Wetlands Ecol Manage (2017) 25:359–367
DOI 10.1007/s11273-016-9522-y

ORIGINAL PAPER

Can we effectively stop the expansion of trees on wetlands? Results of a birch removal experiment

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Received: 28 February 2016 / Accepted: 22 November 2016 / Published online: 30 November 2016

Abstract The main aim of this study was to determine the effectiveness of removing invasive downy birch in non-forest peatland applying a single cut. We tested whether the removal of birch was positively related to the height of cutting, season of the year and age of the trees. Our study showed that birch trees cut at the higher tested height exhibited a lower survival rate than those cut below or just above the ground level. Furthermore, the winter cut produced more non-sprouting stumps than those recorded after the cut performed in autumn. In our opinion, winter cutting at breast height is the best management strategy for downy birch control. However, we suppose that the effective elimination of birch by applying a single cut is not possible, and the treatment should be repeated in subsequent years or boosted by additional treatments.

Keywords Betula sp. · Secondary succession · Sprouting · Tree removal · Vegetation management

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Introduction

Encroachment of woody plants and shrubs in open wetlands and grasslands is a worldwide concern (Bart et al. 2015). Formerly characterized by low-intensive management systems, these ecosystems have undergone a major decline in area in recent decades (COM 2015). The open wetlands are of special concern. While they only comprise a small part of wetlands area, open wetlands are very important for a wide variety of species (EEA 2015). The succession and progression of shrubs and trees was shown to be a direct threat to many shade-intolerant, low herbaceous species that are unsuccessful in competing for resources. Thus, this phenomenon is regarded as one of the drivers of biodiversity loss at ecosystem and landscape scales (Warren et al. 2004, 2007; EEA 2015). This problem is crucial in wetlands where vegetation composition results from long-lasting low-input agricultural use (Kotowski and Piórkowski 2005). Cessation of this traditional land use initiates a secondary succession, which within a few decades results in the progressive decline of less competitive helophytes, especially those that occur at their geographic range limit (Kołos et al. 2015). The secondary succession of trees and shrubs will also be a main challenge for controlling mire hydrology in the near future. The results of preliminary research by Grygoruk et al. (2014) confirmed that tree isles in mire habitats cause a higher degree of water loss through evapotranspiration relative to that of continuous expanding forest.

The shift of peatland vegetation towards tree-dominated ecosystems may likely be accelerated by anthropogenic disturbances (i.e., drainage; Tousignant et al. 2010), climate change (i.e., future warming; Heijmans et al. 2013), external eutrophication (i.e., atmospheric deposition; Riemersma et al. 2006; Jickells 2005; Smith et al. 1999), and abiotic variables (i.e., water fluctuations, N:P ratio; Økland et al. 2001; Jabłońska et al. 2014). Thus, protecting open wetland ecosystems is a priority of nature conservation policy. In the European Union and in other countries, several conservation programs are available to assist landowners in developing wetland management on their property (Baylis et al. 2008; Claassen et al. 2008). Although management and restoration practices are routinely performed, we still lack systematic, evidence-based assessments of their effectiveness (Meli et al. 2014), e.g., in the control of trees encroachment. Some field results suggest that the most effective method for eliminating expanding trees is repetitive mechanical removal coupled with the application of herbicides (Klimkowska et al. 2010; Brisson et al. 2006). Because herbicide treatments may produce unknown cumulative impacts on the environment (Sura et al. 2012), their application (as well as burning) is illegal in protected areas in many countries, including in Poland. Presently, repetitive mowing and/or tree and shrub cutting are acknowledged as the only acceptable and potentially effective tool for vegetation management (Middleton et al. 2006; Kołos and Banaszuk 2013).

Birch a very dynamical pioneer species in peatland is likely to respond well to cutting and pollarding, and the full crown can possibly be removed. Old trees have been documented to die after removal of the crown (Read 2000). The cut disrupts the hydraulic architecture and continuum of the food- and water-conducting tissues ("the soil–plant continuum"). Consequently, it results in a great flow of sap and considerable loss of carbohydrates that serve as the primary energy reserve of trees. Resprouting after severe damage and loss of a majority of aboveground biomass requires resources to support the development of new resprouts (Bond and Midgley 2001; Zhu et al. 2012). Severe depletion of carbohydrate reserves can affect the regeneration capacity of the tree after damage (Luostarinen and Kauppi 2005) and can lead to its death. Wounds also expose the tree to pathogens (e.g., fungi) that may infect and cause decay of the wood (Delvaux 2009). There is evidence that stump survival as well as sprouting ability is related to felling time and residual stump height (Ferm and Kauppi 1990; Hytönen 1994; Jobidon 1997).

