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POPULATION STRUCTURE AND REGENERATION OF *PHRAGMITES AUSTRALIS* (CAV.) TRIN. EX STEUD. IN FLOOD CONTROL DITCHES IN THE DEPRESSION WETLAND (ŻUŁAWY WIŚLANE, NORTHERN POLAND)

ABSTRACT: The population structure of *Phragmites australis* (Cav.) Trin. ex Steud. was examined in seven categories of overgrowing flood control ditches, differing on time which had elapsed from the last clean-up. Density, biomass, frequency of development stages, as well as the size and habit of the shoots, were determined in the populations. Site conditions in the ditches and the proportion of the common reed in the total biomass of plants were also examined. The rate at which populations in cleaned ditches regenerate is very quick. Three years after the maintenance works in ditches the reed population is already fully regenerated. Well developed reed rushes, which biomass is about 650 g d.w.m^{-2}, are dominant. Its density amounts to 76 ± 25 shoots m^{-2}. Flowering and fruiting shoots are the most numerous. The first signs of population regression were observed in the ditches left without cleaning for more than 5 years. Population density is gradually lower, the proportion of generative shoots is reduced, and the reed is lighter and has smaller assimilation area. In the 11-year-old and older ditches the reed is replaced by other plant species, mainly grasses and shrubs.

KEY WORDS: *Phragmites australis* (Cav.) Trin. ex Steud., common reed, population structure, flood control ditches, the Vistula Delta

1. INTRODUCTION

The Vistula Delta (Żuławy Wiślane) in northern Poland is a wetland and agricultural area which is densely populated, and, due to its peculiar hydrological conditions, cut by numerous ditches and drainage canals (Cyberski and Mikulski 1976). The drainage network operates by gravity and poldering. The former system consists of streams flowing from the areas slightly elevated above sea level. In the circuit of the latter, pumps are required to raise the water into the drainage network. Safety of the people inhabiting this region depends to a great extent on the efficiency and openness of both systems, which serve a flood control function.

Regular channel deepening and dike mowing are the necessary conditions for the proper functioning of drainage ditches. In depression region of the Vistula Delta it is unsystematic. That is why ditches overgrow with rushes which limit the water flow. As a consequence, groundwater level rises constantly, which leads to an increase in flood risk. Irrespective of the above-mentioned risk, the region is highly exposed to a flood hazard during the storm surge of Vistula Lagoon waters (the lagoon on the Baltic sea that is cut off from Gdansk Bay by the Vistula Spit). The consequences of the choking of the draining system may be disastrous.

As a result of the mass emergence of vegetation in drainage ditches, more and more organic matter accumulates in them, they become shallower and water flow is slowed down (Murphy and Eaton 1983, Pitlio and Dawson 1990). Overgrowth rate depends to a large extent on the type of vegetation and its structure, i.e. plant species, density of its population, method of reproduction, growth and development rate as well as the rate at which organic matter decomposes. As far as drainage systems around the world are concerned, some invasive species, such as *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. (Pieterse and Murphy 1990), are responsible for the deposition of organic matter. Among the European vegetation, *Ceratophyllum demersum* L., *Elodea canadensis* Michx. and *Myriophyllum spicatum* L. contribute to this process (Madsen 1994, Williamson 1996, Khedr and El-Demerdash 1997, Ennabili *et al.* 1998). Moreover, emergent macrophytes, above all *Phragmites australis*, play a crucial role in the overgrowth of minor ditches and canals (Haslam 1972, Holm *et al.* 1977, Polunin 1982, Ostendorp 1993). This species plays an important role in the accumulation of organic matter in aquatic ecosystems and wetlands, as it is characterised by very high productivity (Westlake 1963, Ho 1979) and slow decomposition of dead organic matter (Gessner 2000, Rooth and Stevenson 2000, Asaeda *et al.* 2002). The common reed is tolerant of many environmental factors, especially substratum fertility and its moisture content (Haslam 1972, Gries *et al.* 1990). These properties make it a strong competitor for free space in comparison with many other plant species (Marks and Randall 1994).

