CONTENTS

Acknowledgement to reviewers of the manuscripts submitted to Forestry Ideas in 2014:

Abdullah Emin **Akay** – Imam University, Kahramanmaras, Turkey

Sezgin **Ayan** – Kastamonu University, Turkey

Martin **Borisov** – University of Forestry, Sofia, Bulgaria

Mihajla **Djan** – University of Novi Sad, Serbia

Ivan **Dombalov** – University of Chemical Technology and Metallurgy, Sofia, Bulgaria

Mariana **Doncheva** – University of Forestry, Sofia, Bulgaria

Ekaterina **Filcheva** – “Nikola Pushkarov” Institute of Soil Science, Agrotechnologies and Plant Protection, Agricultural Academy, Sofia, Bulgaria

Ismail **Ghajar** – University of Guilan, Iran

Zoran **Govedar** – University of Banja Luka, Bosnia and Herzegovina

Melaniya **Gyosheva** – Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria

Anelia **Kenarova** – Sofia University "St. Kliment Ohridski", Bulgaria

Nikola **Kolev** – “Nikola Pushkarov” Institute of Soil Science, Agrotechnologies and Plant Protection, Agricultural Academy, Sofia, Bulgaria

Radka **Koleva** – University of Forestry, Sofia, Bulgaria

Stanimir **Kostadinov** – University of Belgrade, Serbia

Georgi **Kostov** – University of Forestry, Sofia, Bulgaria

Ya-Fu **Lee** – National Cheng Kung University, Taiwan

Ludmila **Malinova** – University of Forestry, Sofia, Bulgaria

Vu Quang **Manh** – Hanoi National University of Education, Vietnam

Ivan **Manolov** – Agricultural University, Plovdiv, Bulgaria

Gerassimos **Martzopoulos** – Aristotle University of Thessaloniki, Greece

Milko **Milev** – University of Forestry, Sofia, Bulgaria

Dusko **Mukaetov** – Institute of Agriculture, Skopje, Macedonia

Mohammad Naghi **Adel** – University of Guilan, Iran

Krastena **Nikolova** – University of Food Technologies, Plovdiv, Bulgaria

Mariyana **Nikolova** – National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria

Maya **Nusturova** – University of Forestry, Sofia, Bulgaria

Conor **O'Reilly** – University College Dublin, Ireland

Sezgin **Özden** – Cankiri Karatekin University, Turkey

Giovanni **Pacioni** – University of L'Aquila, Italy

Denica **Pandeva** – Executive Forests Agency, Sofia, Bulgaria

Ekaterina **Pavlova** – University of Forestry, Sofia, Bulgaria

Yoncho **Pelovski** – University of Chemical Technology and Metallurgy, Sofia, Bulgaria

Krasimira **Petkova** – University of Forestry, Sofia, Bulgaria

Zdravka **Petkova** – "Nikola Pushkarov" Institute of Soil Science, Agrotechnologies and Plant Protection, Agricultural Academy, Sofia, Bulgaria

Rossitsa **Petrova** – University of Forestry, Sofia, Bulgaria

Emil **Popov** – Forest Research Institute, BAS, Sofia, Bulgaria

Ivan **Raev** – Forest Research Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

Oytun Emre **Sakici** – Kastamonu University, Turkey

Vladimir **Shtilyanov** – University of Forestry, Sofia, Bulgaria

Evgeni **Sokolovski** – University of Chemical Technology and Metallurgy, Sofia, Bulgaria

Yulin **Tepeliev** – University of Forestry, Sofia, Bulgaria

Ekaterina **Todorova** – University of Forestry, Sofia, Bulgaria

Toma **Tonchev** – University of Forestry, Sofia, Bulgaria

Nikolina **Tsvetkova** – University of Forestry, Sofia, Bulgaria

Genoveva **Tzolova** – University of Forestry, Sofia, Bulgaria

Petar **Zhelev** – University of Forestry, Sofia, Bulgaria

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 123–133

OVERVIEW OF GENETIC DIVERSITY OF BROWN HARE (*LEPUS EUROPAEUS* PALLAS) FROM BULGARIA

Chavdar Zhelev[1,2*] and Nino Ninov[1]

[1]Department of Wildlife management, University of Forestry,
10 Kliment Ohridski blvd., 1797 Sofia, Bulgaria.
[2]National research station for hunting, biology and game diseases,
5 Iskarsko Shose str., 1528 Sofia, Bulgaria. *E-mail: chavdar.d.zhelev@gmail.com

Received: 29 September 2014 Accepted: 23 December 2014

Abstract

There are so far several studies on the level of genetic diversity and differentiation of the brown hare populations in Bulgaria. Since the information available is not summarized the aim of this review was to summarize previous knowledge on genetic diversity of the brown hares from Bulgaria in order to disclose new horizons and directions for future genetic studies. We did a review of 10 publications on the brown hare genetic diversity, mostly in Bulgaria but also in other adjacent regions, where the brown hare was introduced or naturally presented. The results from allozymic, RAPD and microsatellite markers show that the genetic diversity is the highest in the Anatolian populations, followed by the Greek, Bulgarian, Serbian and finally by the Austrian ones. A fragmentation on a small geographical scale can be seen, illustrated by the presence of regional rare alleles, appearing with a low frequency. Gene flow is present across long geographical distances. There was no negative impact on the genetic diversity, caused by decreasing of population size for long periods of time.

Key words: allelic richness, Bulgaria, heterozygosity, molecular markers, population genetics.

Introduction

The brown hare *Lepus europaeus* Pallas, 1758 is the most widely distributed and one of the most studied species of the genus (Wilson and Reeder 2005). Since 1960s the brown hare populations were decreasing all over the European continent (Smith et al. 2005), and the rate of decreasing was higher at the end of 1990s and the beginning of 2000s (Strzała et al. 2006). In Bulgaria these changes were truly tangible, especially after 2000. The hunting bag reached significantly low level, if compared to other European countries. For instance, in Poland in the early 1970's, harvesting reached 700,000 individuals and in 1990 – 505,000 (Hartl et al. 1992). In Bulgaria the respective quantities were 300,000 brown hares shot in 1970 and only 50,000 in 1990.

The brown hare was included in the Red list of threatened species of IUCN, with the category Least Concern – LC (Smith and Johnston 2008). This category also lists widespread and abundant taxa and those which do not qualify for the other categories. It is included also in Appendix III of the Convention of the Conservation of European Wildlife and Natural Habitats – Bern Convention (Vaughan et al. 2003, Smith et al. 2005), and is classified as a priority species of conservation concern by the UK government (Smith et al. 2005).

Since 1980s many European researchers started studies on the population genetics of brown hares in different habitats of the continent. Most studies were focused to test whether the reduction of population size could cause heterozygote deficiency, decreasing of the mean allele number and allelic richness, extinction of endemic alleles, and the presence of bottleneck effect and inbreeding. The level of genetic variability and differentiation of the Bulgarian brown hare populations were studied as well (Suchentrunk et al. 2000), but all these studies over the years are still not summarized. A summary and/or critical review could be in favour by giving direction for future genetic studies, which can reveal the level of the Bulgarian brown hare genetic diversity, and could serve as opportunity for assessment of an indirect correlation between genetic diversity and population size for different periods. This could help also the decision making related to the needs of translocation and restocking programs. According to the Bulgarian wildlife experts, one of the major reason for the hare stock decreasing is the lack of translocation and restocking for the last 30 years (common practices in the past), no matter if the hares were imported or just locally displaced, in order to improve the genetic diversity. The need to summarize of scientific results on the population genetics research is also determined by the lack of information on this topic in Bulgaria. Therefore, we tried to review the publications related to genetic variability of the brown hare, not only in Bulgaria and Europe, but also in other areas, where it was introduced or occurs naturally. Our aim was to show the results (presented in comparative tables) of studies that include individuals of brown hares from Bulgaria.

Genetic Diversity and Differentiation of Brown Hares Based on Allozyme Gene Markers

The first and the most comprehensive population genetic study of Bulgarian brown hares (Suchentrunk et al. 2000) compared genetic diversity of 8 Bulgarian with 20 Austrian populations, the latter studied by Hartl et al. (1993). Kidney and liver samples were tested from 157 brown hares, collected in 8 country regions in the period 1993–1995 for determining of heavy metal content (Tatatruch et al. 1996), within the research program of Research Institute of Wildlife Ecology (Vienna, Austria). The results (Suchentrunk et al. 2000, Table 1) showed that there was a significant differentiation in allele frequencies between Bulgarian and Austrian populations in 6 loci of a total 50 studied. Only among Bulgarian hare populations, there was significant differentiation at 7 loci.

In Bulgarian populations polymorphism was found at 11 loci, which is very similar to the Austrian ones. Mean number of alleles also had similar values (1.16–1.18 for Bulgaria, 1.08–1.20 for Austria). There was no linkage disequilibrium between the locus pairs. Significant correlation was observed between the expected and observed heterozygosity (p<0.0001). Only in two populations there was a difference in expected heterozygosity for all loci. The genetic differentiation (Fst values) among 8 Bulgarian populations was generally low (probably due to in-country hare translocations in the period 1970–1980). Absolute

Table 1. Comparison of genetic variability in Bulgarian (BG) and Austrian populations (Suchentrunk et al. 2000).

Gen. ind.	Bre	D. Mit.	Vra	Ait	San	St.Z	Vid	Dob	BG Mean	BG Range	Austria Mean	Austria Range
N	22	20	25	20	19	15	16	20	8	157	20	469
Ho	0.017	0.036	0.033	0.025	0.042	0.026	0.029	0.031	0.03	0.017–0.042	0.030	0.020–0.039
He	0.026	0.046	0.038	0.026	0.045	0.031	0.035	0.034	0.035	0.026–0.045	0.027	0.022–0.033
P	10.2	14.3	12.2	10.2	10.2	12.2	14.3	12.2	12	10.2–14.3	10.7	8.2–16.3
A	1.14	1.2	1.18	1.18	1.16	1.16	1.16	1.16	1.17	1.14–1.2	1.13	1.08–1.20

Note: Bre – Breznik, D. Mit – Dolna Mitropolia, Vra – Vratza, Ait – Aitos, San – Sandanski, St.Z – Stara Zagora, Vid – Vidin, Dob – Dobrich; *N* – number of individuals, *Ho* – observed heterozygosity, *He* – expected heterozygosity, *P* – percent of polymorphic loci (99 % criterion), *A* – mean number of alleles per locus.

genetic differentiation occurred among regional and inter-regional samples from Bulgaria and central Europe. This implies considerable gene flow across long geographical distances leading to a rather panmictic network of local populations. Despite the general picture of a high level of gene flow over long geographic distances, there was a tendency of a slight gene pool divergence between local populations of southeastern (Bulgarian) and central (Austrian) European brown hares. Genetic studies showed also that Bulgarian hare populations are very similar, forming a relatively homogeneous gene pool, which is slightly different to other regions in Europe. A new allele was found in the population of Sandanski that was not found in Central European populations. The authors' explanation was related to the possible slight gene flow from North Greece to South Bulgaria. There were no other new alleles in Bulgarian populations, which suppose an absence of a gene flow coming from Asia Minor or North-east of the Black Sea. The results of Suchentrunk et al. (2000) concerning the distribution of allele frequencies in the populations studied reinforce the hypothesis that there was no gene flow coming from Southeast Europe, i.e. Bulgaria, to the Central Europe.

Hare liver samples were sampled from 91 brown hare individuals in seven regions of continental Greece and Crete for the period 1998–2000. In order to compare genetic diversity of these populations with the results obtained by Suchentrunk et al. (2000) the genetic analysis were done using the same methodology and in the same laboratory (Suchentrunk et al. 2003). Three rare alleles with low frequencies are found, probably endemic, in the 35 loci studied. These alleles were not discovered in other populations in Central and South Europe (Hartl et al. 1994, Suchentrunk et al. 2000). This result indicates that during the late Pleistocene Greece was a refuge for brown hares for Southern Balkans. Three other alleles found in Bulgarian and Austrian populations were not presented in Greece (Suchentrunk et al. 2000). The alleles Pep-294, found in Bulgarian populations from the area of Sandanski by Suchentrunk et al. (2000) was not found in Greek ones which refute the hypothesis that this allele comes from Greece, by following the Valley of Struma River. Overall rates of polymorphism, i.e. percent of polymorphic loci (no criterion) did not differ significantly ($p>0.05$, two-sided Fisher's exact test) between Greek (14.3 %) and Bulgarian (20.0 %) hares.

Mean allele number (Table 2) in Greek populations varied weakly – 1.09–1.31 (for Bulgaria 1.11–1.20). For the Greek populations average observed and expected heterozygosity ranged between 0.04–0.05 and 0.036–0.053, respectively. All values of the inbreeding coefficient (*F*is) were not too far away from zero. The genetic diversity between Greek and Bulgarian populations was 3.3 % and between all studied populations it was 6 %. All indices of genetic diversity did not vary significantly between Bulgarian and Greek populations, except the observed heterozygosity, which was higher in Greek populations. Generally, the Greek populations had slightly higher genetic diversity in comparison with the allozymic diversity of Bulgarian and Central European (Austrian) populations (Hartl et al. 1993, 1994; Suchentrunk et al. 1999, 2000, 2001). These results also show that the low population size existing for a long period in Greek populations (Mamuris et al. 2001, Sfougaris et al. 1999) so far did not have a negative effect on their genetic diversity. There was very low differentiation between Bulgarian and Greek brown hare populations (Suchentrunk et al. 2003). The low levels of allozymic demarcation are often normal within the populations of brown hare and other *Lepus* species, even for large geographical distances in Europe (Hartl et al. 1993, 1994; Suchentrunk et al. 1999, 2000, 2001). One of the reasons for the small difference in genetic diversity in Bulgaria and Greece can be explained by the translocation of hares in the past. Indeed, in a preserved reports of Greek ministry of Agriculture there is information that during 1990's there was a big amount of brown hares imported from Bulgaria, raised in Greek farms and then released (Mamuris et al. 2002). The observed low level of nuclear gene pool differentiation in Greek and Central European populations confirms the above mentioned conclusion.

Genetic diversity of 57 brown hares from Anatolia (Sert et al. 2005) was compared with 717 brown hares from Central Europe – Austria (Suchentrunk et al. 2000), Southeastern Europe – Greece (Suchentrunk et al. 2003) and Bulgaria (Suchentrunk et al. 2000), in another study performed in the period of 2001–2003. The common 28 loci for all populations were compared of 48 in total (Table 3). The results showed, that of 48 loci assayed, 19 (39.6 %) were polymorphic with two to four alleles in the Anatolian hares. An interesting fact

Table 2. Indices of genetic variability in brown hare populations from Greece and Bulgaria based on isozyme gene markers (Suchentrunk et al. 2003).

Genetic indices	Bulgaria Mean	Bulgaria Range	Greece Mean	Greece Range
N	8	157	7	91
Ho	0.033	0.015–0.043*	0.044	0.040–0.050
He	0.038	0.026–0.052	0.043	0.036–0.053
P	12	5.71–11.43	9.39	8.57–14.29
A	1.17	1.11–1.20	1.18	1.09–1.31

Note: *N* – number of individuals and populations, *Ho* – observed heterozygosity, *He* – expected heterozygosity, *P* – percent of polymorphic loci (95 % criterion), *A* – mean number of alleles per locus. * In the original paper (Suchentrunk et al. 2003) the values are given in percentages.

is that 14 alleles, although with a low frequencies in 13 loci were not found in European populations. Probably they could have occurred through a gene flow coming from different territories around Anatolia.

Table 3. Indices of genetic variability in brown hare populations from Anatolia (Turkey), Austria, Bulgaria and Greece (Sert et al. 2005) isozymes.

Genetic indices	Anatolia (Turkey) range	Austria range	Bulgaria range	Greece range
N	4	20	8	7
Ho	0.049–0.087	0.018–0.055	0.019–0.054	0.050–0.063
He	0.046–0.071	0.024–0.042	0.032–0.065	0.045–0.067
P	14.25–25	7.14–25	10.71–21.43	10.71–17.86
A	1.18–1.36	1.07–1.39	1.14–1.25	1.11–1.39

Note: *N* – number of populations, *Ho* – observed heterozygosity, *He* – expected heterozygosity, *P* – percent of polymorphic loci (99 % criterion), *A* – mean number of alleles per locus.

None of the four Turkish populations showed evidence for a bottleneck effect during the last generations, but there are doubts about its presence in the past due to low allele frequencies, found only in Anatolia. The comparison of population genetic indices for genetic diversity among Anatolia, Greece, Bulgaria and Austria revealed that the highest values were found in the Anatolian populations followed by Greek and Bulgarian ones, and the last were the Austrian populations. The same trend could be observed in allele frequencies and polymorphism distribution for all 28 loci. Genetic diversity among those 4 populations was 60.28 %, the other 39.72 % due to the diversity within populations. No genetic signal of inbreeding was detected in Anatolian brown hare populations contrary to the Greek and Bulgarian ones, where *F*is values reached values as high as 0.373 and 0.426, respectively. Greek hares are most similar to Anatolian ones, followed by Bulgarian and Austrian hares. The genetic diversity of Anatolian populations was higher, as compared to European ones. According to Suchentrunk et al. (2003) the reason can be found in the continuous hare presence during the periods of glaciations in Greece and Anatolia and probably some other regions of the Balkans during Pleistocene, when the unfavorable climate conditions did not provide habitats good enough in most of the northern territories (Corbet 1986). An additional explanation comes out of the concept that Anatolia is a biogeographical crossroad, with small ecological barriers for the gene flow in many mammals during Pleistocene and Holocene periods (Cheylan 1991). Regarding the brown hare in general, there was some fragmentation, but definitely existing gene flow on longer geographical distances. The Anatolian populations were not genetically different in comparison with European ones and actually they are genetically similar to the continental Greek populations. Many alleles of Anatolian populations were not found in the European ones. Phylogeographic analysis based on allozyme variability revealed close relations, without a strong internal differentiation between Anatolian and European brown hares (Sert et al. 2005).

The studies on brown hares from Central, South Eastern Europe, also England and Anatolia, employing a large number of allozymic loci (Hartl et al. 1990, 1992, 1993, 1994; Suchentrunk et al. 2000, 2001, 2003; Sert et al. 2005) showed variety of rare or regionally distributed alleles and a tendency for decreasing of genetic diversity, from Anatolia toward South East Europe to Central Europe and England (Vapa et al. 2007). Despite the relatively small differences between the gene pools on a long geographical distance, distinct regionally limited alleles, appearing with a low frequency, prove genetic variation of the gene pool on a small geographic scale (Sert et al. 2005). Liver samples of 33 hares, from 8 regions in Vojvodina area (Serbia) were used for the allozyme variability analysis using the same methodology, like the aforementioned researches for Austria, Bulgaria, Greece and Anatolia. Total 40 loci were analyzed and the results for Bulgaria – 157 hares (Suchentrunk et al. 2000) and Austria – 469 hares (Hartl et al. 1993), are compared (Table 4). The percent of polymorphic loci of Serbian hares in 7 loci was 17.5 %, which stays within the range for the Bulgarian (12.5–17.5 %) and Austrian ones (10–20 %). The same trend was found for the mean number and frequencies of alleles. There were 7 alleles found in Bulgarian and Austrian populations not occurring in Serbian ones.

Table 4. Indices of genetic variability in brown hare populations from Vojvodina (Serbia), Bulgaria and Austria (Vapa et al. 2007).

Genetic indices	Vojvodina (Serbia)	Bulgaria	Austria
N	1	8	20
Ho	0.042	0.032–0.056	0.027–0.041
He	0.043	0.033–0.058	0.028–0.042
P	17.5	12.50–17.50	10.00–20.00
A	1.20	1.17–1.25	1.10–1.23

Note: *N* – number of populations, *Ho* – observed heterozygosity, *He* – expected heterozygosity, *P* – percent of polymorphic loci (criterion 99 %), *A* – mean number of alleles per locus.

The heterozygosity (expected and observed) in brown hares from Serbia was slightly higher than in Austrian populations and nearly in the same range as the Bulgarian ones. The Serbian populations were genetically slightly closer to the Austrian than to Bulgarian ones, which were the most distant to the Austrian populations. Generally, Serbian brown hare populations were very close to Bulgarian and Austrian ones. (Vapa et al. 2007). The relatively low values of absolute genetic differentiation between Vojvodina (Serbia) and the populations of Central Europe (Austria) and South East Balkans (Bulgaria) present a slight genetic divergence in general or more precisely, a small genetic differentiation. There were no new alleles discovered in brown hares from Serbia (probably due to the small number of samples, *n*=33) and the most commonly occurring alleles were common for all three countries (Vapa et al. 2007). This research confirms the results obtained by Djan et al. (2004).

Another study on the genetic diversity in 4 regions in Vojvodina (Serbia) based on allozyme markers (Vapa et al. 2002) revealed high values for heterozygosity and polymorphism. This could be a consequence of smaller number of animals analyzed in this study, and smaller number of hypothetical structural loci, which enables detection of more alleles. The percent of polymorphic loci in different populations ranged from 11.76 % to 35.29 %. The overall rate of polymorphism (99 % criterion, 17 loci considered) amounted to 41.17 %.

Mean observed heterozygosity in hare populations from Vojvodina was *Ho*=0.070, and mean expected *He*=0.075 (Table 5). The average number of alleles per locus was 1.35 (Vapa et al. 2002).

Table 5. Comparison of genetic variability in Austrian, Bulgarian, Polish and Serbian brown hare population (Vapa et al. 2002).

Genetic indices	Austria	Bulgaria	Poland	Serbia
N	20	8	1	4
Ho	0,03	0,03	–	0,07
He	0,027	0,035	0,047	0,075
P	0,11	0,12	0,18	0,23
A	1,13	1,17	–	1,35

Note: *N* – number of populations, *Ho* – mean observed heterozygosity, *He* – mean expected heterozygosity, *P* – percent of polymorphic loci (99 % criterion), *A* – mean number of alleles per locus.

Other research (Djan et al. 2004) for allozyme variability in 31 loci was performed on livers of 60 individuals from 15 regions in Vojvodina (Serbia). The result showed that for Serbia the observed heterozygosity was 0.042, compared to Bulgaria 0.030 and Austria 0.030. Expected heterozygosity was higher in Serbian populations – 0.062 than in Bulgarian and Austrian ones – 0.035 and 0.027, respectively (Suchentrunk et al. 2000). The percent of polymorphic loci of Serbian brown hare ranged from 0 to 12.9 % with average 8.39 % as for Bulgaria it was 12 % and Austria 10.7 %. Independently of the fact that heterozygosity and polymorphism were high for Serbian hares, the allozymic variability variety was low, which correspondent with the data about east parts of Austria (Hartl et al. 1993), but lower compared to Bulgaria (Suchentrunk et al. 2000).

Genetic Diversity and Differentiation of Brown Hares Based on RAPD Analyses

The second genetic study including individuals from Bulgaria employed a new class of markers – Random Amplified Polymorphic DNA (RAPD) (Mamuris et al. 2002). Since in Greece it is a practice to import brown hares from different countries, the study of Mamuris et al (2002) included besides 187 Greek hares, individuals from Austria (*n*=10), Poland (*n*=10), Germany (*n*=46), France (*n*=21) and Bulgaria (*n*=42), total 129. According to Mamuris (2002) one recent import from Bulgaria to Greece included 42 brown hares, which were raised in a farm for certain period and then released. Genetic samples were taken before their release in Greece, so Bulgaria was represented by these 42 individuals. The research was done also on samples on wild populations from the continental part of Greece (*n*=149), as 24 hare from them were raised in farms and 14 were semi free from wild populations, thus resulting in a total of 316 brown hares (Table 6). Bulgarian populations had high values on heterozygosity compared with those from Central Europe and a bit lower than the populations from Greece. These facts confirmed the results of Suchentrunk et al. (2003).

The result showed also that the Greek and Bulgarian populations are genetically closer between each other and in the same time divergent from Central Europe (Poland, Austria, Germany and France). Also genetically closer were the three Central European populations.

Table 6. Genetic diversity based on RAPD markers (Mamuris et al. 2002).

Genetic indices	Zal-logo	Vra-deto	Pyrra	Spilia	Elas-sona	Veles-tino	Farm 1	In enclosure	Austria/ Poland	Ger-many	Fran-ce	Bul-garia
N	26	21	36	23	20	23	24	14	20	46	21	42
He	0.269	0.255	0.267	0.264	0.262	0.272	0.202	0.200	0.236	0.238	0.240	0.258
D	0.022	0.019	0.021	0.015	0.019	0.025	0.078	0.077	0.083	0.081	0.081	–

Note: *N* – number of individuals, *H* – expected heterozygosity, *D* – Nei's Genetic Distance between Bulgaria and 11 populations of brown hare based on RAPD analysis.

Genetic Diversity and Differentiation of Brown Hares Based on Microsatellite Variability

The third and last study on Bulgarian brown hares at individual level was done by Estonba et al. (2006). The study included total 100 hares belonging to three species of genus *Lepus*: *L. europaeus* – 39 from Iberian Peninsula and 31 from Bulgaria (Plovdiv – 26, Pazardjik – 4 and Karlovo – 1), *L. castroviejoi* (n=11), and *L. granatensis* (n=19). Genetic diversity and differentiation were documented in six microsatellite loci. The results showed that genetic diversity in the two populations of *L. europaeus* from Iberian and Balkan Peninsula was similar (p>0.061; Student t-test), but there were some differences regarding the distribution of allele frequencies (Table 7). This heterogeneity demonstrates some restrictions on nuclear gene flow between these two populations, which we can expect because of their geographical isolation. This also matches the result from Mamuris et al. (2002). Iberian population clearly group with Bulgarian ones, independently from the big distance between them, compared with the other two species in this research. As a main conclusion the authors pointed that the geographical separation on these two populations should be kept and they should be managed as independent units. Local adapted population has to be preserved, which will lead to protection of the local genotypes. These results have direct influence on future restocking programs.

Table 7. Genetic diversity based on microsatellite markers(Estonba et al. 2006).

Loci	*L. europaeus* (Iberia)			*L. europaeus* (Bulgaria)		
	MNA	*Ho*	*He*	*MNA*	*Ho*	*He*
SOL8	6	0.615	0.594	8	0.806	0.794
SAT2	11	0.579	0.587	16	0.833	0.851
SAT8	3	0.231	0.363	4	0.742	0.535
SOL33	4	0.243	0.225	4	0.414	0.440
SAT12	8	0.821	0.766	7	0.806	0.841
SAT5	7	0.424	0.821	9	0.263	0.707
Mean	6.5	0.486	0.559	8.0	0.644	0.695
S.D.	2.9	0.230	0.230	4.4	0.243	0.171

Note: *MNA* – mean number of alleles, *Ho* – observed heterozygosity, *He* – expected heterozygosity, *S.D.* – standard deviation.

Genetic diversity was analyzed with microsatellites markers in 11 loci of 294 brown hares from genus *Lepus* from 18 different regions from North and South Africa, North and South Israel, Anatolia and Europe (Ben Slimen et al. 2008). Three populations from Bulgaria were included in this study – Yambol, Vratsa and Pleven, and the samples were the same as in the study of Suchentrunk et al. (2000). The variance of observed heterozygosity for all populations was between 0.45 and 0.63 as for Bulgarian ones the values are: Yambol – 0.56, Vratsa – 0.54 and Pleven – 0.48 (Table 8). Expected heterozygosity for the three Bulgarian populations was one of the highest of all. The mean number of alleles per locus was 14.7, as the variation was between 6 and 34. Yambol was one of 7 populations which were in Hardy-Weinberg equilibrium. Genetic diversity decreased from South Africa, North Africa, Israel, Anatolia, the Balkans, central Europe to NW Europe (Ben Slimen et al. 2008).

Table 8. Genetic diversity found by Ben Slimen et al. (2008).

Genetic indices	Yambol	Vratsa	Pleven	All 18 regions
Ho	0.56	0.54	0.48	0.45–0.63
He	0.60	0.68	0.59	0.48–0.71
A	4.64	7.09	5.36	3.90–7.73

Note: *Ho* – observed heterozygosity, *He* – expected heterozygosity, *A* – mean number of alleles per locus.

In total 710 individuals belonging to 6 hare species which are occurring Europe and North Africa were studied. Concerning *L. europaeus* 323 were from Italy, Hungary, Romania, Austria, Bulgaria, Greece and Uruguay. Bulgarian samples have been taken from Estonba et al. (2006) and microsatellites marker were used in 13 loci. The thirteen microsatellite loci showed 97.44 % polymorphic loci and an average number of alleles of 6.8 for each locus (Mengoni 2011). The mean number of alleles for *L. europaeus* for all loci was 13, expected heterozygosity – 0.69 and the observed one – 0.57.

Conclusions

The Bulgarian brown hare samples were so far subject to three different studies of genetic diversity, using allozyme, RAPD and microsatellite markers. The study employing allozyme markers was the most extensive one, and the results were compared with results from Central Europe (Austria). Also, the information from this study served as a base for comparison between many other following researches from South-East Europe (Greece and Serbia) and Asia Minor (Turkey – Anatolia). The other two studies (comparison of Bulgarian populations with Iberian and Greek ones) were done using microsatellite and RAPD markers and they confirmed the earlier results, obtained with allozyme markers. Genetic diversity decreased from South Africa to North West Europe. For the Middle East, the Balkans and Central Europe it had its highest values in Anatolian populations, followed by Greek, Bulgarian, Serbian and finally, the Austrian ones. The genetic similarities among the regions follow the same order. Hypothetically, it was d due to continuous hare presence in Anatolia, Greece and probably other regions on the Balkans during the Pleistocene, when the unfavorable climate conditions did not provide habitats good enough in most of the northern territories. The hare populations of Central Europe could not receive gene flow from Southeastern Europe, including Bulgaria, which could not receive genes from Asia Minor or the North East side of Black Sea. The results also confirmed that the separate populations in Bulgaria are very similar to each other, forming a relatively homogeneous gene pool, which is poorly differentiated from other regions in Europe and Asia Minor. There was a fragmentation of a small geographical scale, from different regionally limited alleles, appearing with a low frequency and decreased, but definitely gene flow exists among longer geographical distances. The hypothesis about potential gene flow from North Greece towards the region of Sandanski (Bulgaria) was denied. There was no negative impact on the genetic diversity caused by decrease of population size, occurred for a long periods of time, as it was the case in Greece.

Acknowledgments

We thank Dr. Franz Suchentrunk (Research Institute of Wildlife Ecology, University of Veterinary Medicine Vienna, Austria) for helpful comments on the manuscript and for providing us some of the published results included in the review.

References

Ben Slimen H., Suchentrunk F., Stamatis C., Mamuris Z., Sert H., Alves P.C., Kryger U., Shahin A. B., Ben Ammar Elgaaied A. 2008. Population genetics of cape and brown hares (*Lepus capensis* and *L. europaeus*): a test of Petter's hypothesis of conspecificity. Biochemical Systematics and Ecology 36: 22–39.

Cheylan G. 1991. Patterns of Pleistocene turnover, current distribution and speciation among Mediterranean mammals. In: R.H. Groves, F. Di Castri. Biogeography of Mediterranean Invasions. Cambridge University Press, Cambridge: 227–262.

Corbet G.B. 1986. Relationships and origins of the European lagomorphs. Mammal Review 16: 105–110.

Djan M., Vapa L., Obreht D., Vapa M., Selmic V. 2004. On gene pool divergence of the brown hare (*Lepus europaeus* Pallas) in Vojvodina. Natural Sciences, Matica Srpska, Novi Sad 107: 13–20.

Estonba A., Solis A., Iriondo M., Sanz M., Maria J., Perez S., Markov G., Palacios F. 2006. The genetic distinctiveness of the three Iberian hare species *Lepus europaeus*, *L granatensis*, and *L. castroviejoi*. Mammalian Biology 71(1): 52–59.

Hartl G.B., Markowski J., Kovacs G., Grillitsch M., Willing R. 1990. Biochemical variation and differentiation in the brown hare (*Lepus europaeus*) of Central Europe. Zeitschrift für Säugetierk 55: 186–193.

Hartl G.B., Markowski J., Swiatecki A., Janiszewski T., Willing R. 1992 Genetic diversity in the Polish brown hare *Lepus europaeus* Pallas, 1778: implications for conservation and management. Acta Theriologica 37: 15–25.

Hartl G.B., Suchentrunk F., Nadlinger K., Willing R. 1993. An integrative analysis of genetic differentiation in the brown hare *Lepus europaeus* based on morphology, allozymes, and mitochondrial DNA. Acta Theriologica 38(2): 33–57.

Hartl G.B., Willing R., Nadlinger K. 1994. Allozymes in mammalian population genetics and systematics: Indicative function of a marker system reconsidered. In: Schierwater B., Streit B., Wagner G. P., DeSalle R. (eds). Molecular Ecology and Evolution: Approaches and Applications, Birkhauser Verlag, Basel, Switzerland: 299–310.

Mamuris Z., Sfougaris A.I., Stamatis C. 2001. Genetic structure of Greek brown hare (*Lepus europaeus*) populations as revealed by mtDNA PCR-RFLP analysis: implications for conserving genetic diversity. Biological Conservation 101: 187–196.

Mamuris Z., Sfougaris A.I., Stamatis C., Suchentrunk F. 2002. Genetic structure of Greek brown hare (*Lepus europaeus*) populations based on the Random Amplified Polymorphic

DNA (RAPD) method. Biochemical Genetics 40: 323–338.

Mengoni Ch. 2011. Phylogeny and genetic diversity of Italian species of hares (genus *Lepus*). PhD thesis. Bologna University, 47 p.

Sert H., Suchentrunk F., Erdogan A. 2005. Genetic diversity within Anatolian brown hares (*Lepus europaeus* Pallas, 1778) and differentiation among Anatolian and European populations. Mammalian Biology 70: 171–86.

Sfougaris A., Papageorgiou N., Giannakopoulos A., Goumas H., Papaevangelou E., Anni A. 1999. Distribution, populations and habitat of the European hare (*Lepus europaeus* Pallas, 1778) in central and western Greece. In: Thomaides C., Kypridimos N. (eds). Proceedings of 24th Congress of International Union of Game Biology: Agriculture–Forestry–Game: Integrating Wildlife in Land Management, Sept. 20–24. 1999. Thessaloniki, Greece: 423–430.

Smith R.K., Jennings N.V., Harris S. 2005. A quantitative analysis of the abundance and demography of European hares *Lepus europaeus* in relation to habitat type, intensity of agriculture and climate. Mammal Review 35: 1–24.

Smith A.T., Johnston C.H. 2008. *Lepus europaeus*. The IUCN Red List of Threatened Species. Version 2014.2. Available: www.iucnredlist.org (Accessed on 05 September 2014).

Strzała T., Kosowska B., Brzezinska K., Moska M. 2006. Charakterystyka genetyczna zajęcy (*Lepus* sp.) w Eurazji [Genetic characteristics of hares (*Lepus* sp.) in Eurasia.] Acta Scientiarum Polonorum, Medicina Veterinaria 5(1): 25–31. (In Polish with English summary).

Suchentrunk F., Polster K., Giacometti M., Ratti P.C.G., Thulin C., Ruhle C., Vasilev A.G., Slotta-Bachmayr L. 1999. Spatial partitioning of allozyme variability in European mountain hares (*Lepus timidus*): Gene pool divergence across a disjunct distributional range? Zeitschrift für Säugetierkunde 64: 1–11.

Suchentrunk F., Mihailov Ch., Markov G., Haiden A. 2000. Population genetic of Bulgarian brown hare *Lepus europaeus*: Allozymic diversity at zoogeographical crossroads. Acta Theriologica 45(1): 1–12.

Suchentrunk F., Jaschke C., Haiden A. 2001. Little allozyme and mtDNA variability in brown hares (*Lepus europaeus*) from New Zealand and Britain – A legacy of bottlenecks? Mammalian Biology 66: 48–59.

Suchentrunk F., Mamuris Z., Sfougaris A.I., Stamatis C. 2003: Biochemical genetic variability in brown hares (*Lepus europaeus*) from Greece. Biochemical Genetics 41: 127–140.

Tatatruch F., Onderscheka K., Botev N., Ninov N., Mihailov Ch. 1996. Die Schwermetallbelastung der freilebenden Wildtiere in Bulgarien. XII IUGB Congress „The Game and the Man“, Sofia, Bulgaria, Sept. 1995: 432–438.

Vapa L., Obreht D., Vapa M., Selmic V. 2002. Genetic variability in brown hare (*Lepus europaeus*) populations in Yugoslavia. European Journal of Wildlife Research 48: 261–266.

Vapa L., Djan M., Obreht D., Hammer S., Suchentrunk F. 2007. Allozyme variability of brown hares (*Lepus europaeus*) from the Vojvodina (Serbia), compared to central and southeastern European populations. Acta Zoologica 53(1): 75–87.

Vaughan N., Lucas E.A., Harris S., White P.C.L. 2003. Habitat associations of European hares *Lepus europaeus* in England and Wales: Implications for farmland management. Journal of Applied Ecology 10(1): 163–175.

Wilson D.E., Reeder D.M. 2005. Mammal Species of the World. A Taxonomic and Geographic Reference (3rd ed), Johns Hopkins University Press, 2142 p.

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 135–140

SOIL TEXTURE CHANGES IN GRAY FOREST SOILS (GRAY LUVISOLS) INFLUENCED BY FOREST FIRES IN DECIDUOUS FORESTS

Simeon Bogdanov

University of Forestry, 10 Kliment Ohridski Bld., 1756 Sofia, Bulgaria. E-mail: sbogdanovs@abv.bg

Received: 16 April 2014 Accepted: 10 June 2014

Abstract

The paper presents results from investigation on soil texture changes caused by forest fires in the Northwestern region of Bulgaria. Gray Forest soils (Gray Luvisols, FAO 1990) influenced by strong surface fire and weak surface fire have been investigated. The sample plots are set up in burned and unburned control areas. They are correspondingly situated in the Lower forest vegetation zone (0–600 m a.s.l.) of the Moesian forest vegetation area. Soil samples have been taken three times for five years in order to investigate the dynamics of the changes. The fractions of sand, silt and clay have been determined by pipette method. A relation was established between soil texture changes and intensity of fires.

Key words: deciduous forests, forest fire, forest soils, soil texture, *Quercus petraea*.

Introduction

The existence and natural ecologic functioning of forest ecosystems depend on natural and anthropogenic fires. A global tendency of increasing the number, intensity and duration of forest fires has been observed in the recent decades. They influence on the growth and development of the forest for long-term period and affect soil-biological and biochemical processes (Kimmins 1996, Tashev and Malinova 1998, Prokushkin et al. 2000, Tsvetkov et al. 2001).