Repeated yearly cutting increases the mortality of trees and reduces sprouting. However, experience and observations gained in managed wetlands have shown that these simple and obvious measures are sometimes either ineffective or, contrary to all expectations, even triggering unwanted successional changes. Moreover, the major drawbacks of repeated management include the high cost of additional treatments and possibility of enhanced environmental stress or disturbances (Banaszuk et al. 2016). The main aim of this study was to determine the effectiveness of removing invasive downy birch in an unwooded peatland by applying a single cut. The principal issues pertained to the effect of both the method and timing of the cutting on the sprouting ability and survival of downy birch *Betula pubescens* stumps. The study addressed the following questions: (i) "does applying a single cut enable the restoration and maintenance of non-forested mires colonized by downy birch?" and (ii) "how does cutting season and cutting height affect the sprouting ability of *Betula*?"

Materials and methods

Study site

This study was conducted in the nature reserve "Stare Biele Mire" located in the Knyszyńska Forest, north-east Poland (53°14′36″N; 23°31′35″E). The mire has an area of 300 ha and was developed in a melt-out depression surrounded by kame hills. The isolated basin is filled with poorly decomposed (fibric and hemic) Carex–Bryales peat of an average depth of 1.7 m, which is underlain by lacustrine deposits (average depth of 1.3 m; Żurek 2000). The mire has a long history of agricultural use. Beginning eighteenth century, it was mown annually for fodder production. By the early 1970s, mowing had ceased, and secondary plant succession had started, which has lead to massive encroachment of downy and silver birch (*Betula pendula*), pine (*Pinus sylvestris*), spruce

(*Picea abies*), grey willow (*Salix cinerea*) and bay willow (*Salix pentandra*), which account for up to 50–70% coverage (Fig. 1). Semi-natural sedge-moss communities dominated by *Carex elata* and *Carex appropinquata* only remained in the middle and eastern part of the peatland. Within the *Carex* community, a few individuals of *Salix lapponum* survived, which is one of the rarest glacial relicts of Polish flora, as well as other rare and endangered species of fauna and flora (Kołos et al. 2015).

The climate is temperate and has a distinctly marked continental and a lesser boreal influence. The mean air temperature is 7.0 °C, the monthly average temperature ranges from −3.9 °C in January to 17.8 °C in July, and the average rainfall is 585 mm year^{-1} (1951–2013), of which 60–80% falls between April and September. Permanent snow cover occurs over 70–80 days on average every year between late December and early March. The maximum snow depth reaches 80 cm in some years. The growing season has mean daily air temperatures >+5 °C, begins on approximately 5 April and lasts 180–200 days.

The experimental period 2010–2013 experienced high precipitation. The wettest year was 2010, when the sum of the precipitation for the growing season alone exceeded 560 mm. Groundwater levels during the experiment showed the highest frequency around the ground surface, with a shallow flood reaching approximately 12 cm (water level was measured using e+ water L 200 data loggers by Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands, in a piezometer close to the experimental plots). In the 4 years study period the mire was flooded every year. Average flood duration was 132 days and usually occurred in the period from the beginning of March