In North America the reed is an invasive species (Tucker 1990, Marks and Randall 1994, Cronk and Fuller 1995, Chambers *et al.* 1999, Weis and Weis 2003). Over the recent two hundred years it has become common in tidal wetlands as well as ditches and irrigation canals. On the other hand, however, in Europe, especially in the central, northern and eastern parts, die-back of the reed in the previously occupied habitats, both natural and anthropogenic, has been observed for many years (Den Hartog *et al.* 1989, van der Putten 1997, Brix 1999). Regression of the reed population from the area of Denmark, the Netherlands, Hungary, the Czech Republic and Scandinavia has been reported (van der Putten 1997). In northern Poland such surveys have not been carried out. Considering the abundance of reed rushes in this region, one can presume that reed populations do not undergo the process of regression there. In this study the following questions were posed:

- does the common reed play a crucial role in the overgrowth of flood control ditches?
- is it an expansive species whose growth should be controlled, or, on the contrary, does it die back and, consequently, will its future impact on the flow of water in the flood control system be negligible?

The aim of this study was to:

1) evaluate the role of the common reed in the overgrowth of flood control ditches in the wetland region (Vistula Delta in Northern Poland)

2) determine the regeneration rate of the common reed population and the proportion of this species in the plant biomass growing in channels and on dikes,

3) compare structural characteristics of the common reed population in ditches differing in terms of the time period from the last clean-up, i.e. channel deepening and dike mowing.

2. METHODS

The study was done in July and August 2001 in seven categories of flood control ditches in the north-eastern part of the Vistula Delta, that is depression wetland area. The ditches were assigned to different categories according to the time which had elapsed from the last clean-up. The following categories of ditches were distinguished: those that had not been cleaned for a year (I), three years (II), four years (III), five years (IV), 6–10 years (V), 11–15 years (VI) and over 20 years (VII). There was one ditch in each category.

The width and depth of ditches were measured. Three water and sediment samples were taken once (in August) from each ditch using tube sampler. Electrolytic conductivity, pH, chloride concentration, total phosphorus concentration (TP; by means of the spectrophotometric molybdate method with ascorbic acid as a reducing agent) and organic and ammonium nitrogen concentration (measured spectrophotometrically following mineralisation and nesslerisation) were determined in all the samples. Chemical analyses were carried out on the basis of the methods given in Clesceri *et al.* (1989) and Hermanowicz *et al.* (1999).

In order to determine the proportion of the common reed in the total biomass of plants growing in ditch channels and on dikes, ten 0.25 m^2 plots were marked out in each ditch. All overground shoots were cut down in each plot and species presence was determined. Then the shoots were dried to solid mass and weighed.

Density, frequency of development stages, as well as the size and habit of the shoots were determined in the reed populations. Population density was examined in 1 m^2 plots (6 plots in each ditch) during the peak growing season (July), following the method of counting living shoots and cutting them down to ground level. The size and habit of the reed were determined for each ditch on the basis of 50 shoots growing on the dike and 50 shoots from the channel. The following features of the shoots were taken into consideration: biomass, height, number of leaves and their weight. The number of development stages was assessed towards the end of the growing season on the basis of 100 shoots collected from the channel and 100 shoots from the dike of each ditch. The following development stages were distinguished: juvenile, mature, generative (i.e. flowering and fruiting), subsenile (yellowing and drying up of leaves as the first symptoms) and senile (desiccated).

The analysis of variance (ANOVA) was used in order to test the significance of the differences between the populations. If the zero hypothesis (there are no differences) was rejected, the Tukey test was applied (Łomnicki 1999, Stanisz 2001).

