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The stand structure and natural regeneration of *Abies alba* Mill. in reserves on the northern margin of its distribution in SW Poland

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Abstract: The silver fir (*Abies alba* Mill.) in the area of Wał Trzebnicki is at the northern limit of its distribution in western Poland. This study was performed in three nature reserves with protected silver fir populations. The stands in these reserves were mixed, with complex spatial structure and abundant tree regeneration. The proportion of fir in stands was around 16% of DBHS, the age of trees reached around 130 years. The silver fir occurs mainly in the sapling stage, whereas the number of seedlings was very low. The results of this study show the influence of forest floor vegetation as well as litter type on the emergence of fir seedlings. The seedlings density was compared with the results of other studies from different geographical areas and stands type in Poland.

Additional key words: *Abietetum polonicum*, mixed forest, population structure, safe sites

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Introduction

The silver fir is a component of mixed forests with complex spatial and age structure (Faliński i Pawlaczyk 1993). The silver fir is known as a species which increases the stability and resilience of forests (Brang 2001) and which is suitable for multifunctional forest management (Shütz 2001). On the other hand, it is a species vulnerable to an improper forest management and air pollution. Since the 1960's there has been observed the phenomenon of "fir decline" over the whole area of its distribution (Boratyński i Filipiak 1997, Thomas et al. 2002, Bigler et al. 2004). The present proportion of silver fir in the forests of Lower Silesia (Poland) is very low, in the area administered by Wrocław Regional Directorate of State Forests the stands with silver fir cover 0.15% of total forest area, mainly in the forests of the Sudety mountains (Barzdajn et al. 1999).

A campaign to increase the silver fir share in forest has recently been started , especially in the Sudety Mts. (Barzdajn et al. 1999, Barzdajn and Raj 2002). One of the key problem in this enterprise is to recognise the mechanism of natural fir regeneration (e.g. Dobrowolska 2000, Filipiak 2002, Robakowski 2004).

The northern limit of silver fir distribution range in western Poland was found in the area of the Wał Trzebnicki foothills (Pacyniak 1966). It is associated with more abundant precipitation than in areas of lowlands, situated on the north (Szafer 1972). To protect the marginal populations a system of reserves was created in the 1950's. However, the number of populations as well as the number of fir individuals within populations – even the protected ones – still decreased. Also, disadvantageous changes in vitality of firs and composition of forest floor vegetations were observed (Szymura 2006). Similar changes were

found in silver fir populations in the Eastern part of Germany (Zigenhagen 1997).

The aim of this study was a) to document the structure of forest with silver fir on margin of its range b) to describe the structure of fir populations, c) to evaluate the natural regeneration of silver fir with respect to forest floor vegetation and the litter type.

Materials and methods

Study area

The study site is situated in Wał Trzebnicki (Western Poland) with a mean elevation of 100–150 m a.s.l. The average annual temperature is 7.7°C. (January 1.7°C, July 17.4°C), the average annual precipitation is 550–560 mm, 60% of precipitation takes place during the growth season (Walczak, 1970, Kondracki 1994). The dominant stand type is pine or less frequently spruce monocultures (Macicka i Wilczyńska 1990).

In the Wał Trzebnicki silver fir occurs in detached groups among other species (Macicka i Wilczyńska 1990). As in the whole northern margin of fir in Western Poland it is the most abundant in plant association *Abietetum polonicum* (Dziub. 1928) Br.-Bl. & Vlieg. 1939. (Pacyniak 1966).

The research was done in three nature reserves established in the1950s:

