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Age structure of natural regeneration of European silver-fir (*Abies alba* Mill.) in the Sudety Mts.

Abstract: In this paper, is presented data on the abundance and age structure of natural regeneration of silver fir in permanent plots in Sudety Mts. In the studied plots the abundance of fir seedlings is usually markedly lower than in the well-regenerating Carpathian forest stands. The major reason for this is the lower contribution of fir trees to forest stands in the Sudety Mts. as compared with the Carpathians. In most plots the process of regeneration is long and extended over many years. Largest numbers of seedlings developed in years of good fir cone crops. An important role in the process of natural regeneration of *Abies alba* in the Sudety Mts. are played by type of site, kind of humus and herb layer density. Most of the studied forest stands in the Sudety are not dense, so the herb layer is well-developed, that strongly restrain fir regeneration especially in fertile soils.

Additional key words: ecology, permanents plots, site conditions.

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Introduction

The impact of environmental factors on the appearance and development of young generations of trees is one of the most interesting, but also difficult, issues of plant ecology. The European silver-fir is one of the species that usually well regenerate under the canopy of a forest stand. Because of the diversity of conditions created in the forest interior, the issue of natural regeneration of this species is very complex. Many research articles are concerned with effects of various factors on the process of fir seed germination and seedling development. In Poland, the largest number of studies on this subject have been conducted by Jaworski (Jaworski 1979, 1984; Jaworski and Szawara 1981; Jaworski and Fajak 1983) This author together with Zarzycki worked out extensive review about ecology of *Abies alba* (Jaworski and Zarzycki 1983).

Despite the large number of published reports on this issue, it has not been fully explained yet. Results presented by different authors are often inconsistent. According to Jaworski and Zarzycki (1983), at least some of the inconsistencies result from differences in geographical conditions (especially in climate and soil type). Those authors suggest also that provenance variation is important, so results should be analysed with respect to the given conditions.

In the Sudety Mts., where fir cultivation was questionable for a long time (Barzdajn et al. 1999), few studies of its natural regeneration have been carried out, although the poor natural regeneration of this species is one of the major reasons for its declining contribution to forest stands in that region. To analyse this process, permanent plots have been established in various types of forest stands in different parts of the Sudety Mts., and long-term monitoring of fir populations has been started.

In this paper data on the abundance and age structure of natural regeneration of this species in the established permanent plots is presented.

Study area and methods

Nearly 800 natural habitats of European silver-fir were surveyed in the field to select sites for permanent plots. To eliminate the pressure of grazing ani-

mals, selected plots should be fenced in. Thanks to a good cooperation with the local Forest Service, the first five plots were established (and fence in) in the spring of 1999, and the next five in the spring of 2001. The plots represent a wide range of site types and regeneration variants (Table 1).

The fenced plots cover area from 0.5 ha (plot 2 in Szklarska Poręba) to 20 ha (plot 3 in Kamienna Góra), on average 4–5 ha. Old fir trees are unevenly distrib-

Table 1. Characteristic of permanent plots for long-term monitoring of fir populations in Sudety Mts.

