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The incidence and distribution of white mistletoe (*Viscum album* ssp. *abietis*) on Silver fir (*Abies alba* Mill.) stands from Eastern Carpathians

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Abstract. In Romania *Viscum album* ssp. *abietis* is one of the most significant biotic factors that affect Silver fir situated on Eastern border of its natural area. The aim of our research is to assess the incidence and distribution of mistletoe in representative Silver fir stands from the Eastern Carpathians (at four forest districts level - Gura Humorului, Vaduri, Mănăstirea Caşin and Agăş). According with this purpose a statistical inventory of Silver fir stands based on 2 x 2 km grid was performed. At the intersection of the gridlines, stands older than 70 years were searched for on a distance of 500 m around. Each Silver fir stand chosen in this way represents a sample plot. In each plot 30 dominant Silver fir trees were chosen. For all this trees, the mistletoe infection degree was quantified using a 4-class rating system: no infection, low infection, moderate infection and heavy infection. The incidence of Silver fir was presented according to the damage degree. The site and stand parameters - elevation, exposure and canopy closure - were analysed to establish whether correlation between these parameters and mistletoe incidence exists. The volume of dead trees (due to the mistletoe infection) in 2004 - 2007 was also compared with mistletoe incidence in order to establish the correlation between these variables. Silver fir trees infected by mistletoe have been found in 55% of all 86 sample plots. Within the studied area 22% out of 2147 Silver fir trees were infected by mistletoe (42.2% - 1st infection class, 32.7% - 2nd class and 25.1% - 3rd class). The highest percentage of infected trees was found in the forest district Mănăstirea Caşin where 42% of examined trees were infected, mostly of the trees being in the 2nd and 3rd infection classes. There was a significant negative correlation between the elevation and mistletoe incidence. Up to 600 m, the most of the trees are heavily infected, while above 800 m the trees are incipiently infected. Regarding the canopy closure, sample plots with understocked and sparsely closed stands have shown a high level of infection compared with plots with closed stands. A significant correlation has been found between the volume of dead Silver fir tees and mistletoe incidence. The highest mistletoe infection was registrated in Silver fir stands at the eastern border of the Eastern Carpathians. There was noticed a decrease of mistletoe infection from the East to the West.
Keywords: Silver fir, *Abies alba*, mistletoe, *Viscum album abietis*, incidence, distribution.

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Introduction

Viscum album L. is an evergreen, perennial, epiphytic, hemiparasitic shrub that lives on the wide range of woody plants species. It is native to Europe and is a known parasite, a pharmaceutical plant and a symbol in mythology (Zuber 2004). The term hemiparasitic is used because most mistletoe do photosynthesize, although they may obtain up to 60% of their carbohydrates from the host (Watson 2001). It has a wide distribution in Europe and has also been introduced to North America (Hawksworth & Scharpf 1986).

In Europe three subspecies occur: *Viscum album* ssp. *austriacum* (Wiesb.) Vollman and *ssp. abietis* (Wiesb.) Abromeit are confined to conifers, and ssp. *album* to the dicotyledonous host trees and shrubs (Tubeuf 1923, Zuber 2004)

Viscum album abietis grows on branches and stems of silver fir trees. The species is dioecious with fly pollinated flowers, viscous fruits and persistent haustoria in the host. In Romania it occurs only on Silver fir (*Abies alba* Mill.) and is one of the most significant biotic factors that has affected silver fir stands (Barbu 2009). In Romania, Silver fir occurs naturally only in the Carpathian Mountains, mainly in mixed forests with beech and spruce on an estimated area of 0.9 mil ha. It is considered the most productive coniferous species in Romania. Only Silver fir represents about 0.3 mil ha, that means 5% of the Romanian forests. Growing stock of Silver fir stands is estimated at over 110 mil. cubic meters, being the second most important conifer species in Romania, after Norway spruce (Barbu & Barbu 2005).

In Romania the decline of Silver fir stands has been observed for a long time (1928, 1948 and 1966). The situation developed mainly after 1980 (Barbu 1991, 1994, 1997, Bândiu 1996) when heavy and increasing damages occurred in pure Silver fir stands from Eastern Carpathians, located on albic luvisoils as well as on the slopes exposed to acid rains coming from Central Europe.