1. "Jodłowice" – location: N 51°17', E 16°48', 137 m. a.s.l., area 9.36 ha. The majority of the protected area is fenced and the silver fir grows on whole territory of the reserve. The *Abietetum polonicum* covers most of the area, while the *Galio sylvatici-Carpinetum* occurred on the remaining area of reserve (Macicka-Pawlik i Wiczyńska 1995). The soil was classified as Dystric Cambisol and Cambic Arenosol (Wilczyńska Macicka-Pawlik 1998).
2. "Gola" – location: N 51°21', E 17°33', 235 m. a.s.l., area 12.05 ha. This reserve is also fenced, the fir occurs on the whole territory of the reserve. The *Abietetum polonicum* covers most of the area with patches of *Querco-Piceetum* and *Leucobryo-Pinetum* (Macicka i Wilczyńska1990). The soil was Dystric Cambisol, Cambic Arenosol and Stagnin Eutric Gleysol (Komendarczyk 1990).
3. "Jodły Ostrzeszowskie" – location: N 51°25', E 17°59', 188 m. a.s.l., area 8.96 ha. The silver fir occurs on the whole area of the reserve and surroundings forests, however the population was small and sparse. Forest management was applied in most of the area. The study was performed only at the eastern part of the protected area, which was less damaged by management practices. On the examined area the soil was Haplic Luvisol (Szymura 2003), the plant community was *Abietetum polonicum* (Macicka i Wilczyńska 1990, Szymura 2003).

According to Pacyniak (1966) the fir populations in the investigated reserves was of natural origin. There was an unsuccessful attempt at planting firs in the recent years. Individuals which survived are easily distinguishable and scarce. They were not included in this study.

Methods

The stand structure was measured on circular sampling plots with area 250 m^2 (radius 8.92 m). These plots was placed in nodes of regular grid 100×100 m. In the "Jodłowice" reserve there were 9 plots, in "Gola" 12 and "Jodły Ostrzeszowskie" 2 plots. In each sampling plots the diameter of trees at breast height and the height of saplings was measured. The number of seedlings and saplings was counted. As a tree classified was individuals with diameter at breast height 7 cm or higher were classified as trees; individuals with height of 50 cm or less were treated as seedlings. Individuals higher than 50 cm and with diameter at breast height lower than 7 cm were considered as saplings. The basal area (DBHS) of a tree was calculated as the area of a circle with diameter equal to the diameter of given tree at breast height. The cores from each adult silver fir growing in the additional concentric plot of radius12.6 m was taken. It was one core per tree at breast height taken by an increment borer. The number of annual increment rings was counted in order to assess trees age.

The spatial structure of fir populations was assessed using the nearest neighbour method (Clark and Evans 1954). In this method compared was ratio between two statistics: average distance to nearest neighbor and expected nearest neighbor distance based on a random distribution. The significance of differences from expected value was tested Z-test which can reveal: cluster, random or regular spatial distribution (Clark and Evans 1954).

In each sampling plot the cover of forest floor vegetation was visually assessed, with distinguished area of patches of dominant species. Similarly assessed was the area covered by coniferous or broadleaved litter.

The preference of silver fir seedlings to occur on different kind of litter type or patches of forest floor vegetation were taken into account. It was done by dividing the percentage share of fir seedlings occurring on a given unit (vegetation patches or litter type) by percentage area covered by this unit. A value above 1 showed more abundant seedlings presence than expected from the relative area of given unit, whereas a value below 1 showed lower seedlings density than expected. The statistical significance of this disproportion was checked by χ^2 test, with Yates' corrections applied in cases of low frequency observations.

The light environment of each sample plot was measured at 1 m above the ground, using hemispherical photographs. The photographs were taken in the centre of each plot, and next analysed using WinScanopy 2003b software by Règent Instruments Inc. Results were expressed as a percentage of photosynthetic photon flux density under canopies (% PPFD).

Results

The stands structure

In each stand the spruce *Picea abies* (L.) H. Karst., silver fir *Abies alba* Mill., beech *Fagus sylvatica* L. and birch *Betula pendula* Roth were common. In "Jodłowice" oaks: *Quercus petraea* (Matt.) Liebl. and *Q. robur* L., pine (*Pinus sylvestris* L.), and larch (*Larix decidua* Mill.), were also found. The hornbeam (*Carpinus betulus* L.) in canopy layer was present in "Jodłowice" and "Gola" whereas rowan (*Sorbus aucuparia* L. em. Hedl.) only in „Jodły Ostrzeszowskie". Additionally in the "Jodłowice" reserve single individuals of *Tilia cordata* Mill. and *Ulmus glabra* Huds. were found (Table 1). On each plot usually 2–4 trees species per plot were present.

