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FIVE YEARS OF EXPERIMENTAL RESTORATION OF VACUUM-MINED BOG IN NORTHERN POLAND

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SUMMARY

Vacuum-mined bogs in Poland occupy an area of about 700 ha. One of these peatlands, Czarne Bagno, has been undergoing restoration since 2006. The restoration involved ditch blocking, decomposed peat removal and spreading of *Sphagnum* shoots. The results of water damming are monitored by automatic water level sensors. Photographs of permanent plots document mosses regeneration. Despite high annual fluctuations, a gradual rise in water table was recorded. The *Sphagnum* cover in some plots has reached 100% and 151 vascular plant species have established among regenerating mosses.

KEYWORDS: *Sphagnum* reintroduction, bog vegetation, bog conservation, industrial peat exploitation

INTRODUCTION

Vacuum-mined bogs are problematic systems for reclamation. The hydrology of the exploited bog's basin is disturbed by draining. The upper layer of peat is decomposed, un-stable and dried (Gorham and Rochefort, 2003). During peat mineralization, large amounts of carbon dioxide are emitted into the atmosphere. Plant diaspores are submitted to blowing away by wind, frizzing or desiccation (Girard *et al*., 2002). Such conditions limit spontaneous regeneration of plant cover. The method of restoration of industrially milled bogs was developed and tested in Canada (Quinty and Rochefort, 2003). It consists of the following steps: surface preparation, plant diaspores collection, plant spreading, straw application, optional fertilization and water out-flow blocking.

In Poland the area of milled bogs is estimated at 700 ha. After cessation of peat mining, the excavation fields are usually left without any reclamation. The first attempt at bog restoration has been made in Czarne Bagno bog (N Poland). Long-term drainage, extensive peat mining up to 1950s, afforestation and superficial fires have seriously damaged the whole mire. In the years 1987-1989 industrial peat extraction was managed in an area of 13.47 ha. Restoration works began in 2006. At that time no more than 5% of the post-excavation area was covered with vegetation. The ground water table was low and unstable and the moorshing process was in progress (Herbichowa *et al*., 2007). The main objectives of our work were to create favourable conditions for plant cover regeneration and to stop further degradation of the peat deposit. The long-term goal is to restore a peat accumulation process. During the experiment,

the Canadian method of bog restoration was adapted to the environmental conditions of Northern Poland.

METHODS

In order to limit water outflow from the bog, 105 wooden dams were built in 2006. The results of water damming are being monitored with a set of 14 automatic meters (Eijkelkamp MiniDiver) which register water level every 6 hours.
Between 2006 and 2011 post-excavation polders were subsequently subjected to restoration works. *Sphagnum* species were introduced in nine mined fields (about 3.5 ha).
Field preparation involved removing 10-50 cm thick layer of decomposed peat, which afterwards was used to fil ditches separating polders. Seven *Sphagnum* species (*Sphagnum palustre*, *S. magellanicum*, *S. cuspidatum*, *S. fallax*, *S. rubellum*, *S. capillifolium* and *S. russowii*) were chosen for introduction. All of them are present in the contemporary flora of the Czarne Bagno bog. We used shoot fragments obtained from the closest, largest populations. Shoots were spread manually and covered with straw mulch. The layer of straw is being replenished every spring. The amount of shoots spread obtained initial coverage of 6% in plots arranged in 2006-2007 and 10% in plots arranged in 2009. In some plots a mixture of different species shoots was applied. Four post-excavation polders are being constantly monitored with the use of photographic method. The photographs are taken in 470 permanent subplots (0.5 x 0.5 m) three times a year. The succession of vascular plants has been observed since 2009 in 163 permanent plots. The abundance of each species was estimated in 7-degree percentage scale.

RESULTS

Changes in water level

The trend of water level curves in all metering points are similar and characterized by the highest level in autumn, slight drop during the period of winter frosts, and an increase in early spring and significant drop in summer (Fig. 1). Since water outflow blocking, despite high annual fluctuations, a gradual rise of water table is observed. In particular, despite the critical period of summer drought - the water table does not drop more than 50 cm below ground, favorable for the development of *Sphagnum*. The periods of water stagnation above the ground level are longer and more frequent.

