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# The influence of stand structure in submontane acidophilous oak forests on the presence of the wild service tree and sword-leaved helleborine

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**Abstract.** The objective of this work was to evaluate the occurrence of two strictly protected vascular plant species in managed stands of submontane acidophilous oak forests (Luzulo luzuloidis – Quercetum petraeae Hilitzer 1932 association) in the Sudeten foothills (Lower Silesia, Poland). During the study, the most important stand parameters influencing the occurrence of the wild service tree (Sorbus torminalis (L.) Crantz) and the orchid sword-leaved helleborine Cephalanthera longifolia (L.) Fritsch) were ascertained. The stands ranged from 50 to 130 years of age and were dominated by sessile oak (Quercus petraea (Matt.) Liebl.), which comprised 5–100% of trees.

Both of the protected plant species were observed in 10% of the examined plots with the most favorable type of forest stand for sword-leaved helleborine as well as the wild service tree being clearly dominated by sessile oak (portion of oak above 80%). The analysis showed that the wild service tree was found in pure oak stands, whereas sword-leaved helleborine was also recorded in mixed stands aged 50–80 years. The increased frequency of sword-leaved helleborine was associated with a higher portion of oak in the tree layer.

The results suggest that the modern silviculture practices, 'close-to-nature' silviculture, transform pure oak forest into mixed forest and allow for natural expansion of hornbeam (Carpinus betulus L.) as well as beech (Fagus sylvatica L.), which can induce the gradual disappearance of the orchid and the wild service tree in submontane acidophilous oak forests. Restoring semi-natural pure oak stands should play a significant role in supporting both protected species in submontane acidophilous oak forests of the Sudeten Region.

**Keywords:** Luzulo luzuloidis–Quercetum petraeae, expansion of hornbeam, Sudeten, protected plants, silviculture

## 1. Introduction

As a result of shaping the species composition of tree stands, forest management has an effect on groundcover species composition and diversity (Barbier et al. 2008). In the Sudeten region, oak acidophilous association *Luzulo luzuloidis–Quercetum petraeae*, the so-called submontane oak forest, embraces forest stands with prevailing sessile oak (*Quercus petraea* (Matt.) Liebl.) (Matuszkiewicz 1988; Reczyńska 2015). In most cases, these stands were formed because of coppicing performed in the region up to the mid-1900s. On account of this practice, more light came into the forest interior, which contributed to the enhancement of species diversity and development of photophilous and thermophilous plant species (Szymura 2010). The structure of single-oak species forests (coppice age of > 80) is most often the result of selection cuts, initially in the coppice-with-standard system (Szymura 2012). The cuts consisted of gradual removal of trees from the top layer of stands in favour of trees with desired breeding characteristics. The economic goal of these treatments was to produce good-quality sawn timber and to prepare stands for better reproduction towards successful regeneration. The structure of 50–80 years old oak forest stands growing on poor sites is first of all a result of cuts with low intensity, whereas on more fertile sites, it is attributable to transformation of coppice stands into mixed high-growing stands as a result of clear-cuts (Szymura 2012).

A typical submontane oak forest is characterised by the presence of sessile oak in the tree layer, along with, less frequently, admixtures, such as silver birch (*Betula pendula* Roth), com-

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mon beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.) H. Karst.) and Scots pine (*Pinus sylvestris* L.). The shrub layer is poorly developed, and it includes the species such as alder buckthorn (*Frangula alnus* Mill.), common hazelnut (*Corylus avellana* L.) and rowan (*Sorbus aucuparia* L. em. Hedl.), along with tree species from the main stand (Matuszkiewicz 1988), including common hornbeam (*Carpinus betulus* L.) (Reczyńska 2015).

Submontane oak forest is the richest and most distinguished association of acidophilous oak forests, which consist of two sub-associations: the characteristic *Luzulo-Quercetum typicum* and the thermophilous *Luzulo-Quercetum genistetosum tinctoriae* (Matuszkiewicz 1988). Recent research has discussed the division of *Luzulo luzuloides–Quercetum* into two sub-associations, that is, *typicum* and *genistetosum tinctoriae* (Reczyńska 2015). In the study on the classification of oak forests in the Sudeten region, Reczyńska (2015) proposed the division into six syntaxonomic units, namely, *Viscario vulgaris-Quercetum petraeae*, *Melico pictae-Quercetum roboris*, *Sorbo trominalis-Quercetum*, *Galium verum-Quercus petraea* and those included in the classification by Matuszkiewicz (2008): *Calamagrostis arundinaceae-Quercetum petraeae* and *Luzulo luzuloidis-Quercetum petraeae*. In Matuszkiewicz (1988), the association *Sorbo torminalis-Quercetum* occurring in the Sudeten Foothills (Pogórze Sudeckie) is referred to as *Luzulo-Quercetum genistetosum tinctoriae*. When compared to the typical form, on patches of the richer sub-association *Luzulo -Quercetum genistetosum tinctoriae*, there is observed a greater constancy of the plant species characteristic for thermophilic communities, including those strictly protected, such as wild service tree (*Sorbus torminalis* (L.) Crantz), and the orchid – sword-leaved helleborine (*Cephalanthera longifolia* (L.) Fritsch) (Rozporządzenie 2014).