Forest fires should not be considered separately from the context for global climatic changes. The fire is an environmental factor whose importance has been increased by human activity. Its suppression is followed by extensive restoration activities in the affected areas. Young stands that are located in the Lower forest vegetation zone have been influenced more often (Alexandrov et al. 2002).

Soil properties are strongly dependent on the soil organic matter created by the vegetation. Both components are removed to a variable degree after fire impact. Consequently, fire has the potential to induce major changes in soils. The degree to which soil properties are altered by fire depends on the fire intensity and the amount of burned organic matter (DeBano et al. 1998, Erickson and White 2008, Úbeda et al. 2009). These in turn are influenced by the amount and the distribution of forest combustible materials, their moisture content and the weather conditions (Kimmins 1996).

Soil texture is a basic soil property and an important indicator of soil classification. It influences soil productivity and forest development. For this reason, it is necessary to clarify the forest fire impact on the soil texture as well as the degree of the changes depending on the intensity of fire.

Generally, sandy soils contain less moisture and nutrient elements in comparison with loam and clay soils. Thus, coarse sandy soils as a rule favor forest stands composed of species with relatively low requirement for moisture and nutrients, whereas loam and clay soils often are favorable for trees with high moisture and nutrient requirements (Pritchett 1979).

Soil texture is defined by proportions of sand (63 μm – 2 mm), silt (2–63 μm) and clay (< 2 μm). The sand fraction is composed of rock fragments and primary minerals, especially quartz. Therefore, it is chemically completely inactive. Sand content directly influences on soil porosity and hydraulic properties. The silt fraction is dominated by primary minerals and has, therefore, a low chemical activity. The silt particles slow down the movement of water and air because of filling soil cavities among sand grains. The soil physical and chemical activity depends mainly on clay fraction (Petrova and Bogdanov 2012).

According to Velizarova et al. (2001), the surface fire impact on soil texture has been expressed by a disintegration of coarse fractions and an increase of fine fractions. Burned clay soils with a sand content less than 5 % and clay content more than 55 % have been investigated by Ketterings et al. (2000). They found a sharp increase in the amount of sand and a decrease in silt and clay. According to Ulery and Graham (1993) the fire causes decomposition of sand grains and leads to increase of silt fraction. Although the low chemical activity of silt fraction, when its share was dominant, it had ability to determine the deep alteration in chemical properties due to a sharp change in its content (Bogdanov 2012).

The paper aimed at establishing soil texture changes caused by forest fires in deciduous forests and the influence of fire intensity.

Material and Methods

Objects of this study were Gray Forest soils (Gray Luvisols, FAO 1990) influenced by fires in the regions of Rabisha and Dolni Lom. They are located in the Northwestern region of Bulgaria.

The sample and control plots have been set up in burned and unburned areas in order to investigate the soil texture changes. They are located in the Lower forest vegetation zone (0–600 m a.s.l.) of the Moesian forest vegetation area.

The soils in Rabisha region (43°42´ N, 22°38´ E) were influenced by weak surface fire under thirty-year-old plantation of durmast oak (*Quercus petraea* Liebl.) in July 2002. The sample and control plots were at 400 m above sea level, at southwest exposition with slope 10 °.

The soils in Dolni Lom region (43°30´ N, 22°46´ E) were influenced by strong surface fire under sixty-year-old plantation of durmast oak (*Quercus petraea*) in July 2007. The altitude was 450 m, at north-northwest exposition, slope 5 °.

The forest fires were classified on the basis of visible impact signs. According to fire intensity they were determined as follows:

– strong surface fire – the stems were burned to a height of more than 0.5–1 m and the fire impact caused a destruction of the stand;

– weak surface fire – the stems were burned to a height of 0.5–1 m and the fire did not cause a destruction of the stand.

Soil samples have been taken one, three and five years after the fires in order to investigate the dynamics of soil texture changes caused by fires. Having in mind that the most significant changes of soil properties occur at 10–15 cm depth (Raison et al. 1985, Barnes et al. 1998, Neary et al. 2008, Bogdanov 2010), the samples were taken from the layer 0–15 cm.

The soil texture was determined by pipette method (ISO 11277). It was founded on separation of the mineral part of the soil into various size fractions and determination of the proportion of these fractions. A special attention was paid to the pre-treatment of the samples aimed at complete dispersion of primary particles. Therefore, cementing materials such as organic matter, salts, iron oxides and carbonates were removed.

The fractions of sand (63 μm – 2 mm), silt (2–63 μm) and clay (<2 μm) have been determined. After shaking with a dispersing agent, sand was separated from silt and clay with a 63 μm sieve. The silt and clay fractions were determined by sedimentation.

A textural class of the soils was determined according to U. S. Texture Triangle.

Results and Discussion

The results from investigated Gray Forest soils (Gray Luvisols, FAO 1990) located in Rabisha region are presented in Figure 1. In unburned control area the share of sand fraction was 49 %, the silt is 34 %

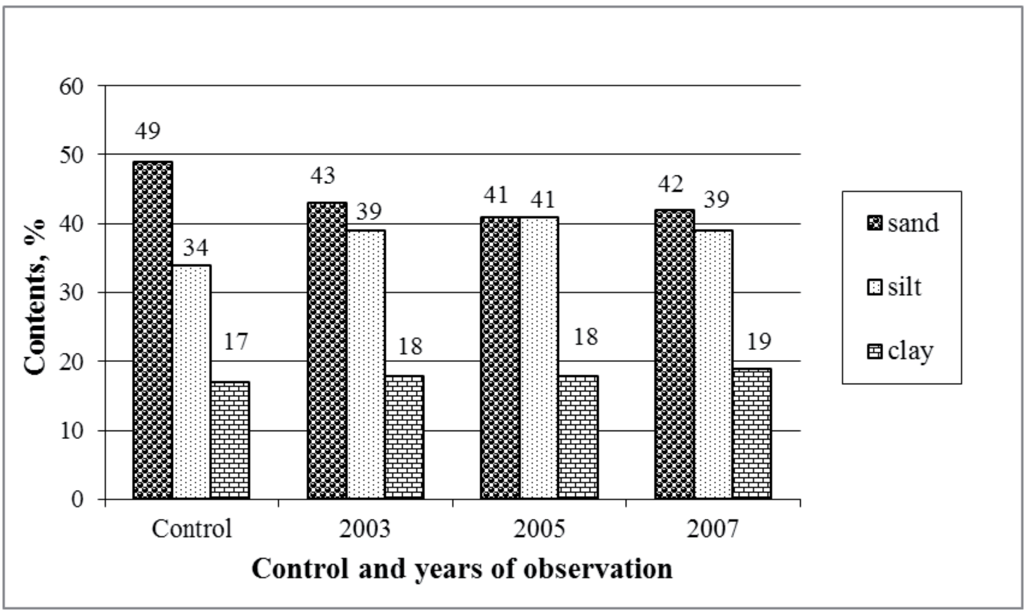

Fig. 1. Soil texture of Gray Forest soils influenced by weak surface fire.

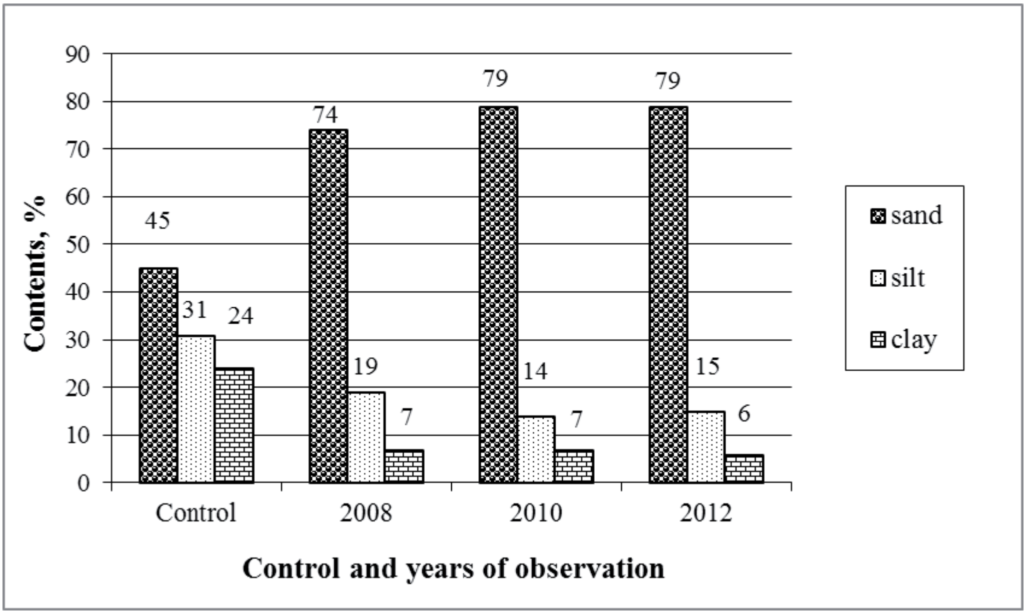

Fig. 2. Soil texture of Gray Forest soils influenced by strong surface fire.

and the fraction of clay was 17 %. The textural class was a Loam.

The data obtained from soil texture analyses showed that the weak surface fire affects mainly the proportion between fractions of sand and silt. The alteration of clay fraction was relatively low. Similar changes were found under burned coniferous stands (Bogdanov 2012).

A decrease in the amount of sand and an increase in silt one year after the fire was established (Figure 1). The share of sand decreased from 49 % to 43 % and the silt increased from 34 % to 39 %. The content of clay was increased by 1 % compared to control plot. The textural class was a Loam and has not changed during the whole period of investigation.

Three years after the fire, in Gray Forest soils influenced by weak surface fire a decrease in sand by 2 % and corresponding increase in silt was recorded. The share of clay did not change.

It was found that soil texture changes in the Rabisha region were kept five years after the fire. The differences in contents of sand and silt between burned and unburned soil were 7 % and 5 %, respectively. The share of clay continued to be 2 % more than in unburned control area.

The results from investigated Gray Forest soils (Gray Luvisols, FAO 1990) located in Dolni Lom region are presented in Figure 2. In unburned control area the share of sand fraction was 45 %, the silt is 31 % and the fraction of clay was 24 %. The textural class was a Clay loam.

In contrast to data obtained from analyzed soils influenced by weak surface fire in Rabisha region, different results were established in investigated soils located in

Dolni Lom region and affected by strong surface fire.

A sharp increase in sand and corresponding decrease in silt and clay was established one year after the fire. The sand increased from 45 % to 74 %. The silt decreased from 31 % to 19 % and the clay decreased by 17 % compared to control plot (Figure 2). The soil has changed over to textural class Sandy loam. Similar results for clay soils have been reported by Ketterings et al. (2000).

The alteration was more significant in Gray Forest soils influenced by strong surface fire as compared to the changes caused by weak surface fire. This fact is indicative for the importance of the fire severity that generally determines the characteristics of fire effect. It was due to a higher volume of burned biomass and more significant changes of vegetation. In the case of strong surface fire the stand has been destroyed and replaced by herbaceous and bush species.

It was found that the share of clay was changed more in Gray Forest soils located in Dolni Lom region. That is in conformity with a higher content of this fraction and shows the importance of the soil textural class for soil properties changes caused by forest fires.

Three years after the strong surface fire the sand increased and the silt decreased by 5 %. The amount of clay did not alter. The burned soil has changed over to textural class Loamy sand.

The differences between burned and unburned areas were kept five years after the fire. The share of sand in burned soil continued to be 79 %. The silt slightly increased and the clay decreased by 1 % compared to unburned soil. The textural class was not altered.

Conclusions

The forest fire causes different changes in investigated soils. The alterations depend on the soil textural class and fire intensity, which is defined by volume of burned biomass and effects on the vegetation. The larger volume of burned biomass and the deep changes of vegetation determine more significant alterations in soil texture.

The weak surface fire caused soil texture changes of burned Gray Forest soils (Gray Luvisols, FAO 1990), which were expressed in change of proportion mainly between fractions of sand and silt. The share of sand decreased and the silt increased compared to control plot. The clay fraction was altered to relatively less extent.

The strong surface fire caused contrary and more significant soil texture changes. The amount of sand increased compared to unburned area. Both silt and clay decreased. The strong surface fire affected to a higher extent the clay content of Gray Forest soils (Gray Luvisols, FAO 1990), which contain a larger proportion of this fraction.

A sharp change of clay fraction, which is characterized by a high chemical activity, might cause significant changes of soil chemical properties.

The results confirm the generally accepted opinion that the fire might cause long lasting changes in soil properties and forest development. Destroying the stands and soil organic matter, forest fires create conditions for erosion and alteration of soil texture.

References

Alexandrov A., Genov K., Stoykov H., Dakov A. 2002. Changes in the biodiversity and management of forests destroyed by fire. Journal of Balkan Ecology 4: 348–358.

Barnes B.V., Zak D.R., Denton S.R., Spurr S.H. 1998. Fire and the Forest Site. Forest Ecology, 4th edition: 290–297.

Bogdanov S. 2010. Soil Characteristics Changes in Soils of Class Luvisols influenced by Forest Fires. PhD thesis. University of Forestry, Sofia. 128 p. (in Bulgarian).

Bogdanov S. 2012. Forest fire influence on soil texture in burned forests in Bulgaria. Forestry Ideas 18(2): 155–162.

DeBano L.F., Neary D.G., Ffolliott P.F. 1998. Fire's Effects On Ecosystems. John Wiley & Sons, New York, USA, 333 p.

Erickson H., White R. 2008. Soils under fire: soils research and the Joint Fire Science Program. Gen. Tech. Rep. PNW-GTR-759. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 17 p.

FAO 1990. Guidelines for Soil Description. 3th Edition. Rome.

Ketterings Q.M., Bigham J.M., Laperche V. 2000. Changes in Soil Mineralogy and Texture Caused by Slash-and-Burn Fires in Sumatra, Indonesia. Soil Science Society of America Journal 64: 1108–1117.

Kimmins J.P. 1996. A Pervasive and Powerful Enviromental Factor. Forest Ecology. 2nd edition: 296–304.

Neary D.G., Ryan K.C., DeBano L.F. eds. 2005. revised 2008. Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol. 4. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p.

Petrova R., Bogdanov S. 2012. Soil Science Guide for Laboratory analyses. ISBN: 987-954-2910176. Online Library – University of Forestry, Sofia: 81–85 (in Bulgarian).

Pritchett W.L. 1979. Properties and Management of Forest soils. N. Y. John Wiley & Sons: 106–110.

Prokushkin S., Sorokin N., Tsvetkov R. 2000. Ecological Consequences of Fires in the Larch Forests in the Northern Taiga (Krasnoyarsk region). Moscow. Lesovedenie (Forest Science) 4: 9–15 (in Russian).

Raison R.J., Khanna P.K., Woods P.V. 1985. Mechanisms of element transfer to the atmosphere during vegetation fires. Canadian Journal of Forest Research 15: 132–140.

Tashev A., Malinova L. 1998. After the forest fire. Gora 5: 7–8 (in Bulgarian).

Tsvetkov P.A., Sorokin N., Prokushkin S., Kavryanina L., Sorokina O., Tsvetkova G. 2001. Trophic conditions and forest regeneration After Fires in the Larch Forests in Evenkiya. Moscow. Forest Science 2: 16–21 (in Russian).

Úbeda X., Pereira P., Outeiro L., Martin D.A. 2009. Effects of fire temperature on the physical and chemical characteristics of the ash from two plots of cork oak (*Quercus suber*). Land Degradation & Development 20: 589–608.

Ulery A.L., Graham R.C. 1993. Forest Fire Effects on Soil Color and Texture. Soil Science Society of America Journal 57: 135–140.

Velizarova E., Yorova K., Tashev A. 2001. Investigations of some characteristics of forest soils influenced by fire in plantation of Black Pine (*Pinus nigra* Arn.). Nauka za gorata 1–2: 29–34 (in Bulgarian).

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 141–150

HONEY FORESTS AS AN EXAMPLE OF AGROFORESTRY PRACTICES IN TURKEY

Sezgin Ayan[1*], Özlem Ayan[2], Tayyibe Altunel[3], and Esra Nurten Yer[1]

[1]Department of Silviculture, Faculty of Forestry, Kastamonu University, Kuzeykent, Turkey.
*E-mail: sezginayan@gmail.com
[2]Sub-Directorate of Non-Wood Forest Products, Kastamonu Forestry Regional Directorate, Turkey.
[3]Department of Forest Economics, Faculty of Forestry, Kastamonu University, Kuzeykent, Turkey.

Received: 08 August 2014 Accepted: 30 September 2014

Abstract

Forest villagers are one of the poorest people in Turkey. Almost 7,8 million people live in forest villages. That's why agroforestry is very strategic tool for supporting this people. In recent years, General Directorate of Forestry in Turkey has given very much importance to establish "Honey Forest". For this reason, various trees and shrubs are used in different regions. The objective of this paper is to present information about convenient species for establishing "Honey Forest" in different regions and as a special honey production in the natural *Pinus brutia* forests in the Mediterranean forests of Turkey. Moreover, one fourth of all the honey produced in Turkey is directly from pines, especially from Forestry Regional Directorate of Mugla. Having about 5 million beehive and approx. 80,000–90,000 tons of honey production, Turkey is an important country for honey production. However, the 16–17 kg production for each beehive is lower than the world average (20–22 kg/beehive). As a result, all agroforestry systems in Turkey need scientific support, institutional financing and legal arrangements to stimulate the increase of production. Promotion of agroforestry in Turkey will help the country to solve various problems, such as environmental degradation, lack of food security, and deforestation.

Key words: beekeeping, diversity, forest villagers, honey plants, production of honey, silvapastoralism.

Introduction

Honeydew honey or forest honey is excreted by plant sucking insects like aphids. It is usually produced from trees but also from grasses and plants. In ancient times people believed honeydew fell from the stars and this belief was held for centuries until the French naturalist Reaumur determined in 1740 that it is produced by aphids. Forest honey is also named after particular source plant "Fir Honey", "Pine Honey", "Lime Tree Honey", "Oak Honey" etc. Forest honey has higher contents of minerals and aminoacids, as well as higher molecular weight sugars. It tends to be darker, less sweet, less acid and resists crystallization when compared to blossom honey (Anonymus 2014a).

More than 9000 years ago, in a rock shelter in the mountains of Eastern Spain, an early artist recorded the exploits of a person surrounded by bees reaching inside a cavity to steal their honey. Honey bees appear as an art also in the temples and tombs of Ancient Egypt as far back as 2400 B.C. (Anonymus 2014b).

Tualang tree (*Koompassia excelsa* (Becc.) Taub.) is Asia's rainforests tallest tree and it's best known as bee's tree. It can reach about 75–80 m and these trees draw world's largest honeybees (2.54 cm) called Asian giant bees to build their colony of hives. This giant bees source the nectar from the native flowers and plants in the deep forests to produce raw honey. The color is darker, compared to other organic raw honey in the market. The price of royal black honey is around 20 euro/kg (340 RM/gallon) (Anonymus 2014b).

Bashkiria is the world's only place where the forest has survived to this day as beekeeping industry. It is located between the Volga River and the Ural Mountains. A real forest beekeeper has a very broad knowledge and diverse skills. So, he knows if the current year is a good "beekeeping year", whether it was time to collect honey and how much. Beekeeping knowledge here goes from family to family. Wild honey is collected only once a year and in one day you can harvest 15 to 25 kg of honey. Forest honey is currently the most expensive honey in the world. In Moscow the price of this honey is between 120 and 200 euro per kilogram (Anonymus 2014c).

In several areas in Indonesia, honey is a major commodity that contributes to improving communities' economies. Honey is also a part of a communities' cultural identity. Many indigenous communities preserve their forests for sustainable honey production. Aside from being consumed directly, honey is also mixed with other foods, drinks and even soap. Honey is still processed traditionally by groups of honey hunters usually consisting of 3-4 people. In sustainable honey production hygiene and post-harvesting processes are important, because it achieves higher selling price. The price for drained honey is IDR 44,000–55,000 (2.88–3.60 euro) while the price for squeezed honey is IDR 20,000–30,000 (1.30–1.96 euro). Furthermore, drained honey can be stored up to 8 years without losing its quality, while squeezed honey only lasts for 2 years (Adnan et al. 2014).

Turkey has 21.7 million ha of forest areas. It means that the forest land covers approx. 27 % of the country's territory. However, approximately 50 % of this forest land is degraded and unproductive. So, it is accepted by FAO that forest areas of Turkey cover only 13 %. According to 9th Forestry Commission Report, 7.8 million villagers live in 20,974 villages. These villagers live inside or around the forest and their livelihood mostly depends on products obtained from forest areas. Their income level is the lowest compared to people living in urban areas. Property ownership for the villagers is also very low – around 0–2 ha per family. Low income level, insufficient property for crop production and being away from health and education services result on high migration rates (40 %) to big cities (Ministry of Development 2013).

Anatolia's geographical location, its land formation, climate types and plant species and also people have brought a natural synthesis. These conditions have generated different agroforestry systems and several plants combination.

Apiculture is the important sub-agroforestry system in the world, including Turkey (Büyükşahin 2010) and also perhaps the oldest system (Sağkaya and Kamiloğlu 1987, Şefik 1995, Yavuzşefik and Akbulut

2005, Tolunay et al. 2007). Implementation of mixed tree species in apiculture describes that it is the sub-practice of agrosilvopastoral system. In this system, various honey (nectar) producing trees and shrubs frequently visited by honeybees are planted on the boundary of the agricultural fields (Anonymous 2013a), forest lands and also natural vegetations. Depictions of humans collecting honey from wild bees date back to 15,000 years ago, efforts to domesticate them are shown in Egyptian art around 4,500 years ago (Anonymous 2013b).

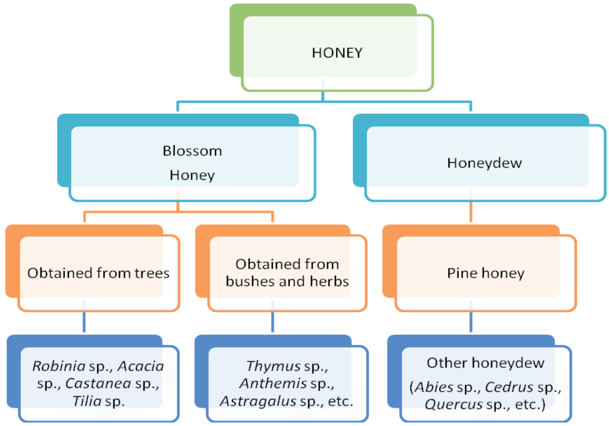

Fig. 1. Types of honey (Anonymous 2009).

Apiculture is a technical procedure and an economic activity done by most of the regions in Turkey. Apiculture makes a great contribution to provide food and income security for the people living in rural areas. It is important to have grassy and woody plants in forest vegetation in order to produce honey. Apiculture provides (Figure 1) in order to secure genetic diversity, resistant individual and presence of population, there should be an effective and natural pollination. Bees are the most important actors in pollination. 85–90 % of the pollination in nature is done by the honey bees (Belen 2010, Anonymous 2013c). It is estimated that there are 25,000 bee species in the world and approximately 2000 species in Turkey (Mere 2010, Anonymous 2013c).

One fourth of all the honey produced in Turkey is pine honey. This particular honey is solely produced by an aphid called *Marchalina helenica* (Gennadius 1883) (Syn. *Monophlebus hellenicus* – bug of Basra, Honeydew) (Figure 2) living on *Pinus brutia* Ten., *Pinus nigra* Arn., *Pinus pinea* L., *Pinus halepensis* Mill. Cochineal makes a living by tapping the tree's sap water. The bug drinks this sap water and after the digestion it gets extracted from its rear end as a sweetened secretion. This sweet substance, which the bugs secrete from October to July is highly favored by honeybee for making honey. To

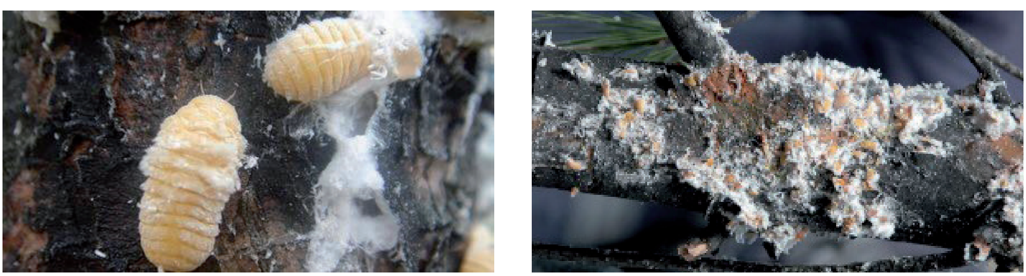

Fig. 2. Adult female of *Marchalina helenica* (left) and secration of honey (right).

produce honey, sweet leftover of the bug are collected by the bees. The most important peculiarity of pine honey is its consistency, preserved for many years. 1000 m2 forest land produces approximately 20–25 kg pine honey (Mere 2010). Major producer of pine honey is Turkey – about 92 % of the global production, followed by Greece with roughly 8 %. Germany, Austria and Spain have also very low production rates (Anonymous 2009, Belen 2010). About 25 % of all the honey produced in Turkey is pine based through forest (Anonymous 2013c). The provinces of İzmir, Aydın, Kusadasi, Dilek Peninsula, Milas, Bodrum, Mugla, Marmaris, Datca, Fethiye, Kas, Balikesir, Manisa and Canakkale in Mediterranean and Aegean regions are major pine honey areas. 80 % of all pine honey in Turkey comes from Pinus brutia in the province of Mugla. Half of the nation's all honey producers comes from this site, which coincides with 4 % of all the global honey producers (Mere 2010).

Beekeepers generally function in forest or vicinity of forests. 85 % of all honey production occurs in or near open areas inside forest land. Since the production is so involved within the forestry, it can be very well considered as part of forestry activities (Anonymous 2009, 2013c).

Since Turkey has various climatic regions and soil diversity and it is situated in the crossing of Europe-Siberian, Iran-Turan and Mediterranean plant regions, its plant diversity is very unique and one of a kind. 75 % of all honeyed plant species in the world exist in Turkey. Although in terms of the number who are engaged in beekeeping (150,000 household) and the number of beehives in the country, Turkey is among the leading countries, it lays behind many of the other producers in terms of the other bee related products (Anonymous 2009, 2013c). 10 % of all beekeepers in Turkey make their living entirely on this and 30 % makes it as a contributor to their living. The vast majority of the rest is hobby type of beekeeping (Anonymous 2013c).

In terms of the number of total beehives and the production capacity (Table 1), Turkey ranks (Figure 3) the 3rd, and the 2nd making one of the major players in this field (TUIK 2012). Although Turkey is in the top three based on the total number of beehives, honey production per hive, which is around 16–17 kg, is below the world average of 20–22 kg. However, the fact that Turkey is placed at 10, based on the global honey trade, is not suitable with its hive wealth and honey production (Anonymous 2013c).

China and Argentina are the top two honey exporters, and EU is the top importer in the world (Anonymous 2009, 2010).

Annual average commercial honey production in Turkey is about 80,000–

Table 1. Honey and wax production in Turkey (TUIK 2012).

Apiculture	2011		2012		Change, %
	Amount, t	Share, %	Amount, t	Share, %	
Honey Production	94,245	100.0	89,162	100.0	–5.4
Wax Production	4,235	100.0	4,222	100.0	–0.3
Number of Hives (Unit)	6,011,332	100.0	6,348,009	100.0	5.6
Old Type	149,020	2.5	156,777	2.5	5.2
New Type	5,862,312	97.5	6,191,232	97.5	5.6

90,000 tons (TUIK 2012), the approximate market value of this production is $ 300,000,000. One fourth of this production comes directly from forests in the form of pine based honey. Forest trees like *Castanea* sp., *Robinia* sp., *Tilia* sp., *Rhododendron* sp., *Pyrus* sp., forest shrubs, small tree-like plants and flowers constitute about 85 % of this production, and such trees and adjoining plant life are predominantly found in state's forests (Mere 2010, Anonymous 2013c).

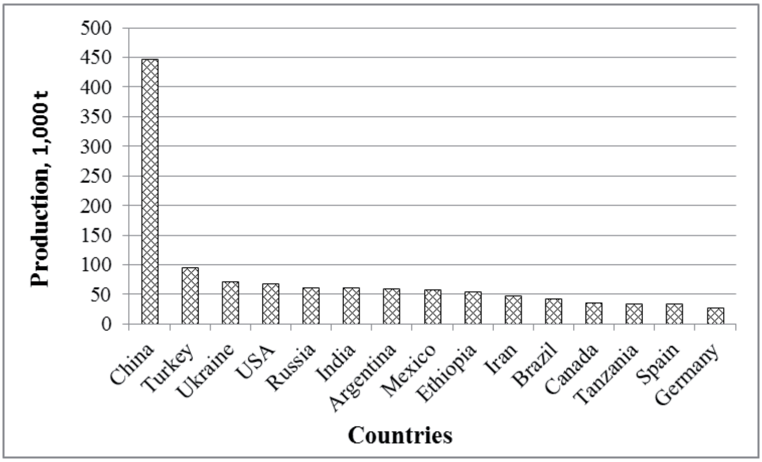

Fig. 3. Honey production and total beehive number according to some producer countries (Anonymous 2013d).

Traditional agricultural practices and widespread use of pesticides adversely affected the nectar sources, which honey bees prefer. In this case, instead of stationary honey production, bee keepers have started embracing a nomadic life style. Recently, biological combat against forest damaging insects keep the forested areas free of chemical agents so honey produced off forest areas is rather healthier regarding food safety. This case validated the thinking that forests can be very well managed considering honey production. In this context, General Directorate of Forestry in Turkey established 205 honey forests in about 20,000 ha forest land to support beekeeping and increase honey production by each beehive. Establishing honey forests are an ongoing and important project for the General Directorate of Forestry (Anonymous 2013e). In the scope of this study, basic rehabilitation and improvement strategies are pointed out to contribute to the "Action Plan and Targets" set by General Directorate of Forestry.

Methodology of the Study

In terms of beekeeping, honey plants are grouped in two categories: 1) Secretion producing; 2) Nectar producing. This study tabulates only some features of the "woody taxa" contributing to honey production via secretion and nectar (flowering as to season, secretion/nectar production potential, honey production potential, species' distribution and habitat, etc.). General rehabilitation strategies are suggested in order to increase the honey production.

Results

Table 2 includes the list of exotic species, small tree and shrubs in Turkey's natural forest vegetation, which contribute to honey

Table 2. Production potential of pollen, excretion and nectar in some characteristics of woody species in Turkey (Webster and Hill 1991; Turna 1992; Belen 2010; Anonymous 2013c, 2013f; TUBIVES 2013).

Latin name	Flowering period	Production potential of Pollen	Nectar	Honey	Altitude / Turkey distribution	General distribution
			A. Nectar, secretion, pollen producing plants in late autumn and winter seasons			
Amygdalus communis L.	January–March	Minor	Minor	1–2	150–1800 m /Anatolia	NW. and Central Asia
Cornus mas L.	February–March	Dominant	Dominant	-	20–1500 m /N. and S. Anatolia	Central and SE. Europe, Crimea, South Russia, Caucasia, N. and NW. Iran, Lebanon
Eucalyptus camaldulensis Dehnh.	November–May	Dominant	Dominant	3	Adana, Antalya, Hatay, İçel, İstanbul, İzmir	Australia, S. Europe
Arbutus unedo L.	March–May	Secondary	Dominant	2–3	0–300 m /Antalya, Balıkesir, Bursa, Çanakkale, İçel, İstanbul, İzmir, Kocaeli, Mugla, Sakarya, Samsun, Sinop, Zonguldak	Atlantic Europe (N. and W. Ireland), Mediterranean Basin, Cyprus, Lebanon, NW. Africa
			B. Nectar, secretion, pollen producing plants in spring season			
Aesculus hipocastanatum L.	April–May	Minor	Trace amounts	-	Turkey	Native of the Balkan peninsula; other species in the family are found in S. and E. Asia and the Americas
Cistus spp.	May–June	Dominant	-	-	0–1200 m /Turkey	Crimea, Georgia, Caucasian, Europe, Cyprus, Mediterranean Basin, N. Iran
Cotoneaster horizontalis Decne	April–July	Secondary	Secondary	-	1250–2300 m /Turkey	Native of W. China
Fagus orientalis Lipsky	April–May	Trace amounts	-	-	30–2000 m /N. Turkey, W. and S. Anatolia	E. Balkan peninsula (Bulgaria, Romania, Greece), Crimea, Caucasian, N. Iran
Juglans regia L.	May	Minor	-	-	0–1550 m /Turkey	Balkans, Lebanon, Caucasian, N. Iraq, Iran, Afghanistan, Central Asia, China
Morus alba L.	May	Trace amounts	-	-	Turkey	China and the Far East
Laurus nobilis L.	March–May	Secondary	Trace amounts	3–4	0–1200 m /Antalya, Aydın, Balıkesir, Bursa, Çanakkale, İçel, İstanbul, İzmir, Kastamonu, Kahramanmaraş, Muğla, Rize, Samsun, Sinop, Trabzon, Zonguldak	SE. Europe, NW. Africa, Syria, Crimea, Mediterranean region
Acer campestre L.	April-May	Secondary	Minor	3–4	0–1200 m /Ankara, Artvin, Balıkesir, Bolu, Bursa, Çanakkale, Giresun, İstanbul, Samsun, Sinop, Tokat, Trabzon, Yozgat	Europe, Caucasia, N. Iran, NW. Africa
Acer negundo L.	March–April	Secondary	Minor	3–4	As ornamental plants /İstanbul, Samsun	N. America
Acer pseudoplatanus L.	March–May	Secondary	Minor	3–4	0–1200 m /Amasya, Antalya, Artvin, Balıkesir, Bitlis, Bolu, Bursa, Denizli, Kars, Kayseri, Kırklareli, Kütahya, Kahramanmaraş, Trabzon	Europe, E. and W. Caucasia
Salix spp.	February–May	Dominant	Dominant	4	0–2000 m /Turkey	NW. Africa, Europe, Central Asia, Siberia
Acacia karroo Hayne	May–June	Minor	Secondary	4–5	0–500 m /İçel	S. Africa, Mediterranean region
Robinia pseudoacacia L.	April–June	Trace amounts	Dominant	6	0–2500 m /Artvin, İstanbul, Sakarya	North America
Pyrus elaeagnifolia Pall.	April–May	Secondary	Dominant	2	0–1700 m /Amasya, Ankara, Antalya, Bolu, Eskişehir, Gümüşhane, İçel, İstanbul, Kars, Kastamonu, Kayseri, Konya, Kütahya, Kahramanmaraş, Muş, Niğde, Sinop, Van	Crimea
Malus sylvestris Mill.	March–April	Secondary	Secondary	-	150–2000 m / Northeast Anatolia	Europe
Pyracantha coccinea Roemer	April–June	Secondary	Trace amounts	-	30–1800 m /N. Turkey, Central and S. Anatolia	S. Europe, Crimea, Caucasian, NW. Iran
Rosa canina L.	April–August	Minor	Trace amounts	-	30–1700 m /Turkey	Temperate Europe, NW. Africa
Cercis siliquastrum L.	April–May	Trace amounts	Trace amounts	3	0–1370 m /Adana, Amasya, Antalya, Balıkesir, Bursa, Çanakkale, İstanbul, Kocaeli, Mardin, Muğla, Şanlıurfa	Central Europe
Tamarix spp.	April–August	Minor	Minor	3–4	0–1300 m /Turkey	Asia, Africa, Greece, Aegean islands, Palestine, Turkestan, Russia, Mediterranean region
Pistacia lentiscus L.	April–May	Secondary	-	3–4	0–200 m /N., W., Central and S. Anotolia	Mediterranean Basin
Pistacia terebinthus L.	March–May (June)	Secondary	-	3–4	0 m /N. and W. Anatolia	NW. Africa, S. Europe
Tilia spp.	June–July	Secondary	Dominant	6	0–1500 m /Artvin, Bolu, Çanakkale, Giresun, Gümüşhane, İzmir, Kars, Kastamonu, Samsun, Zonguldak, W. Anatolia, N. Anatolia	Europe, Balkans, Crimea, Caucasian, N. Iran
Elaeagnus angustifolia L.	April–June	Trace amounts	Minor	4	0–3000 m /Turkey	Caucasian, Syria, Iran, Afghanistan, Pakistan
Arbutus andrachne L.	March–May	Secondary	Dominant	2–3	0–800 m /Amasya, Antalya, Artvin, Aydın, Bursa, İzmir, Çanakkale, İçel, Muğla, Sinop, Trabzon, Zonguldak	Mediterranean region, Crimea and E. Black Sea coast, Cyprus Syria, Lebanon
Crataegus monogyna Jacq.	April–June	Minor	Secondary	-	0–1800 m /Adana, Adıyaman, Amasya, Ankara, Antalya, Aydın, Bitlis, Bursa, Erzincan, İçel, İstanbul, İzmir, Konya, Kütahya, Mardin, Muğla, Samsun, Tekirdağ, Şanlıurfa, Karaman	Europe, Cyprus, Syria, N. Iraq
Crataegus orientalis Pallas ex Bieb.	May–July	Minor	Secondary	-	750–2240 m /Anatolia (except W. and SE.)	S. Europe, Crimea, Caucasian
Crataegus microphylla C. Koch.	April–June	Minor	Secondary	-	20–450 m /N. and Central Anatolia	Crimea, Georgia, Caucasian, N. Iran

Laurocerasus officinalis L.	April–June	Secondary	Trace amounts	-	20–2000 m /Balıkesir, Bolu, Hatay, İstanabul, Kastamonu, Ordu, Rize, Samsun, Trabzon, Zonguldak	Bulgaria, Serbia, Croatia, Bosnia, Slovenia, Macedonia, Montenegro, Kosovo Caucasian, N. Iran
Prunus spinosa L. subsp. *dasyphylla* (Schur) Domin	March–April	Secondary	Minor	-	0–1700 m /Adana, Amasya, Ankara, Balıkesir, Çanakkale, Edirne, Kars, Kocaeli, Kütahya, Manisa, Sinop, Sivas, Zonguldak	Europe, N.W. Africa, Caucasian, NW. Iran
Cupresus sempervirens L.	May–June	Trace amounts	-	-	900–1200 m /Antalya, İçel	E. Mediterranean, N. Iran
Erica arborea L.	March–July	Dominant	Dominant	-	0–900 m /Balıkesir, İstanbul, İzmir, Muğla, Sinop, Trabzon	Tibet, E. Africa and Yemen
Fraxinus excelsior L.	March–April	Trace amounts	Trace amounts	-	900–2100 m /Bolu, Giresun, Hatay, Kars, Kastamonu, Samsun, Sinop, Sakarya	N. and S. Europe, Caucasian
Ligustrum vulgare L.	May–June	Minor	Trace amounts	-	0–1500 m /Afyon, Ankara, Artvin, Bilecik, Çorum, Edirne, İstanbul, Kastamonu, Ordu, Rize, Tekirdağ, Trabzon, Zonguldak	Morocco, W., S. and C. from Europe to the Caucasus and N. Iran
Phillyrea latifolia L.	March–May	Minor	-	-	10–1350 m /Aydın, Çanakkale, Balıkesir, Isparta, İçel, İstanbul,Muğla, Sakarya, Sinop, Tekirdağ, Tokat, Trabzon, Zonguldak	Mediterranean Basin
C. Nectar, secretion, pollen producing plants in summer season						
Castanea sativa Mill.	June–July	Dominant	Dominant	2–3	30–1500 m /Artvin, Balıkesir, Bursa, İstanbul, İzmir, Kastamonu, Kütahya, Ordu, Sinop, Tekirdağ, Trabzon, Van	Europe, Caucasian
Crataegus tanecetifolia (Lam.) Pers.	June	Minor	Secondary	-	1800 m /Ankara, Bolu, Erzincan, Eskişehir, Kastamonu, Malatya, Samsun, Sivas	Turkey
Diospyros lotus L.	May–June	Dominant	Secondary	-	50–1100 m /Artvin, Bursa, Erzincan, Erzurum, Giresun, Kastamonu, Kahramanmaraş, Rize, Samsun, Trabzon, Zonguldak	Caucasian, China, Japan
Diospyros kaki L. Fil.	June, September	Dominant	Dominant	-	Antalya, Hatay, İçel, İstanbul, Trabzon	China, Japan
Sophora japonica L.	July–August	-	-	-	Eastern Anatolia	SW. and E. Asia
Vaccinium spp.	May–July (August)	Minor	Secondary	-	0–1830 m /North of Turkey	SE. Bulgaria, Caucasians, Georgia, N. Iran
Paliurus spina-chritii Mill.	May–July	Minor	Dominant	4–5	0–1400 m /Turkey	S. Europe, Crimea, Caucasian, and Syria, N. and SW. Iran, N. Iraq
Rhododendron ponticum L. subsp. *ponticum* L.	March (May)–June (August)	Minor	Dominant	3–4	0–2100 m /N. Turkey	E. Balkans, Caucasian, Georgia, Lebanon
Quercus robur L.	August–September	Dominant	-	-	100–1800 m /Amasya, Bingöl, Bitlis, Bursa, Erzincan, Hakkâri, İçel, İstanbul, Konya, Muş, Niğde, Sivas, Tekirdağ, Tunceli, Van	Europe, Caucasian
D. Nectar, secretion, pollen producing plants in autumn season						
Pinus brutia Ten.	June (excretion period in September–October	-	-	6	0–1200 m /Adana, Antalya, Aydın, Bilecik, Kütahya, Malatya, Muğla, Sinop, Zonguldak	S. Italy, S. Aegean, Crimea, Cyprus, N. Iraq, W. Syria, Caucasian
Ceratonia siliqua L.	September–November	Secondary	Dominant	4–5	0–300 m /Antalya, İçel, İstanbul, Muğla	S. Europe, Cyprus, Syria
Calluna vulgaris L. Hull	August–October	Minor	Dominant	3–4	150–1000 m /NW. Turkey, NE. Anatolia	Europe, N. Morocco, Açores, West Asia, North America
Erica manipuliflora Salisb.	July, October	Dominant	Secondary	3–4	0–1530 m /W. Turkey, S. Anatolia	Mediterranean, from Italy to the east and Lebanon, Latakia
Eriobotrya japonica (Thunb.) Lindl.	October–January (March)	Trace amounts	Dominant	-	0 m /W. and S. Anatolia	China, Japan

production via secretion or nectar. Besides, within the context of General Directorate of Forestry's 2013–2017 Honey Action Plan, 7 million of the lowest income generating portion of the overall population, forest villagers, are directly or indirectly supported considering the following:

- Within the afforestation done under Burned Forest Rehabilitation and Establishment of Fire Resistant Forest Projects, honey production oriented trees and shrubs are prioritized.
- Unless an imperativeness is on, species which are important in terms of biodiversity and beekeeping like *Castanea* sp., *Tilia* sp., *Rhododendron* sp. will be protected while wood production.
- While producing non-wood forest products, flowering and blooming times (when honey and pollen productivity are at the maximum level) must be paid attention and no harm should be done to the following year's flower buds.
- During afforestation, rehabilitation, erosion control, range rehabilitation and forest maintenance, available flora/vegetation elements structure should be protected as is and in the same context and convenient vegetation for beekeeping must be established.

