MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

**Rocznik Ochrona Środowiska**

Volume 21. Year 2019 ISSN 1506-218X 1175-1201

# Diversity of Vascular Flora in *Salix viminalis* L. Crops Depending on the Harvest Cycle

*Maria Janicka, Aneta Kutkowska*, Jakub Paderewski*

*Warsaw University of Life Sciences – SGGW, Poland*

**corresponding author's e-mail: anetakutkowska@onet.pl*

## 1. Introduction

The strategic objective of Polish state policy is to increase the use of renewable energy resources, with a target of 15% in gross final energy consumption 2020 (Strategy for renewable energy development 2000). One of the activities which contribute to the increase in renewable energy sources is the cultivation of energy crops, including fast-growing trees such as poplar (*Populus* sp.) and willow (*Salix* sp.). Plantations of poplar (short rotation coppices) are mainly established in southern European countries, while willow predominates in northern and central Europe (Reddersen 2001, Rowe et al. 2011, AEBIOM 2017). In Poland, the main energy crop is *Salix viminalis* L. and its numerous varieties and hybrids (Antolak et al. 2014, Stolarski 2015). In the 21st century, willow energy plantations are becoming more and more common on the agricultural land of our country, mainly in the eastern and northern regions. In 2014, they occupied a total area of 7728 ha, of which about 230 ha were in the Łódź voivodeship (Grzybek 2015, estimated by authors).

Due to the easy adaptation of *Salix viminalis* L. to various habitat conditions, willow energy plantations have been established in various sites, i.e. on arable and fallow land or permanent grassland. They are situated among arable fields, on the borders with small rivers and meadows, and they are today one of the most valuable elements of the agricultural landscape (Dudkiewicz & Bolibok 2011, Antolak et al. 2014). The useful life of willow energy crops is estimated to be about 25 years, which makes them a valuable habitat for many species of fauna (mainly birds, insects and soil fauna) and flora (Fry & Slater 2011, Chauvat et al. 2014). It should be also emphasized that the *Salix viminalis* L. plantations compensate in large part the loss of trees and shrubs in the agricultural landscape, taking over their ecological functions.

Most of the studies carried out in Poland and other European countries concern the yield of willow and its energy value (Walle et al. 2007, Szczukowski et al. 2011, Tworkowski et al. 2011, Dimitriou & Mola-Yudego 2017). There are only a few papers discussing the vegetation accompanying the willow (Baum et al. 2012, Birmele et al. 2015). In the literature, only the problem of weed control in the first years of cultivation has been widely discussed (Miziniak 2011, Larsen et al. 2014), while the assessment of floristic diversity in these agro-ecosystems and their importance has been presented only in a few papers (Feledyn-Szewczyk 2013, Birmele et al. 2015). Moreover, they focus mainly on young plantations i.e. 1-3 years old (occasionally 4-5) and harvested usually every 2-3 years (Rola et al. 2007, Wojciechowski et al. 2009). The results of Korniak (2007) and Wojciechowski et al. (2009) showed that, in these years, many groups of plants accompanying the willow are short-lived species. Less short-lived species are found in 3-year-old plantations than in those that are 1 year old (Wojciechowski et al. 2009). Many of these species belong to the *Stellarietea mediae* class (Wnuk & Ziaja 2007, Kutyna et al. 2009). However, there are no studies on the vegetation accompanying the willow in older plantations over 5 years old, or in plantations which are harvested very rarely and irregularly or even not harvested at all, mainly for economic reasons. Such plantations are now more and more common; therefore it is important to know their biodiversity, including floristic diversity.

The research hypothesis assumes that the floristic diversity depends on the age of the plantation and the cycle of willow harvesting. The aim of the study was to assess the vascular flora of plantations of *Salix viminalis* L. which were established on permanent grassland in central Poland, and its multifaceted analysis. The dynamics of changes in the flora developed in older willow crops (over 5 years) on two types of plantations (harvested every 2 years and unharvested) fell within the scope of the study.

## 2. Material and methods

The study area was located in Łódź voivodeship, central Poland. The studies were carried out on 3 *Salix viminalis* L. plantations, in 2 locations: Wojciechowice Duże in Kutno district (2 plantations) and Retki in Łowicz district (1 plantation) (Fig. 1). According to the physicogeographical classification of Poland, the area is located in the Kutno Plain macroregion and in the Central Masovian Lowlands macroregion (Kondracki 2013, www.geoportal.lodzkie.pl).


**Fig. 1.** Location of the study area in Łódź voivodeship: 1 – Wojciechowice Duże, 2 – Retki

### 2.1. Soil conditions and plantation characteristics

The study was carried out in the years 2011–2014 and in 2018, on *Salix viminalis* L. plantations which were previously perennial grasslands. In both locations the plantations were bordered by the small lowland rivers Słudwia and Ochnia, and partly by perennial grasslands. The *Salix viminalis* L. plantations were established on moderately fertile soils which are usually used for perennial grassland. The all plantations were located on soils classified into medium grassland complex (2z). These soils were periodically too dry or to wet. They were light sandy soils with high total porosity and a large water capacity. The content of humus of "muck" type was 1-2%. The soils belonged mainly to III meadow soil-valuation class. The information about the soils was based on agricultural maps on a scale of 1:5000 obtained from the Voivodeship Geodesy Office in Łódź (Solna St. 14, 91-423 Łódź, Poland), and on the Łódź Voivodeship Geoportal (www.geoportal.lodzkie.pl). The studied willow energy plantations were established in the years 2004–2006 (density – 35.000 sprouts per ha), so in the first year of the study (2011) they were 5-7 years old. The studied willow energy crops differed in the cycle of the willow harvest, i.e. one group of plantations was harvested usually every 2 years (only in two cases the plantations were harvested after 3 years), and the other was not harvested throughout the entire research period (Table 1).

**Table 1.** Characteristics of energy willow plantations

| Location | Year of establishment | Harvest cycle | Plantation area |
|---|---|---|---|
| Wojciechowice Duże | 2004 | every 2 years* | 0.45 ha |
| Wojciechowice Duże | 2005 | every 2 years* | 0.40 ha |
| Retki | 2006 | not harvested | 1.71 ha |

*in two cases the plantations were harvested after 3 years

## 2.2. Weather conditions

The weather conditions during the study period were determined based on the dates recorded at the Meteorological Station of the Institute of Soil Science and Plant Cultivation, located in Bratoszewice, near Łódź. Long-term data were recorded for Łódź. The sum of precipitation in the vegetation period was similar in the years 2011, 2012, 2014 and 2018 (400.0-421.7 mm). Mean air temperatures between April and October in 2011-2014 were similar to each other and similar to the long-term mean. In 2018 the temperature was about 2,9°C higher than the long-term mean. Detailed data regarding average monthly air temperatures and sum of monthly precipitation are shown in table 2.