Silver fir in the Carpathians displays a healthy look, mainly at altitudes higher than 800 m and on protected slopes. At low elevations, principally in Eastern and Southern Carpathians, *Viscum album abietis* becomes more and more frequent, causing important damages and wood degradation.

In the last 60 years, in Europe, many reports were made about the mistletoe problem on Silver fir: in France - Plagnat 1950, Plagnat and Brossier 1969, in Switzerland in 1970's, 1980's and 2000's (Hofstetter 1988, Noetzli et al. 2004), in Croatia (Idzojtić et al. 2008), in Spanish Pyrenees (Oliva and Colinas 2007). Mistletoe is also a major problem in the fir forest of Mount Parnis - Greece (Tsopelas et al. 2004).

In Romania the distribution of *Viscum album abietis* is quite unknown and the mistletoe problem on Silver fir is hardly studied (Nanu 1969, Barbu 1991, Şofletea 1993, Barbu 2009).

According to the Flora of RPR (1952) in Romania, *V. a. abietis* is spread in the Northern part of Eastern Carpathians (Maramureş and Bucovina) and Focşani area (Dealul Lung and Pelticu forest). Silver fir mistletoe is also spread in Silver fir stands from forest districts Anina and Oravița (calcareous region of Banat Mountains) (Nanu 1969) and forest districts Sinaia and Braşov (Prahova Valey) (Şofletea 1993). It is also known from Suceava County: forest districts Solca, Marginea, Mălini, Râşca in which Silver fir stand located up to 700 m are infected in proportion of 60-100% (Barbu 1991, Barbu 2009). According to the map that presents the geographic distribution of *Viscum album abietis* in Europe prepared by E. J. Jäger and presented by Zuber (2004), in Romania mistletoe is spread in Northern part of Romanian Carpathians and in Banat Mountains.

The Eastern Carpathians represent the eastern limit of natural range of Silver fir and this is the reason why our study is located in this area. The main objective of our research was to assess the incidence and distribution of mistletoe in representative Silver fir stands from Eastern Carpathians.

Material and methods

The study area of our investigations has cov-

ered the entire altitudinal belt where Silver fir is spread in the Eastern Carpathians (Figure1). The incidence of mistletoe on infested Silver fir trees was assessed in four representative forest districts (F.D.) - Gura Humorului, Vaduri, Mănăstirea Caşin and Agăş.

The forest district Gura Humorului is representative for pure Silver fir stands located on the border of the Carpathians at the contact zone to the Suceava Plateau while the forest district Vaduri is representative for the premountainous zone of the Eastern Carpathians where Silver fir and beech are the predominant forest species. The forest district Mănăstirea Caşin is representative for mixed forests of resinous (Silver fir and spruce) and beech forests, and Forest district Agăş is representative for mixed forests of spruce and Silver fir (Table 1).

To assess the distribution and incidence of mistletoe infection, a statistical inventory of Silver fir stands - from mentioned forest districts - based on 2 x 2 km grid was performed. The grids oriented on an N-S/E-W direction were placed on the maps of the forest districts. At the intersection of the gridlines, stands older than 70 years were searched for on a distance of 500 m around. Each Silver fir stand chosen in this way represents a sample plot. Plots in which Silver fir was not present or the stand age was lower than 70 years were excluded. In each plot 30 Silver fir trees (located at minimum 50 meters from the border of the stand) that belonged to the first three social Kraft classes (predominant, dominant and co-dominant) were chosen. For each tree the degree of infection was quantified using 4-class rating system (Barbu 2009) (Figure 2): (i) class 0 - no infection (absence of mistletoe) (Figure 2a); (ii) class 1 - low infection with high frequency of bushes on lateral branches (Figure 2b); (iii) class 2 - moderate infection with very frequently bushes in the crown, drying branches and moderate swellings on the branches level (Figure 2c); (iv) class 3 - heavy infection with bushes in all the crown and

