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SHORT COMMUNICATION

Dragonfly fauna in rewetted mires in Belarus: diverse but different from natural sites

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Abstract Mire specialist species are under strong anthropogenic pressure. In areas where the exploitation of their habitat has been temporary or unsuccessful, restoration frequently has risen as an objective. The results of the restoration activities for habitat specialists, however, are unclear. In this work we investigated whether raising the water level ca. 10 years ago in degraded bogs has brought back a characteristic group of fauna, and mire specialists therein. Dip-netting for Odonata larvae, together with habitat description, was carried out in restored, unrestored, and natural sites. We found almost no larvae at unrestored sites. The restored sites provided habitat for diverse Odonata fauna, including lagg zone species. Bog specialists only occurred at a former pit-mining site. Based on the study, we suggest three means to support the biodiversity of mire Odonata: (i) protecting the remaining natural mires, (ii) using pit-mining instead of milling for peat extraction, and (iii) creating special pools in former milled sites that have been designated for mire restoration.

Keywords Ditch blocking · Peat excavation · Milling · Habitat specialist · Tyrphobiont · Surrogate habitat

Introduction

Mires have been historically and are today under strong human impact. Mainly the degradation of these natural ecosystems is caused by peat extraction, and drainage for forestry and agriculture; the losses are especially high in Europe (Rydin and Jeglum 2013). This has led to a number of negative impacts—soil erosion, extensive fires, and decrease of biological diversity (Kozulin et al. 2010). The threats to tyrphobiontic biodiversity amplify in lower latitudes as several species that are more generalistic in higher latitudes are narrowly associated with bogs in lower latitudes (Spitzer and Danks 2006; Sommer et al. 2015). Mire restoration approaches have been successful in bringing back some specialist species, but the assemblages, at least in the first years, often remain different from natural mires, because time is needed for ecosystem development, e.g. vegetation and host populations (Mazerolle et al. 2006; Punttila et al. 2016). When the suitable habitat has been formed and if possible source populations are nearby, the colonisation proceeds rapidly (Noreika et al. 2015, 2016). In the case of restoration of peat-extraction sites, the

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substrate may be very different from the pre-disturbance period and limit the establishment of bog species, though it may still be suitable for fen specialists or other wetland species (Mazerolle et al. 2006; Priede et al. 2016).

Odonata include several species characteristic of bogs (Norling and Sahlén 1997; Spitzer and Danks 2006). Their larvae often are the principal biotic factor determining the abundance and distribution of prey organisms in bog pools (Larson and House 1990). Odonata, especially the bog specialist species, are susceptible even to long-distance impacts of peat extraction, because this can result in changing pool characteristics and an extremely open, unfavourable matrix for dispersal and adult habitat (Bonifait and Villard 2010). Similarly, forestry drainage reduces the abundance and diversity of Odonata by reducing the availability and quality of aquatic habitats and increasing the tree cover in surrounding adult habitats (Elo et al. 2015). In restored mires the adults can colonise water-bodies and larvae can develop there within 3 years (Elo et al. 2015). Different kinds of aquatic habitats are suitable for breeding: pools behind ditch dams (Elo et al. 2015; Brown et al. 2016), especially dug pools at mining sites (Mazerolle et al. 2006), as well as remnant pools from pit-mining (van Duinen et al. 2013). The general conclusion may be that restoration is a successful tool to support mire Odonata; however, the species-specific responses are not clear.

The aim of our study was to examine the effectiveness of mire rewetting as a tool for habitat restoration for Odonata, focusing especially on mire specialist species. We sampled Odonata larvae in partly restored mire complexes to describe the assemblages in relation to restoration status and habitat factors.

Methods

Study area

The study was carried out in Belarus—a European country characteristically rich in bog specialist and also eastern Odonata species, including species strongly declined in Middle-Europe (Dijkstra 2006; Sushko 2014). Historically, mires covered 2,939,000 ha or 14.2% of this lowland country (Tanavitskaya et al. 2008). Half of the area of mires has been severely damaged through drainage, peat extraction and agriculture; an additional 30% is hydrologically changed (Tanavitskaya et al. 2008). Restoration appears a reasonable aim for 530,000 ha, 10% of which has been rewetted (Kozulin et al. 2016).