These stands were dominated by spruce with a 35% share in DBHS. The share of silver fir was 16% and beech 9%.

The diameter distribution of all trees in the "Jodłowice" and "Gola" reserves was inverse "j" shaped (Fig. 1c). The silver fir diameter distribution showed shape with the medium class most abundant (Fig. 1a, b). Pines and larches in "Jodłowice" were represented mainly by large individuals. Due to the relatively small area of forest analysed in reserve "Jodły Ostrzeszowskie", the plots of diameter structure were not presented.

The vertical structure on each plot was multi- or two-layered. The upper layer with height 30–38 m was created by spruces, larches, pines, beeches and firs. The trees with height 30 m or highest comprised 70% of DBHS. The frequency of trees in the 5 meters height class was shown in Fig. 2.

In all analysed sites, the amount of standing decaying trees or logs was very small due to management practices.

In the undergrowth, the spruce was also a dominant species – 29% share in sum of saplings height (Table 1). exceptionally high – in relation to share in trees layer – was the share of rowan saplings (27%). The share of fir saplings was 15%, birch 9% and hornbeam 5,5%. The presence of saplings of all species emergent the tree layer was found. Additionally, saplings of *Acer pseudoplatanus* L., *Sambucus nigra* L. and *Frangula alnus* Mill. were found. The saplings occurred on 95% of all sampling plots. Its density changed from 0 up to 6640 N/ha, mean 2314 N/ha, with standard deviation 1984. The silver fir saplings occurred in 83% of all sampling plots. Its density varied from 0 to 2840 N/ha, average 402 N/ha with standard deviation 657.

Seedlings occurred on all sampling plots. Their density varied from 120 up to 11840 N/ha, average 2333 N/ha., among them spruce seedlings were the most common (Table 1).The share of silver fir seedlings was 12%, they occurred on 71% of sampling plots. The density of fir seedlings changed from 0 to 12000 N/ha, mean 232 with standard deviation 315.

Table 1. Stand characteristics in the studied reserves. Species code: FS – *Fagus sylvatica*, BP – *Betula pendula*, CB – Carpinus betulus, QPR - *Quercus petraea and Q. robur*, AA – *Abies alba*, SA – *Sorbus aucuparia*, LD – *Larix decidua*, PS – *Pinus sylvestris*, PA – *Picea abies*, FA – *Frangula alnus*

Reserve	Measured traits		Species*										Sum
			FS	BP	QPR	CB	AA	SA	LD	PS	PA	FA	
Jodłowice	trees basal area	[m²/ha]	1.2	1	6.8	0.1	4.3	–	5.4	5.3	4.1	–	28.7
	trees density	[N/ha]	22	36	124	4	58	–	22	22	111	–	413
	sum of height of saplings	[m/ha]	138	635	233	13	1431	1621	390	36	184	16	4776
	saplings density	[N/ha]	27	213	209	4	547	618	129	36	62	9	1871
	seedlings density	[N/ha]	–	156	387	–	147	218	–	9	53	18	987
Gola	trees basal area	[m²/ha]	2.7	0.2	–	0.1	3.9	–	–	5	14.1	–	25.9
	trees density	[N/ha]	10	10	–	13	33	–	–	30	377	–	473
	sum of height of saplings	[m/ha]	264	302	304	599	359	1793	–	–	2973	27	6679
	saplings density	[N/ha]	130	130	113	130	253	747	–	–	1177	27	2710
	seedlings density	[N/ha]	100	90	177	167	240	200	17	223	1103	23	2340
Jodły Ostrzeszowskie	trees basal area	[m²/ha]	5	2.7	–	–	5.3	0.6	–	–	0.7	–	14.4
	trees density	[N/ha]	20	80	–	–	380	80	–	–	60	–	620
	sum of height of saplings	[m/ha]	–	1420	–	–	1602	–	–	–	870	1740	5632
	saplings density	[N/ha]	–	380	–	–	640	–	–	–	360	560	1940
	seedlings density	[N/ha]	440	400	140	–	340	320	–	700	440	3240	6020

