | 121 | 162 | 192 | | | | | | |
| Michajlova 1964 | Struma River | 83 | 115 | 148 | 176 | 202 | 215 | | | | | |
| Dikov & Zivkov 1985 | Dzerman River | 52 | 101 | 141 | 183 | | | | | | | |
| Marinov 1986 | Chepinska River | 61 | 115 | 152 | | | | | | | | |
| Dikov et al. 1994 | Mesta River | 64 | 114 | 159 | 195 | 214 | | | | | | |
| Dikov et al. 1994 | Struma River | 54 | 119 | 164 | 211 | 223 | 241 | 243 | | | | |
| Stefanova et al. 2008 | Maritsa River | 60 | 95 | 130 | 240 | | | | | | | |
| Zivkov 1973 | Batak Dam | 96 | 163 | 215 | 247 | 272 | 294 | 318 | 352 | 379 | 397 | 406 |
| Boyadgiev 1966 | Pyasachnik Dam | 89 | 155 | 218 | 298 | 316 | | | | | | |

Legend: $S$ – scale radius (measured in divisions of the eyepiece – micrometer); $L1$–$L11$ – fish's body length in the end of every year of life (1 to 11).

in Bulgaria. Thanks to the rich food base (Nikolsky 1965), standing water and favorable temperature conditions in both of the dams, two-year old chub has reached length that the chubin the Stryama River reach in their fourth year. The chub in the rivers Struma, Dzerman and Mesta have relatively slow lentgth growth rate (Michajlova 1964, Dikov et al. 1994). The chub in the Maritsa River has a faster lentgth growth rate thant the chub in all other rivers of the Aegean watershed, including the Stryama River (Table 4).

## The condition factor

The condition factor is shown in Table 5. The chub populations are arranged according to their weight at rounded length (250 mm – $W_{250}$). The chub in the rivers Struma, Dzerman and Mesta have a greater condition factor than these in the Stryama River. The condition factor of the chub in these three rivers is greater even than that of the chub in the Batak dam. The watershed of the rivers Struma, Dzerman and Mesta is at lower altitude then that of the Batak dam. The Mediterranean influence there is much greater and probably the growing conditions there are much better than these in the northern rivers and dams. Moreover the Struma River, a left tributary of which is the Dzerman River, is the sixth longest and the second by water quantity river from all the internal water courses in Bulgaria (Stoyanov et al. 1981, Uzunov and Kovatchev 2002). The condition factor of the chub in the Maritsa River is lower than this of the chub in the Struma River and its tributary the Dzerman River,

**Table 5. Condition factor of the Maritsa chub in different rivers.**

| River, Dam | Author/s and year | Equation of the whole population | Average weight ($W_L$, g) calculated with the same rounded lengths ($L$, mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | $W_{50}$ | $W_{100}$ | $W_{150}$ | $W_{200}$ | $W_{250}$ |
| Arda | Dikov et al. 1994 | $W = 0.00005L^{2.7522}$ | 2.3 | 16.0 | 48.8 | 107.6 | 198.8 |
| Stryama | Our data 2015 | $W = 0.000009L^{3.1154}$ | 1.8 | 15.3 | 54.2 | 132.7 | 265.9 |
| Struma | Dikov et al. 1994 | $W = 0.00003L^{2.9007}$ | 2.5 | 19.0 | 61.6 | 141.8 | 270.9 |
| Batak | Zivkov 1973 | $W = 0.000007L^{3.1662}$ | 1.7 | 15.0 | 54.3 | 135.1 | 273.8 |
| Mesta | Dikov et al. 1994 | $W = 0.00006L^{2.7793}$ | 3.2 | 21.7 | 67.0 | 149.1 | 277.2 |
| Maritsa | Stefanova et al. 2008 | $W = 0.0148L^{3.0595}$ | 2.0 | 17.0 | 58.7 | 141.5 | 280.1 |
| Struma | Michajlova 1964 | $W = 0.00001L^{3.1175}$ | 2.0 | 17.2 | 60.8 | 149.1 | 298.9 |
| Dzerman | Dikov & Zivkov 1985 | $W = 0.0116L^{3.05}$ | 2.2 | 18.6 | 64.1 | 154.3 | 304.7 |

Legend: $W_L$ – weight of the fish with rounded values of body length (50 to 250 mm).

regardless of its greater length growth rate (Stefanova et al. 2008) (Table 5).

The data shows that the chub condition factor in the tributaries of the Maritsa River- the rivers Arda and Stryama is the lowest (Dikov et al. 1994) (Table 5). And there is evidence that the feeding conditions there are worse than these in the other water bodies (Raikova-Petrova and Zivkov 1993, Zivkov 1999, Zivkov and Raikova-Petrova 2001).

## Conclusions

Considering our data on the population of the Maritsa chub in the Stryama River we reached to the following conclusions:

1. The chub population in the Stryama River is dominated by young and middle size groups, with length of 40–50 mm and 100–150 mm due to the elimination of larger fish;
2. The length growth of the chub in the Stryama River is the greatest in the first year;
3. The chub in the Stryama River has relatively slow length growth rate in comparison with the chub in the other water courses of the Aegean catchment area;
4. The condition factor of the chub in the Stryama River is one of the lowest in comparison with the ones of the chub in the other water courses in the Aegean catchment area.

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# AGE, GROWTH RATE AND CONDITION FACTOR OF THE MARITSA BARBEL (*BARBUS CYCLOLEPIS* HECKEL, 1837) IN THE STRYAMA RIVER

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## Abstract

A study of the Maritsa barbel in the Stryama River, a tributary of the Maritsa River was carried out. The material was collected in autumn from 2006 to 2011 by electrofishing. A total of 537 specimens of Maritsa barbel were caught. The population was represented by six age groups. The rate composition was simple. In the catch of the barbels in the Stryama River dominated third age groups. The dominating size group in the sample of barbel in the Stryama River was between 61–70 mm long. The relationship between the average values of *L* (standard length) and *S* (scale radius) was described by the equation: $L = 13.7486+2.8974 \cdot S$; correlation $r = 0.9694$. The barbel in the Stryama River reaches a smaller length than the barbel in the rivers Arda and Doirani. The relation between fish weight (*W*) and length in the population was represented by the equation: $W = 0.00002 \cdot L^{2.896}$; $r = 0.9996$. The Maritsa barbel in the Stryama River had a lower condition factor than the barbel in the rivers Arda and Maritsa.

**Key words:** *Barbus cyclolepis,* growth of weight, linear growth, size and age composition.

## Introduction

The Maritsa barbel (*Barbus cyclolepis* Heckel, 1837) is an endemic species for the Balkan Peninsula. The fish occurs in the Maritsa River and in its tributaries and also in some water courses of the Aegean watershed and the Black sea watershed on the territory of Turkey (Kottelat and Freihof 2007). The Maritsa barbel is one of the most numerous fishe in the middle zone of the Maritsa River tributaries in Bulgaria and also one of the favorite sport fishe in these water courses. The taxonomy of the species was examined by Marinov (1986). The author published some data for the length growth of the Maritsa barbel in the Cheinska River, a right tributary of the Maritsa River. The density, biomass, the growth rate and the condition of the Maritsa barbel in the Arda River, another right tributary of the Maritsa River, was studied by Dikov et al. (1994). Vasiliou and Economdis (2005) studied the ecology of the Maritsa barbel in the rivers of the Northern Greece. Raikova-Petrova and Rozdina (2007) and Rozdina (2009) presented data on the population biology of the Maritsa barbel from the Middle Stream of the Maritsa River.

The aim of the study was to compare the growth rate and the condition factor of the Maritsa barbel in the Stryama River with the results obtained for other rivers.

## Study Area

The study area includes the Stryama River, a left tributary of the Maritsa River coming from the Sredna Gora Mountains (Fig. 1). The Stryama River springs east of peak Vezhen in the Middle Balkan Mountains and flows between the Balkan and the Sredna Gora mountains. Its length is 110 km with a catchment area of 1,789 km$^2$. The river flows into Maritsa River near the village of Manole. Most of the Stryama River is in the Upper Thracian Valley and is characterized by small slope, although its average altitude is high.

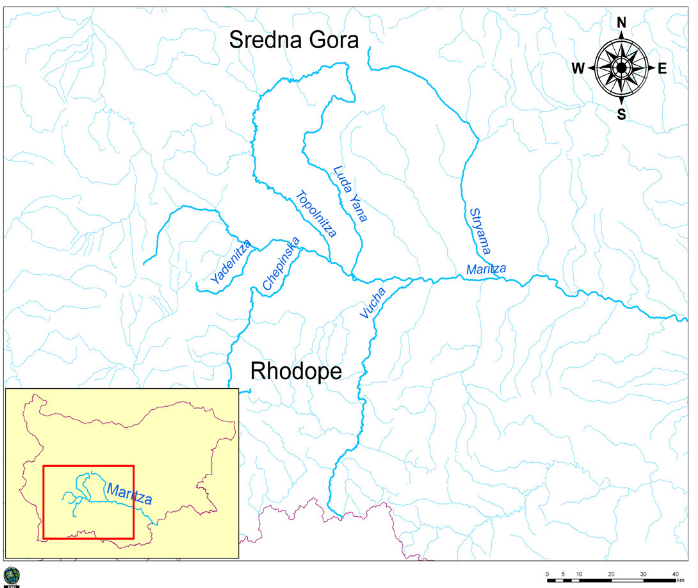


**Fig. 1. Location of the Sryama River, Arc Map 10.0 (ESRI – ArcGIS 2013).**

## Materials and Methods

In the period 2006–2011 537 pieces of Maritsa barbel were collected from the Stryama River by electrofishing. A SAMUS 725G converter was used, providing up to 640 V direct current (DC), frequency 50 Hz and output power reaching up to 200 W. The catch was performed according to the EN 14011:2004 instruction (Water quality – Sampling of fish with electricity). Fish for this study were caught mainly in autumn in four sampling areas (Table 1).

The standard length ($L$) with a precision of 1 mm and weight ($W$) with a precision of 1 g were measured. The age was determined by measuring the fish scales using an Olympus CX 31 microscope at a 40× magnification.

The identification of the species was made according to Kottelat and Freyhof (2007).

An estimation was made of the growth rate of the Maritsa barbel in different water bodies, comparing the average lengths of equal age specimens (Raikova-Petrova and Zivkov 1993, Zivkov 1999). The weight calculated for the specimens of fixed lengths (50, 100, 150, 200, 250, etc., mm) were used as condition factors of the different populations of the Maritsa barbel (Zivkov 1999).

Survival ($S = e^{-z}$) and annual mortality rate ($A = 1–S$) were calculated using

**Table 1. Sampling areas in the Stryama River.**

| No | Location | Geographic coordinates | | Altitude, m a.s.l. | Date of sampling |
|---|---|---|---|---|---|
| | | N | E | | |
| 1 | Near the bridge of the road Plovdiv-Rakovski | 42°15’07.29’’ | 24°50’21.05’’ | 174 | 16.11.2006 |
| 2 | Near the bridge of the road Plovdiv-Banya | 42°32’18.12’’ | 24°49’22.78’’ | 283 | 17.11.2006<br>17.04.2011 |
| 3 | Near the town of Banya next to the fish farm. | 42°33’39.11’’ | 24°47’45.81’’ | 302 | 17.11.2006<br>19.11.2006<br>19.10.2011<br>20.11.2011<br>16.12.2011 |
| 4 | Near the village of Rozino next to the bridge on the Stryama River | 42°41’29.46’’ | 23°34’00.57’’ | 478 | 26.10.2008 |

the equation describing the relationship between the number of fish in the catch and their age (Raikova-Petrova and Zivkov 1993, Zivkov 1999).

## Results and Discussion

The relation between the fish length ($L$) and the scale radius ($S$) is:

$$L = 13.7486+2.8974 \cdot S;\ r = 0.9694.$$

The decrease of mean logarithmic values of the Maritsa barbel’s abundance in the Stryama River is described by the slope regression:

$$\text{Ln } N\% = 4.8856+0.8184 \cdot t;\ r = 0.778;\ n = 537.$$

### Age and size composition

The third age group dominates in the catch. The second and the third age groups form over 50 % of the total catch of Maritsa barbel (Fig. 2). Obviously the greatest was the elimination in the fifth and the sixth age groups. The dominant size group in the sample was the group whith length between 61–70 mm (Fig. 3). The population is characterized with a relatively low survival ($S$ = 44.1 %) and higher annual mortality rate ($A$ = 55.9 %).

The largest specimen is 212 mm long and weights 130 g. The full length of the body of this specimen is 245 mm, the total weight is 146 g and it is five years old (Table 2). The oldest specimen is six years old, 167 mm long and weighs 60 g. Some authors have reported a greater variety of age groups of the Maritsa barbel. Raikova-Petrova (2007) and Rozdina (2009) have found that the maximum age of the barbel in the Maritsa River is 8 years. Vasiliou and Economidis (2005) identify 9 age groups of the Maritsa barbel in the two tributaries of the Vardar (Axios) River – Almopoios and Doirani, on the territory of Greece. It is normal to find to meet bigger fish in the main river than in its tributaries. The weak interest in fishing in the inland water flows in Greece seems to be the reason for the greater survival of the Maritsa barbel there and its higher life expectancy in comparison with the fish in the Stryama River. The third age group dominates in the catch. The dominant size group is 61–70 mm.

The Marisa barbel in the Stryama River is characterized by high rate of the unpredictable mortality and by short life span.

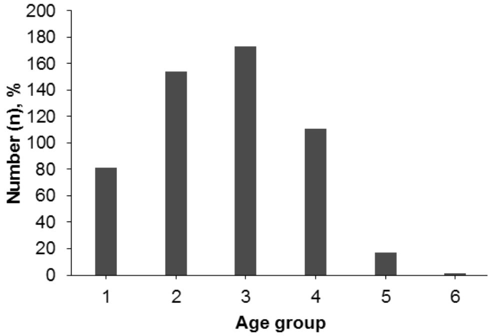


**Fig. 2. Age structure of the population of Maritsa barbel in the Stryama River.**

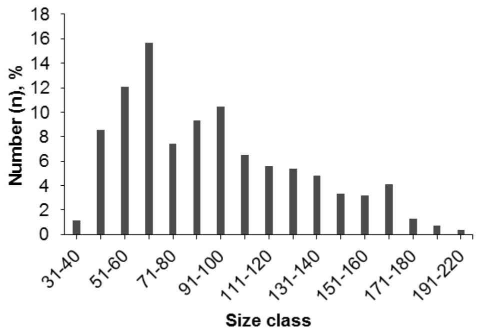


**Fig. 3. Size class of the population of Maritsa barbel in the Stryama River.**

Similar results for this species in the Doirani River has been reported by Vasiliou and Economidis (2005).

## Growth rate

The length Linear and the weight growth are shown in Tables 2 and 3. The Maritza barbel has the greatest lengh growth in the first year of its life. This is due to the fact that one year old fish are not yet sexually mature and use their reserves only for growth (Nikolsky 1965). In subsequent years, length growth is gradually increasing until the fifth year of the life of the fish. In the sixth year the length growth of the barbel slows down. This trend in lengh growth has been observed for the barbel from the Maritsa River too (Table 4) (Rozdina 2009). This is probably a sign of the start of the aging period (Nikolsky 1965).

The weight growth is characterized by a gradual increase to the fifth year

**Table 2. Back calculated body length of the Maritsa barbel in the Stryama River.**

| Generation | Age group | Back calculated body length (*L*, mm) of Maritsa barbel at the end of each year of the life, calculated from scales radius (*S*) | | | | | | Number |
|---|---|---|---|---|---|---|---|---|
| | | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | |
| 2011 | I | 51 | | | | | | 1 |
| 2009 | III | 55 | 67 | 83 | | | | 66 |
| 2008 | IV | 56 | 67 | 94 | 110 | | | 135 |
| 2007 | V | 63 | 76 | 99 | 131 | 152 | | 7 |
| 2006 | VI | 50 | 78 | 86 | 109 | 135 | 156 | 58 |
| 2004 | III | 45 | 53 | 66 | | | | 184 |
| 2003 | IV | 54 | 74 | 99 | 122 | | | 50 |
| 2002 | V | 57 | 67 | 93 | 122 | 153 | | 36 |
| Average body length ($L_{av}$), mm | | 54 | 69 | 89 | 122 | 147 | 156 | |
| Real length ($L_r$), mm | | 45 | n.d. | 69 | 112 | 159 | 165 | |
| Growth length ($t'$), mm | | 54 | 15 | 20 | 33 | 25 | 9 | |

Legend: n.d. – no data.

**Table 3. Back calculated body weight of the Maritsa barbel in the Stryama River.**

| Generation | Age group | Back calculated body weight ($W$, mm) of the Maritsa barbel at the end of each year of the life, calculated from body length ($L$, mm) | | | | | | Number |
|---|---|---|---|---|---|---|---|---|
| | | $W_1$ | $W_2$ | $W_3$ | $W_4$ | $W_5$ | $W_6$ | |
| 2011 | I | 1.8 | | | | | | 1 |
| 2009 | III | 2.2 | 3.9 | 7.3 | | | | 66 |
| 2008 | IV | 2.3 | 3.8 | 10.3 | 16.2 | | | 135 |
| 2007 | V | 3.3 | 5.5 | 11.9 | 27.3 | 41.6 | | 7 |
| 2006 | VI | 1.7 | 5.9 | 8.1 | 16.1 | 29.8 | 44.7 | 58 |
| 2004 | III | 1.2 | 2.0 | 3.7 | | | | 184 |
| 2003 | IV | 2.1 | 5.1 | 11.9 | 21.9 | | | 50 |
| 2002 | V | 2.5 | 3.8 | 10.1 | 22.1 | 42.5 | | 36 |
| Average body weight ($W_{av}$). g | | 2.1 | 2.1 | 4.3 | 9.0 | 22.0 | 38.0 | |
| Real weight ($W_r$). g | | 1.4 | 1.4 | n.d. | 5 | 19.6 | 56.4 | |
| Growth weight – ($t'$). g | | 2.1 | 2.2 | 4.7 | 13.0 | 16.0 | 6.7 | |

Legend: n.d. – no data.

of the life of the fish. The weight growth during the first year is the smallest. For the first year the length growth of the fish is greater than the weight growth. In the sixth year of the life of the Maritsa barbel the weight growth rate also decreases (Table 2 and 3). The data shows that the most rapid growth in length and weight of the Maritsa barbel has the 2007 generation. The next three generations of barbel in the Stryama River have a slower rate of growth in length and weight.

In the Stryama River Maritsa barbel reaches a shorter length in comparison with the two south – flowing rivers Arda and Doirani (Dikov et al. 1994, Vassiliou and Economidis 2005). This is probably due to a longer growing season, warmer winters and better growth conditions in the Arda and Doirani Rivers. In comparison with the

**Table 4. Comparison of average lengths of equal age Maritsa barbel in five rivers area from its habitat.**

| Author/s and year | River | Body length ($L$), mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | $L_7$ | $L_8$ | $L_9$ |
| Rozdina 2009 | Maritsa | 35 | 62 | 91 | 116 | 140 | 152 | 171 | 204 | |
| Our data 2015 | Stryma | 54 | 69 | 89 | 122 | 147 | 156 | | | |
| Vasiliou & Economidis 2005 | Doirani | 68.2 | 97.5 | 121.2 | 144 | 166 | 188 | 213.2 | 226.1 | 236.3 |
| Dikov et al. 1994 | Arda | 64 | 106 | 140 | 182 | | | | | |
| Marinov 1986 | Chepinska | 115 | 139 | 148 | | | | | | |

growth of the barbel in other rivers (Table 4) in the Stryama River the length growth of the Maritsa barbel is closest to this in the rivers Doirani, Arda and Chepinska. Barbel in Stryama River grows faster in length but slower in weight compared with barbel in the Maritsa River (Rozdina 2009).

### The condition factor

The condition factor is shown in Table 5. The populations of Maritsa barbel in the rivers Arda, Maritsa and Stryama are arranged according to their weight for 250 mm. The weight of the Maritsa barbel from the rivers Arda and Maritsa is greater than the weight of the barbel in the Stryama River for equal rounded lengths. The difference in the weight of the Maritsa barbel in the rivers Maritsa and Stryama increases proportionally with the lengths. While the differences in weight for the 50–100 mm long Maritsa barbel in the two rivers are only a few grams, the differences in weight for the 250 mm ones are about 100 grams. The Maritsa River has a low average altitude, its average slope is smaller, its average water temperatures are higher and its capacity is much higher compared to the Stryama River. Perhaps this has an effect on the growth conditions, the abundance of food and the availability of a better habitat. This fact is confirmed by a comparison with the data of Rozdina (2009). This is also shown in the study on the food components of the Maritsa barbel (Rozdina et al. 2008). The better conditions for the Maritsa barbel in the main course of the Maritsa River in comparison with those of the Stryama River are in accordance with the concept of the river continuum – in the lower part of the watercourse nutritional conditions are favorable, the number of fish is larger and they grow more rapidly (Uzunov and Kovatchev 2002). In terms of the Arda River, its watershed is much more to the south, and falling under the strong Mediterranean influence of the climate. It is likely that the warmer climate and the longer growing season lead to the better conditions of the barbel there.

The condition factor of the barbel from the Stryama River is lower than that of the barbel in the rivers Maritsa and Arda.

## Conclusions

Considering our data on the population of the Maritsa barbel in the Stryama

**Table 5. Condition factor of the Maritsa barbel in different rivers.**

| River | Author/s and year | Equation of thewhole population | Average weights ($W_L$, g) calculated with the same rounded lengths ($L$, mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | $W_{50}$ | $W_{100}$ | $W_{150}$ | $W_{200}$ | $W_{250}$ |
| Stryama | Our data 2015 | $W = 0.00002L^{2.896}$ | 1.7 | 12.4 | 40.1 | 92.2 | 176.0 |
| Arda | Dikovet al. 1994 | $W = 0.00002L^{2.9401}$ | 2.0 | 15.2 | 50.0 | 116.5 | 224.5 |
| Maritsa | Rozdina 2009 | $W = 0.0144L^{3.0588}$ | 2.0 | 16.5 | 56.7 | 137.4 | 271.9 |

Legend: $W_L$– weight of the fish with rounded values of the body length (50 to 250 mm).

River we reached to the following conclusions:

1. The third age group dominates in the catch of barbel from the Stryama River;

2. The dominant size group in the sample of barbel from the Stryama River is the group whith a length between 61–70 mm;

3. The population of the Maritsa barbel in the Stryama River is characteristic with a relatively low survival and short life span;

4. The barbel in the Stryama River has its greatest length growth in its first year of life;

5. The barbel from the Stryama River reaches a smaller length than the barbel in the rivers Arda and Doirani;

6. The condition factor of the barbel from the Stryama River is lower than that of the barbel in the rivers Maritsa and Arda.

## Acknowledgments

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# GYPSY MOTH OUTBREAKS IN FOREST COMPLEXES OF JABLANICA REGION (SOUTHERN SERBIA) IN THE PERIOD 1996–2014

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## Abstract

In the area of Jablanica Region (Public Enterprise Srbijasume, Forest Estate Leskovac), after a thirty-year period of latency, significant increase of gypsy moth population level occurred three times (1996–1997, 2002–2005 and 2011–2014). In the culmination phases, attacked areas were: 22,425 ha (1996), 38,856 ha (2004) and 18,272 ha (2013). The retrogradation phases occurred in the autumn of 1998, 2005 and 2014, so it was the result of effective aerial control in the larval instar with microbiological (Foray 48B) and biotechnical (Dimilin SC-48) insecticides as well as of the increased activity of natural enemies. The analysis of gypsy moth egg masses was made on a yearly basis. The average number of eggs ranged from 297.7 (1997; 320 investigated egg masses) to 507.2 (2013; 580 investigated egg masses). The percentage of vital eggs ranged from 89.5 in 2013 to 97.2 in 2012. Average parasitism of eggs ranged from 2.5 % in 2012 to 25.4 % in 2004. Every year only two species of egg parasites *Anastatus japonicus* Ashmead and *Oencyrtus kuwanae* (Howard) were present. Every year the ratio of them was relatively equal with the clear dominance of *O. kuwanae.* In the spring of 2012, 2013 and 2014, the increased mortality rate of larvae was reported and analysed. During the field research clear symptoms of disease caused by *Lymantria dispar* multicapsid nuclear polyhedrosis virus (*Ld*MNPV) and typical symptoms of the fungal diseases caused by *Entomophaga maimaiga* Humber, Shimazu and R. S. Soper were found on dead gypsy moth caterpillars. By microscopic analysis of dead caterpillars, the presence of *Ld*MNPV occlusion bodies, conidiospores and azigospores of *E. maimaiga* was confirmed.

**Key words:** control, egg masses analysis**,** *Lymantria dispar***,** natural enemies.

## Introduction

Gypsy moth (*Lymantria dispar* Linnaeus, 1758), insect from Lepidoptera order (Fam. Erebidae), is one of the major pests of broadleaf forests and orchards. It is characterised by high reproductive capacity, a considerable ecological plasticity and polyphagy. Although present in four continents (North Africa, Asia, Europe, North America), the most damage has been inflicted in the forests of Balkan Peninsula (Bulgaria, FYR Mecedonia, Serbia, Bosnia and Herzegovina, Croatia), Eastern (Romania) and Central Europe (Hungary, Slovakia, Czech Republic, etc), where all environmental conditions for its development are favourable (Tabakovic-Tosic 2004).

Damage caused by gypsy moth is twofold: both direct – defoliation or a loss of leaf mass caused by feeding of caterpillars, and indirect, manifested through the effects of defoliation. Defoliations caused by feeding of caterpillars lead to reduction of increment, lack of acorn crop, physiological weakening and drying of trees, as well as the creation of favourable conditions for attacks of phytopathogenic microorganisms, fungi and xylophagous insects, disruption of spatial aesthetics and other.

The gypsy moth is characterized by cyclical abundance of fluctuations resulting in defoliation of large forest areas (Villemant and Fraval 1998, McManus and Csóka 2007, Tabakovic-Tosic 2013). The occurrence of an outbreak, on one hand, depends on a gypsy moth physiological constitution, and on the other, on impact of external factors – type and quality of food, geographical gradients, meteorological conditions and biotic factors (diseases, natural enemies – mainly *Entomophaga maimaiga* Humber, Shimazu, and R. S. Soper, and competitor species) (Csóka 1997; Klapwijk et al 2013; Marovic et al. 1998; McNamara 1996; Mihajlovic et al. 1998; Tabakovic-Tosic 2012, 2013, 2014a, 2014b; Vanhanen et al 2007; Weiser 1987). Studies on gypsy moth outbreak periodicity conducted in Europe, North America, and Asia suggested oscillation cycles between 4 and 12 years (Hlásny et al. 2015; Johnson et al. 2005, 2006; Marovic et al. 1998; Tabakovic-Tosic and Jovanovic 2007; Weiser 1987).

## Material and Method

Jablanica region (administrative districts: Leskovac, Predejane, Vlasotince, Vucje, Lebane, Bojnik, Medvedja) is located in the southeastern part of Serbia and covers an area of 2,769 km$^2$, with forest complexes spreading over 113,831 hectares, out of which 40,566 ha or 35.6 % is in state, and 73,265 or 64.4 % in private ownership (timber volume amounts to 6,898,554 m$^3$). This area is a natural habitat for deciduous tree species (*Quercus cerris L., Quercus petraea* Liebl., *Quercus frainetto* Ten., *Fagus sylvatica* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Fraxinus ornus* L. and other).

Gypsy moth population control measures were ordered in all deciduous forests every year, regardless of their ownership category (state or private), and in accordance with the Instructions supplied by the officials responsible for Report-diagnostic forecast in the domain of plant protection – forest protection. Gypsy moth population survey in forests was carried out by means of a permanent (25×25 m) and a temporary (10×10 m) sample plot method, as well as a transect method. Permanent sample plots were surveyed every year, whereas temporary sample plots were surveyed only when population increase seemed apparent. The transect method and pheromone trap method were applied as additional measures during gypsy moth latency (low population density) period, whereas they were invariably used during the outbreak period.

A detailed quantitative and qualitative analysis of sampled egg masses was conducted at the laboratory of the Institute of Forestry and, depending on the parameter analysed, the visual method or the method of binocular magnifying glass examination was applied. Additionally, the dynamics of emerging gypsy moth egg parasitoid imagoes from previously analysed masses was monitored in the laboratory conditions in winter period.

100 randomly sampled, previously cleaned eggs from each egg mass were placed in specially prepared test tubes – with distilled water at the bottom and a cotton wool layer in the middle, intended to prevent a total immersion of eggs. The test tubes with sampled gypsy moth eggs were held in a climate chamber. During the experiment, the air temperature

and the light regime were constant (the temperature 19 °C, the light regime – 10 hours night, 14 hours day). The recording of emerging parasitoids was conducted daily until it ceased.

A survey of main predators, parasitoids and pathogens was conducted from May to late November by using the method of hunting, typical for some families to which the insects belong (different kinds of traps, manual method, and method of mowing by using the entomological net).

For different laboratory analyses, from all sites, in the summer and autumn of the period 2010–2014, dead gypsy moth larvae were collected manually from foliage in the lower parts of tree crowns and tree branches and trunks, two to three times per year.

Microscopic (magnification 1200 times) analyses of some dead gypsy moth larvae with typical symptoms caused by *L. dispar* multicapsid nuclear polyhedrosis virus (*Ld*MNPV) was conducted immediately using the standard method of Giemsa's differential staining.

The dead larvae with typical symptoms caused by the entomopathogenic fungus *E. maimaiga* were also placed in Petri dishes and detailed microscope survey of the cadavers was done later. The evaluation of *E. maimaiga* infections was recorded as positive when azygospores and conidiospores were detected in the cadavers of dead gypsy moth larvae. The species identification was based on the size, shape and structural characteristics of different life forms of the fungus – azygospores, conidiospores and mycelia.

## Results and Discussion

In the course of those investigations, during the process of establishing the number of gypsy moth egg masses per surface unit (1 hectare), particular attention was paid on inclusion of all forests complexes. This aspect was of major importance for the areas in which occurrence of a particularly intense attack was observed (over 500 egg masses per hectare), as the amount of damage manifested through leaf mass injury, to be caused by hatched larvae, is not the same under the attack of 501 and, for instance, 50,000 egg masses per hectare.

As can be seen from the data in Table 1, in the area of Jablanica Region (Public Enterprise Srbijasume, Forest Estate Leskovac), after the thirty-year period of latency, the significant growth of gypsy moth population level occurred three times (1996–1997, 2002–2005 and 2011–2014). In the culmination phases, attacked areas were: 22,425 ha (1996), 38,856 ha (2004) and 18,272 ha (2013). The retrogradation phases occurred in the autumn of 1998, 2005 and 2014, so it was a result of effective aerial control in the larval instar by microbiological (Foray 48B in 1998 and 2014) and biotechnical (Dimilin SC-48 in 2005) insecticides as well as of the increased activity of *E. maimaiga* (primarily), *Ld*MNPV and other gypsy moth natural enemies (parasites and predators).