● During afforestation, rehabilitation, artificial regeneration, road side planting, service roads and fire suppression roads by taking the natural growth conditions into account, it is aimed to mix *Acacia dealbata* Link, *Acer* sp., *Tilia* sp., *Castanea* sp., *Rhododendron* sp., *Eucalyptus* sp., *Ceratonia siliqua* L., *Casuarina equisetifolia* L., *Robinia pseudoacacia* L., *Catalpa* sp., *Sophora* sp., *Thymus* sp., *Arbutus andrachne* L., *A. unedo* L., *Cornus* sp., *Pyrus* sp., *Salix* sp., *Myrtus communis* L., *Crataegus* sp., *Cotoneaster* sp., *Vitex agnus-castus* L., *Ziziphus jujuba* Mill.

● In national parks, natural protection areas, special environment conservation areas and other protected areas, within afforestation, rehabilitation, forest management and silvicultural planning stages, and production stages, and production/logging phase, demands coming from honey producers and sectoral representatives will be considered depending on forests and planning principles (Anonymous 2008).

● Starting in 1997, General Directorate of Forestry's "Multipurpose Functional Planning in Forests", "Honey Production from Forests" was included in a plan. Firstly, some parts of *Pinus brutia* forests within the Mugla Regional Directorate of Forestry was left (13,204.5 ha) for pine honey production.

● It is decided that no payment will be required for the beehives placed in state forests with the commitment of not harming the forest (Anonymous 2009, 2010, 2013c; Kılıç 2013; Mere 2010).

Conclusion and Suggestions

In Turkey, forest villagers are one of the most poor people group. In the forest area, about 7.8 million people live in Turkey. Agroforestry is very strategic tool for supporting this people. That's why in recent years the General Directorate of Forestry in Turkey has given very much importance to establish "Honey Forests". Apiculture can be acknowledged as a subsystem of agroforestry. There are numerous factors affecting the establishment of honey forests: highly productive bee races, knowledge and experience in beekeeping, suitability of natural conditions, necessary tools and equipment. There should be planning with clone and genotype selection and rehabilitation in order to establish better honey forests other than choosing tree species. As a general approach, when designing agroforestry systems, the use of a range of tree and shrubs species flowering at different times can provide better forage for bees, therefore enhancing both honey and tree and annual crop production. Establishing honey forests all around Turkey, which started around 2010, is fairly new and we still did not receive any concrete results yet. Also we still need to work on informing/educating forest villagers about these establishments because they have number of reservations to place their beehives in the forest. As of today we have 205 honey forest establishments all around Turkey.

The following conclusions can be drawn from this study: 1) The first step of technical assistance for the families who deal with beekeeping; "phenology flowering maps" according to altitude and region need to be created. 2) More research, especially on exotic species like *Acacia, Robinia* etc., needs to be formulated to extend the flowering time by planting and growing the early, normal and late flowering varieties of the above species and clones. 3) Studies should concentrate on primary species, which have high potential of pollen and nectar and rehabilitate by doing massive and individual selection in certain regions. 4) Also, for the species with high productivity, clone banks and seed origin plantations needed to be established with the individuals which were selected carefully. 5) Besides the experiments done for the selection improvement, further studies should be done for improving hybrid in genotype and clone/species which has long and high flowering characteristics. 6) Conferences/meetings have to be organized in order to acknowledge forest villagers that beekeeping in honey forests is more productive and free. 7) Turkey's honey production takes 3rd place in the world, with the help of "honey action plan" and General Directorate of Forestry it could be in a higher position. 8) In order to increase the income for forest villagers/beekeepers, we should have brand name organic and certificated honey.

References

Adnan H., Sirait J.R., Ali Said L.O., Mahmud A. 2014. Sustainable forest honey. World Agroforestry Center, submitted by EParamita, August 6, 2014. Available: http://www.worldagroforestry.org/newsroom/highlights/sustainable-forest-honey

Anonymous 2008. 4th Clause of Forestry Development Legislation, General Directorate of Forestry which published in Official Gazette, dated 05.02.2008 with the number of 26778. [Orman Genel Müdürlüğü, Orman Amenajman Yönetmeliği'nin. 4. Maddesi 05.02.2008 tarihli ve 26778 sayılı Resmi Gazete yayınlanan]. (In Turkish).

Anonymous 2009. Forests and Beekeeping "Forests Which Produce Honey", Ministry of Environment and Forestry, General Directorate of Forestry, November 2009, Ankara, Turkey. (In Turkish).

Anonymous 2010. "Supporting Beekeeping" Memorandum of General Directorate of Forestry dated 02.03.2010 with the number of B.181 OGM 07203/175, Ministry of Environment and Forestry. (In Turkish).

Anonymous 2013a. Forestry. Tnau Agritechportal. Forestry Technologies. Available: http://agritech.tnau.ac.in/forestry/agroforestry_index.html#types

Anonymous 2013b. Honey. Article. Available: http://en.wikipedia.org/wiki/Honey

Anonymous 2013c. Honey Forest Action Plan (2013-2017) T.R. Ministry of Forest and Water Affair, General Directorate of Forestry [Bal Ormanı Eylem Planı (2013–2017). T.C. Orman ve Su İşleri Bakanlığı, Orman Genel Müdürlüğü]. Ankara. (In Turkish).

Anonymous 2013d. Honey: World Production, Top Exporters, Top Importers, and United States Imports by Country. Phong Son Honey Company. Available: http://honeyvietnam.com/en/component/content/article/11-news/16-honey-world-production-top-exporters-top-importers-and-united-states-imports-by-country.html

Anonymous 2013e. Forest Atlas [Orman Atlası]. General Directorate of Forestry, Ministry of Forest and Water Affairs, Ankara, Turkey. (In Turkish).

Anonymous 2013f. Online Atlas of the British and Irish flora. Available: http://www.brc.ac.uk/plantatlas/

Anonymous 2014a. Honeydew honey or forest honey. Available: http://www.honeytraveler.com/single-flower-honey/honeydew-or-forest-honeys/

Anonymous 2014b. Black honey. Available: http://royalblackhoney.com/royalblackhoney.html

Anonymous 2014c. Forest honey – the most expensive honey in the world. Available: http://beetime.eu/forest-honey-the-most-expensive-honey-in-the-world/

Belen I. 2010. Forests and Beekeeping [Ormanlar ve Arıcılık]. General Directorate of

Forestry, Ministry of Forest and Water Affairs, March 15th 2010, Ordu, Turkey. (In Turkish).

Büyükşahin I. 2010. Studies on Agroforestry Systems in the World and Applicability of These Studies in Turkey [Dünya'da Tarımsal Ormancılık Sistemlerinin İncelenmesi ve Türkiye'de Uygulanabilirliği Üzerine Araştırmalar]. Forest Engineering Department, Life Science Institution, University of Kahramanmaras Sütçü Imam, Kahramanmaras, Turkey. (In Turkish).

Kiliç H. 2013. As a practice of agroforestry, studies the relations between beekeeping and forestry on the bases of law. (In Turkish) Available: http://web.ogm.gov.tr/diger/BalOrmani/Sayfalar/Dok%C3%BCmanlar.aspx

Mere Z. 2010. Relationship of Forests and Beekeeping [Ormanlar ve Arıcılık İlişkileri]. General Directorate of Forestry, Ministry of Forest and Water Affairs, February 2010, Ankara, Turkey. (In Turkish).

Ministry of Development 2013. Forestry Commission Report of 9th Development Plans, Ankara, Turkey: 16–17.

Sağkaya A., Kamiloğlu M.Y. 1987. Mixed Systems in Forestry. [Ormancılıkta Karma Sistemler]. Chamber of Forest Engineers, Publication no 10, Ankara, Turkey. 59 p. (In Turkish).

Sefik Y. 1995. Agroforestry [Tarımsal Ormancılık]. Faculty of Forestry, Karadeniz Technical University, General Publication Number 176, Faculty Publication Number 21, Trabzon, Turkey. 98 p. (In Turkish).

Tolunay A., Alkan H., Korkmaz M., Bilgin-Filiz S. 2007. Classification of Traditional Agroforestry Practices in Turkey. International Journal of Natural and Engineering Science 1(3): 41–48.

TUBIVES 2013. TUBIVES – Turkish Plants Data Service. Available: http://traglor.cu.edu.tr/common/object_show.aspx?id=1263

TUIK 2012. Animal Production Statistics of 2012. Turkish Statistical Institute. [Türkiye Istatistik Kurumu. Hayvansal Üretim İstatistikleri, 2012]. (In Turkish). Available: http://www.tuik.gov.tr/PreHaberBultenleri.do?id=13512

Turna I. 1992. Determination of Agroforestry Potential in Akçaabat Region [Akçaabat Bölgesinde Agroforestry Potansiyelinin Belirlenmesi]. Life Science Institution (M.Sc.-thesis), Karadeniz Technical University, Trabzon, Turkey. (In Turkish).

Webster T., Hill D.B. 1991. Bees and Trees: How tree crops and beekeeping can work together in small farming. Kentucky State University College of Agriculture. 6 p.

Yavuzsefik Y., Akbulut S. 2005. Agroforestry [Tarımsal Ormancılık]. Faculty of Forestry in Düzce, University of Abant Izzet Baysal, Duzce, Turkey. (In Turkish).

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 151–155

IMPROVEMENT OF AGRICULTURAL WASTE AND RESIDUES USE THROUGH BIOGAS PRODUCTION

Anna Aladjadjiyan[1*], Nikolay Kakanakov[2], and Aleksandar Zahariev[2]

[1]Agricultural University, 12, Mendeleev Str., 4000 Plovdiv, Bulgaria. E-mail: anna@au-plovdiv.bg
[2]National Biomass Association, 22, Antim Parvi Str., 4000 Plovdiv, Bulgaria.
*E-mail: animal_bg@abv.bg

Received: 15 September 2014 Accepted: 23 October 2014

Abstract

Processing residues from agriculture for energy production or exploitation of useful materials allows reconnection of crop production and animal husbandry. It becomes also a prerequisite for achieving sustainable agriculture. One of the most common technologies is the anaerobic digestion of plant and animal residues and wastes (manure, straw). As a result of the process, biogas (methane up to 80 %) is produced. This could be used further as fuel for transportation and heating, and in availability of a generator also for electricity production. The fermentation residues are biomass containing essential elements such as nitrogen, phosphorus and potassium, and could be used further as fertilizer.

Key words: agriculture, energy, fertilization, wastes processing.

Introduction

Processing of residues from agricultural production is a major challenge to farms owners from both environmental and economic point of view. Agricultural residues and waste could produce, through a variety of technologies, energy (briquettes, pellets, methane) that reduce greenhouse gas emissions and replace fossil fuels which in Bulgaria are mostly imported. The actuality of the problem for reutilization of farm residues in EC is the reason for funding of the project INEMAD (2012–2016) under the Seventh Framework Programme. Agricultural University and National Biomass Association are partners in this project from Bulgarian side. The project aims to Improve Nutrients (nitrogen, phosphorus and potassium) and Energy Management through Anaerobic Digestion of agricultural residues.

The first pilot biogas installations in Bulgaria have been created between 1980 and 1988 (Baykov and Petkov 1984) but after 1989 they have been snapped up. The first two biogas working installations in the past have been situated close to Silistra and Pleven, in large poultry farms. Later, a scientific project on biogas from animal manure has been developed in Bulgarian Agricultural Academy. In that facility a biogas installation for small size agricultural farms has been designed by Benev et al. (1994). Recently, a paper describing new pilot-scale biogas plant with a computerised monitoring and control system was developed in the Institute of Microbiology of Bulgarian Academy of Sciences by Simeonov et al. (2012). The last publication on biogas has been an assessment of socioeconomic impact from the implementation of biogas production in Bulgaria in the Master Thesis of Stoyanov (2013). The total potential of biogas production in Bulgaria estimated on the basis of data from Ministry of Agriculture and Food, 2011 gives an energy value of 22.2 PJ.

The total number of biogas installations in Bulgaria in 2011 was 3 (Anonimus 2013), all three having processed sewage sludge.

Materials and Methods

Strong restrictions concerning the deposition of animal manure are accepted in the countries of EU related to the ecological requirements for clean soil, underground water and greenhouse gas (GHG) emissions. Farmers are forced to search for ways of waste processing in utilizable products with commercial value. One of the most popular methods is the anaerobic digestion, that results in biogas production and reduction of CO_2 and CH_4 emissions (Anonimus 2009). The dry residue of digestion represents biomass, containing important nutrients as nitrogen, phosphorus and potassium, which could be used for improving soil fertility.

In the frames of project INEMAD the potential of Bulgarian animal husbandry is investigated in order to reveal the possibilities for production of biogas from animal manure, as well as the possibilities for production of standardized fertilizer from the residues of anaerobic digestion (digestate). The feasibility of the project depends on the product's economical parameters.

Data for the evaluation of the potential of Bulgarian animal husbandry have been taken from the Statistical Yearbook (2013).

The energy (E) in MJ, obtained from animal manure having mass (M) in t, can be calculated according the relation (1):

$$E = 22.6\, M \cdot P_{CH_4} \quad (1),$$

where P_{CH_4} is methane yield in m^3 from 1 ton of manure, and the energy of 1 m^3 methane is 22.6 MJ.

Results and Discussion

According to the official statistical data of FAOSTAT the distribution of animal husbandry in Bulgaria is the following: poultry – 84.39 %; sheep and goats – 9.15 %; cattle – 2.94 %, pig-breeding – 3.25 % (Figure 1).

From Figure 1 it can be seen, that poultry represents the more serious resource for processing of animal manure.

The concept of 'animal unit' is introduced on biogas production. One 'animal unit' per twenty-four-hour period gives waste (excrements), from which about 1.5 m^3 biogas can be produced. That makes equal respectively to: 1 cow; 5 calves; 6 swine; 250 hens.

As it can be seen, despite the big part of poultry-farming, its effectiveness for biogas production is not the best one and should be further evaluated.

The content of nutrient elements sodium, phosphorus and potassium in animal manure is definitive for the role of digestate in soil fertilization.

Chemical composition of fresh manure in g/kg is presented in Table 1, according the data from Yancheva and Manolov (2003).

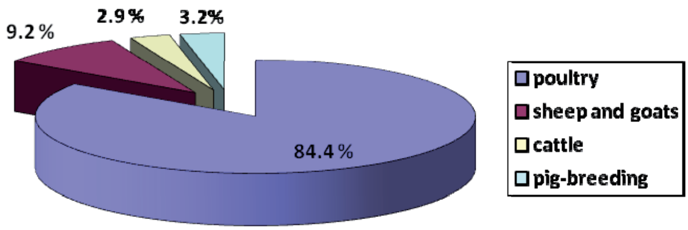

Fig. 1. Distribution of Bulgarian animal breeding by branches.

The total quantity of these elements from poultry excrements is calculated according the data about poultry number in 2011 using the information in Table 1. The results are presented in Table 2.

Table 1. Chemical composition of fresh manure by species and categories poultry.

Elements	Laying hens, g/kg	Broiler chickens, g/kg
Nitrogen – total	10–18	14–22
Phosphorus (as P_2O_5)	8–12	10–12
Potassium (as K_2O)	5–7	5–8

The total quantity of manure from poultry farming (Table 2) is 663,648 t/year. Potential methane yield from 1 t poultry manure is evaluated to 210 m^3 (Yancheva and Manolov 2003).

The potential of poultry manure for biogas production is evaluated using the relation (1); and result is about 3 PJ. This value does not include other categories of birds.

The evaluation of the potential of pig-breeding and cattle-breeding made in analogical method gives respectively 6.7 PJ and 25 PJ (BiG>East 2007–2010). Biogas potential results to 3.7 PJ for total poultry-farming. The total potential for biogas from animal breeding is evaluated to 35.4 PJ. The necessary primary energy for Bulgaria in the year 2005 was 596 PJ (Aladjadjiyan and Kakanakov 2008). From the comparison of those values occurred that biogas potential can supply about 6 % of primary energy.

Prerequisite for production of biogas through anaerobic digestion is the availability of significant amounts of manure at a relatively limited area, which will reduce to a minimum transport costs to biogas plants. The way of collecting the manure is of particular importance.

Table 2. Total amounts of phosphorus (as P_2O_5) and potassium (as K_2O) from poultry in Bulgaria for 2011.

Category birds	Total amount manure, t/year	Total amount nitrogen, t/year	Total amount phosphorus (as P_2O_5), t/year	Total amount potassium (as K_2O), t/year
Hen	312,758	4441	3221.4	1876.5
Chicken	350,890	6421	3754.5	2717.0
Total	663,648	10862	6975.9	4593.5

Biogas production installation needs a regular supply of sufficient raw material. This is possible if the manure is collected in a concrete platforms for storage of fresh manure (especially pigs) and lagoons. Most of the small farmers collect the manure outdoors in the yard and use it for fertilizer on their own small-sized land. That gives them economic advantages – lower costs for fertilizers; but there are ecological disadvantages – odor, contamination of soil and groundwater, higher emissions of CO_2 and CH_4. This way of manure collection is an obstacle for the production of biogas because the irregular and non-guaranteed supply of raw material.

Larger farms collect livestock manure in concrete platforms (for ruminants) or in open lagoons (for pig breeding). The collected manure is stored most often by drying. Currently it is not used but it is possible in the future to be processed for biogas production through anaerobic digestion and subsequent composting of digestate for fertilizer.

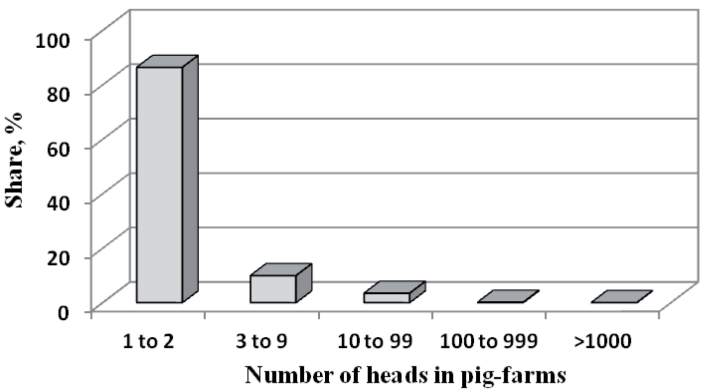

Fig. 2. Distribution according the number of animals in pig farms (BiG>East 2007–2010).

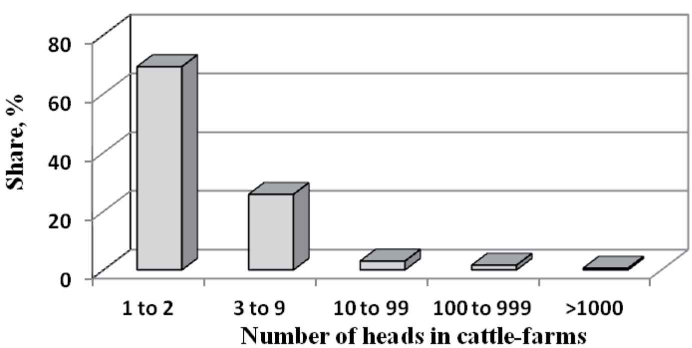

Fig. 3. Distribution according the number of animals in cattle farms (BiG>East 2007–2010).

Pig and cattle breeding farms play a bigger role in biogas production. The following two figures show the distribution of the pig (Figure 2) and cattle farms (Figure 3), according the number of bred livestock units.

As it can be seen from Figures 2 and 3, over 80 % of animals are bred in small farms, with not more than ten heads. The small number of big animal breeding farms is the main obstacle for building of installation for anaerobic digestion. From a technological point of view, small farms are not viable for the production of biogas, as they cannot provide regular inputs to the process of anaerobic digestion. For them it is advisable to create farm cooperatives, but this is a long and complicated process. Obstacles to the introduction of anaerobic digestion are also large distances between farms, lack of state support, etc.

Conclusion

It is necessary to explore the attitudes of owners to operate in regard to agricultural waste processing for production of biogas for energy and compost for soil recultivation, which is the purpose of the project INEMAD.

Acknowledgment

This work received funding from the European Union's Seventh Framework Programme (FP7/2007–2013) under grant agreement No 289712.

References

Aladjadjiyan A., Kakanakov R. 2008. The Role of RES in Future Power Supply of Bulgaria. 7th Balkan Power Conference, Sibenik, Croatia, 10–12 September. Andrej Gubina (Ed.) Proceedings. Published by University of Ljubljana: 15–17.

Anonimus 2009. Livestock in the Balance: The State of Food and Agriculture: 53–74. Available: http://www.fao.org/docrep/012/i0680e/i0680e04.pdf

Anonimus 2013. EUROOBSERV'ER – The state of renewable energies in Europe, 2013 edition. Available: http://www.energies-renouvelables.org/observ-er/stat_baro/barobilan/barobilan13-gb.pdf

Baykov B., Petkov G. 1984. Biogas in Energetic of the Future. Priroda 6: 19–26 (in Bulgarian).

Benev A., Kraichev S.T., Blajev A.E. 1994. Small Energy-effective Systems for Utilization of Waste Biomass. Proceedings of the First National Conference on Renewable Energy Sources, Bulgarian Academy of Sciences, Sofia: 138–141 (in Bulgarian).

BiG>East 2007–2010. Promoting Biogas in Eastern Europe. Available: http://www.big-east.eu/

INEMAD 2012–2016. Reconnecting livestock and crop production. Available: http://www.inemad.eu

Simeonov I., Kalchev B., Mihaylova S., Hubenov V., Aleksandrov A., Georgiev R., Christov N. 2012. International Journal Bioautomation 16(3): 187–202.

Statistical Yearbook of Bulgaria for 2012 2013. Aleksieva M., Ilkova A. (Eds.) Sofia. (In Bulgarian). Available: http://statlib.nsi.bg:8181/FullT/FulltOpen/SG_2011_2012_2013.pdf

Stoyanov T. 2013. Socioeconomic impact from the implementation of biogas production in Bulgaria. MSc Thesis, Aalborg University, 57 p. Available: http://projekter.aau.dk/projekter/files/79955493/Master_thesis.pdf

Yancheva H., Manolov I. 2003. Principles of the organic agriculture. 1st Edition, ed. 'V. Petrov' Ltd, Plovdiv, 480 p. (In Bulgarian).

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 157–169

EFFECTS OF ROAD CONSTRUCTION ON BIODIVERSITY AND COMPOSITION OF HERBACEOUS SPECIES COVER, ASALEM FOREST, NORTHERN IRAN

Hajar Tarvirdizadeh*, Mehrdad Nikooy, Hassan Pourbabaei, and Ramin Naghdi

Department of Forestry, Natural Resources Faculty, University of Guilan, Someh sara, P. O. Box 1144, Guilan, Iran. *E−mail: tarvirdi.1368@gmail.com

Received: 27 August 2014 Accepted: 25 October 2014

Abstract

We assessed a forest road impact on the diversity and the composition of herbaceous plant communities in the forest road margins, referring to illuminance and soil moisture percentage, to understand which of them is more important after more than 50 years from the building of the road. For this purpose six transects of approximately one kilometer length parallel to the forest road were established. Along each transect, 15 square sample plots of 1m^2 each were chosen by systematic random sampling. The average cover of herbaceous species on the cut and fill slopes was significantly higher than that inside the forest and that of the roadsides. There wasn't a significant correlation between biodiversity indicators and illuminance and soil moisture percentage. Entering invasive species altered the composition of the herbaceous cover and increased the richness of species on cut and fill slopes. Roadside plots under completely closed canopies of edge trees since the road has been built, have returned to original composition of the forest vegetation, showing contents similar to that of the forest plots.

Key words: forest roads, herbaceous plants diversity, illuminance, soil moisture percentage, Northern Iran.

Introduction

Due to climate change, rising global temperatures, forest fires and air pollution, the importance of forest conservation is growing (Dale et al. 2001, Honnay et al. 2002, Zhu et al. 2014), and the direct connection between forest sustainability and sustainability of human society is recognized. An issue of significant importance is the construction of forest road network designed to allow access needed for logging, wildlife conservation, entertainment and recreation purposes, pest, diseases and fire control. Forest roads affect forest ecosystem biotic and abiotic factors by changing the population dynamics of plants and animals, entering alien species, redirecting the flow of material, and controlling the accessibility of natural resources such as sunlight, water and nutrients (Angold 1997, Spellerberg 1998, Maynadier and Hunter 2000, Hill and Pickering 2006, Coffin 2007, Flory and Clay 2009, Zang and Ding 2009, Freitas et al. 2010). For understanding the impact of roads on forest ecosystems, the evaluation of edge effects of roads on the diversity and the composition of herbaceous species is crucial.

Biodiversity has been identified as one of the key factors to sustainable forest management (Brand 1995, Research 1999, Castaneda 2000). Loss of biodiversity, therefore, should be addressed as an environmental issue in sustainable forest management and forestry activities (Nouri et al. 2008). Roads increase forest fragmentation and affect species diversity (Laska 2001). Previous studies show that roads affect all herbaceous plants, trees, shrubs and even edge trees regeneration, altering their composition and diversity (Fredericksen and Pariona 2002, Landenberger and Ostergren 2002, Buckley et al. 2003, Bernhardt−Romermann et al. 2006, Bowering et al. 2006, Flory and Clay 2006, Delgado et al. 2007, Parsakhoo et al. 2009, Najafi et al. 2011). Herbaceous plants of these communities play an important role in the conservation of forest soils along roads that often lack trees. In northern Iran, this issue is significant because forests are located mostly on the steep slopes of the mountains. Moreover, herbaceous plants constitute a significant part of Iranian forest biodiversity. Ecological conditions of forest road edges serve as a corridor for invasive and non−native species, and play a major role in the formation of plant communities. At the disturbed road edges, invasive species have more adaptive and competitive abilities compared to native species and are quickly entering open sites. Different levels of degradation have different effects on the biodiversity. In communities that are constantly being destroyed due to the inability of the species to survive, diversity also decreases. Competition between species in moderate levels of degradation is high. No species, however is able to dominate. Thus, the richness of species reaches a maximum and such communities are associated with high diversity (Ejtehadi et al. 2008). In this study, we assessed the forest road impact referring to the rate of illuminance and soil moisture on the diversity and composition of herbaceous plant communities in the margins of forest roads. We assumed that illuminance and soil moisture do not affect biodiversity and composition of edge herbaceous plants.

Material and Methods

Study area

The Shendol study site (inside Asalem forest in Asalem, Gilan – 48°44′36″–48°49′58″ longitude and 37°42′31″–37°37′23″ latitude) with an area of 129 hectare (for 20–27 parcels) is located in watershed No 7 in the Hyrcanian forests of Iran. The dominant forest type in the parcels is *Fagus orientalis* – *Carpinus betulus* – *Acer insigne* as a group mixed with *Alnus subcordata* C.A. Mey, *Tilia begonifolia* Steven, *Ulmus glabra* Huds. With young – middle−aged to older foundations and 2–3 ranches structure. Other details are given in Table 1.

Table 1. Details about study area.

Slope, %	Elevation, m	Herbaceous cover, %	Leaf litter depth, cm	Canopy cover, %	pH	Average annual rainfall, mm	Soil type
31–60	820–1120	15–25	2–3	80–90	5.5–6.2	1867	Sandy Limonite, Clay Limonite

We focused on one kilometer of a secondary unpaved forest road built in the early 1960s to implement shelterwood system. On the basis of conducted surveys and studies the single−tree selection method was replaced with the selection system after three periods with the same logging method. Last logging of the area was performed in 2007 and the roads haven`t been used since then.

Sampling procedure

Six transects of approximately one kilometer length parallel to the road were established. Two of the transects were taken on cut and fill slopes, other two – on roadsides 6 meters above and below cut and fill slopes. To understand different road effects, the last two transects were taken in the forest 150 meters above and below the road axes. Along each transect, 15 square sample plots of 1 m² each were established by systematic random sampling (Buckley et al. 2003) (Fig. 1).

For each plot, we documented slope, aspect, illuminance (measured by TES Digital light meter – Model: TES−1336A between 11:00 and 14:00 hours in sunny days), elevation, canopy cover percentage of trees, herbaceous cover, and the species of forest floor. Additionally, 15 soil samples from the center of each plot, were immediately taken to a laboratory for measuring soil moisture content using the over drying method. Herbaceous species were collected in summer from June 2013 to July 2013. All herbaceous species were identified using resources from the Herbarium of the Faculty of Natural Resources at the Guilan University, the Book of Flora of Iran (Khatamsaz 1991), the Iranian Herbs Guide (Mobin 1984), the Flora of Turkey (Raunkiær 1934, Davis et al. 1988).

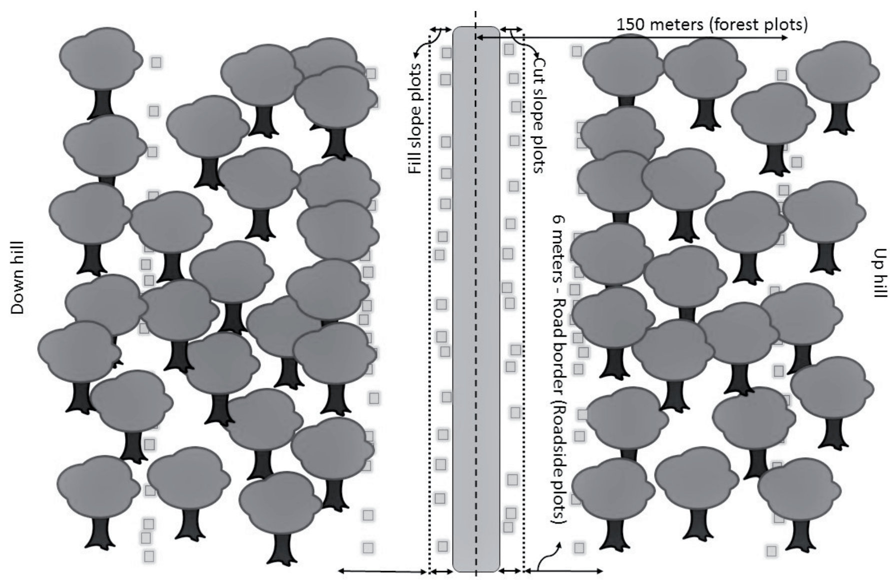

Fig. 1. Herbaceous species sampling design (scales are not considered accurate, drawn by written).

Data analysis

To evaluate the herbaceous diversity, we calculated Shannon−Wiener diversity (*H*') (Ludwig and Reynolds 1988, Krebs 1999), evenness was also assessed using the Pielou's index (*J*) (Krebs 1999) and the species richness was estimated by counting the number of species (*S*) (Humphries et al. 1996). The equations of all indices are presented in Table 2.

Table 2. The equations of indices.

Indices	Details
Shannon−Wiener: $H' = \sum_{i=1}^{n} p_i \cdot \ln p_i$	P_i is the relative frequency of the i^{th} species
Pielou's measure of species evenness: $J = \frac{H'}{\ln(S)}$	H' is Shannon Weiner diversity and S is the total number of species in a sample, across all samples in dataset.
Species richness: $R = S$	*S* is number of species

For statistical analysis, Kolmogorov–Smirnov tests were used to study the normality of the data distribution. A one−way ANOVA test was used for normally distributed data and non−parametric equivalent (Kruskal Wallis test) was conducted. SPSS 22.00, PAST (Hammer et al. 2001) and Ecological Methodology software, version 6.0 (Kenney and Kerbs 2001) were used for statistical analysis.

Results

The average cover of herbaceous species on the cut and fill slopes was significantly higher than these inside the forest and on the roadsides. The lowest cover was found in the forest plots ($\alpha < 0.05$) (Fig. 2).

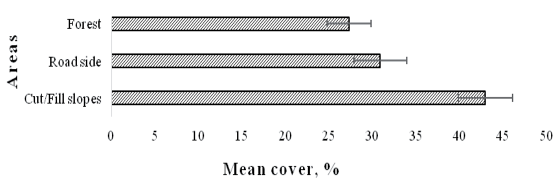

Fig. 2. Mean cover in each area (in percent).

Totally 51 species belonging to 35 families were identified in the three areas of study, at that – 26, 37 and 36 species were found respectively on cut and fill slopes, on roadsides and within the forest.

Average cover showed significant differences in the three areas ($\alpha < 0.05$). *Lolium temulentum* L. had both the highest cover and frequency on cut and fill slopes. On roadsides, highest coverage was shown by *Solanum kieseritzky* C.A.M., and the highest frequency by *Dryopteris pallida* (Bory) Fomin. In the forest plots, *Microstegium vimineum* (T.) was the most frequent species, and *Dryopteris pallida* had the highest percentage cover. Frequency and cover (in percent) of other species are listed in Table 3.

Results show that there is a negative relationship between light and soil humidity at the road edges. Along roads, the canopy opens, the illuminance increases and the soil moisture content is reduced especially on cut slopes. This reduction is also clearly evident on fill slopes except that the amount of light on such slopes is relatively lower than that of cut slopes. With increasing distance from the road, the amount of light is reduced and soil moisture increases. Accord-

Table 3. Frequency and mean cover of herbaceous species on cut and fill slopes, on the roadsides (*RS*) and in the forest.