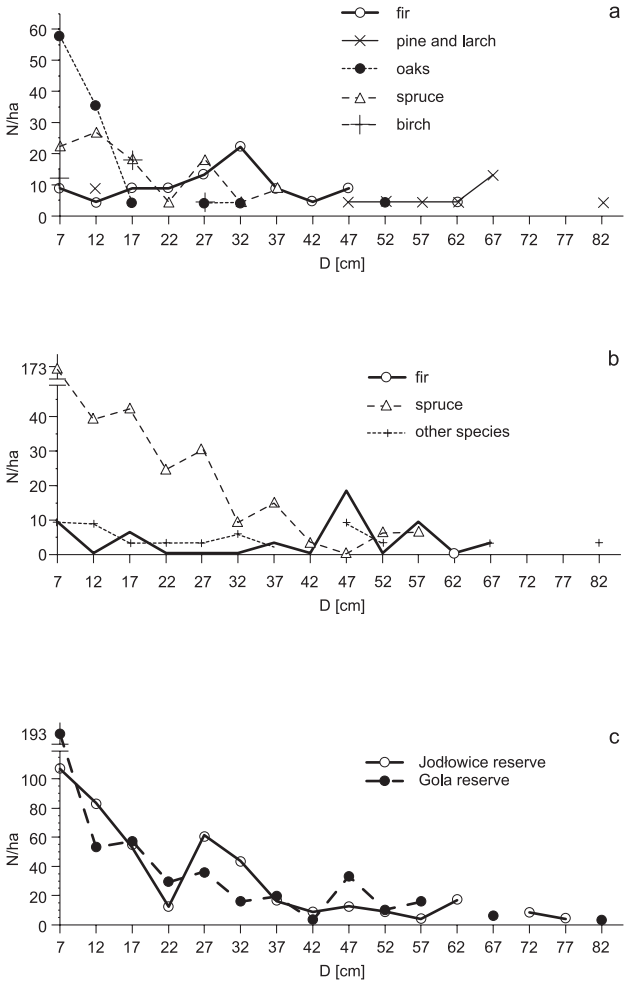

Fig. 1. The diameter distribution of tree species in the reserves Jodłowice (a), Gola (b) and all species together in reserves (c)

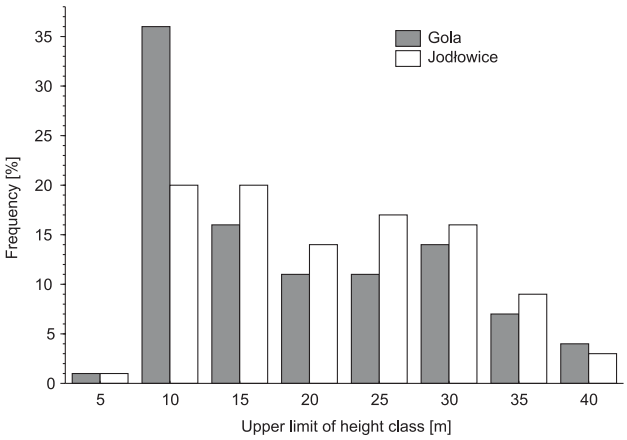

Fig. 2. The height distribution of trees in the "Gola" and "Jodłowice" reserves

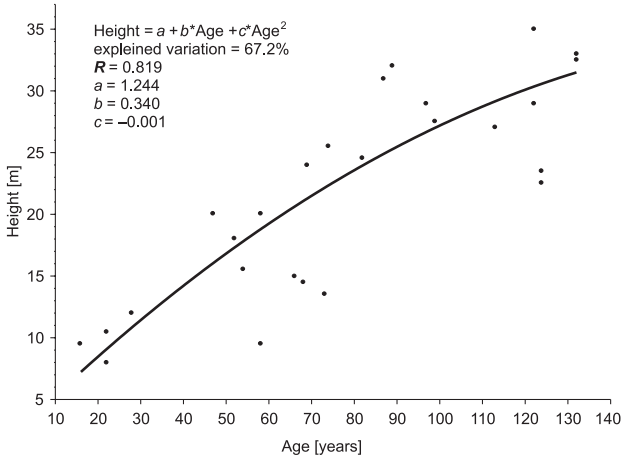

Fig. 3. Tree height as a function of silver fir (*Abies alba* Mill) age

The seedlings were damaged by deers and roe-deers browsing only in the "Gola" reserve, where 25% of seedlings were browsed.