Plots no. Forest District, division Forest community	Region Altitude	Stand description
1. Świeradów, 29b Middle European submontane oak hornbeam forest (<i>Galio sylvatici-Carpinetum betuli</i>), mesotrophic community. Site strongly transformed by human activity	Izerskie Foothills 380 m	Upland deciduous forest (Lwyż). Forest stand aged 115 years (beech 40%, spruce 30%, oak 10%. Pine 10%, fir 10%), broken canopy, soil loamy, moll moder humus. Poor fir regeneration.
2. Szklarska Poręba, 274g Montane acidophilous beech forest with gramineous plants and dwarf-shrubs in undergrowth. Site strongly transformed by human activity	Izerskie Mts. 790 m	Mixed montane deciduous forest (LMG). Forest stand aged 120 years (beech 50%, spruce 30%, fir 20%), broken and open canopy, soil loamy, moll moder humus. Underplanting and undergrowth on 50% area,
3. Kamienna Góra, 334f Montane acidophilous beech forest with gramineous plants and dwarf-shrubs in undergrowth (<i>Luzulo pilosae-Fagetum</i>). Site strongly transformed by human activity	Zawory (Stołowe) Mts 550 m	Mixed montane deciduous forest (LMG). Forest stand aged 120 years (beech 50%, spruce 30%, fir 20%), broken and open canopy, soil loamy, moll moder humus. Undergrowth mainly spruce and beech on 30% area.
4. Kamienna Góra, 155p Montane acidophilous beech fores with graminoides and dwarf-shrubs in undergrowth (<i>Luzulo pilosae-Fagetum</i>). Site strongly transformed by human activity	Krucze Mts. 510 m	Mixed montane deciduous forest (LMG). Forest stand aged 120 years (spruce 60%, fir 30%, 10% Douglas fir), broken and open canopy, soil loamy, moll moder humus. Undergrowth mainly spruce and beech on 30% area.
5. Kamienna Góra, 217c Montane acidophilous beech forest (<i>Luzulo pilosae-Fagetum</i>) with elements of coniferus forest	Zawory (Stołowe) Mts. 520 m	Mixed montane deciduous forest (LMG) to mixed montane coniferus forest (BMG). Forest stand aged 110 years (spruce 60%, fir 20%, beech 20%), moderately dense and in places broken canopy, loamy-sandy soil, moder humus. Young undergrowth, mainly spruce on 30% area.
6. Bardo, 148d Middle European submontane, oak-hornbeam forest (<i>Galio sylvatici-Carpinetum betuli</i>), mesotrophic (poor) community Site slightly transformed by human activity	Bardzkie Mts. 390 m	Montane deciduous forest (LG). Forest stand aged 115 years (beech 40%, spruce 30%, oak 10%. pine 10%, fir 10%), broken canopy, soil loamy, moll moder humus. Poor fir regeneration.
7. Bardo, 155h Submontane maple-lime forest (<i>Aceri Tiliatum</i>)	Bardzkie Mts. 410 m	Montane deciduous forest (LG). Forest stand aged 125 years (spruce 50%, beech 20%, oak 20, fir 10%), moderately dense and in places broken canopy, soil loamy, moll moder humus. in places young fir undergrowth.
8. Zdroje, 232h Submontane Middle-European acidophilous oak forest with strong elements of coniferous forest (<i>Quercro roboris pinetum</i>)	Stołowe Mts. 530 m	Mixed montane coniferous (BMG) forest site. Forest stand aged 90 years (larch 40 %, fir 20%, spruce 20%, pine 20%), canopy moderately dense, sandy soil, moder-raw humus. Fir regeneration good.
9. Międzyzylesie, 110b Montane acidophilous beech forest with gramineous plants and dwarf-shrubs in undergrowth (<i>Luzulo pilosae-Fagetum</i>). Site slightly transformed by human activity	Masyw Śnieżnika 600 m	Mixed montane forest site (LMG). Forest stand aged 125 years (spruce 50%, fir 40%, beech 10%), moderately dense and broken canopy, soil loamy, moder-mool humus.
10. Prudnik 81b Middle european oak-hornbeam forest(<i>Galio sylvatici-Carpinetum betuli</i>), submontane form, fertile series. Site strongly transformed by human activity	Opawskie Mts. 370 m	Montane deciduous forest site (LG). Forest stand aged 85 years (fir 80%, spruce 30%, beech 10%), canopy moderately dense, soil loamy, typical moder humus. Fir regeneration from good to very good, mainly very young seedlings.

uted, and form several groups within each plot. Also natural regeneration has a clumped distribution there. Besides, in some parts of the fenced areas, artificial regeneration takes place. Thus we selected for observations larger patches with old and young fir trees, usually covering several hundred m² each and 0.3–0.5 ha altogether in each plot. The patches were divided into square plots 4 m² area each (2 × 2m), and all old trees and groups of young trees were measured and marked on a plan. Within each big plot, the square plots were numbered from the west to the east and from the north to the south. The total number of square plots was divided by 20, to determine the quotient necessary for selecting 20 square plots for monitoring of the abundance and structure of natural regeneration. The transect method was not used because most of the plots were irregular in shape. In the selected quadrates, all seedlings were counted and assigned to age classes as in Fig. 1.