To study the effectiveness of mire restoration for Odonata, we searched for peatlands, where in addition to the restored part, a natural or exploited, but unrestored part would also be present for reference. We were able to find and investigate three such mires (Fig. 1). Yelnya bog contained restored and natural sites, Gorodnyansky Moh bog contained

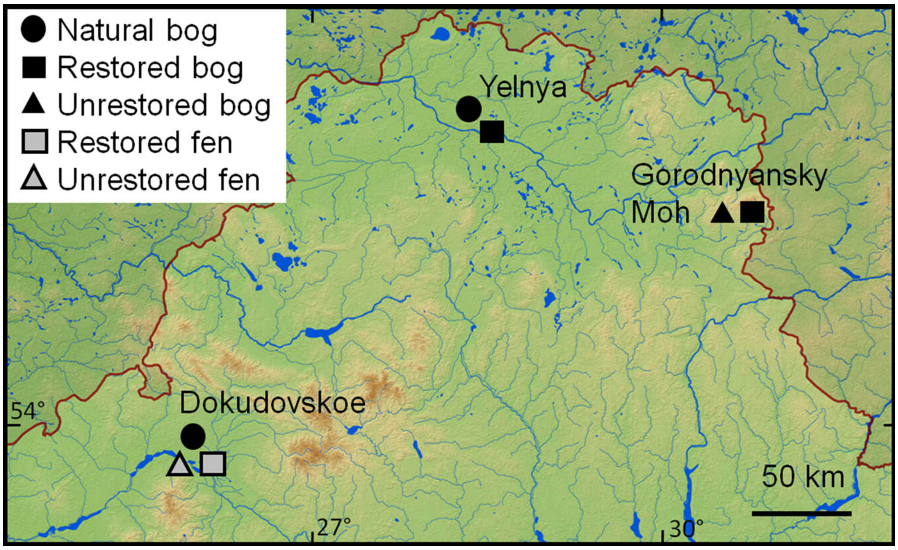

Fig. 1 Locations of the study sites on the map of Belarus

restored and unrestored sites, and Dokudovskoe fen contained restored and unrestored sites. In addition, we used the bog area in Dokudovskoe mire complex as a reference for the restored site in Gorodnyansky Moh.

Yelnya is the largest (200 km^2) and least anthropogenically modified bog in the country (Kozulin et al. 2010). The few ditches have been blocked in recent years. The sample places were located in a ditch dug in the mid-twentieth century and blocked with dams in 2007 and in 2016. The restored site had been burned 17 years before the fieldwork and the vegetation was dominated by heather (*Calluna vulgaris*).

In Dokudovskoe mire complex, the bog part (2.5 km^2) has remained relatively natural and has characteristic bog vegetation, which is, though, slightly impacted by fires and nearby peat extraction (Жилинский 2013). Beside the bog lay tens of square kilometers of fens, which have been wholly taken to peat milling since 1950-ies and partly rewetted in the last decades. At the restoration site under study (3.5 km^2) peat extraction was finished in 2000 and rewetting was done in 2007.

Gorodnyansky Moh is a small bog (3.3 km^2), wholly disturbed by peat extraction (until about 1980) with two techniques: milling and pit-mining. The water level was raised by dams in a part of the former milling field in 2007 and has increased spontaneously at the pit-mining site—both sites were considered as 'restored' and the part of the milling field, where water level has not been raised, was considered as unrestored.

Data collection

The data were collected from 4th to 7th May 2017. At each site we chose five sampling places in typical water-bodies; additionally we took three samples from the pit-mining site in Gorodnyansky Moh. In each sampling place we performed ten 1 m sweeps with a dip net. The net had a rectangular mouth with 40 cm side and 1 mm mesh. Odonata larvae were picked from the sample on site and identified under the microscope in the lab according to Norling and Sahlén (1997). For each sampling place (considering only the dip-netting plot, not the whole water-body) we determined water depth, proportion of the area in shade in mid-day, pH, and the coverage of emergent vegetation and Sphagna.