Species	Family	Mean cover, %			Frequency, %			*p*
		Cut/Fill	RS	Forest	Cut/Fill	RS	Forest	
Acalypha australis L.	Euphorbiaceae	–	–	5.5	–	–	10	0.151
Agrimonia eupatoria L.	Rosaceae	5.5	7	1	10	10	5	0.728
Alliaria petiolaa (M.B.) Cavara & Grande.	Brassiacaceae	–	1	–	–	5	–	0.111
Apium repens (Jacq.) Lag.	Apiaceae	1	–	–	5	–	–	0.368
Asplenium septentrionale (L.) Hoffm.	Aspleniaceae	–	10	7	–	5	10	0.387
Bidens tripartita L.	Compositeae	–	–	4	–	–	5	0.395
Bromus catharticus Vahl	Poaceae	–	6.8	6.6	–	25	25	0.053
Campanula patula L.	Campanulceae	8	–	4	10		5	0.364
Carex buxbaumii Wahlenb.	Cyperaceae	–	5	–	–	15	–	0.035*
Carex conjuncta Boott	Cyperaceae	5.98	3.6	4.83	40	50	30	0.816
Carex hordeistichos Vill.	Cyperaceae	9.2	10	11	25	5	10	0.169
Carex hirta L.	Cyperaceae	–	2.67	–	–	15	–	0.035*
Carex plantaginea Lam.	Cyperaceae	–	1	–	–	5	–	0.340
Chelidonium majus L.	Papaveraceae	4	–	5	15	–	10	0.243
Chenopodium sp. L.	Chenopodiaceae	1	–	–	5	–	–	0.368
Circaea lutetiana L.	Onagraceae	4.11	2	2.25	45	10	20	0.022*
Convolvulus arvensis L.	Convolvulaceae	3.67	5.8	5.67	40	25	15	0.312
Convolvulus sp. L.	Convolvulaceae	–	–	6	–	–	5	0.395
Dactylis glomerata L.	gramineae	–	6	–	–	5	–	0.340
Dryopteris pallida L.	Hypolepidaceae	14.11	7.26	9.31	80	65	90	0.094
Epilobium hirsutum L.	Onagraceae	–	2	–	–	5	–	0.340
Euphorbia heliscopia L.	Euphorbiaceae	1	–	–	5	–	–	0.368
Galium triflorum Michx.	Rubiaceae	–	4.56	1	–	30	5	0.004*
Geranium persicum L.	Geraniaceae	5.5	5.33	2	25	15	5	0.188
Geum urbanum L.	Rosaceae	4.5	5.5	4.67	20	10	15	0.687
Hypericum androsaemum L.	Hypericaceae	5.56	4	2.67	65	10	15	0.000*
Juncus rigidus Desf.	Juncaceae	4	–	–	5	–	–	0.368
Lolium temulentum L.	Poaceae	15.80	9.09	15.10	85	55	65	0.060
Lepidium latifolium L.	Cruciferaceae	–	4	–	–	5	–	0.340
Microstegium vimineum (T.)	Poaceae	7.29	4	23	40	5	15	0.025*
Oplismenus undulatifollius (L.) P.Beauv.	Poaceae	7.14	8.75	10.17	35	20	10	0.187

Phyllitis scolopendrium (L.) Newn.	Aspleniaceae	–	1	2.33	–	5	15	0.175
Phytolacca americana L.	Phytolaccaceae	10	4.81	–	10	35	–	0.007*
Poa pretense L.	Poaceae	–	6.78	3	–	30	5	0.010*
Polygonatum orientale Schrak.	Liliaceae	–	4	–	–	5	–	0.340
Polygonum hydropiper L.	Polygonaceae	–	–	3	–	–	10	0.151
Primula heterochroma stapf	Primulaceae	1	1	2.5	10	5	10	0.837
Prunella vulgaris L.	Labiateae	–	10	–	–	5	–	0.340
Rosa canina L.	Rosaceae	–	10	–	–	5	–	0.340
Rubus hyrcanus Juz.	Rosaceae	9.58	7.38	9.37	80	40	50	0.024*
Rumex sanguinus L.	Polygonaceae	1	–	3	5	–	20	0.070
Salvia glutinosa L.	Labiateae	–	1.5	5.5	–	10	10	0.175
Sambucus ebulus L.	Adoxaceae	8.25	2	12.92	10	5	20	0.341
Scutellaria lateriflora B.	Lamiaceae	–	5.67	2	–	15	5	0.344
Solanum kieseritzky C.A.M.	Solanaceae	–	13.6	13.33	–	25	10	0.044*
Tamus communis L.	Dioscoraceae	–	–	1	–	–	5	0.395
Urtica dioica L.	Urticaceae	4	3.75	2.8	10	40	25	0.080
Urtica urens L.	Urticaceae	–	–	10	–	–	5	0.395
Vaccinium sp. L.	Ericaceae	–	–	2	–	–	5	0.395
Vincetoxicum scandens Sommiers Levier	Apocynaceae	7	5.67	3	10	15	15	0.876
Viola odorata L.	Violaceae	5.73	7.2833	6.25	55	50	60	0.568

Note: * – Represents a significant difference in the percent cover at the 0.05 level.

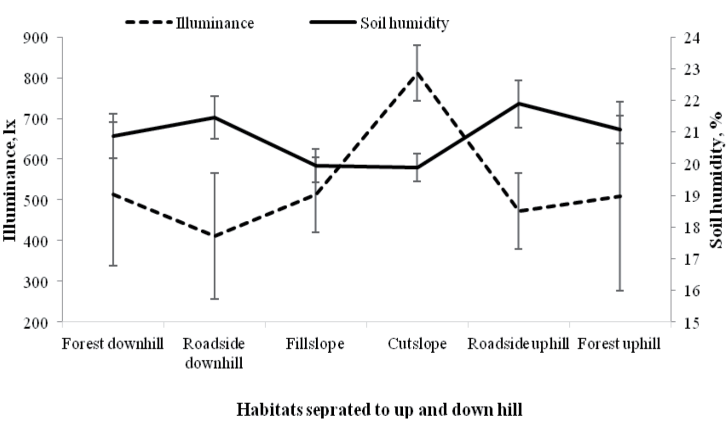

Fig. 3. Illuminance−soil humidity mean curve for the studied types of habitat.

ing to the Kruskal−Wallis test, there were no significant differences between the amounts of soil humidity and illuminance between treatments (Fig. 3).

ANOVA test of results on diversity, richness and evenness indices showed that diversity and richness were significantly higher on the cut and fill slopes compared to forest and roadsides. In

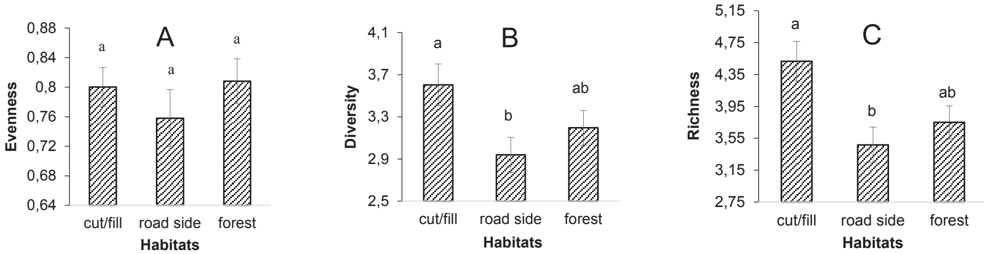

Fig. 4. Comparison of means of evenness (A), diversity (B) and richness (C) indices on cut and fill slopes, roadsides and inside the forest. a, b and ab indicates significant difference.

the forest, these values were greater than on roadsides but not significantly. Evenness index values in the three areas were similar while the highest evenness value was obtained in the forest (Fig. 4).

According to the Spearman correlation test, there is a positive significant difference between the diversity index and richness (at the 0.01 level). On the slopes, the correlation was stronger compared to that of the forest and road edges. However, the observed correlation between diversity and evenness indices in the forest and on the roadsides was higher than on the slopes with lower correlation toward richness indices (Table 4).

On the slopes, diversity, evenness and richness indices showed negative correlation with soil moisture, while the evenness indices showed positive correlation with the amount of light. A significant correlation was observed between the richness and light on the slopes. On the roadsides, diversity and richness indices were correlated positively with soil moisture unlike evenness index. All indicators were negatively correlated with light. Only for inside the forest, the evenness index showed a positive correlation with the amount of light. However, soil moisture continued to correlate negatively. Diversity and evenness indices inside forest were positively correlated with soil moisture and negatively with the light intensity (Table 5).

Based on the results of the CCA ordination test that was performed to investigate the composition of herbaceous species in

Table 4. Spearman correlations between diversity, richness and evenness indices.

Indices	Diversity index		
	Cut and fill slope	Roadside	Forest
R = S	0.945**	0.923**	0.922**
J	0.493**	0.500**	0.599**

Note: ** – Significant at the 0.01 level.

Table 5. Spearman correlations among the soil moisture, illuminance and diversity indices.

Indices	Cut and fill slopes		Roadside		Forest	
	Soil moisture	Illuminance	Soil moisture	Illuminance	Soil moisture	illuminance
Shannon–Wiener	–0.346	0.392	0.115	–0.329	0.265	–0.029
J	–0.159	–0.038	–0.249	–0.128	–0.019	0.240
R=S	–0.273	0.511*	0.203	–0.198	0.292	–0.164

Note: * – Significant at the 0.05 level.

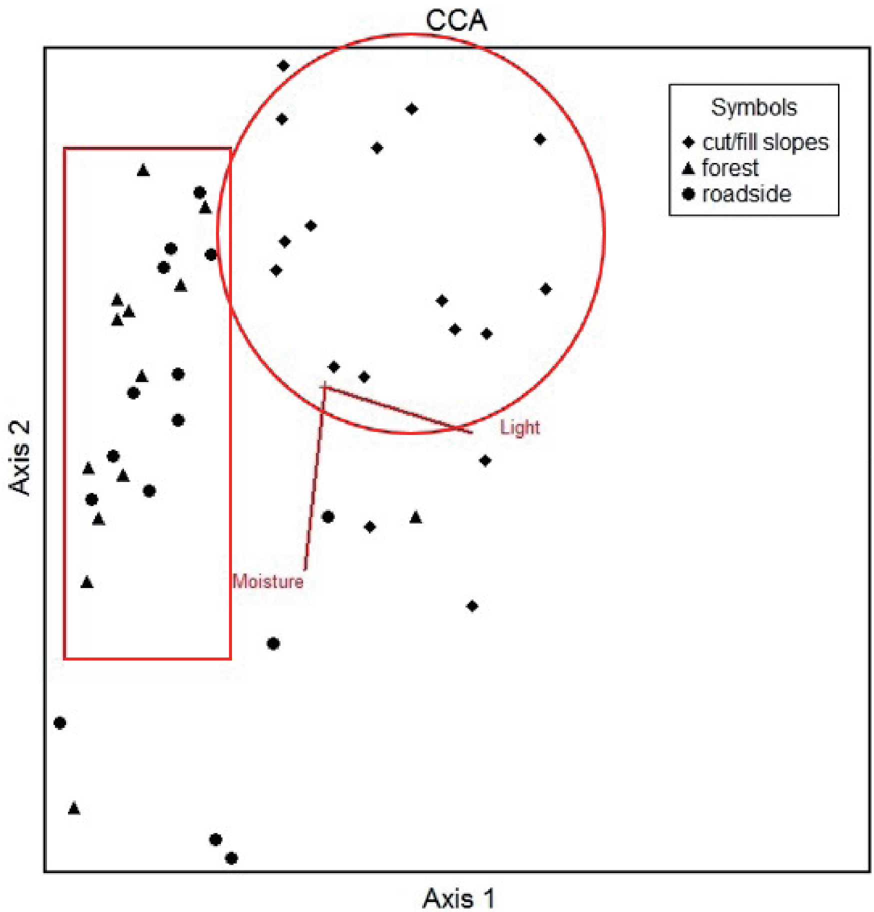

Fig. 5. CCA ordination results performed in PC−ord version 5.0 software (McCune and Mefford 1999).

Note: Ordination have been conducted based on species with light and soil moisture environmental variables entered in the analysis. Cut and fill slope plots are shown as lozenges (♦), roadside plots as circles (●) and forest plots as triangles (▲).

area, two different ecological groups are indivisible in the graph. The first group includes cut and fill slopes plots and the second group – plots of Roadside and within the forest (Fig. 5).

Table 6. Pearson correlations with ordination axes.

Indices	Axis 1		Axis 2	
	R	*r*−square	*R*	*r*−square
Light	0.979**	0.947**	–0.191	0.037
Soil moisture	–0.185	0.034	–0.989**	0.979**

Note: ** – Significant at the 0.05 level.

CCA Ordination analysis showed significant positive correlation between light and Axis 1, and a significant negative correlation between soil moisture and Axis 2 in CCA graph (Table 6).

Discussion

Due to topographic and different environmental conditions, forest roads have wider range of diversity compared to forests (Parsakhoo et al. 2009). Exposure to light and soil moisture are the most important ecological factors affecting biodiversity of the forest communities (Marvie Mohadjer 2011) where soil moisture is controlled by the amount of light (Anderson et al. 1969). Forest herbaceous species require certain amount of light (Tinya et al. 2009) and moisture. Based on our results, the maximum soil moisture and minimum light is reached on the roadsides. Due to exposure to more light and space, the roadside trees are thicker with more leaves than the forest trees, and therefore, have denser canopy cover. This inhibits light penetration under the tree crowns. All of these factors can explain the lower percentage of herbaceous cover on roadsides compared to cut and fill slopes (Fig. 2) but it still was higher compared to the forest closed canopy.

Percent cover of some species (e.g., *Carex buxbaumii*, *Carex hirta*, *Circaea lutetiana*, *Galium triflorum*, *Hypericum androsaemum*, *Microstegium vimineum*, *Phytolacca americana*, *Poa pretense*, *Rubus hyrcanus* and *Solanum kieseritzky*) differed significantly within the roadsides, slopes and forest interior ($\alpha < 0.05$). This can be explained by the differences in the amount of light and soil moisture (Fig. 3). Recent investigation in this area indicate that the growth of some of the native species, such as *Carex buxbaumii*, *C. hordeistichos*, *C. hyrta*, *C. plantaginea*, *Euphorbia heliscopia*, *Galium triflorum*, *Geum urbanum*, *Hypericum androsaemum*, *Primula vulgaris* and *Solanum kieseritzky*, (Natural resources office of Guilan 2006), was suppressed by the road construction, and hence, their percent cover was lowered significantly.

Buckley et al. (2003) found that species richness along forest roads is higher compared to the forest interior. As seen in Fig. 4, there is a significant difference in Shannon diversity and richness values along the road margin, slope and forest interior. The highest values of diversity, richness and evenness have been observed on the cut and fill slopes, with the diversity and richness significantly greater than the other two habitats. After increasing the light over the cut and fill slopes due to clear felling along the road, light tolerant and invasive species such as *Microstegium vimineum* (Devine and Fei 2011), *Sambucus ebulus* (Najafi et al. 2012), *Rumex* sp. (Parendes and Jones 2000) and *Prunella vulgaris* (Godoy et al. 2011) enter the area, increasing species richness (Muthuramkumar et al. 2006). *Lolium temulentum* has especially shown rapid growth in areas with an open canopy and more light. On roadsides, where we observed minimum species diversity, canopy density and low herbaceous cover impact the species richness. Species richness along roads is controlled by several factors such as light, soil moisture (Buckley et al. 2003), soil compaction and disorganization and soil physical properties (Smith et al. 2007). Entering the seeds of alien species due to removal of physical barriers is also a significant factor affecting species richness around forest roads (Buckley et al. 2003).

In addition, the diversity and richness indices on cut and fill slopes are significantly higher than inside the forest and on roadsides. The evenness index is also greater in the forest interior, although not significantly.

Based on the correlation test results between Shannon diversity, richness and evenness, we conclude that the diversity has a significant positive correlation with species richness and evenness and has been influenced more by richness in all areas. This means that with any increase of richness, biodiversity is increasing and the correlation between diversity and richness is much stronger than the correlation between diversity and evenness (Table 4). It can be stated that 94 % of changes in biodiversity on cut and fill slopes depend on evenness value variations ($R^2 = 0.945$) and almost 60 % of biodiversity changes in the forest depend on changes in the values of evenness. Contrary to our assumptions, however, there is no significant correlation between the amount of light or moisture and diversity indicators (Table 5). Hardtle et al. (2003) concluded that in the beech forests, richness is closely correlated with soil activity and with the base and nitrogen supply. Furthermore, several studies show that changes in biodiversity have a direct relationship with the type of forest management (Gardner 2012, Boch et al. 2013). In this study, illuminance and soil moisture, indirectly affected the biodiversity of the ecosystem by influencing its species and community composition (Fig. 5).

As marked with red lines in CCA ordination graph, communities on cut and fill slopes are situated at the top right of the axis 1 and communities on roadsides and forest plots are located to the left along the second axis. In degraded and disturbed areas with open canopy, invasive species affect the community composition (Anderson and Hoffman 2007). Species in plots located above axis 1, were more sensitive to illuminance. Open canopy and increasing illuminance over cut and fill slopes created a competition between native and invasive species where shade−intolerant species like *Dryopteris pallida* are out−competed. Native and shade−tolerant species of beech forests of Iran observed in the study area including *Euphorbia heliscopia*, some *Carex* species, *Chenopodium* sp. and *Galium triflorum* (Abkenar and Pilevar 2008) were eliminated by this competition. As a result, plant communities in this area are currently composed mostly of shade−intolerant species. Due to completely closed canopy of edge trees developed since the road was constructed, roadside plots have returned to original composition of the forest vegetation and show similar compounds to that of forest plots. Similar pattern was observed along moisture gradient.

Conclusions

This study investigated the effects of light and soil moisture on diversity and composition of herbaceous cover of forest road edges. On cut and fill slopes, increasing illuminance followed by decreasing soil moisture and disturbances due to road construction created and enhanced the growth of invasive and shade−intolerant species that are currently replacing the native species. Invasive species altered the composition of the herbaceous cover and increased the richness of species on cut and fill slopes. These changes, however, are only relevant to areas with open canopy. Plots sampled within 6 m distance from the road (along the road border) underneath the closed and large canopy of edge trees kept their composition and were scattered along soil humidity gradient.

Acknowledgement

We thank Jana Müllerová and Solmaz Mohadjer for helpful comments on an earlier version of the manuscript.

References

Abkenar K.T., Pilevar B. 2008. Silviculture. Haghshenas Press, Rasht, Iran, 296 p. (In Persian).

Anderson P., Hoffman M. 2007. The impacts of sustained heavy grazing on plant diversity and composition in lowland and upland habitats across the Kamiesberg mountain range in the Succulent Karoo, South Africa. Journal of Arid Environments 70: 686–700.

Anderson R., Loucks O., Swain A.M. 1969. Herbaceous response to canopy cover, light intensity, and throughfall precipitation in coniferous forests. Ecology 50: 255–263.

Angold P.G. 1997. The impact of a road upon adjacent heathland vegetation: effects on plant species composition. Journal of Applied Ecology 34: 409–417.

Bernhardt−Romermann M., Kirchner M., Kudernatsch T., Jakobi G., Fischer A. 2006 Changed vegetation composition in coniferous forests near to motorways in Southern Germany: the effects of traffic−born pollution. Environmental Pollution 143: 572–581.

Boch S., Prati D., Muller J., Socher S., Baumbach H., Buscot F., Gockel S., Hemp A., Hessenmoller D., Kalko E.K. 2013. High plant species richness indicates management−related disturbances rather than the conservation status of forests. Basic and Applied Ecology 14: 496–505.

Bowering M., Lemay V., Marshall P. 2006. Effects of forest roads on the growth of adjacent lodgepole pine trees. Canadian journal of forest research 36: 919–929.

Brand D.G. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. Biomass and Bioenergy 13: 247–253.

Buckley D.S., Crow T.R., Nauertz E.A., Schulz K.E. 2003. Influence of skid trails and haul roads on understory plant richness and composition in managed forest landscapes in Upper Michigan, USA. Forest Ecology and Management 175: 509–520.

Castaneda F. 2000. Criteria and indicators for sustainable forest management: international processes, current status and the way ahead. UNASYLVA−FAO: 34–40.

Coffin A.W. 2007. From roadkill to road ecology: a review of the ecological effects of roads. Journal of Transport Geography 15: 396–406.

Dale V.H., Joyce L.A., Mcnulty S., Neilson RP, Ayres M.P., Flannigan M.D., Hanson P.J., Irland L.C., Lugo A.E., Peterson C.J. 2001. Climate Change and Forest Disturbances Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience 51: 723–734.

Davis P.H., Cullen J., Coode M.J.E. 1988. Flora of Turkey and the east Aegean islands. Edinburgh University Press, Edinburgh, Scotland, 560 p.

Delgado J.D., Arroyo N.L., Arevalo J.R., Fernandez−Palacios J.M. 2007. Edge effects of roads on temperature, light, canopy cover, and canopy height in laurel and pine forests (Tenerife, Canary Islands). Landscape and Urban planning 81: 328–340.

Devine K., Fei S. 2011. A review of impacts by invasive exotic plants on forest ecosystem services. In, Proceedings of the 17th Central Hardwood Forest Conference, Newtown Square, Pennsylvania, USDA Forest Service, Northern Research Station: 425–435.

Ejtehadi H., Sepehri A., Akkafi H.R. 2008. Methods of Measuring Biodiversity. Ferdowsi University of Mashhad Press, Mashhad, Iran, 228 p. (In Persian).

Flory S.L., Clay K. 2006. Invasive shrub distribution varies with distance to roads and stand age in eastern deciduous forests in Indiana, USA. Plant ecology 184: 131–141.

Flory S.L., Clay K. 2009. Effects of roads and forest successional age on experimental plant invasions. Biological Conservation 142: 2531–2537.

Fredericksen T.S., Pariona W. 2002. Effect of skidder disturbance on commercial tree regeneration in logging gaps in a Bolivian tropical forest. Forest Ecology and Management 171: 223–230.

Freitas S.R., Hawbaker T.J., Metzger J.P. 2010. Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. Forest Ecology and Management 259: 410–417.

Gardner T. 2012. Monitoring forest biodiversity: improving conservation through ecologically−responsible management. Earthscan Publishing Press, London, England, 360 p.

Godoy O., Saldana A., Fuentes N., Valladares F., Gianoli E. 2011. Forests are not immune to plant invasions: phenotypic plasticity and local adaptation allow Prunella vulgaris to colonize a temperate evergreen rainforest. Biological Invasions 13: 1615–1625.

Hammer O., Harper D., Ryan P. 2001. Past: Paleontological Statistics Software Package for education and data analysis. Paleontología Electrónica 4: 1–9. URL: http://palaeo−electronica.org/2001_1/past/issue1_01. html.

Hardtle W., Von Oheimb G., Westphal C. 2003. The effects of light and soil conditions on the species richness of the ground vegetation of deciduous forests in northern Germany (Schleswig−Holstein). Forest Ecology and Management 182: 327–338.

Hill W., Pickering C.M. 2006. Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. Journal of Environmental Management 78: 24–34.

Honnay O., Verheyen K., Butaye J., Jacquemyn H., BOSSUYT B., HERMY M. 2002. Possible effects of habitat fragmentation and climate change on the range of forest plant species. Ecology Letters 5: 525–530.

Humphries C.J., Williams P.H., Vane−Wright R.I. 1996. Measuring biodiversity value for conservation. Annual Review of Ecology and Systematic 26: 93–111.

Kenney A.J., Kerbs C.J. 2001. Ecological methodology software: version 6.0. In, Department of zoology, University of British Columbia, Vancover, B. C. Canada VT6 1Z4.

Khatamsaz M. 1991. Floor of Iran vol. 6: Rosales. Natural resources office, Gilan, Iran, 425 p. (In Persian)

Laska G. 2001. The disturbance and vegetation dynamics: a review and an alternative framework. Plant Ecology 157: 77–99.

Landenberger R.E., Ostergren D.A. 2002. *Eupatorium rugosum* (Asteraceae) flowering as an indicator of edge effect from clearcutting in mixed−mesophytic forest. Forest ecology and management 155: 55–68.

Ludwig A.J., Reynolds F.J. 1988. Statistical Ecology: a primer of methods and computing. Wiley Press New York, US. 471 p.

Marvie Mohadjer M.R. 2011. Silviculture. Tehran University Press, Tehran, Iran, 387 p. (In Persian).

Maynadier P., Hunter J.R.M. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 56–65.

McCune B., Mefford M. 1999. PC−ORD: multivariate analysis of ecological data; Version 4 for Windows; (User's Guide). MjM software design.

Mobin S. 1984. Herbs of Iran. vol. 3: Floor of vascular plants. Tehran University press, Tehran, Iran, 266 p. (In Persian).

Muthuramkumar S., Ayyappan N., Parthasarathy N., Mudappa D., Raman T., Selwyn M.A., Pragasan L.A. 2006. Plant Community Structure in Tropical Rain Forest Fragments of the Western Ghats, India. Biotropica 38: 143–160.

Najafi A., Hosseini S.M., Ezati S., Torabi M., Fakhari M.A. 2011. Comparison of Regeneration and Biodiversity of Trees on Cut and Fill Edges of Forest Road (Case Study: Chamestan and Lavige Forests, Noor). Journal of Wood & Forest Science and Technology: 139–152.

Najafi A., Torabi M., Nowbakht A.A., Moafi M., Eslami A., Sotoudeh Foumani B. 2012.

Effect of Forest Roads on Adjacent Tree Regeneration in a Mountainous Forest. Annals of Biological Reasearch 3: 1700–1703.

Natural Resources Office of Guilan (NROG) 2006. Forestry replanting booklet of 2th series. In: Organization of forest, r.a.w. (Ed.), 701 p.

Nouri Z., Feghhi J., Alava S.J. 2008. Investigation on the sustainability of tree species diversity using common sample plots in forest management planning (Case study: Gorazbon district, Kheyroud Forest). Journal of the Iranian Natural Resources 61: 909–919.

Parendes L.A., Jones J.A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the HJ Andrews Experimental Forest, Oregon. Conservation Biology 14: 64–75.

Parsakhoo A., Hosseini S.A., Pourmajidian M.R. 2009. Plants canopy coverage at the edge of main communications network in Hyrcanian forests. Journal of Ecology and The Natural Environment 1: 037–044.

Raunkiaer C. 1934. The life forms of plants and statistical plant geography, being the collected papers of C. Raunkiaer, 632 p.

Research (CFIF) 1999. The CIFOR Criteria and Indicators Generic Template. CIFOR.

Smith G.F., Iremonger S., Kelly D.L., O'Donoghue S., Mitchell F.J. 2007. Enhancing vegetation diversity in glades, rides and roads in plantation forests. Biological Conservation 136: 283–294.

Spellerberg I. 1998. Ecological effects of roads and traffic: a literature review. Global Ecology and Biogeography 7: 317–333.

Tinya F., Marialigetti S., Kiraly I., Nemeth B., Odor P. 2009. The effect of light conditions on herbs, bryophytes and seedlings of temperate mixed forests in Orseg, Western Hungary. Plant ecology 204: 69–81.

Zang R., Ding Y. 2009. Forest recovery on abandoned logging roads in a tropical montane rain forest of Hainan Island, China. Acta Oecologica 35: 462–470.

Zhu K., Woodall C.W., Ghosh S., Gelfand A.E., Clark J.S. 2014. Dual impacts of climate change: forest migration and turnover through life history. Global Change Biology 20: 251–264.

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 171–180

SOIL ORGANIC MATTER CHANGES IN RESULT OF FOREST FIRES IN VITOSHA MOUNTAIN

Emiliya Velizarova[1*], Rumen Nedkov[2], Ibrahim Molla[1], Mariana Zaharinova[2], and Boyka Malcheva[3]

[1]Department of Forest Ecology, Forest Research Institute – BAS, 132 St. K. Ohridski Blvd., 1756 Sofia, Bulgaria. *E-mail: velizars@abv.bg
[2]Department of Aerospace Information, Space Research and Technology Institute – BAS, Acad. G. Bonchev Str. Bl. 1, 1113 Sofia, Bulgaria. E-mail: rnedkov@space.bas.bg; marianaz@space.bas.bg
[3]Department of Soil Science, University of Forestry, 10 St. K. Ohridski Blvd., 1797 Sofia, Bulgaria. E-mail: boika.malcheva@gmail.com

Received: 15 September 2014 Accepted: 30 October 2014

Abstract

Forest fires in Bulgaria are frequent in recent years, especially when summer droughts are prolonged. The carbon biogeochemical cycle is the most sensible to forest fires. The goal of the present investigation was to study the changes in the quantity and stocks of soil organic carbon in result of the forest fire, occurred on the territory of Biosphere Reserve (BR) ’Bistrishko branishte‘ and ’Vitoshko lale’ in Vitosha Mountain during the summer of 2012. Both territories of Vitosha Natural Park, affected by fires in year 2012 have been mapped. It was established that the total carbon content in the soils in Biosphere Reserve ’Bistrishko branishte‘ and ’Vitoshko lale‘ area decreased significantly as a consequence of the fire. This diminution is more substantial for Biosphere Reserve ’Bistrishko branishte‘ – about 7 %. The fires have led to a significant decrease of organic carbon stocks (ΔSOC_{stock}) in both regions – respectively with about 22 $tC \cdot ha^{-1}$ for BR ’Bistrishko branishte‘ and from 8.0 $tC \cdot ha^{-1}$ to 25 $tC \cdot ha^{-1}$ for ’Vitoshko lale‘. In only one sampling area in ’Vitoshko lale‘, an increase in the carbon stocks by about 10 $tC \cdot ha^{-1}$ has been registered.

Key words: Biosphere Reserve ’Bistrishko branishte‘, soil organic carbon content, soil organic carbon stocks.

Introduction

Forest fires cause more sizable consequences in the environment during the recent decades (Pausas et al. 2008, Bowman et al. 2009). Global trends are to increase the frequency of fires and the damage they cause, which lead to loss of wood material, forest and soil degradation. According to Rapid Damage Assessment, established within European Information System for Forest Fires (EFFIS), in 2012, affected by fire forest areas in 22 countries in Europe and the Mediterranean are about 950,020 ha (Schmuck et al. 2013).

Forest fires in Bulgaria are frequent in recent years, especially when summer droughts are prolonged. The burned forest areas in Bulgaria for 2012 were 12,729.8 ha (Konstantinov 2013).

Carbon biogeochemical cycle seems to be the most sensible of all biogeochemical cycles to forest fires. The vegetation keeps on Earth's surface about 500 PgC (Prentice 2001), while in the soil is kept around 1.5 PgC (Rice 2002).

The sustainability of carbon stocks in forest ecosystems depends on various natural and anthropogenic factors (Larionova et al. 2002), including forest fires (Overby et al. 2003). Consequences of fires on forest ecosystems are enormous, taking into account the fact that forests cover an area of about 4.1 Gha and represent the main 'sink' for terrestrial carbon stocks (Dixon and Wisniewski 1995).

Forest fires affect the soil organic carbon content both by destruction of forests, as a result of which the input of organic materials is reduced and by removal of surface soil layer in result of soil erosion (Elliot 2003). Moreover, the burning of biomass from large areas, including surface organic horizons of the soil, is a huge source of greenhouse gases emissions – carbon dioxide (CO_2) and methane (CH_4) (Crutzen and Goldammer 1993, Nave et al. 2011) that are released into atmosphere and contributing to climate change (Levine 1994). Previous studies performed in Vitosha Mountain have been devoted to assessment of damages in spruce forests by wind fall through Landsat and ICONOS images (Gikov and Pironkova, 2005), and on age structure and historical development of Bistrishka River watershed forest (Tsvetanov and Panayotov 2013). Limited investigations have been performed in relation to the forest fire, occurred in July 2012 and its consequences on the forest ecosystem.

The purpose of present investigation was to study the changes in quantity and stocks of soil organic carbon in result of the forest fires, which occurred on the territory of Biosphere reserve 'Bistrishko branishte' and 'Vitoshko lale' in Vitosha Mountain in 2012.

Materials and Methods

The studied soil and forest litter samples were collected from the area of Biosphere Reserve 'Bistrishko branishte' (BRBB) and 'Vitoshko lale' (VL), located in Vitosha Natural Park (NP), affected by the fire in the summer of 2012. It was performed one month after the fire. Two soil profiles and two mattocks (total three replications at each point) have been established at BRBB – named SS 1 and SS 2. Additionally, two sampling sites have been established in the unburned territory of the BBBR, designated as U1 and U2, respectively. At the same sampling sites, forest litter was also collected. The spatial distribution of soil profiles at BRBB is presented in Figure 1.

The altitude of sampling sites varies between 1490 and 1969 m a.s.l. The slopes are steep (up to 55 %). The soil profiles from the territory of BRBB have a dark brown coloured surface horizon with depth of 50–55 cm, followed by a light brown horizon. There is no clear boundary between the horizons. The chemical and morphological characteristics are representative for the group of Mollic Cambisols (WRBSR 2006).

From the affected by the fire of 12.10.2012 area in the region of 'Vitoshko lale', four soil profiles and two mattocks in the vicinity of each of the soil profiles (three replications) were established three weeks after fire occurrence. The sampling sites, where the soil profiles were established are identified as follows – SS 3, SS 4, SS 5 and

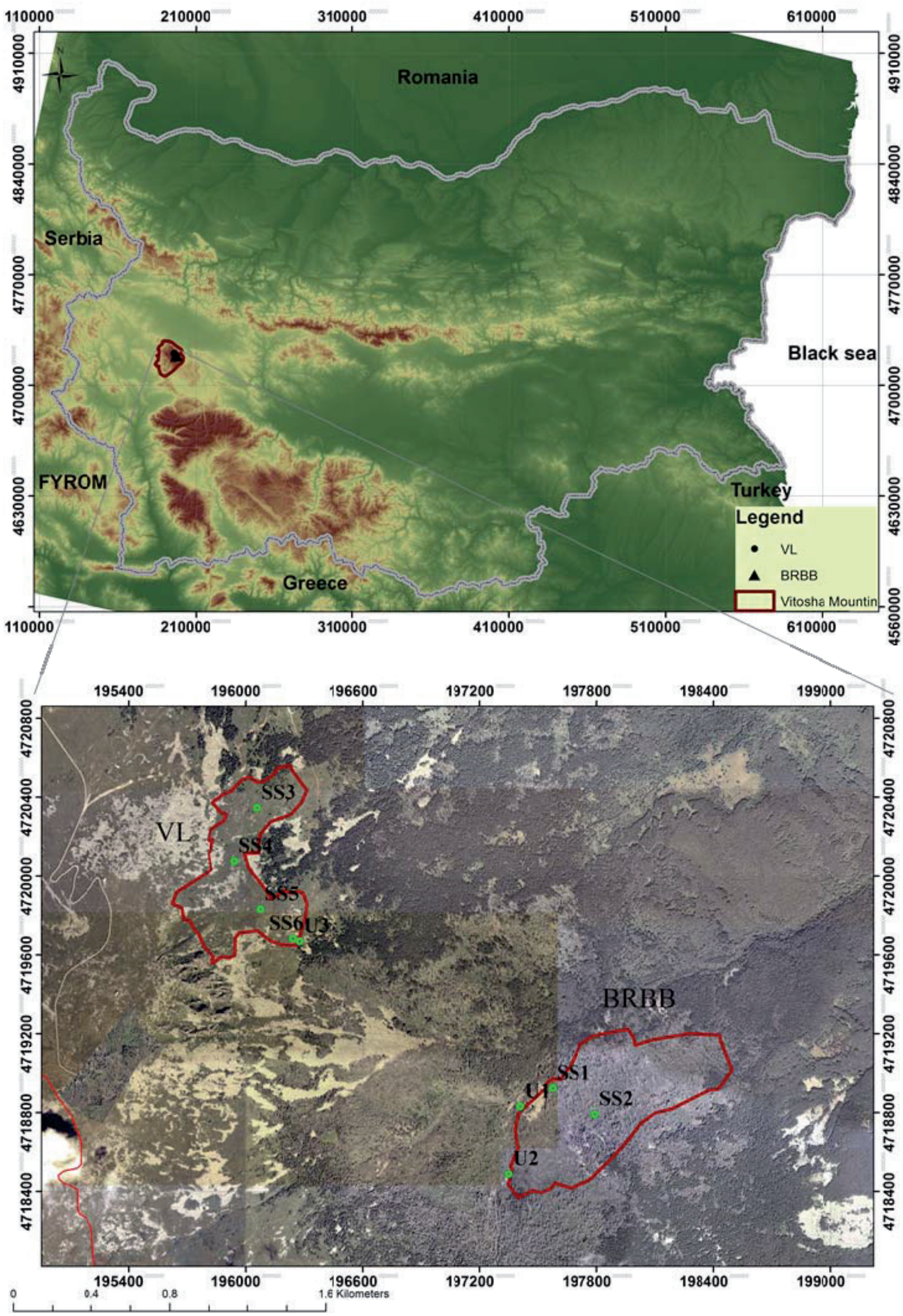

Fig. 1. Map of sampling sites in NP Vitosha, BR ’Bistrishko branishte‘and ’Vitoshko lale‘.

Table 1. Characteristics of the experimental sampling sites.

Studied area	Sampling sites (SS)	Dominant vegetation	Altitude, m	Geographical positions
BR ’Bistrishko branishte’ (BRBB)	SS 1	*Picea abies* (L.) Karsten	1520	42°33’48.5”N 23°18’56.9”E
	SS 2		1529	42°33’44.6”N 23°19’6.7”E
	U 1		1494	42°33’45.3”N 23°18’49.9”E
	U 2		1490	42°33’34.1”N 23°18’47.9”E
’Vitoshko lale’ (VL)	SS 3	*Juniperus sibirica* L. *Vaccinium. uliginosum* L.	1969	42°34’32.4”N 23°17’47.9”E
	SS 4		1965	42°34’23.5”N 23°17’43.3”E
	SS 5		1925	42°34’15.8”N 23°17’49.6”E
	SS 6		1856	42°34’11.2”N 23°17’57.1”E
	U 3		1856	42°34’10.8”N 23°17’58.6”E

SS 6 (Figure 1 – VL). The control soil profile was set up near to affected area at the same altitude and exposure and designated as U3. The soil depth from VL area was between 70 and 80 cm. The surface horizon is dark brown and about 40–45 cm thick, followed by a skeletal BC horizon. Gravel, stones or boulders occur throughout the profile development. According to WRBSR (2006) description, the soil from ’Vitoshko lale‘ area belongs to Mollic Cambisols). The main characteristics of fire space are provided in Table 1.

The fire affected areas were delineated and mapped with GPS. Through 32 points with GPS coordinates, it was found that the fire affected area BR ’Bistrishko branishte‘ is 51.81 ha. Because of the rugged terrain, the fire affected area of ’Vitoshko lale‘ was delineated and mapped through 68 points with GPS coordinates. It was found that it is 33.68 ha. Maps are presented in Figure 2.

Soil samples were taken from layers 0–5 cm and 5–20 cm. Forest litter was collected with a 20×20 cm frame in order to calculate its carbon stocks. The main characteristics of the soil – pH, organic carbon (*C* %) and bulk density were determined by standard methods described by Donov et al. (1971).

Soil bulk density was determined from a sample taken in undisturbed state by a steel ring of a known size. Total nitrogen content in the soil was determined through Kjeldahl method. Soil organic carbon was determined by its oxidation to CO_2 using $K_2Cr_2O_7$ as oxidant in sphuric acid.