The abundance of natural regeneration was recalculated and expressed as the number of young fir

trees per 1 ha. As the contribution of old fir trees varied considerably, also the per 1 old tree was calculated.

Results

Table 2 shows mean numbers of seedlings per 1 old tree and per 1 ha. Fig. 1 show the age structure of natural fir regeneration in the studied plots. The uneven distribution of seedlings in age classes suggests that some years were favourable and others were unfavourable for fir regeneration. Differences between plots can be noticed, but in most plots the largest numbers of seedlings developed in years after good fir cone crops all over the Sudety Mts., for example in 1996 and 1998. Self-sown seedlings are usually unevenly distributed and the most abundant in places free from the cover of herbs. Regeneration is also easier in places where the mineral layer of the soil has been exposed, or at least the leaf litter has been disturbed, for example by logging. In plots established in

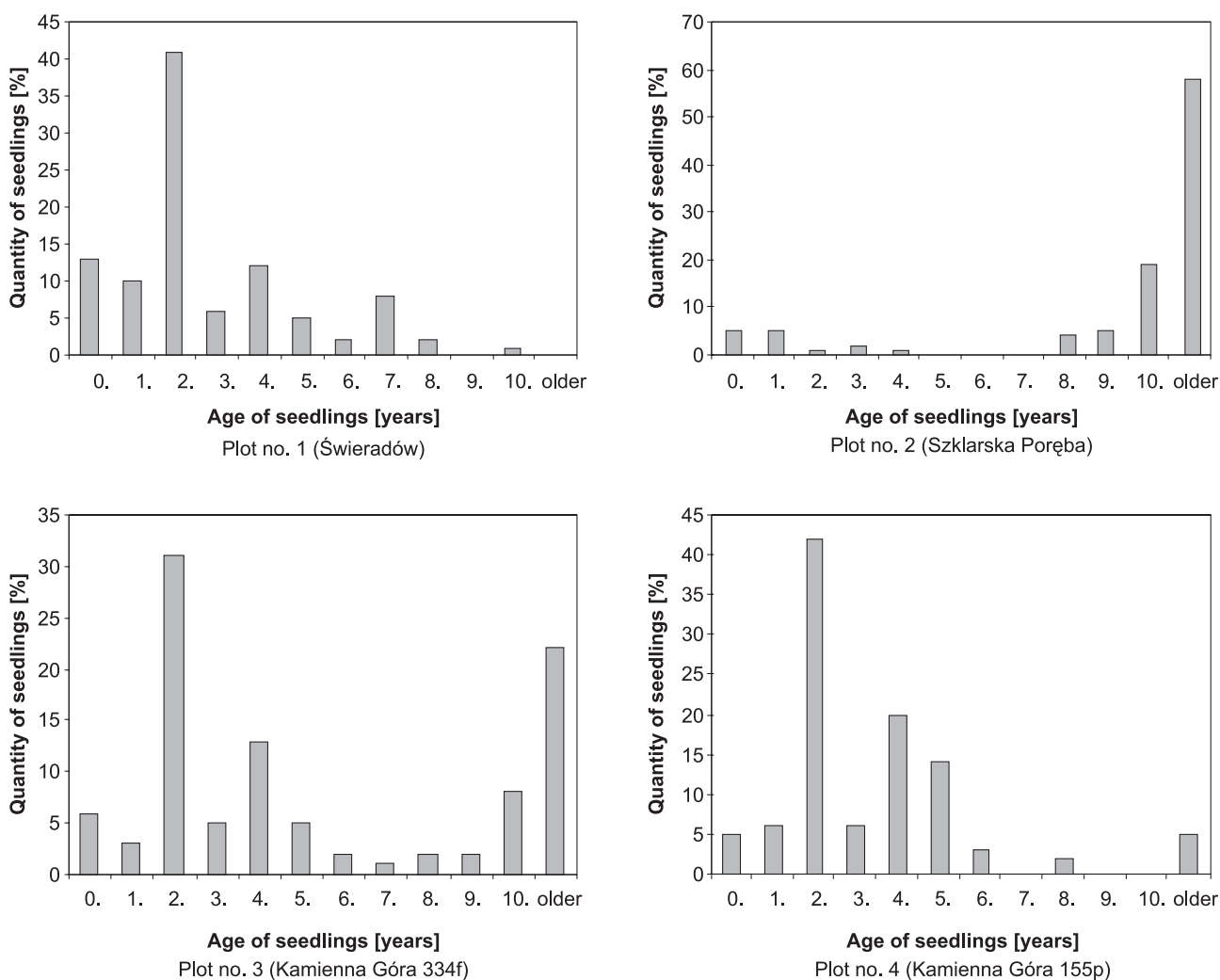


Fig. 1. Age structure of natural regeneration of silver-fir (*Abies alba* Mill.) on permanent plots. July 2000