Data analyses

The effectiveness of restoration efforts was evaluated by comparing the Odonata assemblages in sampling places at 'restoration' sites with those at 'natural' and 'unrestored' sites. As dependent variables, we used abundance and species richness of Odonata in general and of bog and lagg zone specialists (based on van Dijkstra 2006 and van Kleef et al. 2012). Lagg zone species included those adapted to breeding in water-bodies in bog borders (see Howie and Tromp-van Meerveld 2011 for the description of lagg zones) as well as fen areas. Because the data distribution did not allow parametric modelling of abundance and species richness, we used Mann–Whitney U-tests in two sets: (i) sampling places at restored versus unrestored, and (ii) at restored versus natural sites. For each comparison we included only the mires where both types of sites were present: (i) Dokudovskoe fen and Gorodnyansky Moh bog; (ii) restored site from Gorodnyansky Moh bog together with natural reference from Dokudovskoe bog and Yelnya bog. To exclude the geographical variability, we standardised the abundance and species richness data according to the following function:

$$s_{ij} = \frac{t_{ij} - m_j}{d_j}$$

where s_{ij} is the standardised value for the i-th sampling place in j-th mire, t_{ij} is the true value at the place, m_j is the mean and d_j the standard deviation within sampling places in j-th mire.

We further compared the sampling places with and without bog and lagg zone species in respect of the environmental variables. We focused only on bog areas (i.e. left out the fen areas in Dokudovskoe) and pooled all the samples for Mann–Whitney U-tests.

Results

The abundance and species richness of Odonata in restored sites were higher than in unrestored sites. Actually, in unrestored sites we found larvae only in three ditches in Dokudovskoe peatland and these were widespread and generalistic species (Tables 1, 2). In restored and natural sites, the abundance and species richness were similar; both types of sites also hosted species of conservation concern in European Union:

Table 1 The differences of Odonata assemblages in restored, natural, and unrestored sites

		Restored versus natural			Restored versus unrestored		
		Medians	U	p	Medians	U	p
Odonata in general	Abundance	6 and 5.5	48	0.278	11 and 0	9	< 0.001
	Species richness	7 and 4.5	65	1	5 and 0	4	< 0.001
Bog species	Abundance	0 and 1	32	0.041			
	Species richness	0 and 1	32	0.041			
Lagg zone species	Abundance	3 and 0	31	0.035			
	Species richness	1 and 0	22	0.008			

The number of sampling places in natural and unrestored sites was 10. In restored sites we had in total 18 sampling places, but for both comparisons we included 13 places and the samples overlapped partly (see "Data analysis")

Table 2 Total number of individuals of Odonata larvae and number of sites from where the species was caught (in the parentheses)

	Dokudovskoe Restored n = 5	Dokudovskoe Unrestored n = 5	Yelnya Natural n = 5	Yelnya Restored n = 5	Dokudovskoe Natural n = 5	Gorodnyansky Moh Restored n = 8	Gorodnyansky Moh Unrestored n = 5
Aeshna cynea						5(2)	
Aeshna juncea[a]					2(1)	1(1)	
Aeshna subarctica[a]			1(1)				
Anax imperator	1(1)		1(1)			2(2)	
Coenagrion hastulatum[b]					8(1)	10(3)	
Coenagrion pulchellum					4(1)		
Cordulia aena	14(3)		2(1)		28(5)	5(2)	
Enallagma cyathigerum					2(2)		
Erythrosoma najas	6(1)	1(1)					
Leucorrhinia albifrons[a]					5(2)		
Leucorrhinia dubia[a]			12(2)			1(1)	
Leucorrhinia pectoralis[b]	5(1)					2(1)	
Leucorrhinia rubicunda[b]			3(1)	12(2)		26(6)	
Libellula quadrimaculata	25(4)	2(2)		5(3)	12(5)	11(4)	

Mire species are differentiated from more generalistic species (according to van Dijkstra 2006 and van Kleef et al. 2012)

[a]Bog species

[b]Fen or lagg zone species

Leucorrhinia albifrons and *L. pectoralis* (Table 2). However, restored sites hosted fewer bog species and more lagg zone species compared to natural sites (Table 1).