3. RESULTS

3.1. Site conditions

Ditches I–VI are located in arable fields, whereas the oldest one (VII) is situated in a riverside carr. All ditches are shallow (0.3–0.9 m) and not very wide (1.5–3.7 m; Table 1). Ditch I is the deepest, as it was deepened one year before the studies began. In addition, new dikes were constructed and all plants were removed at that time. The remaining ditches are slightly shallower but the differences in depth are statistically significant.

Chemical composition of water and sediment do not differentiate the ditches (Table 1). The sediment and water are slightly acidic (pH 6.2–7.0 and 6.6–7.4), but they are quite fertile, which is indicated by high concentration of total phosphorus and nitrogen. In the old ditches, total nitrogen concentration is a bit higher than in the newer ones. In ditch VII (not cleaned for over 20 years) water is much more brackish (132.7 ± 2.5 mg Cl dm^{-3}) and has higher electrolytic conductivity than the others (Table 1).

3.2. Share of the reed in total biomass

One year after ditch I was cleaned, i.e. its channel was deepened and new dikes were formed, plant biomass is low (Fig. 1). In the 1-year-old ditch, species typical of initial communities dominate, whereas the share of the reed is small. In ditch II (3 years after deepening), there is very high plant biomass (over 900 g d.w. m^{-2}), which is connected with the very quick development of reed rushes. In 3–5-year-old ditches (II–IV) the reed constitutes *ca* 70% of total biomass. It is worth mentioning that, in the ditches older than 5 years, the proportion of *Phragmites australis* in biomass falls, e.g. in the ditch not cleaned for 6–10 years (V) it is only 40%. In this ditch, other perennial plants occur together with the common reed: *Filipendula ulmaria* (L.) Maxim., *Lythrum salicaria* L., *Urtica dioica* L. and *Rubus* sp., whereas in ditch VI, the one left without cleaning for 11–15 years, grasses such as *Calamagrostis epigeios* L. (Roth.) and *Phalaris arundinacea L.* dominate in biomass. In the oldest ditch (VII) biomass is the lowest.

Table 1. Morphometric features of ditches and chemical properties of water (w) and sediment (s); mean value for 3 samples taken in August (mean ± s.d. or Me (for pH);TP – total phosphorus, N – organic and ammonium nitrogen. Categories of ditches: I – the one not cleaned for a year, II – three years, III – four years, IV – five years, V – 6–10 years, VI – 11–15 years, V – over 20 years.

Features	Categories of ditches						
	I	II	III	IV	V	VI	VII
Width (m)	3.5±0.2	2.02±0.7	2.6 ±0.2	2.8 ±0.8	2.7±0.3	3.4±0.3	3.6±0.1
Depth (m)	0.9±0.005	0.5±0.1	0.6±0.04	0.7±0.2	0.7±0.06	0.8±0.1	0.6±0.1
pH_w	6.6	6.7	6.7	6.8	7.4	7.1	6.6
$Conductivity_w$ ($\mu S\ cm^{-1}$)	1285±109.3	1069±14	1401±9.5	939.3±5.2	1055.3±0.6	878.7±3.5	1838.7±6.03
TP_w ($mg\ dm^{-3}$)	0.1±0.03	0.2±0.1	0.2±0.04	0.1±0.03	0.1±0.02	0.3±0.05	0.2±0.01
N_w ($mg\ dm^{-3}$)	1.84	1.8±0.28	1.9±0.3	2.6±1.1	2.5±0.5	3.9±0.4	2.7±0.6
Cl_w ($mg\ dm–^{3}$)	38±13.2	26.3±1.5	85.7±1.5	22.3±0.2	19.03±1.05	18.07±0.6	132.7±2.5
pH_S	6.8	7.0	6.8	6.7	6.6	6.2	6.5
$Conductivity_S$ ($\mu S\ cm^{-1}$)	907.7±148.9	1056.7±439.9	647±49.5	969±117.5	566.7±42.8	448.7±18.04	1296.3±64.5
TP_S ($mg\ dm^{-3}$)	19.8±8.3	29.7±8.9	20.5±3.4	13.9±1.3	23.9±0.9	24.4±3.3	23.9±6.3
N_S ($mg\ dm^{-3}$)	15±4.5	30±8.1	30±6.7	20±3.2	25±7.3	60±20	10±3.1