## 2.3. Methods

The vegetation accompanying willow (*Salix viminalis* L.) energy crops was identified based on an analysis of 24 phytosociological relevés i.e. four relevés carried out in two types of plantations (harvested and not harvested) in each of the three study periods (2011-2012, 2014, 2018). Each of them represented an area of 100 m$^2$, roughly square-shaped, and was made using the Braun-Blanquet (1964) method. Subsequently, the number and share of each species was determined. The share of each plant species was determined based on constancy class (S) and cover coefficient (D) calculated according to Pawłowski (1972). The Latin names of vascular plants were given after Mirek et al. (2002), and the phytosociological classifications were after Matuszkiewicz (2012). For each species, the following parameters were determined: family, geographical and historical groups, apophyte origin, biological stability, life-form, and status as an invasive, endangered, near-endangered, or protected species. If the origin of an apophyte had not been established, it was listed as "other". The geographical and historical groups, apophyte origins, biological stability and life-form were identified based mainly on the following sources: Anioł- Kwiatkowska (1974), Korniak (1992), Mirek et al. (2002), Rutkowski (2008), Sowa & Warcholińska (1981), Szafer et al. (1969), Zając & Zając (1975,1992), Zając (1979). Invasive species status was determined based on Tokarska-Guzik et al. (2012). Endangered species were identified based on the "The Red Book of Plants of Łódzkie Voievodeship"

(Olaczek 2012), and near-endangered species were identified based on the "Polish Red List of Pteridophytes and Flowering Plants" (ed. Kaźmierczakowa et al. 2016). Protected plant species were identified based on the Polish Regulation of the Minister for Environment of October 9, 2014, on Plant Species Protection. Herbs were identified based mainly on Bańkowski & Serwatka (1977) and Mowszowicz (1985).

**Table 2.** Weather conditions in the growing seasons in the years 2011-2014 and 2018 (Meteorological station in Bratoszewice)

| Year / Month | Average monthly air temperature (°C) | | | | |
|---|---|---|---|---|---|
| | 2011 | 2012 | 2014 | 2018 | 1971-2000 |
| IV | 10.5 | 9.2 | 10.2 | 13.2 | 7.7 |
| V | 13.7 | 14.8 | 13.3 | 16.5 | 13.4 |
| VI | 17.9 | 16.5 | 15.7 | 18.3 | 16.1 |
| VII | 17.7 | 19.9 | 20.6 | 20.2 | 17.7 |
| VIII | 18.6 | 18.7 | 17.6 | 20.5 | 17.6 |
| IX | 15.0 | 14.3 | 14.6 | 15.3 | 13.0 |
| X | 8.9 | 8.2 | 9.9 | 9.9 | 8.2 |
| IV-X | 14.6 | 14.5 | 14.5 | 16.2 | 13.3 |
| Sums of monthly precipitation (mm) | | | | | |
| Month | 2011 | 2012 | 2014 | 2018 | 1971-2000 |
| IV | 22.3 | 54.2 | 43.3 | 34.7 | 36.0 |
| V | 46.1 | 21.4 | 106.3 | 44.2 | 51.0 |
| VI | 58.8 | 70.9 | 61.2 | 24.7 | 68.0 |
| VII | 165.2 | 117.6 | 50.4 | 146.6 | 88.0 |
| VIII | 92.4 | 41.1 | 84.9 | 83.9 | 61.0 |
| IX | 6.5 | 58.1 | 31.9 | 29.4 | 51.0 |
| X | 23.1 | 36.7 | 24.4 | 58.2 | 40.0 |
| IV-X | 414.4 | 400.0 | 402.4 | 421.7 | 395.0 |

This paper presents the characteristics of vascular flora accompanying willow (*Salix viminalis* L.) energy crops and an analysis of this flora in two types of plantations: those harvested every 2 years and those not harvested. The analysis of vascular flora was conducted in the years 2011-2012, 2014 and 2018 (i.e. 6-8, 9-10, 13-14 years after planting the willow in the plantations which were cut, and 5-6, 8, 12 years after planting the willow in the plantation which was not cut during the research period).

### 2.4. Statistical analysis

The canonical correspondence analysis (CCA) was performed to describe the species cover in the phytosociological relevés. The explanatory variable (during the CCA analysis) for the phytosociological relevés was the affiliation to one of the 6 combinations of location -by- year of the study (categorical variable, presented in the chart as the ellipses of standard deviations). Thus the CCA chart presents floristic changes (occurrence of individual plant species) in two studied locations over the years.

The principal component analysis (PCA) was performed to describe the changes in the total coverage of species groups from a given family. The first step was to calculate the total coverage of species from a given family in each phytosociological relevé separately. Next the data was centered for the given family across a collection of phytosociological relevés. Such prepared data was analyzed by the PCA. This way the corresponding graph presents changes in the occurrence of main families of species in two studied locations over the years.

The PCA was also performed to describe the changes in the total coverage of species related to the phytosociological classes. The total coverage of species of each class was centered across relevés and such prepared data was analyzed. This way the PCA biplot presents the phytosociological trend in the two locations studied over the years.

The CCA analysis calculations were made in the R software (R Core Team, 2017) using the "cca" function contained in the "vegan" package. The PCA analyses and the biplots were done according Sienkiewicz-Paderewska & Paderewski (2015) by the use of svd function. Biodiversity coefficients were calculated using the "vegan" package by the "diversity" function for H' and "Cspecnumber" for species richness index. The Shannon-Wiener diversity index was also measured for each plantation in each period of study.

## 3. Results

62 vascular plant species were found accompanying willow (*Salix viminalis* L.) energy crops L. crops which were established on permanent grasslands (Table 3). These species belonged to 22 botanical families (Table 4). The most numerous family was *Poaceae*, of which 15 species were found (24.2%). Other numerous families were: *Asteraceae, Rosaceae, Lamiaceae,* which made up about 30% of all identified species. A large number of families (16) were represented only by 1-2 species.

**Table 3.** Species occurring in cut and uncut plantations in the all periods of the study

| No | Species | Harvested plantations | | | Unharvested plantations | | |
|---|---|---|---|---|---|---|---|
| | | 2011-2012 | 2014 | 2018 | 2011-2012 | 2014 | 2018 |
| 1 | *Achillea millefolium* L.s.str. | | x | | | | |
| 2 | *Agrostis canina* L. | x | x | x | | | |
| 3 | *Agrostis capillaris* L. | x | x | | | | |
| 4 | *Agrostis gigantea* Roth | x | x | x | | | |
| 5 | *Alopecurus pratensis* L. | x | | | | | |
| 6 | *Anthriscus sylvestris* (L.) Hoffm. | | | | x | | x |
| 7 | *Arctium minus (Hill) Bernh.* | | | | x | | |
| 8 | *Arrhenatherum elatius* (L.) P.Beauv. Ex J. Presl & C. Presl | | | | x | | |
| 9 | *Artemisia vulgaris* L. | | | | x | | |
| 10 | *Bromus inermis* Leyss. | | | | x | | |
| 11 | *Carex hirta* L. | x | | x | x | | |
| 12 | *Carex ovalis* Gooden. | x | | | | | |
| 13 | *Chelidonium majus* L. | | | | x | | x |
| 14 | *Cirsium arvense* (L.) Scop. | x | x | x | x | | |
| 15 | *Convolvulus arvensis* L. | x | x | x | x | x | x |
| 16 | *Crataegus monogyna* Jacq. | x | | x | | | x |
| 17 | *Dactylis glomerata* L. | | | x | | | |
| 18 | *Deschampsia caespitosa* (L.) P. Beauv. | x | x | x | x | x | x |
| 19 | *Elymus repens* (L.) Gould | x | x | x | x | | |
| 20 | *Equisetum arvense* L. | x | | x | | | |
| 21 | *Equisetum palustre* L. | x | | | | | |