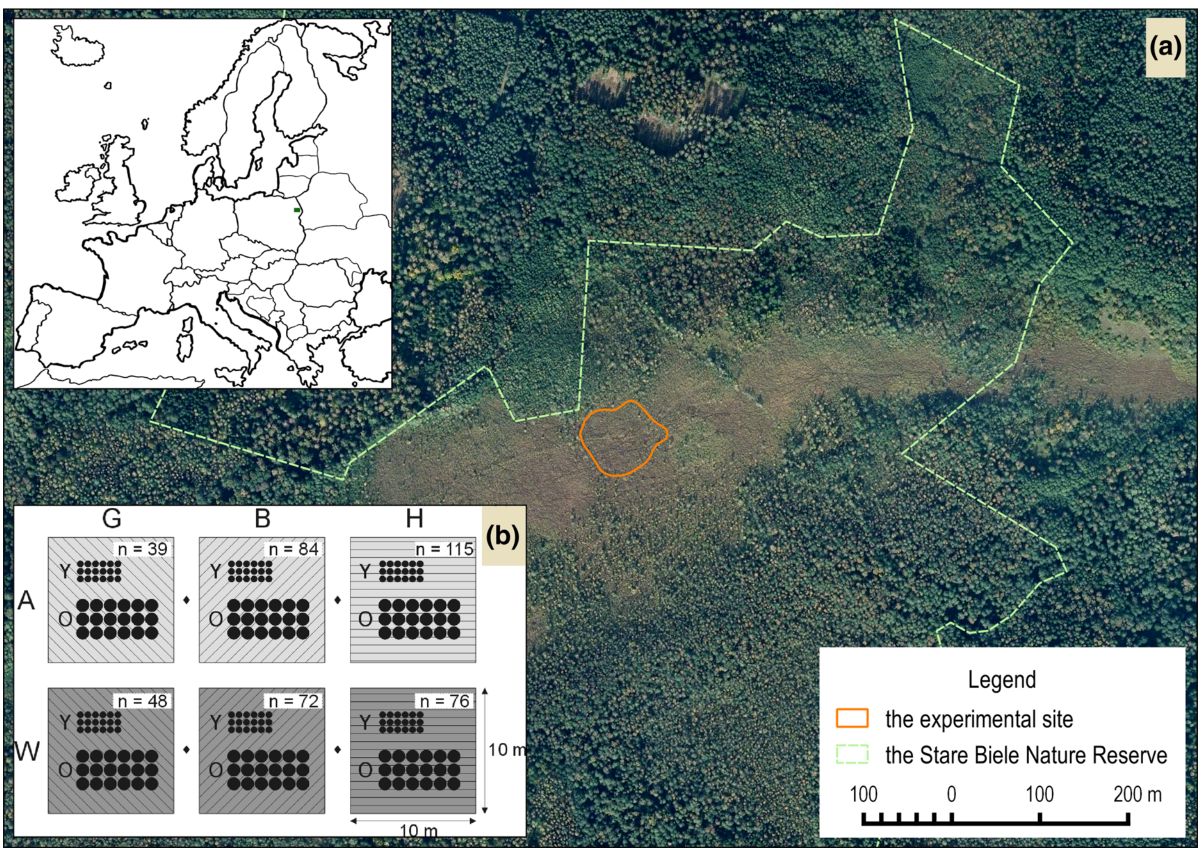

Fig. 1 Stare Biele Mire study site (**a**) and sampling scheme (**b**). Total number of treated individuals is shown in the *top right corner* of each plot. *A* cut in autumn season, *W* cut in winter season, *Y* young trees with the trunk diameter <12 cm, *O* older trees with a diameter >12 cm, *G* cutting below the ground surface, *B* cutting 5–10 cm above the ground; *H* cutting 120 cm above the ground

until June. The minimum recorded water table was −17 cm; however, temporary shortages in soil moisture were efficiently replenished by the frequent rainfall.

The shallow groundwater/pore water from the depth of the rooting zone was sub-neutral with an average pH of 6.7 ± 0.27 and exhibited a rather low mean electrical conductivity (EC) of 258 ± 29.2 $\mu S\ cm^{-1}$ (measurements were repeated once a month; n = 18; Hach Lange HQ40D). The groundwater of this oligotrophic mire had a low $N\text{-}NO_3$ concentrations (mean 0.03 ± 0.01 $mg\ L^{-1}$). The concentration of $N\text{-}NH_4^+$ was 0.67 ± 0.41 $mg\ L^{-1}$, and $P\text{-}PO_4{}^{3-}$ was 0.04 ± 0.02 $mg\ L^{-1}$. Relatively high concentrations of Ca^{2+} (mean 63.1 ± 16.1 $mg\ L^{-1}$) and Mg^{2+} (mean 10.5 ± 1.0 $mg\ L^{-1}$) confirm that the water feeding the wetland has a groundwater origin.