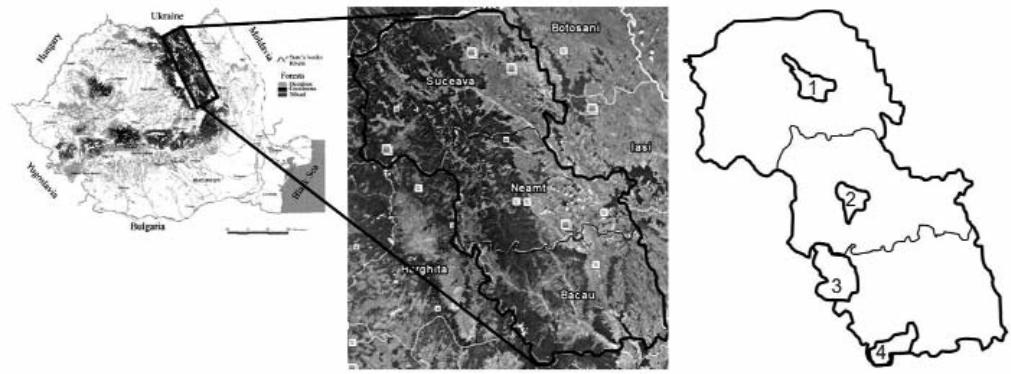

Figure 1 Research area: 1 - F. D. Gura Humorului, 2 - F. D. Vaduri, 3 – F. D. Agăş, 4 – F. D. Mănăstirea Caşin

Table 1 Geographic coordinates and distance from the Eastern Carpathians border of investigated forest districts

Forest district	Geographic coordinates range			Distance from the Eastern Carpathians border (km)
	Latitude N	Longitude E	Altitude (m)	
Gura Humorului	47°43'43" - 47°23'55"	25°44'36" - 26°01'36"	400-1000	3-10
Vaduri	47°00'57" - 46°47'43"	26°10'46" - 26°23'29"	500-1000	10-30
Mănăstirea Caşin	46°15'01" - 46°01'49"	26°20'45" - 26°47'25"	600-1200	30-80
Agăş	46°42'84" - 46°18'44"	25°58'51" - 26°24'03"	700-1600	80-100

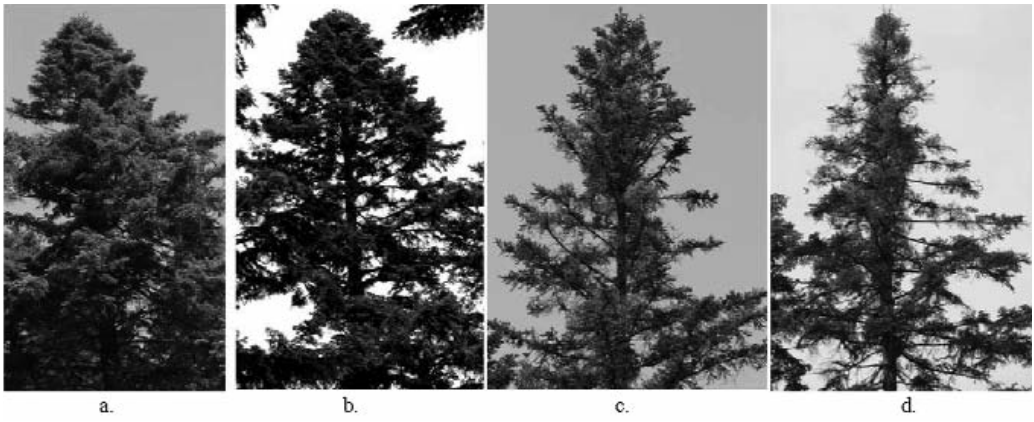

Figure 2 Examples of trees from each infection classes

stem, asymmetrical crowns, often with dying back top and heavy swellings on the branches and on the stem (Figure 2d).

In total, within the area of the 4 forest districts (FD), 23 production units (PU) and 86 plots in which Silver fir proportion is between 20 and 100% as many as 2147 trees were examined (Table 2). The results from each sample plot are associated to a square of 2 km side (400 hectares).

For the study area a database containing information about the elevation, crown closure and stand age was made using the management plans. The data were statistically processed in order to establish whether there was a correlation between the mentioned parameters and mistletoe incidence.