Mechanical and chemical suppression measures undertaken in the egg stadium, did not produce satisfactory results. In the summer period of 2004, air-suppression in the larval instar was conducted by means of a biological preparation D-stop (active ingredient: spores and crystals *Bacillus thuringiensis* ssp. *kurstaki* Berliner, 1915), which also proved ineffective. A partial or total defoliation occurred in the entire area. On the account of an enormous number of voracious larvae and lack of food, a large number of caterpillars died,

**Table 1. Outspread of gypsy moth in the forests of Jablanica region in the period 1996–2014.**

| Year | Attack intensity and attacked area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low intensity 1–10* egg masses | | Medium intensity 11–100 egg masses | | High intensity 101–500 egg masses | | Severe intensity over 500 egg masses | | Total, ha |
| | ha | % | ha | % | ha | % | ha | % | |
| 1996 | 1,917.00 | 8.55 | 4,190.00 | 18.68 | 4,886.00 | 21.79 | 11,432.00 | 50.98 | 22,425.00 |
| 1997 | 5,327.00 | 27.27 | 3,903.00 | 19.98 | 10,016.00 | 51.28 | 287.00 | 1.47 | 19,533.00 |
| 1998–2002 – gypsy moth latency period | | | | | | | | | |
| 2002 | 163.00 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 163.00 |
| 2003 | 6,453.00 | 42.35 | 7,782.00 | 51.07 | 25.00 | 0.16 | 979.00 | 6.42 | 15,239.00 |
| 2004 | 2,373.00 | 6.11 | 6,419.00 | 16.52 | 3,920.00 | 10.09 | 26,144.00 | 67.28 | 38,856.00 |
| 2005–2010 – gypsy moth latency period | | | | | | | | | |
| 2011 | 100.14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 100.14 |
| 2012 | 2,063.37 | 59.21 | 1,295.82 | 37.20 | 125.00 | 3.59 | 0 | 0 | 3,484.19 |
| 2013 | 1,434.60 | 7.85 | 5,686.51 | 31.12 | 1,398.16 | 7.65 | 9,752.70 | 53.38 | 18,271.97 |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: * Number of oviposited egg masses per one hectare at the end of summer period.

but nevertheless, a sufficient number of them remained, continuing their development. In autumn of 2004, newly-laid gypsy moth egg masses were found in the area of 38,856 ha. Following the partial elimination of egg masses, performed in the autumn-winter period in spring of 2005, a repeated air-suppression was conducted, but this time a third generation chemical insecticide Dimilin SC 48 (active ingredient diflubenzurone) was selected.

The analysis of gypsy moth egg masses, collected in Jablanica region (Table 2), was conducted every year during the investigation period. The average number of eggs in an egg mass ranged from 297.7 (1997; 320 investigated egg masses) to 507.2 (2013; 580 investigated egg masses). The percentage share of vital eggs in the total number of eggs ranged, on average, was from 89.5 % in 2013 to 97.2 % in 2012. The average egg parasitization rate ranged from 2.5 % in 2012 to 25.4 % in 2004. The above-stated parasitization values should not be considered final, as they concern laboratory conditions, which prevent the activity of a number of parasites and predators, to which egg masses are exposed in nature.

The results of analysed quantitative and qualitative parameters of gypsy moth egg masses confirm the above-stated assertion that the increase of gypsy moth population density above normal values in the forest area of Jablanica region in the period 1996–2014 occurred three times.

The dynamics of emerging parasite imagoes from the previously analysed egg

**Table 2. Laboratory analysis of gypsy moth egg masses.**

| Year | Number of egg masses | Average number of eggs in an egg mass | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Fertilised | | | | Unfertilised | | Total |
| | | Vital | | Parasitised | | | | |
| | | Number | % | Number | % | Number | % | Number |
| 1996 | 370 | 291.3 | 90.0 | 29.8 | 9.2 | 2.6 | 0.8 | 323.7 |
| 1997 | 320 | 278.5 | 93.5 | 15.7 | 5.3 | 3.5 | 1.2 | 297.7 |
| 1997–2002 gypsy moth latency period | | | | | | | | |
| 2003 | 239 | 417.8 | 93.6 | 25.5 | 5.9 | 2.0 | 0.5 | 445.3 |
| 2004 | 154 | 406.4 | 92.3 | 31. | 25.4 | 2.7 | 0.6 | 440.3 |
| 2005–2010 gypsy moth latency period | | | | | | | | |
| 2011 | 100 | 393.4 | 90.5 | 36.4 | 8.4 | 4.7 | 1.1 | 434.5 |
| 2012 | 53 | 439.3 | 97.2 | 11.4 | 2.5 | 1.1 | 0.3 | 451.8 |
| 2013 | 580 | 456.2 | 89.5 | 4 7.0 | 9.7 | 4.1 | 0.8 | 507.2 |

masses was monitored in special trials. Only two egg parasites species *Anastatus japonicus* Ashmead (syn. *A. disparis* Ruschka) and *Oencyrtus kuwanae* (Howard) were present every year. Their ratio was relatively consistent in every year – 33 % : 67 % (±2 %), with clear domination of *O. kuwanae.*

During the observed period, at the sample plots, gypsy moth eggs were attacked by seven predator species [*Trombidium holosericeum* (Linnaeus, 1758); *Forficula auricularia* Linnaeus, 1758; *Carabus latus* Dejean, 1826; *Dermestes erichsoni* Ganglbauer, 1904; *Julistus floralis* (Olivier, 1790); *Malachus bipustulatus* (Linnaeus, 1758); *Formica sp.*], larvae by six [*Silpha quadripunctata* Schreber, 1759; *Carabus coriaceus* (Linnaeus, 1758); *C. cancellatus* (Linnaeus, 1758); *C. cavernosus* Frivaldsky, 1837; *C. intricatus* (Linnaeus, 1758); *C. scabriusculus bulgarus* Lapouge, 1908] and larvae and pupae by two [*Calosoma sycophanta* (Linnaeus, 1758); *C. inquisitor* (Linnaeus, 1758)]. Regarding the density of some predator species, *Trombidium holosericeum, Forficula auricularia*, *Silpha quadripunctata*, *Calosoma sycophanta* and *Carabus* sp. were most abundant ones. *Calosoma sycophanta*, which regularly occurs during gypsy moth outbreak,was found more frequently than other predator species, and it reduced its population size both in the larval and imago instars.

There were two parasitic species of gypsy moth eggs [*Anastatus japonicus* Ashmead, 1904; *Oencyrtus kuwanae* (Howard, 1910); fourteen parasitic species of gypsy moth larvae [*Phobocampe disparis* (Viereck, 1911); *P. pulchella* (Thomson, 1887); *Apanteles glomeratus* (Linnaeus, 1758); *Cotesia melanoscela* (Ratzeburg, 1844); *C. ocneriae* (Ivanov, 1898); *C. scabricula* (Reinhard, 1880); *Protapanteles liparidis* (Bouček, 1834); *P. porthetrie* Muesebeck, 1954; *P. fulvipes* (Haliday, 1834); *Meteorus versicolor* (Wesmael, 1835); *Exorista larvarum* (Linnaeus, 1758); *Parasetigena silvestris* (Robineau-Desvoidy, 1863); *Compsilura concinnata* (Meigen, 1824); *Blepharipa pratensis* (Meigen, 1824)] , and four parasitic species of the gypsy moth pupae [*P. inquisitor* (Scopoli, 1763); *P. turionellae* (Linnaeus, 1758); *Lymantrichneumon disparis* (Poda, 1761); *Brachimeria intermedia* (Nees, 1834)]. The cocoons of parasitic species from the families Braconidae and Tachinidae were regularly found in spring. Other species were considerably less frequent and were found individually.

During the field research in the spring of 2012, 2013 and 2014, at sample plots in the oak and beech forests, the increased mortality rate of younger and older larval instars in comparison with the expected one was reported and clear symptoms of disease caused by *Ld*MNPV and characteristic symptoms of fungal diseases caused by *E. maimaiga* were found on dead gypsy moth caterpillars.

By detailed microscopic analysis, the presence of *Ld*MNPV occlusion bodies, conidiospores and azigospores of entomopathogenic fungus *E. maimaiga* was confirmed. *Ld*MNPV occlusion bodies were observed in 7.1 (2012) and 16.3 (2013) percent of the dead older caterpillars ($L_4$–$L_6$). Conidiospores and azigospores of *E. maimaiga* were at 90.5 (2012), 80.1 (2013) and 90.9 (2014) percent of the reported dead gypsy moth larvae. In the early spring of 2014, the largest number of gypsy moth larvae died in the second instar.

Bulgaria has been the second in the world and the first in Europe country in which *E. maimaiga* was introduced successfully (Pilarska et al. 2006). For a period of 10–12 years it expanded its range (naturally and by introductions) and is now found throughout Bulgaria (Mirchev et al. 2013). This entomopathogenic species has slowly spread along the Balkan Peninsula and Southeast Europe, and so far its presence has been reported also in European part of Turkey (Georgiev et al. 2012), Serbia (Tabakovic-Tosic et al. 2012, 2013), Greece, FYR Macedonia (Georgieva et al. 2013), Croatia (Hrašovec et al. 2013), Hungary (Csóka et al. 2014), Slovakia (Zúbrik et al. 2014), Bosnia and Herzegovina (Milotić et al. 2015). Regarding the situation in Serbia, *E. maimaiga* was introduced or found in many places of the country (Tabaković-Tošić 2014a, 2014b). In the forests area of Jablanica region this entomopathogen was spread naturally from Bulgaria.

## Conclusions

In the forest area of Jablanica region (Southern Serbia) in the period 1996–2014, the increase of gypsy moth population density above the normal level occurred three times. Natural enemies of gypsy moth, as well as the control measures undertaken in egg and larval stadium, although adequately prepared and timely applied, did not always produce satisfactory results (first and second outbreak).

In 1998, 2005 and 2014, regressive phases occurred as a result of a successful gypsy moth suppressions in the larval stadium, as well as the increased activities of gypsy moth natural enemies – predators, parasites and pathogens. Disease caused by pathogens – *Ld*MNPV and fungus *E. maimaiga* especially, the most contributed to the decline of gypsy moth in broadleaf forests of Jablanica region.

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# NATURAL AND ARTIFICIAL REGENERATION OF MONTANE *PICEA ABIES* FORESTS IN A CLEARED WINDTHROW AREA IN VITOSHA NATURE PARK

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## Abstract

The regeneration of montane Norway spruce (*Picea abies* (L.) Karst.) forests is among the most challenging silvicultural issues due to the extreme climatic conditions at high altitudes, particularly after large-scale natural disturbances. The aim of the study was to compare the development of the natural and artificial regeneration in the period 2006–2014 in a cleared windthrow area of 14 ha, which resulted from a wind-disturbance in 2001. The study area was situated in Ofeliite site, Vitosha Mountain, West Bulgaria. The forest regeneration was studied in 16 permanent sample plots of size 10 m × 10 m (100 m$^2$). We found that the intensity of natural regeneration decreased significantly five years after the windthrow. Dominant species was *Picea abies*, which regenerated most frequently on decaying deadwood. The artificial regeneration had 5 times lower numbers than the natural one. This could be due to the low planting density and the higher mortality rate of planted spruce seedlings in comparison to the naturally established ones. The risk of mortality was highest among saplings lower than 0.5 m. The main reasons for the observed mortality were the withering and suppression by other plant species such as *Rubus ideaus* L. and *Calamagrostis arundinacea* (L.) Roth. Our results suggest that the natural regeneration was more important than the artificial planting for the restoration of the wind-disturbed spruce forest in Ofeliite site. In this respect, sustaining abundant seedling bank as well as sufficient quantities of decayed deadwood as regeneration substrate and microhabitat in the managed spruce forests can help adequate natural regeneration after large-scale disturbances.

**Key words:** montane Norway spruce, mortality, natural regeneration, plantation, regeneration substrate, wind disturbance.

## Introduction

Wind disturbances form an integral part of the natural dynamics of Norway spruce (*Picea abies* (L.) Karst.) forests in Europe (Korpel 1995, Panayotov et al. 2011, Svoboda et al. 2010, 2012, 2014, Ulanova 2000, Wohlgemuth et al. 2002). Dependent on their magnitude, the impact of wind disturbances can vary from the creation of forest gaps to the emergence of larger windthrow areas. In recent decades an increasing number of large-scale windthrows in the Norway spruce forests was reported all over Europe (Schelhaas et al. 2003), which can be associated with the increased frequency of weather extremes such as wind storms and droughts (Dale et al. 2001, Schlyter et al. 2006). In Bulgaria the last large windthrow took place in Vitosha

Nature Park in 2001 affecting a total of 74 ha of Norway spruce forests (Dountchev et al. 2014). It was followed by a bark beetle outbreak which killed another 181 ha spruce forests in reserve non-intervention territories and 63 ha in managed forests, which were cleared and replanted.

After severe wind disturbances the most important question is how to reduce the calamity risk and to accelerate the forest restoration (Brang et al. 2006, Schönenberger 2002). Traditionally the silvicultural measures after natural disturbances include salvage logging and replanting of the cleared areas. In the high mountain zone the replanting is considered as a key measure for forest restoration since the tree regeneration processes in open areas can be slow as a result of the unfavourable ecological conditions and the effective suppression by the dense vegetation cover (Brang et al. 2006, Dimitrov 1999, Milev and Iliev 2000, Pavlov et al. 1996, Wohlgemuth et al. 2002). Unfavourable environmental factors such as climatic extremes, drought and suppression by grass or shrub vegetation can have negative impact also on the survival of planted trees (Frehner 2002, Jonsson 1999, Milev and Iliev 2000, Penev and Marinov 1964, Schönenberger 2002).

Recent studies showed, however, that the natural regeneration can play key role in the recovery of wind disturbed spruce forests (Dimitrov 1999, Jehl 2001, Jonášová et al. 2010, Wohlgemuth et al. 2002). A precondition for abundant spruce recruitment is the availability of sufficient advance regeneration, as well as the presence of appropriate regeneration substrates such as decayed deadwood and exposed mineral soil when seed sources are available (Brang et al. 2006, Holeksa et al. 2012, Kuuluvainen and Kalmari 1993, Penev and Marinov 1964, Zielonka 2006). Moreover, the natural regeneration is considered as more sustainable and economically advantageous option for forest restoration in comparison to artificial plantations (Schönenberger 2002).

In spite of the existing information about these advantages of natural over artificial regeneration, there are still some debates mostly concerning whether this advantage is valid also under the conditions of Vitosha Mountains (Naidenov 2006).

Therefore, our aim was to compare the development of the natural and the artificial regeneration in a cleared windthrow area and to make recommendations for enhancement of the effectiveness of the restoration measures after wind disturbances in montane *Picea abies* forests. For this purpose we studied the regeneration dynamics 5 years and 13 years after a wind disturbance in 2001 and examined the effect of the microsites on the establishment and growth of the *Picea* saplings.

## Material and Methods

### Study site

The study site is situated at an altitude of 1500–1700 m a.s.l. in the mountain valley of Vladaiska river in Vitosha Nature Park, South-Western Bulgaria (42°33' N; 23°18' E). The site is named “Ofeliite” (Fig. 1) and falls within a forest complex of 700 ha dominated by Norway spruce (*Picea abies* (L.) Karst.), to lesser extent European beach (*Fagus sylvatica* L.) and small share of *Salix caprea* L., *Sorbus aucuparia* L. and *Betula pendula* Roth. According to the formerly used Russian approach for classification (Aleksandrova 1978), the forest communities in the study area belong to the associations *Piceetum calamagrostosum, Piceetum myrtilloso-calamagrostosum* and *Piceetum Fageto herbosum* (Pavlov and Dimitrov 1995). No special phytosociological studies following Braun-Blanquet approach were done in Vitosha, but the Norway spruce communities in Rila were classified into alliance *Piceion excelsae*, subaliances *Eu-Piceenion* and *Abieti-Piceenion* (Roussakova and Dimitrov 2005). The mean age of the stands is 120 years. Having predominantly homogeneous structure, the forests are considered to be in the self-thinning phase. The bedrock is formed by syenite rocks and is covered by Dystric and Umbric Cambisols. In some areas the soils lie on large spherical syenite blocks and therefore the rooting depth is limited.

The average annual temperature at 1700 m a.s.l. is 4.0 °C, ranging from a mean monthly temperature of –5.2 °C in January to +12.9 °C in July–August. The annual precipitation is 1060 mm with a maximum in May–June and a minimum in August–September. The snow cover reaches up to 100 cm and lasts less than 150 days.

In 2001, nearly 14 ha of the Norway spruce forests in the area were blown down by a wind storm. The windthrow area (NW exposure) was subject to salvage logging. After 2003 the adjacent forest stands were clear cut as a sanitary measure against the bark beetle outbreak which followed the windthrow. The salvage logging was followed by artificial reforestation of the cleared area which took place in the period 2003–2008. The technological plans recommended planting of 2500–3000 2-year-old Norway spruce saplings per hectare in the cleared windthrow area. Information about the origin of the saplings was either not provided or limited to the name of the forest nursery – Godech, Pirdop or Samokov. The planting was prescribed to be carried out in the spring period, whereby the saplings should be planted without a planting scheme in 30-cm-deep hand-made holes. The cultivation measures included removal of the suppressive grass vegetation, as well as additional planting in areas with high saplings' mortality.

## Data Collection and Analysis

In 2006, the 14-ha windthrow area at the study site was identified by GPS measurements and subsequently mapped in GIS using ArcGIS 10 software (ESRI Inc.). In the same year we established 16 permanent sample plots of size 10 m × 10 m (100 m$^2$) (Fig. 1). Tree recruitment, field vegetation and regeneration microsites

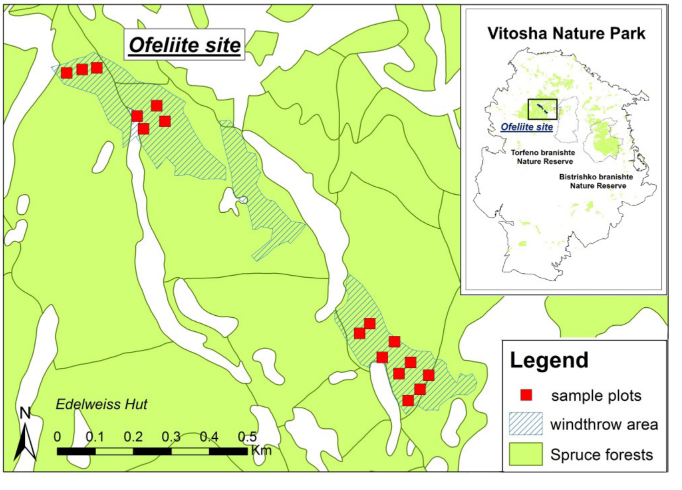


**Fig. 1. Study site.**

were scored in each sample plot in 2006 and 2014, following methodologies applied by Fischer et al. (2002), Jehl (2001) and Siegrist (2000). First, we made a record of the species composition, density, height and the type (i.e. natural or artificial) of the tree recruitment. The planted saplings were distinguished by the presence of planting holes. Further, the coverage of the main types of microsites (e.g. windthrow mounds, decayed deadwood, litter, bare ground, vegetation cover and rocks) were estimated on basis of subplots of 1 m$^2$ and the type of regeneration substrate of each *Picea abies* sapling was determined. The regeneration was classified into 6 height groups: <10 cm, 11–25 cm, 26–50 cm, 51–100 cm, 101–150 cm and >151 cm. The average mortality rate was estimated as a ratio of the number of saplings, which have not survived in the period 2006–2014 compared to all saplings registered in 2006.

The normality of data distribution was checked by Shapiro-Wilk test. The normality tests showed that all data had non-normal distribution requiring non-parametric tests to be applied for statistical analyses. Mann-Whitney rank sum test was used to check for significant differences between the natural and artificial regeneration. Wilcoxon Signed Rank tests were applied to check for changes in *Picea* regeneration during the period of the study. Chi-square test was used to check for significant differences in the mortality levels between natural and artificial regeneration.

## Results

### Regeneration dynamics

Thirteen years after the disturbance, the regeneration registered in the sample plots was formed by both naturally established and planted saplings. The natural regeneration consisted of 7 tree species. Most abundant were *Picea abies* (831 ha$^{-1}$ or 56.8 %), *Sorbus aucuparia* (319 ha$^{-1}$ or 21.8 %), *Salix caprea* (150 ha$^{-1}$ or 10.3 %) and *Fagus sylvatica* (100 ha$^{-1}$ or 6.8 %). Typical pioneer species such as *Betula pendula*, *Populus tremula* L. and *Pinus peuce* Griseb. had altogether nearly 4 % participation (Fig. 2). The artificial plantation consisted exclusively of *Picea abies* saplings (375 ha$^{-1}$).

The regeneration dynamics and the effectiveness of the planting activities were

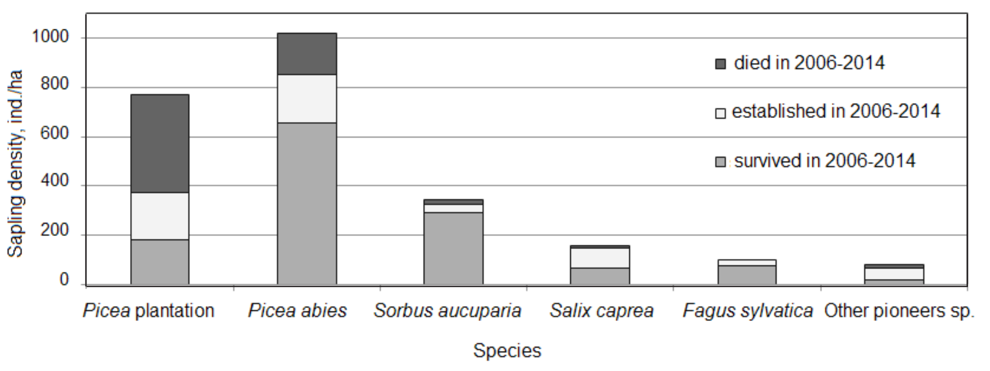


**Fig. 2. Sapling density in the windthrow area in 2014.**

assessed by comparison of the regeneration numbers in 2006 and 2014. In 2006 the total regeneration numbers in the sample plots were on average 1919 ha$^{-1}$. The natural regeneration accounted for 1344 saplings per 1 ha (of which 825 ha$^{-1}$ were *Picea abies*), while the artificial plantation was significantly lower – 575 ha$^{-1}$ (Mann Withney test, $p$=0.009). In 2014 the total regeneration numbers decreased slightly to 1863 saplings ha$^{-1}$, consisting of 1488 ha$^{-1}$ natural regeneration (of which 831 ha$^{-1}$ were *Picea abies*) and 375 ha$^{-1}$ planted saplings. The increase in the natural regeneration from 1344 to 1488 ha$^{-1}$ was not significant (Wilcoxon Signed Ranked test, $p$=0.6) and was attributed to the establishment of 369 saplings per 1 ha after 2006 – mainly *Picea abies* (200 ha$^{-1}$) and *Salix caprea* (81 ha$^{-1}$). Yet, we found that 213 saplings per 1 ha which had been registered in 2006 had not survived by 2014. This indicated an average mortality rate of 16 % for the study period, with highest values for *Betula pendula* (50 %) and *Picea abies* (20 %) (Fig. 2).

The comparison of the height structure of the natural regeneration in 2006 and 2014 (Fig. 3a, 3b) showed that during the study period all species exhibited a clear shift in the regeneration numbers from the lower height classes to the higher ones. For instance, the number of the *Picea* saplings in the first two height classes differed significantly between 2006 and 2014 – 362 ha$^{-1}$ and resp. 50 ha$^{-1}$ (Wilcoxon Signed Ranked test, $p$=0.002).

The number of registered planted saplings in the artificial plantation dropped

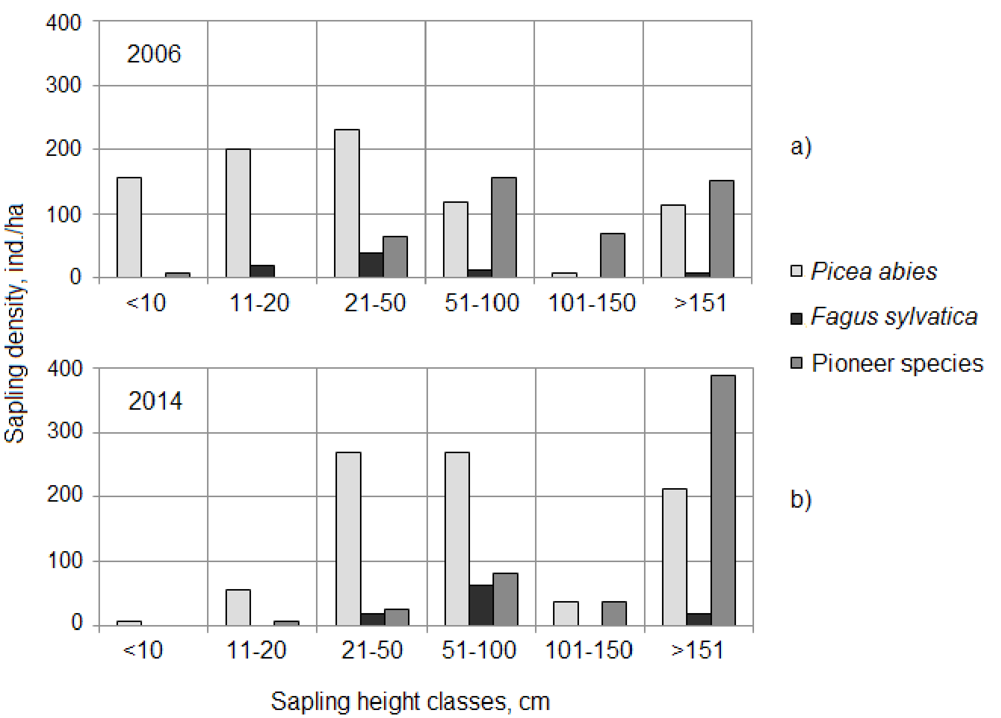


**Fig. 3. Height structure of the natural regeneration in: a) 2006 and b) 2014.**

from 575 $ha^{-1}$ in 2006 down to 375 $ha^{-1}$ in 2014. Even if another 200 saplings per 1 ha were planted additionally in the period 2007–2014, the number of the saplings which died in this period was twice higher – 394 saplings per 1 ha. By 2014 the number of planted saplings in the sample plots varied between 0 and 2000 $ha^{-1}$.

## Mortality of *Picea abies* saplings

Mortality of the dominant species *Picea abihes* was registered in saplings with height up to 1 m. It was highest for individuals lower than 20 cm in 2006 and varied per sample plot between 0 % and 86 % (Fig. 4a). Yet, the mortality rate of the natural *Picea* regeneration (<1 m height) was significantly lower than that of the artificially planted – 24 % vs. 69 % (Chi-square test $p$=0). The mortality rate of the planted saplings was highest among individuals that were lower than 50 cm in 2006 (Fig. 4b) and it varied per sample plot between 33 % and 100 %.

The highest mortality rates of the natural *Picea* regeneration were found among saplings that had been registered in 2006 on stones covered by thin organic layer (86 %) and on windthrow mounds (50 %), whereas lower mortality rates were regis-

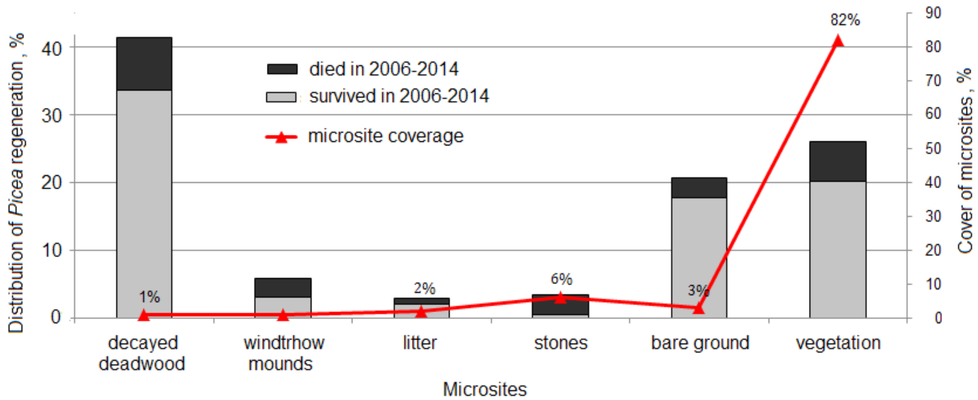


**Fig. 4. Mortality of *Picea* regeneration per sapling height classes: a) natural regeneration; b) artificial regeneration.**

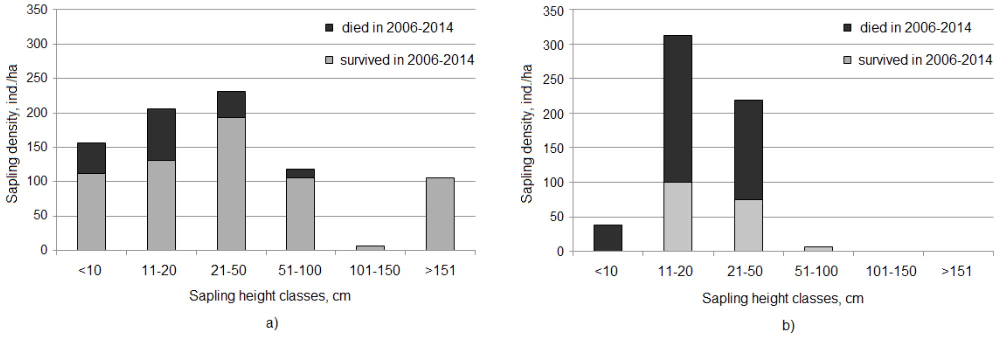


**Fig. 5. Distribution of the natural *Picea* regeneration per substrate type.**

tered on litter (30 %), vegetation covered ground (22 %), decayed deadwood (19 %) and bare ground (14 %) (Fig. 5). It was assessed that the critical factor for 67 % of the saplings, which have not survived in the period 2006–2014, was drought, for 8 % – erosion of the soil layer on mounds, and for the remaining 25 % the mortality factors were not identified.

All planted *Picea* saplings that did not survive in the period 2006–2014 were found in patches of grass and shrub vegetation dominated by *Calamagrostis arundinacea* or *Rubus ideaus*, and in areas with excessive soil moisture – *Juncus effusus* L. In 10 % of the mortality cases the planted saplings were missing, what was considered as indication for frost heaving. In the other 90 % of the mortality cases the saplings either showed signs of damages as result of careless cultivation or seemed to have withered.

### Regeneration substrates of *Picea abies*

In 2006, 74 % of the naturally established *Picea* saplings with height <50 cm were observed on vegetation-free substrates such as decayed deadwood, bare ground, windthrow mounds and litter (Fig. 5). The highest regeneration densities were registered on decayed deadwood and on bare ground – 269 per 100 $m^2$. Despite its extremely low coverage of less than 1 % (e.g. <5–10 $m^3$/ha) this substrate hosted 41 % of all *Picea* saplings, often forming groups of individuals. On vegetation-free substrates such as bare ground and windthrow mounds we found 45 and 38 saplings per 100 $m^2$, respectively. In contrast, the regeneration density on vegetation covered ground was 2 saplings per 100 $m^2$, situated individually. In 2006 this microsite covered 82 % of the area of the sample plots but accounted for only 26 % of all *Picea* saplings. In 2014, the distribution of the *Picea* regeneration among the regeneration substrates did not change considerably, as the vegetation-free substrates hosted 68 % of all *Picea* saplings compared to 74 % in 2006.

## Discussion

### Regeneration dynamics

Our results showed that the wind disturbance and the subsequent salvage logging did not lead to considerable changes in the species composition of the disturbed Norway spruce forest. Most abundant was the tree recruitment of species such as *Picea abies* and *Sorbus aucuparia,* which are characteristic for this type of climax forest. This is not surprising since these species rely both on advance and post-disturbance regeneration in order to persist after natural disturbances such as windthrows and bark beetle outbreaks (Jehl 2001, Schönenberger 2002, Żywiec and Ledwoń 2008). Moreover, before the outbreak of the bark beetles in 2003, the cleared area had a maximal width of 150 m and was compact enough for the wind-dispersal of the *Picea abies* seeds, which is most intensive up to 100–200 m from the intact forest edge (Lässig et al. 1995).

However, the dominance of *Picea abies* and *Sorbus aucuparia* was not actually a result of high regeneration numbers, assessed at less than 1500 $ha^{-1}$ in 2014. In contrast to the general knowledge about forest succession, we found that in the cleared winthrow area the recruitment of pioneer species was rather limited. The regeneration numbers of species such as *Pinus* sp., *Salix* sp., *Populus tremula* or *Betula pendula* did not exceed altogether 300 $ha^{-1}$ in 2014. This was opposite to observations in windthrow areas situated at lower altitudes (Fischer et al. 2002, Ilisson et al. 2007, Moćalov and Lässig 2002, Pavlov et al. 1996, Siegrist 2000) where the milder climatic conditions favoured more abundant tree regeneration and higher participation of pioneer species. Moreover, except for *Salix caprea,* all other pioneer species were represented by a negligible number of seeding trees in the adjacent forest stands. This, in our view, limited their specific potential to populate disturbed areas including microsites with exposed mineral soil created by the uprooting of wind-felled trees and the harvesting (Ilisson et al. 2007, Jonášová et al. 2010, Schönenberger 2002, Ulanova 2000).