**Table 3.** cont.

| No | Species | Harvested plantations | | | Unharvested plantations | | |
|---|---|---|---|---|---|---|---|
| | | 2011-2012 | 2014 | 2018 | 2011-2012 | 2014 | 2018 |
| 22 | *Erigeron annuus* (L.) Pers. | | | | x | | |
| 23 | *Festuca rubra* L. | x | x | x | | | |
| 24 | *Filipendula ulmaria* (L.) Maxim. | x | | | x | | |
| 25 | *Galeopsis bifida* Boenn. | x | | | | | |
| 26 | *Galeopsis ladanum* L. | x | | | | | |
| 27 | *Galeopsis tetrahit* L. | x | x | x | | | |
| 28 | *Galium aparine* L. | x | x | | x | x | |
| 29 | *Galium mollugo* L. | x | x | | | | |
| 30 | *Geum urbanum* L. | x | x | x | x | | x |
| 31 | *Glechoma hederacea* L. | x | x | | x | x | x |
| 32 | *Holcus lanatus* L. | | | | x | | x |
| 33 | *Hypericum perforatum* L. | | x | | | | |
| 34 | *Iris pseudacorus* L. | | | | x | | |
| 35 | *Juncus effusus* L. | x | | | | | |
| 36 | *Lactuca serriola* L. | | x | | | | |
| 37 | *Lychnis flos-cuculi* L. | | | | x | | |
| 38 | *Lysimachia nummularia* L. | | x | | x | x | x |
| 39 | *Melandrium album (Mill.) Garcke* | | | x | x | | |
| 40 | *Phalaris arundinacea* L. | x | x | | | x | |
| 41 | *Phleum pratense* L. | x | x | x | | | |
| 42 | *Plantago lanceolata* L. | | x | | | | |
| 43 | *Plantago major* L. | | | | x | | |
| 44 | *Poa pratensis* L. | x | x | | x | x | |
| 45 | *Poa trivialis* L. | x | | | x | | |
| 46 | *Polygonum hydropiper* L. | x | x | | | | |
| 47 | *Polygonum persicaria* L. | x | | x | | | |
| 48 | *Potentilla anserina* L. | x | | | | x | |

**Table 3.** cont.

| No | Species | Harvested plantations | | | Unharvested plantations | | |
|---|---|---|---|---|---|---|---|
| | | 2011-2012 | 2014 | 2018 | 2011-2012 | 2014 | 2018 |
| 49 | *Potentilla reptans* L. | x | x | x | x | x | x |
| 50 | *Quercus robur* L. | | | x | | x | |
| 51 | *Ranunculus repens* L. | | | | x | | |
| 52 | *Rosa canina* L. | | x | x | | | |
| 53 | *Rubus caesius* L. | | | | x | x | x |
| 54 | *Rumex acetosella* L. | x | x | x | | | |
| 55 | *Sambucus nigra* L. | | | x | x | | x |
| 56 | *Stachys palustris* L. | x | | | x | | |
| 57 | *Stellaria graminea* L. | | x | | | x | |
| 58 | *Stellaria media* (L.) Vill. | | | x | x | | |
| 59 | *Taraxacum officinale* F.H. Wigg. | | | | | x | |
| 60 | *Torilis japonica* (Hoult.) DC. | | x | | | | |
| 61 | *Urtica dioica* L. | x | x | x | x | x | x |
| 62 | *Veronica chamaedrys* L. | | x | x | | | |

**Table 4.** Botanical systematics of species accompanying the *Salix viminalis* L. crops

| No | Name of family | Number of species |
|---|---|---|
| 1 | Poaceae | 15 |
| 2 | Asteraceae | 7 |
| 3 | Rosaceae | 7 |
| 4 | Lamiaceae | 5 |
| 5 | Caryophyllaceae | 4 |
| 6 | Polygonaceae | 3 |
| 7 | Cyperaceae | 2 |
| 8 | Apiaceae | 2 |
| 9 | Equisetaceae | 2 |
| 10 | Plantaginaceae | 2 |

**Table 4.** cont.

| No | Name of family | Number of species |
|---|---|---|
| 11 | Rubiaceae | 2 |
| 12 | Convolvulaceae | 1 |
| 13 | Caprifoliaceae | 1 |
| 14 | Fagaceae | 1 |
| 15 | Iridaceae | 1 |
| 16 | Papaveraceae | 1 |
| 17 | Primulaceae | 1 |
| 18 | Ranunculaceae | 1 |
| 19 | Urticaceae | 1 |
| 20 | Juncaceae | 1 |
| 21 | Hypericaceae | 1 |
| 22 | Scrophulariaceae | 1 |
| Total | 22 | 62 |

The willow energy plantations differed in the species richness and species composition of the accompanying vegetation. The plantations which were harvested every 2 years were characterized by greater species richness (48 species) compared to the plantation which was not harvested (37 species). This resulted mainly from better light conditions for the plants.

Consider the two type of plantations: harvested and unharvested together we can say that dominated meadow species (31% in harvested plantations and 24 in unharvested) and woodland-shrub species (25% in harvested plantations and 30% in unharvested). The shares of species from segetal and ruderal habitats were 27% in harvested plantations and 24% in unharvested, and from other habitats – 17%-22% subsequently in harvested and unharvested plantations.

The dynamics of the flora species in the studied willow energy crops differed depending on the cycle of willow harvest (Fig. 2). The 5-7 years old plantations differed in plant composition. The most willing species in cut plantations were: *Equisetum palustre* L., *Galeopsis bifida* Boenn., *Polygonum persicaria* L., *Carex ovalis* Gooden., *Galeopsis ladanum* L., *Equisetum arvense* L., *Juncus effuses* L., *Potentilla anserina* L., *Alopecurus pratensis* L., *Galium mollugo* L. and *Poa trivialis* L. whereas in uncut plantation *Melandrium album* (Mill.) Garcke, *Lychnis flos-cuculi* L., *Erigeron annuus* (L.) Pers., *Plantago major* L., *Iris pseudacorus* L., *Artemisia vulgaris* L., *Arctium minus* (Hill) Bernh., *Bromus inermis* Leyss., *Ranunculus repens* L. and *Arrhenatheretum elatius* (L.) P. Beauv. Ex J. Presl & C. Presl occurred more often in the same time. After 2 years the species compositions in cut plantations approached to uncut plantation and they were close to each other. The most common species for both plantations in 2014 were: *Galium aparine* L. and *Poa pratensis* L. In uncut plantation there were also the same species as before (*Quercus robur* L., *Stellaria graminea* L., *Taraxacum officinale* F.H. Wigg.). In the cut plantations there were many species occurred 2 years before (*Deschampsia caespitosa* (L.) P. Beauv., *Agrostis canina* L., *Cirsium arvense* (L.) Scop., *Rumex acetosella* L., *Phalaris arunidnacea* L., *Phleum pretense* L., *Polygonum hydropiper* L., *Festuca rubra* L., *Filipendula ulmaria* (L.) Maxim., *Agrostis capillaris* L., *Hypericum perforatum* L., *Plantago lanceolata* L., *Achillea millefolium*, *Lactuca serriola* L., *Veronica chamaedrys* L., *Torilis japonica* (Houtt.) DC., *Stachys palustris* L., *Galeopsis tetrahit* L.). After next 4 years in uncut plantation the most occurred species were: *Rubus caesius* L., *Chelidonium majus* L., *Lysimachia nummularia* L. and *Crataegus monogyna* Jacq. In the same time the species composition in cut plantation were more stable. The succession trend was similar (to the upper-left part of the Figure 2) but the plant compositions were similar to those seen four years earlier. The species especially connected with such conditions were: *Urtica dioica* L., *Dactylis glomerata* L., *Agrostis gigantea* Roth, *Anthriscus sylvestris* (L.) Hoffm., *Geum urbanum* L. (Fig. 2).