In the 'Red List of Vascular Plants in Poland', the sword-leaved helleborine is classified as the species endangered by extinction (Zarzycki, Szeląg 2006). According to Jakubska-Busse et al. (2014), the decline of orchids in Lower Silesia from the beginning of the 1900s has been a result of the introduction of coniferous monocultures and eutrophication of forest ecosystems in agro-forest complexes. On the other hand, since 1945, a decline in the share of the wild service tree in oak forests has been mainly caused by abandoning management with the use of the coppice-with-standard system (Szymura 2012). According to Kopecký et al. (2013), cessation of coppicing in the 1900s has gradually lead to the extinction of many photophilous species representative for forest communities in Europe's lowlands.

The loss of light-loving species has been repeatedly observed over the past decades throughout Poland's forests, at the same time, as oak forests have become more shady and compact because of the natural expansion of common beech in oak associations of the Małopolska variety (Matuszkiewicz 2007a), as well as hornbeam expansion in thermophilous oak forests (Kwiatkowska et al. 1997; Matuszkiewicz 2007b). Currently, in managed submontane oak forests, transformation of single-oak species forests into mixed stands with common beech admixture has been carried out (Forest Management Plans), which further restricts the access of light to the forest interior. Photophilous sword-leaved helleborine prefers damp and calcium-carbonate-rich soils (Delforge 2006). According to the classification by Reczyńska (2015), it is a common species in thermophilous oak association *Melico pictae-Quercetum roboris*, growing on deep mesotrophic soils on less than 10% slopes. Thus, the occurrence of this orchid in unfavourable habitat conditions of compacted submontane oak stands may be controlled by the availability of adequate light to the forest bottom. The light factor is also important for the regeneration of wild service tree in forests with sessile oak trees (Müller et al. 2000).

The question was raised when assessing forest management in submontane oak forest: whether basic elements of the stand structure, such as stand species composition and age, affect the occurrence of two important and protected plant species: wild service tree and sword-leaved helleborine?

## 2. Materials and Methods

### 2.1. Research area

Study areas were established in the uplands of south-western Poland (Fig. 1), which comprise two macro-regions: the Western Sudetes Foothills and the Sudeten Foothills (Kondracki 2002). The Western Sudetes Foothills range from the micro-region of the Pogórze Złotoryjskie, where submontane oak forest is the most common forest type (Kwiatkowski 2001). The area is characterised by one of the largest concentrations of oak stands in Poland, the share of which exceeds 33% in the area of the Sudeten Foothills (Trampler et al. 1990; Siedliskowe podstawy hodowli lasu 2004). There occur one of the most abundant wild service tree populations (Bednorz 2004) as well as those of *Cephalanthera* orchids (Jakubska -Busse et al. 2014). Within the study area, the bedrock is by and large formed by acidic crystalline rocks – metamorphic and magmatic rocks and alkaline greenstones, sometimes covered by quaternary sediments (Kondracki 2002). In the studied region, there prevail shallow and skeletal acid brown soils (cambisols), prone to dryness, as well as leptosols with pH 4.0–4.5 (BULiG, Brzeg). All the study areas were situated in the Forest Districts, Henryków, Świdnica, Miękinia, Złotoryja, Jawor and Lwówek Śląski, on 25% slopes at the altitude of 330 m ASL, with S–SW exposure.

### 2.2. Research methods

The study areas were established at nodal points of 50 m × 50 m grid. In the process of study site selection, 1:25,000

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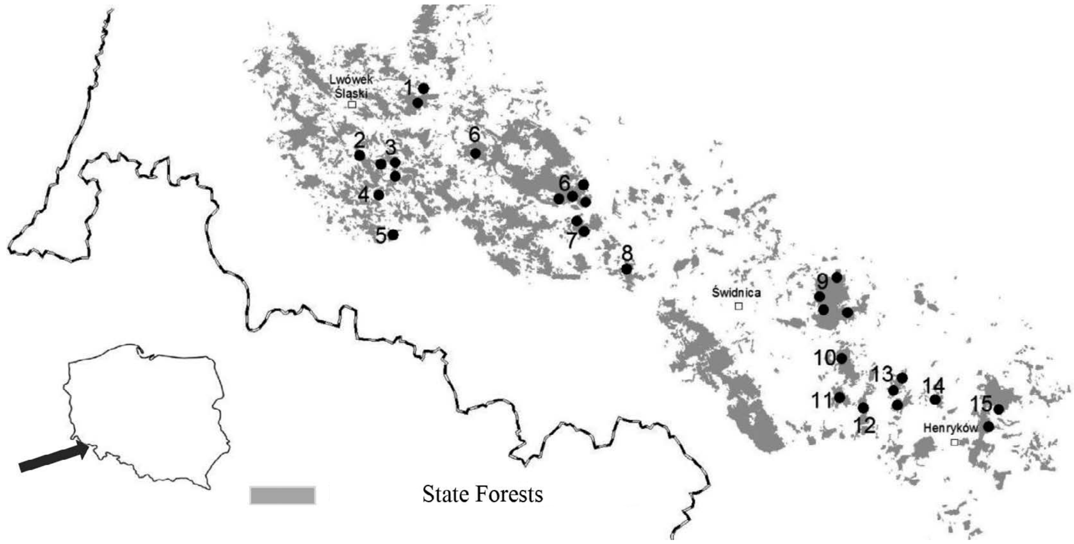