Soil carbon stocks was determined according to the methodology described in detail by Stolbovoy et al. (2007). The main steps for calculation are the following:

$$SOC_{site} = \sum_{layer=1}^{j}[SOC_{content} \cdot BD \cdot D \cdot (1-F)] \qquad (1),$$

where:

$SOC_{content}$ – total soil organic carbon content (C_{total}), % of mass $\frac{C, kg}{Soil, kg} \cdot 100$;

BD – soil bulk density, $\frac{kgSoil}{dm^3}$;

D – thickness of the sampled layer, dm;

F – volume of coarse fragments (d > 2 mm), % of mass or $\frac{Stone, m^3}{Soil, m^3}$.

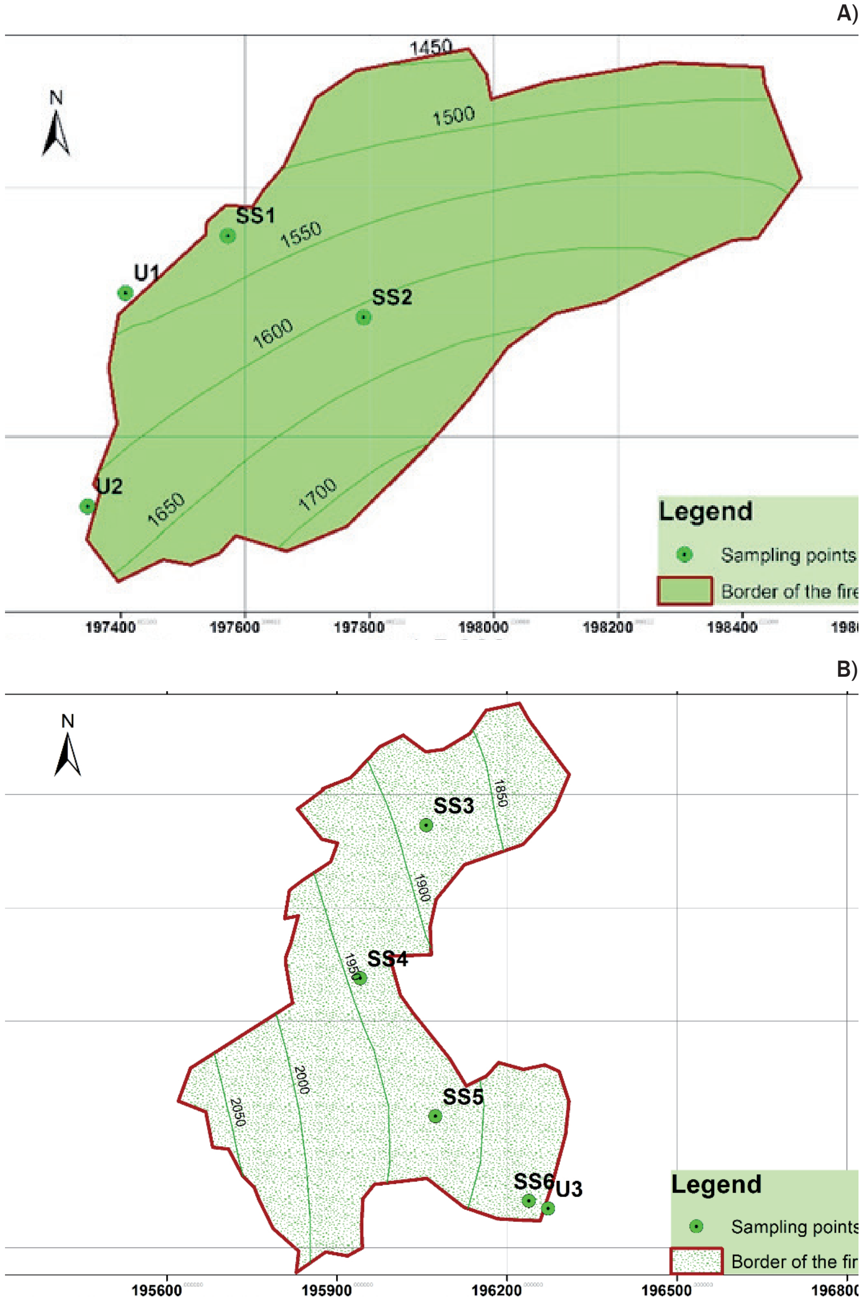

Fig. 2. Maps of the areas of the BR ’Bistrishko branishte‘ (A) and ’Vitoshko lale‘ (B), affected by fire.

The changes of soil carbon stock for a given area (ΔSOC_{stock}) could be calculated through the equation:

$$\Delta SOC_{stock} = SOC_{new} - SOC_{ref.stock} \quad (2),$$

where:

$SOC_{ref.stock}$ is soil carbon stocks value, calculated by equation 1, and refers to values, obtained for unburned territory (control) sampling site;

SOC_{new} – refers to soil carbon stocks after the influence of forest fire.

Results and Discussion

The results for total soil organic carbon content $SOC_{content}$ vuv formulata izglezda po drug nachin in the surface 0–5 cm of the soil from BRBB show that it is about 10.0 %, while in the control sampling sites (U1 and U2) is much higher and range from 17 to 18 % (Table 2). In the surface 0–5 cm soil layer from 'Vitoshko lale' area, $SOC_{content}$ ranged from to 14.2 % in the soil from SS 5 to 17.0 % in the soil of SS 3. A probable reason for this variation in $SOC_{content}$ is the difference in the content and composition of forest litter stocks, which is formed on the surface of the mineral soil layer. Cui et al. (2014) found that the total amount of SOC in the surface 0–10 cm of soil was dynamic after fire disturbance, and the direction and magnitude of the changes largely depended on burning severity and post-fire period. The content of fallen biomass and forest litter stocks from BR 'Bistrishko branishte' suppose a higher fuel load and organic carbon input. In our study, a tendency for decreasing of soil organic carbon content was found for variants, affected by forest fire in comparison with values for control (unburned) sampling site – U1, U2 and U3. The differences in the values of this index for fire affected soils from BR 'Bistrishko branishte' and the control variant were –7.1 % and –7.7 %, while for the soil from 'Vitoshko lale' area were as a minimum of – 0.75 % for SS 3 and as a maximum of –3.50 % for SS 5. The higher severity of fire spread on the territory of BR 'Bistrishko branishte' has obviously caused a significant immediate carbon loss in topsoil through direct combustion. Similar results for coniferous forests have been reported by Cui et al. (2014). The deeper soil layer (5–20 cm) from BR 'Bistrishko branishte' was influenced by the forest fire to a lesser degree, than the surface one. The $SOC_{content}$ of this layer has decreased by about 3.0–3.6 % in comparison with control variants.

It was found that the fire has affected stronger the 5–20 cm soil layer from 'Vitoshko lale' area. Our results are in agreement with similar observations reported by other authors (Brender and Cooper 1968, Cole et al. 1992), established that effects of direct combustion are typically limited to the unconsolidated leaf litter. Thus, our results show that SOC_{conten} in the forest litter from BR 'Bistrishko branishte' was 30.1 % after the fire and 53.5 % before it. The average $SOC_{content}$ in the forest litter for 'Vitoshko lale' area after the fire was higher and varied from 43.0 % to 63.0 %. Obviously, the forest fire released the carbon (C) and nitrogen (N), stored in biomass and surface soil layers through combustion. The sensitivities of $SOC_{content}$ and *SCD* to fire disturbance were inconsistent due to changes in soil bulk density. It has been reported that post-fire increase in *SCD* resulted from the shrinkage (which associated with the destruction of macro-aggregate) of topsoil, while the magnitude of $SOC_{content}$ changes depend on the burning severity (Cui et al. 2014).

The results for SOD_{site} demonstrate the successive decline in soil organic car-

Table 2. Carbon stocks in soil/forest litter from BR 'Bistrishko branishte' and 'Vitoshko lale'.

Sampling site	Horizon, cm	Soil/*FL organic carbon content ($SOC_{content}$), Mean (± SD)	Total soil nitrogen (N), % Mean (± SD)	C/N	**BD, kg soil·dm^{-3} or FL mass, kg·m^{-2}	Soil carbon density (SCD_{site}), kg C·m^{-2}	SCD_{site} (for each studied soil depth), t·ha^{-1}	SCD_{site}, t·ha^{-1}	Soil organic carbon stocks ΔSOC_{stoc}, tC·ha^{-1}
SS 1	*FL* 1 (L+F+H)	31.20 (1.077)	0.38 (0.065)	82.1	109.64	–	–	342.10	–223.6
	0–5	10.39 (0,142)	0.66 (0.081)	15.8	0.39	2.03	20.25	53.74	–21.4
	5–20	7.44 (0.097)	0.44 (0.055)	16.9	0.30	3.35	33.48		
SS 2	*FL* 2 (L+F+H)	28.94 (1.066)	0.31 (0.054)	93.4	101.25	–	–	395.10	–198.7
	0–5	9.77 (0.112)	0.59 (0.043)	16.6	0.34	1.66	16.61	47.44	–22.0
	5–20	6.85 (0.107)	0.40 (0.047)	17.1	0.30	3.08	30.83		
U 1	*UFL* 1 (L+F+H)	53.51 (1.174)	0.86 (0.104)	62.2	22.14	–	–	118.50	
	0–5	18.11 (0.126)	0.77 (0.087)	23.5	0.26	2.35	23.54	75.12	
	5–20	11.09 (0.097)	0.48 (0.055)	23.1	0.31	5.16	51.57		
U 2	*UFL* 2 (L+F+H)	51.77 (1.233)	0.75 (0.075)	69.0	18.61	–	–	96.40	96.4
	0–5	16.94 (0.118)	0.77 (0.075)	22.0	0.25	2.12	21.18	69.48	
	5–20	9.79 (0.104)	0.48 (0.044)	20.4	0.33	4.38	48.29		
SS 3	*FL* 3 (L+F+H)	54.45 (1.211)	nd	–	20.09	–	–	109.40	
	0–5	16.95 (0.123)	0.59 (0.045)	28.7	0.35	2.97	29.7	111.0	–25.2
	5–20	11.30 (0.088)	0.54 (0.041)	20.9	0.48	8.14	81.4		
SS 4	*FL* 4 (L+F+H)	43.80 (1.066)	nd	–	21.19	–	–	92.80	
	0–5	15.00 (0.115)	0.57 (0.055)	26.3	0.45	3.38	33.8	120.4	–15.9
	5–20	10.50 (0.082)	0.52 (0.043)	20.2	0.55	8.66	86.6		
SS 5	*FL* 1 (L+F+H)	63.45 (1.532)	nd	–	30.68			194.70	
	0–5	14.20 (0.077)	0.58 (0.043)	24.5	0.46	3.27	32.7	128.1	–8.2
	5–20	10.10 (0.067)	0.43 (0.037)	23.5	0.63	9.54	95.4		
SS 6	*FL* 1 (L+F+H)	42.75 (1.306)	nd	–	18.45			78.90	
	0–5	15.75 (0.113)	0.57 (0.054)	27.6	0.50	3.94	39.4	146.1	9.9
	5–20	10.95 (0.123)	0.37 (0.022)	29.6	0.65	10.68	106.8		
U 3	0–5	17.70 (0.233)	0.60 (0.051)	29.5	0.30	2.66	26.6	136.3	
	5–20	13.80 (0.118)	0.54 (0.035)	25.6	0.53	10.97	109.7		

Note: nd – no data; *FL – Forest litter; **BD – Soil bulk density.

bon density (*SOCD*) for 0–5 cm soil layer from SS 1 and SS 2 sites, while the *SOCD* was significantly elevated for all variants from VL fire affected area. The forest fire in BRBB consumed more litter and soil organic material, which suggest a more severe burning.

In the fire-affected soil of BR 'Bistrishko branishte', the total nitrogen content decreases in comparison with the control variant – for both studied soil layers – 0–5 cm and 5–20 cm (Table 2). As reported in the literature, clearly, the type and composition of the vegetation affect nitrogen content of soil after a fire (Bonan 1990, Barbosa et al. 2009). More considerable losses (about 40.0 %) of the total content of nitrogen were observed in the forest litter. In a review of the impacts of fire on nutrient cycling, Boerner (1982) reported net losses of 30–100 % of litter N during fire as the result of direct volatilization and ash convection. Direct losses of nitrogen (in form of NH_3 and NO_x) in the course of organic matter (OM) destruction were reported by Gleixner et al. (2001). It can be concluded that the decomposition and nitrogen availability in result of forest fire is a function of substrate quality, the soil thermal regime, or their interactive effects.

In order to compare the results of soil organic carbon stocks changes (SOC_{stock}) the results in Table 2 are normalized for an area of 1 ha. For this area, the soil organic carbon stocks was range from 70 to 75 tC·ha^{-1} in the unaffected by forest fire soil, but much higher in forest litter – 100–120 tC·ha^{-1}. The results show that the carbon stocks in the surface 20 cm hsoil layer decreased by about 22.0 tC·ha^{-1} due to the fire in BRBB area. Depletion of SOC_{stock} to a different extent was established also for SS 3, SS 4 and SS 5 of 'Vitoshko lale', however, the decrease ranges from 8 to 25 tC·ha^{-1}. Only for the soil from SS 6, a slight increase in carbon stocks by about 10 tC·ha^{-1} was found. As the vegetation cover of 'Vitoshko lale' area was presented mainly by shrubs, bushes and grass and rarely by spruce trees, forest litter was not formed. Thus, the fire severity was due to living biomass load and surface soil organic carbon content. The importance of dominant C concentration gradient for fire severity was discussed in more detail by Kasischke et al. (2005).

Conclusions

The territories of Biosphere Reserve 'Bistrishko branishte' and 'Vitoshko lale' area of Vitosha Natural Park, affected by fires in year 2012 have been mapped. A v matmet i cel e edin pozar

It was established that the total carbon content in the control (unaffected) soils in Biosphere Reserve 'Bistrishko branishte' is between 17.0 % and 18.0 % but decreases significantly as a consequence of the fire to about 10.0 %.

The decrease in total carbon content in soils from 'Vitoshko lale' is maintained as a trend, but the differences in comparison with the control soils are much lower – from 0.75 % for SS 3 to a maximum of 3.50 % for SS 5.

In fire-affected soils in 'Bistrishko branishte', the nitrogen content decreases. Similar tendency was established in fire-affected soils in 'Vitoshko lale'. In these soils the nitrogen content decreases after fire.

Organic carbon stocks in the surface 20 cm soil layer (for a unit area – 1 ha), are 70.0–75.1 tC·ha^{-1} in the soils of 'Bistrishko branishte' and 140 tC·ha^{-1} in the soils of 'Vitoshko lale' area.

The fires have led to a significant decrease of these organic carbon stocks in both regions (SOC_{stok}) – respectively with about 22 tC·ha^{-1} for BR 'Bistrishko branishte' and from 8.0 tC·ha^{-1} to 25 tC·ha^{-1} for 'Vitoshko lale'. In only one sampling area in 'Vitoshko lale', an increase in the carbon stocks by about 10 tC·ha^{-1} has been registered.

Among the various possible factors leading to a different degree of carbon stocks reduction in the investigated soils, the main reasons could be attributed to different severities of the fires and peculiarities of the vegetation covers in both studied regions. Changes in the soil bulk density can also influence the organic carbon stocks.

References

Barbosa P., Camia P., Kusera J. 2009. Assessment of forest fire impacts and emissions in the European Union based on the European Forest Fire Information System. In: Bytnerowicz M. Arbaugh and C. Andersen (Eds.). Wildland Fires and Air pollution. Elsevier: New York: 197–208.

Boerner R. 1982. Fire and nutrient cycling in temperate ecosystems. BioScience 32: 187–192.

Bonan G. 1990. Carbon and nitrogen cycling in North American boreal forests. Biogeocchemistry 10(1): 1–28.

Bowman D., Balch J., Artaxo P., Bond W., Carlson J., Cochrane M., Antonio C., DeFries R., Doyle J., Harrison S., Johnston F., Keeley J., Krawchuk E., Kull M., Marston C., Moritz J., Prentice M., Roos I., Scott A., Swetnam T., Van der Werf G., Pyne S. 2009. Fire in the Earth system. Science 324: 481–484.

Brender, E., Cooper E. 1968. Prescribed burning in Georgia's piedmont loblolly pine stands. Journal of Forestry 66: 31–36.

Cole K., Klick K., Pavlovic N. 1992. Fire temperature monitoring during experimental burns at Indiana Dunes National Lakeshore. Natural Areas Journal 12: 177–183.

Crutzen P., Goldammer J. 1993. Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. John Wiley and Sons: New York, 456 p.

Cui X., Gao F., Song J., Sang Y., Sun J., Di X. 2014. Changes in soil total organic carbon after an experimental fire in a cold temperate coniferous forest: A sequenced monitoring approach. Geoderma 226–227: 260–269.

Dixon R., Wisniewski J. 1995. Global forest systems: an uncertain response to atmospheric pollutants and global climate change. Water Air Soil Pollut 85: 101–110.

Elliot W. 2003. Soil erosion in forest ecosystems and carbondynamics. In: Kimble J.M., Heath L.S., Birdsey R.A., Lal R. (Eds.). The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, Boca Raton, FL: 175–190.

Gikov A., Pironkova Z. 2005. Using geoinformation technologies for assessment of Tornado damages in forest areas. In Proceeding Scientific Conference 'Space, Ecology, Safety' with International Participation. SES'2005. 10–13 June 2005, Varna, Bulgaria: 269 – 274 (in Bulgarian).

Gleixner G., Czimczik C. I., Kramer C., Lükher B., Schmidt M.W.I. 2001. Plant compounds and their turnover and stability as soil organic matter. In: Schulze E.-D., Harrison S.P., Heimann M., Holland E.A., Lloyd J., Prentice I. C., Schimel D. (Eds.). Global Biogeochemical Cycles in the Climate System. Academic Press, San Diego: 201–215.

Kasischke E., Johnstone J. 2005. Variation in post fire organic layer thickness in a black spruce forest complex in interior Alaska and its effects on soil temperature and moisture. Canadian Journal of Forest Research 35: 2164–2177.

Konstantinov V. 2013. Preservation and protection of forest territories from fires in 2012. Gora 2: 19–21 (in Bulgarian).

Larionova A., Rozanova L., Evdokimov I., Ermolaev A. 2002. Carbon budget in natural and anthropogenic forest-steppe ecosystems. Euroasian Soil Science 35(2): 156–164.

Levine J. 1994. Biomass burning and the production of greenhouse gases. In: Zepp RG, editor. Climate biosphere interaction: biogenic emissions and environmental effects of climate change. New York, USA: John Wiley & Sons: 139–159.

Nave L., Vance E., Swanston C., Curtis P. 2011. Fire effects on temperate forest soil C and N storage. Ecological Applications 21: 1189–1201.

Overby S., Hart S., Neary D. 2003. Impacts of natural disturbance on soil carbon dynamics in forest ecosystems. In: Kimble J., Heath L., Birdsey R., Lal R. (Eds.). The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, Boca Raton, FL: 159–172.

Pausas J., Lovet J., Rodrigo A., Vallejo R. 2008. Are wild fires a disaster in the Mediterranean basin? – A review. International Journal of Wildland Fire 17: 713–723.

Prentice I.C. 2001. The carbon cycle and atmospheric carbon dioxide. In: Houghton J.T. (Ed.). Climate change 2001: the scientific basis: contribution of Working Group I to the Third Assessment Report of the Intergouvernmental Panel on Climate Change. Cambridge University Press: 183–237.

Rice C.W. 2002. Geotimes – January 2002 – Carbon in Soil. Geotimes. Retrieved June 30, 2008, Available: http://www.agiweb.org/geotimes/jan02/feature_carbon.html

Schmuck G., Ayanz J., Camia A., Durrant T., Boca R., Libertà G., Schulte E. 2013. Forest Fires in Europe Middle East and North Africa. Office of the European Union. Luxembourg, 109 p.

Tsvetanov N., Panayotov M. 2013. Age Structure and Historical Development of Forests in 'Bistrishko branishte' Biosphere Reserve in Vitosha Mountain (Bulgaria). Ecologia Balcanica 5(1): 129–136.

WRBSR 2006. World Reference Base of Soil Resources (WRBSR), 2006. World Soil Resources Reports 103, 127 p.

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 181–187

QUANTIFICATION, MAIN CHARACTERISTICS AND POSSIBILITIES FOR RECOVERY AND DISPOSAL OF FOOD WASTE

Dilyana Yordanova* and Vanya Kyoseva

Department of Environmental Engineering, University of Chemical Technology and Metallurgy, 8 St. K. Ohridski Blvd., 1797 Sofia, Bulgaria.
E-mail: dilyana.yordanova@outlook.com*, vanya_kyoseva@uctm.edu

Received: 07 July 2014 Accepted: 30 October 2014

Abstract

Food waste is a serious global problem that leads to negative environmental, social and financial impacts. Worldwide losses of food in the stages of production, transportation, retail and consumption of food are significant – a third of the annual production output falls in the waste stream. A quantification of food waste in the country is presented in the paper. An analysis of the possibilities for sustainable management of food waste in Bulgaria by introducing measures to prevent its generation, separate collection implementation and application of proven technologies such as composting and anaerobic digestion, to ensure protection of the environment and human health is done.

Key words: anaerobic digestion, bio-waste, composting treatment, Introduction, utilisation.

Introduction

Food waste has important economic, environmental and social implications. As the global population continues to increase, the security of food supply is an issue that challenges governments all over the world.

Inappropriate management of municipal solid waste (MSW) in landfills contributes from 4 % to 11 % of the world's Greenhouse Gas (GHG) emissions (Ingram 2011). Properly managed food waste by means of separate collection and recycling has a positive impact on climate change – by transforming food waste into compost by means of a low-cost and immediately available technique, the organic matter is stored in soils and not lost into the atmosphere as CO_2 or methane (Bond et al. 2013).

Food waste also classified as ʼbio-waste‘ is a major group of biodegradable waste. The concept of food waste includes food from households, restaurants, caterers and retail premises, obsolete and expired food, inedible stocks from food processing plants (Henningsson et al. 2004). Table 1 presents the main groups of food waste according to Bulgarian legislation.

Main Characteristics of Food Waste

From a life cycle perspective, the term ʼfood waste‘ includes large sources of biogenous waste (bio-waste) along the food production chain:

Table 1. Major food waste types (Regulation No2 2014).

Description	Code	Waste
Food waste from households and catering	20 01 08	biodegradable kitchen and canteen waste
Expired food products of animal origin	02 02 03	materials unsuitable for consumption or processing
Expired food products of plant origin	02 03 04	materials unsuitable for consumption or processing
Only biodegradable waste equivalent to codes 20 01 08 and 20 02 01	20 03 02	waste from markets

- losses after harvesting;
- losses during transportation to industry;
- losses and surplus from food industry;
- residues from markets;
- residues from restaurants and catering;
- household food waste.

Estimates of how much food is wasted vary. The most recent report commissioned by the Food and Agriculture Organization (FAO) of the United Nations indicates that approximately 1,32 billion tonnes of food is lost or wasted annually, equivalent to about one-third of food produced for human consumption (Flammini et al. 2013). A recent study conducted on behalf of the European Commission's DG Environment estimated that approximately 89 million tonnes of food waste (674,000 tonnes in Bulgaria) was generated in 2006 within the EU-27, equivalent to 179 kg per person (Buchner et al. 2012). This amount is expected to rise to approximately 126 million tonnes (40 % increases) by 2020 unless additional preventive measures are taken (Kalley 2013).

The proportion of food waste arising at different stages of food supply chain varies depending upon the level of industrialisation (Gustavsson et al. 2011). Lower income countries tend to produce proportionally more food waste during production and processing, as these tend to rely on low-tech production methods. In higher income industrialised countries food is wasted because of the high expectations placed on the supply chain by retailers, consumers and society on the quality and visual appearance of food products (Parfitt et al. 2010).

Figure 1 provides specific information about the breakdown of total food wastage across food supply chain in European Union.

Food wastage by consumers has a direct impact on the quantity and composition of municipal solid waste MSW. As food waste is readily biodegradable, it has a direct impact on its biodegradability if mixed with food waste, which in turn affects how MSW is collected, treated and disposed of. The higher percentage of food wastes in MSW, the more crucial the need for source separation of waste. This is because separately collected food waste (together with other bio-waste) could be recycled into quality compost and could also be used to produce biogas as a renewable source of energy.

When food waste is not source-separated, it can only be partly sorted by mechanical methods, however the quality of recycled materials (particularly the end compost) largely decreases due to source contamination with other substances which might be hazardous. Alternatively, mixed waste could be incinerated, however the high water content of food waste reduces the combustion efficiency and energy recovery efficiency.

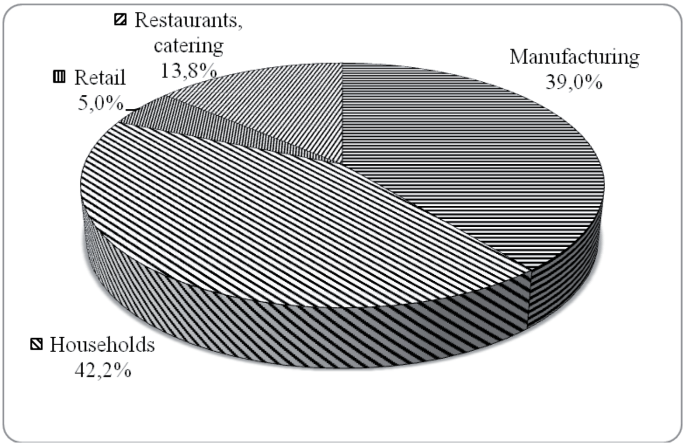

Fig. 1. Breakdown of Food Waste across EU-27 (Monier et al. 2010).

Analysis of Possible Methods for Recovery and Disposal of Food Waste

The Waste Management Act sets out a 'waste hierarchy', from prevention through to disposal via preparation for reuse, recycling and recovery. As applied to food, the waste hierarchy translates into a 'food use hierarchy' from prevention to landfill via redistribution to humans, feeding to animals and energy or nutrient recovery by methods such as anaerobic digestion and in-vessel composting (Figure 2).

The necessity for solution for the recovery and disposal of food waste is defined by some of its key features:

- easily contaminated by hazardous substances;
- unstable, source of nuisance and of pollution in landfills (emission of greenhouse gases, groundwater contamination and contamination of surface waters by leachate);
- moisture of food waste is variable, which has an influence on the logistical and technical requirements for its collection and further processing and also on the net calorific value.

There are several alternatives for managing food waste, including anaerobic digestion, composting (aerobic digestion), incineration and landfill.

Disposal of mixed municipal solid waste collected without pre-treatment or separation of food waste is common in almost all Bulgarian municipalities. This is an unacceptable practice as disposal of bio-waste involves a number of risks to the environment such as generation of landfill gas with a high global warming potential, leachate formation and occupation of space. It is a general requirement

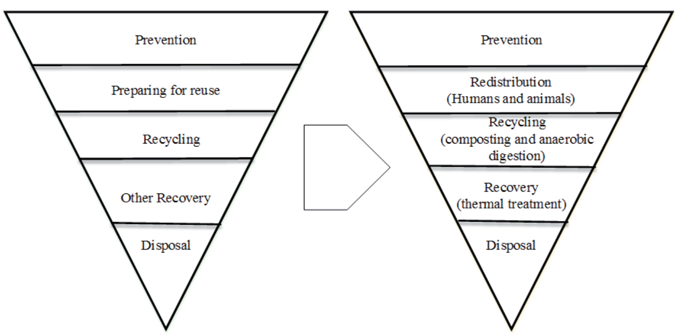

Fig. 2. Application of waste management hierarchy to food waste.

of EU Landfill Directive that all Member States have to reduce the amount of biodegradable municipal waste landfilled by 35 % by 2016. The target is related to the generated amount of bio-waste in 1995 (2,248,000 t). However, Bulgaria has benefited from a four- year derogation period.

Combustion of food waste is economically inefficient. The reason for this is high water content of food waste and its relatively low calorific value, which varies in the range of 1.8–4 GJ/t. However, these properties of food waste make it very suitable for disposal through biological treatment. By integrating anaerobic digestion and composting, both energy yields of 0.6 MWh/t and material recycling rates of 40 % could be achieved (Lipinski et al. 2013). Thus biological treatment contributes positively to CO_2 savings both by saving the use of fossil fuels through the production of biogas and by sequestration of carbon into soils through composting.

Composting is the decomposition process of food waste under controlled aerobic conditions. Compost is a valuable end product which contains recycled nutrients and carbon. Composting associated emissions include CO_2 (of biogenic origin), CH_4, NH_3 and N_2O, which should be minimized by using bio-filters. Measures to ensure the necessary qualities for the use of compost as a soil improver include the introduction of separate collection of food waste to avoid contamination with toxic elements such as heavy metals and organic pollutants, and carry out the process under optimum conditions (O_2 content, humidity, temperature, C/N ratio and maturing time).

Anaerobic digestion is a process of degradation of organic matter into simpler compounds in the absence of oxygen. When anaerobic digestion is applied to food waste, it can be operated under different technological conditions (Gray et al. 2008). Currently available technologies can be divided into three categories based on the amount of total solid (TS) content:

- dry: more than 20 % TS;
- semi-dry: between 10 and 20 % TS;
- wet: less than 10 % TS.

In wet systems the liquid is used as a transport media. Consequently food waste has to be made easy for pumping. Pumpability requires two conditions – the waste has to be very well separated from impurities to avoid damage to the installation and the waste has to be mashed so that a high degree of degradation can be achieved. In the following stage, energy gain in the form of biogas from the mashed fraction could be very high. The end products of anaerobic digestion are digested semi-product which can be composted and nitrogen-rich process water which is to be treated and discharged or may be used as liquid fertiliser after sanitation.

In dry systems the transport of waste is done mechanically by conveyer belts, screw conveyers, front loaders, etc. One of the advantages of dry systems is that the digested semi-product is better suited for composting because of its higher share of solids. Another advantage is that less waste water is produced compared to wet systems. The disadvantages are a lower amount of recoverable energy.

Integrating anaerobic digestion and composting offers the potential to adapt the process layout in order to enhance each specific aspect of both technologies, producing energy through biogas from anaerobic process and compost, nitrogen and nitrogen derivatives from aerobic technology (Figure 3). It enables both material and energy recovery from food waste, corresponding in an effective way to the waste management hierarchy.

The analysis of the advantages of integrated systems for anaerobic digestion and composting of food waste shows that they offer:

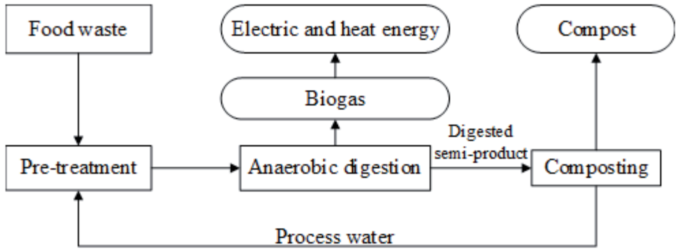

Fig. 3. Integrated system for food waste treatment.

- a better energy balance with a net production of energy, providing alternative renewable energy source replacing fossil fuels;
- a lower use of land surface compared to an only composting solution for the same amount of waste treated;
- a reduction in CO_2 emission because of the reduction in using fossil fuels and substitution of chemical fertilisers;
- a higher homogeneity of flows entering the aerobic section, with a better agronomic use of the fertilising elements (Nitrogen and other micronutrients are fixed);
- lower use of structuring material (i.e. green and park waste) compared to an only composting solution;
- a high efficiency in recovering material (compost) and energy (biogas), in order to reduce the climate impact and to close the nutriment cycle using digestion residues as fertiliser.

Results and Discussion

Prerequisites for the choice of food waste treatment method are its quantity and quality, and the availability of markets for related products. Table 2 shows a comparative analysis of different technologies for biological treatment of food waste.

In order to choose the most environmentally sound technology for the treatment of food waste, ensuring maximum use of their raw material and energy resources it is necessary to carry out a life cycle assessment of the processes. In some cases, the energy resulting from incineration of food waste (dry matter content <25 %) can be in a smaller quantity than from anaerobic digestion. The advantages of incineration of wet food waste are limited to emissions saved.

When comparing anaerobic digestion and subsequent composting of the digested semi-product and direct composting the key question is whether they produce a similar amount of compost and whether the composition of the compost-output from both processes is similar. If the composition is similar and the amount generated is similar, then the integrated system is likely to be environmentally preferable to direct composting. When anaerobic digestion is not technically feasible but composting is technically feasible, the choice is mainly between composting and incineration. In this case, a life cycle assessment is necessary to balance both types of benefits – key parameters include process efficiency, waste composition, transportation distances, etc.

Table 2. Comparison of options for biological treatment of food waste.

Treatment method	Capacity		End product		Energy yield, kWh/t
	Minimum, t/y	Maximum, t/y	Type	Application	
Open windrow composting	–	15,000	Compost	Growing media, soil improver	0
In-vessel composting	20,000	>200,000	Compost	Growing media, soil improver	0
Wet anaerobic digestion systems	30,000	>200,000	Digested semi-product	Soil improver	645
Dry anaerobic digestion systems	20,000	>200,000	Digested semi-product	Soil improver	600
Integrated systems anaerobic digestion + composting	20,000	>200,000	Compost	Growing media, soil improver	510

Conclusion

The review and analysis of alternatives for the treatment of food waste allows to formulate the following conclusions:

- food waste is generated at all stages of food production and supply chain – from agriculture, transport and storage, production, retail and consumption but priority should be given to biodegradable components of MSW and food storages, because of the quantities released and negative health and environmental effects;
- the percentage of food waste in the mixed municipal solid waste stream varies between 30 and 40, which means that in Bulgaria about 1.3 million t/y of food waste is generated;
- currently there is an effective system for recovery of food waste as raw material and energy resource;
- the analysis of applicable treatment technologies for food waste shows that the most preferable method for Bulgaria is an integrated system of anaerobic digestion and composting.

References

ANONYMOUS 2009. Green Paper on the management of bio-waste in the European Union. Committee on the Environment, Public Health and Food Safety.

ARSOVA L. 2010. Anaerobic digestion of food waste: Current status, problems and an alternative product. Columbia University, 77 p.

BOND M., MEACHAM T., BHUNNOO R., BENTON T.G. 2013. Food waste within global food systems. A Global Food Security report, 43 p.

BUCHNER B., FISCHLER C., GUSTAFSON E., REILLY J. 2012. Food waste: causes, impacts and proposals. Barilla Center for Food and Nutrition, 71 p.

FLAMMINI A., HOOGEVEEN J., IWEINS M., TUBIELLO F. 2013. FAO, Food Wastage Footprint. Impacts on Natural Resources, 63 p.

GRAY D., SUTO P., PECK C. 2008. Anaerobic Digestion of Food Waste, Final Report. U.S. Environmental Protection Agency, 62 p.

GUSTAVSSON J., CEDERBERG C., SONESSON U., VAN OTTERDIJK R., MEYBECK A. 2011. Global Food Losses and Food Waste: Extent, Causes and Prevention. FAO, 23 p.

HENNINGSSON S., HYDE K., SMITH A., CAMPBELL M. 2004. The value of resource efficiency in the food industry: a waste minimisation project, East Anglia UK Journal of Cleaner Production 12(5): 505–512.

INGRAM J. 2011. A food systems approach to researching food security and its interactions with global environmental change. Food Security 3(4): 417–431.

KALLEY T. 2013. Municipal waste management in Bulgaria. European Environment Agency, 16 p.

Lipinski B., Hanson C., Lomax J., Kitinoja L., Waite R., Searchinger T. 2013. Reducing Food Loss and Waste. Working Paper, Instalment 2 of Creating a Sustainable Food Future, Washington, DC: World Resources Institute, 40 p.

Monier V., Mudgal S., Escalon V., O'Connor C., Gibon T., Anderson G. 2010. European Commission, Preparatory Study on Food Waste across EU 27 (2010) Technical Report 2010 – 054, 213 p.

Parfitt J., Barthel M., Macnaughton S. 2010. Food waste within food supply chains: quantification and potential for change to 2050. Philosophical Transactions of the Royal Society 365(1554): 3065–3081.

Regulation No2 2014. Regulation No2 from 23.07.2014 on waste classification. Ministry of Environment and Water. (In Bulgarian).

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 189–196

SATELLITE MAPPING OF BULGARIAN LAND COVER – CORINE 2012 PROJECT

Anton Stoimenov[1], Radka Koleva[2*], Ventzeslav Dimitrov[1], Youlin Tepeliev[2], Todor Lubenov[1], and Julia Kroumova[3]

[1]Space Research and Technology Institute – BAS, Acad. G. Bonchev Str. Block 3, 1113 Sofia, Bulgaria.
[2]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria.
*E-mail: rad_koleva@abv.bg, rad.koleva@gmail.com
[3]National Institute of Geophysics, Geodesy and Geography – BAS, Acad. G. Bonchev Str. Block 3, 1113 Sofia, Bulgaria.

Received: 19 June 2014 Accepted: 06 November 2014

Abstract

CORINE Land Cover 2012 Bulgaria is a part of the Pan-European project CORINE Land Cover (CLC). Experts from 39 countries participate in this GMES/Copernicus program's project. The main aim of the project is to identify and map the changes of land cover/land use for the period 2006–2012 using multitemporal/multispectral satellite imagery. Harmonized methodology with a 44 class nomenclature and a computer assisted photo-interpretation are applied for creating a geospatial database of Bulgarian territory for the year 2012. In addition to the CLC work, a task for evaluation of five High Resolution Layers (HRL) is included. They are complementary to CLC and provide information on specific land cover characteristics: degree of imperviousness; forest, permanent grasslands, wetlands and permanent water bodies. A brief description of the applied methodology and the main results achieved are presented. The whole Bulgarian territory is mapped in details adequate for the 1:100 000 scale with a minimum mapping unit of 25 ha and a minimum change area of 5 ha. For the investigated period (2006–2012) dominant changes are observed in forests and semi-natural areas – 27,628 ha or 54.65 % of all changes, followed by agricultural lands (21 618 ha or 42.76 %). The statistical analysis of the created databases and a comparison between main land cover changes for the 1990–2000, 2000–2006 and 2006–2012 time periods are discussed. The average annual land cover change rate is 0.17 % which positions Bulgaria among the majority of the European countries having relatively small land cover changes.

Key words: change detection, CORINE Land Cover 2012, HRL, land use, remote sensing, satellite images.