Further, we found that the intensity of the natural regeneration was highest shortly after the disturbance and the salvage logging (Dimitrov 1999, Wohlegemuth et al. 2002). On the one side, this was evident from the increase in the number of saplings in the height classes above 50 cm in the period 2006–2014. This increase resulted both from the release of the advance regeneration and the rapid grow-up of saplings which have established in the period 2001–2006. On the other side, the significant decrease in the numbers of individuals registered in the height classes lower than 20 cm in 2014 compared to 2006 revealed a clear drop in the regeneration numbers after 2006. Since the mortality of the natural regeneration was relatively low (i.e. 17 %), the regeneration drop resulted most probably from decline in the recruitment levels.

Whereas the surge in the regeneration process after 2001 was favoured by the improved light conditions after the removal of the forest cover, the observed drop in the regeneration intensity after 2006 indicated that the regeneration conditions have considerably worsen some years after the disturbance. As main factor for this negative trend was considered the rapid expansion of the grass and shrub vegetation, which is known to effectively suppress the regeneration of *Picea abies* and other tree species (Pavlov et al. 1996, Wohlgemuth et al. 2002). In particular, we found that five years after the removal of the forest cover the grass vegetation occupied more than 80 % of the disturbed area.

In terms of sapling density the artificial plantation played minor role compared to the natural regeneration for the restoration of the wind disturbed Norway spruce forest. This was shown by the significant differences between the number of naturally established saplings (mainly *Picea abies*) and the number of planted *Picea* saplings in the sample plots. Provided that the prescribed planting density was between 2500 and 3000 *Picea* saplings per hectare, the observed regeneration density of 375 $ha^{-1}$ in 2014 could be explained by severe losses in the number of planted saplings. Indeed, the average mortality rate reported by the forest authorities for only two years in the period 2004–2005 was 48 %. In addition, we found that for the study period 2006–2014 the mortality rate was on average 69 %. In contrast, the observed lower mortality rates of species such as *Fagus sylvatica* and *Pinus* sp. indicates their potential for larger use by the artificial plantations in mountain forests (Dimitrov 1999).

## Mortality of *Picea abies* saplings

The significantly lower mortality rate for the period 2006–2014 registered among the naturally established *Picea* saplings with height of <1 m in comparison to the planted ones (25 % vs. 69 %) suggests that the natural *Picea* regeneration was more resistant against the critical micro-environmental conditions than the artificial plantation. However, it should be noted that part of the natural regeneration can be damaged during the salvage activities in the disturbed forests (Wohlgemuth et al. 2002). For instance, we documented severe damages to the advance regeneration as result of controlled burning of the slash across the disturbed area.

Further, our results confirmed the finding of Milev and Iliev (2000) that *Picea* saplings lower than 100 cm have lower resistance against the unfavourable ecological factors. Particularly critical for the survival of the young trees was the period of growth to a height of 20–50 cm. In this regard, Schönenberger and Wasem (1997) reported that the mortality of planted saplings was highest in the first three years as result of the planting shock. These findings can be explained by the importance of the well-developed root system (Frehner 2002) for the resistance of the plants against the unfavourable micro-environmental conditions and the ability of the larger plants to out-compete the suppressive grass and shrub vegetation.

The potential mortality reasons by all saplings were assessed indirectly. As the most critical ecological factor for the mortality of the natural *Picea* saplings was considered the poor moisture retaining ability of particular regeneration substrates. In this way was explained the observed withering of saplings established on windthrow mounds, on sun-exposed deadwood and particularly on stones covered by thin organic layer. Soil slides on mounds during heavy rains also may lead to loss of individuals (Ilisson et al. 2007, Holeksa et al. 2012, Ulanova 2000). Further, we assume that the suppression of saplings growth due to grass vegetation as well as frost could have also negatively impacted the survival of individual saplings.

Most of the dead planted saplings (often 2-years-old) were found in patches of *Rubus ideaus* and *Calamagrostis arundinacea*, as well as in areas with excessive moisture covered by *Juncus effusus*. Provided that the mortality was highest by saplings lower than 50 cm, we suppose that the suppression by the grass and shrub vegetation may have aggravated the impact of other ecological factors such as frost or drought (Milev and Iliev 2000, Schönenberger and Wasem 1997).

Yet, our observations on the mortality patterns of the planted saplings suggest that the implementation of the artificial planting and the cultivation technology should be improved. In the first place, the risk of frost heaving or drought can be reduced by selecting planting microsites without excessive soil moisture, respectively by selecting moderately elevated planting microsites close to standing trees, shrubs or lying logs which can provide shelter to the planted saplings. Since in the montane and the sub-alpine zones the initial growth of the spruce saplings is rather slow, higher resilience of the planted saplings to critical ecological factors such as the suppressive vegetation, the frost or the drought is observed when well-developed plants, i.e. older than 4–5 years, are used (Milev and Iliev 2000). Particularly potted plants show higher survival rates (Schönenberger and Wasem 1997). Moreover, the higher survival rates of the naturally established regeneration of *Fagus sylvatica* and most of the pioneer species in Ofeliite site indicates the potential of these species to be effectively used by the replanting of the cleared windthrow area.

It is also expected that the usage of planting material, which is better adapted to the site-specific ecological conditions, can reduce the planting shock. For instance, the planting material in Ofeliite site was procured in forest nurseries situated at much lower altitude, while the *Picea* seeds presumably originated from spruce forests, where the ecological conditions considerably differed from the ones on the study site.

In the second place, the survival of the planted saplings can be increased if the removal of the competing vegetation during the cultivation of the *Picea* plantations is carried out until the saplings grow higher than 50 cm, i.e. for a period of not less than 3–5 years. Besides this, the mowing of the grass vegetation should be carried out in a way that no damages to the planted saplings are caused. As observed in the study site, the damaged coniferous saplings are the first to be suppressed and killed by the competing vegetation.

## Regeneration substrates of *Picea abies*

Our results show that vegetation-free substrates such as decayed deadwood, bare ground, windthrow mounds and litter were of key importance for the natural regeneration of the dominant species *Picea abies*, despite their limited coverage in the windthrow area (less than 18 %). Shortly after the disturbance and the salvage logging these substrates provided the *Picea* seedlings a safe place to develop free of competing vegetation (Ulanova 2000, Schönenberger 2002, Kuuluvainen and Kalmari 2003). This means that even saplings, which have been registered in patches of grass and shrub vegetation had most probably germinated on bare ground before the expansion of the vegetation.

Most favourable for the regeneration of *Picea abies* proved to be the substrate formed by decayed logs and stumps, which exhibited the highest sapling density both in 2006 and in 2014. When available in sufficient quantities this substrate type is considered as critical for the regeneration of high mountain *Picea abies* forests (Hofgaard 1993, Holeksa et al. 2012, Jehl 2001, Svoboda et al. 2010). Since it takes at least 2 decades before the deadwood is sufficiently decayed to allow establishment of the *Picea* recruitment (Holeksa et al. 2012, Zielonka 2006), we assume that the decayed deadwood was present in the study site before the disturbance of 2001.

In terms of saplings density high importance for the regeneration of *Picea abies* had also the windthrow mounds, which resulted from the up-rooting of mature trees. Similarly to deadwood, this elevated microsite provides the seedlings better protection against the frost resulting from the stagnation of cold air in the shallow areas (Penev and Marinov 1964, Ilisson et al. 2007). Moreover, the windthrow mounds are mainly formed by exposed mineral soil, which is considered as optimal substrate for the regeneration of as well *Picea abies* as most of the pioneer species.

In contrast, the lowest importance for the regeneration of *Picea abies* had the vegetation covered ground exhibiting the lowest regeneration densities (less than 2 saplings per 100 $m^2$). The grass and shrub vegetation was mainly formed by dense patches of the species *Rubus ideaus* and *Calamagrostis arundinacea*, which are known to effectively suppress the germination and survival of *Picea* seedlings (Pavlov et al. 1996, Wohlgemuth et al. 2002). Since these species sustain an abundant seed bank in the soil and emerge immediately after increase of the light levels (Fischer et al. 2002), the germination of *Picea* seeds on bare ground after a disturbance may be successful in a very short time lapse.

### Conclusion and implications for forest management

Our results show that the natural regeneration compared to the artificial planting can be a more sustainable and cost effective option for the recovery of wind disturbed spruce forests. Before taking a decision on the type of restoration measures needed it is advisable to observe the potential of the natural regeneration for a period of up to 5 years after the disturbance. When adequate advance regeneration is available, we suggest that the salvage logging as a traditional sanitary measure against potential outbreak of bark beetles is replaced by debarking of the wind-blown trees, as practiced in protected areas and hardly accessible territories in Central Europe (Dountchev et al. 2014). In general, the resilience of montane *Picea abies* forests against large-scale disturbances can be preliminary enhanced by sustaining abundant seedling bank, leaving sufficient quantities of deadwood as regeneration substrate and tolerating pioneer species as seeding trees (Brang et. al 2006).

When indispensable, the artificial reforestation should be implemented by strict application of the planting technology, usage of planting material adapted to the site-specific ecological conditions and complementation of the *Picea* plantations with saplings of pioneer species or *Fagus sylvatica*. The spruce plantations should be created by using of well-developed and preferably potted saplings with an age of at least 4 years (Frehner 2002, Milev and Iliev 2000) and with special preference to grass-free substrates and elevated microsites which are well-drained and airy. These measures are particularly important in areas with extreme climatic conditions, where the slowly growing spruce saplings most often die out as result of frost heaving or suppression by the high grass and shrub vegetation.

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# BLACK LOCUST WOOD – PERSPECTIVE RAW MATERIAL FOR PRODUCTION OF CHEMICAL PULP AND GLUCOSE

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## Abstract

The potential of Black locust (*Robinia pseudoacacia* L.) wood for production of chemical pulp and glucose was studied. Different clones of Black locust growing in various habitats in Bulgaria were analysed and their chemical composition and density was compared. It was established that the differences in the content of cellulose, lignin, pentosanes and extracted substance in the respective clones were not high and were within the range of 10 % of the corresponding component. Hence, the effect of the chemical composition on the pulp yield was relatively low. The differences in the planting schemes (density) of the Black locust clones had greater influence on the productivity and efficiency of the pulping process. The authors found that *Robinia pseudoacacia* L. has the highest potential in Bulgaria for glucose production. The glucose yield after enzymatic hydrolysis of steam-exploded Black locust is approximately higher in comparison with corresponding treatment of maize stalks, wheat straw and fast-growing poplar and willow. The conclusion is that there are opportunities for plantation harvesting in Bulgaria of separate *Robinia pseudoacacia* L. clones for chemical pulp or glucose for production bioethanol.

**Key words:** chemical composition, chemical pulp, density, enzymatic hydrolysis, fast-growing trees, *Robinia pseudoacacia* L.

## Introduction

The progressive depletion of non-renewable fossil fuels and mankind's growing concern regarding climate change and atmospheric pollution, has led to an interest in the use of renewable fuels. Biomass from plantations of fast growing tree species represents large renewable resources for lignocellulosic bioconversion (González-García et al. 2010). The potential of fast growing forest trees high productivity, coppice ability and ease of vegetative propagation in SRIC plantations has been recognized for over thirty years (Aravanopoulos 2010). The most popular fast growing trees are willow, poplar, eucalyptus, paulownia, etc. The susceptibility of lignocellulosic substrates to cellulose depends on the structural features of the substrate including the cellulose crystallinity, the degree of cellulose polymerization, the surface area, and the lignin content (Ioelovich and Morag 2011). Black locust (*Robinia pseudoacacia* L.) is a fast-growing tree species. It was introduced in Bulgaria more than two hundred years ago (Naydenov et al. 1981). It is considered as naturalized species, which is characterized by high ecological plasticity and is widely spread in the lowlands of the country (Panayotov et al. 2006). It is widely used for wood production, fire wood, as well as for the utilization of degraded and slightly productive lands and soil erosion control. In addition, Black locust is used for feeding of bees and highly valued honey is produced. The timber texture is considered by many people as equally beautiful as that of mahogany and teak, while the strength characteristics are often higher than those of oak and beech wood. Black locust wood has wide application in the woodworking industry and for production of bleached cellulose (Panayotov et al. 2005). In Bulgaria the share of the species is about 2.5 % of the total forest area and the interest to this tree species constantly increases. During the period 2005–2010, its area has increased with 7.13 % from 139,855 ha to 150,590 ha. For the same five-year period the stock wood has increased with 984,832 $m^3$. During the last twenty years the attention of the scientific community was directed towards improvement and establishment of more productive clones with improved production qualities (Tsanov et al. 1990). More than 100 sample trees were planted, a method for vegetative planting by root seedlings was developed, clonal seed orchards were established. During the last 20 years the company Lignum Bulgaria – Ruse established more than 12,000 dka of crops for the production of large-sized timber with vegetative seedlings of selected clones by using scientific consultations and clones from the Experimental Station for Fast-Growing Tree Species in Svishtov (Kalmukov 2002, 2005, 2007). Yet, the high clone variety is still not well studied. This is needed to provide possibilities for a more differentiated usage of the important clones.

The aim of this paper is to study the timber of selected Black locust clones and to evaluate this raw material for production of chemical pulp and glucose as sources for bioethanol production of second generation.

## Material and Methods

Characteristics of the conditions for plant growth of the sample trees

The samples for analysing the physical and chemical properties wood from the separate Black locust clones are taken from the clone collection in the village of Vardim (43°36′33.3″ N, 25°29′22.8″ E), district of Veliko Tarnovo, Northern Bulgaria. The nursery at the Experimental station at Vardim village is situated on the second terrace of the Danube river. The soil is calcic chernozems, according to the new classification-brown (WRBSR 2006). The parent material is sandstone. The terrain is flat. The ground water level is above 8 meters. The carbonates in the surface horizon are above 3.5 %. The soil reaction in a water extract is alkaline, from 7.63 to 7.95. According to the mechanical properties of the soil, it can be classified as heavily sandy-clayey. The water-and-physical properties are good. The porosity is 50 %. The capacity of active soil moisture in one meter soil layer is 217 mm and in the two-meter layer it is 452 mm. For the last 25 years the average annual quantity of rainfall is 510.9 mm with precipitation sum of 236.6 mm April-August.

The Black locust clones collection is created in 1995 and 1996 and more than 50 clones are used. Before the plantation, full soil preparation was carried out. One-year-old seedlings produced by root seedlings were used for planting. The forestation is carried out in 30/30/30 cm hand-made holes. The initial planting scheme is 3.0×3.0 m. In the first three years the seedlings are entrenched 3 times and the space between the rows is disc-plowed 3 times during the growing period. In the following years one disc-plowing between the rows is carried out.

## Characteristics of the Black locust trees

For analysis, washers from breast height (1.30 m) from the sample trees were taken. The clone ′Jazskiseri′ is considered the best in Hungary. It is distinguished by faster growing and straight trunk. The crown takes ½ of the height. It is used for the production of technological chips, semi-mechanical pulp, fibreboards and particleboards. In Bulgaria it is one of the clones with good growth. The self-pruning of the trunk was 11 m. The height of the tree was 17.95 m and diameter at breast height was 22.2 cm. The tree was 19-year-old. The clone has been researched at a young age – 8 years under the code B54 within the project "Danube-Agro".

The clone ′Pordim′ is selected in the region of the Game Hunting Station Pleven (Fig. 1). The terrain was flat with slightly frayed black soil (Highlight). The clone was distinguished by good growth and straight trunk. The self-pruning of the trunk was 8.3 m, the height was 18.20 m, the diameter 24.8 cm. The tree was 18-years-old. The clone has been studied at a young age – 8 years under the code

**Clone ′Jazskiseri′** **Clone ′Pordim′** **Clone ′Tsarevets′**

**Fig. 1. Plantations of Black locust clones.**

B4 within the project “Danube-Agro”. This previous study pointed out the clone to be with the hardest wood.

The clone ′Tsarevets′ is selected from the region of the State Game Station Svishtov (Fig 1). The crop is announced to be for seed base. The terrain is steep with a southern exposure. The soil is calcic chernozem. This clone is distinguished with good growth and productivity and withstands soils with the availability of carbons in the surface horizon. The tree was 18 years old with diameter of 23.4 cm. The trunk was self-pruned to the height of 10 m. The height of the tree was 18.30 m. So far this clone has not been included into previous studies.

All clones were promulgated vegetative through root cuts and the mother trees were kept.

### Chemical analyses

Chemical analysis of the raw materials is based on the following methods: cellulose (Kurschner and Hoffer 1993), lignin (TAPPI standard T222 om-11), pentosans (BDS 11449:1973), ash (TAPPI standard T211 om-12) and substances soluble in hot water (TAPPI standard T207 cm-08). The craft cooking is carried out with hand cut and sorted chips with average length of 20 mm thickness 4–6 mm. The chips (100 g oven dried) are cooked in 2 $dm^3$ stainless steel laboratory autoclaves rotated at a constant rate in a polyglycol bath. The liquor-to-wood ratio during cooking was 4:1. The sulfidity was 12 % and the active alkali charge is varied from 17 to 20 % as $Na_2O$.

The cooking is started at 80 °C and the durations of the heating time to the full cooking temperature 165 °C was 140 min, while the H-factor varied from 1000 to 1500. The black liquor impregnation and pre-steaming was carried out at 100 °C for 30 min at atmospheric pressure before cooking and the total black liquor charge was the same as in the conventional cooking regime. The Kappa number is measured according to ISO standard (ISO 302:2004).

The steam explosion pre-treatment of wood chips is performed in 2 $dm^3$ stainless steel laboratory installation at the following conditions: liquid to solid ratio was 10:1; initial temperature was 100 °C; maximum temperature was 200 °C; pressure was 15.85 bar; heating time was 60 min followed by additional 10 min at the maximum temperature. The steam exploded lignocelluloses was washed with distilled water and subjected to enzymatic hydrolysis.

### Enzymatic hydrolysis

The cellulose complex NS22086 with activity 1000 BHU/g and β-glucosidase NS22118 with activity 250 CBU/g of Novozymes AS were used for the enzymatic hydrolysis. The enzyme charge of NS 22086 was 5 %, while that of NS 22118 was 0.5 %, both referred to dry mass of the lignocellulose. The enzymatic treatment is carried out in polyethylene bags in a water bath previously heated to 50 °C; pH was 5.0–5.6 and reaction time was 48 h. The glucose content is analysed with a Dionex HPLC system, according to the NREL standard laboratory analytical procedure.

## Results and Discussion

Different clones of Black locust growing in various habitats in Bulgaria have been investigated and comparison has been made of their chemical composition and

**Table 1. Chemical composition and density of wood from different Black locust.**

| Tree species | Lignin, % | Cellulose, % | Pentosans, % | Ash, % | Substances soluble in hot water, % | Oven dry wood density, kg/m³ |
|---|---|---|---|---|---|---|
| Black locust ′Pordim′ | 27.5 | 48.7 | 21.3 | 0.32 | 6.6 | 769 |
| Black locust ′Tsarevets′ | 23.0 | 49.0 | 22.9 | 0.43 | 3.7 | 659 |
| Black locust ′Jazskiser′ | 27.7 | 45.4 | 21.0 | 0.61 | 7.9 | 734 |
| Black locust without bark from different clones | 21.1–27.5 | 44.4–49.1 | 17.5–22.9 | 0.2–0.7 | 3.7–9.8 | 600–855 |
| Black locust with bark from different clones | 21.2–28.6 | 43.9–49.1 | - | 1.7–2.8 | - | - |
| Common beech | 24.2 | 45 | 24.2 | 0.7 | 2.6 | 680 |

density (Table 1). It has been established that the difference in the content of cellulose in the respective clones is 10 %, while difference in the content of lignin, pentosans and extracted substances were within the range of 25 % of the corresponding component. Highest cellulose content and lower amount of lignin was established in Black locust ′Tsarevets′ having the lowest density. The determined up to 25 % differences in the wood density of the Black locust clones can exert comparatively greater influence on the productivity and effectiveness of the cellulose production processes.

Svilocell EAD plant use mixed hardwood species such as Turkey oak, Sessile oak, Black locust, Common beech and Common hornbeam (Table 2).

Poplar is used as an individual brand. It is known that the properties of pulp from Black locust are similar than these obtained from mixed hardwood without Black locust. But, a problem is found during the blowing of Svilocell pulp.

The effect of cooking conditions on the Kappa number and pulp yield of Black locust with different density is investigated (Tables 3 and 4).

It has been established that to achieve a Kappa number below 20 after cooking of Black locust clone ′Tsarevets′ with the lowest density (659 kg/m$^3$), the alkali charge should be 18.5 % $Na_2O$ at H-factor

**Table 2. Hardwood species used in Svilocell.**

| Hardwood species | Amount, % |
|---|---|
| Common beech | 11.5 |
| Turkey oak | 50.5 |
| Sessile oak | 5.6 |
| Common hornbeam | 15.9 |
| Black locust | 16.5 |

**Table 3. Cooking parameters for the Black locust ′Tsarevets′ with low density.**

| A.A. charge as $Na_2O$, % | Sulfidity, % | H-factor | Kappa, number | Screening yield, % | Total yield, % |
|---|---|---|---|---|---|
| 17 % $Na_2O$ | 12 | 1000 | 25.0 | - | - |
| 17 % $Na_2O$ | 12 | 1200 | 23.4 | - | - |
| 18.5 % $Na_2O$ + Steaming | 12 | 1200 | 21.4 | 36.5 | - |
| 18.5 % $Na_2O$ | 12 | 1500 | 22.0 | 38.8 | - |
| 18.5 % $Na_2O$ + Steaming | 12 | 1500 | 19.8 | 43.9 | 45.7 |

1500. On the other hand, due to the higher density, the Black locust clone ′Pordim′ is cooking more difficult and needs a higher alkali charge of 20 % to achieve Kappa number 23.8; moreover the total yield and screening yield was lower.

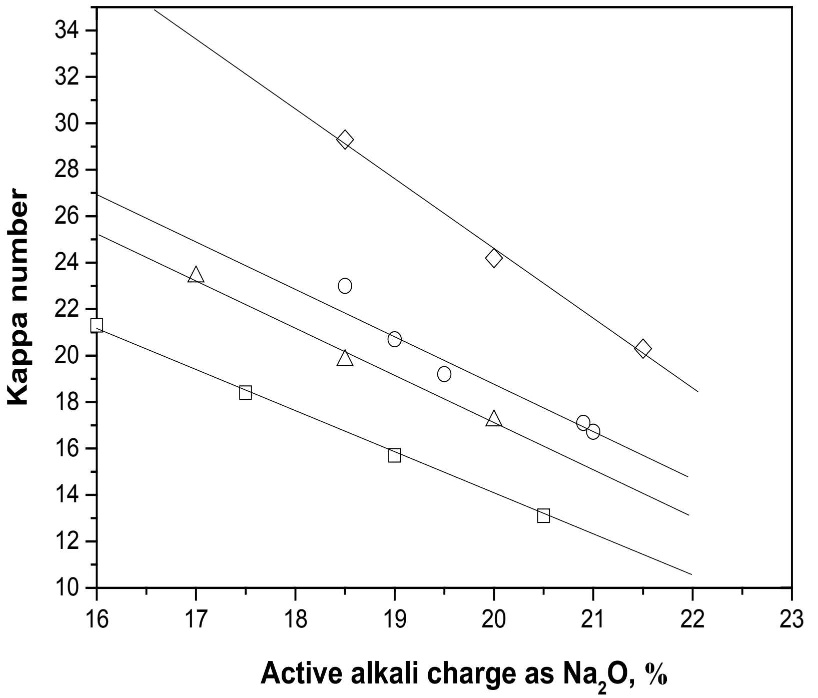
Figure 2 shows that Black locust clone ′Tsarevets′ with the lowest density is cooking easier than Svilocell's mix wood (Table 2), but more difficult in comparison with the common beech.

As it can be seen from Figure 3, the dependence between total pulp yield and Kappa number for low density Black locust clone ′Tsarevets′ and common beech was on the one line, while this dependence for high density (769 kg/$m^3$) Black locust clone ′Pordim′ and Svilocell's mix is on the another line.

The potential of Black locust wood as a source for glucose production was also researched. Steam explosion pre-treatment

**Table 4. Cooking parameters for the Black locust ′Pordim′ with high density.**

| A.A. charge as $Na_2O$, % | Sulfidity, % | H-factor | Kappa, number | Screening yield, % | Total yield, % |
|---|---|---|---|---|---|
| 17 % $Na_2O$ | 12 | 1200 | 33.3 | | - |
| 18.5 % $Na_2O$ | 12 | 1200 | 31.0 | | - |
| 18.5 % $Na_2O$ | 12 | 1500 | 29.3 | 32.4 | - |
| 20.0 % $Na_2O$ | 12 | 1500 | 27.8 | 38.5 | - |
| 20.0 % $Na_2O$ + Steaming | 12 | 1500 | 23.8 | 40.9 | 43.2 |




Legend: □ – Common beech; Δ – clone ′Tsarevets′; ○ – Svilocell's mix; ◊ – clone ′Pordim′.

**Fig. 2. Effect of the active alkali charge on the pulp Kappa number after cooking of different wood.**

of the wood samples before enzymatic hydrolysis was carried out. During the pretreatment, process to 32–38 % of the wood were dissolved, especially due to removal of hemicelluloses (Table 5).

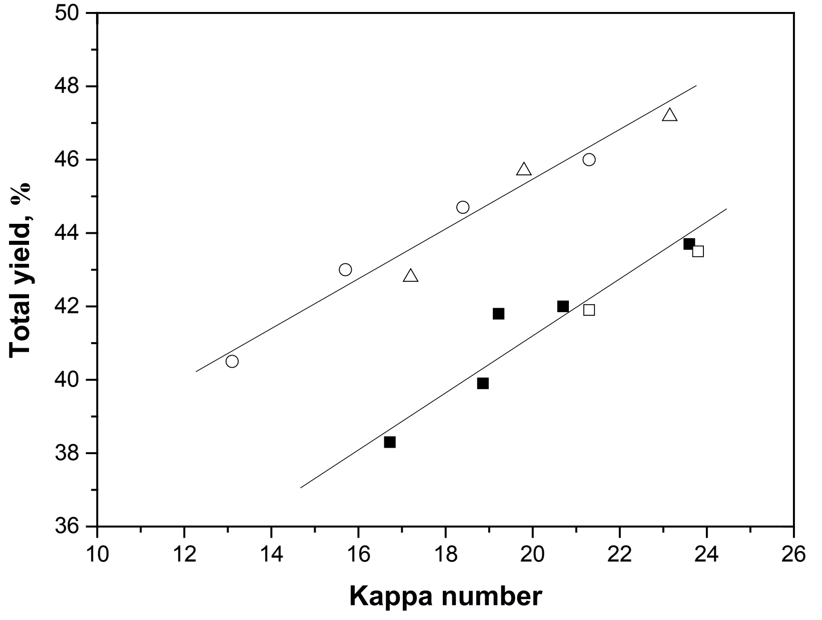
The results of enzymatic hydrolysis of pre-treated samples of Black locust with different density is presented on Figure 4. The best result was obtained for low density Black locust ′Tsarevets′, while the glucose yield for high density wood of Black locust ′Pordim′ was 25 % lower.

The dependence between wood density and glucose yield after enzymatic hydrolysis is presented on Figure 5.

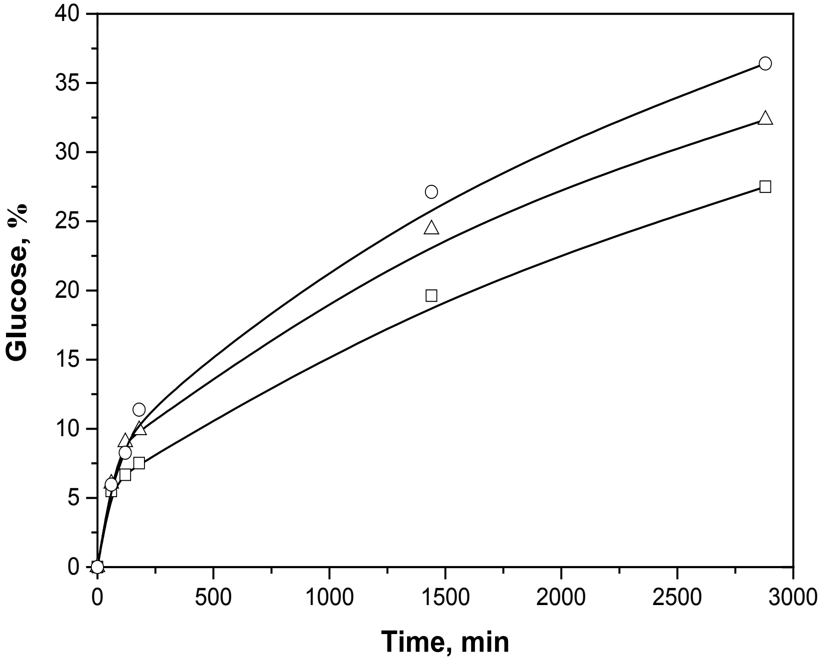
Comparison of various wood species showed that enzymatic digestibility of pretreated samples of *Paulownia tomentosa* (Thunb.) Steud., *Robinia pseudoacacia*

**Table 5. Chemical composition of pulp after steam explosion.**

| Tree species | Lignin, % | Celluloese, % | Ash, % | Yield, % |
|---|---|---|---|---|
| Black locust ′Pordim′ | 30.4 | 70.0 | 0.5 | 64.41 |
| Black locust ′Tsarevets′ | 29.1 | 72.8 | 0.4 | 66.98 |
| Black locust ′Jazskiser′ | 37.6 | 63.3 | 0.6 | 66.80 |




Legend: ■ – Svilocell’s mix; □ –clone ′Pordim′; Δ – clone ′Tsarevets′; ○ – Common beech.
**Fig. 3. Dependencies between total yield and kappa number after cooking of different wood species.**




Legend: ○ – clone ′Tsarevets′; Δ – clone ′Jazskiseri′; □ – clone ′Pordim′.
**Fig. 4. Glucose yield after enzymatic hydrolysis of pre-treated different clones of Black locust.**

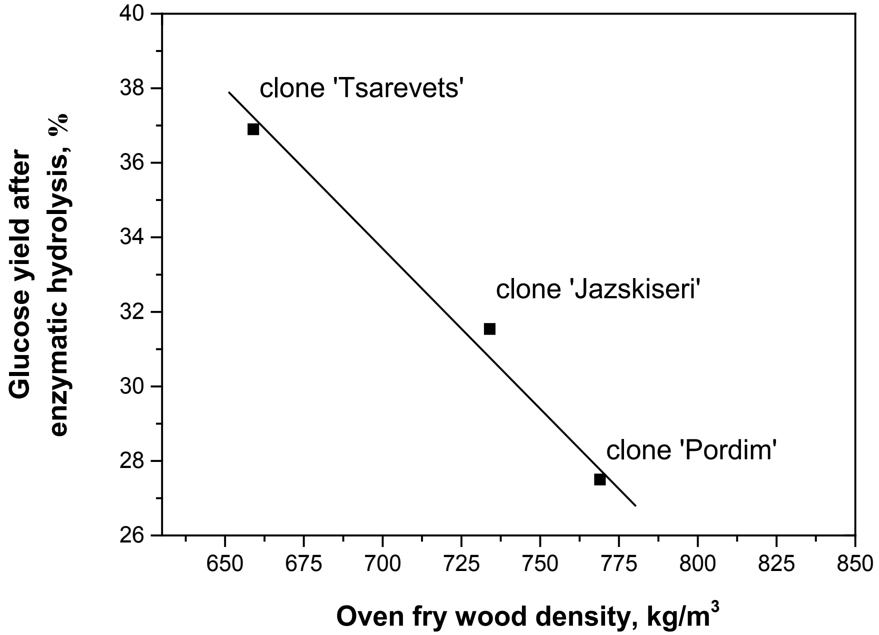
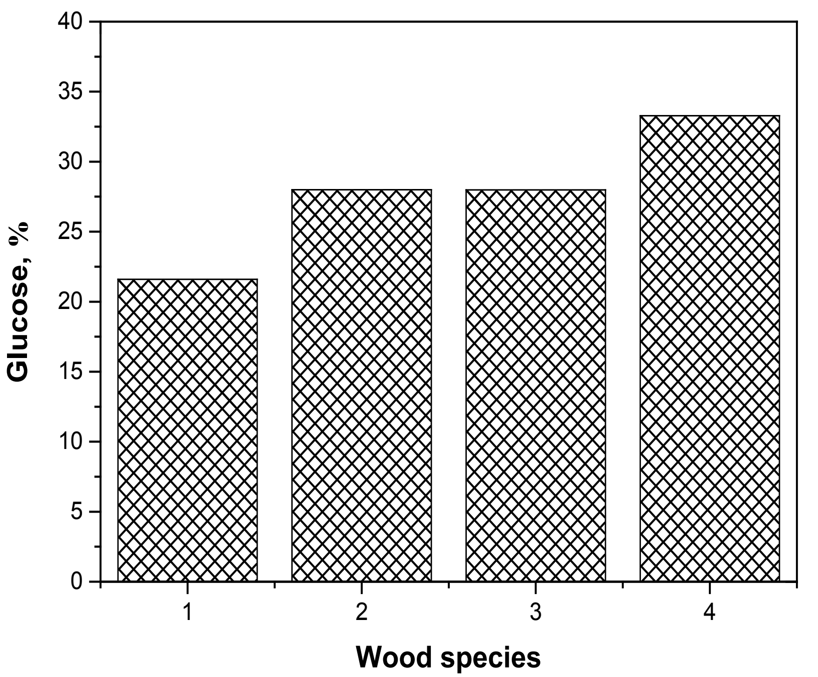



**Fig. 5. Dependence between wood density and glucose yield.**




Legend: 1 – Populus alba; 2 – Robinia pseudoacacia; 3 – Paulownia tomentosa; 4 – Paulownia elongata.