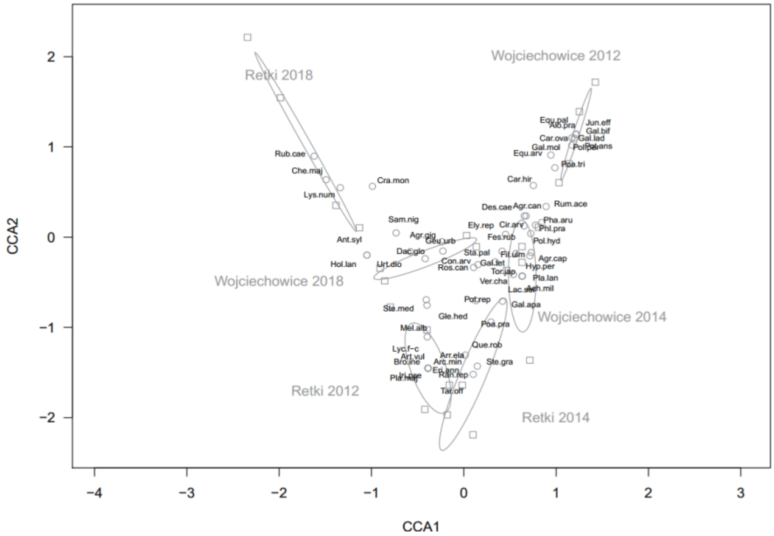


**Fig. 2.** The canonical correspondence analysis plot for species cover in phytosociological relevés belonging to six groups defined by location and study time (categorical explanatory variable). Squares – phytosociological relevés; Ellipses – ellipses of standard deviations for phytosociological relevés grouped by location and time; circles – species. Wojciechowice Duże – harvested plantations; Retki – unharvested plantation

The dynamics of the number of flora species in the studied willow energy crops differed depending on the cycle of willow harvest. The number of plant species in both types of plantations (harvested every 2 years and uncut) decreased over time (Fig. 3). But this process occurred faster in the uncut plantation. A clear reduction in the number of species in the uncut plantation was recorded in 2014 (8 years after planting the willow crop and 4 years after the last harvest). As a result, in 2018 (i.e. after 7 years of research) the number of species in the uncut plantations was more than 50% lower, while in the plantations which were harvested this number was about 1/3 less (Fig. 3).

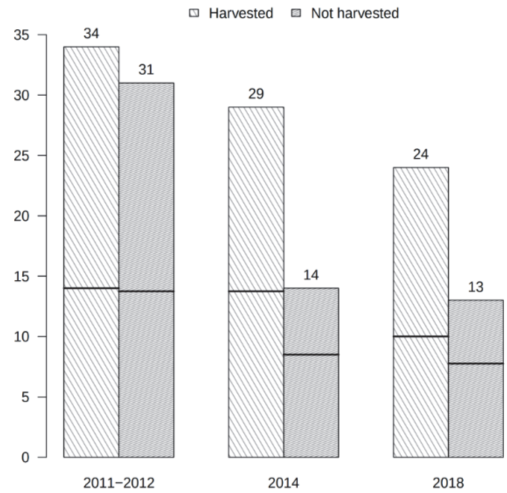


**Fig. 3.** Number of species in two types of *Salix vimin*alis L. plantations: harvested and not harvested in three periods of study; the horizontal lines mean the average number of species in one phytosociological relevé

Analysis of the proportion of different geographical and historical plant groups showed that in two types of plantations, native (apophyte) species definitely dominated (Table 5 and 6). The share of apophytes in the harvested plantations was about 97% in 2011-2012 and 2014 and 100% in 2018 year. While in the unharvested plantations the share of apophytes was 100% already in 2014. Among apophytes in harvested plantations, the most numerous groups of plants were meadow species (39.3-51.6%) and woodland/shrub species (27.3-39.3%). In the uncut plantation, a slightly larger proportion of woodland/shrub apophytes (forest origin) was found – 42.9-69% (Table 5 and 6). Among apophytes, the groups with the smallest share were photophilous sandyside species and other (3.0-4.1%) in the harvested plantations and xerothermic grassland and waterside and wetside species (6.7-8%) in the uncut plantation (Table 5).

**Table 5.** Characteristics of flora of *Salix viminalis* L. in uncut plantations in the years 2011-2012, 2014 and 2018

| Category | 2011-2012 | | 2014 | | 2018 | |
|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % |
| Total number of species | 31 | 100 | 14 | 100 | 13 | 100 |
| Geographical and historical groups | | | | | | |
| Antropophytes | 1 | 3.2 | 0 | 0.0 | 0 | 0.0 |
| Apophytes | 30 | 96.8 | 14 | 100 | 13 | 100 |
| Apophytes origin | | | | | | |
| Meadow species | 12 | 40.0 | 6 | 42.9 | 3 | 23 |
| Woodland and shrub species | 15 | 50.0 | 6 | 42.9 | 9 | 69 |
| Xerothermic grasslands | 2 | 6.7 | 1 | 7.1 | 1 | 8 |
| Waterside and wetside | 1 | 3.3 | 1 | 7.1 | 0 | 0.0 |
| Biological stability | | | | | | |
| Perennial species | 25 | 80.6 | 13 | 92.9 | 13 | 100 |
| Short-lived species | 4 | 12.9 | 1 | 7.1 | 0 | 0 |
| Short-lived species-perennial species | 2 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Life-form | | | | | | |
| Hemicryptophyte | 18 | 58.0 | 8 | 57.4 | 8 | 61.5 |
| Therophyte | 3 | 9.7 | 1 | 7.1 | 0 | 0.0 |
| Geophyte | 5 | 16.1 | 1 | 7.1 | 1 | 7.7 |
| Herbaceous chamaephyte | 2 | 6.5 | 1 | 7.1 | 1 | 7.7 |
| Nanophanerophyte | 2 | 6.5 | 1 | 7.1 | 3 | 23.1 |
| Megaphanerophyte | 0 | 0.0 | 1 | 7.1 | 0 | 0.0 |
| Hydrophyte,Helophyte | 1 | 3.2 | 1 | 7.1 | 0 | 0.0 |
| Phytosociological classes | | | | | | |
| *Agropyretea intermedio-repentis* | 2 | 6.5 | 1 | 7.1 | 1 | 7.7 |
| *Artemisietea vulgaris* | 11 | 35.6 | 4 | 28.6 | 6 | 46.1 |
| *Epilobietea angustifolii* | 1 | 3.2 | 0 | 0.0 | 1 | 7.7 |
| *Festuco-Brometea* | 1 | 3.2 | 0 | 0.0 | 0 | 0.0 |
| *Molinio-Arrhenatheretea* | 13 | 41.9 | 6 | 42.9 | 4 | 30.8 |
| *Phragmitetea* | 1 | 3.2 | 1 | 7.1 | 0 | 0.0 |
| *Rhamno-Prunetea* | 0 | 0.0 | 0 | 0.0 | 1 | 7.7 |
| *Stellarietea mediae* | 1 | 3.2 | 0 | 0.0 | 0 | 0.0 |
| Sporadic species | 1 | 3.2 | 2 | 14.3 | 0 | 0.0 |