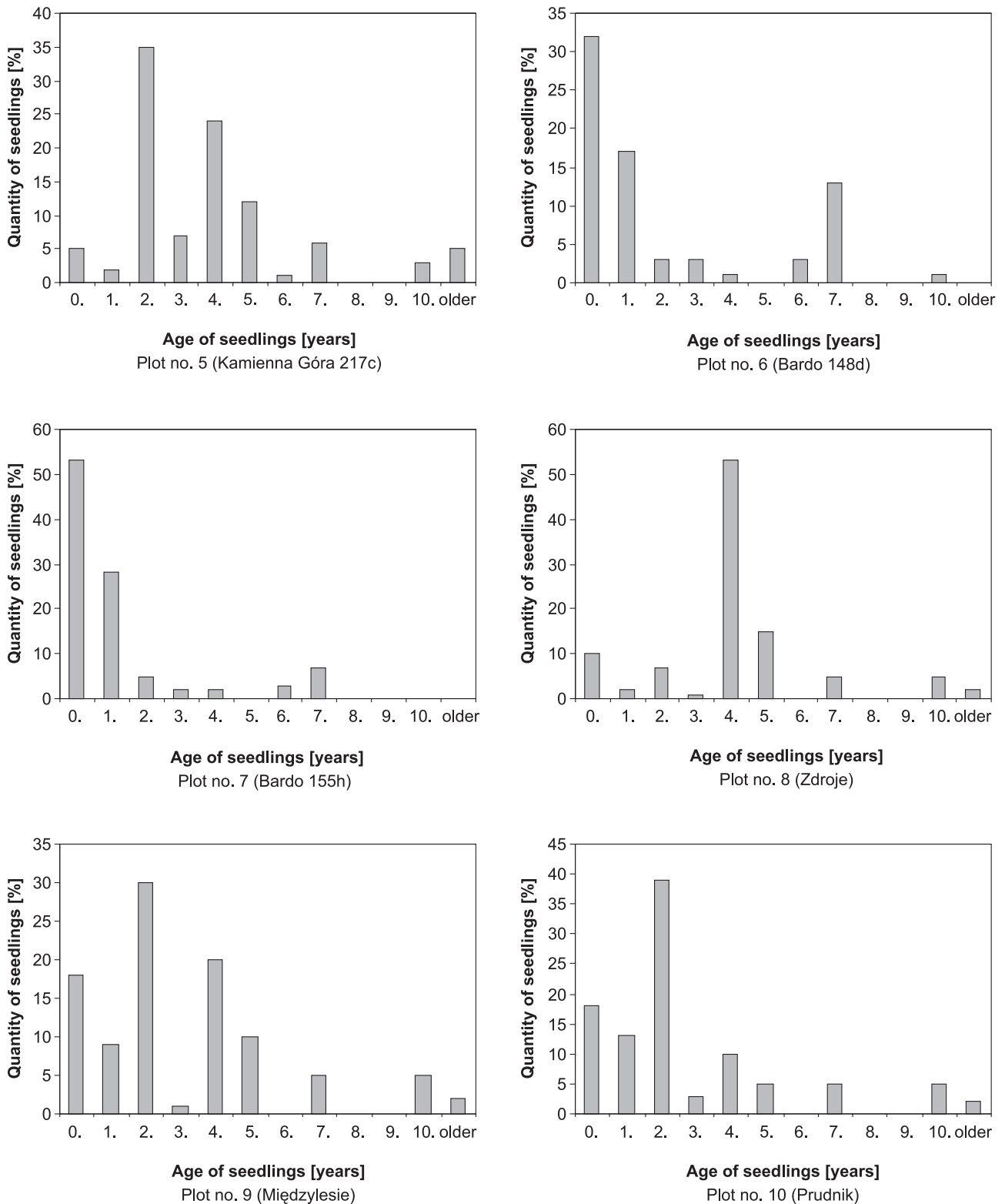


Fig. 1. cont.