Structure of the silver fir population

The saplings stage was the most abundant and represented 67% of all fir individuals. The share of seedlings was 27% including 3% of one-year seedlings.

The trees showed random distribution in "Jodłowice" and "Gola" whereas in "Jodły Ostrzeszowskie" their distribution was clumped. The saplings and seedlings in all reserves showed clumping distribution. The age of fir trees, varied from 16 to 132 years (Fig. 3). The fit second order polynomial function explains 67% of fir trees height variation, as a function of their age.

The ratio of trees number/seedlings number was the highest in "Gola", where it reached 18.5 and much smaller in "Jodły Ostrzeszowskie"and "Jodłowice", 1.9 and 4.8 respectively. The average value was 8.4.

There were not statistically significant differences between sum of height of saplings, as well as saplings and seedlings density in the analysed sites (Kruskal-Wallis Anova test: saplings density – $H=2.38$, $p=0.30$, sum of height of saplings – $H=3.59$, $p=0.17$, seedlings density $H=2.57$, $p=0.28$).

Forest floor vegetation and light conditions

The forest floor vegetation covered from 5 up to 95% of ground, in average 39%. The dominant species was: *Rubus* sp., *Vaccinium myrtillus* L., *Athyrium filix–femina* (L.) Roth and *Dicranum polysetum* Sw.

The ratio of photosynthetically photon flux density (PPFD) at height 1m above ground layer to PPFD above canopy layer was 5.3% to 43.8%. The mean percentage of PPFD was 17.8%. There was no statistically significant relationship between silver fir seedlings density and light conditions or forest floor vegetation cover.

The silver fir seedlings occurred often in patches of seedlings of other species (established usually on bare ground) and patches of mosses, *Oxalis acetosella*,

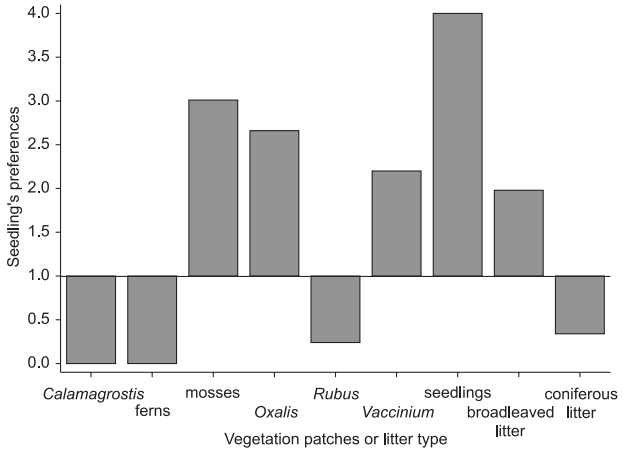

Fig. 4. The preferences of silver fir (*Abies alba* Mill.) seedlings for different patches of vegetations or litter types. For further explanation see the text

Vaccinium myrtillus or on broadleaved litter. In patches of *Rubus* sp. or coniferous litter the fir seedlings occurred less frequent. In patches of ferns (A*thyrium filix-femina*, *Pteridium aquilinum* and *Dryopteris carthusiana* grouped in one category) and *Calamagrostis arundinacea* the seedlings was absent (Fig. 4). These disproportions was statistifically significant in cases of mosses ($\chi^2 = 9.07$, $p=0.003$), broadleaved litter ($\chi^2 = 8.86$, $p=0.003$), *Rubus* sp ($\chi^2 = 6.79$, $p=0.009$), coniferous litter ($\chi^2 = 18.28$, $p=0.000$) and ferns ($\chi^2 = 4.08$, $p=0.043$)

Discussion

In comparison to the commercial forest which dominated the area of Wał Trzebnicki the investigated stands were more diverse both in the species and spatial structure aspects. The share of large trees in these stands is higher than in the surrounding plantations. The multi-layered vertical stand structure and presence of variously-aged trees is considered as a preferential form of *Abietetum polonicum* habitats (Mróz and Łabaj 2004). However the results of long-term comparison showed a decrease in the number of large trees as well as silver fir individuals in the "Gola" and "Jodłowice" reserves (Szymura 2006). The sum of basal area (DBHS) in "Jodłowice" and "Gola" corresponds to basal area of mixed forest with silver fir on the northern margin of distribution in Poland in "Jata" reserve where DBHS was 29,3 m^2/ha in optimal phase of stand development (Dobrowolska 1998 a).