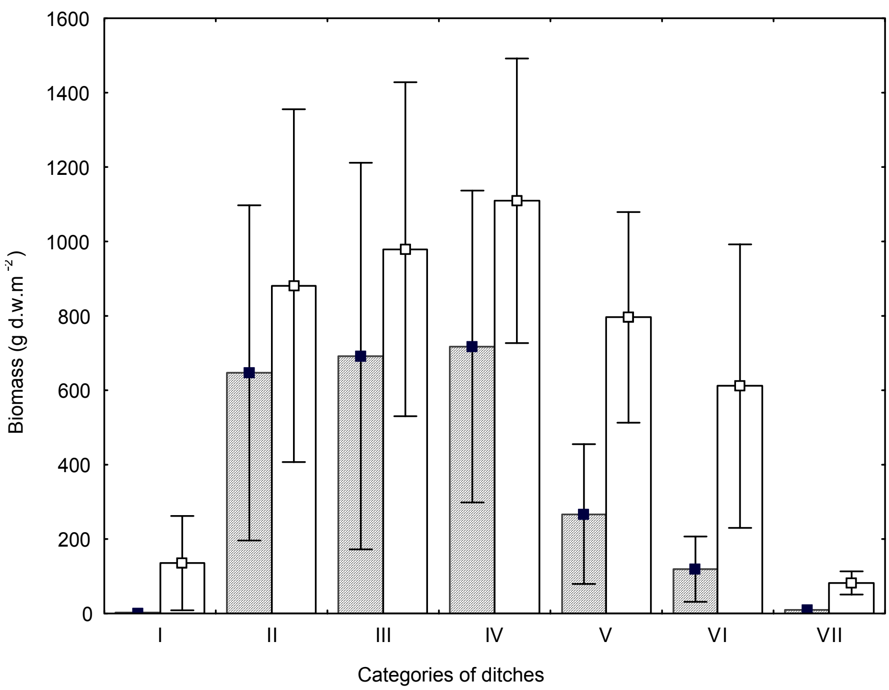

Fig. 1. Reed biomass (dark bars) and total plant biomass (white bars; mean value n = 10, standard deviation) in the following categories of ditches: the one not cleaned for a year (I), three years (II), four years (III), five years (IV), 6–10 years (V), 11–15 years (VI) and over 20 years (VII).

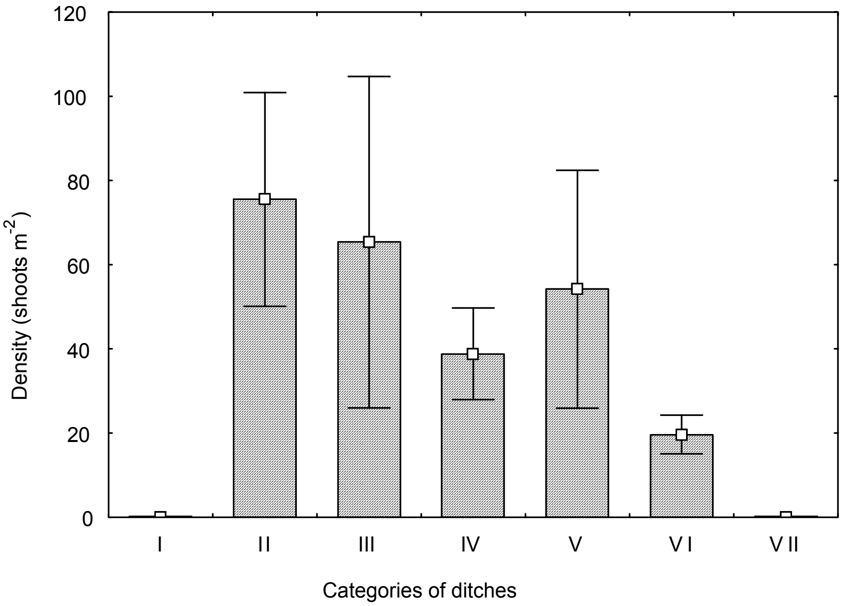

Fig. 2. Population density (mean value n = 6, standard deviation) of the reed in the ditches (for explanations see Fig. 1).