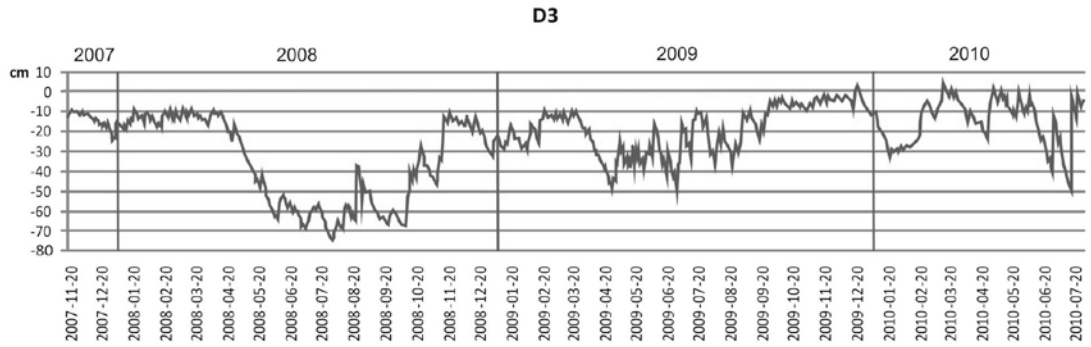

Fig. 1. Water level fluctuations between 2007 and 2010 (metering point D3, central part of Czarne Bagno).

Development of *Sphagnum* layer

Plots arranged in 2007, initial Sphagnum *cover – 6%, introduced species:* S. cuspidatum, S. magellanicum, S. russowii, *the mixture of* S. magellanicum, S. russowii *and* S. palustre.
The cover of all species during the first observation in June 2008 did not exceed 2%. A significant portion of the introduced shoots did not survive the period of dry and hot weather in late spring. In 2009 and 2010 the rate of *Sphagnum* regeneration was relatively slow (Fig. 2A). In 2011 *S. cuspidatum*, *S. magellanicum* and *S. russowii* regenerated well, increasing their cover up to 23 – 25%. The lowest rate of regeneration was observed in the case of the species mixture.

Plots arranged in 2009, initial Sphagnum *cover – 10%, introduced species:* S. palustre, S. russowii, S. cuspidatum, *the mixture of* S. palustre, *and* S. russowii (MIX), *the mixture of* S. palustre, S. russowii *and* Eriophorum vaginatum.
In the first season after introduction, the development of the *Sphagnum* layer was moderately intensive. *Sphagnum palustre* (Fig. 2B) reached the highest cover (on average 13%). In 2011 the regeneration rate was high. The cover of all introduced species has doubled. The most significant development was observed in the case of *S. palustre* and *S. cuspidatum*, whose cover in some subplots reached 100%.

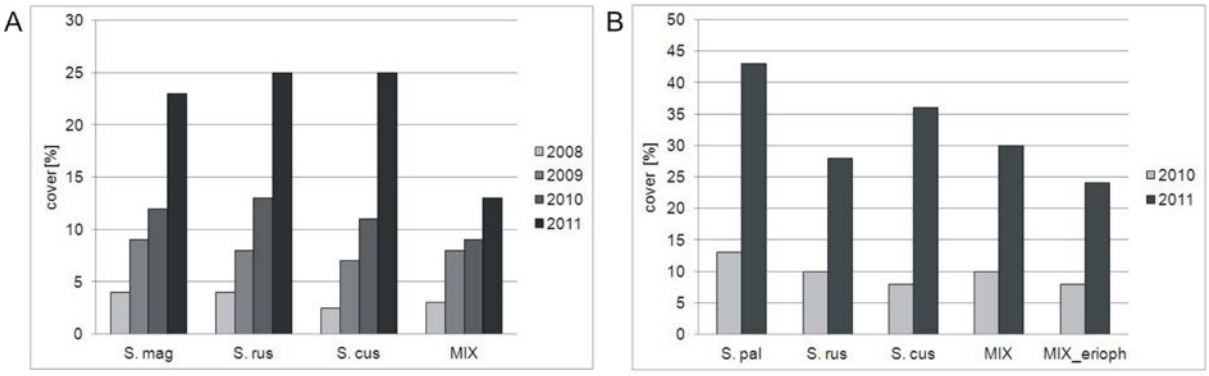

Fig. 2. Changes in *Sphagnum* cover in plots arranged in 2007 (A) and 2009 (B). Results of measurements taken in late autumn. S. mag – *S. magellanicum*, S. rus – *S. russowii*, S. cus – *S. cuspidatum*, S. pal – *S. palustre*, MIX – the mixture of *Sphagnum* species, MIX_erioph – the mixture of *Sphagnum* species and *Eriophorum vaginatum*.