**Figure 1.** Location of plots:
**1 – Wzniesienia Płakowickie, 2 – Wzgórza Radomickie, 3 – Wysoczyzna Ostrzycka, 4 – Obniżenie Świerzawy, 5 – Obniżenie Jeleniej Góry, 6 – Pogórze Złotoryjskie, 7 – Pogórze Wojcieszowskie, 8 – Pogórze Świebodzickie, 9 – Masyw Ślęży, 10 – Wzgórza Krzyżowe, 11 – Wzgórza Gilowskie, 12 – Wzgórza Gumińskie, 13 – Wzgórza Dębowe, 14 – Wzgórza Lipowe, 15 – Wzgórza Strzelińskie**

maps of the Forest District areas and 1: 300,000 map of potential vegetation were used (Matuszkiewicz et al. 1995). In order to fit the scale of the maps used, a proper calibration was performed. So as to ensure the comparability of the results, the following criteria were met for each site: (1) habitat type, fresh upland mixed forest; (2) soil subtype, strongly skeletal acid brown soils and leptosols; (3) 300–355 m altitude; (4) 15–35% slope; (5) SW–SE exposure; and (6) the first floor of the stand with not less than 70% crown closure. The accepted selection criteria are optimal for *Luzulo luzuloidis–Quercetum petraea* and in accordance with Matuszkiewicz (1988). Owing to the diversity of upland habitats, field verification of the study areas was carried out with the use of the above set of criteria. In total, 176 circular plots were established in the homogeneous patches of submontane oak forest.

Soil and habitat reports of the Forest Districts along with associated habitat maps served as source materials for the determination of characteristics of soil conditions (soil type, subtype and kind). Geological units were distinguished based on the ‘Detailed geological maps of the Sudety Mts.’, scale 1:25,000 (PIG).

The size of the study plot designated for the examinations of the stand structure was 400 $m^2$; the phytosociological data were also collected using the relevé method. The area of the circular plots was permanently marked with oak stakes. The centre of each plot was determined by means of GPS coordinates (4 m accurateness), and the altitude was specified based on the maps (5 m accurateness).

In 2010–2011, diameter at breast height (DBH) of all trees and shrubs that reached the height of $\geq$ 1.3 m was measured. In order to avoid measurement errors, the arm of the caliper always faced the centre of the plot. The share of individual species of trees and shrubs was calculated based on the DBH basal area. The age of the stand (in coppice stands – coppice age) was adopted from the current taxonomic descriptions of the stands.

In 2011–2012, in spring (May) and summer (July–August), phytosociological data were collected by using the relevé method (Braun-Blanquet 1964). In line with the purpose of this study, the frequency (% constancy) of wild service tree and sword-leaved helleborine was calculated for six variants of stands, grouped according to the share and age of oak (Table 1). The cover-abudance of both species were observed and converted to mean coverage values in percent as proposed by Pawłowski (1977).

Phytosociological data were arranged in the tables, taking into account the distribution of stands with wild service tree and sword-leaved helleborine and those without these species. Tree and shrub coverage along with coverage coefficients for three syntaxonomic units described in the study by Matuszkiewicz (2008), that is, characteristic for the class *Quercetea robori-petraeae* as well as the alliances *Fagion sylvaticae* and *Carpinion betuli*, were calculated. The coverage coefficients were calculated using the Barkman formula (Zelený, Tichý 2006). The result was rounded by multiplying the quotient by 100. For climate and soil conditions, the method of phytoindication was used, which takes into account the mean values of the numbers (indexes) of ecological herbaceous plants (Zarzycki et al. 2002). Average values of the following indicators were calculated: light (L), thermal (T), humidity (W), acidity (R) and soil trophism (Tr). The numbers of trees and shrubs

**Table 1.** Number of plots in a relation to the share of oak and age of stand

| Variants | Share of oak [%] | Age | Number of plots |
|---|---|---|---|
| I | 5–40 | 50–80 | 18 |
| II | 41–80 | 50–80 | 24 |
| III | >80 | 50–80 | 22 |
| IV | 5–40 | >80 | 16 |
| V | 41–80 | >80 | 22 |
| VI | >80 | >80 | 74 |
| | | Total: | 176 |

with a given thicknesses were compared and their shares in two thickness groups ($d_{1/3} < 7$ cm and $d_{1/3} \geq 7$ cm) were analysed. Differences between the means obtained were tested using the Student's t-test and its nonparametric equivalent, the Mann–Whitney U test, at a significance level of $p < 0.05$.

Spearman's correlation ($p < 0.05$) was performed to analyse the relationships between the mean values of sword-leaved helleborine and wild service tree coverage and the stand structural elements (basal areas of trees and shrubs, stand basal area, stand layers and age). The species names of vascular plants are given according to Mirka et al. (2002).