We found bog specialists in both natural sites (Table 2). Bog specialists at restored sites only occurred in pit-mining area in Gorodnyansky Moh: two larvae of two species (*Aeshna juncea* and *Leucorrhinia dubia*). This area was also notably species rich (median per sampling place: four species, c.f. Table 1). The only detected habitat difference between sampling places with or without specialist species was the greater depth of the places where we found bog specialists ($U = 31$, $p = 0.011$, $n = 28$). The shallowest place where bog specialists occurred was 30 cm deep.

Discussion

Our observations at restoration sites draw attention to three phenomena: (i) no comprehensive return of bog specialists, (ii) occurrence of lagg zone species, and (iii) rich community of Odonata at former pit-mining sites. We call for testing those results in other regions as our study included only three mires and the sites have been visited only once.

Our data suggest that ditches in peat milling fields were inhospitable for Odonata in general. At such a site in Dokudovskoe, we only found three larvae of two species: *Libellula quadrimaculata*, a generalist species that was most widespread across all habitat types in our study, and *Erythromma najas*, a species not characteristic of bogs.

Our results show that the colonisation of restoration sites by bog specialists is not straightforward. For example, in the studied areas *L. albifrons* and *Aeshna subarctica* only occurred at natural sites, probably because the water-bodies at restoration sites were too shallow. Even in the dammed ditch with relatively ombrotrophic habitat characteristics and location in the intact bog landscape in Yelnya, we did not detect any bog specialist species, though the surrounding populations should have ensured colonisation. Elo et al. (2015) found several bog specialists at such unmined restoration sites just 3 years after damming: *A. juncea*, *Coenagrion hastulatum* and *A. subarctica*, whereas *L. dubia* inhabited even drained sites in their study. The reason for the scarcity of bog specialists in the dammed ditch in Yelnya may lay in the greater attractiveness and quality of nearby natural pools. Also the fact that the dams did not block the water flow completely may be a deterring factor for bog species, which are adapted to lentic water-bodies. Even if not creating habitats in ditch, the damming is necessary for surroundings: to prevent pool overgrowth by Sphagna and trees, considering that adults in many species of Odonata avoid shaded areas (Remsburg et al. 2008).

The dragonfly assemblages indicated that rewetting of the degraded bogs provided water-bodies resembling those in lagg zones and fens. This could increase biodiversity at landscape scale. Lagg zones can develop inside bogs after rewetting; and compared to bogs, they have higher pH, Ca concentrations, and larger fluctuations in hydroregime (Howie and van Meerveld 2018). We could not find environmental variables responsible for the occurrence of lagg zone species, but probably a complex of habitat factors is the reason. For example, the hydrochemistry may be modified due to exposure of underlying fen peat or mineral soil after mining or digging the ditches; and water level may be more fluctuating in restoration sites than in intact bogs (Klavinš et al. 2011; Jarašius et al. 2015). Developing of lagg surrogates within former bogs could be a positive outcome of rewetting, because mire edge habitats are even more degraded than raised bogs, but difficult to restore, because of the adjacent land-use (Howie and Tromp-van Meerveld 2011; Verberk et al. 2010).

Our sampling in Gorodnyansky Moh suggested that the biodiversity of Odonata at former peat extraction sites tightly depends on the mining technique and rewetting effectiveness. The remnant water-bodies from pit-mining were inhabited by diverse and rarity-rich fauna containing several bog specialists as well as species characteristic of lagg zones. This result could probably be generalised to the whole assemblage of aquatic invertebrates as has been shown at analogous sites in Netherlands (van Duinen et al. 2013). Similarly, the recolonization of mire plants is much facilitated in the traditional, old-style pits due to their maintenance of a high water table (Soro et al. 1999).

Based on our findings, we suggest three means to support the biodiversity of mire Odonata: (i) protecting the remaining natural mires, (ii) replacing milling with methods like pit-mining that do not need large areas kept drained (see e.g. Mikhailov et al. 2017) and therefore inhospitable for Odonata, and (iii) sustaining or digging depressions in former milled sites now designated for restoration to create pools for Odonata, especially bog species.

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Conflict of interest The authors declare that they have no conflict of interest.

Appendix

See Table 3.