Also, the volume (m^3/ha) of dead trees (due to the mistletoe infection) in 2004-2007 was compared with mistletoe incidence for the production units of the forest district Vaduri in order to establish the correlation between these variables. The data have been provided by the County Forest Administration Neamț. The volume of the extracted dead fir trees was registered in management plans as sanitation cuttings.

Pearson correlation coefficient (r) was used to determine relationships between mistletoe incidence and selected variables. The mistletoe incidence was presented according to the percentage of infected trees for each infection class. The statistical procedures were performed using MyStat v.12 computer program (2008).

Results

In half of all analysed sample plots the proportion of Silver fir is higher than 50%, in 34% of the plots the proportion of Silver fir range between 26 and 50%, while only in 16% of the plots the proportion of Silver fir is lower than 25%. The situation for each forest district is presented in Figures 3-6.

Silver fir trees infected by mistletoe were found in 49 of 86 sample plots installed in the field area (Table 2). The mean percentage of infected sample trees range between 3 and 100%. On the whole area, 22% of the sample trees were infected by mistletoe. As for the infection degree, the trees are distributed as follows: 42.2% in 1st infection class, 32.7% in 2nd infection class and 25.1% in 3rd infection class.

Out of the 721 predominant sample trees from all plots, 36.8% were infected by mistletoe, 6.3% with low infection and 30.5% with moderate and heavy infection. Of the 814 dominant trees, 29.3% were infected, 5.2% with low infection and 24.1% with moderate and heavy infection. In co-dominant trees the intensity of infection was lower, only 15% of the trees being infected (Figure 7).

On the forest districts the situation is presented as follows. In forest district Gura Humorului mistletoe was found in 58% of the sample plots (Figure 8). The mean percentage of parasited trees is 8% with large variability from 28% to 60% in P.U. V Păltinoasa (located between 450 and 600 m altitude) and 3-10%

in PU IV Mănăstirea Humorului (750-1000 m altitude). In P.U. II and III the percentage of Silver fir trees damaged by mistletoe was lower than 3%. According to the damage degree, the highest incidence (78.9%) was observed for 1st infection class (Table 2).

The mean percentage of parasited trees in forest district Vaduri was 27%. Higher values were found at low altitude stands (P.U. III - 40% and P.U. IV- 30%) and less infection in P.U. II - 25% (Figure 9). In the composition of the P.U. I, the main species is beech and only in upper part of this production unit there are mixed forests with Silver fir and beech. For this reason in that production unit the proportion of infested trees is lower (19%).

According to the damage degree, the highest incidence (47.9%) was observed for 3rd infection class (Table 2). The incidence was also considerable for trees from 2nd infection class (34%).

On the forest district Mănăstirea Caşin level, in the sample plots situated on the eastern part of the forest district, the incidence of mistletoe is higher than 25% (in P.U. II - 45%), while in P.U. IV the percentage of infected trees

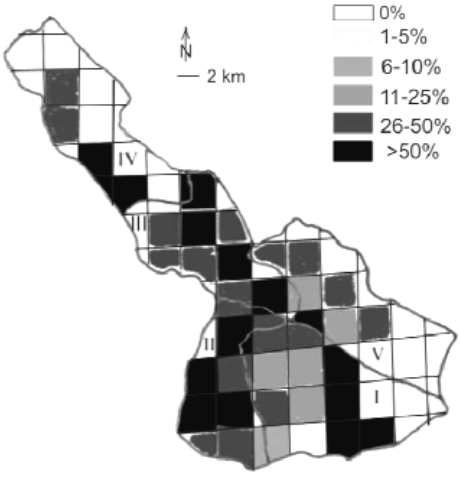

Figure 3 Silver fir percentage in stands older than 70 years in the F.D. Gura Humorului