The relationship between silver fir height and age (Fig. 2) shows that in these sites, in range of its distribution , silver fir was in second class of stand quality (according to the tables of Szymkiewicz 2001). However, it should be pointed out that "breast height age" presented there can be much more lower than real trees age, due to potential long persistence at saplings stage. In the analysed stands the age of fir saplings varied form 11 up to 101 years (Szymura 2005).

The silver fir is a species with life strategy fit to both stress and competition (Brzezicki and Kienast 1994). Its stable presence in mixed forest is related to the production of a durable "saplings bank" (Faliński i Pawlaczyk 1993). Actually, the saplings form the most abundant developmental stage of silver fir in all the investigated reserves. The share of seedlings, especially one-year old, is small. In the "Jodlowice" the amount of seedlings could be affected by regular collection of fir cones as a requirement of local forest administration. In other reserves this procedure was not applied.

Generally, the density of fir seedlings (average 232 N/ha) in the Wał Trzebnicki region (Table 2) is exceptionally low. In the centre of fir distribution in Poland, in the forest of the Karpaty Mts., the seedlings density was highest in pure fir stands in the lower mountain zone (Paluch 2005). The density in the Karpaty Mts was lower than in Wał Trzebnicki only in one case – in Bieszczczadzki National Park in beech – maple stands where the presence of adult silver fir in stand was neglegible (Jaworski 2000). In an area of more abundant fir occurrence closer to Wał Trzebnicki, in the Sudety Mts. the density of fir seedlings is

Table 2. Comparison of silver fir (*Abies alba* Mill) seedlings and saplings densities reported from different sites in Poland

Geographical area or plant community	Seedlings [N/ha]	Saplings [N/ha]	Data source
Karpaty Mts	6,590	621	Chwistek et al. 1997
	417–62,083	0–34,250	Jaworski 1979
	154–13,142	0–1,079	Jaworski 2000
	7,000–65,000	321–359	Paluch 2005
Sudety Mts	453–1,832	–	Dobrowolska 2000
	108–9,794	0–498	Filipiak 2002
	500–22,416	0–8,560	Jaworski 1979
Abietetum-polonicum	4,225	1,058	Dobrowolska 1998b
	30,117	630	Mazur 1989
Margin of silver fir distribution in Poland	271–6,839	27–1,383	Dobrowolska 1998b
	18,800	10,000	Sowa i Olaczek 1971

definiteds as much less than in Karpaty Mts. (Filipiak 2002) and highly variable due to the high mortality of young seedlings occurred after mast year (Dobrowolska 2000). The seedlings density reported from other sites of *Abietetum polonicum* is also higher (Mazur 1989, Dobrowolska 1998 b) than in this study. The low seedlings density seems to be not a an attribute of fir range boundary. In the "Gałków" reserve, near Łódź, in fir-beech forest in *Galio-Abietion* alliance Sowa and Olaczek (1971) found the seedlings density around 18,800 N/ha. The participation of fir in stand biomass there was 37–56%. In the "Jata" reserve on the Łukowsko-Siedlecki plateau seedlings density differs due to site properties and forest structure (Dobrowolska 1998 b). The lowest density (271 N/ha) was in broadleaved forest where fir participation was lower than 10%, but with increase of share of fir in stands it increased up to 6,839 N/ha.

Weak regeneration of silver fir in the investigated sites is similar to that reported from Sudety Mt., where only 1.39–37.9 seedlings per single adult fir individual was found (Filipiak 2002). In the presented study the average value was 7.2.