## 3. Results

The presence of sword-leaved helleborine and wild service tree was observed in 17 of the 176 plots, which accounts for almost 10% of all the plots examined. The sword-leaved helleborine was recorded on 14 plots (Pogórze Złotoryjskie, 11; Wzgórza Gilowskie, 2; Wzgórza Lipowe, 1) and the wild service tree on three plots (Pogórze Złotoryjskie).

Wild service trees were observed in single-oak species forests (50–80 years old), in the dominant tree layer as well as in the groundcover, at 5% frequency (Table 2). However, in older oak stands (>80 years), its attendance was decreased.

Not like wild service tree, sword-leaved helleborine occurred in all the variants of young stands (50–80 years old), and its frequency was increasing with the increase in the share of oak in the stand (Table 2). In comparable mixed stands (>80 years old), sword-leaved helleborine utterly disappeared, whereas in single-oak species stands (>80 years old), its frequency decreased.

In all the research plots, there was a significant positive correlation between sword-leaved helleborine coverage and the hazelnut basal area (Table 3). Also, a weak but significant positive correlation between sword-leaved helleborine coverage and the oak basal area was found. The observed orchid species preferred dense canopy stands; however, the strength of this relationship was insignificant.

**Table 2.** Frequency of the wild service tree and sword-leaved helleborine in a relation to the share of oak and age of stand

| Species | Variants | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| | n=18 | n=24 | n=22 | n=16 | n=22 | n=74 |
| *Sorbus torminalis* a1 | 0 | 0 | 5 | 0 | 0 | 0 |
| *Sorbus torminalis* a2 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Sorbus torminalis* b | 0 | 0 | 0 | 0 | 0 | 1 |
| *Sorbus torminalis* c | 0 | 0 | 5 | 0 | 0 | 3 |
| *Cephalanthera longifolia* | 6 | 8 | 14 | 0 | 0 | 11 |

Explanations as in Table 1.

In the group of stands with the examined protected species (17 plots), a significant negative correlation was found between the canopy density in the upper floor (measured by the degree of coverage) and the occurrence of wild service tree under the canopy (Spearman's correlation coefficient r = −0.61).

The average age (88 years) and the canopy density (A = 95%, A1 = 90%, A2 = 11%) of the stands with wild service tree and sword-leaved helleborine were not significantly different from those in other stands examined (age = 88 years; canopy density: A = 91%, A1 = 86%, A2 = 10%). The main component of the examined oak stands in the crown layer (a1) was sprout-origin sessile oak, which showed the highest constancy (degree V) and the highest coverage degree of 7,382 ($V^{7382}$) in the stands with wild service tree and sword-leaved helleborine. The slightly lower degree values were obtained in the stands without wild service tree and sword-leaved helleborine ($V^{6486}$). In the first floor of the two groups of the stands examined, naturally regenerated birch species and occasionally hornbeam were also observed. On the other hand, derivation of the observed admixtures of common beech and European larch (*Larix decidua* Mill.) is unclear. Wild service tree and sword-leaved helleborine avoided artificially regenerated stands with Scots pine ($II^{772}$) and Norway spruce ($II^{439}$) in the first floor. Sword-leaved helleborine was found on only one plot, with artificially restored stands of *Quercus robur* L. and common beech, as well as natural admixture of hornbeam and wild cherry (*Cerasus avium* (L.) Moench).

Under the canopy of the oak forests with protected species, more developed undergrowth layer (average coverage 17%) was observed when compared with the remaining stands examined (6%); however, the difference was not statistically significant. The undergrowth layer mainly composed of common hazelnut ($III^{1413}$) – a species characteristic for deciduous forests. Nonetheless, in the stands without wild service tree and sword-leaved helleborine, the share of common hazelnut in the shrub layer was significantly lower ($I^{101}$).

**Table 3.** Spearman correlation analysis between the variables of stand structure and cover of sword-leaved helleborine

| The variables of stand structure | *Cephalanthera longifolia* |
|---|---|
| Basal area | |
| *Quercus* sp. | 0.17* |
| *Fagus sylvatica* | 0.02 |
| *Betula pendula* | 0.01 |
| *Picea abies* | -0.12 |
| *Pinus sylvestris* | - |
| Oak–lime–hornbeam forest | 0.05 |
| *Corylus avellana* | 0.32* |
| Stand | 0.05 |
| Cover layers | |
| a | 0.19* |
| a1 | 0.17* |
| a2 | 0.04 |
| b | 0.18* |
| Age | -0.03 |

*Marked correlations are significant at $p < 0.05$ and $n = 176$

Amongst all the tree species, sessile oak showed the greatest regeneration capacity. Seedlings of this species occurred abundantly in the herbaceous layer of both groups of the stands examined (constancy degree is V, coverage degrees are 1,235 and 1,065, respectively). In both groups of stands, sessile oak showed poor ability to move into the undergrowth higher layer. The shape of young sessile oaks suggested slowed down growth of the trees.