1999 (Rębiszów, Dobromyśl and Lubawka), several dozen so-called plates were made by removing leaf litter in area 0.5–1.0 m square. In the spring of 2001, the number of seedlings in the cleared plates was from 5 (in places covered with a dead leaf litter) to 30 (in places with a thick herb layer) times higher than

around them. More seedlings were recorded if leaf litter was dominated by fallen spruce needles, rather than beech leaves. The vigour of the majority seedlings is improving, which is reflected in the fast elongation of their stems.

Table 2. Numbers of seedlings per 1 old tree and per 1 ha in permanent plots

Plots no. Forest District, division	New growth		Undergrowth	
	number of seedlings per 1 ha	number of seedlings per 1 old tree	number of seedlings per 1 ha	number of seedlings per 1 old fir tree
1. Świeradów, 29b	233	4.65	–	–
2. Szklarska Poręba, 274g	108	1.13	498	5.19
3. Kamienna Góra, 334f	1203	12.5	77	0.81
4. Kamienna Góra, 155p	471	3.27	–	–
5. Kamienna Góra, 217c	2994	28.24	148	1.4
6. Bardo, 148d	391	8.50	–	–
7. Bardo, 155h	634	11.96	–	–
8. Zdroje, 232h	510	37.93	–	–
9. Międzyzlesie, 110b	1278	9.12	4.8	0.025
10. Prudnik, 87h	9794	21.35	–	–

Discussion and conclusions

The abundance of fir seedlings (Table 2) in the studied plots is markedly lower than in the well-regenerating Carpathian forest stands (Jaworski 1979). The major reason for this seems to be the lower contribution of fir trees to forest stands in the Sudety Mts. (Table 1), as compared with the Carpathians. An additional reason is the poor cone cropping in the Sudety Mts., caused by considerable damages to fir tree crowns due to industrial pollution (Boratyński, Filipiak 1997) and the higher inbreeding coefficient of their seeds, resulting from the smaller number of specimens in local populations. Large differences between plots in abundance of fir seedlings are also observed. Jaworski (1979) noted that young fir trees are more numerous in potential sites of coniferous forest (*Vaccinio-Piceetalia*) than in sites of acidophilic beech forest (*Luzulo-Fagetum*). Also in our study the best results were recorded in potential sites of coniferous forest: plot 8 at Polanica (mixed mountain coniferous forest), and plot 5 at Dobromyśl (intermediate between mixed coniferous and mixed deciduous forest). Less effective fir regeneration was observed in plots representing acidophilic beech forest, and the least effective in potential sites of oak-hornbeam forest. According to Jaworski (1979), a favourable substrate for fir regeneration is row humus, which is characteristic of poor sites. Regeneration of this species in such a substrate is usually free from the negative influence of the fungus *Cylindrocarpon destructans*, and from periodical accumulation of manganese. In the light of our results, an important role may be also played by the lower competition of the herb layer of vegetation in poor sites. Most of the studied forest stands in the Sudety Mts. are not dense, so the herb layer is well-developed, especially in potential sites of oak-hornbeam forest (plots 1, 6 and 7) and slightly poorer in the case of acidophilic beech forest (plots 3, 4 and 9). Plots 2 and 10 are examples of relatively good fir re-

generation in fertile sites with a lower density of the herb layer. The development of the herb layer in plot 2 was limited by erosion, and in plot 10 by a higher density of the canopy.

The age structure of the studied forest stands attests to the importance of good cone crops in the process of natural regeneration of the studied species. Despite this, in most plots the process of regeneration extended over many years. In none of the plots the process end. On the contrary, in most plots the process is at an initial stage. Both the differences between plots in respect of regeneration effectiveness in years of good cone crops, and the clumped distribution of fir seedlings, indicate that the appearance of regeneration in a given year is determined not only by the number of viable seeds, but also by other factors, e.g. the density of the plant cover and soil moisture level.

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