The successsion of vascular plants in post-exploitation fields

Between 2006 and 2011 151 vascular plant species have spontaneously established in the post-exploitation fields. The flora consists both of mire species and species typical to heathlands, forests, swamps, meadows or synanthropic habitats. The diaspores of mire species originate both from the area surrounding the reclamation fields and from *Sphagnum* donor sites. The most probable source of diaspores of meadow and synanthropic species was hay, used once on site instead of straw mulch.

A gradual increase cover is observed in the case of some bog species (*Eriophorum angustifolium, E. vaginatum, Oxycoccus palustris* and *Rhynchospora alba*), poor fen species (*Carex canescens*), (*Carex rostrata*) and heathland species (*Calluna vulgaris*). Two meadow species, *Molinia caerulea* and *Juncus effusus*, are also quite extensive and their cover continues to increase. The establishment of weeds was rapid just after application of straw, but their number and cover, in most of plots, has been gradually decreasing.

One of the problems, which occured during the restoration work, was an invassion of seedlings and young specimens of *Betula pendula* and *Betula pubescens*. In these polders, where the succession of *Betula* was advanced, young seedlings were manually removed.

DISCUSSION

The results show that a rate of *Sphagnum* regeneration depends on: the season of diaspore introduction, the presence of optimally thick straw layer, soil moisture and the amount of introduced mosses shoots (Herbichowa *et al*., 2008; Cwiklinska and Herbichowa, 2011).

A crucial factor in the stimulated succession of mosses is the appropriate water regime in a bog. It seems that flooding does not negatively affect the introduced species, but desiccation during periods of dry and hot weather is critical. Nevertheless, results show that prolonged flooding (over 1 month) can also slow down *Sphagnum* regeneration. A similar case was outlined by Quinty and Rochefort (2000). The above observation leads to the assumption that, for restoration purpose, *Sphagnum* species should be chosen, that are resistant to soil moisture fluctuations, long term flooding and desiccation. In the Czarne Bagno bog, *S. palustre* and *S. cuspidatum* tolerate such conditions exceptionally well. *S. palustre* has a wide ecological range and is able to adapt to different conditions. *S. cuspidatum*, which is typical to very wet habitats, endures flooding well and quickly regenerates after the period of drought. The application of the mixed shoots of different *Sphagnum* species or mixture of *Sphagnum* and *Eriophorum vaginatum* may also be a good solution. Individuals of more durable species, growing relatively fast, can be the 'nursing species' for fragile ones. Several studies demonstrate that cotton grass can perform this role successfully (Tuittila *et al*., 2000). We have not noticed however that species introduced in a mixture regenerate better than in monocultures. This may be caused by unfavourable moisture conditions in plots with a species mixture, located at the margin of restoration area.
The rate of moss succession can be also influenced by the amount of introduced plant material. The regeneration of *Sphagnum* in the Czarne Bagno is 2-3 times faster in plots, where initially 10% of area was covered with moss shoots, than in those, where introduced shoots covered only 6%.

The early succession of vascular plants in restoration field is very dynamic. The contemporary flora is ecologically diverse, but the species enrichment is probably only temporal. The process which is unfavourable for *Sphagnum* development is the expansion of birch. Birch

seed are caught by the straw-net, which acts as “artificial plant cover” Salonen (1992). Moreover, germinating trees may take advantage of short-term input of nutrients from decaying straw. *Betula* specimens compete with *Sphagnum* mosses and, as an effect of intensive transpiration, can cause decrease in soil moisture, so they must be inevitably removed. The intensive development of *Molinia caerulea* and *Juncus effusus* is possibly connected with a fluctuating water table and slight fertilisation (Smart *et al*., 1989, Friedrich *et al*., 2011), which resulted both from mineralisation of straw and from avifauna activity.

The long term objective of peatland restoration is to return the cutover areas to functional peat accumulating ecosystems and CO_2 sinks (Rochefort, 2000). Some research carried out in European bogs revealed, that just after a few years of restoration, the CO_2 emissions from peat deposits reduces (Augustin, 2007). Carbon dioxide emission in the Czarne Bagno bog is being monitored since 2011.

The applied method of restoration can prevent the further degradation of seriously damaged mire and gives a chance for peatland vegetation to recover. Long-term observations are needed to evaluate the success of our restoration work.

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