In general, deciduous trees with 'shadowy crowns' regenerated better in the stands with wild service tree and sword-leaved helleborine. In the groundcover layer, there were recorded the characteristic species of *Carpinion* alliance, that is, hornbeam ($IV^{122}$), wild cherry ($IV^{36}$), and small-leaved lime (*Tilia cordata* Mill) ($III^{5}$). In the groundcover, sycamore maple (*Acer pseudoplatanus* L.) ($IV^{151}$) – originating from shadowy deciduous forests of the order *Fagetalia sylvaticae* – as well as Norway maple (*Acer platanoides* L.) ($III^{62}$), occurring in the class *Querco-Fagetea*, were also observed. Nevertheless, both maple species were not present in the higher stand layers. On the other hand, common beech was observed more frequently under the canopy of the stands where wild service tree and sword-leaved helleborine were not recorded.

Amongst the trees and shrubs, common hazelnut was the most abundant species in the undergrowth layer of the stands with wild service tree and sword-leaved helleborine (Table 4). This was reflected by a considerable share of common hazelnut in the stand layer with the diameter subclass: DBH < 7 cm (Fig. 2). Common hazelnut numbers and proportion were significantly lower in the stands without wild service tree and sword-leaved helleborine. In the submontane forest examined, other shrubs, such as alder buckthorn (*F. alnus* Mill.) and rowan and common hawthorn (*Crataegus monogyna* Jacq.), occurred quite sparsely when compared to hazel.

In the two groups of the stands with the diameter subclass DBH 9–37 cm, examined with regard to the number of trees, obvious domination of sessile oak was observed (Table 4). In the stands with wild service tree and sword-leaved helleborine, the most numerous group was that with the diameter subclass 17 cm, and here birch admixture deserved attention. In the stands without wild service tree and sword-leaved helleborine, Scots pine admixture was characteristic for tree fraction with the diameter subclass 21 cm (most abundant). This was not the case for Norway spruce and some deciduous species (characteristic for oak–lime–hornbeam forests), which were mainly represented by thin trees (Table 4). A slight increase in the role of small-leaved lime and wild cherry was observed in the stands with wild service tree and sword-leaved helleborine, whereas that of hornbeam and Norway spruce was observed in

**Table 4.** Diameter structure of 1 ha stands: (1) with wild service tree and sword-leaved helleborine, (2) others

| Species | Stand | Number of trees and shrubs in the grades of DBH [cm] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 5 | 9 | 13 | 17 | 21 | 25 | 29 | 33 | 37 | 41 | 45 | 49 | 53 | 57 | 61 | 65 | 69 | 73 |
| *Quercu petraea* Liebl. | 1 | 7 | 19 | 62 | 81 | 144 | 103 | 97 | 59 | 41 | 19 | 10 | 3 | 1 | 3 | – | – | – | – | – |
| | 2 | 8 | 16 | 31 | 58 | 97 | 106 | 80 | 54 | 26 | 14 | 7 | 3 | 1 | 2 | <1 | <1 | <1 | – | <1 |
| *Betula pendula* Roth | 1 | 4 | – | – | 4 | 18 | 19 | 10 | 1 | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 2 | 1 | 1 | 2 | 5 | 5 | 3 | 2 | 1 | 1 | <1 | <1 | – | – | – | – | – | – | – |
| *Picea abies* (L.) H. Karst. | 1 | – | – | 3 | – | 1 | 3 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 10 | 20 | 12 | 5 | 4 | 4 | 6 | 5 | 3 | 2 | 1 | 1 | <1 | 1 | <1 | – | – | – | – |

| Species | Stand | Number of trees and shrubs in the grades of DBH [cm] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1,5 | 5 | 9 | 13 | 17 | 21 | 25 | 29 | 33 | 37 | 41 | 45 | 49 | 53 | 57 | 61 | 65 | 69 | 73 |
| *Pinus sylvestris* L. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | <1 | 1 | 3 | 6 | 11 | 10 | 9 | 8 | 3 | 4 | 1 | <1 | <1 | 1 | <1 | <1 | – | – |
| *Fagus sylvatica* L. | 1 | – | – | – | – | – | 1 | – | – | – | – | 1 | 1 | 1 | – | – | – | – | – | – |
| | 2 | 5 | 5 | 3 | 3 | 5 | 3 | 3 | 2 | 2 | 1 | 1 | <1 | – | <1 | <1 | <1 | <1 | – | – |
| *Quercus robur* L. | 1 | – | – | 4 | 7 | 1 | 1 | 1 | 1 | 3 | – | 1 | – | – | – | – | – | – | – | – |
| | 2 | 1 | 1 | <1 | 1 | <1 | 2 | 1 | 1 | <1 | <1 | <1 | <1 | – | – | – | – | – | – | – |
| *Larix decidua* Mill. | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | – |
| | 2 | – | <1 | <1 | 1 | <1 | 2 | 3 | 1 | 1 | 1 | 1 | <1 | – | – | – | – | – | – | – |
| *Carpinus betulus* L. | 1 | 13 | 1 | 3 | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | – | – |
| | 2 | 39 | 13 | 6 | 2 | 2 | <1 | 1 | – | <1 | – | – | – | – | – | – | – | – | – | – |
| *Tilia cordata* Mill. | 1 | 21 | 9 | 1 | 6 | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 7 | 5 | 2 | 3 | 2 | 1 | 1 | <1 | <1 | <1 | – | <1 | – | – | – | – | – | – | – |
| *Cerasus avium* (L.) Moench | 1 | 19 | 15 | 3 | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | <1 | – | <1 | – | – | – | – | <1 | – | – | – | – | – | – | – | – | – | – | – |
| *Corylus avellana* L. | 1 | 740 | 188 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 26 | 8 | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Sorbus aucuparia* L. em. Hedl. | 1 | 12 | – | – | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 7 | <1 | 1 | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Sorbus torminalis* (L.) Crantz | 1 | – | – | 1 | 3 | – | – | – | 1 | 1 | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Crataegus monogyna* Jacq. | 1 | 6 | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 1 | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Frangula alnus* Mill. | 1 | 7 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 2 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Acer pseudoplatanus* L. | 1 | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | 1 | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Abies alba* Mill. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | – | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Malus sylvestris* Mill. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Sambucus nigra* L. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Sambucus racemosa* L. | 1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | 2 | – | <1 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