Introduction

Until recently, it was generally assumed, that in the long term, human activity had little lasting effect on lands thanks to nature's ability to restore itself. This view remained prevalent for a long time, despite the fact that farming practices have been causing irreversible damage in certain areas for centuries (Heymann et al. 1994). Over the next few decades the global effects caused by land use and cover changes may be as significant as those associated with the climate changes. Changes in Land Use and Land Cover (LCLU) are directly linked to many facets of human health and welfare, including biodiversity, food production, and the origin and spread of diseases. Yet, we know very little about this important human-caused agent of global change (Fisher 1995, Skole 1996). As a response to these challenges many Land Cover projects are implemented on national, regional and global level. Most of them, including CORINE Land Cover are based on series of satellite imagery interpretation and classification. There are two main reasons making this approach extremely suitable for land cover mapping and change detection of large territories:

- Earth observation satellites provide repetitive coverage of our planet territory with an abundance of spatial and spectral resolution and rich archive data for the last 40 years;
- Changes in land cover result in changes in radiance values registered by satellite multichannel scanners;
- Changes in radiance due to land cover changes are large with respect to radiance changes caused by others factors such as differences in atmospheric conditions, differences in soil moisture and differences in sun angles.

Strategic discussions among European Environmental Agency (EEA) member countries and the main EU institutions, responsible for environmental policy, reporting and assessment, have underlined an increasing need for quantitative information on the state of the environment based on timely, quality-assured data, concerning in particular land cover and land use (Heymann et al. 1994). Based on these requirements EEA has been collaborating since 2006 with the European Commission and the European Space Agency in the implementation of a fast track service on land monitoring as part of the implementation of GMES (now – Copernicus Land Monitoring Services).

EEA aims at providing those responsible for and interested in the European environmental policy with qualitative and quantitative land cover data, which is consistent and comparable across the continent. As a part of the EEA mandate, the CORINE Land Cover (CLC) database initiated by the Commission in 1985 should be further maintained and updated regularly. Consistent geo-referenced land cover information has been identified by different national and European policies as a key database for integrated environmental assessment.

CORINE Land Cover 2012 (CLC2012) is the fourth European Land Cover inventory (1990, 2000, 2006 and 2012). The number of participating countries is increasing, at present being 39 with a total of mapped area of 5.8 million km^2 (Fig. 1).

In Bulgaria the project has been implemented by a team of academic experts – five from the Space Research and Technology Institute (SRTI), two from the University of Forestry (UF) and one from the National Institute of Geophysics, Geodesy and Geography (NIGGG). The monitoring and the control have been provided by the Executive Environment Agency at the Ministry of Environment and Waters.

Methodology and Data Used

The CORINE Land Cover 2012 Bulgaria project includes two main tasks: a) CLC2012 visual computer assisted

LCLU mapping and 2006–2012 change detection (the focus of this paper) and b) Verification and Enhancement of five land cover High Resolution Layers (HRL).

Methodology

Fig. 1. Countries participating in CORINE Land Cover 2012 pan-European Project.

The CLC2012 project's implementation is based on a harmonized and approved by all participating countries methodology. A detailed description of the first developments is described in EEA guideline publications (Heymann et al. 1994, CORINE … 1997, Bossard et al. 2000, CLC2006 … 2006) and accessed through the EEA official CORINE Land cover website (http://www.eea.europa.eu/publications/COR0-landcover). Developed in the 1980s, the methodology has been permanently improved to respond to the new technological achievements of Remote Sensing and Geoinformatics. The last methodological elaborations are described in a series of EEA documents and scientific publications (Büttner et al. 2011, 2012, 2004).

The main features of the methodology are:

- Basic input data – high resolution multispectral, multitemporal satellite images, covering vast territories in a short time;
- Use of a large amount of ancillary/*in situ* data – mainly orthophotos, topographic and thematic maps, specialized geo-databases (agriculture, forest, hydrology etc.);
- A land cover nomenclature on three levels: First level – 5 headings (1. Artificial surfaces, 2. Agricultural areas, 3. Forests and semi-natural areas, 4. Wetlands, 5. Water bodies), Second level – 15 headings and Third level – 44 headings;
- Creation of GIS databases by means of a Computer Aided Photo-Interpretation (CAPI), scale – 1:100 000 (for best cost/performance ratio);
- Minimum area of a mapped polygon – 25 ha;
- Minimum area of a mapped change – 5 ha;
- Minimum separation between the borders of polygons – 100 m.
- Time consistency: 2011/2012.
- Only real changes mapped – thematic accuracy: ≥ 85 %.

The developments in automated LCLU classification during the last 15 years result in a CLC2012 project extension – production of High Resolution Layers: imperviousness, forests, grasslands, wetlands and permanent water bodies. HRL mapping unit is 20 m × 20 m – 625 times smaller than the previous minimal mapping unit of 25 ha. The compromise is a drastically reduced nomenclature – only 6 LCLU classes. The input HRLs produced by a consortium of European companies are subject to verification and enhancement activities implemented by separate countries (Langanke 2013). The purpose of the verification is to identify the systematic classification errors in a HRL (commission and omission) suitable for further correction. It is accomplished through visual inspection using stratified sampling and involving in-situ data sets. The enhancement based on the results of verification is then applied aiming at HRL improvement (Büttner G. 2013). Ultimately, final HRL products are obtained at a country level.

Forest HRLs include two forest products: Tree Cover Density and Forest Type (Table 1). The latter, in turn, consists of two raster layers: Dominant Leaf Type and Additional Support layer.

Table 1. Forest HRL overview.

Product	Layer	Description
Tree cover density	Tree cover density	Pixel values from 1–100 %
Forest type	Dominant Leaf Type	Binary product: coniferous and broadleaved. MMU of 0.5 ha and 10–100 % tree cover density
	Additional Support layer	Marks non-forest trees: under agricultural use and in urban context (from CLC and imperviousness)

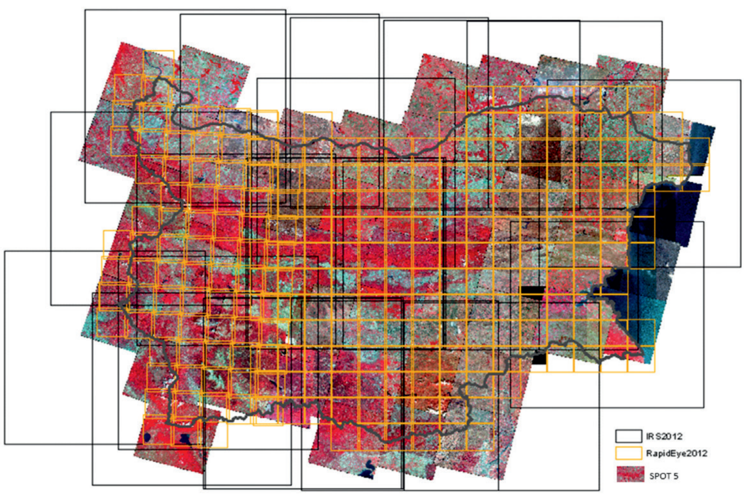

Fig. 2. IMAGE2012 database for Bulgaria – 1236 scenes.

Satellite image data used

Satellite imagery used includes IMAGE2006 database (IRS P6, SPOT4 and SPOT6 – a total of 78 scenes) and IMAGE2012 database (IRS P6, Rapid Eye and SPOT5 – 1236 scenes, see Fig. 2). The basic input data are high resolution multispectral, multitemporal satellite images and a large amount of ancillary data.

Ancillary (*in-situ*) data

Large amount of geo-referenced vector and raster data are used:

- Digital orthophoto map from 2005–2006 and 2011–2012, scale 1:5,000;
- Topographic maps in scales 1:25,000, 1:50,000 and 1:100,000;
- Physical blocks from the LPIS system 2011 and 2012 – a vector database;
- National database of Water – vector data for rivers, channels, lakes;
- Cadastral database of the settlements;
- Database of land property restitution, 1: 5,000;
- RAMSAR sites – a vector database (polygons);
- Digital Elevation Model (DEM) from SRTM mission;
- 2006 Pan-European forest cover map;
- Forest database with detailed attributes;
- Databases of the national parks Rila, Pirin and Central Balkan.

Computer Aided Satellite Imagery Interpretation

Land cover change detection is performed in interactive mode by means of a specialized Hungarian InterChange 3.1. software package (CLC2012 2012). Two synchronized windows are used – "revision" and "change" (Fig. 3).

In the "revision" window satellite images (IMAGE2006 database) are visualized in false colors and also the respective ancillary (*in situ*) data current for the year 2006 overlaid. In the "change" window – 2012 imagery (IMAGE2012 database)

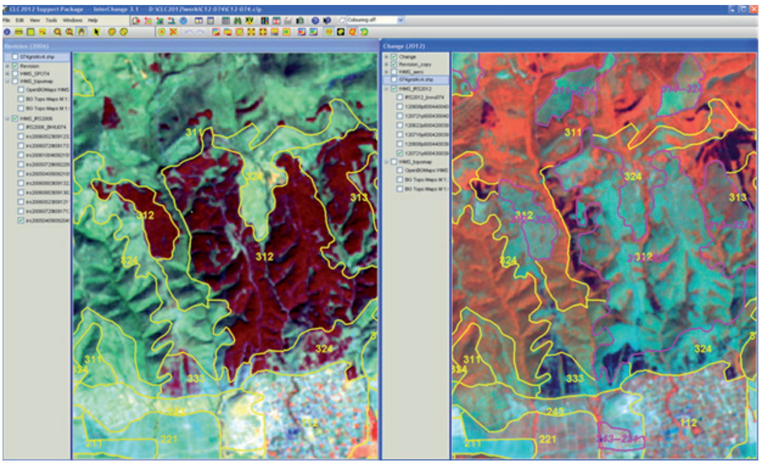

Fig. 3. Left window – Revision coniferous forest in 2006 and right window – Change 312–324 coniferous forest to burned area in 2012, Dalboki village, Stara Zagora region.

and the respective ancillary (*in situ*) data current for the year 2012 are displayed. The CLC2006 vector database to be corrected is visualized in both the windows – "revision" and "change". The interpreter is correcting eventual thematic and/or geometric mistakes in the CLC2006 database followed by a change detection based on spectral, texture and ancillary images visualized in the right window. To the thematic and geometric accuracy of the produced databases of key importance are the 0.5 pixel size color digital orthophoto maps produced by the Ministry of Agriculture and Food for 2006 and 2011, together with GoogleEarth historic images used (in some cases with StreetView).

Results and Discussion

As a result of the interpretation process two databases are created – the revised CLC2006 and CLC-Change$_{2006–2012}$ complemented with respective Metadata. After an exhaustive internal and external (by EEA Technical Team experts) verification and validation procedures the new CLC20012 DB is produced with a complex overlay GIS operation presented by the (+) symbol in the following equation:

CLC2012=CLC2006(+)CLC-Change$_{2006–2012}$

Table 2. CORINE Land Cover Bulgaria 2012 Level 1 statistics.

Code	CLC class name	Area, ha	Part of total area, %	Number of polygons
1	Artificial surfaces	532,731	4.74	5,862
2	Agricultural areas	5,774,288	51.37	23,826
3	Forest and semi-natural areas	4,769,853	42.43	23,406
4	Wetlands	11,319	0.10	85,000
5	Water bodies	152,558	1.36	462,000
	Total	11,240,749	100.00	53,641

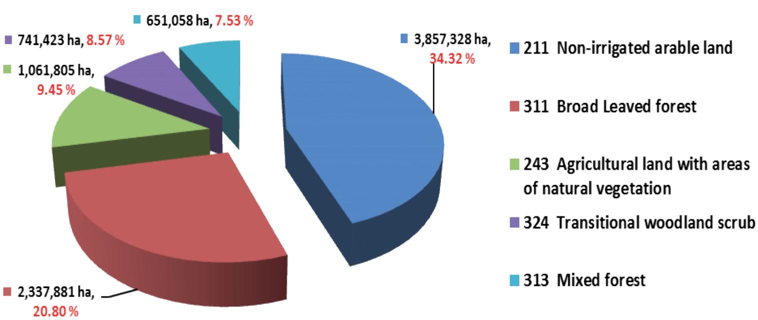

Fig. 4. The 5 CLC2012 level 3 classes forming ¾ of all the area of the country, ha.

A comprehensive statistical analysis of the CLC2012 data and a comparison with the results from the previous 3 projects are presented in the National team report. Table 2 shows the LCLU class distribution for CLC level 1 nomenclature.

More than 93 % of country territory is occupied by two classes – Artificial surfaces and Forest and semi-natural areas. If only pure forests areas are in count (broadleaved, coniferous and mixed) their total area is 3,531,711 ha or 31.42 % of the territory of the country. Moors and heathlands and Natural grasslands will add 26,738 ha (0.24 %) and 414,911 ha (3.69 %) respectively.

Fig. 4 shows the five CLC classes which total area is more than 75 % of the area of the country. The non-irrigated arable land (3 857 328 ha) and Broadleaved forests (2 337 881 ha) cover more than half of the Bulgarian territory.Of special interest are the LCLU changes for the period of investigation (2006–2012). Table 3 illustrates the changes of pure forest areas for the time period 2006–2012.

Totally 21,511 ha of forests have been transformed, the largest changes being in class 311 (Broadleaved forest) – 15,190 ha. Most of these changes

Table 3. Transformation (changes) of forest areas during the period 2006–2012 – area, ha.

Labels	122	131	132	133	142	211	231	321	323	324	334	512	Total
311	22.9	326.3	55.8	32.1	56.9	73.9	6.3	48.0	5.7	14,317.2	15.0	230.3	15,190.4
312					12.7	5.5				3,726.7	68.9		3,813.8
313		30.5		32.1						2,444.3			2,507.0
Total	22.9	356.8	55.8	64.3	69.6	79.3	6.3	48.0	5.7	20,488.2	83.9	230.3	21,511.1

(14,317 ha) are towards class 324 (clear cuts, burned forests, deforestation). Transformations into artificial surfaces include: change 311 to 122 (Road and rail networks) – 23 ha; 311 to 131 (Mineral extraction sites) – 326 ha; 311 to 132 (Dump sites) – 55.8 ha; 311 to 133 (Construction sites) – 32 ha and 311 to 142 (Sport and leisure facilities / golf courses) – 57 ha.

Implementing the verification task on Tree Cover Density and Dominant Leaf Type HRLs, respectively 15 and 12 thematic strata were created. Between 5 and 10 samples were taken in each stratum. During the enhancement work, the logically connected three forest layers were changed together. Automated changes were accomplished through relevant thematic selections of features in the reference data sets, accompanied with a lot of manual editing.

Conclusions and Future Work

In this paper a brief description of the methodology and the results of the CORINE Land Cover 2012 Bulgaria project are published. More detailed explanation could be found in the National CLC 2012 Final Report. Detailed statistical analysis and explanation of the change processes driving forces will be accomplished and published after the official validation of our report by EEA. Comparisons will be made and discussed with the results of other participating countries.

Acknowledgments

The CORINE Land Cover 2012 Bulgaria project is financed jointly by the Ministry of Environment and Waters and the EC Executive Environment Agency under the Contract No 2469/05.03.2013 between the Ministry and the Space Research and Technology Institute at the Bulgarian Academy of Sciences. Special thanks to Mrs. Borislava Borisova (National Contact Point) for her permanent care, help and support and to George Büttner and Barbara Koszhra from the EEA Technical team for their cooperation and support during the project implementation.

References

Bossard M., Feranec J., Otahel J. 2000. CORINE land cover technical guide – Addendum 2000. EEA Technical report No 40.

Büttner G. 2013. Guidelines for verification of high-resolution layers produced under GMES / Copernicus Initial Operations (GIO) land monitoring 2011–2013, EEA.

Büttner G., Kosztra B. 2011. Manual of CORINE Land Cover Changes (ETC-SIA 2011).

Büttner G., Kosztra B. 2012. CLC2012 Addendum to CLC2006 Technical Guidelines. Available: http://gamta.lt/files/Addendum_finaldraft.pdf

Büttner G., Feranec J., Jaffrain G., Mari L., Maucha G., Soukup T. 2004. The CORINE Land Cover 2000 Project. EARSeL eProceedings 3(3): 331–346.

Skole D. 1996. Land use and land cover change: an analysis. IGBP Newsletter No 25: 4–7.

CLC2006 technical guidelines 2007. EEA Technical report No 17. Available: http://www.eea.europa.eu/publications/technical_report_2007_17

CLC2012 Support Package 2012. Available: http://CLC2012.taracsak.hu

CORINE Land Cover Technical Guide 1997. Available: http://image2000.jrc.ec.europa.eu/reports/technical_guide.pdf

Fischer G. 1995. IGBP/HDP science plan for land-use and cover change (LUCC), Proceedings of Conference on Land Use for Global Environmental Conservation (LU/GEC) – Global Environment Tsukuba ,94. Available: http://www.iiasa.ac.at/publication/more_XP-95-026.php

Heymann Y., Steenmans Ch., Croisille G., Bossard M. 1994. CORINE Land Cover. Technical Guide. Luxembourg (Office for Official Publications of European Communities). Available: http://las.physik.uni-oldenburg.de/eProceedings/vol03_3/03_3_buttner2.pdf

Langanke T. 2013. GIO land High Resolution Layers (HRLs) – summary of product specifications – EEA. Available: http://land.copernicus.eu/user-corner/technical-library/gio-land-high-resolution-layers-hrls-2013-summary-of-product-specifications/at_download/filev

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 197–210

METHODOLOGY FOR ASSESSING OF ECOLOGICAL CONDITIONS IN FOREST ECOSYSTEMS UNDER CLIMATE CHANGES

Ivan Ts. Marinov

Department of Forest Ecology, Forest Research Institute – Bulgarian Academy of Sciences, 132 St. Kliment Ohridski blvd., Sofia 1756, Bulgaria. E-mail: marinovbg02@yahoo.com

Received: 10 September 2014 Accepted: 10 November 2014

Abstract

A methodology for determining of ecological conditions in forest ecosystems in order to assess their future variations under expected climate change has been developed. Complex index for ecological conditions (K_{ec}) was established including hydrothermal (precipitations, temperature and duration of drought period in the region), soil (depth and erosion) and relief (exposure and inclination of slope) parameters. The expected changes of climatic elements were assessed based on data from climatic scenarios. Model verification was performed for Sedelska River basin, a tributary of Struma River, South-western Bulgaria. Distribution and division into 5 groups of main tree species within the watershed area was performed in accordance to the values of K_{ec}. Distribution of forest ecosystems in groups according to expected ecological conditions for the period of 2021–2049 and 2071–2099 was established and their spatial distribution for Sedelska River basin was mapped. It was established that nowadays about 30 % of stands and forest plantations are in the first group – under 'bad' ecological conditions. The results showed that for the period 2021–2049 the area of these forests will increase and will reach 36.9 %, and for the period 2071–2099 more than the half of these forest ecosystems (51.2 %) will be under 'bad' ecological conditions.

Key words: complex index, drought periods, hydrothermal parameters, erosion, tree species, Sedelska River.

Introduction

The climatic characteristics, such as temperature and amount of precipitation, are important for forest growth, regeneration and optimal distribution. The long-term data about precipitations and temperatures show trends, which, together with soil and relief characteristics, could explain the present ecological conditions for the development of vegetation. For assessment of the simultaneous effect of these ecological factors, De Marton index and climatograms after Walter (1963) were used as complex climate characteristics. The bioclimatic modeling determines climatic characteristics as limits of the species distribution within certain climatic niche (Box et al. 1993, 1999). The relation between vegetation and climate was included in the model developed by Holdridge (1967). Within this model an elaborated life zone classification is based on biotemperature, mean annual precipitation and on a potential evapotranspiration ratio. This classification was used to assess the climate change impact on vegetation (Emanuel et al. 1985, Leemans 1990). Box (1981) involved in a model several factors including minimal and maximal values of precipitation and temperature, evapotranspiration, etc. Other models, which divide plant species into functional groups and can be applied under different climate regimes, especially for scenarios of future developments, are BIOME models (Prentice et al. 1992, Cramer 2002). Ecological models were used to predict the climate change threshold for shift of geographic distribution of tree species. As a result of climate change some terrestrial plants have shifted their ranges and likely migrate to areas with more suitable climates (IPCC 2007, 2014; Penuelas et al. 2007) but it is important to project the changes in ecological conditions on regional level – economic regions, watersheds, etc. In this case the planners and managers will know which measures for adaptation of tree species should undertake. Adaptation to climate change could occur naturally, through natural regeneration and tree migration, and could also be facilitated by human action if managers replant disturbed forests by species or varieties more suitable to the changed climate and establish new, replacing plantations in more suitable locations (Sedjo 2010).

Many researchers studied plant – climate relationships and estimated impact of climate change on forested ecosystems. The results showed that deterioration of the vitality and stability of forest ecosystems may lead to a degradation of forests and soil, aridification of the region, change of species distribution area, which impose the necessity of activities for adaptation (Rehfeldt et al. 2006, Crookston et al. 2010, Matyas 2010, Matyas et al. 2010, Halofsky et al. 2013).

The indicator values of tree species for temperature (temperature index) and for soil moisture (humidity index) are accepted as the most important factors, which could be affected by climate change and are used in tree-ecogram method (Ellenberg et al. 1992). The estimation of possible changes in forest stands due to climate change should focus on the tree species. The indicator values do not describe ecological demands of the trees in forest stands but they indicate their ecological behaviour. If a tree species is found to beless adaptable under climate change conditions for a certain region, the tree-ecogram method gives opportunity to estimate the most appropriate alternative tree species for this region (Ellenberg et al. 1992). This method was applied in the SEE-Project 'Climate Change and Impacts on Water Supply CC-WaterS', supported by European Regional Development Fund (Koeck 2012).

In Bulgaria, during the last decades the problem of establishment of sustainable forest ecosystems and agricultural crops according to climatic conditions, which is in relation with expected trends for climate change, has been discussed (Raev 1995, 1997; Raev et al. 1996; Raev and Slavov 1996; Slavov and Aleksandrov 1996; Knight et al. 2004). Underestimation of this problem could have serious ecological and economic consequences. In Bulgaria such an example is the afforestation with coniferous tree species out of their ecological optimum. The coniferous plantations suffered the chronic water deficit in the drought period from 1982 to 1994, which affected the plantations up to about 800 m a.s.l. and caused destruction of about

18 % of the established coniferous forest ecosystems (Knight et al. 2004). The main reason for this is unconformity between climatic conditions and ecological characteristics of coniferous species used for afforestation (Raev 1995, Raev et al. 1996). Knight et al. (2004), after applying Holdridge's model, determined that in XXI century changes could be expected in lowland of the country from 'moderate cool fresh forest' towards 'moderate warm dry forest'. In southern parts of the country, including Struma River basin area, in the area below 800 m, transition to 'subtropical dry forest' could be expected. Elements of a strategy for limitation of the consequences for forest vegetation, with a view to preserve vitality of tree species in changing climatic conditions are suggested.

Rationale and Purpose

Air temperature in Europe is expected to increase between 2.5 °C and 4.0 °C by 2071–2100. Expectations for Southern Europe include decreasing of precipitations as a whole, but increasing the number of days with heavy precipitation and as a result – decreasing of forest growth (EEA 2012). These projections show that climate change will have crucial impact on the natural resources and in particular on the development of forestry and forest industry.

European Commission is developing European Adaptation Strategy, which includes further proposals for adaptation actions across EU. All this is recognised in the developed 'National strategy for sustainable development of the forestry sector 2013–2020' (Anonymous 2013), where the main priority is given to 'maintaining of the vital, healthy, productive and multifunctional forest ecosystems favouring mitigation of negative consequences of climate change' and measures for enhancing the resilience and adaptability of forest ecosystems to climate change are foreseen.

Applied climatic scenarios for Bulgaria are allowed to define the 'areas of vulnerability' of forest ecosystems (risky regions such as North-eastern Bulgaria). On this basis, a 'Programme of measures for the adaptation of forests to climate changes in Bulgaria and reduce the negative impact of climate change on forests' was developed (Raev et al. 2011). In the Programme, the measures for adaptation of forests that are largely applicable to most countries of Southeastern Europe as well as some specific measures for Bulgaria, are presented. The connecting link between the programme and the specific practical approach is not clearly defined, i.e. how the stands (plantations) on a given area will be classified as stands subjected to the risk for normal development as a result of climate change (first of all to the increases in temperature, changes in precipitation and snow). Implementation of adaptation measures to all existing forest vegetation within the risky regions is uneconomic. It is necessary to be able to apply the measures just to those stands in which the habitat changes due to climate change are expected to take place until the end of the century, and which will affect negatively the function and structure of plantations. For these stands appropriate forestry activities will be planned in the forest management plans with priority and will be applied in order to adapt to climate change.

The methodology for determining the ecological conditions of forest ecosystems was developed with the aim to assess climatic, soil and relief conditions, under which tree species grow and the change of these conditions under the expected climate change. A complex index for ecological conditions (K_{ec}) has been developed. It was applied to ecological (site) conditions (soil, relief, precipitation and temperature) assessment of ecosystems, defined by dominating tree species in the stands, according to the data of forest management plans. The change of climatic elements was assessed on the basis of data taken from climatic scenarios. It should be taken into account that K_{ec} values do not give estimation of the ecological requirements of trees in forest stands, rather a rating of site conditions and the ability of a site to provide conditions for normal development of forest vegetation and production of wood.

The necessary forest activities for adaptation and future forests composition could be determined on the basis of obtained values of index K_{ec}. The forest management plans contain data about the structure and composition of stands, and habitat conditions (exposure, topography, soil, erosion) there are data about each stand, representing a management operational unit (compartments and subcompartments). These parameters, together with climatic characteristics (rainfall and temperature) can be used to assess the current environmental conditions, and also changes in these conditions using the climatic scenarios for future periods. Depending on the purpose of the study an object of survey may be a part of a forestry administrative unit, or could include the territory of several such units, most often within one catchment area. The use of GIS allows processing of large datasets characterising of the conditions in all of the surveyed area.

Methodology Description

The methodology was based on environmental factors including hydrothermal, soil and relief conditions, and dynamics of precipitation and temperature, obtained from climatic scenarios. Description of the methodological approach for assessment of environmental conditions is presented in the project 'Climate Change and Impacts on Water Supply – CC-WaterS' (Marinov et al. 2012, Koeck 2012). Testing of methodology in real conditions has shown that in order to reflect in more details the changing weather conditions it is necessary to make a correction in the initial version, related with the values used for precipitation and temperatures. The change is insignificant – instead of 'maximum average monthly temperature' and 'maximum average monthly rainfall' for period April – October, the average monthly data were used as indicators. It does not change the essence of methodology but is done just for higher precision of estimations, particularly for regions where climate scenarios do not show (prognosticated) significant changes in the climatic characteristics.

The complex index for ecological conditions (K_{ec}) was determined by hydrothermal (precipitations, temperature and duration of drought period in the region), soil (depth and development of erosion processes) and relief (exposure and inclination of the slope) conditions through the equation:

$$K_{ec} = K_t \cdot K_p \cdot S_m \quad (1),$$

where: K_{ec} – complex index for hydrothermal, soil and relief conditions; K_t – temperature index; K_p – index of precipitations; S_m – combined/integrate index for soil conditions, erosion processes, relief and drought.

Methodology Parameters

Temperature conditions. For determining temperature conditions, only data for the period of the year – from April to October, was used. These conditions were expressed through temperature index (K_t), determined by average, maximal and minimal average monthly temperature °C during these months:

$$K_t = [(T_{v\,max} – T_{v\,min})\cdot T_{v\,av}]/100 \quad (2),$$

where: $T_{v\,max}$ – maximal average monthly temperature °C in the period April–October; $T_{v\,min}$ – minimal average monthly temperature °C in the period April–October; $T_{v\,av}$ – average monthly temperature °C in the period April–October.

Precipitations. The vegetation growth was determined in considerable extent by the moisture, especially in warm months of the year. That's why the model showed the impact of precipitations in these months – from April to October. The index of precipitations (K_p) was calculated according to the following equation:

$$K_p = (P_v/P_y)\cdot P_{v\,av} \quad (3),$$

where: P_v – amount of precipitations in the period April – October, mm; P_y – amount of annual precipitations, mm; $P_{v\,av}$ – average monthly precipitations in the period April–October, mm.

For the characteristics of main climatic elements (precipitations and temperature), data for each climatic stations were analysed for the present period (usually covering the previous 30–40-year period or that one accepted as basic climatic period), as well as data predicted from climatic scenarios (for one or two periods, from 30 to 50 years each). For the assessment of precipitations and temperature, a complex characteristic of climate was used through climatogram after Walter (1963), which determines durability of drought period for climatic stations in catchment area (region) for the present period and for one or two prognostic periods.

Soil, erosion, relief and drought. An integrate index (S_m) for soil conditions, erosion processes, relief and drought was calculated using the following equation:

$$S_m = [(K_{dp}\cdot K_e\cdot K_a\cdot K_s)\cdot K_d]/100 \quad (4),$$

where: K_{dp} – depth of soil; K_e – soil erosion; K_a – slope exposure; K_s – slope inclination; K_d – drought period.

The individual parameters of S_m index were classified into classes, and they participated in the integrate coefficient by classes (Table 1).

Final assessment of ecological conditions has to be performed on the basis of obtained values for the index of ecological conditions (K_{ec}) listed in Table 2.

In order to distribute K_{ec} values in groups, the clustering algorithm could be used (MacQueen 1967). The studied territory could be distributed in 5 clusters (groups), according to ecological conditions. Based on the above mentioned algorithm for data distribution in the groups, the much higher percentage of the studied territory usually refers to the group of bad ecological conditions.

The complex index for ecological conditions (K_{ec}) was determined separately for all stands, distributed according to dominating tree species in ecosystems. Due to similarity in growing conditions of tree species K_{ec} could have equal values for two and more species, which will be referred (allocated) in the same group according to ecological conditions. The areas and spatial distribution of each group of ecological conditions determined according to the growing at these conditions tree species, their origin and soil conditions were defined by forest management

Table 1. Classification of soil conditions, erosion processes, relief and drought for determination of S_m.

K_{dp}		K_e		K_a		K_s		K_d	
Class	Depth, cm	Class	Erosion	Class	Exposure	Class	Inclination in degrees	Class	Drought
1	< 30	1	Yes	1	Sunny (S, SW, SE, W)	1	> 21	0.5	> 3 months
2	30–50	2	No			2	11–20	1	1–3 months
3	50–120	-	-	2	Shady (N, NW, NE, E)	3	< 10	2	< 1 month
4	> 120	-	-	-	-	-	-	3	no

plans and present and prognostic climatic data, using GIS data of maps developed for each forest vegetation belt in the studied territory.

Table 2. Classification of K_{ec} values and assessment of ecological conditions.

K_{ec}	Description of ecological conditions	Group of the ecological conditions
< 5	Bad	I
5.0–10	Relatively good	II
10.1–20	Good	III
20.1–50	Good to very good	IV
> 50	Very good	V

Obtained database allows to go back to the initial data about forest ecosystems with dominating tree species and to determine the precise location of compartments and sub-compartments (through the maps done by GIS), as well as the forest survey from the management plan for each sub-compartment, classified in groups according to ecological conditions. This capability of the model is particularly important, because it supports authorities in their decision about determining specific forest ecosystems, where activities should be directed to adaptation to changed climatic conditions. These activities will be different according to dominant tree species in sub-compartments and whether before the period of assessment some management activities in the stands and forest plantations have been performed (thinning, sanitary logging, etc.).

Testing of the Methodology for Sedelska River Basin – Approach and Results

Initial testing of methodology for determining of ecological conditions of forest ecosystems has been performed for Sedelska River (Marinov et al. 2012). Here the main results are presented in order to follow the sequence of parameters' practical defining.

Sedelska River is the right tributary of Struma River. Its catchment area covers 50.2 km^2 of eastern slopes of Maleshevska Mountain.

Defining of Parameters

Climatic elements

For characteristics of main climatic elements (precipitations and temperatures), data from Bulgarian National Institute of Meteorology and Hydrology have been used (Aleksandrov and Spiridonov 2010). The dynamics of annual precipitation and temperature was represented for the period until 2005 and from climatic scenarios up to 2049 and 2099. For assessment of common influence of precipitations and temperatures as factors for vegetation growth, a complex climatic characteristic was used. For this purpose the drought periods were determined by graphic method through climatogram after Walter (1963). Duration of these periods were determined for different climatic stations in Struma River basin for the period until 2005 and for the two periods of prognoses – 2021–2049 and 2071–2099. For Sedelska River basin data from neighbouring stations were used for each vegetation belt, according to altitude.

Climatograms showed that precipitations are sufficient in the higher parts of the mountains, where there is no drought and the hydrothermal conditions are adequate for forest vegetation growth. Durability of drought period for climatic stations in Struma River basin for the period until 2005 was about 4 months for Sandanski (191 m a.s.l.), about 3 months for Kresna (180 m), 2 – for Blagoevgrad (410 m), around 1 for Rila (470 m).

Determining of drought periods for 2021–2049 and 2071–2099

Climatograms for the periods 2021–2049 and 2071–2099 showed that considerable changes in climate will occur in the southern part of Struma catchment area and in Kyustendil region, which will lead to droughts with duration of 4–5 months in Sandanski, Kresna and Blagoevgrad (up to 6 months in Blagoevgrad for the period 2049–2099), in Rila, Kyustendil (520 m) and in Pernik (700 m) – more than 2 months. Only in the highest parts of catchment area (1150 up to 1640 m) there will not be drought period, which could have an impact on the growth of forest vegetation.

The main factor for drought is the Mediterranean climatic influence, which defines to a great extent the climate in Struma River basin and in particular in Sedelska River basin. Drought in the area up to about 600 m will be significant and an impact on forest vegetation and changes in natural vegetation could be expected. As a result of this drought part of forest ecosystems will deteriorate change their status. The range of main tree species will undergo substantial changes. Forest plantations on non-typical sites most probably will sustain significant losses. To prove this, however, a reliable assessment of ecological conditions at the present distribution of species and their modification as a result of predicted climate change is necessary.

Relief

For the assessment of topographic conditions (inclination and exposure of slopes) and presence of erosion, data from Forest Management Plans of State Forest Enterprise (SFE) Tsaparevo were used, as well as classifications according to Regulation No6/February 2004 (Regulation 6 2004).

Distribution of main tree species, provenance and soils

Distribution of main tree species in Struma River basin has been classified according to the altitude following Velchev et al. (1992). For Sedelska River basin the main tree species were identified according to the information of Forest Management Plan of SFE Tsaparevo (Anonymous 2005). The largest area is covered by Oaks (*Quercus* sp.) – 40.3 % of the investigated territory, followed by Scots pine (*Pinus sylvestris* L.) – 24.3 %, Austrian black pine (*Pinus nigra* Arn.) – 19.6 %, European beech (*Fagus sylvatica* L.) – 10.0 %, Hornbeams (*Carpinus betulus* L. and *C. orientalis* Mill.) – 4.7 % and Sweet chestnut (*Castanea sativa* Mill.) – 1.1 %. Sedelska River basin was divided into three vegetation belts – up to 1500 (1600) m using GIS. The belt of xerothermic oak forests was divided into two subbelts – up to 400 and from 400 to 600 m. In each of them the range of dominating tree species was determined.

The following codes assigned by letters have been used to identify tree species: sp – Scots pine, bp – Austrian black pine, bch – European beech, hor – Hornbeams, oak – Oaks, ch – Sweet chestnut and numerical codes: 1 – sp, 3 – bp, 11 – bch, 29 – hor, 76 – oak, 87 – ch. Hornbeam numerical code (29) includes codes 17 and 29 and Oaks code (76) includes codes 12, 13, 14, 15, 16, 28 and 76, according Regulation No6 (2004).

For the origin grouping with code 1 were assigned natural stands and with code 3 – forest plantations. Soils are grouped, based on the codes, used for practical purposes in Forest management plans of SFE Tsaparevo as follows: 2 – Leptic-chromic Luvisols; Leptic-chromic Cambisols + Rendzic Leptosols (14, 15, 16, 17, 27); 3 – Leptic Cambisols; Leptic-eutric Cambisols + Leptic-humic Umbrisols (19, 20, 21, 25, 28). In Sedelska River basin there are no soils from other soil groups identified in Struma River basin.

Possible combinations were determined for tree species, according to their origin and soil type. Each tree species gets a 3-numerical code in eight variants depending on the origin and soil type, in which: the first number is code for tree species, the second – origin and the third – soil type. For example Oaks have code *oak3* at the combination 76.1.3., i.e. natural origin of the stand (1) and soils from a third group (3).

To every code of tree species (8 options for each type) were given four-digit code formed by classes for: thickness of soil (K_{dp}), erosion (K_e), exposure (K_a) and slope gradient (K_s). For example *oak3 / res 17* (see Fig. 1) is a combination 2.2.1.2. equal to 17 res, i.e. K_{dp} = 2, K_e = 2, K_a = 1 and K_s = 2.

That is the first part of the integrate coefficient for site conditions (soil, relief and climate) (S_m) – formula (4) of the model for determination of K_{ec}. The second part is the period of drought.

Areas and spatial distribution in the belt up to 400, 400 to 600, 600 to 800 and 800 to 1500 m were determined with GIS and mapped (Marinov et al. 2012).

Current ecological conditions in forest ecosystems in Sedelska River basin

After mapping of the distribution in each group of dominant tree species, each distinguished group was classified using the model for determination of ecological conditions in forest ecosystems equation 1. The entire system of coefficients was constructed basing on the above described steps.

The current distribution of areas according to main tree species availability and the values of other parameters the complex index K_{ec} in Sedelska River basin

Table 3. Present distribution of the main tree species in Sedelska River basin according to K_{ec} values.

Group according to ecological conditions	K_{ec}	Altitude, m	Area, ha			Part from total investigated territory of the catchment, %
			Stands	Plantations	Total	
I – Bad	< 5	<400	231.4	25.3	1055.4	30.0
		400–600	324.4	384.3		
		800–1500	57.5	32.7		
II – Relatively good	5.0–10	<400	35.1	2.2	944.4	26.9
		400–600	111.0	65.1		
		600–800	160.5	418.5		
		800–1500	47.8	4.2		
III – Good	10.1–20	400–600	4.2	38.4	554.0	15.7
		600–800	217.7	123.1		
		800–1500	89.1	81.5		
IV – Good to very good	20.1–50	400–600	0.7	0.8	955.3	27.2
		600–800	305,5	241.8		
		800–1500	267.6	138.9		
V – Very good	> 50	600–800	1.9	-		
		800–1500	-	4.0	5.9	0.2
Total investigated area					3515.0	100.0

was obtained for each sub-compartment in vegetation belt. Then the stands were classified to their origin and altitude (Table 3).