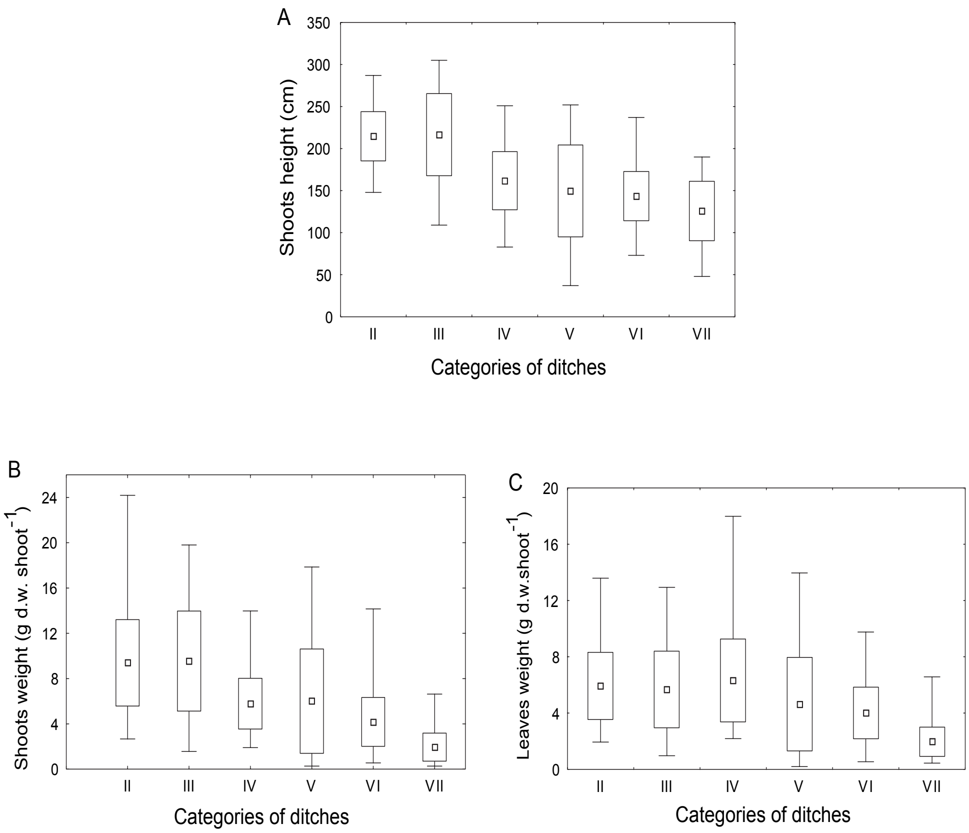

Fig. 3. Characteristics of reed shoots height (A), weight (B), leaves weight (C) (mean value n = 100, standard deviation, range) in the ditches (for explanations see Fig. 1).