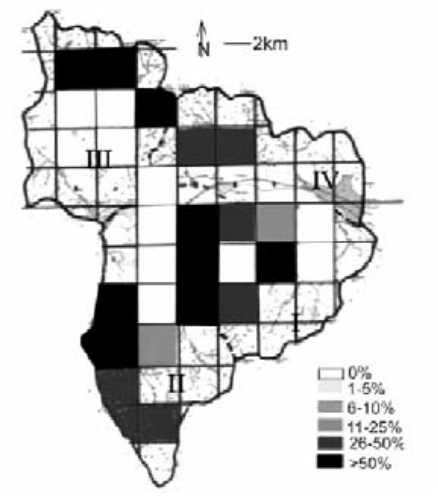

Figure 4 Silver fir percentage in stands older than 70 years in the F.D. Vaduri

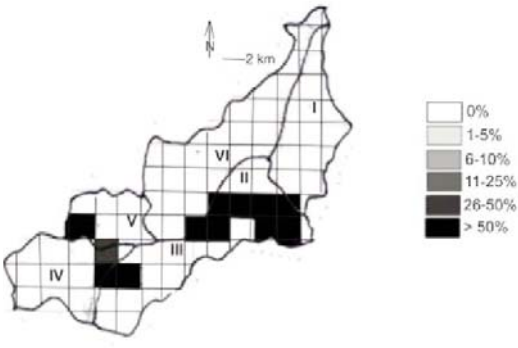

Figure 5 Silver fir percentage in stands older than 70 years in the F.D. Mănăstirea Caşin

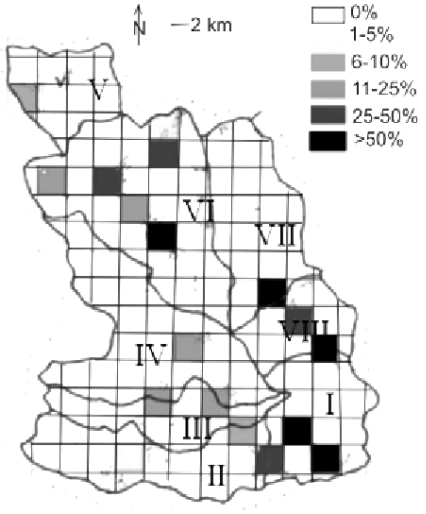

Figure 6 Silver fir percentage in stands older than 70 years in the F.D. Agăş

Table 2 Frequency of silver fir trees infected by mistletoe of installed sample plots

Forest district	Number of sample plots	Number of sample plots where mistletoe is present	Number of sample silver fir trees	Number of uninfected trees (class 0)	Number of infected trees	Relative frequency of infected trees for each infection class		
						1	2	3
Gura Humorului	38	22	1067	896	171	78.9	15.8	5.3
Vaduri	19	13	561	417	144	18.1	34.0	47.9
Mănăstirea Caşin	13	11	316	186	130	49.8	40.2	10.0
Agăş	16	3	203	171	32	22.0	40.7	37.3
Ó	86	49	2147	1670	477	-	-	-

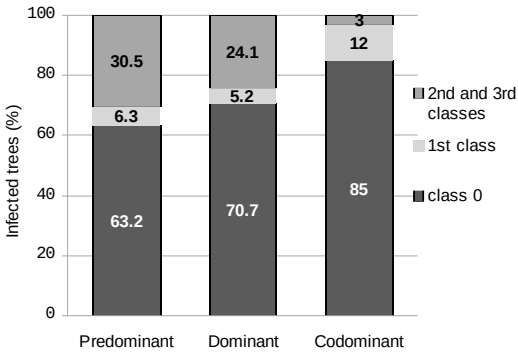

Figure 7 Percentage of infected trees in each one of the three Kraft classes

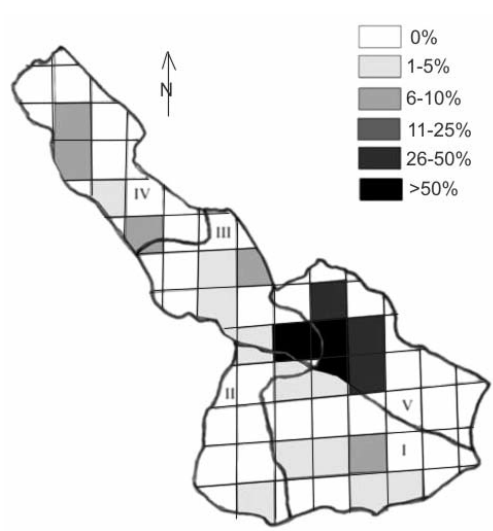

Figure 8 Percentage of silver fir trees infected by mistletoe in the F.D. Gura Humorului

decreases to 10% (Figure 10).