The results show that 1055.5 ha, or 30 % of the investigated forest ecosystems in Sedelska River basin, are classified in group I – under ’bad‘ ecological conditions. This territory is occupied by dominating tree species, the most spread within Struma River basin.

These forests are predominantly in the belt up to 600 m, and insignificant part – 8.5 % –above this altitude, very close to the second group according K_{ec} (K_{ec} = 4.85). The dominant tree species in natural stands are oaks and hornbeams, and in the plantations – Austrian black pine and Scots pine. The site conditions for I group are mainly as follows: soils – Leptic-chromic Luvisols (smaller area with Leptic Cambisols), shallow (small share are with medium depth), eroded (small share non-eroded), predominantly on sunny exposures and drought period duration > 3 months (with small exceptions). Up to 400 m at ’bad‘ conditions the forests are presented mainly by natural stands. Within the belt from 400 to 600 m the areas of stands and plantations at ‘bad’ conditions are equal and above this altitude, the forest stands cover almost twice larger area.

The area of forest ecosystems within the belt 600–800 m, which is classified as group with ’relatively good‘ ecological conditions, exceeds 60 %. The area of the forest plantations within this belt is 3 times larger than that for the stands at this altitude. Stands and plantations at altitude higher than 400 m are only 4 % of the total area of this group, while their total area above 600 m is 22.5 %. Hydrothermal conditions at an altitude above 600 m are relatively favourable but probably other conditions of the environment (soil, relief and presence of erosion processes) are decisive for the classification of these stands in this group.

The distribution of stands and plantations between the other three groups (III – ’good‘, IV – 'good to very good', V – 'very good') can be seen in Table 3. The ecological conditions for these groups are good and very good and they most probably will not be influenced significantly by climate changes.

Distribution of forest ecosystems in groups according to ecological conditions for the periods 2021–2049 and 2071–2099

The distribution of part of catchment area with main tree species, according to values of K_{ec} for the periods 2021–2049 and 2071–2099 is presented in Table 4 and Fig. 1 (for K_{ec} > 5 and K_{ec} < 5).

The total area of xerothermic oak forests belt (up to 600 m) was 1222.4 ha. According to the current status of the vegetation here 965.4 ha are classified in first group ('bad' ecological conditions), which is 79 % of the total belt area. It is predicted that for the period 2021–2049 the space of forest ecosystems belonging to this group will increase with only about 12 ha. This insignificant change in the distribution of areas included in the group of forests under 'bad' ecological conditions reveals the dominant influence of environmental conditions (soils, erosion, relief) over precipitations and temperature changes, but also shows that almost all ecosystems in this vegeta-

Table 4. Distribution of the main tree species in Sedelska River basin according to K_{ec} values (prognosis 2021–2049 and 2071–2099).

Group according to ecological conditions	Altitude, m	2021–2049				2071–2099			
		Stands, ha	Plantations, ha	Total, ha	Investigated territory, %	Stands, ha	Plantations, ha	Total, ha	Investigated territory, %
I	<400	266.5	25.3			266.5	25.3		
	400–600	322.5	362.7			423.6	404.4		
	600–800	68.4	251.0	1296.3	36.9	160.5	518.6	1798.8	51.2
II	<400	0.0	2.2			0.0	2.2		
	400–600	101.2	41.6			15.8	83.2		
	600–800	92.0	267.6			217.8	123.1		
	800–1500	57.4	32.7	594.8	16.9	57.4	32.7	532.2	15.1
III	400–600	15.76	83.20			0.0	0.0		
	600–800	217.8	123.1			296.0	251.2		
	800–1500	61.78	41.65	543.3	15.5	61.8	41.6	650.7	18.5
IV	400–600	0.7	0.8			0.7	0.8		
	600–800	296.2	251.2			0.0	1.9		
	800–1500	342.7	183.0	1074.5	30.6	342.7	183.0	528.9	15.0
V	600–800	0.0	1.9			0.0	0.0		
	800–1500	1.1	3.0	6.0	0.2	1.0	1.3	4.0	0.1

tion belt are under ’bad‘ ecological conditions. From the point of view of single stands and plantations, it should be mentioned that in the lower zones of catchment area (up to 600 m) forest area assessed under ’bad‘ climatic conditions remains almost the same under conditions of climatic scenario for the period 2021–2049 (Fig. 1).

During the next period (2071–2099), however, the group under ’bad‘ ecological conditions will include significant part of the stands and plantations situated at higher altitude. There will be no change in the areas in the belt up to 400 m due to the fact that all stands and plantations in this period are under ’bad‘ ecological conditions. For altitude from 400 to 600 m, the area of stands included in this group is predicted to increase by 100 ha, and that of plantations – by 40 ha, compared to the previous projected period. The changes of vegetation in the belt from 600 to 800 m will be also considerable. Over twice will be the area of stands and plantations classified to ’bad‘ ecological conditions.

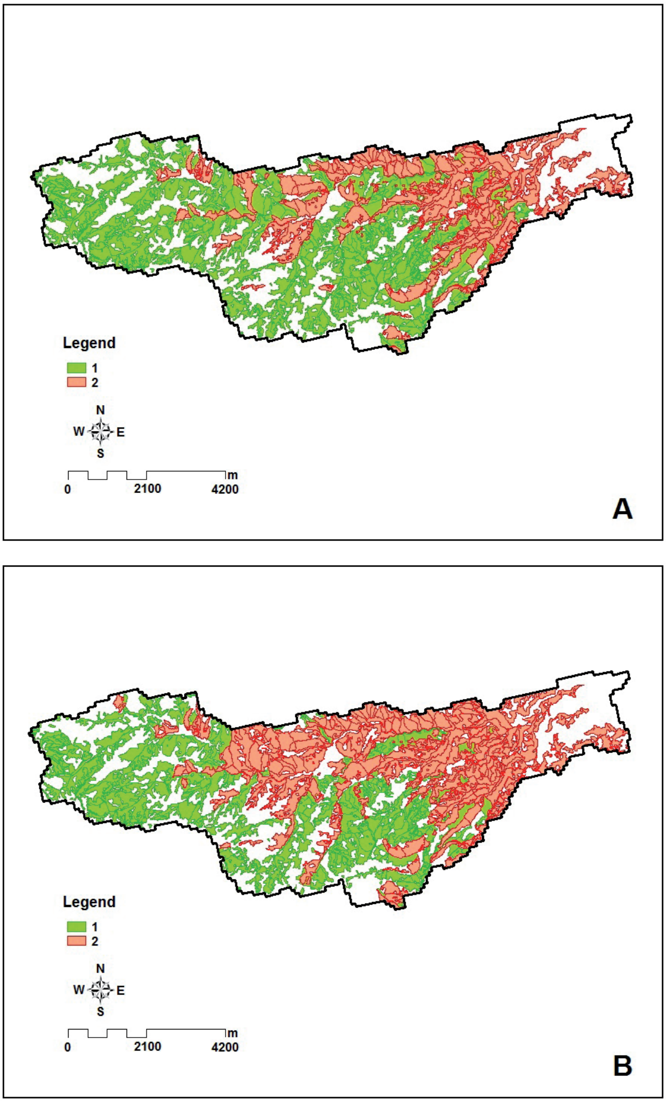

Fig. 1. Distribution of Sedelska catchment area according the values of K_{ec}: 1 – K_{ec} > 5, 2 – K_{ec} < 5; A – period 2021–2049, B – period 2071–2099 (Marinov et al. 2012).

A question that arises based on the results is about the future species composition of forests in the belts of xerothermic oak forests and xeromesophytic oak and hornbeam forests in the region of study. Evidently, appropriate activities and investment plans should be developed for adaptation of present forest ecosystems to expected climate changes, and at the same time for developing a strategy for conservation of autochthonous vegetation.

Conclusions and Recommendations

A methodology for determining of ecological conditions in forest ecosystems on the basis of a complex index (K_{ec}) was developed. For K_{ec} index calculation temperature and precipitation indexes and combined index for soil conditions, erosion processes, relief and drought have been involved. With K_{ec} index expected changes of ecological conditions in forest ecosystems as a result of climate change can be assessed.

Ecological conditions for forest ecosystems were determined for Sedelska River basin a tributary to Struma River, Southwest Bulgaria. The current distribution of main tree species in the watershed was determined according to the values of K_{ec} and they were divided into 5 groups according to ecological conditions. The spatial distribution of main tree species according to altitude was performed and after that mapped as a basis for their grouping in conformity of ecological conditions. Distribution of forest ecosystems in groups according their ecological conditions for the periods 2021 2049 and 2071–2099 in Sedelska River basin was done.

It was established that nowadays 30 % of the stands and forest plantations, are in the first group – under ’bad‘ ecological conditions, according to dominating tree species. Results show that for the period 2021–2049 their area will increase and will reach 36,9 %, and for the period 2071–2099 more than the half of these forest ecosystems (51.2 %) will be under ’bad‘ ecological conditions.

In the vegetation belt of xerothermic oak forests (up to 600 m a.s.l.), 79 % of the total investigated area was classified in the first group (‘bad‘ ecological conditions). After application of the model for determining of K_{ec} for first climatic scenario (2021–2049), the area of this group increases insignificantly, while during the next period (2071–2099), under ’bad‘ ecological conditions will increase till 92 % of forest ecosystems. These data show that in the belts of xerothermic oak forests and xeromesophytic oak and hornbeam forests in this part of the country it is necessary to apply activities for adaptation of present forest ecosystems to expected climate changes but they also show that it is necessary to develop a strategy for conservation of autochthonous vegetation, as well as methods for scientifically well-grounded selection of tree species for afforestation on the basis of specific ecological conditions.

Acknowledgments

This study was supported by Climate Change and Water Supply (CC-WaterS) project implemented by Executive Forest Agency under the Transnational Cooperation Programme in Southeastern Europe, and funded by SEE programme, European Regional Development Fund, Ministry of Regional Development.

References

Aleksandrov V., Spiridonov V. 2010. Climate Change and Impact on Water Supply.

CC Waters project. Final report – WP 3. (manuscript).

Anonymous 2013. National strategy for sustainable development of the forest sector. 2013–2020. Executive Forest Agency, Ministry of Agriculture and Food, 207 p. (In Bulgarian).

Box E.O. 1981. Macroclimate and Plant Forms: an Introduction to Predictive Modeling in Phytogeography. Dr W. Junk Publishers, the Hague, 272 p.

Box E.O., Crumpacker D.W., Hardin E.D. 1993. A climate model for location of plant species in Florida. Journal of Biogeography 20: 629–644.

Box E.O., Crumpacker D.W., Hardin E.D. 1999. Predicted effects of climate change on distribution of ecologically important native tree and shrub species in Florida. Climatic Change 41: 213–248.

CC-WaterS 2012. Climate Change and Impacts on Water Supply – Programme: South East Europe – project code: SEE/A/022/2.1/X. Available: http://www.ccwaters.eu/

Cramer W. 2002. BIOME Models. In: Munn T. (Ed.) Encyclopedia of Global Environmental Change. John Wiley & Sons, Chichester. Mooney H.A., Canadell J.G. (Eds.) vol. 2. The Earth system: biological and ecological dimensions of global environmental change: 166–171.

Crookston N.L., Rehfeldt G.E., Dixon G.E., Weiskittel A.R. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. Forest Ecology and Management 260: 1198–1211.

Ellenberg H., Weber H.E., Düll R., Wirth V., Werner W., Paulissen D. 1992. Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica XVIII, 2. Auflage, Goltze Verlag, Göttingen. 258 p.

Emanuel W.R., Shugart H.H., Stevenson M.P. 1985. Climatic Change and the Broad-scale Distribution of Terrestrial Ecosystems Complexes, Climatic Change 7: 29–43.

Executive Forest Agency 2005. Forest management plans of State Forest Enterprise Tsaparevo. (In Bulgarian).

European Environmental Agency (EEA) 2012. Climate change, impacts and vulnerability in Europe 2012. An indicator-based report. European Environment Agency, Report No 12, 300 p. Available: http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012

Halofsky J.E., Hemstrom M.A., Conklin D.R., Halofsky J.S., Kerns B.K., Bachelet D. 2013. Assessing potential climate change effects on vegetation using a linked model approach. Ecological Modelling 266: 131–143.

Holdridge L.R. 1967. Life Zone Ecology. Revised edition, Tropical Science Center, San Jose, Costa Rica, 149 p.

IPCC 2007. Energy Supply. Chapter 4 in the Assessment Report of Working Group III. New York: Cambridge University Press. Available: http://www.ipcc.ch/ipccreports/ar4-wg3.htm

IPCC 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report – Changes to the Underlying Scientific/Technical Assessment. Available: http://www.ipcc.ch/report/ar5/wg2/

Knight C.G., Raev I., Staneva M. (Eds.) 2004. Drought in Bulgaria: a contemporary analog for climate change. Ashgate, UK, USA, 336 p.

Koeck R. (Ed.) 2012. Climate change and impacts on water supply – CC-WaterS Monograph, 240 p.

Leemans R. 1990. Possible changes in natural vegetation patterns due to a global warming. Publication number 108 of the biosphere dynamics project. IIASA. Laxenburg, 13 p.

MacQueen J.B. 1967. Some Methods for classification and Analysis of Multivariate Observations. Proceedings of 5th Berkeley Symposium on Mathematical Statistics and Probability, Berkeley, University of California Press 1: 281–297.

Marinov I., Velizarova E., Niagolov I., Nikolova K., Ilcheva I., Zlatanov Ts., Mirchev P., Zaharieva V., Yordanova A., Nikolov I., Pavlova E., Miteva S. 2012. Climatic changes and their influence on the forest ecosystems and water resources in the Struma river basin. Publishing house BON, Blagoevgrad, Bulgaria, 160 p. (In Bulgarian).

Matyas Cs., Berki I., Czúcz B., Gálos B., Móricz N., Rasztovits E. 2010. Future of Beech in Southeast Europe from the Perspective of Evolutionary Ecology. Acta Silvatica & Lignaria Hungarica 6: 91–110.

Matyas Cs. (Ed.). 2010: Forests and Climate Change in Eastern Europe and Central Asia. Forests and Climate Change Working Paper 8, Rome, 189 p.

Penuelas J., Ogaya R., Boada M., Jump A.S. 2007. Migration, invasion and decline: changes in recruitment and forest structure in a warming-linked shift of European beech forest in Catalonia (NE Spain). Ecography (Cop.) 30: 830–838.

Prentice I.C., Cramer W., Harrison S.P., Leemans R., Monserud R.A., Solomon A.M. 1992. A Global Biome Model Based on Plant Physiology and Dominance, Soil Properties and Climate. Journal of Biogeography 19: 117–134.

Raev I. 1995. Main reasons for drying of coniferous plantations in Bulgaria. Gora 1: 25–28 (in Bulgarian).

Raev I. 1997. Climatologic conditions in the representative Scots pine forest ecosystems in Bulgaria. Nauka za gorata 3/4: 9–19 (in Bulgarian).

Raev I., Grozev O., Aleksandrov V., Vasilev Z., Rosnev B., Delkov A. 1996. 2.1. Sector Forests. In: Research in Bulgaria focused on global problems of climate change. Unit 2: Vulnerability and adaptation of the forest and agricultural vegetation under climate changes. Final report. Enegryproject Ltd. Investor: Ministry of energy USA. Contract: DE-FC02-93PO10099: 1–109 (in Bulgarian).

Raev I., Slavov N. 1996. Vulnerability to climate change and measures for forest and agricultural vegetation adaptation in Bulgaria. In: Research in Bulgaria focused on global problems of climate change. Energoproject: 22–40 (in Bulgarian).

Raev I, Zhelev P., Grozeva M., Markov I, Velichkov I., Zhianski M., Georgiev G. Miteva S., Aleksandrov V. 2011. Programme of measures for adaptation of forests in Bulgaria and mitigate the negative impact of climate changes. FUTURE forest project. 2009–2011. Programme INTERREG IV C, EU, 194 p.

Regulation 6 2004. Structure of forests and forest lands in hunting regions in Bulgaria. National Assembly of the Republic of Bulgaria State Forestry Agency, 216 p. (In Bulgarian).

Rehfeldt G.E., Crookston N.L., Warwell M.V., Evans J.S. 2006. Empirical analyses of plant–climate relationships for the western United States. International Journal of Plant Sciences 167: 1123–1150.

Sedjo R.A. 2010. Adaptation of forest to climate changes: Some estimates. Resources for the Future DP 10-06, 54 p.

Slavov N., Aleksandrov V. 1996. Impact of expected climate change on agro-climatic resources in Bulgaria. Plant-growing Science 33(9): 72–77 (in Bulgarian).

Velchev V., Kozuharov S., Anchev M. (Eds.) 1992. Atlas of the Endemic Plants in Bulgaria. Publishing House Bulgarian Academy of Sciences, Sofia, 204 p. (In Bulgarian).

Walter H. 1963. Climatic diagrams as a means to comprehend the various climatic types for ecological and agricultural purposes. In: Rutter A.J. and Whitehead F.H. (Eds.) A symposium of the British Ecological Society, The water relations of plants. London: Blackwell Scientific Publications: 3–9.

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 211–217

ANALYSIS OF THE POSSIBILITIES OF RECOVERY AND DISPOSAL OF SLUDGE FROM WASTEWATER TREATMENT PLANTS

Svetla Angelova* and Evgeni Sokolovski

Department of Environmental Engineering, Faculty of Chemical and System Engineering, University of Chemical Technology and Metallurgy, 8 Kl. Ohridski blvd., 1797 Sofia, Bulgaria.
*E-mail: svetleto_007@abv.bg

Received: 07 July 2014 Accepted: 14 November 2014

Abstract

The paper analyses treatment options for sewage sludge generated in wastewater treatment plants and the available options for its recovery and disposal in the country. In parallel, a review of existing legislation concerning the use/utilization of sewage sludge for various purposes is done. Currently, treatment of sludge generated in the Republic of Bulgaria is mainly carried out through landfill or improper disposal and a very small quantity is used in agriculture. The need to seek other approaches to the sustainable management of sewage sludge is defined by two main factors: increasing the amount of sludge from urban wastewater treatment and compliance with requirements of Directive 1999/31/EC on the landfill of waste to reduce the amount of biodegradable waste going to landfills. Given the availability of sufficient quantities of sludge from wastewater treatment plants (stabilised properly) they could be regarded as a valuable energy resource.

Key words: agriculture use, dewatering, drying, incineration, sewage sludge.

Introduction

Nearly all wastewater treatment techniques have one thing in common: the formation of solids or residue from filtration or sedimentation. With that the separation of the pollutant from the aqueous medium is possible, resulting in pollutant-enriched sludge. In as much as this sludge is not returned into the process of direct wastewater treatment, it becomes necessary to have it safely treated on site or forwarded to disposal with different options of secondary use.

The application of appropriate thickening, stabilisation and dewatering processes is crucial in order to get sewage sludge disposed of correctly and efficiently. Thickening and dewatering must be well adapted to the further processes of sewage sludge utilisation. Only input material suiting the subsequent treatment processes will allow the optimum treatment results to be attained. Before a material utilisation, recovery of energy from the organic components or final depositing of the sludge takes place, various stages of pre- and post-treatment must be passed. Within the individual steps and procedures leading to the ultimate use of sludge a variety of process configurations can be applied (GFEA 2013).

An overview and detailed information on the state of the art can meanwhile be obtained from compendia and technical fact sheets, including the Best Available Techniques Reference Documents (BREF).

● Reference Document on Best Available Techniques for the Waste Treatment Industries (BREF WT),

● Reference Document on the Best Available Techniques for Waste Incineration (BREF WI), and

● Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector (BREF TCI).

Many of the wastewater plants in Bulgaria treat domestic and industrial wastewater and therefore the generated sewage sludge is classified as hazardous waste, which also defines the necessity for an adequate solution.

Table 1. Quantity of generated sewage sludge based on tonne of dry matter per year for individual RIEW in the country for 2009 and 2012.

No	Riew	Quantity of sewage sludge, t dry matter per year	
		2009	2012
01	Blagoevgrad	465	882
02	Burgas	2,906	6,541
03	Varna	8,292	5,146
04	Veliko Tarnovo	1,158	1,655
05	Vratsa	109	390
06	Montana	0	364
07	Pazardzhik	0	724
08	Pleven	1,084	1,679
9	Plovdiv	6,150	5,620
10	Ruse	14	2,090
11	Smolyan	131	419
12	Sofia	15,516	29,168
13	Stara Zagora	447	3,173
14	Haskovo	0	400
15	Shumen	429	755
16	Pernik	38	248
	Total	36,639	59,261

According to the definition given in Regulation No 2 on the classification of the waste, sewage sludge from wastewater treatment plants (WWTP) in Dobrich, Razgrad, Pernik and Dupnitsa is hazardous. Regulations do not allow recovery of hazardous sludge in agriculture, which is why its disposal could be done by incineration in appropriate facilities or in extreme cases to be disposed of at landfills for hazardous waste and/or regional landfills, which have a cell for hazardous waste disposal. As shown in Table 1 the total amount of raw sludge in 2009 was 294 322 tons, of which 13 284

Table 2. Chemical characteristics of sewage sludge – average to absolutely dry matter.

Parameter	Average value
Abs. dry substance, %	100
Ash, %	65.92
N (NH_3-), %	0.10
N (total), %	1.20
P_2O_5 (total), %	0.20
K_2O (total), %	0.50
NaO, %	0.10
MgO, %	0.30
CaO, %	6.80
Zn, mg/kg dry substance	622
Cu, mg/kg dry substance	289
Cd, mg/kg dry substance	5
Pb, mg/kg dry substance	104
Ni, mg/kg dry substance	46
Cr, mg/kg dry substance	80
As, mg/kg dry substance	5
Hg, mg/kg dry substance	2
pH (H_2O)	11.6

tons – hazardous and 281 038 tons – non-hazardous (EEA 2009, 2010, 2011, 2012).

The data shows that the amount of sludge generated is unevenly distributed throughout the country mainly due to the uneven distribution of population. This makes it necessary to find a common decision on national level to that take into account the availability of sludge treatment in other areas (respectively RIEW).

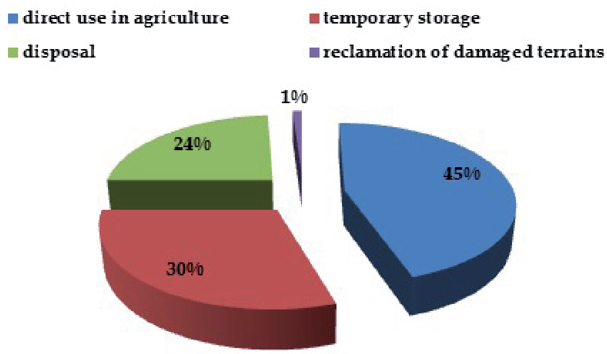

Fig. 1. Methods applied in the country for sewage sludge treatment (EEA 2009, 2010, 2011, 2012).

Average elemental composition of sewage sludge generated in Bulgaria is presented in Table 2.

According to the annual report of the EEA (EEA 2009, 2010, 2011, 2012) of the total amount of sludge generated in Bulgaria in 2009 (Fig. 1) is as follows: 24 % landfilled, 30 % is subjected to temporary storage, 45 % are used directly in agriculture and only 1 % is used for reclamation of damaged terrains.

Given the above, the current situation regarding the management of sewage sludge in Bulgaria can be defined as disturbing. The only normative document is Regulation on the manner of utilisation of sludge from wastewater treatment through its use in agriculture, approved by Decree No 339 of 14.12.2004 (State Gazette No 112/23.12.2004, amended and supplemented No 29/08.04.2011) which examines issues related to requirements to be met in order for the sludge to be utilised in agriculture. Indicated obligations of operators generating WWTP sludge as to achieve sustainable management of waste, sludge must be treated in a way that is environmentally effective, economically accessible and socially acceptable. However, the regulation does not specify methods for sludge treatment (EEA 2009, 2010, 2011, 2012, GFEA 2013).

Materials and Methods

According to Directive 86/278/EEC methods and technologies for the treatment of sewage sludge must meet the requirements for effective and efficient use of natural resources. Choice model for sludge management should lead to minimal negative impact on the environment and human health and to give priority to their use as a resource. The following figure is a block diagram of possible technologies for recovery/disposal of sludge.

EU policy in the field of waste applied five stage hierarchies for waste management. Utilisation of sewage sludge is within the highest priority of the "waste hierarchy" and landfilling – the lowest under the Waste Framework Directive 2008/98/EC and contrary to the fundamental principles of EU waste and sustainable resource management. Management of sludge nationwide is based on the legal framework for waste management. Direct disposal of dewatered sludge in landfills for non-hazardous waste is the most reliable way for recovery in the long term. In subsequent years the landfill will be one of the most expensive and ecologically – as an unacceptable method of sludge treatment.

It should be noted that every application has its advantages and disadvantages, and that therefore not one process technology can claim to provide the “ideal” solution. It is important that local conditions and needs are adequately taken into consideration while selecting the appropriate disposal paths and technologies.

Basic stages of the recovery / disposal of sewage sludge are:

- Sewage sludge generated during wastewater treatment is subjected to stabilization, to end the ongoing fermentation processes and decontamination to prevent the spread of pathogens and reduce unpleasant odours.
- For the further utilisation of sludge and in particular to make the necessary transport efficient, it is essential to reduce significantly the water content in the sludge. A first technical step which goes far beyond the simple thickening of the sludge at the WWTP is dewatering.
- Drying – Reduces the amount of precipitate which must be transported and treated, and increases the heating value.
- Conversion – Conversion stands for a wider range of processes in which a material transformation of the sewage sludge is taking place for the purpose of using its ingredients and to substantially neutralize the potentially hazardous components it contains. Conversion processes may require dewatering and/or drying as a pre-treatment stage, under certain

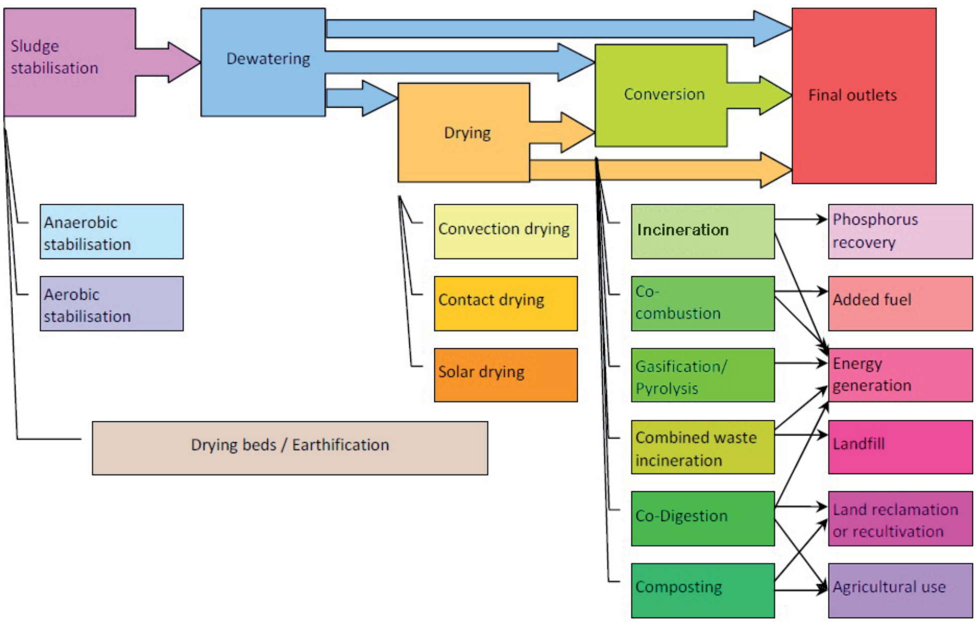

Fig. 2. Overview on possible options for a sludge management process (GFEA 2013).

conditions their application next to stabilisation can also be possible (see Fig. 2).

● Outlets – Pre-processing and conversion of the sludge have one principal purpose; to minimise volume and risks of the sludge to be disposed of and make beneficial use of it whenever possible and economically feasible. Part of the conversion process or ultimate step in the pre-processing chain is the end use of the sludge. Forwarded to thermal processes, sludge can be used as an added fuel for the production of electric energy and heat. It serves the same purpose if used in digesters for biogas production. Principally, the electrical energy can be used to operate the WWTP or it can be fed into the grid. Excess heat contained in the exhaust gases of the turbine or gas engine, from heating the pyrolysis kiln or the support combustion can be used for the thermal drying of sewage sludge. Excess steam or heat from cooling water (from the gas engines) is generally suitable for heating where appropriate users are available in closer distance (e.g. greenhouses) (Amarantos et al. 2007, GFEA 2013, Hall 2000).

From the ash which remains after a monovalent incineration, phosphorous can be directly recovered as a precious resource. Ashes from sludge incineration and the mineral granule respectively vitrified residue left after pyrolysis/gasification may also be used as aggregates or additive in the construction sector.

In the case of compost (or completely stabilised sludge as result of stabilisation and earthening procedures), the final outlets are found in agriculture, wood plantations, landscaping and land reclamation/recultivation activities where it is used as a soil conditioner, fertiliser, or a growth medium. Where landfills come to a close and interim safeguarding and remediation is undertaken, sludge compost can also be a useful substrate for the covering layers (GFEA 2013, Todorova and Yordanova 2012).

Results and Discussion

Based on the sludge treatment methods from the world practice reviewed and the amounts of generated sewage sludge the treatment options for sewage sludge for the country could be the following:

● Energy recovery by incineration of sewage sludge – Obtaining energy from biodegradable waste and is encouraged by energy policy. Equipment used must meet higher standards to meet the requirements of Directive 96/61/EC on integrated pollution prevention and control. This approach to treatment of the sludge is acceptable, if the input cost commensurate with the benefits/effects of these. An example is the co-incineration of sludge in cement plants equipped with an integrated permit for this activity. The aim is obtaining/energy recovery and partial replacement of fuel used therein. In this case, except for calorific requirement and requirements placed on the quality of sediments – dry matter content and presence of contaminants in them most often in relation to the content of halogens and heavy metals (Todorova 2004, EC 2006).

● Use in agriculture – Direct use of sludge on agricultural land is possible only when the sludge meets the requirements of the legislation. Use of sewage sludge in agriculture is not a widespread practice in Bulgaria. Direct deposit of sediment in the soil should be made mandatory after appropriate treatment and in compliance with the regulations. The Regulation on the procedure and manner of utilisation of sludge from wastewater treatment through its use in agriculture requires that the sludge to be classified as non-hazardous waste under Regulation No 3/01.04.2008 on waste classification (Todorova 2005, Todorova and Yordanova 2012).

● Used for reclamation of damaged terrains – The use of pre-treated sludge (mainly in the form of compost) for reclamation of disturbed areas is well known option in the world practice. Import of large quantities of organic matter to the sediments is useful for restoring the humus layer of the terrain and soils affected by the extraction of natural resources, mines, abandoned quarries, reclamation of landfill sites and more. Practice in Spain shows that the direct use of sludge for reclamation of degraded forest land is unacceptable, the reason for this being the high risk of contamination of surface and groundwater (GFEA 2013, Amarantos et al. 2007).

● Biogas and electricity generation from sewage sludge – With the implementation of Directive 2001/77/EC on the production of electricity from renewable energy sources (RES) 2020 Bulgaria should produce 16 % of its electricity through renewable energy sources. In this regard, there are technological solutions for co-generation of biogas, electricity and / or heat. Co-generation in this case is the result of a joint anaerobic fermentation of sewage sludge and all kinds of manure derived from pig, poultry and / or cattle farms. This approach has a considerable environmental impact, since it does not depend on the quality of the sludge and in the fermentation process, the generated biogas high in CH_4 – 60–70 % and 30–40 % CO_2. This makes it very suitable for direct use in the production of heat and / or electricity. On the one hand, such technological solutions allow utilization of an extremely problematic waste from livestock, such as manure from pig farms. Currently, it is hard to find an environmentally sound solution for its. On the other hand, the final product after the fermentation process of these technologies is quality compost, which could be used as a fertiliser in agriculture or for reclamation of damaged terrains. All this proves the high ecological relevance of this type of technology. For Bulgaria financing facilities for co-generation for the current programming period was decided on several measures of the Program for Rural Development 2007–2013 (Arlt et al. 2002, Bardarska 2012).

● Use of sewage sludge for other purposes – After suitable stabilisation sludge could be used for incorporation into building materials (cement production/blocks) for the manufacture of an organic substrate used in horticulture, the breeding of worms in fish farming or in appropriate mixing with other edible substances for the production of bio fertiliser.

Conclusion

Based on the data from the analysis of possible treatment methods of this type of waste, the country's ability to manage it and existing legislation, the following conclusions can be made:

● Existing methods for treatment and disposal of sludge in the country do not achieve the expected results and should be improved.

● There are gaps in the legislation regarding the control of direct use of untreated sludge in soil which pose a risk to human health and the state of the environment (soil resources, groundwater and surface water).

- In order to achieve appropriate utilisation of sludge generated in the country the practice to incinerate sludge in power plants or co-incineration plants should be introduced.

References

Amarantos P., Buttol P., Maiorino L. 2007. An Environmental LCA of Alternative Scenarios of Urban Sewage Sludge Treatment and Disposal. International Scientific Journal of Thermal Science 11(3): 153–164.

Arlt A., Seifert H. Nieke E., Furniss B. 2002. Processing of Sewage Sludge for Energetic Purposes – a Challenge for Process Technology. Bioprocessing of Solid Waste & Sludge 2: 19–29.

Bardarska G. 2012. Methane production in anaerobic digester by sludge of wastewater treatment. [Vodno delo] Water Affairs, vol. 1/2: 7–14 (in Bulgarian).

Garvanska S. 2008. Sludges from waste water treatment stations and rules from their utilization. PublishScieSet-Eco Publisher. ISBN: 978-954-749-076-5, 122 p. (In Bulgarian).

European Commission (EC). 2006. Integrated Pollution Prevention and Control, Reference Document on the Best Available Techniques for Waste Incineration, Seville, Spain, 602 p.

Executive Environment Agency (EEA). 2009. Report under Article 16, paragraph 2 of the Regulation on the terms and procedures for utilization of sewage sludge from wastewater treatment through its use in agriculture. Sofia. (In Bulgarian).

Executive Environment Agency (EEA). 2010. Report under Article 16, paragraph 2 of the Regulation on the terms and procedures for utilization of sewage sludge from wastewater treatment through its use in agriculture. Sofia. (In Bulgarian).

Executive Environment Agency (EEA). 2011. Report under Article 16, paragraph 2 of the Regulation on the terms and procedures for utilization of sewage sludge from wastewater treatment through its use in agriculture. Sofia. (In Bulgarian).

Executive Environment Agency (EEA). 2012. Report under Article 16, paragraph 2 of the Regulation on the terms and procedures for utilization of sewage sludge from wastewater treatment through its use in agriculture. Sofia. (In Bulgarian).

German Federal Environment Agency (GFEA). 2013. Technical Guide on the Treatment and Recycling Techniques for Sludge from municipal Wastewater Treatment with references to Best Available Techniques (BAT), Project No FKZ 380 01 233, Dresden, 56 p.

Hall J. 2000. Ecological and economical balance for sludge management options. In: Session 3. Technology and innovative options related to sludge management: 155–172. Available: http://ec.europa.eu/environment/waste/sludge/pdf/workshoppart4.pdf

Todorova Ek. 2004. Applicability of waste as alternative fuels. Forestry Ideas 2: 59–65 (in Bulgarian).

Todorova Ek. 2005. Possibilities for obtaining of compost from municipality and agriculture wastes. Journal of Environmental Protection and Ecology, book 4, vol. 6: 679–686.

Todorova Ek., Yordanova M. 2012. Utilization of biodegradable waste by composting. Bulgarian Association of Municipal Environmental Experts (BAMEE), 34 p. (In Bulgarian).

FORESTRY IDEAS, 2014, vol. 20, No 2 (48): 219–232

VERTICAL STRUCTURE ASSESSMENT OF SPRUCE ALPINE FORESTS IN THE RHODOPE MOUNTAINS

Neno Aleksandrov[1] and Emil Molle[2]

[1]Department of Silviculture, University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. E-mail: n_al@abv.bg
[2]Department of Ecology, Protection and Remediation of the Environment, University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. E-mail: emilmolle@gmail.com

Received: 10 October 2014 Accepted: 28 November 2014

Abstract

Forest vertical structure is a characteristic which is of interest for many disciplines and is often discussed in the context of forest ecosystems management. The vertical stratification of tree crowns influences the growth of the single tree and also it determinates the communities thriving beneath the canopy. Close to nature forest management demands the application of silvicultural activities that will maintain the natural structure of the forest. With regard to this, the quantitative assessment of the vertical structure is a particularly important feature. Forest vertical structure is biologically important also because of its relationship with biodiversity. However, the present methods for quantitative analysis are either randomly determined and do not characterize the natural stratification of canopy stand, or they are too time consuming and are developed for analysis on landscape level. The TSTRAT program has been developed in order to define tree stratification in vertical space at stand level. Another approach used for evaluation of structural heterogeneity of stands is the use of different types of indexes. The most commonly applied indexes for vertical structure assessment are *FHD* index, Gini index, Shanon-Winen index, Pielou index and *STVI*. The connection between them and the canopy layer determined by TSTRAT, has not yet been clarified. The correlation between different indexes and canopy stratification determined by TSTRAT is being analyzed in this article. Through the execution of multiple simulations on Monte-Carlo method were determined the bootstrap intervals for each index.

Key words: bootstrap, Foliage Height Diversity **(***FHD***),** Gini, Pielou, Shannon-Wiener, Structure index based on variance **(***STVI***),** vertical structure TSTRAT.

Introduction

A vast variety of forest structure is observed in nature, which is a result of forest vegetation adaptation to the complex impact of environment factors. The results from a series of scientific studies confirm the hypothesis that the forest structure is the main factor determining the processes in a forest ecosystem (Jeffrey 1961, Franklin et al. 1981, Oliver and Larson 1996, Kimmins 1997, O'Hara et al. 1996, Spies 1998). According to O'Hara et al. (1996) the conditions which are desirable in a stand, and also satisfy the multifunctional needs, can be expressed the best by its structure. The importance of forest structure and its possible variations in time has always been useful information, which lays in the basis of planning a silvicultural strategy. The term 'stand structure' includes the idea of the location of stand elements (not only trees) in space. Forest can be described by its composition, the vertical and horizontal model of distribution of trees, the age and size of trees (Whittaker 1975, Franklin et al. 1981, Kimmins 1997cvbb). The stand structure can be looked at as a product of forest dynamics and biophysical factors, and at the same time as an engine of the processes in the ecosystem and the biodiversity (Spies 1998). According to contemporary understanding it is a result of autogenic development processes (regeneration, competition, etc.) and disturbances caused by nature's forces nowadays and in the past (Kuuluvainen et al. 1996, Spies 1998).