**Fig. 6. Glucose yield after enzymatic hydrolysis of pre-treated samples.**

and especially of *Paulownia elongata* S.Y.Hu*,* was higher than that of *Populus alba* L. (Fig. 6).

## Conclusions

A correlation is established between chemical composition and density of wood for Black locust different clones. The highest cellulose content and the lowest amount of lignin was observed for low density wood of Black locust 'Tsarevets'.

The wood of Black locust 'Tsarevets' with the lowest density can be used for production of kraft pulp. On the other hand, to obtain delignified kraft pulp from high density Black locust 'Pordim', the cooking conditions must be very strong.

The low density Black locust 'Tsarevets' has a great potential for conversion in glucose to produce second-generation bioethanol. It is found that the glucose yield after enzymatic hydrolysis of steam-exploded Black locust was higher in comparison with other typical fast-growing tree species of Bulgaria. A correlation between the yield of glucose and wood density is found.

There are possibilities the plantation harvesting in Bulgaria of separate Black locust clones having low density wood, which can be used for production of chemical pulp and glucose.

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# HARVESTING AND PROCESSING OF FOREST WOOD BIOMASS FOR ENERGY PURPOSES IN BULGARIA

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## Abstract

Having in mind the assortment and age structure, the tree composition and other specific peculiarities of Bulgarian forests, as well as the national timber market, about 70 % of the harvested timber is used for technological purposes, e.g. for production of particle boards, cellulose and for energy purposes, like firewood for residential heating. Along with the harvested logs (saw logs, pulpwood and firewood), Bulgaria has also considerable recovery of other biomass. In 2014, the share of the categories ’woods‘ and ’brushwood‘ is about 50 % of the total timber harvested volume in Bulgaria. Practically, in our country the wood waste from felling together with the brushwood is about 1.4 Mio ($m^3$/y) of solid waste. That wood waste presents a significant energy potential but the degree of its quantitative concentration is low and often this resource is at big distances from the settlements. The most important advantages and benefits of the utilization of solid wood biofuels in the form of pellets, briquettes, charcoal and chips for energy purposes are: ecological – decrease of the carbon emissions and air pollution and economic (social in this account) – decrease of the costs of energy resources, which ensures both economic and social effect of the use of biofuels produced from wood biomass. In Bulgaria, the volume of wood energy products in 2014 is: 52,550 t pellets, 6,800 t briquettes, 11,550 t charcoal and 9,400 t wood chips, respectively. About 60 % of the number of pellet producing companies has a share of 15–20 % in the total pellet production. Such small-size firms use small-size pressing machines. The general analysis related to the sale of wood pellet and briquette shows that about 2/3 are realized for export based on preliminary signed contracts and the introduction of quality requirements. Most often the export is for Greece, Turkey and Italy. According to our assessments, the best conditions for development exist for briquettes production and wood chips designed to home market, of pellets designed to international one and of charcoal for both.

**Key words:** biofuels, briquettes, charcoal, chips, wood biomass, wood pellets.

## Introduction

The wood biofuels market is scarce in Bulgaria as no conditions have been created therein for a complex use of the forest wood biomass and for subsidies of heating systems which are relatively expensive. And besides, there is also a rather poorly developed distribution. Market conditions have to be created there for a supply of home produced biofuels. As a whole, the waste biomass potential is estimated to amount to 91.5 PJ/year. Including the forest potential is equal to 19 %, approximately and it is expected to go on rising, The technical potential of the forest biomass for energetic utilization is equal to 44.4 PJ/year, approximately (Dinev and Trichkov 2010, Trichkov and Dinev 2013).

Many studies prognosticate a significant increase in the use of woody biomass for energy in the forthcoming years (Ferranti 2014, European Commission 2014, Sikkema et al. 2011) and the forest industry is already exploring this new growing market. There is no doubt: the biomass harvesting contributes to the complexity of forestry and similarly offers a significant opportunity of increasing efficiency, raising the value recovery and reducing the logging and management costs (Pelkonen et al. 2014).

A strong connection exists between the energy sector and the forestry and forest products industry, because the direct harvest of fuel wood and other forest fuels implied a certain amount of wood residues generated at different stages in the production chain for different wood products (Thiffault et al. 2015, Sikkema et al. 2014).

According to Korpunen et al. (2011), the increasing use of forest raw materials for energy production gives a rise to a necessity of an effective system of planning for management and planning of supply chain. Such system includes decisions on how, when and where wood and its waste could be processed and how, when and where it could be stored and transported to the consumers.

As the forest wood biomass is generally spread within a large geographic region, the supply chain simulation requires true and correct information on the biomass location and accessibility (Cozzi et al. 2013, Goltsev 2014, Alam et al. 2012). The quality management of forest biomass is relevant to the functioning of the entire supply chain and economy (Hillebrand and Raitila 2013). The conformity of business processes to the supply chain demonstrates that their number varies significantly, depending upon different operational environments (Windisch et al. 2011).

It has been established by Baker et al. (2010) that the integration of small-sized chippers systems (< 300 kW) could be successful within a restricted range of logging conditions, depending upon the volume of the produced biomass, compared to the volume of the round wood.

The basic objective of this study is to expand the range of previous ones related to the potential of forest wood biomass and its utilization for biofuels production in Bulgaria (Dinev and Trichkov 2010, Trichkov and Dinev 2013).

According to Sabeva et al. (2012), the standard components of biomass in Bulgaria do not exceed the maximum admissible values implemented by EU into production, wood chips, briquettes and pellets included.

## Material and Methods

It is pointed out, in the analytical part of the National strategic documents related to Forestry sector, the National Strategy for Development of Forestry Sector in Bulgaria, 2013–2020 (National … 2013), as well as in the Strategic Plan for Development of Forestry Sector, 2014–2023 (Strategic… 2014), that a perpetual increase in the volume of wood obtained from the forests in Bulgaria, has been reported, as following: within the period 2005–2010, the annual average harvesting has arrived at 6,450,000 m$^3$ of standing timber, subsequently, during the period from 2012 up to 2014, comprised, it has raised by 1.3 Mio m$^3$ and reached the average amount of 7,758,000 m$^3$.

According to its predictions for the maximum sustainable use, logging should reach 8,587,000 $m^3$ towards 2015 and 8,825,000 $m^3$ towards 2020 (Kostov and Rafailova 2009). Taking into consideration other analyses, if the elaboration of such forestry plans starts, which ones aim at the utilization of about 75 %, at least, of the total annual growth, and the adoption of a number of measures for that, the annual use in all the forest territories could reach an amount of nearly 10.8 Mio $m^3$ of standing timber; obviously, in case, a right policy is led by our State and State Forestry enterprises towards the private entrepreneurs in the field of wood harvesting in the forests, tending to provide and stimulate investments into the infrastructure, new machinery and equipment (Marinova and Trichkov 2014). If the above indicated prognostic values are leading, they would contribute to keeping the actual state and even to increasing the amounts of firewood and forest wood biomass waste.

According to the National Strategy for Development of Forest Sector in Bulgaria, 2013–2020 (National... 2013) a change should be made in the existing models of utilization of forest resources promoting measures for stimulation and modernization of logging machinery, applying updated technologies to the logging and the development of our home market for wood, as well as tending to stabilize the demand and to adapt it to the market economy of the trade policy.

Taking into consideration the assortment and age structure, the tree species and other specific characteristics of Bulgarian forests, nationwide, there are 70 %, approximately, of the harvested wood which is used for technological and energetic purposes, i.e. for plates, cellulose and firewood production. In the recent years, the share of the wood belonging to category 'wood' and 'brushwood' is about 50 % of the entire amount of wood harvested in Bulgaria. The wood biomass, firewood, wood waste and their derivates included have a high energetic potential but a low degree of quantitative concentration; and, moreover, that kind of resource is often distant from settlements.

Energetic chips are usually sold by ton; their value depends, to the highest extent, on humidity. It is much easier to provide for a control of the volume in supply as it is used to be done in firewood supply. The tree species is of a great importance for the energetic chips and so important is the fraction size. The most serious problem in chips production, considered by the firms dealing with wood chips harvesting in our country, is the value of chips transportation. The wood chips are too voluminous, of a low specific weight, and all that results unprofitable on road transportation, at a distance of more than 1500 km. That is why for local utilization, i.e. for short-distance transport, it is appropriate to use wood chips for burning. The future trend will be the wood chips incineration. The chips market in our country is still underdeveloped, compared to the one in other states, even though certain good practices already exist, in the recent years. Such kind of heating is applicable mostly to houses where people still use to store firewood. To date, the population in Bulgaria has predominantly used firewood for heating; and it is really a pity that wood is burnt in incineration facilities which energetic efficiency is low (efficiency up to 50–60 %). If such incineration facilities are replaced by high energy efficient ones, the quantity of used combustibles, i.e. wood, can be increased about twice. The highest potential is that one in the public sector premises: schools, hospitals, kindergartens comprised. Besides, there are 5 thermal power stations in our country where wood chips of moisture content up to 45 % are utilized. There is also logistics which plays a very important part, taking into account the way of performing such operations as packing, loading and unloading which raise the fuel cost.

For the time being, the most economic kinds of fuels produced from forest wood biomass are briquettes and wood, but some defects can also be found out therein, as following: a need of a larger areas or rooms for storage; wood chopping and subsequent piling; a larger quantity of ash released in burning; a longer and harder operations related to the boiler; there is also a lower efficiency of the boiler for firewood or briquettes, compared to the one for pellets: such fact shall not be neglected.

As regard to charcoal, it is the restrictive legal frame in Bulgaria, which shall be placed at the very first place as a hindrance because it puts under a ban the open-ended method for its production. There are also the economic aspects of production, where the retort method is used. The modern bio-refinery makes the wood consumption for of 1 ton charcoal production decrease from 30 to 50 %. Such process under oversight permits performance of a strict control on quality, a choice of the charring level, even a creation of different classes of products: from low to top quality ones, and the relative different prices.

The crisis in economy has also reflected on the producers themselves, as the greatest part of them use as a raw material technological waste generated from wood processing enterprises. And with the reduction of the material requisitions delivered to the above mentioned factories, the waste products, used as a raw material for production of pellets, have decreased, as well.

For keeping the biomass on as a competitive energy source, it is very important to provide for the optimization of the chain from the source to the end consumer. This study identifies the trends of utilization of the main wood biomass kinds in Bulgaria, regarding their quantity and spread, demonstrating how the forestry waste utilization can be optimized.

## Results and Discussion

The modern trends to implementation of wasteless technologies and to economically efficient use of raw materials impose the all-round and full value utilization, even of the limited biomass resources. In logging conducted in the cutting areas or stacks, there are branches of different size, known under the common denomination of brushwood or slash, which are not used: they get burnt or are left in the cutting areas, instead, and then decay. Part of them with diameter greater than 3 cm can be used as firewood, while boughs of a diameter less than 3 cm are left unused in them. Taking into consideration the mountain scenery of our forest massifs, and not only it, along with what above mentioned, it has to be added that there are also some quantities of usable wood waste mainly consisting of branches and thin-size stems left in the cutting areas after cutting, and it is due to the fact that the transportation leads to decrease machinery productivity, hence, to a worsening of the economic indices. For that reason, there is a trend to increase such dropping material.

In that relation, there is a need of optimization consisting of a preliminary preparation by collecting of waste piles, chipping and transportation of chips to the end consumer: i.e. to the factory for pellets or briquettes production. When the logging technology is not followed, it reflects on the biomass utilization chain and leads to a pile processing of less quantities of wood waste; hence, the device (machine) shall be continuously moved from one point to another, during the operation, which causes significant increase of the operating costs.

In the recent years, the cutting area residues utilization has been starting in our country, and it is a very important step to the assimilation of that biomass which consists of about 1.1 Mio $m^3$. Technologies are adopted, being already in the process of exploitation, for the post cutting assimilation of branches chipped by movable chippers in the cutting area. The loading of the chips is directly performed on trailers or trucks adapted for that purpose. The yield is of 10–18 solid $m^3$/day. Further on, that same technology is applied to work in stationary conditions; and the chips, obtained in the forest and subsequently processed, are used for production of briquettes made from forest waste. For example, when such technology is applied, 1 ton of briquettes can be obtained from an average quantity of 5 $m^3$ waste wood, using 3 presses. Annually, only in the summer, 350–400 t or about 1200 solid cubic meters of forest waste branches are processed. A positive trend is also the use of unutilized – even considered unnecessary – undergrowth: South European flowering ash (*Fraxinus ornus* L.), European hornbeam (*Carpinus orientalis* L.) and others, in parallel to the forest waste removal from the cutting areas.

Easier solutions could be found out regarding poplar and acacia cultures where whole trees are harvested and hauled. Usually, before chipping, huge piles are prepared which volume is of 150 t. ’JENZ HEM 581‘ or ’Doppstadt DH 608‘ chippers are used which productivity is of 70 t daily. The problem is that the working capacity of these machines cannot be sufficiently exploited. The chips obtained from the above mentioned cultures are designed to be burnt, for example, in thermal-electric power stations and others.

Along with the fast rising firewood and charcoal consumption, such a trend is also noted in pellets and briquettes instead of firewood consumption. There are reasons to suggest that the same trend would also be kept in the future, taking into account the high potential of wood-based biofuels, compared to all the renewable energy sources.

A table and a map have been elaborated, containing the main companies-producers, their location and the volume of production: pellets, briquettes and charcoal, respectively (Fig. 1 and Table 1). The surveys are related to 2014 and the expectations for 2015, on the basis of the data provided by Bulgarian National Statistical Institute and by a WS survey, after site visits to the firms-producers. The reasons for which we have had recourse to different sources are some doubts about incomplete information given to us by the firms.

The average annual production volume of the companies varies from 250–5000 t of pellets, 300–1000 t of briquettes and 100–4600 t of charcoal, respectively. The low volumes produced by small-scale firms while the high ones by large-scale producers: i.e. factories. The factories have put in their business plans production which is about twice higher than its volume indicated in documents. There are 60 %, approximately, of the pellet producers (where the pellet share amounts to 15–20 % of the total production) who use small-size presses.

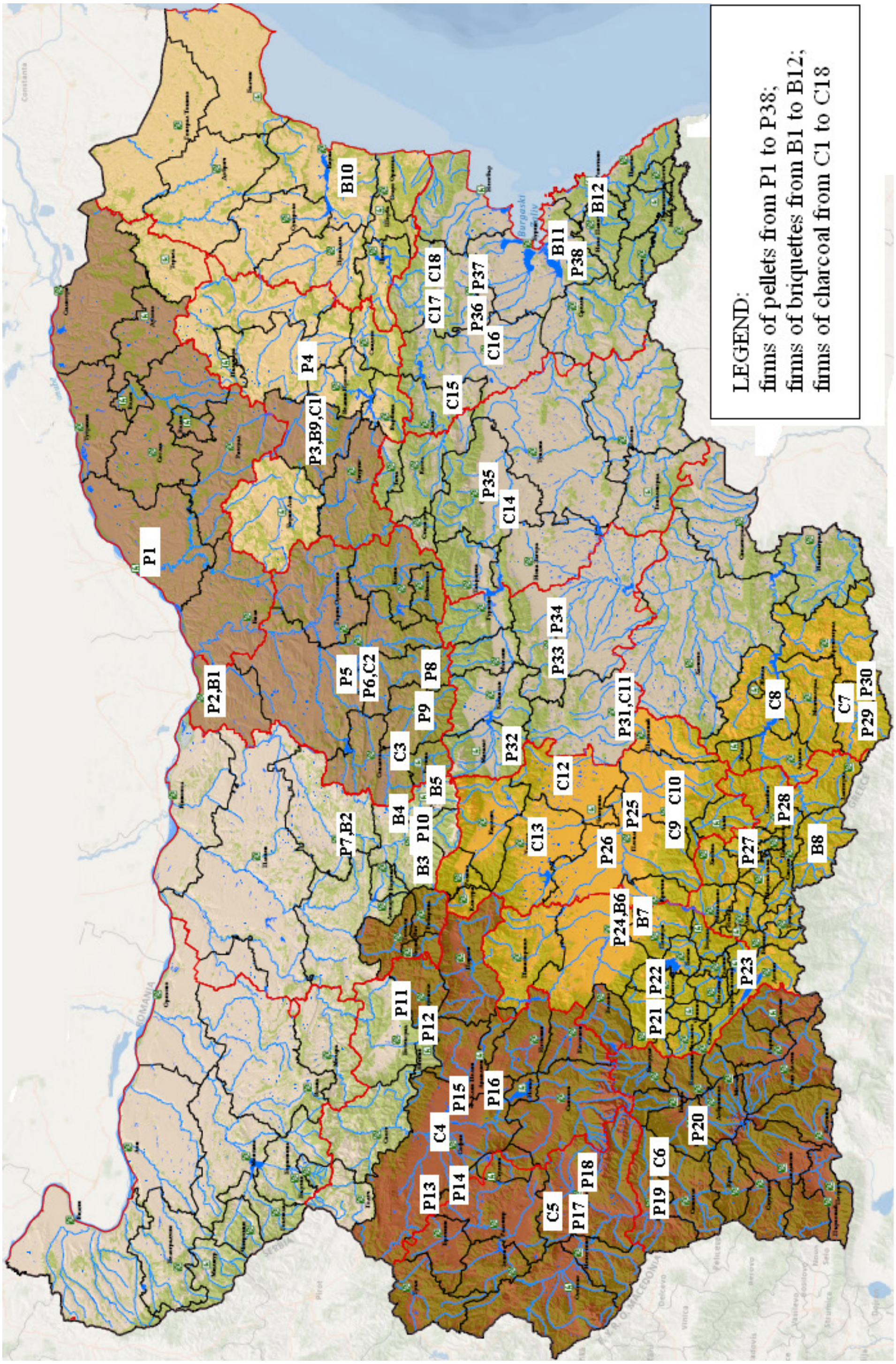


**Fig. 1.** Map illustrating the location of manufacturers producing pellets, briquettes and charcoal from the forest wood biomass in Bulgaria (in 2014).

**Table 1. Real production from forest wood biomass in Bulgaria (2014).**

| No | Producer | Volume, t/year | No | Producer | Volume, t/year | No | Producer | Volume, t/year |
|---|---|---|---|---|---|---|---|---|
| | | | | **Pellets** | | | | |
| P1 | Dentem | 500 | P14 | Peleti Energy | 2000 | P27 | Yola | 500 |
| P2 | Ecoteknika | 800 | P15 | Krearo | 1000 | P28 | Vizor | 5000 |
| P3 | Forinvest | 2500 | P16 | Eco Aktiv | 1000 | P29 | Bori | 300 |
| P4 | Leskomers | 500 | P17 | Eco Bio Fuel | 500 | P30 | Daris | 300 |
| P5 | DVT | 1500 | P18 | Rosen Ganchev | 500 | P31 | Carboni | 1200 |
| P6 | Milev | 250 | P19 | Supereco | 300 | P32 | Tron | 15,000* |
| P7 | MM Grun | 500 | P20 | Tehnowood | 1000 | P33 | Sredna gor | 500 |
| P8 | DIM Invest | 500 | P21 | Toria-08 | 1500 | P34 | Eco Power | 1000 |
| P9 | Ekoflame | 300 | P22 | Tehnobio | 1000 | P35 | BB Pelet | 5000 |
| P10 | Bioenergy | 300 | P23 | Inter Machinex | 1200 | P36 | Ais Les | 2000 |
| P11 | Eco Plam Produkt | 500 | P24 | Primatex | 1500 | P37 | Arex | 1500 |
| P12 | National 7 | 1000 | P25 | Ahira | 10,000 | P38 | Trakia Les | 2000 10,000* |
| P13 | Eco Flama | 2000 | P26 | Bio heat | 600 | | | |
| | | | | **Briquettes** | | | | |
| B1 | Eкoteknika | 500 | B5 | Ekoflame | 1000 | B9 | Ecokomers | 300 |
| B2 | Eco plam | 500 | B6 | Primateks | 700 | B10 | Rudi-An | 1000 |
| B3 | Eko brik | 300 | B7 | Bulpol | 500 | B11 | Emko-G | 600 |
| B4 | Elma 13 | 500 | B8 | Ekoterm | 500 | B12 | Hodja Yurt | 400 |
| | | | | **Charcoal** | | | | |
| C1 | Ecokomers | 300 | C7 | Daris | 300 | C13 | Carbol | 1000 |
| C2 | Milev | 200 | C8 | Gorsi | 300 | C14 | Apolon | 300 |
| C3 | Carbo Plus | 100 | C9 | Nikimol | 300 | C15 | Bulcarbon | 200 |
| C4 | Arkan | 500 | C10 | Okai | 1000 | C16 | Ivmobil | 500 |
| C5 | Balkanika | 600 | C11 | Carboni | 300 | C17 | Gorprom Invest | 4600 |
| C6 | Rosima Charcoal | 600 | C12 | Vibien | 600 | C18 | Ruen Les | 250 |

Note: * – data for 2015 (prognosis).

Such presses are of the so-called ’homemade machines’ (constructed from different parts and accessories, here and there gathered) where saw-dust waste from own production is used as a raw material; it is considered a mainspring for the rise of unfair competition because of undeclared production of pellets and their lower purchase prices. Other reasons are related to the existence of unregulated and vague market, disloyal firms and companies dealing with pellet production; scarce business opportunities in the country, on the one side, a low control not only on production but also on purchase, on the other, and the small targets set in front of the firms.

The distribution of biofuels produced in Bulgaria in 2014 and the prognosis for 2015 are indicated in Figure 2.

It is obvious that the prospective for biofuels production from wood is good, especially for pellets. At the end of 2014, a new factory for pellets in the environs of Burgas started working with a production volume amounting to 10,000 t per year, and in the beginning of 2015 another plant like the former one will start in the environs of the town of Kazanlak, with a prognosticated production volume over 15,000 t per year.

Production of pellets in Bulgaria in 2013, 2014 and a prognosis for it in 2015, according to the type of wood used for, is illustrated in Figure 3.

What makes an impression is that the production volume of pellets from coniferous wood has been growing on and it should be noted, significantly, according to the expectations for 2015 while a slight change only has been found out if other type of wood is used for.

The most frequent is the use of Bulgarian and Chinese machines (a small-size pressing machine and a small-size dryer) with some modifications (improvements) introduced by producers. Usually, such firms find niches at home market for placement of their production.

There is an enormous difference between the operating conditions in large-scale and small-scale firms. For example, in contemporaneous plants the process of production is dustless and completely automated while the operations in small workshops (most of which are no else but reconstructed ex-agricultural premises) are sordid and suffocating. As about the operational control, it is provided for the large-scale enterprises, but it is highly undervalued for the small-scale ones.

The total analysis of wood pellets and briquettes sales shows that about 2/3 of sales have been – and are being – real-

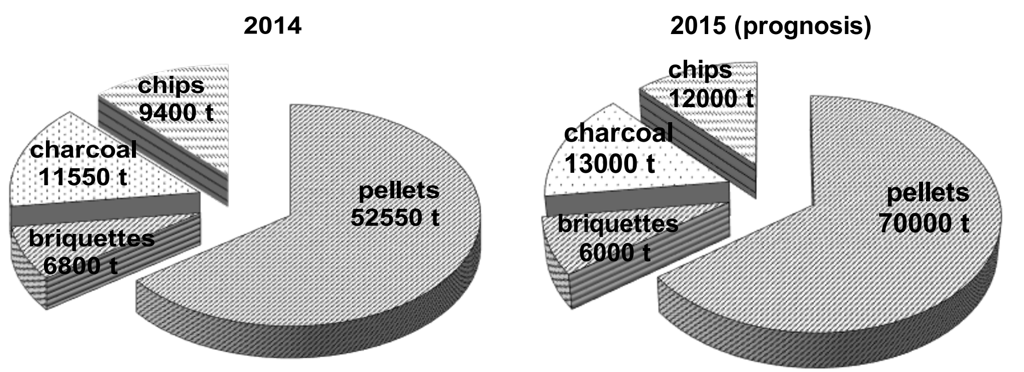


**Fig. 2. Distribution of biofuels in our country in 2014 and 2015 (prognosis).**

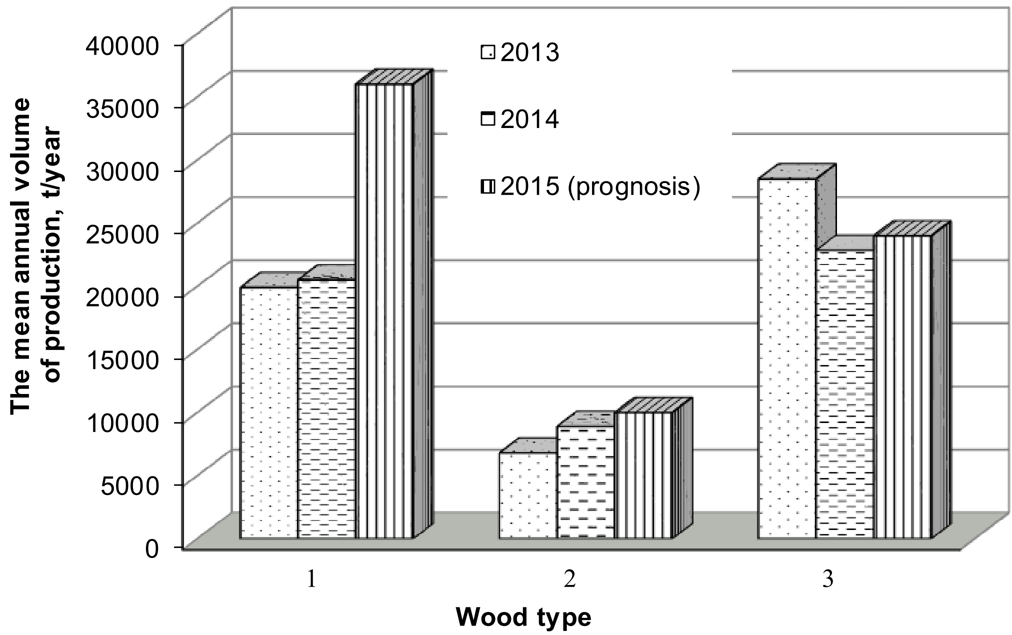


**Fig. 3. Production of pellets.**

Note about wood type: 1 – Coniferous (Black pine, Scots pine, Norway spruce, etc.); 2 – Deciduous (Oaks, Common beech and Black locust, Poplars, Limes, Common hornbeam, etc.); 3 – Mixture of deciduous and coniferous.

ized at home market, under previously concluded contracts, especially after quality requirements adoption. The most frequent exports are for Greece, Turkey and Italy.

Observations have been conducted where the costs for raw materials are considered to take the main part in the prime cost of production of pellets production. Other basic components of the costs and expenses are payroll and manufacturing costs where costs for drying are included: of 25 % and 20 %, respectively. In general, two workers only are necessary for the whole process of production.

Pellets of the best quality are produced from deciduous wood: from logs and not from wood waste. Higher is the content of bark in wood, worse is its quantity, i.e. the best pellets are produced by logs while the worst ones – from cuttings, shavings, branches etc.

According to our assessments, the most favourable production climate for development of briquettes, pellets and charcoal production is created when briquettes are produced for the home market, pellets for the foreign one and charcoal – for both of the markets.

On the grounds of the studies, conducted up to now, it has been stated that there are serious problems, in our country, regard to the construction of the plants and the production of biofuels from wood biomass (Table 2).

This study has examined mainly the aspects relative to production and some economic ones regarding indentifying the trends in the use of basic wood types in Bulgaria, in quantitative aspect, and their spread.

**Table 2. Problems regarding the construction of plants and biofuel production.**

| Main problems | Explanation |
|---|---|
| Incorrect suppliers | Incorrect suppliers of machines and equipment. |
| Incomplete knowledge | When plants are tested, either suppliers or buyers are often not too familiar with the process; hence, such an incomplete knowledge leads to a delay in the credit allotment and repayment; subsequently, the amounts of the interests rise creating pecuniary embarrassments for both of the parties. |
| Maintenance services | Missing services for maintenance. |
| Provision of raw material | The large-scale companies are provided of raw material while the small-scale firms often miss it. |
| VAT registration | The small-scale firms have no VAT registration; that is why their purchase prices are lower. |
| Workers | It is very hard to find quality workers. Preliminary training should be provided but it is not regulated. |
| Purchase of standing timber | When raw material is purchased, especially if it is a purchase of standing timber, wood is not separated raw material designed for pellets, briquettes and charcoal but it is mixed with technological wood used for plates and cellulose production. |
| Unfair competition | There is also unfair competition in the field of charcoal production and sale both at home and international markets, especially, by states which are not EU members, and more concretely, in some neighbour countries bordering Bulgaria, as charcoal is produced therein using the open-ended method. |
| Funds | To start building a plant, one shall also rely on one` s own funds. One cannot rely on 100 % crediting by banks. |

Further studies shall be performed on ecological and social consequences resulting from forest wood biomass use. Regardless the fact that the quality of the materials is an important parameter of the precarious forest wood biomass supply chain, reflecting on the quantity and the price of produced biofuels, we intend to make it the object of our next study.

## Conclusions

In our country the production volume of energy products from wood in 2014 is, as following: 52,550 t of pellets, 6,800 t of briquettes, 11,550 t of charcoal and 9,400 t wood chips, respectively. The prospective for biofuel production from wood is good, especially if related to pellets where, according to the expectations for 2015, the production volume should amount, at least, to 18,000 t, mainly from coniferous wood, while if other type of wood is used for, a slight change only could be expected.