Table 3 The sampling places

Latitude	Longitude	Mire	Restoration status	Type of water body
53.82564	25.41393	Dokudovskoe	Restored	Flooded area
53.82518	25.41317	Dokudovskoe	Restored	Flooded area
53.82111	25.40966	Dokudovskoe	Restored	Flooded area
53.81506	25.41222	Dokudovskoe	Restored	Beaver-flooded area
53.81847	25.41648	Dokudovskoe	Restored	Pool
53.79892	25.44142	Dokudovskoe	Natural	Bog lake
53.79974	25.44368	Dokudovskoe	Natural	Bog lake
53.79904	25.44461	Dokudovskoe	Natural	Bog lake
53.79818	25.4433	Dokudovskoe	Natural	Bog lake
53.7976	25.44081	Dokudovskoe	Natural	Bog lake
53.83076	25.43265	Dokudovskoe	Unrestored	Canal
53.83017	25.43124	Dokudovskoe	Unrestored	Canal
53.83103	25.43089	Dokudovskoe	Unrestored	Ditch
53.83164	25.43165	Dokudovskoe	Unrestored	Ditch
53.83189	25.43321	Dokudovskoe	Unrestored	Ditch
55.07867	30.14947	Gorodnyansky Moh	Restored	Flooded area
55.07708	30.14856	Gorodnyansky Moh	Restored	Flooded area
55.07746	30.14847	Gorodnyansky Moh	Restored	Ditch
55.07768	30.14837	Gorodnyansky Moh	Restored	Flooded area
55.07831	30.14813	Gorodnyansky Moh	Restored	Flooded area
55.08058	30.151	Gorodnyansky Moh	Unrestored	Flooded area
55.08027	30.15029	Gorodnyansky Moh	Unrestored	Flooded area
55.07984	30.15168	Gorodnyansky Moh	Unrestored	Ditch
55.08008	30.15209	Gorodnyansky Moh	Unrestored	Flooded area
55.08025	30.15165	Gorodnyansky Moh	Unrestored	Ditch
55.08583	30.13379	Gorodnyansky Moh	Restored	Pool
55.08593	30.13378	Gorodnyansky Moh	Restored	Pool
55.17975	30.22193	Gorodnyansky Moh	Restored	Pool
55.56766	27.82035	Yelnya	Restored	Pool in a dammed ditch
55.56669	27.82075	Yelnya	Restored	Pool in a dammed ditch
55.56548	27.8212	Yelnya	Restored	Pool in a dammed ditch
55.564	27.8217	Yelnya	Restored	Pool in a dammed ditch
55.56223	27.82253	Yelnya	Restored	Pool in a dammed ditch
55.57157	27.81512	Yelnya	Natural	Flooded area
55.57309	27.81651	Yelnya	Natural	Flooded area

Table 3 continued

Latitude	Longitude	Mire	Restoration status	Type of water body
55.57385	27.81748	Yelnya	Natural	Pool
55.57424	27.81685	Yelnya	Natural	Pool
55.57432	27.81612	Yelnya	Natural	Pool

References

Bonifait S, Villard M (2010) Efficiency of buffer zones around ponds to conserve odonates and songbirds in mined peat bogs. Ecography 33:913–920. https://doi.org/10.1111/j.1600-0587.2009.06088.x

Brown LE, Ramchunder SJ, Beadle JM, Holden J (2016) Macroinvertebrate community assembly in pools created during peatland restoration. Sci Total Environ 569:361–372

Dijkstra KDB (2006) Field guide to the dragonflies of Britain and Europe. British Wildlife Publishing, Gillingham

Elo M, Penttinen J, Kotiaho JS (2015) The effect of peatland drainage and restoration on Odonata species richness and abundance. BMC Ecol 15:11

Howie SA, Tromp-van Meerveld I (2011) The essential role of the lagg in raised bog function and restoration: a review. Wetlands 31:613–622

Howie SA, van Meerveld HJ (2018) Laggs can develop and be restored inside a raised bog. Wetl Ecol Manag. https://doi.org/10.1007/s11273-018-9597-8

Jarašius L, Lygis V, Sendžikaitė J, Pakalnis R (2015) Effect of different hydrological restoration measures in Aukštumala Raised Bog damaged by peat harvesting activities. Baltic For 21:192–203