Experiment

Our project was situated in the nature reserve; therefore, a randomized experiment faced some constraints for legal and ethical reasons. To mitigate any potential negative impact on the fragile peat soil and vegetation, we had to restrict the spatial extent of the field work and management practices. Within the mire, we identified relatively uniform fragments characterized by similar peat depth, hydrology and soil properties. The area had an almost even-aged stand of *Betula* in which the difference in the age between the oldest and youngest trees did not exceed 10–20 years. The stand density in the plots varied between 39 and 115 individuals/100 m^2.

Within this fragment of peatland, we randomly selected 6 plots (10 m × 10 m). The tree cutting was applied to all individuals and was performed in two different periods: at the end of the growing season in the middle of October 2011 [Autumn (A)] and in February 2012 [Winter (W)] using three methods: cutting below the ground (peat) surface (G), cutting 5–10 cm above the ground at the base of the trunk (B) and cutting the trunks at breast height (120 cm; H). Thus, six different treatment combinations were obtained: AG, AB, AH, WG, WB and WH. For each plot, we randomly assigned the treatment type that each plot was to receive. Before the treatment, the perimeter of tree trunks was measured at breast height. The measurements were noted on a plastic plate, which was then stuck into peat nearby the trunk. The cut trees were aged from several to more than a dozen years old, and they were up to 6 m tall. Age was presented in a simplified dichotomous scale: young trees with a perimeter of trunks $<\sim 12$ cm (~ 4 cm in diameter; Y) and older trees with perimeter >12 cm (O). A relative homogeneity of the habitat allowed us to suppose that the differences in the tree perimeter reflected fairly accurately the difference in the age and thus might be a good proxy of tree age. The stand density and the number of trees in the analyzed plots were different from each other; therefore, to consider the individuals within every single plot, we sampled equal-size groups (n = 18 individuals) that represented the specific combinations of factors: young trees cut below ground level in October (YBA), young trees cut below ground level in February (YBW), etc.—in sum, n = 12 groups. All trunks and branches were removed from the site. We did not test the effectiveness of *Betula* removal in the summer half-year because, in protected areas, all management measures are restricted during the bird-breeding season, which extends between April and August. After applying the appropriate treatment independently to each plot, we made no further manipulations until mid-August of next year. The response of downy birch to cutting was monitored during two consecutive seasons in 2012 and 2013. The proportion of dead, damaged or diseased trees along with decreased production of sprouts by the stumps and roots of cut trees were accepted as indicators of successful tree removal. In addition, the post-treatment damages of the stems (e.g., infection by fungi) were also monitored.

Data analysis

The experimental units were the individual trees, to which treatment was assigned. The treatment's impact on the mortality of *Betula* was tested using a multifactor analysis of variance (MANOVA). We tested whether successful eradication (measured as a decrease of sprouts produced by the treated tree) was positively related to the method of cutting (G, B and H), the season when the treatment was performed (A and W) and the age of the trees. The data were used to test the null hypothesis that differences would not be found in the mean number of sprouts across the different treatment groups. In all cases, the statistical design was balanced with type III sum of squares (SS). The dependent variable was log10 transformed. Differences in the sprouting ability of *Betula* among treatments were analyzed using a non-parametric Kruskal–Wallis test. A Chi squared test was performed to determine whether significant differences occurred among the proportions of dead trees within the treatment groups. An analysis of means (ANOM) was used to determine the proportions that were significantly different compared to the overall average. All analyses were performed using Statgraphics XVI Centurion software (Statpoint Technologies, Inc.).

Results

Effect of cutting season and height on sprout production and birch survival

In the first year after the treatment (2012), we recorded significant effects of the season when a treatment was applied on the sprouting ability of birch ($p < 0.05$; Kruskal–Wallis test; Fig. 2). The median number of sprouts per stump after the winter cut (1.0) was significantly lower than those recorded after the cut performed in autumn (2.0). The most effective method was winter cutting at breast height (WH; the median sprouting per trunk = 1); the least effective was winter cutting below the ground surface (WG; median = 2).