Although stand structure is most often described through the distribution of trees in width class (O'Hara 1998), vertical structure is also an important feature of forest ecosystems, since it shows key factors such as habitat conditions and ecological processes like competition or natural disturbance regime (Montes et al. 2008). Svensson and Jeglum (2001) use the distribution of trees in height class as a proper criterion of forest structure and the current processes within an ecosystem.

Canopy state, determined through the level of closing and the presence or absence of 'gap' disturbances, is often used to characterize forest vertical structure. The level of canopy closing determines the light regime in the stand and thus influences the understory dynamics, as well as the process of natural regeneration. Canopy disturbances are an important structural element and along with level of canopy closing are used for the differentiation between different phases of forest stands dynamics (Franklin et al. 2002, Oliver and Larson 1996). While the level and condition of canopy closing are important elements of forest structure, they are rather seldom used in literature. Characteristics connected to the size of tree stems such as diameter, height and volume are used in most studies. This, to some extent, shows the connection between stem size and other structural features, such as the LAI index, crown size and the presence of heartwood of different size (Spies 1998) and also is due to the fact that the data about stem size are rather easy to gather.

The vertical location of trees' crowns is one of the most often used features in stands' vertical structure characterization (Brokaw and Lent 1999). A straight subjection has been determined between the foliage height diversity (*FHD*) index, which characterizes the arrangements of leaves within the range of different vertical layers and the variety of bird species (McElhinny et al. 2005). This stimulates the use of *FHD* as a vertical structure measure and its acceptance by some authors for a reliable indicator of biodiversity (Gove 1996, Buongiorno et al. 1994), although there is not much evidence to confirm that *FHD* can explain the differences in the variety of faunistic groups other than birds. Despite the usage of that index there is no standard method for its definition. Different authors use random height classes (McElhinny et al. 2005). An alternative of randomly determined height classes is the use of separate canopy layers (Bebi et al. 2001, McElhinny et al. 2005). Each and every one of these approaches suggests that the separate layers in the canopy can be clearly and consecutively defined.

Parker and Brown (2000) reexamined the idea of 'canopy stratification' in ecological literature and found out that the term had different meaning and methods of definition, which depend on the aims of the specific study. The authors suggested that separate canopy layers should be determined on the basis of ecological gradients, determined by tree crowns (for example, changes in light regime). Vertical stratification of tree crowns is a structural characteristic of stands and determines the distribution of light and precipitation underneath the forest canopy (Latham et al. 1998). It is also used to explain the spatial heterogeneity and time dynamics of understory, to characterize the microclimate differences in the formed gaps and as a factor determining the process of natural regeneration. Vertical structure has also been used for determination of the ecologic niches of different animal and bird species (Ulyshen 2011).

The arrangement and vertical distribution of tree crowns foliage changes during the development of stands, due to different competition and self-thinning rate, release of oppressed trees or the appearance of natural regeneration. Distinct differences in vertical structure in different development phases according to Oliver and Larson (1996) have also been observed by O'Hara et al. (1996). Despite this fact, the differences in vertical structure are often very hard to see, especially in stands dominated by shade tolerant species, which form unbroken vertical stratification (Latham et al. 1998). In this case it is very different to distinguish the differences between the models of vertical stratification, because stands are in a lap between structural phases.

An overview of the literature connected with a description of alpine spruce forests structure in Europe, presented by Kucbel et al. (2008), showed that vertical structure is a key element for the differentiation of phases of forest natural development (Korpel 1995, Hladik et al. 1993). In broad outlines, natural forests are considered structurally heterogenic, compared to managed ones (Svensson and Jeglum 2001). Structural analysis of alpine spruce forests in Babia Hora reserve in Slovakia found out that the self-thinning phase is characterized with the most differentiated vertical structure. As the altitude increases the differences between the vertical structures of stands in regeneration phase and Old growth forests decrease, while the differences between self thinning phase and the other phases become more and more distinguishable (Merganič et al. 2011).

Thorough studies on the vertical structure of alpine forests in our country are missing. Most often canopy stratification is illustrated by profile diagrams (Rafailov 2003). This approach can be used for the clarification of some common models of stand development, such as vertical differentiation of tree crowns in layers or classes but it is impossible to use for quantitative analyses of the structural heterogeneity of different stands. For this purpose the distribution of the basal areain height classes or canopy layers and the number of formed horizons are used, as well as the calculation of height variation coefficient, *FHD* index, Gini index, Shanon-Winen index, *STVI* (Zenner and Hibbs 2000).

Study Area

The aim of the present study is characterization of natural alpine spruce stands vertical structure in the Rhodope Mountains. The research was conducted in relatively undisturbed natural spruce stands.

The main criteria for the selection of studied stands were:

- Stands should be located in subalpine spruce forests;

● Stands should be representative for the variety of forest structures in spruce forests;

● They should be more than 80–100 years old;

● Stands should be a result of natural regeneration.

On the basis of the criteria pointed out, three sites located in the highest parts of the Rhodope Mountains were chosen – the foot of Goliam Perelik peak (2190.2 m), Goliama Siutka peak (2185.8 m) and Goliam Persenk peak (2094.5 m). The first site is located at the foot of Goliam Perelik peak. Since forest massifs in this part of the Rhodope Mountains are highly influenced by human activity in the past, two Permanent Sample Plots (PSP) were founded established. One of them is in the territory of 'Sokucheto' reserve, declared as a reserve with order No 508/28.03.1968 and total area of 177.5 ha and altitude between 1400 and 1700 m. The spruce forests in that region were identified as Acidophilic *Picea abies* forests in the mountainous and alpine belts (*Vaccinio-Piceetea*) according to NATURA 2000 classification of natural habitats. The second site is located at the foot of Goliam Persenk peak. There are three PSPs in this site. The spruce stands belong to 'Roman road' protected territory. The third site includes spruce stands in the territory of 'Beglika' reserve (Order No 751/11.05.1960), located in Western Dospat-Batak region of Western Rhodope subarea. General characteristics of SP are presented in Table 1.

Table 1. Sites and trial areas.

Sample plot	Geographic coordinates X	Geographic coordinates Y	Altitude, m	Exposure	Slope, °	Soil type	Site type*
'Beglika' reserve							
BG1	41522381	24024066	1850	SE	7	Umbric Cambisols	B_2(85)
BG2	41521988	24030089	1750	W	12	Distric Eutric Cambisols transitional	C_2(82)
BG3	41530885	24014684	2100	SW	2	Plan – Umbric Cambisols	C_3(86)
DGS 'Hvoina'							
HV1	41495954	24330482	1850	S	5	Distric Eutric dark	B_2(83)
HV2	41495191	24332406	2050		5	Plan – Umbric cambisols	B_2(87)
HV3	41495535	24331522	1950	NE	3	Plan – Umbric cambisols	$CD_{2,3}$(84)
'Soskucheto' reserve							
PR1	41363444	24374496	1700	SW	4	Distric Eutric transitional	C_2(82)
PR2	41363375	24355159	2000	NE	6	Plan – Umbric cambisols	C_3(86)

Note: *A–D – richness of the soil in ascending order; 0–4 – soil moisture in ascending order; (82–87) – number of site indexes.

Method

According to O'Hara et al. (1996) vertical structure assessment requires the appliance of different methods and approaches. According to them, agreement and consistency on stand characterization for different purposes still have not been reached. The authors pointed out the need of new approaches for structure description that will include development of models of crown dynamics, foliage distribution in space and classification, based on growth and competition. In this study were used complex methods including the use of vertical tree stratification program, TSTRAT (Latham et al. 1998, Lazarov 2002) and the definition of a group of indexes used for evaluation of stands' structural heterogeneity (Valbuena et al. 2012, Staudhammer and LeMay 2001, Pommerening 2002, Neumann and Starlinger 2001). The diameters, heights and lengths of the crowns in each width class measured in the sample plots were used as initial data.

TSTRAT has been developed for the quantitative determination of vertical structure of stands. The program simulates natural vertical arrangement of tree crowns and is used for the identification of stands' vertical layers, which are biologically connected to the process of natural stratification. TSTRAT algorithm determines multiple points of interruption based on tree height and crown length and thus arranges separate trees in vertical layers depending on the relative position of their crowns and these interruption points. The interruption points are based on the competition zones of the crowns, where most of the photosynthesis runs. For competition zone between trees has been determined a part of the crown, including 60 % of its length. Each canopy layers horizon is characterized by basic statistic indexes – average diameter, height, crown length and circular surface.

In the last decade there has been a trend towards wider appliance of the use of a number of indexes for forest structure variety (Buongiorno et al. 1994, Kuuluvainen et al. 1996, Latham et al. 1998, Pretzsch 1999, Neumann ahd Starlinger 2001, Lazarov 2002, Barbeito et al. 2009). These indexes usually, used in population ecology, are appropriate for quantitative evaluation of stand structure complicity. The use of indexes allows making direct comparisons and at the same time provides a relatively easy way for structure control with different management strategies.

For the assessment of vertical structure of observed stands the following indexes were calculated:

Shannon-Wiener index (1) widely used in ecology studies and proved to be a good index of structural complicity of forests (Kuuluvainen et al. 1996).

$$H' = -\sum p_i \ln p_i \qquad (1),$$

where p_i– relative basal area in i height class.

Pielou index (2) (Pielou 1969) is derived from Shannon-Wiener's index but is easier to interpret since it varies in the interval 0÷1 and its maximal value corresponds to the maximal heterogeneity (variety).

$$J = \frac{-\sum p_i \ln p_i}{\ln S} = \frac{H'}{\ln S} \qquad (2),$$

where S – number of height classes.

Gini index (3) is used as a measure of structural heterogeneity (Latham et al. 1998, Dixon et al. 1987). The values of the index belong to the interval 0÷1 and 1 shows the maximal possible theoretical variety.

$$GC = \frac{\sum_1^n (2j-n-1)H_i}{\sum H_i(n-1)} \quad (3),$$

where:

i – separate tree height class determined in ascending order;

H_i– height of the *i* tree;

n – number of trees.

FHD index (4) (foliage height diversity) (McElhinny et al. 2005). When this index is calculated, the separate height classes are adopted to be identical with phytocenotic horizons shared with TSTRAT program, as instead the foliage surface, for each horizon has been used the basal area of trees included. This substitution has been made possible since the proportional coherence between foliage surface and stem diameter is well-known (Whitehead 1978).

$$FHD = -\sum W_S \ln W_S \quad (4),$$

where W_s – relative basal area (foliage area) in corresponding horizon *s*.

STVI index (5) (Staudhammer and LeMay 2001, Barbeito et al. 2009) – it does not use height classes and therefore is considered more objective index for structural heterogeneity.

$$STVI_h = \left\{ \begin{array}{l} 1-\left(\dfrac{S_{hu}^2 - S_h^2}{S_{hu}^2}\right)^{p_1}, when\ S_h^2 \le S_{hu}^2 \\ 1-\left(\dfrac{S_h^2 - S_{hu}^2}{m \cdot S_{h\max} - S_{hu}^2}\right)^{p_2}, when\ S_h^2 > S_{hu}^2 \end{array} \right\} \quad (5),$$

where: $S_{hu}^2 = \frac{(b-a)^2}{12}$ is the theoretical variation of tree distribution in height in uniform distribution;

$S_{h\max}^2 = \frac{(b-a)^2}{4}$ is theoretical variation of distribution of tree number in height in bimodal distribution;

$S_h^2 = \frac{\sum_{j=1}^n w_j \cdot (H_j - \overline{H})^2}{\sum_{j=1}^n w_j}$ is actual variation in height, expressed by w_j – correlation between the circular surface of the *j* tree and the total circular surface in the trial area;

H_j is height of *j* tree from the trial area;

$\overline{H}$ is average height;

a is smallest height measured;

b is greatest height measured;

p_1= 2.40094 is a constant;

p_2 = 1.1281 is a constant.

The statistical analysis includes calculation of a correlation matrix for structural variety indexes. The analysis of variation is used for calculation of the correspondence between canopy stratification with TSTRAT program and calculated indexes. Due to the relatively small volume of the extracts the confidential intervals for indexes with identified practical importance are calculated through the bootstrap procedure (Leisch 2013). Bootstrap procedure is implemented by the method Monte-Carlo. The term Monte-Carlo depicts computational techniques based on simulation procedures. These techniques have become an essential part of the statistician's toolbox. Bootstrap in particular is a highly useful procedure, as it mimics sampling techniques that utilize repeated randomization of a real sample. The biological concept is critical when applying the bootstrap procedure, as it provides solutions to particular problems through statistical means. The illustration of index variation is presented by the box-plot diagrams of Tukey.

Results

TSTRAT graphics show a general picture of tree arrangement is DBH classes in the air space. The number of horizons, obtained as a result of competition analysis, gives the evaluation of stand structure complicity. The graphic image of tree width and the length of its crown provides visualization about the position of trees in the stand hierarchy according to their width class and also opportunity to foresee the ways of development (e.g. small height and small crown suggests higher possibility for the tree to drop off). Indicators for competition activation are: increase of stem self-pruning parts percentage; smaller crown length of trees of lower DBH classes and complication of vertical structure, expressed through increase in the number of horizons.

TSTRAT diagrams for two types of structure: stands with two or three formed horizons are presented in Fig. 1. The application of TSTRAT is delimited. The specific cases, which represent respectively the initial and final phase of stand development, show some resemblance in the heterogeneity classes in the vertical structure (Lazarov 2002).

The combination between the lowest level of heterogeneity of vertical structure (one canopy horizon) and the lowest level of diameter variations can be accepted as typical feature of the stand initiation phase. In the present article the type of diameter distribution is not examined and therefore the stands have not been classified according to the dynamics of their natural regeneration. The certain canopy horizons are basis for the evaluation of how adequate are the calculated different types of vertical structure assessment indexes.

The calculated indexes give assessment of structural heterogeneity of the stand according to its height. The data are presented in Table 2 along with the determined by TSTRAT canopy horizons, as well as the variation coefficient (*Wh*) for every sample plot.

The range of variation intervals of the separate indexes is different, as well as their medians (Fig. 2). It is clear that the sensibility of the indexes is represented in a different range.

With minimal variation scope is Gini index, and Shannon and *FHD* indexes vary considerably. For some of the indexes that variation is symmetrical, while for others the symmetry is broken. This raises the question about synchrony in variation, which has been studied through correlation analysis.

After the conducted correlation analysis a statistically important positive correlation has been determined between Shannon and Pielou indexes. It ensues from the way both indexes have been formulated, not from their different biological sense. Between Shannon and Gini indexes, a statistically important positive correlation has been determined, while despite the wide use of *FHD* and *STVI*, none such correlation has been established between them. Table 3 visualizes that in spite of how close Shannon and Pielou indexes are the correlation between Pielou and Gini indexes has turned out to be statistically insignificant. This fact should be looked at as an indication of the necessity of calculation of number of indexes instead of single ones.

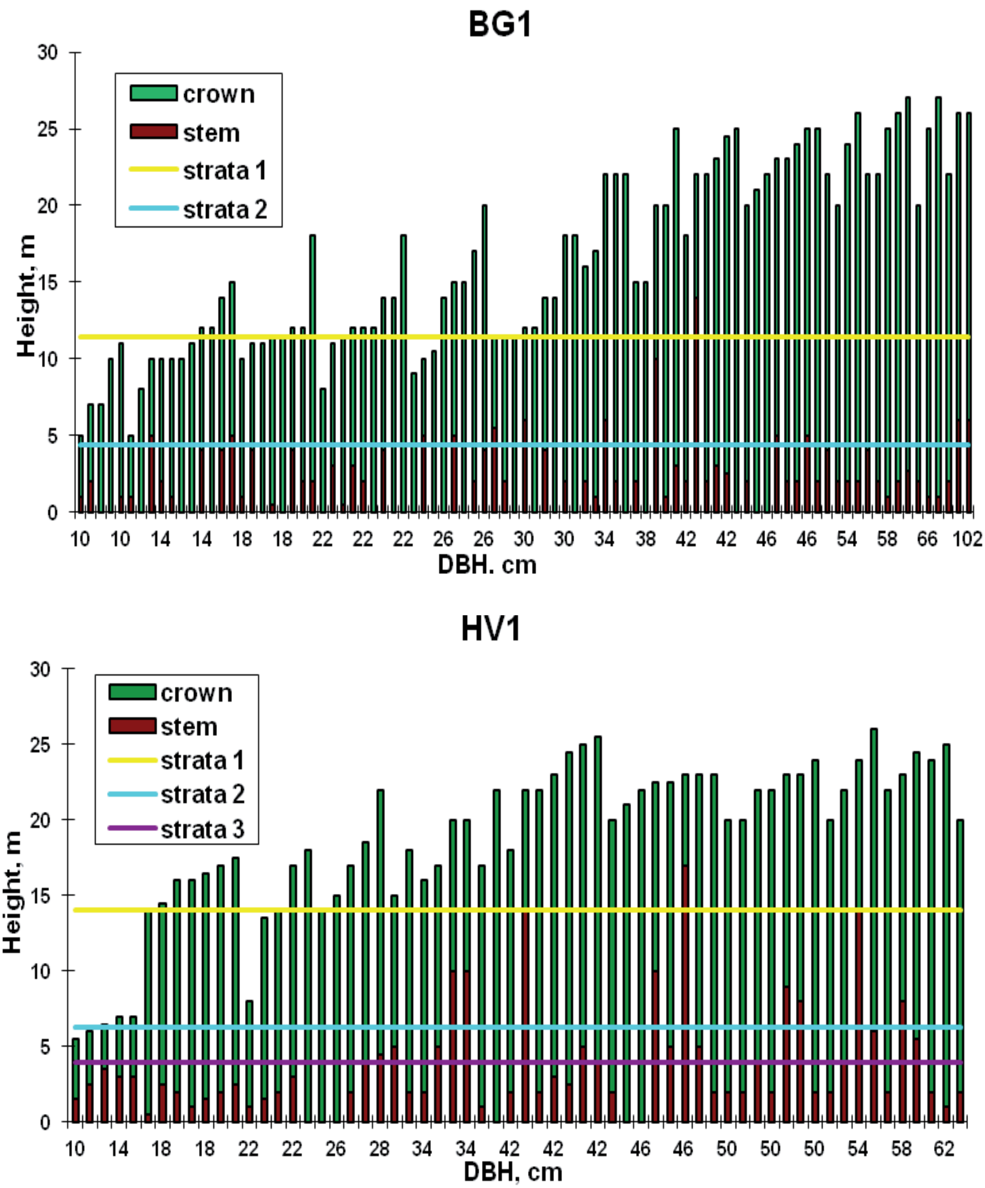

Fig. 1. TSTRAT diagrams for two types of structure.

In order to identify the correlation between indexes and determined by TSTRAT canopy horizons, an ANOVA analysis has been conducted (Table 4). It has been determined that the values of Shannon index statistically significantly (*p*=0.023) depend on the canopy stratification.

To determine the confidence interval

Table 2. Results from TSTRAT data analysis in trial areas (TA).

Sample plot	Shannon Index	Pielou Index	*STVI*	*GINI*	*FHD*	TSTRAT	*Wh*
BG1	1.3937	0.7779	0.6842	0.215	0.412	2	35,051
BG2	1.1968	0.7436	0.9958	0.196	0.544	2	36,642
BG3	0.8560	0.6175	0.8814	0.113	0.603	2	25,811
HV1	0.9791	0.6084	0.8175	0.145	0.640	3	28,462
HV2	0.8112	0.5041	0.6880	0.121	0.781	3	23,246
HV3	0.8701	0.5406	0.7547	0.161	0.488	3	38,526
PR1	0.7276	0.4521	0.7692	0.235	0.610	3	35,057
PR2	1.2732	0.7911	0.8806	0.223	0.566	2	40,374
Tp1	1.0980	0.6128	0.6941	0.213	0.435	2	36,666
Tp2	1.0238	0.6361	0.8036	0.205	0.460	2	35,395
Tp3	0.9359	0.6751	0.9364	0.157	0.235	2	24,891
Tp4	0.7834	0.4868	0.6887	0.142	0.518	3	27,371
Tp4.2	1.0403	0.6464	0.9224	0.201	0.442	3	31,291
Tp5	1.0090	0.6269	0.9859	0.179	0.510	3	37,434

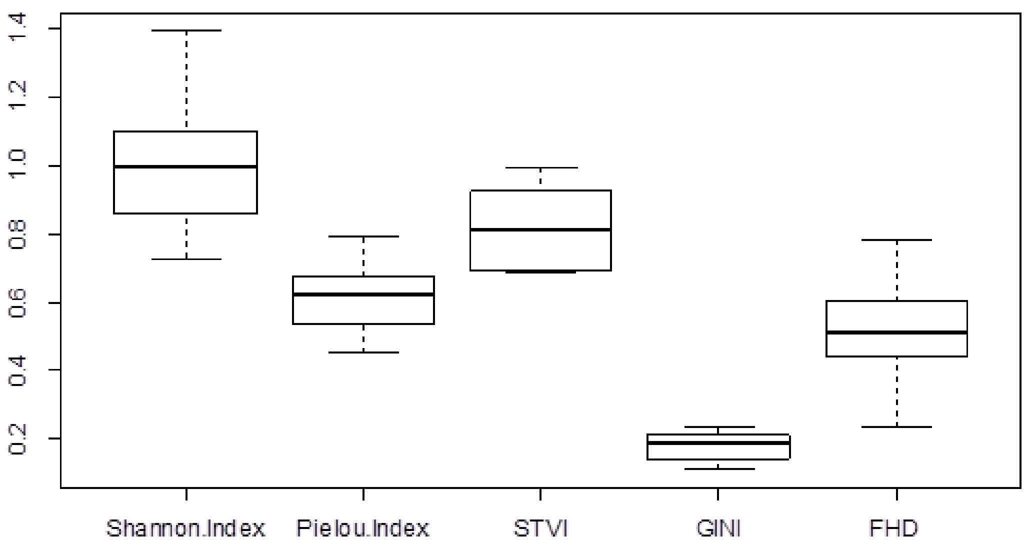

Fig. 2. Box-plot diagrams for the variation of separate indexes.

of Shannon index, which is needed for its comparative characteristic formed by strata with TSTRAT bootstrap procedure is implemented by the method Monte-Carlo. The results are presented graphically in Fig. 3. From the resulting intervals it is clear that Shannon index can be used as an objective evaluator of height forest

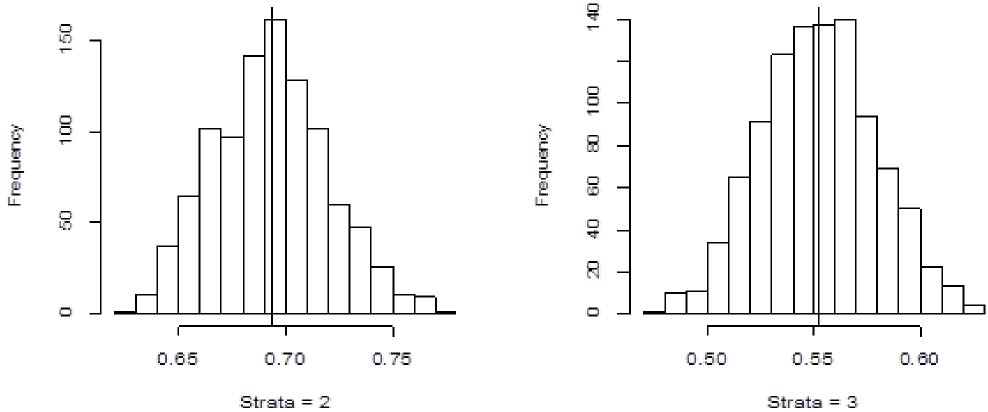

Fig. 3. Bootstrap intervals of Shannon index in canopy stratifications.

structure in terms of canopy stratification.

The figure shows that both confidence intervals do not overlap significantly, i.e. Shannon index clearly has a different range of variation for both strata's.

ANOVA analysis (Table 5) applied to Pielou index found statistically significant (p = 0.00459) variation between the levels of strata obtained by TSTRAT and the index value.

The designed bootstrap intervals for this index are presented in Fig. 4. The lack of overlapping between both intervals determines that index as a better indicator of structural heterogeneity and canopy stratification.

ANOVA analysis applied to Gini index does not show a statistically proved variation in horizons. However, the bootstrap procedure shows certain differences in the index distribution in both horizons (Fig. 5).

The solid lines show the average values of Gini index for both strata. Despite overlapping histograms, Monte-Carlo simulation shows that low values of Gini are more typical for strata 3 and outlines both index ranges.

Table 3. Correlation matrix of the used indexes.

Index	Shannon	Pielou	*STVI*	*GINI*	*FHD*
Shannon	1.0000	0.9209	0.1774	0.5305	-0.3265
Pielou		1.0000	0.4466	0.3627	-0.4002
STVI			1.0000	0.0497	-0.2205
GINI				1.0000	-0.3163
FHD					1.0000

Table 4. Shannon-index ANOVA.

Source of Variation	*Df*	Sum *Sq*	Mean *Sq*	*F* value	*Pr* (>*F*)
Strata	1	0.1731	0.1731	6.7870	0.023*
Residuals	12	0.3060	0.0255		

Table 5. Pielou-index ANOVA.

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Strata	1	0.0699	0.0699	12.0700	0.00459 **
Residuals	12	0.0694	0.0058		

Note: `Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

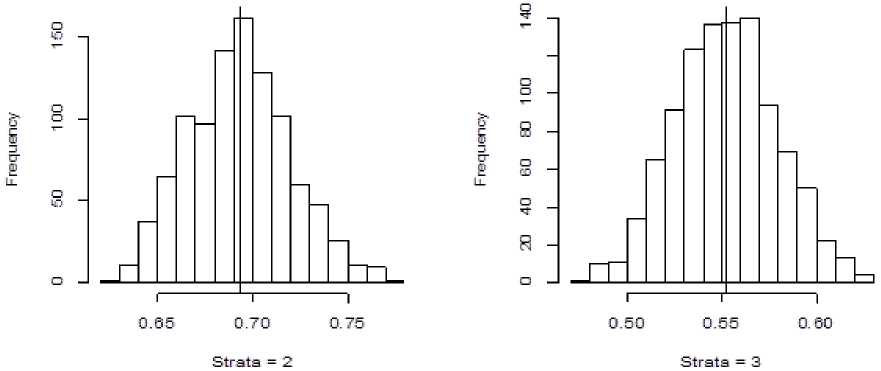

Fig. 4. Bootstrap intervals of Pielou index in the canopy stratifications.

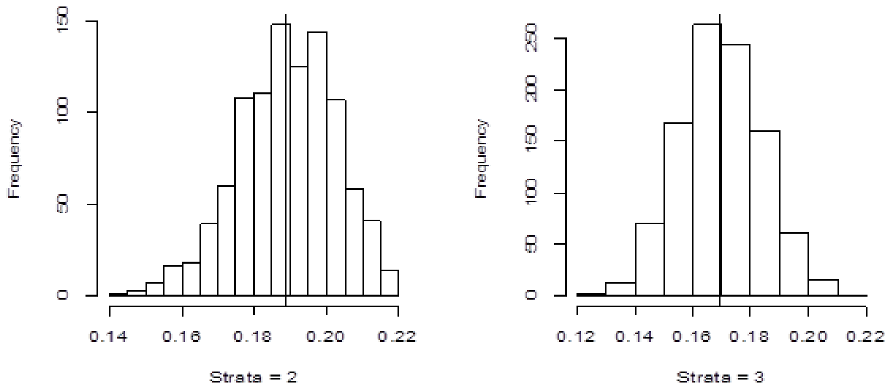

Fig. 5. Bootstrap intervals of Gini index in canopy stratifications.

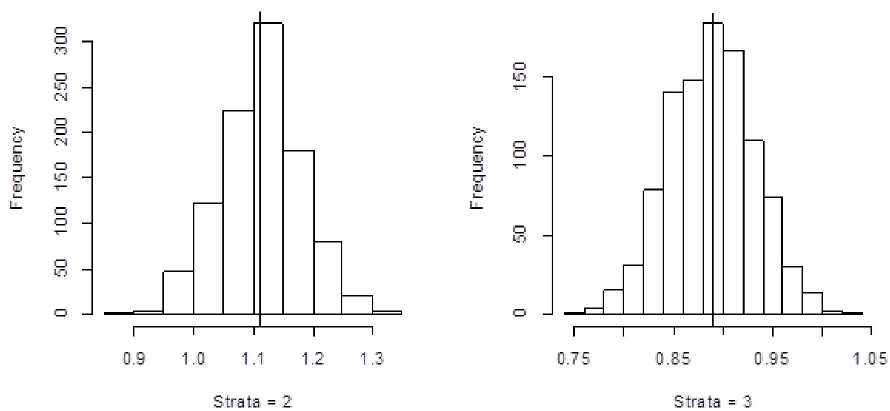

Fig. 6. Bootstrap intervals of Gini index in strata based on Shannon index.

The determined statistically significant correlation between Shannon and Gini indexes, allows the following approach towards the confidential interval of Gini index: We are trying to create a model for the correlation between both indexes – Shannon and Gini, using data for both strata numbers 2 and 3. The model was statistically significant with *F*-statistic: 4.7 on 1 and 12 *Df*, and *p*-value: 0.05099 – very close to 95 % level of significance.

This means that it can be build a bootstrap interval for Gini index indirectly using two bootstrap simulations for Shannon index to the respective strata and calculating Gini-bootstrap values under the received straight line model (Fig. 6.).

This means that we can build a bootstrap interval for Gini index indirectly using two bootstrap simulations for Shannon index to the respective strata and calculating Gini-bootstrap values under the received straight line model.

Conclusion

The correlation analysis of the most commonly used indexes for assessment of structural variation in height and the obtained results through TSTRAT program confirmed a strong correlation between Shannon-Wiener index, Pielou and Gini indexes. These may be used successfully for evaluation of stands' vertical structure. On the basis of the data calculated by TSTRAT program application for alpine spruce forests in the Rhodope Mountains and the calculated indexes for the same sample plots, and through the application of a bootstrap procedure and multiple simulations through Monte-Carlo method, the intervals of variation of indexes were determined. Pielou index turned out to be the best indicator of canopy stratification in the observed stands. The use of this index, along with Gini one, as an assessment of the structural irregularity of stand height, as well as the graphic visualization through TSTRAT diagrams, enables the making of a complex evaluation of forest vertical structure. Thus, the changes in forest structure after different forestry impacts or natural disturbance can be evaluated and also the natural development phase of the forest may be determined.

Acknowledgement

This work was supported by the Swiss Enlargement Contribution in the framework of the Bulgarian-Swiss Research Programme, project IZEBZO_143109

References

Barbeito I., Canellas I., Montes F. 2009. Evaluating the behavior of vertical structure indices in Scots pine forests. Annals of Forest Science 66, 710 p.

Bebi P., Kienast F., Schönenberger W. 2001. Assessing structures in mountain forests as a basis for investigating the forest's dynamics and protective function. Forest Ecology and Management 145(1–2): 3–14.

Brokaw N.V.L., Lent R.A. 1999. Vertical structure. In: Hunter I., Malcom L. (Eds.), Maintaining Biodiversity in Forest Ecosystems. Cambridge University Press, Cambridge: 373–399.

Buongiorno J., Dahir S., Lu H., Lin C. 1994. Tree size diversity and economic returns in uneven-aged forest stands. Forest Science 40: 83–103.

Dixon P.M., Weiner J., Mitchell-Olds T., Woodley R. 1987. Bootstrapping the Gini coefficient of inequality. Ecology 68: 1548–1551.

Franklin J.F., Cromack K.J., Denison W., McKee A., Maser C., Sedell J., Swanson F., Juday G. 1981. Ecological Characteristics of Old-Growth Douglas-Fir Forests. USDA Forest Service General Technical Report 118, 48 p.

Franklin J.F., Spies T.A., Van Pelt R., Carey A.B., Thornburgh D.A., Berg D.R., Lindenmayer D.B., Harmon M.E., Keeton W.S., Shaw D.C., Bible K., Chen J. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-Fir forests as an example. Forest Ecology and Management 155: 399–423.

Gove J.H. 1996. Optimising the management of uneven-aged Spruce-Fir stands while preserving structural diversity. In: Bachmann P., Kohl M., Paivinen R. (Eds.), Assessment of Biodiversity for Improved Forest Planning. Kluwer Academic Publishers, Monte Verita, Switzerland: 123–134.

Hladik M., Korpel S., Lukac T., Tesar V. 1993. Management in mountain forests. Matice lesnicka Pisek, 123 p.

Jeffrey W. 1961. Origin and structure of some white spruce stands on the lower Peace River. In: Gap dynamics of forest trees: A review with particular attention to boreal forests. 2001. McCarthy J. Environmental Reviews 9(1): 1–59.

Kimmins J.P. 1997. Forest ecology. A foundation for sustainable management. Prentice-Hall, New Jersey, 560 p.

Korpel S. 1995. Die Urwealder der Westkarpaten. In: Selection Management of Forests. 2003. Rafailov G. Publishing house of University of forestry, 213 p. (In Bulgarian).

Kucbel S. Vencurik, J., Jaloviar P., Kuris P. 2008. Analysis of the structure of a subalpine protection forest in the Low Tatra Mts. Acta Facultatis Forestalis Zvolen L 2: 57–65.

Kuuluvainen T., Penttinen A., Leinonen K., Nygren M. 1996. Statistical opportunities for comparing stand structural heterogeneity in managed and primeval forests: An example from boreal spruce forest in southern Finland. Silva Fennica 30(2–3): 315–328.

Latham P.A., Zuuring H.R., Coble D.W. 1998. A method for quantifying vertical forest structure. Forest Ecology and Management 104(1): 157–170.

Lazarov S. 2002. Study of the prerequisites for selection management of young fir-spruce stands in the Western Rhodopes. PhD Thesis, Sofia, 135 p. (In Bulgarian).

Leisch F. 2013. S original, from StatLib and by Rob Tibshirani. (bootstrap: Functions for the Book 'An Introduction to the Bootstrap'. R package version 2012.04-1. Available: http://CRAN.R-project.org/package=bootstrap

McElhinny C., Gibbons P., Bauhus J., Brack C. 2005. Forest and woodland stand structural complexity: Its definition and measurement. Forest Ecology and Management 218: 1–24.

Merganič J., Merganičová K., Vorčák J. 2011. Height structure of spruce mountain forests of Babia hora – Oravské Beskydy. Beskydy 4(1): 27–38.

Neumann M., Starlinger F. 2001. The significance of different indices for stand structure and diversity in forests. Forest Ecology and Management. 145: 91–106.

O'Hara K.L. 1998. Silviculture for structural diversity: a new look at multiaged? systems. Journal of Forestry 96(7): 4–10.

O'Hara K.L., Latham P.A., Hessburg P., Smith B.G. 1996. A structural classification for inland northwest forest vegetation. Western Journal of Applied Forestry 11(3): 97–102.

Oliver C.D., Larson B.C. 1996. Forest Stand Dynamics. McGrawHill, New York, 520 p.

Parker G.G., Brown M.J. 2000. Forest Canopy Stratification – Is It Useful? The American Naturalist 155: 473–484.

Pommerening A. 2002. Approaches to quantifying forest structures. Forestry 75(3): 305–324.

Pretzsch H. 1999. Structural diversity as a result of silvicultural operations. In: Olsthoorn A.F.M., Bartelink H.H., Gardiner J.J., Pretzsch H., Hekhuis H. J. & Franc A. (Eds.)

Management of mixed of mixed species forest: silviculture and economics. DLO Institute for Forestry and Nature Research (IBN – DLO), Wageningen: 157–174.

RAFAILOV G. 2003. Selection Management of Forests. Publishing house of University of forestry, 213 p. (In Bulgarian).

SPIES T.A. 1998. Forest structure: a key to the ecosystem. Northwest Science 72: 34–39.

STAUDHAMMER C.L., LEMAY V.M. 2001. Introduction and evaluation of possible indices of stand structural diversity. Canadian Journal of Forest Research 31(7): 1105–1115.

SVENSSON J.S., JEGLUM J.K.. 2001. Structure and dynamics of an undisturbed old-growth Norway spruce forest on the rising Bothnian coastline. Forest Ecology and Management 151(1–3): 67–79.

ULYSHEN M.D. 2011. Arthropod vertical stratification in temperate deciduous forests: Implications for conservation-oriented management. Forest Ecology and Management 261(9): 1479–1489.

VALBUENA R., PACKALEN P., MARTIN-FERNANDEZ S., MALTAMO M. 2012. Diversity and equitability ordering profiles applied to study forest structure. Forest Ecology and Management 276: 185–195.

WHITEHEAD D. 1978. The Estimation of Foliage Area from Sapwood Basal Area in Scots Pine. Forestry 51(2): 137–149.

WHITTAKER R.H. 1975. Communities and Ecosystems. 2nd edition, MacMillan, Ney York, 385 p.

ZENNER E.K., HIBBS D.E. 2000. A new method for modeling the heterogeneity of forest structure. Forest Ecology and Management 129: 75–87.

International Scientific Conference “Forestry: Bridge to the Future” 6–9 May 2015, Sofia, Bulgaria

SECOND ANNOUNCEMENT

University of Forestry Sofia has the pleasure to invite you to participate in the International Scientific Conference “Forestry: Bridge to the Future”, which will take place on 6–9 May 2015 in Sofia, Bulgaria. The venue of the Conference will be Park Hotel Moskva, Sofia.

The Conference is dedicated to the 90th Anniversary of higher forestry education in Bulgaria and is organized by the University of Forestry, Sofia and Faculty of Forestry.

The Conference sessions will be focused to various topics, starting from global problems like impact of climate change on forests, forest ecology and dynamics to applied issues related to management and use of forest resources.

Eminent keynote speakers will take part in the work of Conference: Kevin O'HARA (University of California, Berkeley, CA, USA), Jean-Luc PEYRON (ECOFOR, France), Marcus LINDNER (European Forest Institute, Germany/Finland), and Ivan RAEV (Forest Research Institute, Sofia, Bulgaria).

Further information about the Conference concerning all details of registration, accommodation, program, and abstract submission can be found on the official conference web-site: http://conf2015.forestry-ideas.info

We look forward to meet you in Sofia in May 2015.

Prof. Dr. Veselin Brezin
Chairman of the Organizing Committee
Rector of the University of Forestry
Sofia, Bulgaria

Assoc. prof. Dr. Milko Milev
Vice-chairman of the Organizing Committee
Dean of the Faculty of Forestry
University of Forestry, Sofia, Bulgaria