In Agăş forest district only in 18% of the sample plots we found trees with mistletoe infection (Figure 11). The mistletoe is spread in P.U. I and VIII situated in the South-Eastern part of the forest district. Out of the 203 infected trees more than 90% fall into the 1st and 2nd infection classes with incipient and moderate infection. In PU II, IV, V, VI and VII mistletoe is missing.

There was a negative significant correlation between the mistletoe incidence on silver and elevation (r = - 0.8; $p < 0.01$ in Gura Humorului forest district, r = - 0.7; $p < 0.01$ in Vaduri forest district). The mean elevation of the sample plots is between 525 and 880 m in Gura Humorului forest district and between 520 and 930 m in Vaduri forest district. Up to 600 m, 31% of the sample trees from the forest district Vaduri and 13% of sample trees from the forest district Gura Humorului were infected. Most of the infected trees are assessed in 2nd and 3rd infection classes (moderate and heavy infection). Above the 800 m 25% of the trees from forest district Vaduri and only 3% in forest district Gura Humorului were infected (Figure12-13).

Concerning the canopy closure (Figure 14) in Gura Humorului forest district three percent of the trees from plots with closed stands are infested by mistletoe (all trees being assessed in 1st infection class) compared with 11% in plots with sparsely close stands. In sample plots with understocked stands 5% of the sample trees were infected.

In Vaduri forest district 14% of the trees

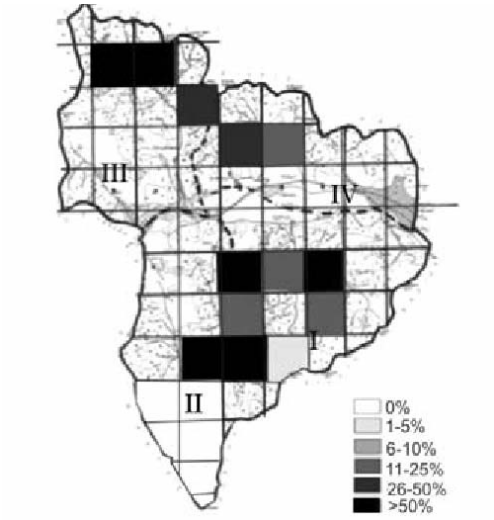

Figure 9 Percentage of infected trees related to canopy closure in the F.D. Vaduri

Figure 10 Percentage of silver fir trees infected by mistletoe in the F.D. Mănăstirea Caşin

from sample plots with closed stands are infested by mistletoe (all trees with low infection) compared with 23% in plots with sparsely closed stands and 72% in plots with understocked stands (only trees with moderate and heavy infection) (Figure 15).

In 38 of the all sample plots the age of Silver fir stands range between 70 and 100 years, in 20 plots range between 100 and 120 years and in 18 plots the age of Silver fir stands was more than 120 years. The highest incidence was observed in plots with very old trees (over 120 years) - 51.2% of the sample trees were infected, 33.6% with heavy infection, 13.2% with moderate infection and 4.4% with low infection.

The correlation coefficient (r) between the volume of dead Silver fir trees and mistletoe incidence was 0.8, and the correlation was significant ($p < 0.01$). In the plots in which the mistletoe incidence was higher (100%) the mortality of Silver fir is highest (18 m^3/ha).