The average annual production volume of the companies varies from 250–5000 t of pellets, 300–1000 t of briquettes and 100–4600 t of charcoal, respectively. The low volumes produced by small-scale firms while the high ones by large-scale producers: i.e. factories. The factories have put in their business plans production which is about twice higher than its volume indicated in documents. There are 60 %, approximately, of pellet producers (where the pellet share amounts to

15–20 % of the total production) who use small-size presses.

It is necessary to apply simpler and clearer administrative procedures to investments into the production of fuels from biomass, technologies and means for their utilization. Corporate taxes and corporate tax fees shall be reduced for companies producing fuels from wood biomass and firms producing ecological and efficient appliances for wood-based biofuels.

Biological and ecological studies should be performed in the cutting areas, especially in those ones where a higher intensity of cutting is made, to determine the long-term consequences from wood waste removal and collection, after logging, aiming at waste utilization for energetic purposes.

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# IMPACT OF ENVIRONMENTAL FACTORS ON THE SIZE OF RED DEER (*CERVUS ELAPHUS* L.) ANTLERS

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## Abstract

Red deer has been reintroduced in 18 lowland and mountain former habitats by releasing animals from two neighbouring populations, supposed to be genetically identical. The mean values of measurements of trophies obtained from newly-created and initial populations have been compared by Student's t-test. The significant differences found did not depend on new habitats remoteness, as well as on the mean age of animals hunted for trophy. Evidently, it seems that ecological variables are the most important cause of red deer trophy size variability, and further investigations are needed to study the relationship between altitude, climate, vegetation, etc. and the most important trophy measurements.

**Key words:** antler size, beam length, circumference of beam and coronet, trophy quality, weight of antlers.

## Introduction

Red deer (*Cervus elaphus* L.) is the most famous large game species in Bulgaria. This animal became nearly extinct during the 19th century. About 1850 the red deer disappeared from North-East Bulgaria but several hundred individuals were still present in their habitats over Stara Planina Mountain and the Valley of Kamchia River. About 50 years later, at these same regions, only about 50 red deer have been counted (Bajchev 1968).

It can be assumed that at the end of the century, no more than several hundred individuals were still present at two neighbouring game-breeding stations in Eastern Bulgaria – Palamara and Sherba.

Since 1945, a project for red deer reintroduction has started. Animals from both stations have been released into former red deer habitats all over the country. During the period 1946–1981, 981 red deer from Palamara as well as 269 animals from Sherba were released. Thus, it has been reintroduced in former habitats.

This process might be considered as a large scale field experiment, where red deer originated from two interrelated neighbouring areas and supposed to be similar genetically, has been released into regions with different ecological (environmental) variables.

The problem of possible predominance either of genetic or ecological factors influences on the shape of red deer trophy is still open. This paper aims at showing similarity or differences between trophies obtained from different habitats, where red deer populations have been created by use of genetically similar animals.

## Study Areas, Material and Methods

Since about 1970 trophy hunting has started as an aspect of 'harvesting' the newly-created red deer populations.

According to CIC Formula for the Measurement and Evaluation of Trophies (Ninov 2004), 253 red deer trophies, obtained by international hunters in 19 hunting areas all over Bulgarian territory within the period 1983–1987, have been measured, i.e. from: 1) Palamara and Sherba – *n*=47; 2) Seslav – *n*=3; 3) Karakus – *n*=10; 4) Tundzha – *n*=3; 5) Slanchev briag – *n*=5; 6) Trakia – *n*=5; 7) Tervel – *n*=27; 8) Cherni Lom – *n*=24; 9) Preslav – *n*=16; 10) Buzludzha – *n*=17; 11) Bukovets – *n*=28; 12) Chumerna – *n*=3; 13) Uzana – *n*=5; 14) Ticha – *n*=3; 15) Murgash – *n*=19; 16) Izvora – *n*=16; 17) the Rhodopes – *n*=17; 18) Pirin – *n*=5.

Measurements considered to be of the greatest importance to the total evaluation of trophy quality, have been taken into account: the weight of antlers (W), kg; average length of mean beam (ALMB), cm; average circumference of coronet (ACC), cm; circumference of lower beam, left (CLBL), cm; circumference of lower beam, right (CLBR), cm; circumference of upper beam, left (CUBL), cm; circumference of upper beam, right (CUBR), cm and the number of tine ends (NTE).

The age-group of animals, as well as the approximate age (years), have been determined by using the degree of teeth wear either on supramaxilla and mandible. The height and thickness of antler base-bone, as well as the transparence of skull sutures, have been used as additional criteria for age determination of red deer (Stubbe and Lockow 1994).

Distances between Palamara, Sherba and the remaining hunting areas have been measured on a map.

Arithmetic mean (*M*) and standard deviation (*Sd*) of trophy measurements have been calculated. The significance of differences between the mean values of the same measurements of trophies obtained from 'initial' and 'newly-created' red deer populations have been accessed by Student's t-test.

## Results and Discussion

Mean values (*M*) and standard deviations (*Sd*) of the most important measurements of red deer trophies from the 'initial', i.e. Palamara and Sherba, and 'newly-created' populations are given in Table 1. Due to lack of significant differences in trophy size between Palamara and Sherba ($t_{max}$ = 1.267; $df$ = 45; $P$ > 0.05), trophies originated from both hunting areas have been grouped (Table 1).

Trophies from Buzludzha, Bukovets, Murgash, Izvora and the Rhodopes had significantly lower weight and circumferences than animals originated from 'initial' population (Table 1 and Table 2).

Deer from Tervel, Cherni Lom, Uzana and Ticha have formed longer beams than in Palamara and Sherba, while beams from Izvora have been significantly shorter (Table 1 and Table 2).

The results obtained have shown that red deer tended to form longer antlers but with lower weight in mountain habitats of Stara planina Mountains and the Rhodopes Mountains.

As red deer origin was considered identical, the significant differences in

**Table 1. Mean values and standard deviations (*M/Sd*) of the most important red deer trophy measurements from 'initial' (Palamara and Sherba) and 'newly-created' populations.**

| Area/n | Age, years | W, kg | ALMB, cm | ACC, cm | CLLB, cm | CLRB, cm | CULB, cm | CURB, cm | NTE |
|---|---|---|---|---|---|---|---|---|---|
| Palamara and Sherba | 10.0 | 7.22 | 104.18 | 26.3 | 16.0 | 15.8 | 15.1 | 15.1 | 13.0 |
| *n*=47 | 1.9 | 1.27 | 6.0 | 1.9 | 1.4 | 1.1 | 1.2 | 1.1 | 2.3 |
| Seslav | 9.3 | 8.2 | 100.3 | 27.3 | 15.6 | 15.3 | 14.0 | 14.3 | 13.0 |
| *n*=3 | 1.7 | 1.7 | 9.7 | 2.8 | 1.5 | 1.7 | 0.7 | 0.6 | 1.7 |
| Karakus | 9.3 | 7.4 | 106.3 | 27.1 | 15.8 | 15.3 | 14.7 | 14.8 | 13.4 |
| *n*=10 | 1.7 | 1.4 | 8.2 | 2.3 | 1.8 | 1.2 | 1.1 | 1.3 | 2.6 |
| Tundzha | 8.3 | 6.5 | 98.0 | 25.7 | 14.7 | 15.0 | 14.0 | 13.9 | 12.0 |
| *n*=3 | 1.5 | 1.0 | 2.7 | 1.8 | 0.5 | 0.7 | 0.5 | 1.0 | 1.7 |
| Slanchev briag | 8.4 | 6.2 | 100.5 | 25.5 | 15.4 | 15.3 | 14.5 | 14.6 | 12.6 |
| *n*=5 | 1.8 | 1.3 | 9.2 | 1.9 | 1.4 | 1.4 | 1.5 | 1.6 | 2.1 |
| Trakia | 8.2 | 6.5 | 104.4 | 25.2 | 14.9 | 15.0 | 14.2 | 14.5 | 13.2 |
| *n*=5 | 2.9 | 1.9 | 4.2 | 2.1 | 1.2 | 1.0 | 1.4 | 1.1 | 1.3 |
| Tervel | 10.2 | 7.8 | 108.6 | 27.4 | 15.9 | 15.7 | 15.1 | 15.2 | 13.4 |
| *n*=27 | 1.5 | 1.4 | 8.8 | 2.14 | 1.2 | 1.4 | 1.4 | 1.2 | 2.3 |
| Cherni Lom | 10.9 | 7.8 | 107.7 | 27.5 | 15.6 | 15.9 | 15.2 | 15.3 | 14.2 |
| *n*=24 | 1.9 | 1.2 | 6.6 | 2.4 | 1.5 | 1.7 | 1.8 | 2.0 | 2.6 |
| Preslav | 9.0 | 6.6 | 100.6 | 25.4 | 14.6 | 14.9 | 13.8 | 13.9 | 12.6 |
| *n*=16 | 1.8 | 1.5 | 12.5 | 2.2 | 1.6 | 1.7 | 1.1 | 1.3 | 2.4 |
| Buzludza | 9.2 | 5.4 | 102.0 | 23.6 | 14.6 | 14.8 | 13.6 | 14.1 | 12.8 |
| *n*=17 | 2.4 | 1.2 | 7.3 | 1.5 | 1.5 | 1.7 | 1.4 | 1.8 | 2.1 |
| Bukovets | 10.0 | 5.6 | 101.3 | 24.0 | 14.4 | 14.4 | 13.2 | 13.3 | 12.4 |
| *n*=28 | 2.0 | 1.1 | 7.4 | 2.2 | 1.4 | 1.2 | 1.1 | 1.1 | 2.3 |
| Chumerna | 9.7 | 8.0 | 101.6 | 26.8 | 15.7 | 15.3 | 14.3 | 14.4 | 14.5 |
| *n*=3 | 1.5 | 0.8 | 4.6 | 1.8 | 1.3 | 0.8 | 1.1 | 1.0 | 0.7 |
| Uzana | 10.8 | 7.7 | 115.6 | 25.3 | 16.2 | 16.5 | 15.1 | 15.1 | 14.8 |
| *n*=5 | 1.9 | 1.5 | 9.0 | 0.8 | 1.8 | 1.7 | 1.2 | 0.9 | 3.4 |
| Ticha | 9.0 | 7.5 | 112.6 | 26.4 | 16.3 | 16.6 | 14.7 | 15.1 | 13.7 |
| *n*=3 | 1.0 | 1.1 | 7.6 | 3.0 | 2.0 | 2.4 | 1.8 | 2.0 | 1.2 |
| Murgash | 9.1 | 5.9 | 102.8 | 24.3 | 14.6 | 14.6 | 13.4 | 13.5 | 12.4 |
| *n*=19 | 1.7 | 1.4 | 7.7 | 2.2 | 1.4 | 1.6 | 1.4 | 1.4 | 1.9 |
| Izvora | 8.9 | 6.2 | 99.5 | 25.9 | 14.9 | 14.7 | 14.3 | 14.3 | 12.2 |
| *n*=16 | 2.6 | 1.8 | 11.7 | 3.9 | 1.6 | 1.7 | 2.2 | 2.2 | 2.6 |
| The Rodopes | 9.7 | 6.3 | 106.6 | 25.9 | 15.0 | 14.9 | 14.5 | 14.7 | 12.1 |
| *n*=17 | 2.4 | 1.4 | 6.8 | 2.7 | 1.3 | 1.2 | 1.4 | 1.9 | 1.8 |
| Pirin | 9.0 | 6.8 | 104.2 | 25.7 | 14.8 | 15.2 | 14.2 | 14.5 | 14.4 |
| *n*=5 | 1.4 | 1.7 | 8.6 | 1.4 | 1.1 | 1.2 | 1.0 | 1.3 | 1.3 |

Note: Area/*n* – hunting area/sample size; arithmetic mean values/standard deviations of: W, kg – weight of antlers; ALMB, cm – average length of mean beam; ACC, cm – average circumference of coronets; CLLB, cm – circumference of lower left beam; CLRB, cm – circumference of lower right beam; CULB, cm – circumference of upper left beam; CURB, cm – circumference of upper right beam; NTE – number of tine ends.

**Table 2. Significance of differences between the mean values of red deer trophy measurements from ‘initial’ and ‘newly-created’ populations.**

| Area | W, kg | ALMB, cm | ACC, cm | CLLB, cm | CLRB, cm | CULB, cm | CURB, cm |
|---|---|---|---|---|---|---|---|
| Initial population | ns | ns | ns | ns | ns | ns | ns |
| Seslav | ns | ns | ns | ns | ns | ns | ns |
| Karakus | ns | ns | ns | ns | ns | ns | ns |
| Tundza | ns | ns | ns | ns | ns | ns | ns |
| Slanchev briag | ns | ns | ns | ns | ns | ns | ns |
| Trakia | ns | ns | ns | ns | ns | ns | ns |
| Tervel | ns | + | + | ns | ns | ns | ns |
| Cherni Lom | ns | + | + | ns | ns | ns | ns |
| Preslav | ns | ns | ns | -- | - | -- | -- |
| Buzludza | -- | ns | -- | -- | -- | -- | -- |
| Bukovets | -- | ns | -- | -- | -- | -- | -- |
| Chumerna | ns | ns | ns | ns | ns | ns | ns |
| Uzana | ns | ++++ | ns | ns | ns | ns | ns |
| Ticha | ns | +++ | ns | ns | ns | ns | ns |
| Murgash | ---- | ns | ---- | ---- | ---- | ---- | ---- |
| Izvora | - | - | ns | - | -- | ns | ns |
| The Rhodopes | -- | ns | ns | - | -- | ns | ns |
| Pirin | ns | ns | ns | ns | ns | ns | ns |

Note: ++++ – values are higher at level $P \leq 0.001$; +++ – values are higher at level $P \leq 0.02$; + – values are higher at level $P \leq 0.05$; ---- – values are smaller at level $P \leq 0.001$; -- – values are smaller at level $P \leq 0.01$; - – values are smaller at level; $P \leq 0.05$; ns – not significant at $P \leq 0.05$.

some antlers parameters observed might be related to other factors, i.e. (i) age of animals; (ii) population density (Schreiber and Lockow 1988); geographic isolation or remoteness of ’new-created‘ populations from ’initial‘ one; (iii) ecological variables (mostly in connection with availability of forage), such as altitude, climate (Mysterud et al. 2005, Torres-Porras et al. 2009), vegetation, etc. but mostly during early life stage (Schmidt et al. 2001).

In the most of scientific articles studying impact of environmental factors on red deer population, body mass of both sexes was used as dependent variable instead of antlers weight (i.e. Langvatn and Albon 1986, Langvatn et al. 1996, Mysterud et al. 2001). Although it was known that antler size to be heritable despite substantial age- and environmental-related variations, till present day it is very little known about environmental influences on growing dynamics of some parts of antlers. Heritability, the proportion of variation in antler size, attributable to genotype, varied from 25 % to 75 % (Harris et al. 2002). It is known that growth of antlers depends on age (Harris et al. 2002), but also on individual’s nutritional state and fitness (Kruuk et al. 2002). For example, after heavy snow winters stags develop antlers with significantly smaller number of tines than in mild winters.

The trophy measurements tend to increase with the age of red deer and reach their maximal values at the age of 11–13 along European distribution of the game species (Bečejac et al. 1984, Botev 1985, Lockow 1991). As shown in Table 1, red deer have been hunted at the age of 8–10 and the differences between the mean age of animals harvested from ‘initial’ and ‘newly-created’ populations were not significant at $P < 0.05$, as well as the mean number of tine ends; as the animals from ‘initial’ and ‘newly-created’ populations in analyses came from the same age group, the antlers size differences could not be assigned to the stags' age. But today it is known that one of the most important factors in comparison of wild ungulates is cohort effect (Post et al. 1997, Rose et al. 1998, Forchhamer et al. 2001, Gaillard et al. 2003).

The average distance between Palamara and Sherba and the other hunting areas examined has been positively but not significantly correlated with the number of significant differences in mean values of trophy measurements ($r$ = +0.187 to +0.2; $df$ = 15; $P > 0.05$). Thus, geographic isolation between Bulgarian red deer populations might not been considered of great importance concerning trophy size.

## Conclusion

Evidently trophy size differences could be better explained by ecological factors in different habitats. Genetic factors and geographic isolation could have minor importance. Further investigations are needed to study the role of biological (such as age) and environmental variables in red deer trophy formation.

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# STUDY ON MILLING TECHNOLOGY UNIT PERFORMANCEFOR SITE PREPARATION FOR AFFORESTATION

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## Abstract

Contemporary technologies for afforestation of forest areas, based on the use of specialized milling units for soil preparation, mulching, shredding of stumps and other typical forest operations, are characterized by relatively high environmental and quality indicators, lower cost of labor and a smaller number of used technical means. These indicators are due to the use of specialized milling machines, which can operate in wide range of strength and type of deformation and interaction of the cultivated object. To achieve good results and low technology speeds, more energy and powerful tractors are needed. This article presents results of some basic performance of forest milling aggregate PT-400, with multi-purpose forest tiller FAE 300/S. The survey has been carried out on experimental poplar sites and slashes along the Danube river valley in the north-west region Bulgaria. For the purpose of the study the following parameters were determined: fuel consumption, operating speed and operational performance of the milling unit under certain conditions: 1) crushing stumps with diameters up to $d_{av}$ = 65 cm, mulching False indigo-bush (*Amorfha fruticosa*) with height of 2.5–3.0 m and clearing debris; 2) milling of the soil to a depth of 0.5 m. The obtained results will be useful for better determination and establishment of technological capacities and performance of the studied specialized milling unit.

**Key words:** fuel consumption, operating speed, poplar plantations, productivity.

## Introduction

The cultivation of intensive poplar plantations in Bulgaria has already extensive experience. The first specialized experimental station and poplar farm were established in Bulgaria in the early 1960's. They were used to conduct research and development activities in the field of growing, cultivating and production of reproductive material of different poplar species. Since then a significant part of Bulgarian forest areas along the biggest rivers were used for establishment and cultivation of intensive poplar plantations for accelerated timber production, and energy plantations.

Physical and mechanical characteristics of the soil are important factors for the soil resistance to processing with tillage machines and directly affect the energy consumption. Such factors are the mechanical structure, hardness and soil moisture of the arable area. The structural distribution of the soil after its treatment is a qualitative factor affecting the soil fertility, development of erosion and growth of the planted poplar cultures.

Afforestation and cultivation of poplar plantations is a well-studied process in Bulgarian forestry (Kolarov 1988, 1996; Kalmukov and Alexandrova 1999, 2003; Tzanov et al. 2001; Vasev et al. 2003; Kalmukov 2008; Vasev 2009, 2013). Very few international studies have examined wood production potential in poplar plantations and site preparation (Anonymous 2007; Anonymous 2009; Böhlenius 2015; Christersson 2008, 2010; Hansen et al. 1984, 1993; Keča and Pajić 2015; Löf 2012). Afforestation and cultivation of poplar plantations are very dynamic processes demanding constant development and application of newer production technologies. The afforestation through establishment of intensive poplar plantations is a laborious and complex activity as it covers most labor-intensive processes, such as soil preparation, weeding and pushing the stumps, and planting. Therefore, it is necessary to introduce innovative mechanized technologies and systems of machines in an attempt to achieve full mechanization of the main technological processes. This will allow to increase the percentage of mechanization in silvicultural activities and thereby to enlarge timber output, to decrease the labor costs and the cost per unit area new forest plantation. Such machines must fulfill all agricultural, forestry and environmental requirements of modern forest management. In countries with well-developed intensive poplar plantations specialized machines with high quality and technical-economic indicators are more frequently used.

The main technological schemes currently applied for soil preparation of poplar clearings in Bulgaria are based entirely on the use of tooth and rotor eradicator. One of the major disadvantages of older but still widely used technology based on frontal tooth eradicators is the removal of a significant part of the upper and fertile soil. As a result, the physical, mechanical properties and the fertility of the soil deteriorate with each subsequent production rotation. Also, while using this technology some additional operations such as removal of stumps, and leveling the area are required. These operations necessitate the use of relatively heavy and energy-intensive bulldozer aggregates. On the other hand, the second and newer technological scheme uses rotary eradicators with positional action for the grinding of stumps. The main disadvantages are minimized in it, but it has a limited area application. It can be used only on clean slashes without wood residues and woody and shrub vegetation, rocks-free and very deep soils.

Recently, forest managements in many countries, including Bulgaria, apply innovative specialized milling machines for soil preparation for afforestation of forest lands. According to its purpose and technological capabilities, these machines can be used for shredding and mulching stumps, roots and wood resides, and primary tillage.

In the past several years three types of milling machines were used for soil preparation of non-renewable forest areas within the North-east Regional Forestry Enterprise „Shumen” – forestry mulcher FAE UMH/S-200, ameliorative tiller SSH 200 and milling machine for crushing stumps AHWI SF 100. The first studies of the work of these machines conducted in Bulgaria showed that under certain operating conditions they show good performance and their wider use in Bulgarian afforestation practice is recommended (Marinov 2014). In 2013 new specialized milling unit – Prime Mover PT-400 was introduced to the territory of North-west Regional Forestry Enterprise „Vratza”. It is used in soil preparation for establishment intensive poplar plantations. The operating body of the milling unit is multifunctional forest cutter FAE 300/S-225, and the energetic machine is crawler PT-400.

The initial studies (Jordanova and Marinov 2014) on the operational work of the milling aggregate have shown that it has broad technological capacities. These surveys have found that the multifunctional milling unit can shatter stumps with diameters up to 0.8 – 1.0 m, it can shred standing trees and shrubs with height up to 10–12 m and wood residues with a weight of 0.8 m. Simultaneously, it performs basic soil processing in depth of 0.55 m, while the crushed wood chips are evenly mixed with the soil at full depth. The introduction of such aggregates leads to rationalization of shredding and grubbing technology due to dropping out of operations like stumps and roots pushing out of the area and leveling the terrain. During the working process strong crushing, mixing and aeration of the soil layers and debris occur, while the field is perfectly aligned. The treated soil is already suitable for planting without the need of subsequent pre-sowing treatment. The introduction of such specialized milling machines would facilitate our forestry practice to develop intensive poplar plantations establishment and to apply more efficient and high-performance technologies.

The purpose of this study is to present the work of forest milling unit PT-400 with multifunctional forest tiller FAE 300/S-225, with nominal motor power 310 kW (415 hp) (Anonymous 2014). The aim is achieved by studying the following parameters: operating fuel consumption, productivity and grain structural composition of the treated soil and wood chips under predefined conditions.

## Materials and Methods

The experiments were carried out on two experimental poplar sites along the Danube river valley in the region of Northwest State Forestry Enterprise „Vratza", within the territory of State Forestry Service (SFS) „Lom" and State Forestry Service (SFS) „Oryahovo" (Fig. 1).

### Operational site conditions

The study was performed over two plots situated in fresh poplar clearings, at aver-

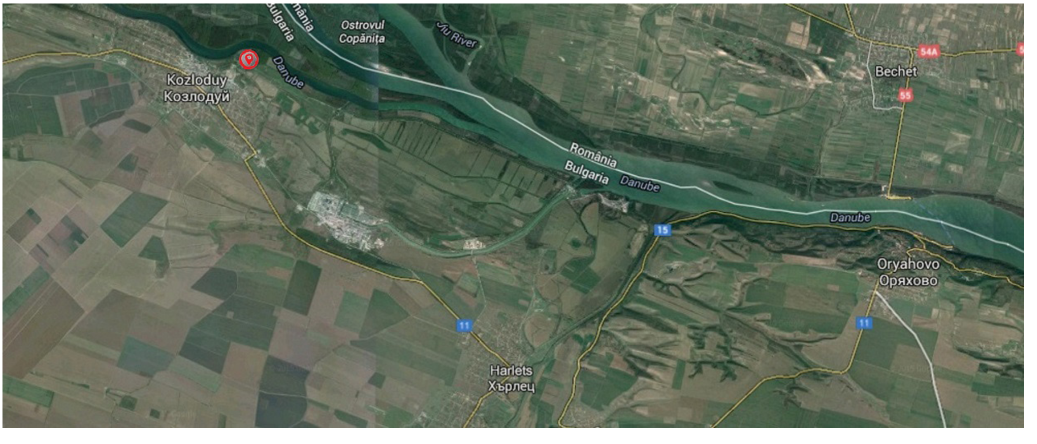


**Fig. 1. Map of the site for afforestation in SFS „Oryahovo".**

age altitude up to 30 m. According to the forest management plans of SFS „Lom“ and SFS „Oryahovo“ the sites would have been prepared for afforestation with 1-year old poplar saplings (*Populus* × *euramericana* cv. Agathe-F), in 4 × 4 m scheme (Anonymous 2006a; Anonymous 2006b). The two operational sites belong to the sub-belt of floodplain and riparian forests type, and the landscape consists of flat or inclined terrains with northern exposure. The soil depth is up to 1.0 m, which favors deeper soil preparation. Location of the experimental plots at Danube River is a prerequisite for the systematic flooding of the area, leading to water logging of soil and in many cases hinders and delays afforestation work. To prevent formation of erosion and to protect the workers and the unit while processing the soil, the working moves were performed from the coast inwards perpendicular to the river. Timing observations were done in the two working sections – one in SFS „Lom” and another in SFS „Oryahovo”. Representative samples of soil and crushed wood chips were taken from the two clearings. They were used to determine the texture composition distribution of the soil and the structural composition distribution of shattered wood residues.

First operational site (OS-1, coordinates 43°50'28.24" N and 23°15'45.87"E, 30 m a.s.l.), is located along the Danube River, in subsection $53^{d}$ within SFS „Lom”. The total area is 10.4 ha with an average slope up to 2˚. The soil is alluvial, sandy loam, very deep and free of stone particles. The contour of the terrain has rectangular shape. The stumps scheme was 4 × 4 m. The land is non-renewable clearing, after 100 % felling. About 70 % of the terrain was invaded by False indigo-bush (*Amorpha fruticosa* L.) and inferior vegetation with height of 2.0–2.5 m. The average density of stumps was 75 pcs per 1 dka, with average diameter $d_{av}$ = 50.1 cm, while $d_{max}$ = 68 cm and $d_{min}$ = 41 cm. The land preparation for afforestation includes mulching the stumps and other clearing debris, and deep loosening up to 50 cm. The average length of the working area is 121.4 m. Samples of wood chips were taken to determine the structural composition, soil sample to determine grain-mechanical composition and the moisture. Two timing observations were made during two operators' shifts.

**Fig. 2. Specialized milling unit Prime Mover PT-400 with multifunctional forest tiller FAE 300/S, subsection $13^{e}$ in State Forestry Service „Oryahovo”.**

Second operational site (OS-2, coordinates 43°44'28.45" N and 23°56'23.08" E, 30 m a.s.l.), is located along the Danube River, subsection $13^{e}$ of SFS „Oryahovo” (Fig. 2) with an average slope up to 2 °. The soil is alluvial, sandy – loam, very deep and free of stones. The contour of the terrain has a rectangular shape with total area of 9.5 ha. The average length of operational site is 44.7 m. The area is renewable clearing, after 100 % felling and scheme of the stumps 4.5 × 2 m. Average density is 101 pcs per 1 dka, with average diameter at the base of the stumps $d_{av}$ = 40.8 cm, as $d_{max}$ = 47 cm and $d_{min}$ = 35 cm. Preliminary preparation includes crushing stumps and deep loosening of the soil up to 50 cm. The hardness of the soil was measured. Samples of crushed chips and soil to determine the size distribution and humidity were taken.

## Tasks and parameters

For the purpose of the present study the following tasks have been fulfilled:

- assessment of the timing of operations;
- determination of the fuel consumption;
- determination/assessment of the structural composition of treated soil;
- determination/assessment of the structural composition of the wood chips residues after treatment.

The parameters as slope of terrain; diameter and density of stumps; density and height of trees and shrubs; depth of processing; length of the work area; type, mechanical composition, humidity and hardness of the soil were set constant. During the study they were maintained at the same level.

Demanded parameters of the study as duration of observed operations; volume of work performed (productivity); structural texture composition of wood chips; soil moisture, grain and texture, and fuel consumption are measurable quantities. They were obtained during the process of the study.

## Methods and equipment

The time spent for individual operations and processes was determined by composing a workday route picture. For the purpose the estimated analytical methods for standardization of processes for monitoring of the fieldwork was used. Time within one working day was measured with an accuracy of 1 min. Operating time was determined by performing full Timing observations with an accuracy of 1 s (Stoyanov and Stoyanova 2005). The grain structure of the treated soil and the texture composition of the wood residues were determined by sieve method. The equipment for the survey consistsed of:

- Stopwatch with accuracy up to 1 s;
- Tape measure with accuracy up to 1 cm;
- Electronic scale model „Sartorius" and „Radwag", accuracy up to 0.1 g;
- GPS system model „Garmin Montana 650 T", for the field work;
- Penetrometer „Dickey-John Corporation", Auburn, Illinois, USA;
- Electric laboratory dryer – MK „Opticoelectron" Plant 7 – Velingrad;
- Screens sizes: 30 mm, 25 mm, 20 mm, 11 mm, 5 mm, 2.5 mm, 2.0 mm, 1.6 mm, 1.0 mm, 0.5 mm, 0.25 mm, and 0.10 mm.

The samples used to determine the texture distribution, soil moisture and structural composition of shredded wood residues were tested at the laboratory „Mechanization of forestry activity", Department "Technology and mechanization of Forestry", University of Forestry in Sofia.

Initially, the average diameters of the stumps, planting scheme and existing vegetation were determined onsite. Soil hardness was measured with a penetrometer. For the purpose of the study 20 soil samples at depths up to 30 cm were taken and the average hardness was defined by statistical methods. The moisture of the soil samples was obtained by gravimetric method, as percentage of field soil samples with humidity to absolute dry soil mass. The workday photo and the timing of the operations were scored by chronometric measurements. To determine the grain mechanical structure of the soil and the soil moisture were taken samples from the two OS.

For the purpose of the study two timing observations were carried out. The total duration of a recording timing observation was six hours. The way of movement of the studied aggregate in the sample area was defined at the beginning of the working day by selecting the most rational scheme.

The rate of use of milling unit within one shift was expressed by the coefficient of use of work time in one shift – $\tau_{cm}$. This coefficient was defined as the ratio between the time spent on operational work and the total duration of one shift – $\tau_{cm} = T_{stroke} \cdot T_{shift}^{-1}$. Due to the specific workflow workday was divided into two shifts by six hours. The coefficients of the use of the working time for both OS were ascertained based on the data obtained from the timing and route images. Route pictures were done within two working days.

Measurements of timing included strokes and idle state of the machine were noted down in a special timing-form. Within a shift the duration of all times were measured and they were recorded in tabular form. After that a workday-route picture was composed. The performance of one shift was determined by measuring of the processed area at the end of the shift. For Timing of all operations 20 to 30 experimental observations were done. Comparative method which measures the impact of various factors on the processes studied was used.

The survey was conducted from 24th of November, 2014 until 25th of April, 2015. Three soil samples from both areas were taken and the texture composition of the soil was established by sieve method. Two samples were taken to define the percentage distribution of structural composition from shattered wood residues. Three soil samples were taken to specify the soil moisture by using gravimetric method.

## Results and Discussion

The soil is alluvial, with sandy – loam mechanical composition. The average hardness of the soil for the OS-1 is 792 kN/m² (8.1 kg/cm²), and in the OS-2 – 1380 kN/m² (14 kg/cm²). The measurement in the second operational site where flood waters had retired earlier and the soil was drier showed higher hardness. The results show that the type of the soil has lesser impact on its hardness than the time of withdrawal of flood waters and its current humidity.

Soil moisture for the first working site was 40.8 % and for the second – 22.2 %. Soil moisture for the OS-1 is more favorable for the mechanical processing of alluvial soils, while for the OS-2 it is dry and hard, which effects on the higher costs of energy.

The moisture of the treated soils show that the soil from the first studied OS-1 is $W_{av}$ = 40.8 %, as for the second OS-2 is $W_{av}$ = 22.2 %.

Figures 3 and 4 represent the percentage distribution of the texture composition of the soil samples from the two studied operational sites.