Measurements repeated in the subsequent year (2013) showed that median sprouting per trunk was slightly lower (1.5) than in 2012. However, the observed difference was not statistically significant. There were no significant influences of cutting method or season on the number of sprouts.

The MANOVA results revealed that the age of the trees under treatment was the only factor that had a significant effect ($p < 0.05$) on the condition of the cut birch with young trees producing less sprouts (Fig. 3). A comparison between the variability among treatment effects and that of the residuals indicated that only this factor showed a difference of a greater magnitude than could be accounted by experimental error alone. A height of tree cut appeared to be marginally significant at $p < 0.10$ ("treatment" in Fig. 3).

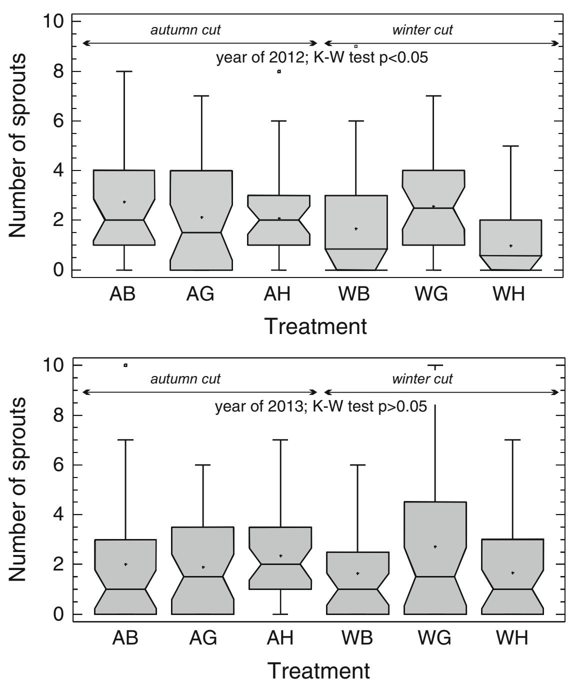

Fig. 2 Sprout production per stump after applying different methods of birch removal, as recorded in 2012 (*upper panel*) and 2013 (*lower panel*). *G* cutting below the ground surface, *B* cutting 5–10 cm above the ground, *H* cutting 120 cm above the ground, *A* autumn, *W* winter

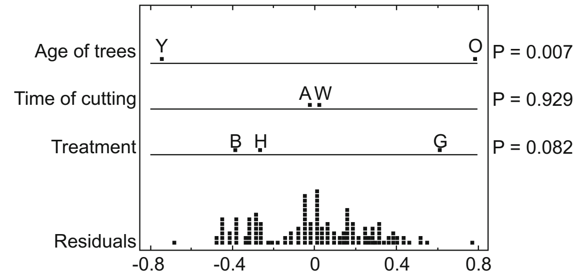

Fig. 3 A graphical ANOVA plot comparing the variability among treatment effects on the number of sprouts per one stump to that of the residuals. Each factor was scaled so that the "effect" of a factor equaled the difference between the least squares mean for a factor level and estimated grand mean. The natural variance of the points in the diagram is comparable to that of the residuals, which are displayed at the bottom of the plot. The p-values for the main effects are displayed along the *right-hand side* of the plot. *Y* young trees with the trunk diameter <12 cm, *O* older trees with a diameter >12 cm, *G* cutting below the ground surface, *B* cutting 5–10 cm above the ground, *H* cutting 120 cm above the ground, *A* autumn cutting, and *W* winter cutting

Effectiveness of the cut treatment estimated according to the number of dead trees

In the first year (2012) after performing the cut, the proportion of dead (non-sprouting) trees varied according to the method and season of treatment. The most successful (Chi square test, $p < 0.05$) combinations were the winter cuts performed at the base of the trunk (WB) and at breast height (WH). In both cases, the proportion of dead trees was slightly higher than 50%. Cutting below the peat surface (WG) resulted in over 80% tree survival. The ANOM showed that these proportions were significantly different ($p < 0.10$) than the overall average from all of the experimental plots (Fig. 4). Birch tree removal in autumn was less successful than that performed in winter. Trees cut below the ground surface (AG) provided a 40% success rate, cut AB eliminated ~13%, whereas cut AH eliminated 16% of the trees.