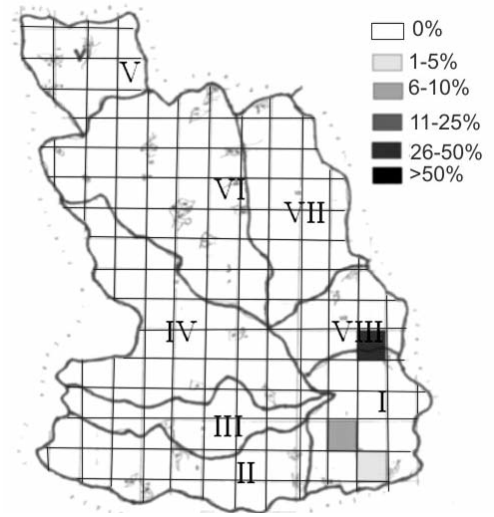

Figure 11 Percentage of silver fir trees infected by mistletoe in the F.D. Agăş

Discussion

In the forest district Gura Humorului the proportion of stands with more than fifty percent Silver fir is higher in the production units: II, III, I and IV in which even pure Silver fir stands were found. In the lower and middle part of the forest district (production unit V) the mean frequency of Silver fir decreases under 25%. Only in 10% of the analysed sample plots of the forest district Vaduri the proportion of Silver fir is lower than 25%.

In the area of the forest district Mănăstirea Caşin, Silver fir occurs especially in the P.U. II, III and IV with South and South-West expo-

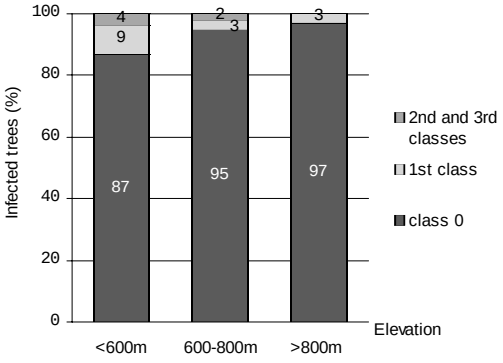

Figure 12 Percentage of infected trees related to elevation in the F.D. Gura Humorului

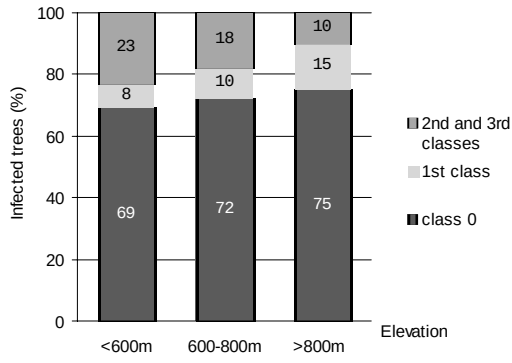

Figure 13 Percentage of infected trees related to elevation in the F.D. Vaduri

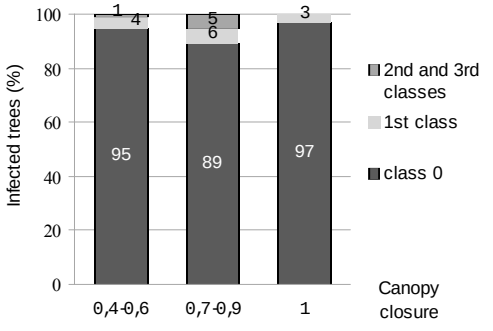

Figure 14 Percentage of infected trees related to canopy closure in the F.D. G. Humorului

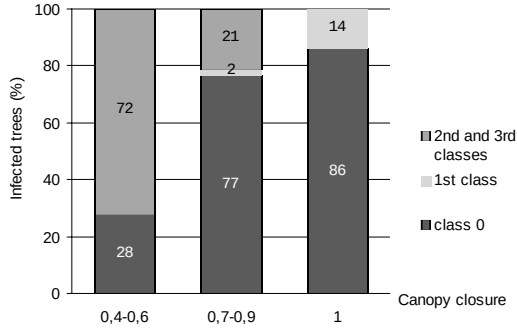

Figure 15 Percentage of infected trees related to canopy closure in the F.D. Vaduri

sure. In PU I, VI and V with East, North and North-West exposure Silver fir stands are poorly represented. In 92% of the sample plots the proportion of Silver fir is higher than 50%. In Agăş forest district the occurrence of Silver fir trees in sample plots is variable. In the P.U. I, VII and VIII there are four plots where Silver fir proportion is higher than 50%. In P.U. IV and VI the frequency of Silver fir ranges between 10 and 50%. In these production units the mixed forests of conifers and beech are frequent and Silver fir establish pure stands or mixed stands with beech.