**Table 6.** Characteristics of flora of *Salix viminalis* L. in cut plantations in the years 2011-2012, 2014 and 2018

| Category | 2011-2012 | | 2014 | | 2018 | |
|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % |
| Total number of species | 34 | 100 | 29 | 100 | 24 | 100 |
| Geographical and historical groups | | | | | | |
| Antropophytes | 1 | 3.0 | 1 | 3.4 | 0 | 0.0 |
| Apophytes | 33 | 97.0 | 28 | 96.6 | 24 | 100 |
| Meadow species | 17 | 51.6 | 11 | 39.3 | 10 | 41.9 |
| Woodland and shrub species | 9 | 27.3 | 11 | 39.3 | 9 | 37.5 |
| Xerothermic grasslands | 1 | 3.0 | 1 | 3.6 | 1 | 4.1 |
| Sandyside | 1 | 3.0 | 1 | 3.6 | 1 | 4.1 |
| Waterside and wetside | 4 | 12.1 | 3 | 10.6 | 2 | 8.3 |
| Other | 1 | 3.0 | 1 | 3.6 | 1 | 4.1 |
| Biological stability | | | | | | |
| Perennial species | 28 | 82.4 | 24 | 82.8 | 20 | 83.3 |
| Short-lived species | 6 | 17.6 | 5 | 17.2 | 4 | 16.7 |
| Life-form | | | | | | |
| Hemicryptophyte | 18 | 53.0 | 17 | 58.7 | 10 | 41.7 |
| Therophyte | 6 | 17.7 | 4 | 13.8 | 4 | 16.7 |
| Geophyte | 8 | 23.5 | 4 | 13.8 | 5 | 20.9 |
| Herbaceous chamaephyte | 0 | 0.0 | 2 | 6.9 | 1 | 4.1 |
| Nanophanerophyte | 1 | 2.9 | 1 | 3.4 | 3 | 12.5 |
| Megaphanerophyte | 0 | 0.0 | 0 | 0.0 | 1 | 4.1 |
| Hydrophyte,Helophyte | 1 | 2.9 | 1 | 3,4 | 0.0 | 0.0 |
| Phytosociological classes | | | | | | |
| *Agropyretea intermedio-repentis* | 3 | 8.9 | 2 | 6.9 | 3 | 12.5 |
| *Artemisietea vulgaris* | 5 | 14.7 | 6 | 20.7 | 4 | 16.7 |
| *Bidentetea tripartiti* | 1 | 2.9 | 1 | 3.4 | 0 | 0.0 |
| *Epilobietea angustifolii* | 0 | 0.0 | 0 | 0.0 | 1 | 4.1 |
| *Molinio-Arrhenatheretea* | 15 | 44.2 | 10 | 34.5 | 7 | 29.3 |
| *Phragmitetea* | 1 | 2.9 | 1 | 3.4 | 0 | 0.0 |
| *Rhamno-Prunetea* | 1 | 2.9 | 0 | 0.0 | 1 | 4.1 |
| *Scheuchzerio-Caricetea nigrae* | 1 | 2.9 | 1 | 3.4 | 1 | 4.1 |
| *Stellarietea mediae* | 2 | 5.9 | 3 | 10.3 | 3 | 12.5 |
| *Thlaspietea rotundifolii* | 1 | 2.9 | 0 | 0.0 | 0 | 0.0 |
| *Trifolio-Geranietea* | 1 | 2.9 | 1 | 3.4 | 0 | 0.0 |
| Sporadic species | 3 | 8.9 | 4 | 13.8 | 4 | 16.7 |

Changes in the geographical and historical groups over the seven years of the study indicate a slight increase in the share of apophytes and the decrease of anthropophytes (Table 5 and 6). These changes were found earlier in the vegetation of the uncut plantation than in the harvested plantation. The long period of willow cultivation and the lack of systematic harvesting created appropriate light conditions for development of woodland/shrub apophytes, rather than meadow apophytes, which increased their share by 10 pts.% in both types of plantations (Table 5 and 6).

An analysis of changes in vegetation accompanying the willow crops throughout the 7 years of the study showed an increase in the share of perennial species and a decrease in the share of short-lived species only in the unharvested plantation (Table 5 and 6). In this plantation, the presence of short-lived species was not found at all in the third research period, i.e. 12 years after planting the willow crops and 8 years after its last harvest. However, on the harvested (every 2 years) plantations, the share of perennial and short-lived species throughout the study period remained almost the same.

In both types of plantations, most species were hemicryptophytes (the life form of Raunkiaer): 58.0-61.5% in the uncut plantation and 41.7-58.7% in the harvested plantations (Table 5 and 6). The proportions of therophytes and geophytes were higher in the cut plantations than in uncut plantation (Table 5 and 6). An increase in the number of nanophanerophytes was found in the third period of the study in both types of plantations, as well as a decrease in the number of hemicryptophytes in harvested plantations. Over the years the disappearance of the therophytes and geophytes in the uncut plantation were noted and in 2018, therophytes were not observed. There were only very small changes in the share of species with other life-forms.

The vast majority (in each type of plantations about 70%) of species achieved low degrees of phytosociological constancy, i.e. I and II classes. The higher constancy classes (III, IV, V) were reached about 30% of species which are given in Table 7. The species which achieved higher classes of phytosociological constancy (III, IV, V) were mainly native, perennial, meadow and woodland/shrub species e.g. *Deschampsia caespitosa* (L.) P. Beauv. (S = V) and *Geum urbanum* L. (S = III), and segetal-ruderal species (30%) e.g. *Convolvulus arvensis* L. (S = III).

Over several years of willow cultivation, the species composition and cover with the accompanying vegetation changed. The lack of systematic harvest of the willow plants contributed to considerable development of the trees. An abundance of some species systematically increased for example ruderal plants as *Urtica dioica* L., in cut plantations. Its cover coefficients were 130 in 2011-2012, 1002 in 2014 and 3062 in 2018 year. In the harvested plantations, the abundance of woody and shrub species remained at a similar level throughout the whole research period for example: *Crataegus monogyna* Jacq. abundance was: in 2011-2012 (+) and in 2018 (1), *Rosa canina* L. in 2014 (+) and in 2018 (+).