Based on the results obtained, we can assume that after processing the drier soil from the OS-2, the structure of the soil is relatively even measured, and the participation of large aggregates with a size above 20 mm is negligible. Coarse

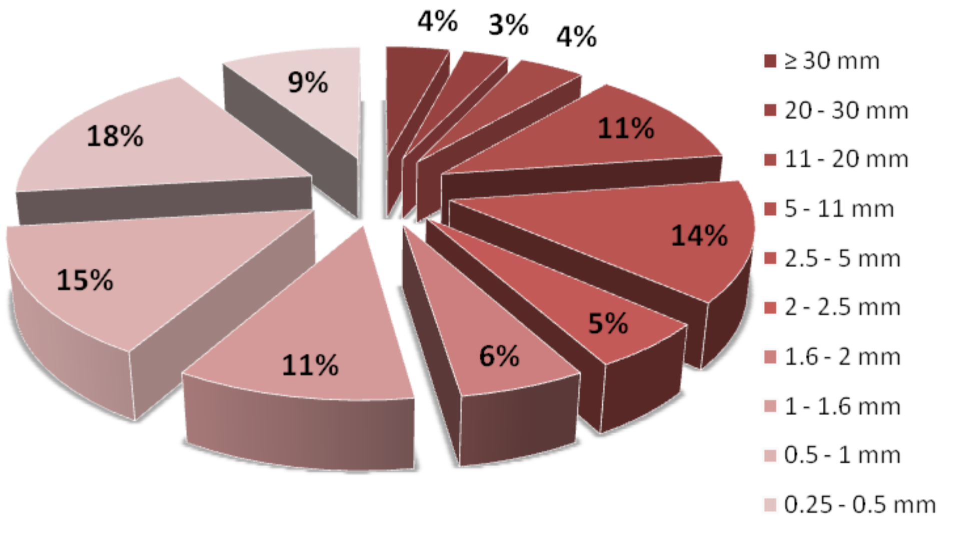


**Fig. 3. Texture composition distribution of the soil from the OS-1.**

soil aggregates from the first soil sample are about 7 %. Both samples show that the milling unit crushed and loosened soil very good, while leaving the soil aggregates within the sizes larger than the levels of dusting (>0.25 mm).

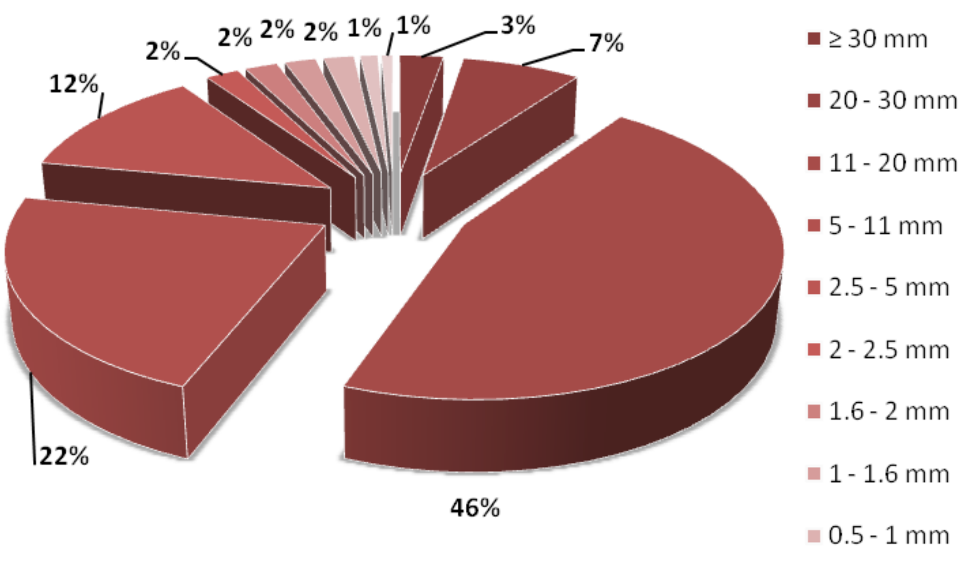


**Fig. 4. Texture composition distribution of the soil from the OS-2.**

In agriculture a valuable agronomic soil is considered the one containing soil aggregates with size between 0.25 mm and 10 mm. The beginning of wind erosion in agricultural areas is reckoned (Gyurov and Artinova 2015) to occur when there is presence of at least 30 % soil aggregates with size below 1 mm in the total soil volume. Thereby the erosion risk is about 50%. Therefore the application of the specialized unit preserves the soil fertility and minimizes the development of wind erosion.

## Characteristics of splintered wood into the soil

Figure 5 and Figure 6 show the percentage distribution of the shattered wood chips. Figure 5 shows the percentage distribution of the wood chips, after the PT-400 has moved forward i.e. after the process of mulching. Figure 6 shows the percentage distribution after the milling unit has moved in reverse i.e. after the process of tilling. There is a tendency that after the unit move in reverse the wood chips become more shattered and the highest percentage of the wood chips bigger than 30 mm after the forward stroke transfers to wood chips with size between 11–20 mm after the reverse stoke.

The size of wood chips is an important factor for the rapid absorption of splintered wood into the soil and for the reduction of the total resistance, which they perform upon the machine working body during the followed operations (additional tillage and cultivating). The structural composition of chips was defined in two different technological operations: 1) after mulching (grinding of stumps and standing ground woody shrubs) – after the first run of the unit forward gear the tractor (Fig. 5), and 2) after basic processing (deep milling) – after subsequent passage of the unit in the same trace reverse gear of the tractor (Fig. 6). Samples of the two OS showed similar re-

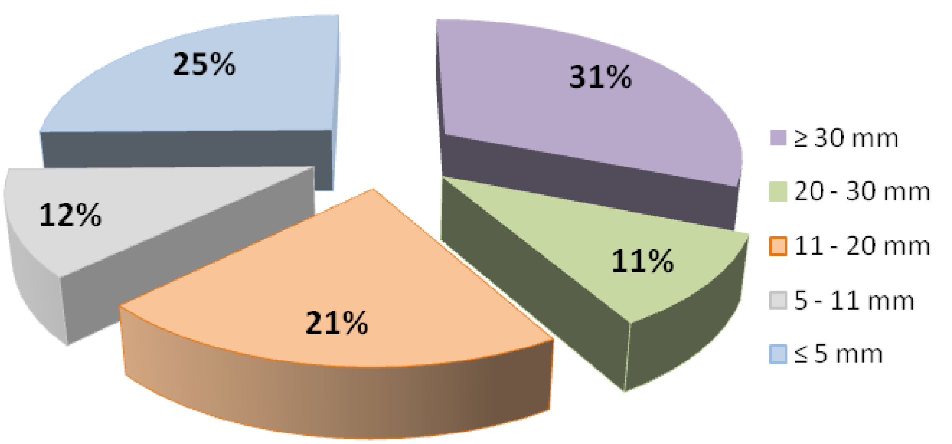


**Fig. 5. Structural composition distribution of shattered wood residues after the first pass of the unit.**

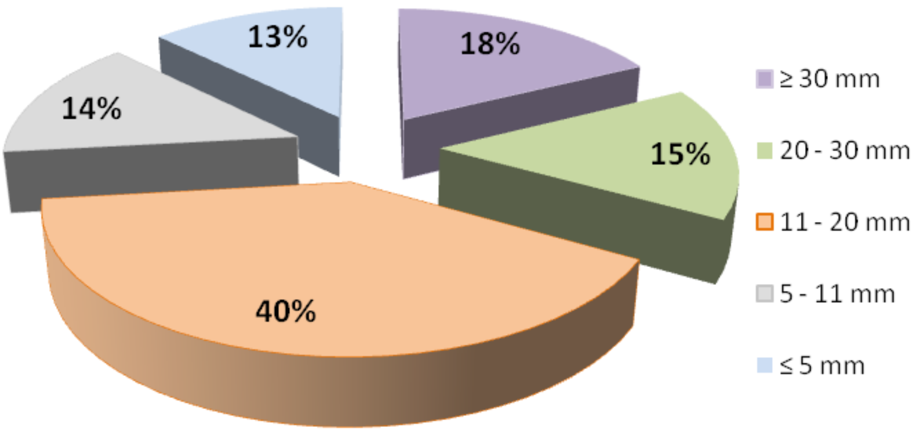


**Fig. 6. Structural composition distribution of shattered wood residues after the second pass of the unit.**

sults. Chip distribution after milling were relatively uniform, predominantly consisting of particles between 11–20 mm. The grinding of the particles and their mixing with soil layers helps to facilitate their decomposition.

## Determination of performance and fuel consumption

Timing observations of the working day were performed to determine the operating performance of engine tests. Average timing is given in Table 1. The coefficient of basis time – $\tau_{cm}$, is higher for the first site, because the service (repair) and idle time are shorter.

The characteristic of the production conditions in the two OS which affect these

**Table 1. Timings of milling unit PT-400 operations.**

| Observed time, min | First experimental site, SFS „Lom“ | | Second experimental site, SFS „Oryahovo“ | |
|---|---|---|---|---|
| | 1st shift | 2nd shift | 1st shift | 2nd shift |
| $T_{stroke}$ | 284 | 277 | 268 | 269 |
| $T_{idle}$ | 17 | 18 | 22 | 20 |
| $T_{op.t}$ | 267 | 259 | 246 | 249 |
| $T_{prep.fin.t}$ | 30 | 30 | 35 | 32 |
| $T_{serv.t}$ | 13 | 14 | 18 | 20 |
| $T_{rest.t}$ | 14 | 18 | 15 | 16 |
| $T_{org}$ | 2 | 3 | 2 | 3 |
| $T_{notw.t}$ | 59 | 65 | 70 | 71 |
| $T_{shift}$ | 360 | 360 | 360 | 360 |
| $T_{cm}=T_{stroke}/T_{shift}$ | 0.789 | 0.769 | 0.744 | 0.747 |

Note: The duration of one shift is six hours. The indications of time spent in the table are: $T_{stroke}$ – time stroke unit; $T_{idle}$ – time to maneuver and idle units; $T_{op.t}$ – operating time; $T_{prep.fin.t}$ – time for preparatory-final work; $T_{serv.t}$ – time maintenance of machinery (includes greasing); $T_{rest.t}$ – time for vacations and natural needs of workers; $T_{org}$ – downtime due to organizational reasons; $T_{notw.t}$ – time during which technological activities were not carried out directly; $T_{shift}$ – hours of work in one shift.

**Table 2. Data of performance of milling unit PT-400 for soil preparation.**

| Technical performance | First experimental site SFS „Lom“ | Second experimental site SFS „Oryahovo“ |
|---|---|---|
| Productivity, dka per shift | 3.35 | 2.53 |
| Hourly output, $dka \cdot h^{-1}$ | | |
| - Mulching | - | 0.664 |
| - Deep milling | - | 0.468 |
| - Average for the soil preparation | 0.715 | 0.566 |
| Operating speed, $km \cdot h^{-1}$ | | |
| - Mulching | - | 0.51 |
| - Deep milling | - | 0.56 |
| - Idle stroke | 2.36 | 1.95 |
| Relative fuel consumption, $l \cdot dka^{-1}$ | | |
| - Mulching | 30.2 | 54.7 |
| - Deep milling | 66.3 | 113.8 |
| - Idle stroke | - | 1.6 |
| - Total for the soil preparation | 96.5 | 170.1 |

parameters is presented in paragraph 2.1 „Operational site conditions”. Productivity of mobile machine-tractor unit is directly dependent on the technological parameters of the machines: working speed, working width and coefficient for using working time. The obtained results in the form of averages for different operations are presented in Table 2. The results show the main performance of the research milling unit at predefined production conditions.

The results of the study showed a higher operating performance of the unit in the OS-1 – $W_h$ = 0.715 $dka \cdot h^{-1}$, compared to $W_h$ = 0.566 $dka \cdot h^{-1}$ in the OS-2. To a large extent this is due to the lower density of stumps – 56 pcs per 1 dka to 101 pcs per 1dka in the OS-2, regardless of stumps that have larger average diameter – 51 cm to 41 cm. The results about fuel consumption showed that the greater density of stumps is reflected more strongly in the relative cost per unit area. For example, for the OS-2 relative fuel consumption of one decare area prepared for afforestation is 170.1 liters and for the OS-1 is – 96.5 liters, which is nearly 77 % more.

Despite of the higher fuel consumption the specialized milling unit Prime Mover PT-400, shattered completely the stumps, roots and competitive vegetation to chips, and simultaneously mixed intensively and aerated the crushed biomass into the soil. Thereby conditions for improvement the soil fertility and reduction of the risk of spreading diseases and pests were created. The main deep milling process of heavy clay forest soils allows stabilization, airing and raise the fertilization of the soil, meanwhile to level the terrain without subsequent further processing, such as disking and harrowing.

## Conclusions

The use of the studied specialized forest milling machine PT-400 with multi-purpose forestry tiller FAE 300/S for mulching, stump grinding and deep soil preparation leads to increasing the productivity and improvement the quality of the work. Such innovative aggregates will lead to soil enrichment and will reduce almost twice the time for the soil preparation for afforestation by shortening the number of operations. At the same time, they are expected to reduce the total cost of the final production. The treated soil has ecologically suitable grain-mechanical structure and there is no need for further processing of preparation. Organic residues from the crushed wood debris (wood chips), mix with the rest of the soil, and during their degradation they enrich the soil with minerals and other nutrients.

The conducted study on specialized forest milling unit Prime Mover PT-400 for soil preparation of poplar clearings under predefined conditions resulted in established operating fuel consumption, productivity and the grain structural composition of the processed soil and shattered wood chips. The obtained results can be used to determine productivity and labor costs for land preparation with forest milling unit PT-400 equipped with multifunctional cutter FAE 300/S for afforestation with poplar cultivars.

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# SUSTAINABILITY IMPACT ASSESSMENT (SIA) OF RENEWABLE ENERGY SYSTEMS: OVERVIEW OF INDICATORS AND NEEDS FOR FUTURE DEVELOPMENTS

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## Abstract

In the last decades, the international energy demand has risen greatly due to the world's population growth and the economic development of some big countries (e.g. China, India, Indonesia). The intensive use of fossil fuels is recognized as unsustainable in the long-term period. In this framework, renewable energies represent important sources in order to satisfy the energy demand in a sustainable way. European Union (EU) promotes the use of renewable energy sources (RES) to reduce greenhouse gas (GHG) emissions, to increase energy independence and to promote the renewable industry. Renewable energy policy must take into account the technical aspects of energy production and also the environmental, economic and social aspects, following an integrated approach. Consequently, sustainability assessment has become a fast developing research field and impact assessment tools – based on methods that take in consideration stakeholders' opinions and expectations – are commonly used to support policies or projects implementation. Sustainability Impact Assessment (SIA) is a tool that supports decision-makers in identifying potential impacts of possible policy actions. Environmental, economic and social aspects related to renewable energies are often analyzed with sectorial approaches. To overcome this gap, it is fundamental to develop practical instruments useful for an integrated assessment considering environmental, technical-logistics, financial and social parameters of renewable energy systems. Starting from these considerations, this research investigates the indicators useful to support the SIA of a policy, a plan or a single action related to a renewable energy system. Social and economic dimensions and related indicators are analyzed, also including indicators which straddle between socio-economic and environmental sector. A comprehensive in-depth literature review has been made in order to create a database of criteria and indicators. After creating the database, authors selected 308 suitable indicators: 93 relating to the economic dimension, 152 to the socio-political and cultural one and 63 to the social-environmental dimension. Furthermore, indicators were aggregated into three main impact dimensions (economic, social-political and social-environmental) and six general criteria. Finally, some recommendations are given to contribute at developing new indicators for the assessment of effects of renewable energy systems on sustainability.

**Key words:** energy-demand, forest biomass, hydropower, socio-economic indicators, solar thermal power, sustainable development, wind power.

## Introduction

The world's demand for energy has risen greatly in the last decades, due to population growth and industrialization of some big countries, e.g. China, India, Indonesia (Bronfman et al. 2012, Rotty 1979). In view of the current world energy consumption the extensive use of fossil fuels and non-renewable resources is widely accepted as unsustainable in the long term (Robèrt et al. 2002, Twidell and Weir 2003). In this framework, the search for energy alternatives, involving locally available and renewable resources, is one of the main concerns of scientists, governments, and various stakeholders worldwide. Renewable energies (REs) play a key role for meeting of energy demand in several contexts and RE systems are crucial in sustainable development policies definition (Krajačić et al. 2011, Pistorius et al. 2012, Wilkens and Schmuck 2012).

European Union (EU) promotes the use of energy from RE sources (RES) to reduce greenhouse gas (GHG) emissions, to increase energy independence (Reiche and Bechberger 2004) and to promote the renewable industry, which would encourage technological innovation and employment in Europe (Nishizono et al. 2005, Mathiesen et al. 2011). The Directive 2009/28/EC is one of the main tools to fulfill the EU's Climate and Energy Package "20-20-20" targets for 2020: 20 % rise in energy efficiency, 20 % less GHG emissions and 20 % increase in energy generation from renewable sources.

Renewable energies are a strategic issue for the linkage between environmental services and actual policies (Pistorius et al. 2012) and bioenergy from renewable energies can lead to an increase of employment opportunities and new market orientation (Demirbas 2009). In order to implement sustainable development in the energy sector, RE policies must therefore take into account not only the technical aspects of energy production but also social, economic and environmental aspects following an integrated approach by incorporating the links between energy and society, economy and environment in a single framework (Bassi et al. 2010). Moreover, compared to traditional systems, renewable energies systems have a more decentralized structure and their local impacts are more significant (Wilkens and Schmuck 2012): lack of public support can seriously reduce the viability of implementing a given technology (Bronfman et al. 2012).

Sustainability assessment has become a fast developing area also in the renewable energies sector and in the last decades the numbers of tools that can be used for assessing sustainability have grown rapidly (Mascarenhas et al. 2010). In this framework, according to the categorization of sustainability assessment tools by Ness et al. (2005), there is the umbrella of impact assessment tools. This is a small group of tools – based on methods that take in consideration stakeholders opinions and expectations – commonly used to support policy or project implementation (Ness et al. 2005).

Among impact assessment tools Environmental Impact Assessment (EIA) has been developed since sixties to evaluate the impacts on the environment of development projects (Sadler 1999) and after the United Nations Framework Convention on Climate Change (1992) and the third Conference of the Parties (1997) has become a commonplace also in the field of RE systems (Afgan et al. 2003). On the contrary, the assessment of social and cultural aspects of sustainability is still in its infancy in renewable energies sector (Gallego Carrera and Mack 2010).

More recently, in 2002, the European Commission introduced the more comprehensive Sustainability Impact Assessment (SIA) defined as "*a tool to improve the quality and coherence of the policy development process. Impact Assessment identifies the likely positive and negative impacts of proposed policy actions, enabling informed political judgments to be made about the proposal and identify trade-offs in achieving competing objectives*" (European Commission 2002). The importance of SIA as a process more than a simple tool is further emphasized in the revised version of the European Commission's SIA guidelines: "*Impact assessment is a set of logical steps to be followed when you prepare policy proposals. It is a process that prepares evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impacts*" (European Commission 2009).

The field of renewable energies often presents a lack in practical tools useful for relating the complexity of interaction among environmental, economic and social aspects that are often considered with sectorial and fragmented approaches. Instead, an accurate planning and setting of both investments, interventions and plants impacts is fundamental to develop an integrated assessment considering environmental, technical-logistics, financial and social parameters of RE systems.

For policies, programs and plans with potential impacts on the environment is usually required the application of SEA (Strategic Environmental Assessment). In this kind of tool, environmental aspects are deeply investigated while in the SIA the analysis of environmental aspects is limited in comparison with social and economic factors (Arbter 2003, Wilkinson et al. 2004).

In the light of these considerations, the objective of the paper is to investigate – through a literature review – the availability of indicators useful to support the SIA of a policy, a program, a plan or a single action related to a RE system. In particular, the authors concentrated their investigation on the social and economic dimensions and related indicators, also including indicators which straddle between socio-economic and environmental sector. Indicators are then aggregated into impact dimensions (economic, social-political and social-environmental) and general criteria, to give to the reader a schematic and synthetic view of the available indicators. Furthermore, the authors select a set of indicators, that are proposed as a contribution for moving forward in implementing and evaluating sustainability indicators for RE systems across different settings and scales. Finally, some recommendations are given with the objective of contributing in the development of new indicators for the assessment of the economic and social effects of RE systems on sustainability.

## Material and Methods

### Literature review and database creation

A comprehensive in-depth literature review has been made in order to create a database of criteria and indicators of economic and social impacts of RE systems. The literature review was concerned with the impact assessment of four renewable energies: solar thermal power, wind power, hydropower and biomass. Geothermal and marine energies were not included in the present study.

At present biomass is the largest and most important option among renewable energies and the fourth largest energy source after coal, oil and natural gas (Ladanai and Vinterbäck 2009). Concerning the three main sources of biomass (agriculture, forest and waste) authors focused their investigation on forest biomass. This choice is due to the fact that forest biomass is one of the renewable and sustainable sources of energy that can be used for producing electricity, heat, and biofuel and the economic and social impacts related to forest biomass energy systems are an important sector of investigation.

The literature review has been made with special regards to the developed countries, since the same energy policy recommendations could hardly be adapted to such different social and economic contexts like the ones of developing countries. Considering the gap between developed and developing countries on the use of renewable energies producing technologies (El Fadel et al. 2013), to take into consideration developing countries own specificities would require an additional and specific research.

In consideration of the recent development of these issues and of the rapid change of the legislative and political framework only documents published after 2000 have been selected.

For the literature review a set of keywords has been defined and used to browse publications in major online scientific databases and search engines. The keywords employed were: “renewable energies” (i.e. “hydropower”, “solar”, “wind”, “forest biomass”), “sustainability impact assessment”, “social impact assessment”, “indicator/index” (and “socio-economic indicator”), “socio-economic/cultural dimension”, “socio-economic/cultural impacts”. Other papers were identified from reference lists of retrieved papers. Through this cascading research 85 documents have been selected (Fig. 1).

As the next step, a database was developed characterizing the documents and their results in a common framework. The database was created in order to manage the collected bibliographic information and to identify and systematically collect indicators related to effects of RE systems on sustainability. All studies were thoroughly reviewed and the relevant information and characteristics were extracted and inserted into the database. The database was filled following nine key information: year of publication, authors’ nationality, type of document (research article, review, book, report, web site, mixed typology), analysis of case studies in the document (yes or no, and if yes: scale and

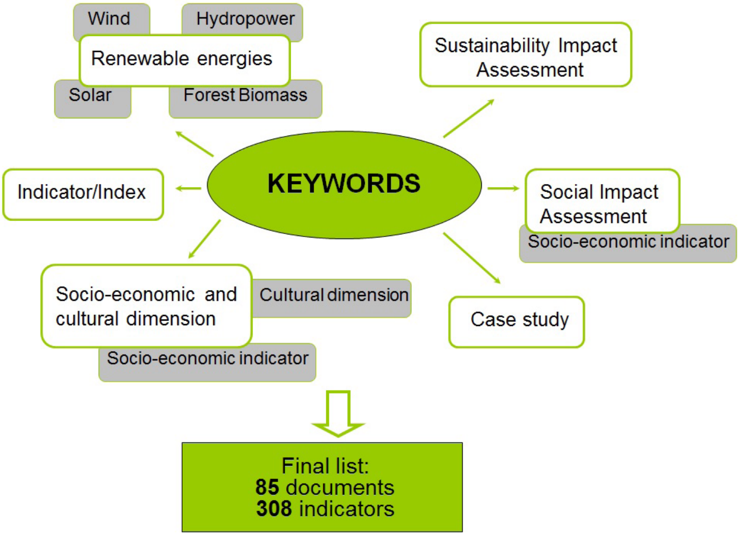


**Fig. 1. Review methodology.**

geographical area of the case study), used methodology (macro-category of the methodology or specific methodology), existence of a detailed list/review of indicators (yes or no), construction of a general/aggregate index (yes or no).

Since sometimes the methodologies and the assumptions used in the studies differ considerably, results were presented using different formats, and other documents had shortfalls, authors decided to exclude from the analysis some documents which could not be placed in a common framework.

**Selection of indicators**

After database establishment, indicators fields were analyzed to selected suitable indicators assessing economic and social effects of RE systems on sustainability. As a result, 308 indicators were found: 93 relating to the economic dimension, 152 to the socio-political and cultural dimension and 63 to the social-environmental dimension.

A detailed table has been drawn in order to put together all the available information about the selected indicators. The table is structured to include "description of the indicator", "recommendations for the use", "unit of measure", "methodology" for the definition of the indicator and "bibliographic references".

As next step indicators were evaluated and selected with respect to their suitability to assess energy systems effects on sustainability. In literature it is possible to find several criteria to assess valid indicators, and the appropriateness of the criteria depends on the purpose for which indicators are selected. The selection was guided by the quality criteria. Authors selected indicators modifying the criteria defined by Meadows (1998) and successively expanded by Gallego Carrera and Mack (2010). The selection of "good" indicators was guided by the following relevant aspects:

i) Indicators with a clear value;

ii) Indicator coherent and consistent (logical);

iii) Indicators sufficient in information;

iv) Indicators that can be applied throughout Europe;

v) Indicators that can be disaggregated at small scale level.

After the selection process, indicators which passed the filter process were aggregated into three main impact dimensions (economic, social-political and social-environmental) and six criteria. Criteria define the essential components of socio-economic context against which the impacts of RE development may be assessed. In particular, criteria encompass impacts on local economy, on societal values and visions and on cultural sphere and specifically concern: (1) the impact and the efficiency of the system in the ambit of the local economy; (2) the impact on the quality of life and on the social stability,

**Table 1. Indicators: impact dimensions and criteria.**

| Impact dimension | Criteria |
|---|---|
| Economic | Changes in local economy |
| | Efficiency and reliability of the energy system |
| Social/political | Political stability, participation, human capacity and system legitimacy |
| | Quality of life |
| | Local traditions, cultural values and property rights |
| Social/ environmental | Social component of risk |

involvement and legitimacy; (3) the impact tied to the social risk; (4) the impact on local traditions and cultural values (Table 1).

## Results and Discussion

### Literature review and database creation

The results of the in-depth literature review showed that almost 50 % of the selected documents have been published between 2006 and 2011. This period can be rightly considered the period of highest scientific development of the SIA issue. From the geographical point of view (Fig. 2), the largest amount of studies has been made in Greece (11 peer-review articles), followed by Germany (9), Switzerland (8), Portugal (6), United Kingdom and China (5), United States, Jordan and Italy (4). For 18 other countries were selected from three to one documents.

It was not possible to find any detailed information for about 17 % of the selected documents, due to the impossibility to access the full text of the document or because they were written in original language (not English, French or Italian). For this reason, authors decided to keep them as references since they had been cited as important sources from other authors included in the list.

When considering the scale of analysis, 31 out of the 85 documents (37 % of the total) present one or more case studies analysis (Fig. 3), most of which are case studies at national scale (45 %) or at regional scale (29 %).

The scale of analysis is an important element because studies related to renewable energies plants impacts – like other analyses in different sectors – have different resolutions and range of applicability that depend largely on the focus and scale of analysis. Furthermore, a large number of indicators are used to assess different kinds of impacts on sustainability and the choice of appropriate indicators usually depends on the context and scale of analysis. In addition, when considering social/political impact, according to the scale of analysis there are different social groups and social interests involved in the decision-making process (Mohammadi et al. 2013).

Finally, 24 of the selected documents (29 %) showed an aggregate sustainability index.

Aggregate indices are formed by the combina-

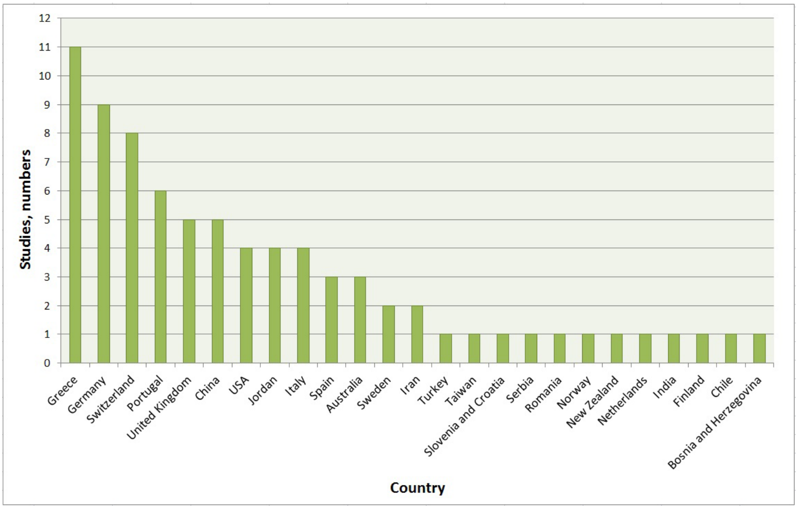


**Fig. 2. Distribution of the analyzed documents by country.**

tion of several indicators in order to provide a more complete and synthetic picture, compared with the individual indices. We conducted a careful analysis of documents containing aggregate sustainability index, because they can incorporate several key sustainability indicators in a single framework, allowing the consideration of the multi-dimensionality of sustainability. Moreover, an aggregate sustainability index can be easily interpreted and communicated to the stakeholders and citizens; for this reason these indices are useful in analyzing the effect of a policy or plan implementation (Böhringer and Löschel 2006).

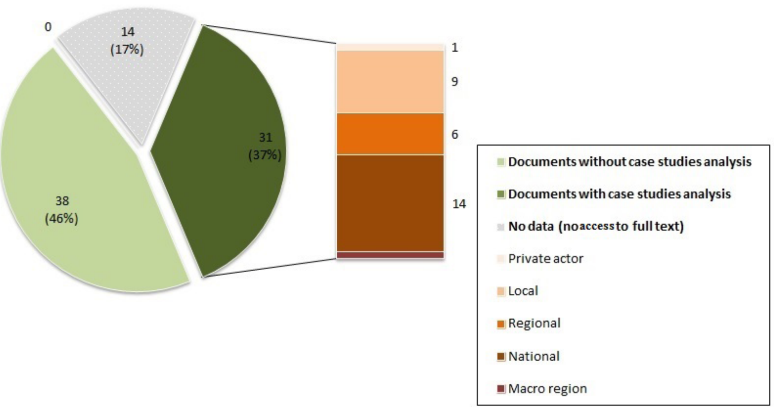


**Fig. 3. Documents with a case-study approach and scale of the analysis.**

With regard to the methodology used, all studies applied a Multi-Criteria Analysis (MCA). Such results confirm, in line with other studies (Omann 2004), that sustainability is more and more intended as a multi-dimensional issue and that MCA can give good results, when sustainable development is concerned and social context of the process is considered.

## Selection of indicators

As discussed above, 308 indicators and sub-indicators have been selected, which evidenced that social and political impacts turned out to be the most investigated ones, while the cultural aspects seem to have been significantly less developed by existing literature. It would thus be interesting to conduct further research on them, also because public policies aiming at promoting environmental awareness and a more sustainable consumer behaviour among citizens are crucial in order to integrate renewable energies into local systems.

Without claiming to be complete, having a list including such a large number of indicators could be useful for practitioners or researchers interested in the field, for example in order to create a synthetic index to be used for the assessment of the social sustainability of renewable energies projects.

According to the quality criteria described, 28 of the 308 indicators were selected in order to reach a comprehensive assessment of the impacts of RE development at the local or regional scale. The indicators were allocated to six overarching criteria as illustrated in Tables 2, 3 and 4. This set of indicators allow a balanced analysis of the three impact dimensions.