the remaining stands. In general, in the layer with the diameter subclass DBH below 7 cm, the species share of the stands with wild service tree and sword-leaved helleborine was less diverse when compared to the remaining stands examined (Fig. 2). A considerable decrease in the share of the species characteristic for oak-hornbeam forests in the layer with DBH above 7 cm was observed (Fig. 3).

The basal area of oak and common hazelnut in the stands with wild service tree and sword-leaved helleborine was larger when compared to that in the rest of the stands examined (Fig. 4). Scots pine was not recorded in the basal area of the stands with wild service tree and sword-leaved helleborine.

The stands with wild service tree and sword-leaved helleborine grow on more fertile and less acidic soils when compared to the soils of other stands examined (Fig. 5). In addition, the analysis of moisture and thermal indicators showed that wild service tree and sword-leaved helleborine prefer stands growing in warmer and drier habitats.

Inverse proportions of the sums of species coverage coefficients for the species characteristic for the alliance *Carpinion betuli* and *Fagion sylvaticae* were shown in Fig. 6. Regarding the group of species typical for acidophilous oak forests (*Quercetea robori-petraeae),* the coverage coefficients were similar. In the groundcover of the allianceCarpinion betuli, a gallium (bedstraw) species (*Galium schultesii* Vest – $V^{474}$) dominated, whereas wood bedstraw (*Galium sylvaticum* L.) was not recorded. On the other hand, the alliance *Fagion sylvaticae* with oak forest wood-rush (*Luzula luzuloides* (Lam.) Dandy & Wilmott) was recorded in both the stands with wild service tree and sword-leaved helleborine and those without these protected species ($III^{193}$ and $III^{811}$, respectively).

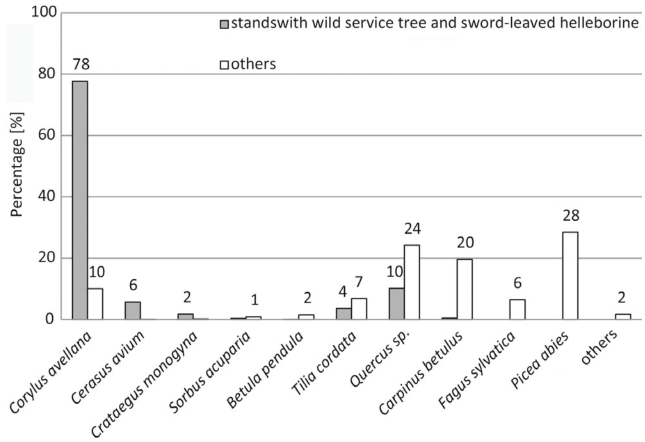


**Figure 2.** Share [%] of trees and shrubs in the layer of DBH <7 cm

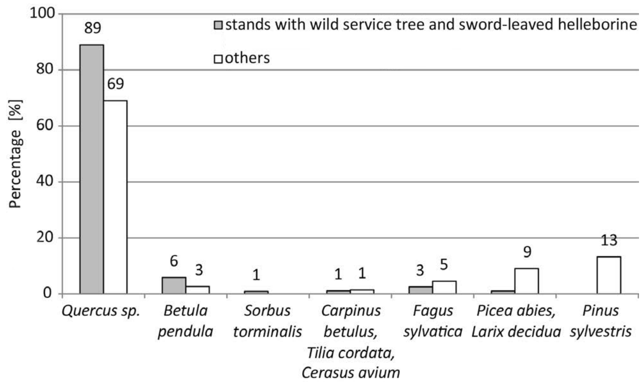


**Figure 3.** Share [%] of trees and shrubs in the layer of DBH ≥7 cm

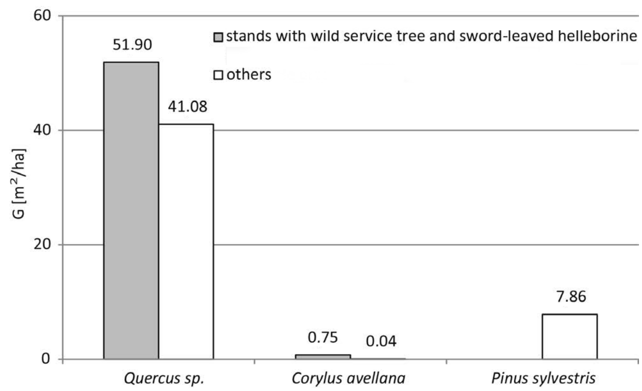


**Figure 4.** Mean of basal area (G) of trees and shrub species. Differences between means are significantly different at α=0.05