Counting repeated in the second year after treatment (2013) revealed the greatest tree mortality in the plot with autumn cuts below the ground surface (AG), which gave 46% of dead trees (Fig. 5). The worst results were observed with autumnal cuts at breast height (AH), which produced a proportion of dead trees of 17%. Surprisingly, the proportion of stumps without sprouts in the plots with the highest success in 2012 (WB and WH) decreased in the next year. The same tendency was also observed in other plots (AB, AG, and WG), where the rate of success decreased to 30–40%.

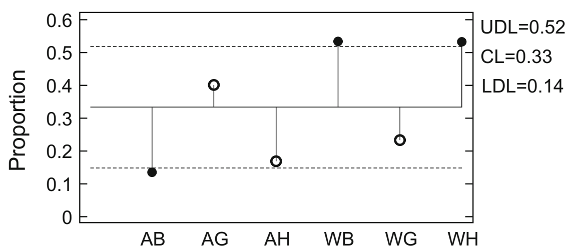

Fig. 4 The success in removal of birch recorded in 2012 expressed as a percentage of non-sprouting stumps. Winter cuts at breast height (WH) and at the base of the trunk (WB) provided the highest proportion of non-sprouting stumps (Chi square test; $p < 0.05$). *G* cutting below the ground surface, *B* cutting 5–10 cm above the ground, *H* cutting 120 cm above the ground, *A* autumn, and *W* winter. Analysis of means with 90% decision limits. *UDL* upper decision limit, *CL* center line, *LDL* lower decision limit

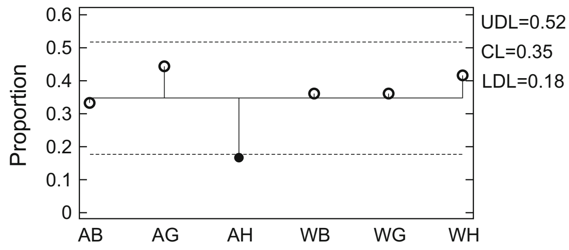

Fig. 5 The success in removal of birch recorded in 2013 expressed as a percentage of non-sprouting stumps. The most effective treatment was autumn cuts below the ground surface (AG), whereas autumn cutting (AH) was the least effective; however these differences were not significant (Chi square test) at $p = 0.05$. For explanations, see Fig. 4

Discussion

Betula pubescens is a biologically vigorous pioneer species that invades abandoned and unmanaged open peatlands. Therefore, its control is regarded as fundamental for the successful protection of wetland biodiversity (Faliński 1980; Smit and Olff 1998). Compared to other species, downy birch is more sensitive to cutting, while willow and poplar species can withstand numerous consecutive harvests without decrease in their sprouting capacity (Harrington and DeBell 1984; Paukkonen et al. 1992; Willebrand et al. 1993). The successful removal of invasive trees and shrubs is dependent on many factors, including the species, age of the trees, diameter of the trunk as well as timing and frequency of the cutting (Lust and Mohammady 1973; Johansson 1992b, 2008; Hytönen 1994).

In our experiment, the sprouting ability of *Betula* trees after the cut was highly dependent on the age of the trees, what was a rather obvious finding. Younger, thinner trees produced a smaller amount of sprouts than older individuals after the cut. A positive correlation between the stump size of *Betula pendula* and *B. pubescens* and sprouting has been observed also by Johansson (1992b). We also found that the winter cut gave more non-sprouting stumps than the cut performed in autumn. The positive effect of season of the treatment was amplified by the height of the cut. Stump height is considered as an important factor that affects the sprouting of harvested shrubs and trees. However, the literature presents different and sometimes contradictory results. In an experiment by Johansson (1986), a cut of *Betula* at ground level resulted in lower sprout production compared to cuts at 10 cm, while Kauppi et al. (1988) reported rapid growth of birch sprouts that may catch up with the main stem cut just above the ground. Fällman et al. (2003) found that top cutting of *B. pubescens* at higher heights above ground level resulted in fewer forks, straighter stems, higher live crown height and smaller thickest branch diameters compared to cutting just above ground. According to Karlsson and Albrektson (2000), cutting at least 40% of the main stem height should prevent production of side/lower shoots. Our findings are to some extent consistent with the cited results. In Stare Biele, trunks cut in autumn at higher height exhibited a lower survival rate than those cut just above ground level, with the largest number of non-sprouting birch stumps (up to 50%) yielded by a cut at breast height. Removal of downy birches seemed also be more efficient before they reached age of ~15 years. Younger trees produce a smaller number of sprouts and lighter sprouts than larger birch trees.