**Table 2. Criteria and indicators used to quantify the economic impacts of renewable energy development.**

| Criteria | Indicators | Unit of measure |
|---|---|---|
| Changes in local economy | Local system flexibility to market changes | Sensitivity to fuel price fluctuations |
| | Effects on business opportunities and productive diversification of the area | Number of new jobs/year |
| | Regional/local value added | Euro/year and MWh exergy |
| | Heat price package (total cost of heat for the village) | Euro/year and MWh exergy |
| Efficiency and reliability of the energy system | Continuity of energy service | Interruption of the energy supply |
| | Independence from non-renewable energy sources | MWh/year and MWh exergy |
| | Resources efficiency | Percentage of consumption |
| | System efficiency | Percentage of energy losses |
| | Costs efficiency | €/MW |
| | Reliability of the system | Ordinal Scale |

It is important to remember that the multiplicity of indicators developed in the RE field evidences the importance of a methodological and conceptual work in this area (Voinov 1998). When applying SIA to a specific RE system, the set of indi-

**Table 3. Criteria and indicators used to quantify the social-political impacts of renewable energy development.**

| Criteria | Indicators | Unit of measure |
|---|---|---|
| Political stability, participation, human capacity and system legitimacy | Compatibility with the national energy policy objectives | Ordinal scale |
| | Local people empowerment, stakeholders participation, | Percent of documented responses addressing stakeholders and local people suggestions |
| | Improvement in energy-related education and research | Ordinal scale |
| | Social and political acceptance of the system and potential of conflicts | Percent favourable opinion |
| | Effects on social cohesion | Relative scale (number of households) |
| Quality of life | Job creation | Number of full time equivalent jobs |
| | New jobs related benefits for local people and workers | Euros per day |
| | Traffic contribution | Ordinal scale |
| | Impacts on the quality of landscape | $m^2$ of landscape/KWh |
| | Impacts on people's habitat and quality of life | Percentage of the population that perceives the impact |
| | Economic benefits for local community | Euros per day |
| | Noise exposure | Ordinal scale (number or resident feeling affected by noise) |

**Table 4. Criteria and indicators used to quantify the social-environmental impacts of renewable energy development.**

| Criteria | Indicators | Unit of measure |
|---|---|---|
| Social and social-environmental component of risk | Perceived risks and benefits related to the energy system | Ordinal scale for psychometric variables (personal control, catastrophic potential…) |
| | Mortality due to accidents | Fatalities/GWh |
| | Risk prevention and management | Ordinal scale |
| | Exceptional risk | Maximal number of fatalities |
| | Trust in risk management agencies | Ordinal scale |
| | Impacts on atmospheric emissions | Kg/MWh energy |

cators must allow the assessment of the relationships between RE system and environment, showing how well the system is working and measuring its impact on various dimensions of sustainability (Afgan et al. 2003).

The selected indicators range from the economic to ecologic and social aspects because, respect to traditional energy systems, renewable energies systems are characterized by less environmental pollution but more local impacts (Polatidis et al. 2006).

The objective of the authors was to select a set of indicators that are feasible to measure. In fact, while efforts have been made to build consensus about the necessity of addressing renewable energies production impact on sustainability, practical and measurable indicators that cover social, economical and cultural aspects of sustainability are still scarcely developed. Moreover, many proposed indicators lack precision in definitions and protocols for measurement.

## Conclusions

Shifting from traditional energy systems to RE systems is one of the most important challenge in the context of sustainable development policies aiming at facing climate change. At the same time, RE promotes sustainable energy production, a more developed environmental awareness and more sustainable consumer behaviour. RE development is one of the fundamental objectives of our society in order to satisfy the increasing demand for new energy resources.

If renewable energies are considered to be an effective way to reduce negative environmental impacts, their sustainability needs to be assessed not only from an environmental or technical point of view, but also regarding the socio-economic aspects.

Newer tools such as the EU Sustainability Impact Assessment (SIA) represent an area where guideline set-up is still in early developmental stages and results of the present research showed that further research on the link between SIA and RE systems is desirable as it turned out to be the less investigated dimension of sustainability.

After completing the review, we can confirm that there is a great variety of valuable socio-economic indicators for RE systems management. In this respect, tree groups of indicators were presented in this research, which reflect the economic, social-political and social-environmental criteria.

It is necessary to remind that when adopting and implementing a set of indicators, an in depth evaluation of the feasibility of the indicators to the specific context is needed. Frequently managers of renewable energies systems have a limited social science background, and they need to improve their skills and expertise in the sector to objectively ponder their choices. Otherwise, the database structured with the present work can be useful to various stakeholders including policy-makers, planners, managers and other actors of the renewable energies sector. Moreover, it seems a valid starting point for the developing of sustainable strategies in the field of renewable energies.

The literature review highlighted that SIA covers fields within social sciences, economy, engineering, human health and other disciplines. As a major conclusion, interdisciplinarity is seen as a tendency in sustainability issues and an interdisciplinary approach is required when approaching to developing synthetic and composite indexes, to be used for the assessment of the social sustainability of renewable energies projects.

The present contribution hopes to provide a first and limited step also for future researches aimed at assessing the impacts of energy systems via multidimensional indicators.

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# ASSESSMENT OF SOME PERFORMANCE INDICATORS FOR BLACK PINE (*PINUS NIGRA* ARN.) PROVENANCE TRIALS IN PETROHAN TRAINING AND EXPERIMENTAL FOREST RANGE, NORTH WEST BULGARIA

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## Abstract

Black pine (*Pinus nigra* Arn.) provenance trials were established in North West Bulgaria in 1978 to study the hereditary potential of selected offspring of some of the most valuable populations in Bulgaria. Given the planting interval of 2 × 2 m, 13 provenances are assessed through three performance indicators including survival rate, quality of stems and general health status. At the age of 36, the average survival rate of the plantation is 68 %, varying between 38 % and 92 % for the different plots, without specific linkage to the altitude of origin. The impacts of wet snowfalls have played a primary negative role on the status of the plantation. Competition has also been an important factor for the survival rates as expected, with the most significant losses endured during the early life of the plantation. The field data reveals that there are no definite evidences on the influence of the provenance on mortality, quality and general health of the stands. Thus, the considerations on the provenance selection in afforestation practices may not have such a significant role and visible effect within the established plantations. A possible reason for this is that nature conditions of the specific site, although outside the natural range of distribution of Black pine, are relatively favourable but not within the range limits for its survival.

**Key words:** hereditary potential, impact, origin, plantation.

## Introduction

The increasing demand of modern society for timber and other forest products worldwide inevitably leads to excessive use of natural forest resources resulting into a continuous loss of forest cover and irreversible loss of biodiversity. This calls for placing a stronger emphasis on the establishment of forest plantations, which have substantial potential for maximized yields of raw material, in terms of quantity and quality, on one hand, and easing off the pressure on natural forests and biodiversity on the other hand (Evans 1999b, 2001; Kanowski 1997; Milev 2013; Savill et al. 1997; Sedjo and Botkin 1997; Stephens and Wagner 2007). There is abundant evidence that plantation forests can even provide valuable habitat, even for some threatened and endangered species, and may contribute to the conservation of biodiversity by various mechanisms (Brockerhoff et al. 2008). Although artificially established forests account to only about 7 % of all forests in the world

(Evans 1998), they provide about 27 to 35 % of the industrial wood demand and under certain scenarios plantation share of industrial roundwood production is estimated to increase up to 64 % in 2050 (FAO 2001). The role and interrelationship between forest plantations and climate change is also noted (Pawson et al. 2013). So the adequate treatment of the issues related to the establishment of sustainable forest plantations would also contribute to reducing $CO_2$ concentrations, as plantations are part of the broader package of measure of reducing harmful emissions (van Minnen 2008).

In order to be successful, forest plantations need to be, above all, sustainable (Milev 2013, Milev et al. 2015). Historically, Bulgarian afforestation practices have not always adapted differentiated approaches, which take into consideration site conditions, the influence of the origin and the hereditary qualities of the sawing materials as major factors, for ensuring sustainability and desired phenotypic showing of the plantations. As a result, coupled to a large extent with the untimely implementation of the tending and thinning operations, part of the established plantations – predominantly composed of coniferous species including Black pine (*Pinus nigra* Arn.), deteriorate in general, have reduced growth characteristics, unfavourable environmental and commercial effect, which places serious questions over their future use.

Competition as a rule is the chief factor influencing survival, growth and regeneration of forest plantations (Keddy 1989, Schoener 1983). Taking this into account, researchers place a substantial emphasis on the issue of initial and optimal planting density. For the establishment of intensive plantations of Black pine, data in this respect is not straightforward. Some authors point that a maximum profitable stock in long rotation periods without active management could be achieved with initial planting density of 2500–3400 seedlings per hectare (Stankova 2006), but the application of statistical modelling does not exclude optimum management regimes with initial density of around 9000–10000 seedlings per hectare (Stankova and Zlatanov 2010) although the latter are not fully substantiated by practice.

Pests and diseases, as wetll as damages caused by storms and forest fires, are also among the key factors for sustainability of forest plantations in a global scale (Evans 1999a). As for the Black pine, a number of authors point out its vulnerability to snow as a key risk (Hatzistathis 1985, Kostov 1971, Schütz 1999, Wheeler et al. 1976, Varelides et al. 2001). The threat here depends mainly on the climatic conditions, geographic location and topography on one hand, and the stand characteristics on the other. Of the latter, the most significant role is given to stem taper and crown characteristics (Nykanen et al. 1997). The opinions about the impact of density on stand stability found in various sources are also diverging (Stankova 2010). Some authors point out that denser stands are less stable (Nykanen et al. 1997), while other authors offer proof of the opposite (Schütz 1999).

Specialists are uniform though (Evans 1999a, Evans 1999b, Fussi et al. 2015, Zahariev 1977), that to great extent sensitivity towards unfavourable factors, sustainability respectively, is determined by the specific biological features and ecological requirements inherent in the different geographic variations. As a rule, it is considered that local variations of the species are most sustainable. Local populations are a result of a long standing natural selection in the course of which nature sustainability comes first. Longevity and productivity of established plantations, but also value of stands and individual trees such as straightness, self-pruning, wood characteristics and other features are all dependent on the geographic origin. Desired results can be achieved only if sawing materials are taken from a source, which matches the nature conditions of the sites to be afforested. Obviously, the knowledge on the influence of the geographic origin is of substantial importance, and this should be taken as a basis for developing and optimizing the zoning of seed sources and the conditions for using these sources for securing reproductive materials. It is why a number of countries have enforced regulations, as is the case with the EU (Council Directive 1999/105/EC 2000), to guarantee observation of this rule. Bulgaria moved towards maintaining an electronic register of sources of forest reproductive material in 1998 (Milev et al. 2015). In compliance with this EU requirement, the regions of provenance were defined in 2012 and a Map of the Regions of Provenance (EFA 2012) was developed using the forest vegetation zoning of the country. In 2013, Rules and Specific Exceptions for Moving forest Reproductive Material within or between Regions of Provenance (EFA 2013b) were adopted. A National List of the Approved Basic Material (EFA 2014) is being maintained with updates published on an annual basis.

The provenance trials (geographical, ecological plantations) network established throughout the world and Europe in particular form a good basis for studying the abovementioned topics. Taking into account Black pine's ecological plasticity and above all drought resistance (Mataruga et al. 2010, 2012), the species will continue to play an important role in afforestations and reforestations in part of the lower and the middle (in terms of altitude) forest zone in South-Eastern Europe.

Through the methods of selection, some 650 ha (EFA 2013a) of Black pine provenance trials have been established in Bulgaria since the beginning of XX century, where some of the most valuable local provenances, as well as some foreign were represented. Provenance trials abroad prove also useful. While the purpose of some of these was to further clarify the taxonomy of the species or its morpho-anatomical features (Arbez and Millier 1971; Matziris 1984; Matziris 1989a, 1989b; Matziris 1994, Sıvacıoglu and Ayan 2010, Ayan et. al. 2011) others serve for obtaining data on provenance performance (Gökdemir et al. 2012, von Röhrig 1966, Varelides et al. 2001, Wheeler et al. 1976) as is the current study. Gökdemir et al. (2012) report for Turkey that from 36 Turkish provenances of *P. nigra* ssp. *pallasiana* tested in 6 sample plots per year, 25 did not show differences for height, diameter and volume but there were considerable differences among provenances for stem form. Provenances differed for survival percentage at one out of the six sites (Gökdemir et al. 2012). Varelides et al. (2001) studied the performance of 17 provenances (from Greece, Turkey, Corsica and Calabria) on 3 sites in Northern Greece to reveal, at year 9, differences in height, diameter and survival on two of the sites with varying results per site. The analysis of 12 provenances common to the two sites where differences were identified showed significant site-provenance interactions (Varelides et al. 2001). In Germany, von Röhrig studied 18 European provenances of the species on 4 sites, where by year 7 significant differences in frost resistance were observed for two of the sites and only minor differences in growth in height (von Röhrig 1966).

In order to further enhance selection work, along with the general importance of the geographic origin, it is also necessary to reveal and assess the individual characteristics (those of the genotype). Valuable information in this relation could be obtained from the provenance trials, containing the offspring of tracked mother trees.

This current study sets itself the objective to assess some of the performance indicators having direct impact on sustainability, as well as to add to the criteria for assessing the success of the forest plantations. What is useful in this case is the possibility to analyse the impact of provenance on these indicators for the particular site conditions and thus provide a site specific provenance selection in Black pine afforestations.

## Materials and Methods

### Site characteristics

Subject to research is a plantation, which is part of series of provenance trials from Bulgaria's main coniferous species, established in the 1970s. The plantation, located in the Training and Experimental Range (TER) "Petrohan" of the University of Forestry – Sofia (Fig. 1), was established in 1978 with a main objective to study the hereditary potential of selected offspring and provenances at the existing environmental conditions, through testing sustainability, growth and productivity of the most valuable natural Black pine populations in Bulgaria. The initial concept included the idea, that after some additional selection, plantations may be used also as a source of reproductive material


**Fig. 1. Location of the provenance trial and provenances used.**

with improved qualities – form the categories “selected” and “qualified” (Bogdanov and Dakev 1982) as per the provisions of National Ordinance No 12 of 12.11.2012 on the conditions and order for determination, approval, registration and cancellation of sources from the forest seed production base, collection and yield of forest reproductive material, their grading, trade and import (MAF 2012).

For the establishment of the provenance trial, seedlings were produced from reproductive material derived from plus trees selected within the best autochthonous Black pine stands in Bulgaria. The planting was carried out in the spring of 1978 in an area known as Kolchova polyana (N 43°11’38”, E 23°82›18» at 600 m altitude) formerly used as a pasture with scattered low-stem trees of *Carpinus betulus* L. and *Fagus sylvatica* L. Applying a permanent 2 × 2 m planting intervals, 11 provenances of the species (where reproductive material of one of the provenances is derived from two different altitudes) were introduced, represented by generative offspring of 28 plus trees and 12 provenance aggregations.

The scheme used is in line with the common methodology developed under the auspices of IUFRO, providing opportunities for comparison of results with other similar trials (Lines 1965). The original location of the provenances used, sorted down per altitude and the features of the mother plus trees, are presented in Table 1.

The trial is composed of 26 rectangular plots (cells). Most of these consist of 12 rows each with 13–14 seedlings, making 156–168 seedlings in total per cell. Depending on the availability of

**Table 1. Provenances used and their basic features of origin.**

| Provenance | | Altitude, m | Mother trees, number | Age, years | Mean height, m | Mean diameter, cm |
|---|---|---|---|---|---|---|
| Name | App. coordinates | | | | | |
| Hristo Danovo – lower | N 42°43’ E 24°35’ | 400 | 2 | 60 | 14.5 | 22 |
| Borika (Haskovo) | N 41°54’ E 25°09’ | 400 | 1 | 150 | 12.5 | 35 |
| Borovo | N 41°50’ E 23°16’ | 590 | 2 | 60 | 19.2 | 32 |
| Ploski | N 41°39’ E 24°51’ | 700 | 3 | 60 | 23.5 | 43 |
| Zhenda | N 41°47’ E 25°10’ | 740 | 5 | 70 | 20.7 | 32 |
| Tzarvaritza (Gabra) | N 42°01’ E 22°50’ | 980 | 12 | 120 | 34.4 | 47 |
| Gorno Izvorovo | N 42°39’ E 25°28’ | 750 | 5 | - | - | - |
| Razlog | N 41°53’ E 23°24’ | 1050 | 5 | 85 | 29.2 | 43 |
| Momchilovtzi | N 41°37’ E 24°45’ | 1000 | 5 | 75 | 29.0 | 41 |
| Orehovo | N 41°52’ E 24°35’ | 1100 | 5 | 90 | 31.9 | 47 |
| Goleshevo (Petrodan) | N 41°24’ E 23°35’ | 1100 | 7 | 120 | 24.5 | 41 |
| Hristo Danovo – upper | N 42°45’ E 24°35’ | 1200 | 3 | 90 | 20.7 | 34 |

Note: The popular names of the geographic provenances are given in brackets.

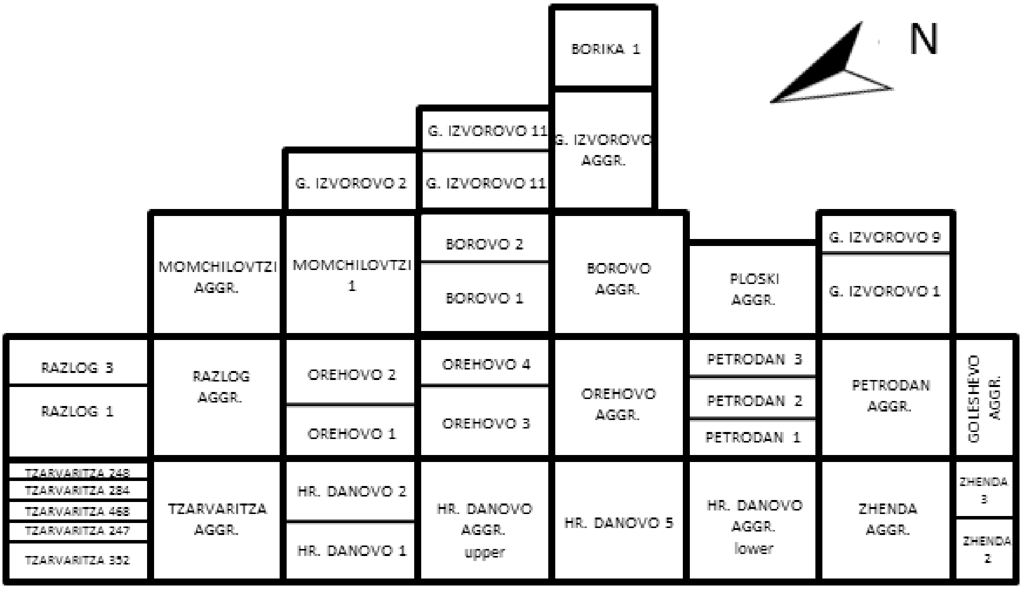


**Fig. 2. Composition (design) of the experimental scheme.**

planting material, some of the variants were reduced and formed smaller cells, while for others the offspring of different plus trees, but from one and the same provenance, were combined into a single cell (Fig. 2).

For clear distinction of the plots, isolation rows of *Picea abies* (L.) Karst. were planted among them, using the same density of 2 m. This has guaranteed good clarity of the adopted scheme and avoids mistakes during observations and measurements. The pure area of the Black pine (without the spruce isolations) in the provenance trial is 1.4 ha, and the total area of the site is 1.7 ha (Fig. 3).


**Fig. 3. Aerial photo of the investigated plantation.**

## Methods

The field work was implemented using an adapted methodology for forest plantations analysis (Milev 2013). A detailed inventory of the site was carried out, where presence (taking note of normal, dry, died out and cut trees) and condition (including curvatures, bifurcation, damages) of every individual tree was evaluated. To assess the damages of wet snowfalls, the 4 categories described by Nykanen et al. (1997) were used. Diameter measurements at breast height with 1 cm accuracy were also taken. Field investigations were carried out in the autumn of 2007 and the autumn of 2013, which gave the opportunity to extract trends in the main sustainability indicators. On this basis, analysis of the dynamics of mortality was carried out by comparing data about three conditional periods: 1) the early life of the plantation or until its 20$^{th}$ year (mortality during this period is determined via the number of empty planting spots counted in 2007); 2) mid-term – 20–30 years of age (calculations based on the number of dry, but still present trees in 2007); and 3) for the last 6 years - 30-36 years of age (based on the number of died out trees in the period 2007-2013).

To determine the studied factors, the statistical package of MS Excel was used, while for assessing the impact of the origin, field data were subject to ANOVA.

## Results and Discussion

The results of the survey regarding survival and quality of stems are summarized in Table 2 below.

Of all 3654 seedlings planted at the trial, 2501 trees have survived in 2013. Thus, at the age of 36, the average survival of the plantation is 68.4 %, varying between 38.1 % (Zhenda 2) and 91.9 % (Gorno Izvorovo 11) for the different plots. The results reveal a weak correlation with the altitude of the provenance, however a slight trend is observed where provenances originating from higher altitudes show relatively better resistance (Fig. 4). Most preserved are the variants of G. Izvorovo 11, Momchilovtzi and Hr. Danovo 2, while highest mortality is revealed for Zhenda 2, Hr. Danovo 1 and 5, which are peripheral for the scheme. If calculations for these three latter provenances omit the data for the outer row on the edge of the plantation, because it has been subject to highest external impacts, including human interventions, the survival rates improve but do not change the status of these three weakest provenances.

The general picture for the 13 provenances shows that the most sustainable, if sustainability is measured through survival, are the provenances from Momchilovtzi, Petrodan, Borovo, Goleshevo and Razlog. No clear trend showing differences in survival between the offspring of plus trees and the provenance aggregations could be observed.

The analysis of variance applied does not provide clear evidence on the influence of provenance on the survival rate. This in general supports the findings of Varelides et al. (2001), Nicolic and Tucic (1983), that differentiations among Black pine provenances are primarily related to heterogeneity and the site conditions within the natural distribution of the species. These results also indicate that plasticity and heterozygosity of the planting material exists within the studied provenances, because of the wide variation among parent trees within each provenance (Mataruga et al. 2012).

**Table 2. Data on survival and stem quality.**

| Provenance with plus tree No | Seedlings planted initially, number | Living trees, number | | Survival, % | | | Normal, % | Bifurcated, % | Curved, % | Bent, % | With side shoots, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2007 | 2013 | 2007 | 2013 | Δ | 2013 | 2013 | | | |
| Tzarvaritza 352 | 34 | 25 | 24 | 73.5 | 70.6 | 2.9 | 91.7 | 4.2 | 0.0 | 0.0 | 4.2 |
| Tzarvaritza 247 | 26 | 20 | 17 | 76.9 | 65.4 | 11.5 | 82.4 | 5.9 | 11.8 | 0.0 | 0.0 |
| Tzarvaritza 468 | 42 | 30 | 28 | 71.4 | 66.7 | 4.8 | 25.0 | 10.7 | 64.3 | 0.0 | 0.0 |
| Tzarvaritza 284 | 42 | 36 | 33 | 85.7 | 78.6 | 7.1 | 63.6 | 9.1 | 27.3 | 0.0 | 0.0 |
| Tzarvaritza 242 | 14 | 10 | 9 | 71.4 | 64.3 | 7.1 | 77.8 | 0.0 | 22.2 | 0.0 | 0.0 |
| Tzarvaritza – total for + trees | 158 | 121 | 111 | 76.6 | 70.3 | 6.3 | 64.0 | 7.2 | 27.9 | 0.0 | 0.9 |
| Tzarvaritza | 139 | 98 | 84 | 70.5 | 60.4 | 10.1 | 70.2 | 14.3 | 15.5 | 0.0 | 0.0 |
| Razlog 1 | 98 | 81 | 70 | 82.7 | 71.4 | 11.2 | 60.0 | 17.1 | 21.4 | 0.0 | 1.4 |
| Razlog 3 | 70 | 58 | 52 | 82.9 | 74.3 | 8.6 | 57.7 | 25.0 | 15.4 | 0.0 | 1.9 |
| Razlog – total for + trees | 168 | 139 | 122 | 82.7 | 72.6 | 10.1 | 59.0 | 20.5 | 18.9 | 0.0 | 1.6 |
| Razlog | 156 | 123 | 113 | 78.8 | 72.4 | 6.4 | 62.8 | 21.2 | 15.9 | 0.0 | 0.0 |
| Momchilovtzi 1 | 156 | 117 | 109 | 75.0 | 69.9 | 5.1 | 71.6 | 23.9 | 4.6 | 0.0 | 0.0 |
| Momchilovtzi | 156 | 137 | 131 | 87.8 | 84.0 | 3.8 | 71.8 | 20.6 | 7.6 | 0.0 | 0.0 |
| Hristo Danovo 1 | 78 | 48 | 43 | 61.5 | 55.1 | 6.4 | 76.7 | 0.0 | 23.3 | 0.0 | 0.0 |
| Hristo Danovo 2 | 78 | 66 | 65 | 84.6 | 83.3 | 1.3 | 72.3 | 6.2 | 21.5 | 0.0 | 0.0 |
| Hristo Danovo 5 | 156 | 100 | 86 | 64.1 | 55.1 | 9.0 | 59.3 | 20.9 | 19.8 | 0.0 | 0.0 |
| Hristo Danovo – total for + trees | 312 | 214 | 194 | 68.6 | 62.2 | 6.4 | 67.5 | 11.3 | 21.1 | 0.0 | 0.0 |
| Hristo Danovo – upper | 156 | 109 | 96 | 69.9 | 61.5 | 8.3 | 50.0 | 17.7 | 31.3 | 0.0 | 1.0 |
| Hristo Danovo – low | 156 | 100 | 97 | 64.1 | 62.2 | 1.9 | 57.7 | 28.9 | 13.4 | 0.0 | 0.0 |
| Orehovo 1 | 65 | 45 | 45 | 69.2 | 69.2 | 0.0 | 44.4 | 42.2 | 13.3 | 0.0 | 0.0 |
| Orehovo 2 | 91 | 61 | 59 | 67.0 | 64.8 | 2.2 | 66.1 | 11.9 | 16.9 | 0.0 | 5.1 |
| Orehovo 3 | 104 | 68 | 65 | 65.4 | 62.5 | 2.9 | 60.0 | 23.1 | 16.9 | 0.0 | 0.0 |
| Orehovo 4 | 52 | 42 | 37 | 80.8 | 71.2 | 9.6 | 73.0 | 13.5 | 13.5 | 0.0 | 0.0 |
| Orehovo – total for + trees | 312 | 216 | 206 | 69.2 | 66.0 | 3.2 | 60.7 | 22.3 | 15.5 | 0.0 | 1.5 |
| Orehovo | 156 | 134 | 111 | 85.9 | 71.2 | 14.7 | 51.4 | 14.4 | 34.2 | 0.0 | 0.0 |
| Gorno Izvorovo 1 | 95 | 62 | 62 | 65.3 | 65.3 | 0.0 | 75.8 | 9.7 | 14.5 | 0.0 | 0.0 |
| Gorno Izvorovo 9 | 65 | 54 | 43 | 83.1 | 66.2 | 16.9 | 44.2 | 11.6 | 44.2 | 0.0 | 0.0 |
| Gorno Izvorovo 2 | 89 | 69 | 65 | 77.5 | 73.0 | 4.5 | 78.5 | 18.5 | 1.5 | 0.0 | 1.5 |
| Gorno Izvorovo 10 | 104 | 82 | 75 | 78.8 | 72.1 | 6.7 | 74.7 | 14.7 | 9.3 | 0.0 | 1.3 |
| Gorno Izvorovo 11 | 37 | 34 | 34 | 91.9 | 91.9 | 0.0 | 64.7 | 17.6 | 17.6 | 0.0 | 0.0 |
| Gorno Izvorovo – total for + trees | 390 | 301 | 279 | 77.2 | 71.5 | 5.6 | 69.9 | 14.3 | 15.1 | 0.0 | 0.7 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gorno izvorovo | 120 | 83 | 75 | 69.2 | 62.5 | 6.7 | 58.7 | 10.7 | 18.7 | 12.0 | 0.0 |
| Borovo 1 | 91 | 80 | 73 | 87.9 | 80.2 | 7.7 | 79.5 | 8.2 | 12.3 | 0.0 | 0.0 |
| Borovo 2 | 65 | 52 | 46 | 80.0 | 70.8 | 9.2 | 78.3 | 15.2 | 6.5 | 0.0 | 0.0 |
| Borovo – total for + trees | 156 | 132 | 119 | 84.6 | 76.3 | 8.3 | 79.0 | 10.9 | 10.1 | 0.0 | 0.0 |
| Borovo | 156 | 133 | 112 | 85.3 | 71.8 | 13.5 | 60.7 | 15.2 | 24.1 | 0.0 | 0.0 |
| Ploski | 117 | 91 | 75 | 77.8 | 64.1 | 13.7 | 54.7 | 18.7 | 26.7 | 0.0 | 0.0 |
| Zhenda 2 | 42 | 20 | 16 | 47.6 | 38.1 | 9.5 | 93.8 | 0.0 | 6.3 | 0.0 | 0.0 |
| Zhenda 3 | 30 | 23 | 18 | 76.7 | 60.0 | 16.7 | 61.1 | 33.3 | 5.6 | 0.0 | 0.0 |
| Zhenda – total for + trees | 72 | 43 | 34 | 59.7 | 47.2 | 12.5 | 76.5 | 17.6 | 5.9 | 0.0 | 0.0 |
| Zhenda | 156 | 111 | 91 | 71.2 | 58.3 | 12.8 | 72.5 | 15.4 | 12.1 | 0.0 | 0.0 |
| Goleshevo | 72 | 56 | 55 | 77.8 | 76.4 | 1.4 | 80.0 | 18.2 | 1.8 | 0.0 | 0.0 |
| Petrodan 1 | 52 | 45 | 38 | 86.5 | 73.1 | 13.5 | 68.4 | 18.4 | 13.2 | 0.0 | 0.0 |
| Petrodan 2 | 52 | 42 | 39 | 80.8 | 75.0 | 5.8 | 74.4 | 10.3 | 15.4 | 0.0 | 0.0 |
| Petrodan 3 | 52 | 46 | 39 | 88.5 | 75.0 | 13.5 | 56.4 | 23.1 | 20.5 | 0.0 | 0.0 |
| Petrodan – total for + trees | 156 | 133 | 116 | 85.3 | 74.4 | 10.9 | 66.4 | 17.2 | 16.4 | 0.0 | 0.0 |
| Petrodan | 156 | 125 | 117 | 80.1 | 75.0 | 5.1 | 71.8 | 14.5 | 13.7 | 0.0 | 0.0 |
| Total | 3654 | 2776 | 2501 | 76.0 | 68.4 | 7.5 | | | | | |

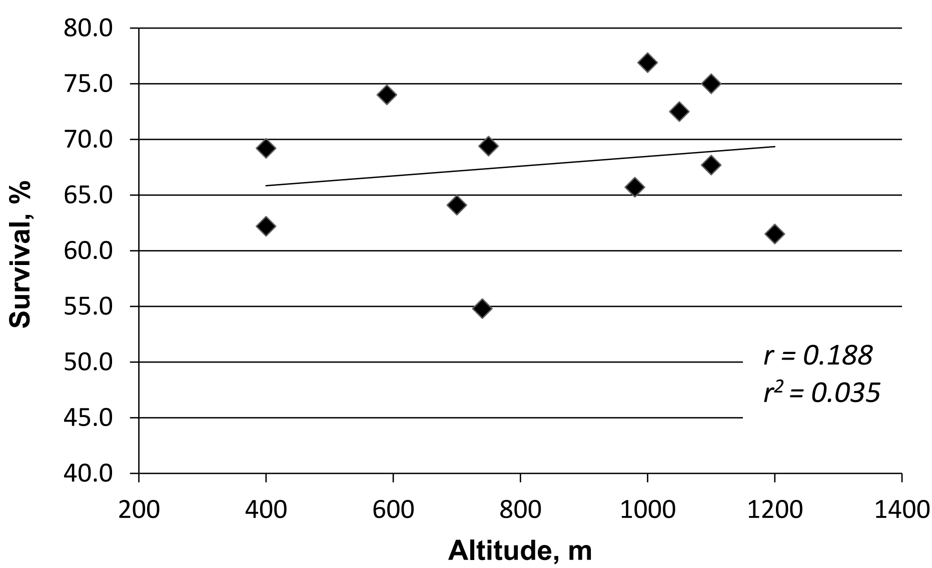


**Fig. 4. Correlation between survival rates and altitude of provenances (data aggregated per provenance).**

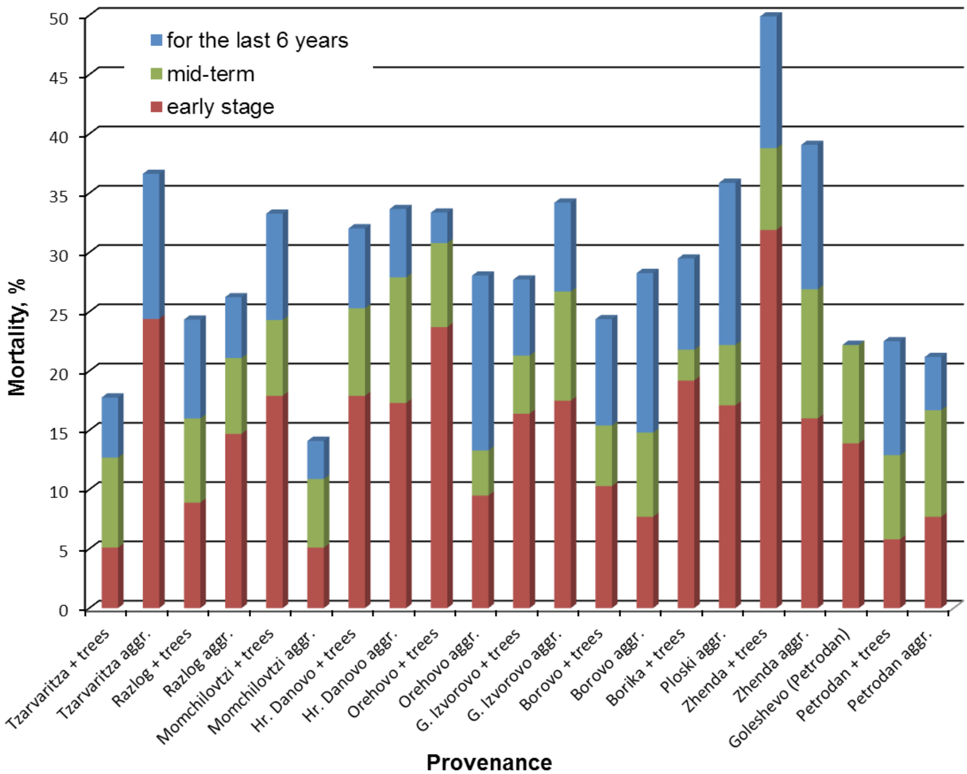


**Fig. 5. Dynamics of mortality in 3 stages – early stage (3–20 years), mid-term (20–30 years) and for the last 6 years (30–36 years).**

The dynamics of mortality (Fig. 5) reveals that it has been relatively constant – more intensive during the early life of the plantation but with no indications of decline for the moment. During the 6-year period between the two investigations, no new dead trees have been observed for three of the provenances – Orehovo 1, Gorno Izvorovo 1 and 11, thus maintaining survival rates of 96.2 %, 65.3 % and 91.9 % respectively. Most dramatic changes occurred for Zhenda 3 (16.7 %) and Orehovo (difference of 14.7 %). For the first mentioned, falling out of trees lagging in their growth is observed with survival currently at 60.0 %, while for Orehovo falling out of trees with different defects (mainly curvatures) is recorded thus reducing survival to 71.2 %. Averaged by provenances (but differentiated between the offspring of plus trees and aggregations), between 2.6 % (Orehovo plus trees) and 13.7 % (Ploski) of the trees within the plantation have been lost for the last 6 years. A specific note should be taken of Borovo, where the 13.5 % mortality rate in the last period is almost two times higher than during the early stages (by 20$^{th}$ year) and mid-term (by 30$^{th}$ year).