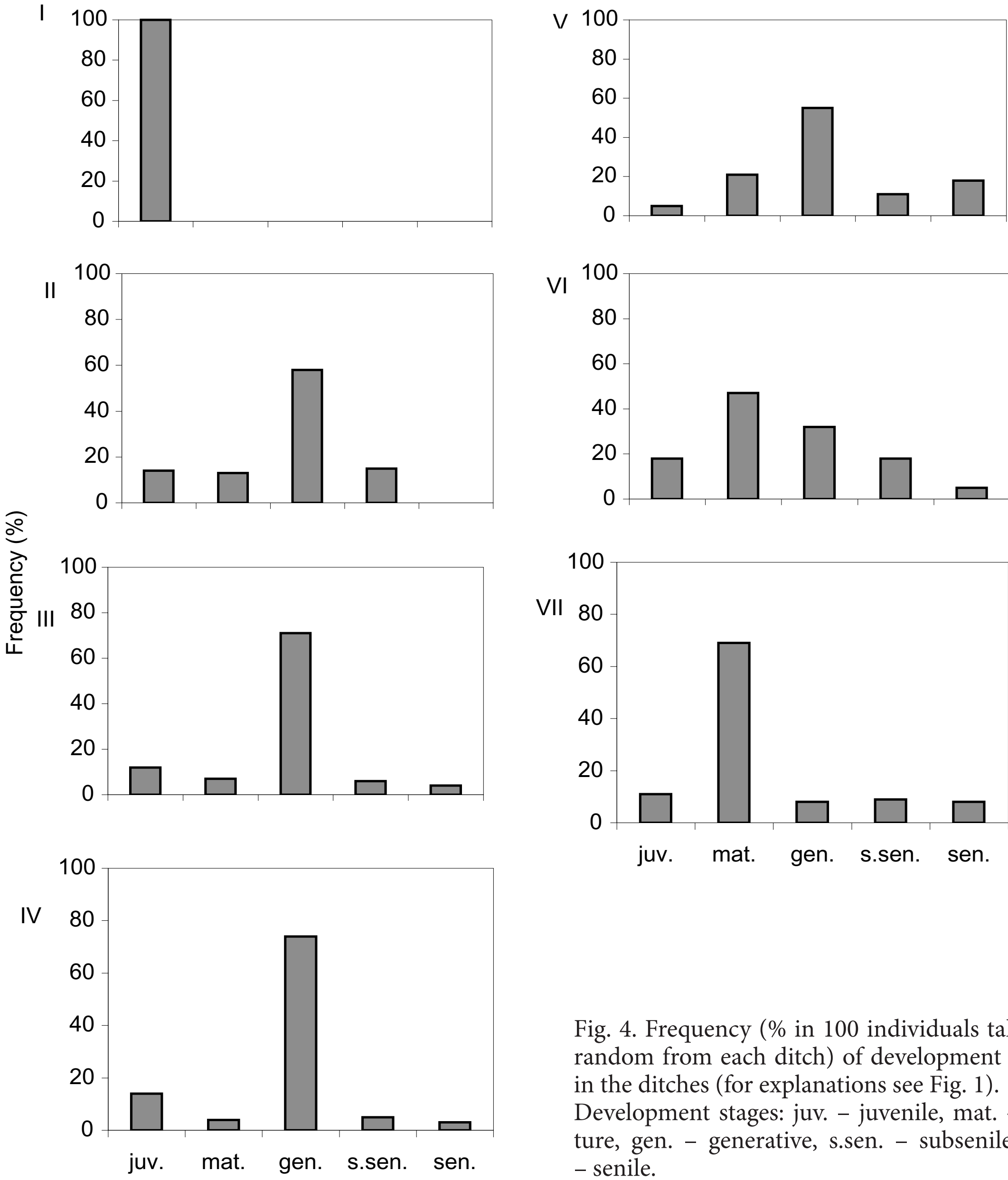

Fig. 4. Frequency (% in 100 individuals taken at random from each ditch) of development stages in the ditches (for explanations see Fig. 1). Development stages: juv. – juvenile, mat. – mature, gen. – generative, s.sen. – subsenile, sen. – senile.

It consists, above all, of the elements of riparian forest ground flora. The proportion of the reed in the biomass is low. One should also bear in mind that in the channels of all ditches the proportion of the reed is always higher than on the dikes.