Surprisingly, birch appeared to be resistant to the joint interplay of mechanical and microbial interactions, and as early as spring 2013, some of the "dead" trees started to vigorously produce sprouts from the root zone. After cutting, birch produce stump sprouts primarily from dormant basal buds, and 72 to 95% of the buds appear below ground on the roots (Johansson 1992a). The "success" in eradication of *Betula* declined and offset to 30–40% in all the treatment plots in the second year after performing the cut (the only exception was AH). Similar results were published by Kauppi et al. (1988) and Rinne et al. (1994). In places, newly grown burgeons formed a close burst that overshaded the soil surface and threatening shadow intolerant herb layer species to a much greater extent than the original tree crown, which put the aptness of the applied treatments into question. Nevertheless, a considerable number of the living trees after cutting were infected by fungi, which suggests a progressive tree mortality in subsequent years. Trees cut above the peat surface in winter are particularly susceptible to infections by pathogens. In the treatments with cutting at the base of the trunk and at breast height in winter (treatments WB and WH), all of the stumps that had not produced sprouts and nearly 60% of the living trees were seriously infected by fungi. We noticed that the amount of living stumps attacked by fungi after cutting in autumn was only 22–25% (generally in AB and AH plots). Cutting below the peat surface (WG and AG plots) in autumn and winter did not favor fungal infections because only single stumps (3–6%) infected by pathogens were observed. Repeated field observations revealed that most of the stumps weakened by fungi were broken by wind and disappeared by the second year after treatment.

Betula pubescens has been shown to be unsuitable for sprouting when short rotation periods of harvesting were applied (Rydberg 2000). Hyttönen and Issakainen (2001) reported harvesting that was repeated every 1–2 years to increase the mortality of birch stumps. The second cut yielded three times less biomass than the first one, and the sprouting ability of downy birch was significantly reduced (87% stumps failed to sprout) after just four seasons of cutting. However, in some cases, a number of birches were able to sprout for more than 10 years of management (Hyttönen and Issakainen 2001). The experiment carried out in the "Rynki" peatland located in the Narew National Park showed that 94% of the treated birch resprouted vigorously despite four successive cuts performed year by year (Kamocki, unpublished raw data). In some cases, tree growth and sprouting after the implementation of cutting management can be inhibited by such factors as frost damage in early autumn or late spring (Linkosalo et al. 2000), browsing by large herbivores (Gill 1992; Barančeková et al. 2007) or destruction by insects (Tenow et al. 2005). Nonetheless, this additional effect was not observed in the studied peatland.

Conclusions

Restoration and conservation efforts of reforested wetlands often lack experimental validation, particularly for different methods of cutting and terms of treatment. Our study showed that birch trees cut at the higher tested height exhibited a lower survival rate than those cut below or just above the ground level. Furthermore, the winter cut produced more non-sprouting stumps than those recorded after the cut performed in autumn. In our opinion, winter cutting at breast height is the best management strategy for downy birch control. We recommend the removal of downy birch trees from peatlands before they have achieved an age of 15 years. Younger trees produce a lower number of sprouts and lighter sprouts compared to larger birch trees.

Our results suggest that effective elimination of *Betula* by a single cut is rather unlikely and that control measures should be either repeated in subsequent years or boosted by additional treatments, e.g., applications of herbicide. However, the secondary impact of the control operation on the environment must be considered because there is a hazard of aquatic toxicity and bioaccumulation, especially in the case of sensitive ecosystems of high ecological value. Nevertheless, the planning of active protection measures in such habitats requires great caution because birch trees are not always invasive species within peatland communities and they may not cause a threat in specific environments.

Acknowledgements We gratefully acknowledge two anonymous reviewers for their thoughtful comments and suggestions which helped to improve our manuscript. This research was supported by Polish Ministry of Science and Higher Education (Grant N N305 3673 38).

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