Among the species accompanying willow energy crops, a large percentage is represented by herbs. In harvested plantations their share ranged from about 50% in 2011-2012 to about 66% in subsequent years (2014 and 2018, Table 3). In unharvested plantation the share of herbs in each period of the study was slightly higher than in harvested plantations and ranged from 54% to 69%. However the melliferous species long flowering, with colorful and fragrant flowers in willow crops were recorded sporadically, only in harvested plantations and only in the first and second study periods (5% in 2011-2012 and 3% in 2014, Table 3).

**Table 7.** Species with the highest constancy (III-V) in harvested and unharvested plantations in all period of the time

| No | Species | Constancy classes | Cover coefficient | Constancy classes | Cover coefficient |
|---|---|---|---|---|---|
| | | harvested | | unharvested | |
| 1 | *Deschampsia caespitosa* | V | 2396 | V | 502 |
| 2 | *Urtica dioica* | V | 1398 | V | 1250 |
| 3 | *Cirsium arvense* | IV | 377 | - | - |
| 4 | *Rumex acetosella* | IV | 334 | - | - |
| 5 | *Convolvulus arvensis* | III | 126 | V | 48 |
| 6 | *Geum urbanum* | III | 459 | III | 208 |
| 7 | *Galium aparine* | III | 313 | III | 250 |
| 8 | *Festuca rubra* | III | 250 | - | - |
| 9 | *Agrostis canina* | III | 208 | - | - |
| 10 | *Glechoma hederacea* | III | 167 | V | 791 |
| 11 | *Potentilla reptans* | III | 167 | IV | 250 |
| 12 | *Phleum pratense* | III | 126 | - | - |
| 13 | *Rubus caesius* | - | - | III | 1104 |
| 14 | *Poa pratensis* | II | 459 | III | 520 |
| 15 | *Lysimachia nummularia* | I | 41 | III | 604 |

Among the few anthropophytes in the willow plantations, only two invasive non-native species (neophytes) were recorded: *Erigeron annuus* (L.) Pers. and *Quercus robur L.* They occurred sporadically (in 3 relevés) and in the lowest abundance (+, 1) (Table 3). However, in the studied willow plantations, no endangered and near-endangered species, for either Poland or the Łódź region, were found.

The PCA biplot, based on total abundance of species belonging to each family, concerned on the changes in the occurrence of *Poaceae, Rosaceae and Urticaceae* families (Fig. 4). Generally, the *Poaceae* family more often occurred in 2012 and gave the place for the *Rosaceae* family (especially in uncut plantation) or *Urticaceae* family (especially in cut plantations, Fig. 4) in 2018.

It was found that the average cover coefficient of vegetation accompanying the *Salix viminalis* L. crops was higher in harvested (80%) than in unharvested plantations (68%). The average cover coefficient of the crop plant (*Salix viminalis* L.) was completely different: higher in unharvested (77%) than in harvested plantations (66%).

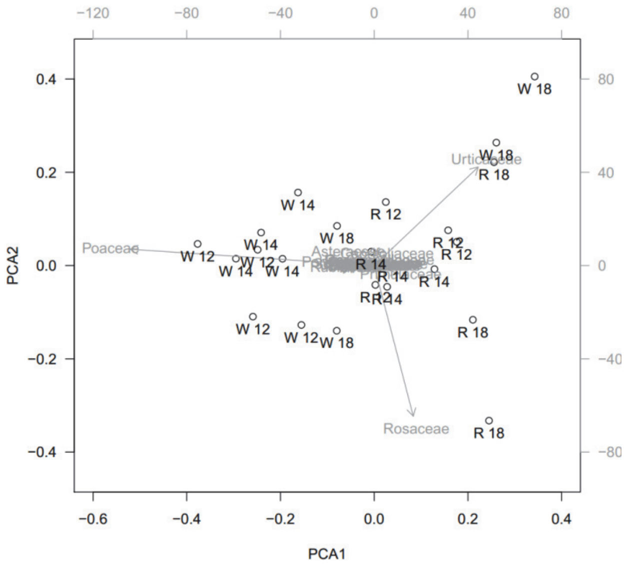


**Fig. 4.** The principal component (PC) analysis biplot for the total coverage of species belonging to botanical families. The PCA1 has retained 54% of the variability and PCA2 24%; W – harvested plantations, R – unharvested plantation; 12 – phytosociological releves made in the 2011 or 2012 years; 14 – phytosociological releves made in the 2014 year; 18 – phytosociological releves coming from 2018 year

The number of phytosociological classes and the number of species belonging to individual classes were more varied in cut plantations. Generally, the class *Molinio-Arrhenatheretea* with more total cover in 2012 was swapped in 2018 into *Artemisieta vulgaris* class (Fig. 5). The vegetation in harvested plantations represented more phytosociological classes than in the uncut plantations. The largest share of vegetation in harvested plantations was made up of species from the following classes: *Molinio-Arrhenatheretea, Artemisieta vulgaris*, *Agropyretea intermedio-repentis* and *Stellarietea mediae* (in total over 70%). But in unharvested plantations, most species belonged to the *Molinio-Arrhenatheretea* and *Artemisieta vulgaris* classes (in total over 70%) (Table 5 and 6).

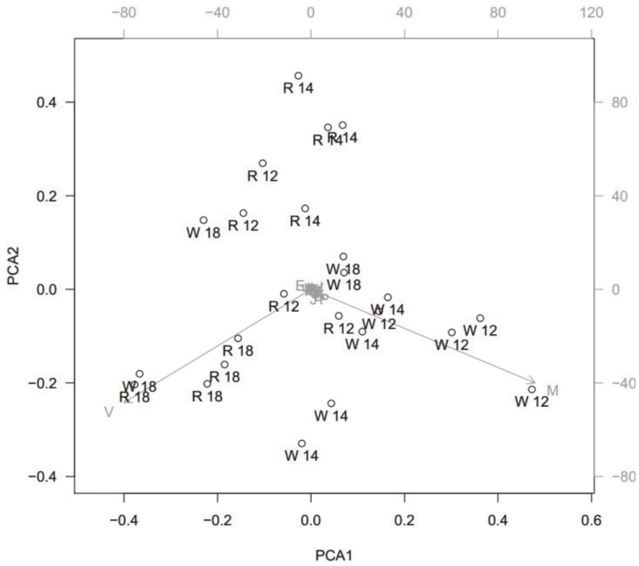


**Fig. 5.** The principal component (PC) analysis biplot for the total coverage of species groups associated with phytosociological classes. The PCA1 has retained 75% of the variability and PCA2 19%; W- harvested plantations, R – unharvested plantation; 12 – phytosociological relevés made in the 2011 or 2012 years; 14 – phytosociological relevés made in the 2014 year; 18 – phytosociological relevés coming from 2018 year; V – class *Artemisietea* vulgaris; M – class *Molinio-Arrhenatheretea*

The analysis of changes in the share of phytosociological classes showed that in cut plantations, the share of species belonging to the *Molinio-Arrhenatheretea* class decreased (from 44.2% in 2011-2012 to 29.3% in 2018) and species belonging to the *Stellarietea mediae* class (characteristic for arable land) increased (from 5.9% in 2011-2012 to 12.5% in 2018). This was related to the availability of light after subsequent willow harvests. Whereas in the uncut plantation the share of ruderal species from the *Artemisieta vulgaris* class increased slowly (from 35.6% in 2011-2012 to 46.1% in 2018), the share of meadow species of the *Molinio-Arrhenatheretea* class decreased from 41.9% to 30.8% in the last year (Table 5 and 6).