As factors influencing weak fir regenerations in Sudety Mt. Filipiak (2002) proposed sparse cone production, due to high crown damage and also a high ratio of inbreeding in small Sudety populations. Observations from Stołowe Mt. confirm the relationship between fir health state and cone production (Sznajder 2001). The observed average relative crown length of silver fir in the studied reserves was 45–70% (Szymura in preparation). According to Jaworski (1988) fir with relative crown length above 40% schowed normal growth dynamic. The observation of a small residual population of silver fir from Ore Mountains (Saxony, Germany), showed that only 6% of seeds in cones was filled – this phenomenon was connected with high rates of inbreedings (Zigenagen et all 1997). It is probably that a similar effect occurs in small, isolated populations of fir from Wał Trzebnicki. Another factor considered as influencing seedlings density was the participation of fir in stands (Dobrowolska 1998 b, Farfał 1999, Filipiak 2002). The previously cited results of Dobrowolska (1998 b) showed that seedlings density was average 3683 N/ha when the share of fir in stands was 20–40%. When the share of fir 10%, the seedlings density decreased to 679 N/ha. The reported range of silver fir share is similar to that presented here (16%) but the seedlings density was much higher than in this study. Also the results of Jaworski (2000) showed that seedlings density in mixed forest of the lower mountain zone of the Karpaty Mts. where the participation of silver fir in stands was 16–8% was much higher (1000–8214 N/ha) than in this study.

The density of fir saplings (average 402 N/ha), likewise the seedlings, was relatively small in relation to other sites (Table 2). However, this disproportion was smaller than in the case of seedlings. Saplings density reported from Sudety is even smaller than that presented here (Filipiak 2002): there the highest saplings density is similar to the average value in Wał Trzebnicki. The small saplings density reported in pure fir stands from Karpaty Mts. (Paluch 2005) is probably the result of stand structure in the young and dense forests he explored (trees density 569–752 N/ha).

The light environment under canopy in the investigated stands seems to be favourable to fir regeneration. Dobrowolska (1998 c) presented the value 10–25% of PPFD as proper to growth and the development of fir regeneration. However, results of other research show a higher density of fir seedlings and saplings in lower light intensity 2.3–3.1% PPFD (Diaci 2002). Also from the Alps a higher density of fir saplings under canopy than in the gaps was reported (Grassi et al 2004). This phenomenon can be connected with effect of indirect facilitation. The results of Pages et al. (2003) showed that in worse light conditions competition of herb is weaker than in better light environment, thus the survival rate of seedlings is higher in lower PPFD. Finally, this produces a higher seedlings density in worse light condition (Pages et al. 2003).

The results presented here showed the influence of forest floor vegetation as well as litter type on the presence of fir seedlings. Patches of the mosses, *Oxalis acetosella*, *Vaccinium myrtillus,* patches abundant in seedlings of other species and on broadleaved litter can serve silver fir as safe sites (in sense of Harper 1977) (Fig. 4). The mosses, *Oxalis acetosella* and *Vaccinium myrtillus* Jaworski and Zarzycki (1983) confirmed as an indicator of appropriate light environment for the development of fir regeneration. Paluch (2005) stated that *Oxalis acetosella* and *Vaccinium myrtillus* indicate the trophic and moisture soil properties favourable to the establishment and survival of silver fir seedlings. This study confirms results mentioned above, however in cases of *Oxalis* and *Vaccinium* the overrepresentation of silver fir seedlings was not statistically significant. Ferns such as *Dryopteris filix-mas* and *Pteridium aquilinum* Jaworski and Zarzycki (1983) were considered as indicators of improper light conditions. In the case of *Pteridium aquilinum* the absence of firs seedlings can be related to the high competition impact of bracken. As shown Dolling (1996) this fern is a highly – competitive species due to its allelopathic influence, among other properties. Sparse fir regeneration in patches of grass vegetation was observed by Hunziker and Brang (2005). In this study this phenomenon was also observed in patches of *Calamagrostis,* however it was not statistically significant. The relatively more frequent occurrence of fir seedlings on broadleaved litter than on coniferous

litter could be connected with the different kind of humus which originate from this substrata (Jaworski 1973).

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