Mistletoe represents a major problem in the Silver fir stands located on the Eastern border of natural area since almost one fourth of the sample trees were infected by the parasite. Birds are the natural vectors of mistletoe and can transmit seeds to new hosts. In the Silver fir forest of the Carpathians Mountains, *Turdus viscivorus* L. is considered the main vector of mistletoe as in many areas of Europe (Frochot & Sallé 1980). The "6-class" rating system of Hawksworth (Hawksworth 1977) - designed for dwarf mistletoe - is usually used to quantify the degree of infection (Maloney & Rizzo 2002, Tsopelas et al. 2004). This method takes into consideration only the percent of infected branches from each one of the three part of the crown (top, middle and lower). In our study we used a "4 class" method which takes into consideration some other external symptoms of mistletoe infection (Barbu 2009).

According with Barbu (1995) and Noetzli (2003), there is an age threshold around 70 years thereafter the trees are infested by the mistletoe. Other authors consider that Silver fir become susceptible to infection after 50 years

(Zuber 1983) or after 120 years (Plagnat 1969). Our results also show that infection was more severe in old trees; many of these were older than 120 years.

The light plays an important role in mistletoe growth. In the absence of light, the mistletoe can be installed only on higher trees (predominant and dominant trees). Thirty seven percent of predominant trees were infected by mistletoe, while only 15% of co-dominant trees were infected. When the trees stay in light the mistletoe is more and more active, growing abundantly and increasing its infection (Plagnat 1950). That explains why sample plots with understocked and sparsely closed stands have shown a high incidence of infection compared with plots with closed stands. This result matches with other studies of the same host-parasite combination (Tsopelas 2004, Idzojtić et al. 2008). In forest district Vaduri in plots located in understocked stands the proportion of damaged trees is higher than 70%, all trees being heavily infected (3rd infection class).

Our results showed a significant correlation (r = - 0.7; $p < 0.01$ in the F.D. Gura Humorului, and r = - 0.8 in the F.D.Vaduri respectively) between the elevation and mistletoe incidence. Idzojtić et al. (2008) had found, also a negative and significant correlation between these parameters. As most of the Silver fir trees located in stands above 800 m are assessed in the incipient infestation class, and most of the trees located under 600 m elevation are assessed in moderate and heavy infestation classes, one can conclude that mistletoe strives to go higher and higher, keeping up with other phenomenon more or less related to fir tree dieback. Upwards shifts have been also reported for *Viscum album austriacum* in Switzerland (Dobbertin et al. 2005).

A significant correlation (r = 0.8, $p < 0.01$) has been found between the volume of dead Silver fir trees and mistletoe incidence. The researches made by Tsopelas et al. (2004) in Mount Parnis and Idzojtić et al. (2008) in Dinaric Alps shows similar results. Mortality of Silver fir due to the mistletoe was higher in old stands located near the margins of Silver fir range.

On our study area the incidence of mistletoe was higher in forest district Vaduri and forest district Mănăstirea Caşin than it was in forest districts Agăş and Gura Humorului. Stands with Silver fir from the forest district Agăş are located at the upper elevation boundary of the Silver fir within the full extent of coniferous forests. The sample plots installed in this forest district are located above 900 m. This is the reason why here the incidence of mistletoe is lower. There was noticed a decrease of mistletoe incidence from the East to the West.

Development of mistletoe infection on Silver fir stands is faster in pure Silver fir stands, heavily thinned and prematurely aged. This parasite has been observed occurring interacting with other pathogens as *Melampsorella caryophyllacearum* and bark beetles (Barbu 1995, Tsopelas et al. 2004).

Conclusion

Mistletoe is mostly spread in Silver fir stands older than 100 years of lower elevation boundary. At the same elevation the mistletoe incidence is higher in Silver fir stands located at the border of their natural range. Up to 600 m the most of the trees are heavily infected, while above 800 m the trees are incipiently infected. The highest incidence was registered in Silver fir stands from the limit of the Eastern Carpathians while the lower incidence on the origin of the brooks which furrow transversal the mountainous chain.

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