A biodiversity analysis in the plant communities accompanying willow crops, using the Shannon-Wiener diversity index (H), showed differentiation depending on the age of *Salix viminalis* L. (Table 8). The floristic diversity decreased in uncut plantation with the age of willow – H from 2.5 to 1.6. In cut plantations floristic diversity was a bit higher; H in the first period of study was 2.2, in the second – 2.5 and in the year 2018 was 1.8.

**Table 8.** Values of Shannon-Wiener index (H') for each period of study in harvested and unharvested *Salix viminalis* L. plantations

| Plantation | 2011-2012 | 2014 | 2018 |
|---|---|---|---|
| harvested | 2.2 | 2.5 | 1.8 |
| not harvested | 2.5 | 2.2 | 1.6 |

## 4. Discussion

The species of flora occurring among older willow (*Salix viminalis* L.) energy crops (aged 5-7 years to 12-14 years) established on permanent grassland belong mainly to meadow-pasture communities. This indicates that the vegetation accompanying the willow energy crops, despite the passage of time, had not completely lost all features of the previous habitat communities. A decline in the number of species observed over a seven–year period indicates that the vegetation accompanying older willow energy crops is relatively poor in terms of species richness. A similar change in floristic diversity in younger plantations was observed by Korniak et al. (2009) and Wojciechowski et al. (2009). These authors reported 13.3% and 21.2% fewer species respectively in 3-year-old plantations compared to those which were 1-2 years old.

The results of our study show that, regardless of the age of willow plantation, native species (apophytes) predominate in the flora accompanying the willow crop. A high proportion of this group of plants (82-89%) was found in 2-4-year-old willow plantations by, among others, Jezierska-Domaradzka & Domaradzki (2009) and Korniak et al. (2009). The low proportion of species of foreign origin (anthropophytes), which was about 3% in our studies, is probably the result of the technology of willow cultivation. This technology is not conducive to the development of anthropophytes, which was previously noticed by Anioł-Kwiatkowska et al. (2009). The high share of meadow and woodland apophytes in the flora of the studied *Salix viminalis* L. plantations is the result of the lack of willow harvesting and the age of the plantations in question. As is well known, a lack of harvesting enables slow secondary succession towards a forest ecosystem. In the last year of the study (2018), the share of woodland and shrub apophytes was more than 30 pts.% higher in the uncut plantation than in the harvested ones. In both types of plantations dominated perennial species over short-lived species (82.4-83.3% in harvested plantations and 80.6-100% in unharvested plantations). This was related to the age of the *Salix viminalis* L. crops, which were 5-7 years in the first year of the study.

Analysis of the dynamics of changes in the participation of groups (according to geographical-historical classification of species) showed that the share of apophytes increases and the share of anthropophytes decreases with the age of willow plantations. A systematic increase in the share of perennial and woodland species was also noted. The increase in perennial species correlated with the age of willow recorded in our studies was also noted by Kościk & Ziemińska-Smyk (2009). Similar values for the proportion of perennial species was also observed by Jezierska-Domaradzka & Domaradzki (2009) and Korniak et al. (2009) in younger willow energy crops (2-4 years old), as well as by Sekutowski et al. (2014) in canary grass (*Phalaris arundinacea*) crops (1-4 years old). Studies presented in the literature usually concern the initial period of cultivation of *Salix viminalis* L., i.e. years 1-3, in which vegetation shows greater changes than in older plantations (9-10 years old). However, there are no studies on the dynamics of flora changes in older *Salix viminalis* L. crops (from 5-7 years to 12-14 years old) in either domestic or foreign literature. It should also be emphasized that in the available literature no reference was found to the dynamics of flora changes in unharvested plantations. The discussion of our results is also made more difficult by the fact that many authors do not mention the age of the studied willow energy crops, which is essential for vegetation dynamics analysis.

The long willow cultivation period creates favorable conditions for the development of hemicryptophytes, plants whose buds are protected against frost by the layer of leaves and soil. A high proportion (38-60%) of this group of plants in younger willow energy plantations (1-3 years old) was recorded by Wojciechowski et al. (2009).

Analysis of the flora of willow energy crops showed that most species achieved low constancy classes. It was proved that despite the age of the willow (12-14 years), the proportions of the constancy classes are similar to that of the 3-year-old plantations, in which Korniak et al. (2009) found that 89% of species had either I or II phytosociological constancy classes. The small share of species with higher phytosociological constancy classes indicates the transience and instability of plant communities found in willow plantations.

The average cover coefficient of vegetation accompanying energy willow crops was higher in harvested plantations. This was related to the amount of light available to the plants. It is difficult to compare these results with other studies due to the lack of research on harvested and unharvested plantations.

Analysis of the studied flora in terms of belonging to phytosociological classes showed that the willow communities of older (12-14 years old) plantations consist mainly of two classes: *Molinio-Arrhenatheretea* and *Artemisieta vulgaris.* The earlier statement of Jezierska-Domaradzka & Domaradzki (2009) with regard to 2-4- and 5-7-year-old plantations indicated also a considerable share of species from *Stellarietea mediae* class. In our studies, species from this class were present only in cut older (12-14 years old) plantations. While in unharvested plantations species from *Stellarietea mediae* class had a small share (3.2%) only in 5-7-year-old plantations.

Among the species accompanying willow energy crops, a large percentage is represented by herbs. These plants are important for human and animal health (Bańkowski & Serwatka 1977). However the melliferous species long flowering, with colorful and fragrant flowers in willow crops were recorded sporadically. Among the few anthropophytes in the willow plantations, only two invasive non-native species (neophytes) were recorded: *Erigeron annuus* (L.) Pers. and *Quercus robur* L. They occurred sporadically. In the studied willow plantations, no endangered and near-endangered species, for either Poland or the Łódź region, were found. An analysis of published national papers showed that the problem of invasive, endangered and near-endangered species in *Salix viminalis* L. crops has not been discussed. In foreign literature, authors have proved the presence of several invasive species occurring amongst energy crops, recognizing their presence as harmful (Fehér et al. 2013, Pučka et al. 2016). The presented results of our own research may be a contribution to this issue in the study of energy crop flora in the future.

Results of our study confirmed the research hypothesis. The floristic diversity depended on the age of the plantation and the cycle of willow harvesting. The highest value of the Shannon-Wiener diversity index in uncut plantations was in the first year of the study. In cut plantations the highest value of this diversity index was in the 2014 year which was probably the result of the willow harvesting. Diversity index reported by Marks et al. (2014) in 4 years old willow plantations had a similar values (1,96 -2,10). Feledyn-Szewczyk (2013) studying various energy crops (miscanthus, reed canary grass, big bluestem, switchgrass, false acacia, prairie cordgrass, virginia mallow, Jerusalem artichoke, poplar, willow), presented overall values H 1.8–2.7 (including 4-5 years old willow, harvested every year or every 3 years). Whereas Wróbel et al. (2011) reported that the flora accompanying 4-5 years old energy willow crop characterized by relatively high floristic diversity (H 2.72-3.5). But this plantation was established on wet grassland, on pure silts, over-dried and fertilized with sewage-sludge.