Regarding quality of stems, if taken as a criterion for sustainability, the following became evident: normally developed without defects and curvatures are about 66 % of the trees (Fig. 6). The biggest share of such trees is observed for the offspring of the plus trees of Zhenda 2 (but as mentioned, the relatively higher mortality rate in this cell seems to have provided a larger living space for the remaining trees) and Tzarvaritza 352 (over 90 %), while lowest figures are recorded for Tzarvaritza 468 (25 %, Fig. 7), Gorno Izvorovo 9 and Orehovo 1 – under 44.5 %. Generalized per provenance, the provenances of Goleshevo, Borovo, Zhenda and Momchilovtzi excel in a positive aspect.

Observations through the years confirm that wet snowfalls have been the key negative factor for the plantations, thus confirming the findings of a number of authors studying the sensitivity of the species to this factor. Recorded in our case are 3 out of all 4 types of damages described by Nykanen et al. (1997) with the only exception being uprooting. The effects here result mainly in stem bending, which is very common in spots within the plantation with changing slope, as is the case with Orehovo 1. A more rare case is crown breakage, smaller scale curvatures and bifurcation. Of all defects most common in general are the curvatures – 17 % on average and bifurcation – about 15 %. The presence of curvatures varies between 0 and 64 % (Fig. 7). For two of the variants, steeply bent trees are observed – Gorno Izvorovo (12 % of the living trees) and Borika 1 (7.4 %). Bifurcation among the different trials varies between 0 and 42 % (in most of the cases observed in the upper part of the stem), which confirms the importance of this factor for Black pine plantations revealed by Kostadinov (1975) and Thanasis et al. (2007). For 7 of the trial variants, strongly developed side shoots are common, mainly as a result of biotic factors. The highest percentage in this respect is recorded for Orehovo 2

**Fig. 6. Straight stems of Gorno Izvorovo 2.**

**Fig. 7. Curvatures caused by wet snow in Tzarvaritza 468.**

where over 5 % of the living trees have this shortcoming.

The overall health status of the plantation could be defined as very good, with no severe impacts of pests and diseases.

## Conclusion

With over 68 % survival and over 66 % of quality trees within the different variants, the provenance trial plantation shows relatively favourable signs of sustainability. The main factor having negative impact is wet snowfalls, causing different types of curvatures. Comparable data from consecutive field observations provide sufficient ground to consider that once affected by the wet snow, the sustainability of the trees weakens, resulting in higher mortality afterwards (even towards the 36$^{th}$ year of the trials). Among the other factors having impact on mortality is competition (evidenced by the remaining dry trees) although the 2 × 2 m planting intervals used has provided a relatively good living space until this age and some anthropogenic impacts. The biggest share of the fall out had occurred in the early life of the trials, but processes at the moment do not show indications for it ceasing.

At this stage there are no definite evidences, supported statistically, on the influence of the provenance on mortality and quality of the stands. This comes to show that the factors having impact on sustainability relate mainly to internal competition, individuality and micro conditions, and not so much with the ecological specifics of the geographic provenances and their offspring. These findings should be interpreted additionally, once data from the tree measurements for determining growth rates get included in the analysis.

A more general assessment, combining all observed indicators, reveals that the provenances of Gorno Izvorovo, Goleshevo, Momchilovtzi and Borovo demonstrate best performance at the particular site conditions based on the observed and measured properties.

As a whole, a greater remoteness of the geographic provenance does not result in lower sustainability. The species is ecologically plastic enough or the represented populations are homogenous. In this sense, provenance selection in afforestation practices may not have the most significant role and visible effect regarding sustainability of the Black pine plantations under local nature conditions. A possible reason for this is that nature conditions at the specific site, although outside the natural range of distribution of the species, are relatively favourable but not within the range limits for its survival.

A more distinct impact of the geographic origin and the use of enhanced reproductive material (from the best populations and their plus trees) could be expected with regard to growth and productivity.

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# RADIAL GROWTH OF SCOTS PINE (*PINUS SYLVESTRIS* L.) IN VARIED ENVIRONMENT INFLUENCED BY AIR POLLUTION IN THE EUROPEAN NORTH OF RUSSIA

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## Abstract

The paper presents results of a study on the radial growth of Scots pine (*Pinus sylvestris* L.) in lichen-green moss pine forests of III–IV age class in natural conditions and in varied environment influenced by air pollution in the European North of Russia. We found that the growth of pine in young age depends more on intrapopulation interactions than on climatic factors, which is confirmed by the data on dynamics of radial growth of overripe pines. It is observed that while radial increment of pine has natural fluctuations, its dynamics changes significantly induced by atmospheric pollutants. The significant negative correlation between radial growth of pine and volume of pollutants emitted by 'Severonickel' smelter is determined.

**Key words:** atmospheric pollution, competition, growth, North of Russia, Scots pine.

## Introduction

The in-depth study of the growth and development of dominant forest species is important both for evaluation of biological efficiency of forest ecosystems, and estimation of intrapopulation relations effects as well as understanding reasons of individual variability and stability in woody species influenced by natural and anthropogenic factors (Fritts 1976, Hustich 1978, Shiyatov 1986, Yarmishko 1997, Malkonen 2000, Yarmishko and Lyanguzova 2013).

Studies on anthropogenic dynamics of northern taiga suggest that regeneration of disturbed forest communities has different patterns in different localities (Zyabchenko 1984; Tsvetkov and Semenov 1985, Listov 1986; Kryuchkov 1991, Gromtzev 2000, Chernen'kova 2002; Tsvetkov and Tsvetkov 2003, Yarmishko, 1990, 1993, 1997, 2009; Yarmishko and Yarmishko 2015). These local patterns depend on a number of factors that altogether are described as habitat conditions. However, the above publications provide little information on the effect of intrapopulation interactions on growth and development of single trees and forest stands.

In the European North of Russia, where the numerous industrial enterprises are located ('Severonickel', 'Pechenganickel', 'ANBP-Apatity', 'Olenegorsk GOK' and others), atmospheric pollution remains one of the major anthropogenic factors causing damage and even destruction of vegetation. The central area of Kola Peninsula serves in our research as representative pilot region for the assessment of impact of powerful source of long-lasting industrial pollution (‘Severonickel’ Cu-Ni smelter) on forest vegetation at the northern limit of its distribution. The region is characterized by relatively severe climatic conditions substantially limiting growth rate and efficiency of plant reproduction processes, as well as intensity of biological matter cycles. Primary pollutants of the territory are sulphur dioxide and heavy metal compounds.

One of the main goals of current study was to evaluate Scots pine individual trees and tree stands reactions to the pollution with sulphur dioxide and heavy metal compounds (Ni, Cu) especially with the significant decrease of emission in recent years. The radial growth is used as basic integrated quantitative indicator for evaluation of the sates of Scots pine trees in the studied conditions.

## Materials and Methods

The long-term integrated researches were held at Kola Peninsula in lichen-green moss pine forests of III–IV age classes at various distances from the major emission source of the studied territory ‘Severonickel’ smelter (Monchegorsk, Murmansk oblast) in prevailing winds directions within the limits of three zones: impacted, buffer and background (Yarmishko 1997, 2009). The types of communities that are of the same forest type but have different level of disturbance were determined by their landscape position, characteristics of forest communities and their components, types of parent rock material and soil types.

The series of permanent sample plots (PSP) of 0.1–0.15 hectares each were set within each zone. PSPs were selected and set according to commonly recognized and clearly described approaches (Zagreev et al. 1992, Yarmishko 1997, Sanitary rules… 1998, Yarmishko and Lyanguzova 2002). Table 1 gives brief characteristic of tree layer of PSPs. Special at-

**Table 1. Brief characteristics of the studied stands.**

| Sample plot, number | Distance to the emission source, km | Coordinates and altitude, m | Stand composition, ratio | Average height, m | Average diameter, cm | Stand density, ha$^{-1}$ | Age, years |
|---|---|---|---|---|---|---|---|
| Background area | | | | | | | |
| 31 | 70 | 67°33′227" N 31°04’751" E, 180 m | 10 P | 7.1 | 9.4 | 2800 | 65 |
| 32 | 65 | 67°35’356" N 31°39’159 " E, 161 m | 10 P | 6.9 | 7.6 | 5150 | 55 |
| 33 | 60 | 67°33’334" N 32°07’326" E, 181 m | 10 P | 7.3 | 7.9 | 4500 | 60 |
| Area of moderate atmospheric pollution | | | | | | | |
| 3 | 35 | 67°38’168" N 32°42’234" E, 165 m | 10 P+B | 9.1 | 9.1 | 2120 | 65 |
| Area of heavy atmospheric pollution | | | | | | | |
| 29 | 10 | 67°41’216" N 32°46’447" E, 166 m | 10 P | 3.9 | 4.5 | 4220 | 60 |
| 29-a | 12 | 68°00’384" N 32°55’540" E, 198 m | 10 P | 4.3 | 6.1 | 3150 | 65 |

tention was given to the studies of Scots pine communities in the background area, where effects of air pollutants were negligible or absent.

To obtain quantitative data on the specificity of radial growth of Scots pine 15–20 sample trees were selected in each PSP within the working zones. The chosen trees were drilled by Pressler borer. The increment cores were taken from two sides of the trunk – northern and southern – at height of 1.3 m from root collar. The age of the trees was identified by cores sampled from the root collar of the studied trees. The annual rings width was measured with LINTAB 6 measuring system. The SAS/Stat program was used for statistical analysis of the data and calculation of correlation factors (SAS/Stat 1990). The methodical specifics of the carried research was comparison of the obtained data on the annual radial increment of Scots pine growing in natural conditions and in the communities influenced by different volumes of pollution.

The major source of industrial pollution in the area is Cu-Ni ‘Severonickel’ smelter (Monchegorsk, 67°55’ N, 32°48’ E), which is in operation since 1939 (Pozdnyakov 1999). At the peak of emission in 1973 – 1992 (Fig. 1) the average annual emission was about 230,000 t of $SO_2$ and 15,000 t of fine heavy metal polymetallic dust of mainly Ni and Cu sulphides and oxides. Between 1993 and 1999 the factory’s treatment facilities were improved, that lowered emission of sulphur dioxide eight times, and polymetallic dust five times compared to their maximum values. Since 1999 onwards, annual emission is relatively stable and makes on the average 40,000 t of sulpfur dioxide and 5,000 t of a polymetallic dust (Kola MMC 2007).

## Results

The pinewoods in the European North of Russia are intensively utilized for a long time. In the middle of the last century, forest harvesting was especially active in the studied region. Long-term observation over the second growth and formation of tree stands in lichen and lichen-green moss pine forests with insignificant or zero anthropogenic impact upon forest phytocoenosis allowed us to suggest generalized approach to disturbed forests recovery.

The pine seedlings appeared in amount of 12,000–15,000 (sometimes 30,000–35,000) per hectare on new fellings, and on fellings damaged by surface fires. However, significant number of seedlings and saplings died in the first years (soil drought, diseases, etc.). It is has been known that in further years of growth and development, competition between individual trees increase, both in above-ground parts, and in root systems (Zyabchenko 1984, Tsvetkov and Semenov, 1985, Listov 1986). As a result, an intensive differentiation occurs in juvenile growth: the strongest occupy leading positions, the weakest – die, and some persist as suppressed juveniles for a long time in the understorey of the young forest.

Lichen-green moss pine forests studied in three PSPs in the background area are characterized by good growth and development, the upperstorey trees are in regular distribution and there are about 4000–4500 trees per 1 ha on average. There are about 2000–3000 trees per 1 ha of strongly suppressed alive and dry trees in the understorey. The analysis of the data on radial wood growth of Scots pine suggests (Fig. 2) that in first 12–15 years of tree life, when there was almost no competition, the annual radial wood

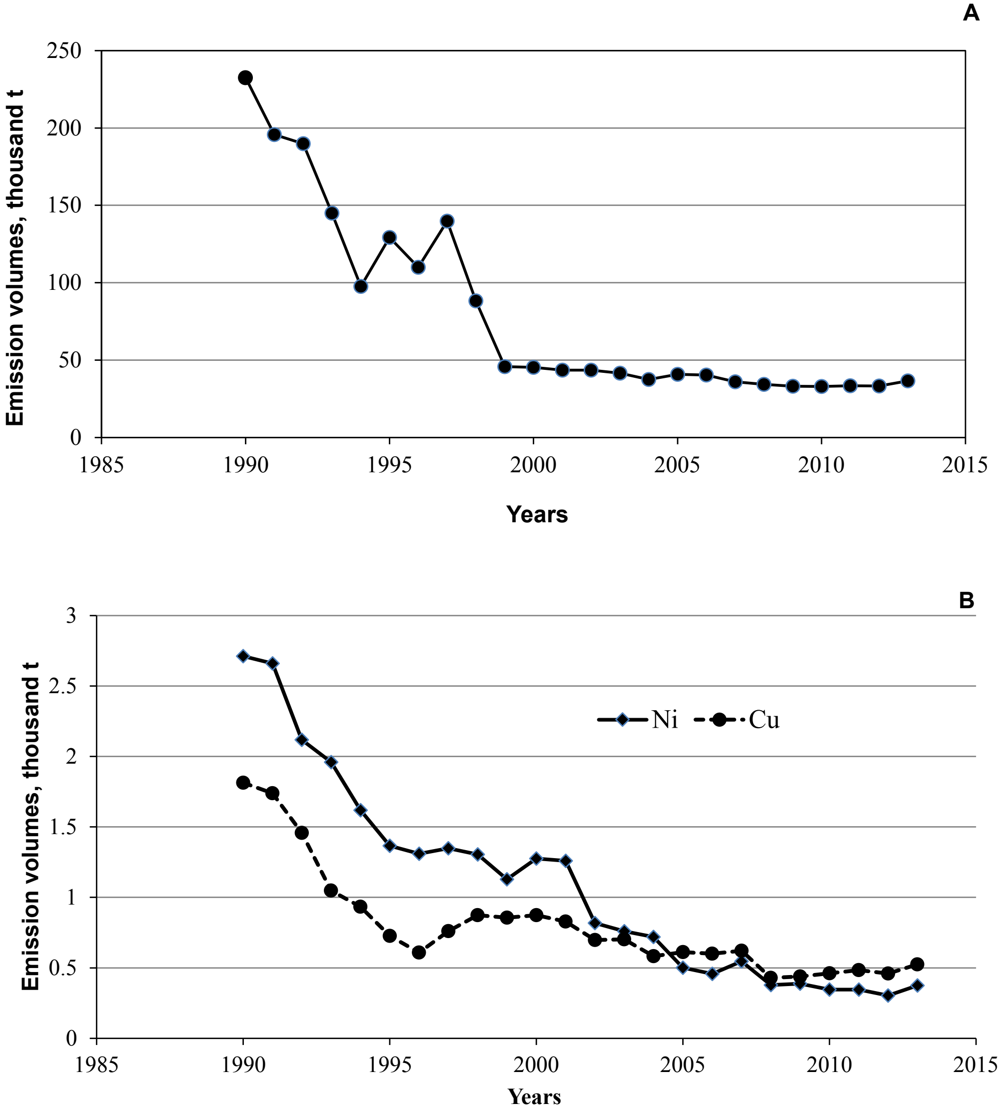


**Fig. 1. Dynamics of atmospheric emission of sulphur dioxide (A) and Ni and Cu compounds (B).**

increment was active (about 1.2–1.5 mm/year). Later, as juvenile pines grew bigger and the associated ground cover developed, the intensity of radial wood growth decreased by 23–25 % to little more than 1 mm/year. In the beginning of 1980s radial increment reached the minimum of 0.6–0.7 mm/year and has been stable for almost 30 years by now. It proves that competition in intrapopulation interaction in this stage is less than in the earlier phases of community formation. It is possible to predict further extension of differentiation process as based on the data on

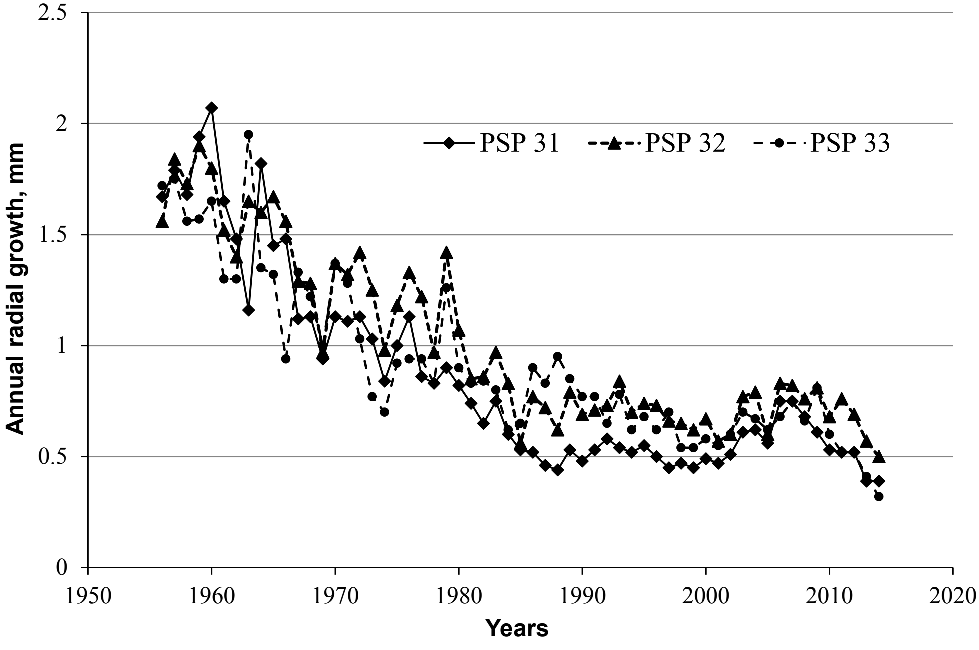


**Fig. 2. Dynamics of annual radial growth of Scots pine of III–IV age class in lichen and lichen-green moss pine forests in three sample plots of the background area.**

the pine forest density (trees per hectare), existence of thin stems and severely suppressed tress. Fig. 2 shows definite short-term fluctuation cycles of radial wood increment registered for each of three studied PSPs. These cycles are probably related to the changing weather conditions. They are generally synchronous though the fluctuation amplitudes of radial growth slightly differ. Within several last years the annual radial growth after some short-term increase again decreased on all studied plots (Fig. 2), we think this is associated with increasing competition within the maturing communities.

Of a special interest is Fig. 3 demonstrating data on radial growth of individual 300-year-old overripe pines growing in young secondary pine stands of III–IV age class. Trunk and crown morphometric characteristics of old trees demonstrate their good state. There are no signs of mechanical or fire injuries on the trunks. No heart rot was seen in the core samples collected for measuring annual radial growth and age at root collar or at breast height. These old pines that survived logging and fires were the mother trees for the disturbed forests.

Information obtained from the core samples shows that in young age, during the first 35–40 years of tree life the annual radial growth of now overripe trees, was 2–3 mm/year and decreased for up to 0.9–1.3 mm/year later (Fig. 3). The reason for such decrease in wood growth was increasing plants' competitive interactions in developing young community. Further, during next 160–170 years, the radial growth was relatively stable on the average of 0.6–0.7 mm/year with some fluctuations that obviously are related to the changing

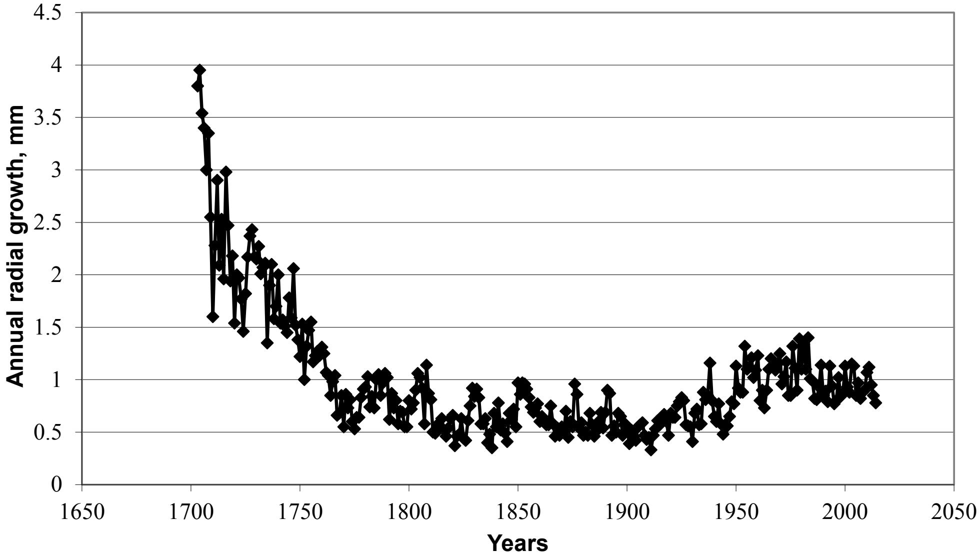


**Fig. 3. Dynamics of the annual radial growth of Scots pine of XVI age class in lichen and lichen-green moss pine forests of the background area in the north of European Russia.**

weather. In the mid-1950s a notable increase in radial wood increment occurred (Fig. 3). At that time intensive logging for highly valued Scots pine timber begun in the studied part of Kola Peninsula (Tsvetkov and Semenov 1985, Kryuchkov 1991). Hence, the plants competition essentially weakened after logging, fires frequently arising on fellings and significant destruction of ground cover. The remaining mother trees (sort of seed banks) demonstrated positive response increasing annual wood growth 1.3–1.5 times (1.0–1.1 mm/year). This indicator did not vary for almost 50 years (Fig. 3). Over the last years, the decline of wood increment in mature trees due to increasing competition from the intensively developing young Scots pine stands was observed (5,150 trees/ha).

Previous correlation analysis (Yarmishko 1997) demonstrated no significant association between radial growth of a pine in background area and basic climatic indices (average temperature and precipitation of July, total temperature and precipitation for growing season). Analysis of meteorological conditions in the years of maximum and minimum radial wood increment allows only in general determine most basic trends of Scots pine wood increment in the background areas of Kola Peninsula (Yarmishko 1997). This means that observed decrease in intensity of radial growth of young pine stands is connected with strong competition in developing communities (for light, nutrients, etc.).

Annual dynamics of Scots pine radial growth in young stands of III–IV age class at the territories with various degree of pollution in the central part of Kola Peninsula is shown in Fig. 4. The intensity of wood increment of Scots pine at the zone of moderate air pollution (buffer zone, within 35 km radius from the emitting source) was similar to the controls until early 1990s. Later the annual radial growth curve demonstrated notable descending character. That to our opinion, is related to the pollutants accumulated in the soil and continuous intrapopulation competition processes. The correlation analysis of data series of radial increment of Scots pine from the areas of moderate pollution with volumes of emitted air pollutants demonstrates negative association ($r = -0.47$; $n = 24$; $P < 0.05$). Here we should note that the pine responded to decrease of toxic emission with increasing wood growth of 10–15 % in early 2000s as compared to the previous period. The recent years are characterized by decrease in wood increment in the studied region.

The radial growth of Scots pine in a zone of heavy pollution (impacted zone, within 8–12 km radius from emitting source) in the early stages of tree stands formation was moderate and did not exceed 0.8–0.9 mm/year. No matter there is visible similarity of the curves of young community growth in impacted zone (descending character) with those in background area and buffer zone, the pollutants had sufficient negative effect on the pine from the moment of its germination. In early 1970s the annual pine wood increment essentially decreased (as low as 0.3 mm/year). This is seen as a direct response to the 1970s 'Severonickel' smelter combine capacity boosted and started importing Norilsk ore that is characterized by increased content of sulphur (Fig. 4).

The intensity of Scots pine wood increment in the heavily contaminated territories have been gradually increasing form early 1990s and by 2000s was similar to the growth rate in background communities and in the areas with low contamination. The correlation analysis of data series on Scots pine radial wood increment in the areas of heavy pollution and volumes of emitted pollutants provides reliable negative association. There is significant correlation of the radial growth with amount of sulphur dioxide emitted to the

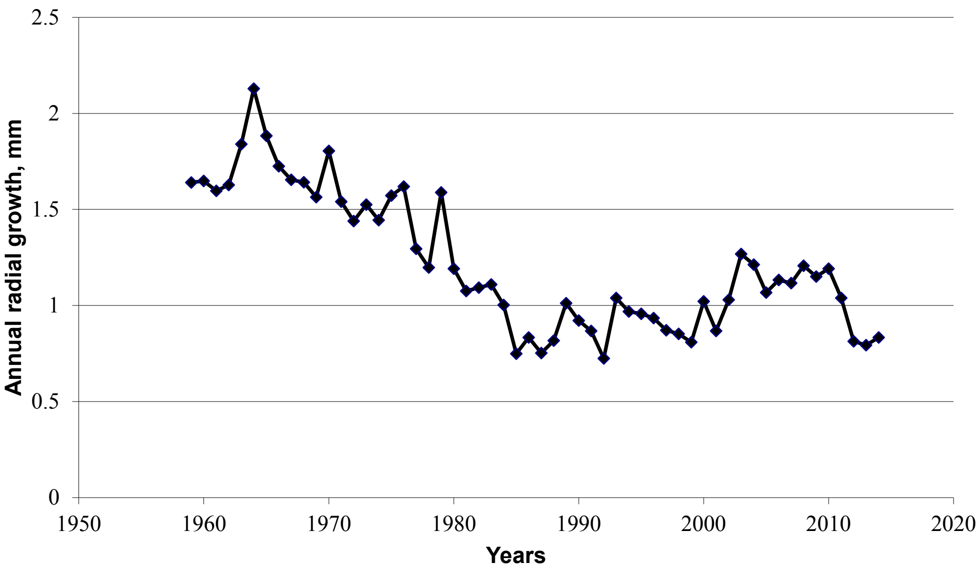


**Fig. 4. Dynamics of annual radial growth of Scots pine in the areas with different levels of pollution.**

atmosphere ($r = -0.80$; $n = 24$; $P < 0.05$) and amount of solid particles ($r = -0.85$; $n = 24$; $P < 0.05$). It is necessary to note, that the established association is much stronger in heavily polluted area, than in the moderate one. In more affected territories the growth and development of individual trees and tree stands of Scots pine depend rather on intensity of environment pollution with sulphur dioxide and oxides of heavy metals, than on changing climatic factors. Though even in this affected territories the factor of intrapopulation competition is to be taken in account, as the tree density is still high (3,500–4,200 trees/ha) although trees are damaged.

## Discussion

The high uniformity of spatial structure and similarity of tree age are the features of young forests due to specificity of forest formation on the logged and burned areas in the European North of Russia. Until the formation of stand canopy, young forests differs in stand density, closeness and state. It is in young forests that the disproportion between these characteristics is more obvious. The uniformity of tree distribution and narrow crowns of pine explains this phenomenon. One more feature of the dense young forests is the slow natural mortality.

Intensive annual radial increment of Scots pine in the north of Kola Peninsula lasts for 45–50 years, and according to Tsvetkov and Tsvetkova (1985) even longer, for 50–60 years. In dense young forests (12,000–15,000 trees/ha) the radial growth notably reduces from the age of 25–30. According to downfall trend, radial growth of pine in young age depends in a greater degree on intrapopulation interactions, than on climatic factors. The data on radial increment of overripe pines, as well as on communities affected by atmospheric pollution proves this observation. Fig. 4 demonstrates recent decrease in radial growth of Scots pine in all studied territories. To our opinion, this is related to the global environmental changes and continuous intrapopulation processes characteristic to developing young forest communities.

## Conclusion

In conclusion, it is necessary to say that the growth of Scots pine (*Pinus sylvestris* L.) in the European North of Russian in young age depends more on intrapopulation competition than on climatic factors. This conclusion is confirmed by the data on dynamics of radial increment of the overripe pines. Essential changes of annual radial growth of Scots pine influenced by atmospheric pollutants are registered, while natural fluctuations exist. The significant negative correlation between annual radial increment of Scots pine and volume of toxic substances emitted by ‘Severonickel’ combine is established. Synergetic effects of various natural and anthropogenic factors have significant influence on formation, growth and vitality of Scots pine communities at the northern limit of its distribution.

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