3.3. Population density and structure

In ditch I the reed is widely scattered (4 shoots within several hundred metres). In ditch II (cleaned 3 years earlier), the population is already fully regenerated and characterised by the highest density (76 ± 24 shoots m^{-2}; Fig. 2). In the ditch cleaned 3–5 years before (III), population density remains at a similar level (65 ± 39 shoots m^{-2}), while in the ditches left without cleaning for 6 and more years it gradually declines (Fig. 2). Population density is usually higher in the channels than on the dikes, e.g. in ditch V it is 77 ±18 and 31 ± 20 shoots m^{-2}, respectively.

The older a ditch is, the greater the changes in the size and habit of shoots are (Fig. 3). The tallest, heaviest and most leaved shoots grow in ditches II and III, i.e. under the conditions of the highest population density. The older a ditch is, the shorter, lighter and less leaved the shoots are. The analysis of morphometric features by means of ANOVA and Tukey's test (*P* <0.05) showed that the differences among the populations of all the ditch categories are statistically significant.

The proportion of development stages changes with the age of ditches. Only juvenile shoots occur in ditch I. In ditches II–V, generative shoots are present almost exclusively, whereas mature ones, most of which do not reproduce generatively, dominate in VI and VII. All the populations are characterised by a small proportion of senile shoots (Fig. 4).

The share of development stages in the channels is different from the one on the dikes. Many more shoots flower and fruit in the channels. The proportion of juvenile shoots on the dikes is higher than in the channels, which can be explained by the differences in the phenological development of the reed in both types of habitats.

4. DISCUSSION

The fact that water flow in flood control ditches and canals in the studied wetland region (Vistula Delta; northern Poland) is slowed down results from negligence in channel deepening and dike mowing. Quick growth of *Phragmites australis* in ditches is the main hazard. The common reed is a R-C strategy species and, as a consequence, it requires disturbance habitats, which it colonizes quickly and successfully. After maintenance works in ditches, the first shoots emerge from the fragments of rhizomes which have not been removed. Vegetative propagules, as it has been determined for some European populations (e.g. Haslam 1973), play the main role in the regeneration of the populations. The reed occupies free space thanks to rhizome spread and clonal growth (Rice and Stevenson 1996), which has been confirmed also by genetic studies (Hauber *et al.* 1991). The role of generative reproduction of this species is negligible (Gervais *et al.* 1993, Meyerson *et al.* 2000). It is also known that seed germination and seedling growth exhibit rather small range in favourable conditions (Haslam 1972, Weisner *et al.* 1993).

Owing to the clonal growth of the reed, the rate at which populations in cleaned ditches regenerate is very quick. The first shoots of the reed emerge in the following growing season. Considerable habitat fertility and free space after the removal of vegetation from the soil surface encourage quick regeneration. In such conditions, the reed is competitively stronger than other plant species.

Three years after the maintenance works in ditches were done the reed population is already fully regenerated. Well developed reed rushes, which biomass is about 650 g d.w. m^{-2}, are dominant. Its density amounts to 76 ± 25 shoots m^{-2}. Flowering and fruiting shoots are the most numerous. Compared to other scientific data, population density in the ditches is not high. According to van der Putten (1997), if populations which density is smaller than 100 shoots m^{-2} dominate in a given region, it may be connected with die-back stands. However, if shoot dry mass is compared in the present study (i.e. Żuławy wetland) and in the stands of the quoted study, vigour of the shoots in the Żuławy wetland stands out.