To summarize, it should be stated that the presented analysis of vegetation accompanying willow in harvested plantations (every 2 years) to a large extent coincides with changes in younger plantations (mainly 4 years old) reported by other authors, in different regions of Poland, and reflects general trends in the transformation of flora in willow plantations.

## 5. Conclusion

1. The species composition of the *Salix viminalis* L. plantations, established on perennial grassland, is related to the previous use of the land (i.e. meadow communities).

2. Analysis of changes in flora in both types of plantations (i.e. harvested and unharvested) showed a downward trend in the number of species and anthropophytes. This was more evident in the unharvested plantations.
3. In older plantations of the *Salix viminalis* L., native and perennial species are dominant. Changes in the floristic composition of *Salix viminalis* L. plantations over the seven years studied (2011-2018) were mainly due to the age of the willow plantations and the degree of soil shading by the willow plants. These changes in the unharvested plantations led to the formation of forest communities.

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## Abstract

The aim of the study was to assess the vascular flora of plantations of *Salix viminalis* L. which were established on permanent grassland in central Poland, and its multifaceted analysis. The dynamics of changes in the flora developed in older willow crops (over 5 years) on two types of plantations (harvested every 2 years, and unharvested) fell within the scope of the study.

The study was carried out in the years 2011-2014 and in 2018, on three *Salix viminalis* L. plantations in two locations of the Łódź region. The plantations were established in the years 2004-2006, so in the first year of the study they were 5-7 years old. Plantations differed in the cycle of the willow harvest, one group was harvested every 2 years, and the other was not harvested throughout the entire research period. The vegetation accompanying willow energy crops was identified based on an analysis of 24 phytosociological relevés which were made using Braun-Blanquet method. For each species, the following parameters were determined: family, geographical and historical groups, apophyte origin, biological stability, life-form, and status as an invasive, endangered, near-endangered, or protected species. The CCA and PCA analysis were done and Shannon-Wiener diversity index was calculated.

The species composition of the *Salix viminalis* L. plantations was related to the previous use of the land i.e. to meadow communities. In total, 62 vascular plant species were found in willow energy crops, which belonged to 22 botanical families. The most numerous families were: *Poaceae*, *Asteraceae, Rosaceae* and *Lamiaceae*. In harvested plantations were found more species than in not harvested. The number of plant species in both types of plantations decreased over time but faster in the uncut plantation. In two types of plantations, native (apophyte) species, perennial species and hemicryptophytes dominated. The long period of willow cultivation and the lack of systematic harvesting created appropriate light conditions for development of woodland/shrub apophytes, rather than meadow apophytes, which increased their share in both types of plantations. The vast majority (about 70%) of species achieved only I or II degrees of phytosociological constancy.

The analysis of changes in the share of phytosociological classes showed that in cut plantations, the share of species belonging to the *Molinio-Arrhenatheretea* class decreased and the share of species belonging to the *Stellarietea mediae* class increased. While in the uncut plantation the share of ruderal species from the *Artemisieta vulgaris* class increased slowly and the share of meadow species of the *Molinio-Arrhenatheretea* class decreased. Shannon-Wiener diversity index in uncut plantation decreased with the age of *Salix viminalis* L. from 2.5 to 1.6. In cut plantations floristic diversity was a bit higher.

**Keywords:**
*Salix viminalis* L. crops, vascular flora, dynamic of flora, age of plantation, biodiversity

## Różnorodność flory upraw *Salix viminalis* L. w zależności od cyklu zbioru wierzby

### Streszczenie

Celem pracy było określenie składu gatunkowego roślin naczyniowych na plantacjach *Salix viminalis* L. założonych na trwałych użytkach zielonych w środkowej Polsce oraz szeroka jego analiza. Ponadto celem badań było poznanie dynamiki zmian flory starszych upraw wierzby (ponad 5 letnich) na dwóch rodzajach plantacji: ciętych co 2 lata i nieciętych.

Badania przeprowadzono w latach 2011-2014 i 2018 na trzech plantacjach *Salix viminalis* L. w dwóch miejscowościach województwa łódzkiego. Plantacje założone były w latach 2004-2006, a więc w pierwszym roku badań były to plantacje 5-7 letnie. Plantacje różniły się cyklem zbioru wierzby, tj. jedna grupa cięta była co 2 lata, a druga przez cały okres badań nie była cięta. Roślinność towarzyszącą uprawom wierzby energetycznej oceniono na podstawie analizy 24 zdjęć fitosocjologicznych wykonanych według metody Brauna-Blanqueta. Florę naczyniową scharakteryzowano pod względem: przynależności do rodziny botanicznej i grupy geograficzno-historycznej. W odniesieniu do apofitów podano ich pochodzenie, trwałość biologiczną oraz formę życiową. Ponadto określono status rośliny inwazyjnej, zagrożonej, bliskiej zagrożeniu i chronionej. Obliczono wskaźnik różnorodności biologicznej Shannona-Wienera oraz wykonano analizę PCA i CCA.

Skład gatunkowy flory upraw *Salix viminalis* L. nawiązywał do wcześniejszego sposobu użytkowania terenu tj. do zbiorowisk łąkowych. Flora naczyniowa plantacji wierzby energetycznej liczyła 62 gatunki, które należały do 22 rodzin botanicznych. Najliczniej reprezentowanymi rodzinami były: *Poaceae, Asteraceae, Rosaceae* i *Lamiaceae.* Plantacje cięte co 2 lata charakteryzowały się większym bogactwem gatunkowym w porównaniu do plantacji nie ciętej. Liczba gatunków na obu typach plantacji zmniejszała się wraz z wiekiem plantacji, lecz proces ten szybciej postępował w uprawie nie ciętej. Na obu typach plantacji dominowały apofity, gatunki wieloletnie oraz hemikryptofity.

Długoletni okres uprawy wierzby oraz brak systematycznego jej cięcia stwarzał warunki do rozwoju apofitów leśno-zaroślowych, które zwiększyły swój udział kosztem apofitów łąkowych na obu typach plantacji. Zdecydowana większość (ok. 70%) gatunków osiągnęła niskie stopnie stałości fitosocjologicznej tj. I i II.

Analiza przemian udziału klas botanicznych wykazała, że na plantacjach regularnie ciętych zmniejszył się udział gatunków klasy *Molinio-Arrhenatheretea* a zwiększył udział gatunków klasy *Stellarietea mediae.* Na plantacji nie ciętej następowało natomiast powolne zwiększanie się udziału gatunków ruderalnych klasy *Artemisietea vulgaris* a zmniejszanie udziału gatunków łąkowych z klasy *Molinio-Arrhenatheretea.* Wartości wskaźnika Shannona-Wienera zmniejszyły się wraz z wiekiem uprawy; na plantacji nie ciętej z 2.5 do 1.6. Na plantacji ciętej wskaźniki różnorodności były nieco wyższe.

**Słowa kluczowe:**
*Salix viminalis* L., flora naczyniowa, dynamika flory, wiek plantacji, bioróżnorodność