## 4. Discussion

When assessing the effect of forest stand structure on the occurrence of protected species in submontane oak forest, the important aspects such as spatial variability (geographical) or management using the coppice-with-standard system cannot be disregarded. According to Szymura and Szymura (2013), in the uplands of the Sudeten region, the differences in the composition of the floristic associations associated with oak forests, managed in a traditional way (coppicing) in the past, are strongly influenced by spatial differentiation. Forest fragmentation, typical for upland habitats, limits the range and number of photophilous species that have low dissemination capacity (Szymura et al. 2015). Spatial differentiation can have a greater effect on the vegetation than soil acidity and slope exposure (usually southern) (Szymura, Szymura, 2013). Spatial differentiation may be reflected in the fact that all the examined plots with wild service tree and the majority of those with sword-leaved helleborine were located in the area of the Pogórze Złotoryjskie. The presence of protected species in submontane acidophilous oak habitats may also depend on the geological characteristics, as in the area of the Pogórze Złotoryjskie, the geologic substrate is greenstone regolith, whereas that in the Sudeten Foothills consists of gneisses with amphibolites. Unlike acidic rocks, these are more abundant in mineral nutrients available to plants.

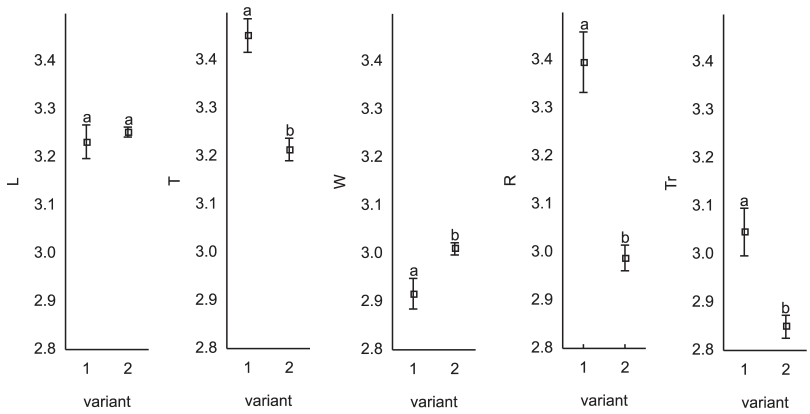


**Figure 5.** Mean indicator values + S.E. (%) in stands: (1) – with wild service tree and sword-leaved helleborine, (2) – other stands. Explanations: L – light, T – temperature, W – moisture, R – soil reaction, Tr – fertility. Differences between means followed by a common letter are not significantly different at α = 0.05.

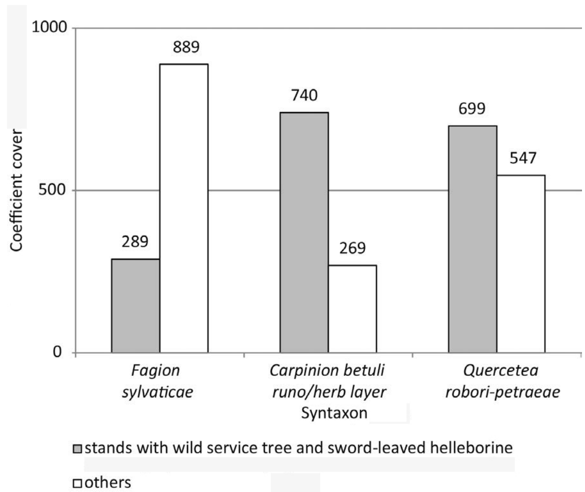


**Figure 6.** Cover coefficient of syntaxonomical units

According to Augusto et al. (2003), geographic and geological characteristics of the site may have more influence on vegetation and chemical properties of the soil than on tree species. Amongst important environmental factors affecting the oak forest vegetation in the Sudeten region, Szymura et al. (2015) list the moisture and calcium contents in the soil. This seems to be confirmed by the analysis of ecological indicators carried out in the present study. The soils in the stands with wild service tree and sword-leaved helleborine were less acidic, more fertile and less damp when compared to those of other stands examined. However, taking into account the average values of the ecological numbers according to Zarzycki et al. (2002), in both stand groups examined, the soils still remain fresh, moderately poor and with acidic reaction. This characteristic of soil conditions is suitable for the acidophilous oak subfamily and is consistent with Matuszkiewicz (1988) and Reczyńska (2015). On the one hand, both examined stand groups exhibited a similar share of species characteristic for the acidophilous oak forest class, as well as there the presence of oak-forest wood rush – a common species in submontane oak forests (Matuszkiewicz 2008, Reczyńska 2015) – was observed at III degree of constancy. On the other hand, the presence of mesotrophic *Galium sylvaticum* in the stands with wild service tree and sword-leaved helleborine corresponds to the association of thermophilic oak forest *Sorbo torminalis-Quercetum* (Reczyńska 2015).