The conclusion is that the common reed in the studied depression wetland of the Vistula Delta (northern Poland) does not display any symptoms of die-back during first 5 years after cleaning. The first signs of population regression were observed in the ditches left without cleaning for more than 5 years. Population density is gradually lower, the proportion of generative shoots is reduced, and the reed is lighter and has smaller assimilation area. It may be due to sediment changes resulting from the deposition of organic matter. Dead biomass decomposes slowly (Gessner 2000, Rooth and Stevenson 2000). At the same time, phytotoxins form and influence vigour and growth of rhizomes and roots in a negative way (Kovács *et al.* 1989, Armstrong *et al.* 1996a, b, van der Putten 1997). It is also worth mentioning that the depositing organic matter causes shallowing of the channel and its drying up. Such conditions are favourable to the settlement of many perennial plants and shrubs. The oldest ditches, i.e. the ones cleaned 20 years earlier and located in the riparian forest, are occupied by forest ground flora, whereas the reed can be found only sporadically, and is widely scattered.

Fluctuating water level, which enables the partial mineralization of organic matter and counteracts the accumulation of toxic by-products of its decomposition, is probably the factor encouraging the maintenance of the reed population in the drainage system of the studied wetland region (Vistula Delta, northern Poland). It is assumed that the die-back of the reed in other regions of Europe is due to a combination of eutrophication and the artificial regulation of water tables (van der Putten 1997). In such conditions, excessive production and deposition of litter might result in population die-back (Čižková *et al.* 1996, Graveland and Coops 1997).

The increase rate of population density and abundance is quicker than in other species which occur in flood control ditches. Therefore the reed is too strong competitor for many species. In order to ensure that ditch channels remain open for the water flow for a longer time, regeneration rate of the reed population should be controlled, and the competition from other species, especially stoloniferous grass, should be encouraged in a way which would allow them to occupy free space much more quickly. Due to the quick regeneration of the reed population, the results of ditch maintenance works are visible only for two years. Effectiveness of these works depends on the precision in removing the rhizome remains, which are durable and play the deciding role in the regeneration rate of the population (Čižková and Bauer 1998). The removal of most rhizomes is very often impossible, as they can occur in the substratum at depths ranging from 1.5 to 2 m (Szczepański 1978, Haslam 1972). Effectiveness of engineering and technical works can be enhanced by covering the dikes, just after their construction, with fragments of turf formed by stoloniferous grass, which will slow down the process of reed colonization and reduce the rate of the population development. In the works by Howard *et al.* (1978) and Cross and Fleming (1989) other methods of nuisance species removal are discussed, such as herbicides mowing, disking, dredging, flooding and draining. Reed elimination methods by means of some herbivores should also be considered (Tewksbury *et al.* 2002). However, in the wetland area of the Vistula Delta, a very productive region in terms of agriculture, this method could be hazardous.

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5. SUMMARY

The population structure of *Phragmites australis* (Cav.) Trin. ex Steud. was examined in seven categories of overgrowing flood control ditches, differing on time which had elapsed from the last clean-up. Site conditions in the ditches and the share of the common reed in the total biomass of plants growing in the ditches were also determined. Chemical composition of water and sediment do not differentiate the ditches. The sediment and water are neutral or slightly acidic (pH 6.2–7.0 and 6.6–7.4), but they are quite fertile, which is indicated by high concentration of total phosphorus and organic together with ammonium nitrogen (Table 1). The rate at which populations in cleaned ditches regenerate is very quick. The first sparse shoots of *Phragmites australis* emerge one year after the ditch was cleaned. In the 3–5-year-old ditches the proportion of the common reed in total biomass exceeded 60% (Fig. 1), shoots are tall and robust (average shoots height 161.7–216.5 cm, average shoots weight 5.78–9.55 g d.w.; Fig. 3), and the proportion of generative shoots is large (58–74%; Fig. 4). The population density is high especially in the 3–4-year-old ditches (on average 65.3–75.5 shoots m^{-2}; Fig. 2). In the 6–10-year-old ditch, generative shoots dominate (55%; Fig. 4), whereas height of shoots and their biomass are smaller (Fig. 3). In the 11-year-old and older ditches reed regression is in progress, which manifests itself in lowering of its density, as well as in the decrease in generative fraction and the reduction in shoot height and assimilation area (Figs 2–4). The reed is replaced by other plant species, mainly grasses and shrubs.

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