In submontane acidophilous oak forests with the dense canopy, species composition constitutes the most important element of the stand structure that influences the presence of wild service tree and sword-leaved helleborine. With regard to these species, most favourable were single-oak species stands, typical for the thermophilic variant of the plant association. These comprised sessile oak originating from traditional management based on coppicing along with minor admixtures of other tree species. Undoubtedly, the high share of oak is the merit of a man who has for centuries promoted oak forests, because of their usefulness and cultural values. It is noteworthy that wild service tree and sword-leaved helleborine were not recorded in artificially regenerated stands with a share of Scots pine. The results of Jakubska-Busse et al. (2014) confirm the disappearance of orchids in conifer stands. The results of the present study showed that, in general, wild service tree and sword-leaved helleborine occur more often in younger single-oak species stands (50–80 years) when compared to those older than 80 years. Sword-leaved helleborine appeared in younger mixed birch stands, increasing its frequency with the increase in the share of oak in the stand. Higher frequency in younger stands may have been a result of shorter period of time since coppicing was ceased, as this type of forest management was beneficial for photophilous species occurring in oak forests of the foothills (Szymura 2010). Furthermore, in older tree stands, a comparatively higher proportion of conifers was observed. The occurrence of wild service tree in the thermophilic variant of submontane oak forest in the Sudeten region can be probably attributed to deliberate breeding in the coppice-with-standards system in the years 1890–1945 (Szymura 2012). In order to protect this species, it is not excluded to return to this traditional management practice (Szymura 2010).

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In the past decades, the increase in share of common beech in Poland's submontane oak forest of the Małopolskie variety has resulted in successive transformation of the latter into beech forest (Matuszkiewicz 2007a). Nevertheless, in the Sudeten region, the dynamics of development of stands with wild service tree and sword-leaved helleborine indicates the regeneration potential of oak–lime–hornbeam forests in submontane oak forest. This is evidenced by spontaneous regeneration of lime and hornbeam in the lower layers of single-oak species forests, despite their absence in the tree layer. On the other hand, common beech was observed only in the shrub and herbaceous layers. In the study plots with recorded sword-leaved helleborine, there was observed a rich appearance of hazelnut trees, which earlier than hornbeam and lime colonized substitute plant communities on potential sites for oak-lime -hornbeam forest (Czerepko 2004). The loss of photophilous species because of hornbeam regeneration was observed in thermophilic oak forest association *Potentillo albae-Quercetum petraeae* (Kwiatowska et al. 1997). Kwiatkowski (2003) pointed out a growing role of hornbeam in the structure of submontane oak-wild service tree forest *Sorbo torminalis-Quercetum* in the Pogórze Złotoryjskie. In the group of the examined tree stands with the protected species examined, a negative impact of the dense canopy in the upper forest layers on wild service tree coverage was observed. Especially, in more fertile habitats, wild service trees compete with other tree species in the tree layer (Szymura et al. 2015); therefore, this species requires active protection measures (Bednorz 2009).

Natural regeneration of lime and hornbeam in oak forests indicates that potential natural vegetation is subject to constant dynamic changes (Czerepko et al. 2008). In order to maintain wild service tree and sword-leaved helleborine in submontane oak forest, management of the latter should aspire to maximise the natural regeneration potential of local sessile oak ecotypes. Oak regeneration successes can contribute to controlled loosening of the stand canopy. The use of clear-cuts in oak forests can be an important tool not only for the protection of rare species but also for the overall growth of biodiversity in compact forest ecosystems (Sebek et al. 2015). Many contemporary studies also underline a positive influence of traditional coppicing on the increase in the share of photophilous species in oak stands (Szymura 2010, Kopecký et al. 2013, Vild et al. 2013, Müllerová et al. 2015). According to Vild et al. (2013), the wider use of the coppicing technology in European forests not only will increase the share of light-demanding and acidophilous species in the groundcover but can also constitute promising support for biofuels.

## 5. Conclusion

The occurrence of wild service tree and sword-leaved helleborine in 50- to 130-year-old submontane acidophilous oak forests depends on geographic variability, the number of years from the abandonment of coppicing and the structure of the stands. The most important element of the stand structure, which conditions the occurrence of protected plant species, is stand species composition. The highest frequencies of wild service tree (5%) and sword-leaved helleborine (14%) were recorded in coppice system-derived, single-oak species stands with 50–80 years old sessile oaks. Unlike wild service tree, sword-leaved helleborine also occurred in 50–80 years old mixed stands with birch, where this orchid incidence was increasing with the increase in oak share. More abundant presence of wild service tree and sword-leaved helleborine in younger oak stands is likely associated with a shorter period of time since the abandonment of coppice-with-standards management. Both protected species did not occur in Scots pine stands. In the stands with wild service tree and sword-leaved helleborine, a higher proportion of common hazelnut in the stand area was demonstrated. The degree of common hazelnut coverage was significantly related to the degree of sword-leaved helleborine coverage. In the future, the observed spontaneous succession of the species in the lower layers of the stand and the increase in share of artificially introduced common beech may threaten wild service tree and sword-leaved helleborine populations in the association of submontane acidophilous oak forests.

## Conflict of interest

The author declares no potential conflicts.

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