Kļaviņš M, Kokorīte I, Spriņge G, Skuja A, Parele E, Rodinovs V, Druvietis I, Strāke S, Urtāns A (2011) Water quality in cutaway peatland lakes in Seda mire, Latvia. Ecohydrol Hydrobiol 10:61–70

Kozulin A, Zuyonok S, Rakovich V (2010) Local and global impacts of mire drainage: an impetus for hydrology restoration: Yelnia Mire, Belarus. In: Eiseltová M (ed) Restoration of lakes, streams, floodplains, and bogs in Europe: principles and case studies, vol 3. Springer, Dordrecht, pp 355–366

Kozulin A, Grummo D, Zeliankevich N (2016) Wetland restoration experience in Belarus. Presentation in the international workshop "Harvested and damaged peatlands: prospects of restoration and conservation"

Larson DJ, House NL (1990) Insect communities of Newfoundland bog pools with emphasis on the Odonata. Can Entomol 122:469–501

Mazerolle MJ, Poulin M, Lavoie C, Rochefort L, Desrochers A, Drolet B (2006) Animal and vegetation patterns in natural and man-made bog pools: implications for restoration. Freshw Biol 51:333–350

Mikhailov AV, Zhigulskaya AI, Yakonovskaya TB (2017) Excavating and loading equipment for peat mining. IOP Conf Ser Earth Environ Sci 87:022014

Noreika N, Kotiaho JS, Penttinen J, Punttila P, Vuori A, Pajunen T, Kotze DJ (2015) Rapid recovery of invertebrate communities after ecological restoration of boreal mires. Restor Ecol 23:566–579

Noreika N, Kotze DJ, Loukola OJ, Sormunen N, Vuori A, Päivinen J, Penttinen J, Punttila P, Kotiaho JS (2016) Specialist butterflies benefit most from the ecological restoration of mires. Biol Conserv 196:103–114

Norling U, Sahlén G (1997) Odonata, dragonflies and damselflies. In: Nilsson A (ed) Aquatic insects of North Europe: a taxonomic handbook, vol 2. Odonata-Diptera, Apollo Books, Stenstrup

Priede A, Mežaka A, Dobkeviča L, Grīnberga L (2016) Spontaneous revegetation of cutaway fens: can it result in valuable habitats? Mires Peat 18:1–14

Punttila P, Autio O, Kotiaho JS, Kotze DJ, Loukola OJ, Noreika N, Vuori A, Vepsäläinen K (2016) The effects of drainage and restoration of pine mires on habitat structure, vegetation and ants. Silva Fenn 50:1462

Remsburg AJ, Olson AC, Samways MJ (2008) Shade alone reduces adult dragonfly (Odonata: Libellulidae) abundance. J Insect Behav 21:460–468

Rydin H, Jeglum JK (2013) The biology of peatlands, 2nd edn. Oxford University Press, Oxford

Sommer RS, Thiele V, Seppä H (2015) Use and misuse of the term 'glacial relict' in the Central European biogeography and conservation ecology of insects. Insect Conserv Divers 8:389–391

Soro A, Sundberg S, Rydin H (1999) Species diversity, niche metrics and species associations in harvested and undisturbed bogs. J Veg Sci 10:549–560

Spitzer K, Danks HV (2006) Insect biodiversity of boreal peat bogs. Annu Rev Entomol 51:137–161. https://doi.org/10.1146/annurev.ento.51.110104.151036

Sushko G (2014) The zoogeographic composition of the insect fauna (Odonata, Coleoptera, Macrolepidoptera) in the raised bogs of the Belarusian Lakeland. Entomol Rev 94:40–48

Tanavitskaya N, Kozulin A, Thiele A (2008) Inventory overview of status of Peatlands in Belarus. In: Thiele A (ed) Inventory on area, situation and perspectives of rewetting of peatlands in Belarus, Russia & Ukraine. Michael Hermsen Foundaton, Bremen, pp 3–32

van Duinen G-J, Verberk W, van Kleef H, van der Velde G, Leuven R (2013) Pristine, degraded and rewetted bogs: Restoration constraints for aquatic macroinvertebrates. In: van Duinen Rehabilitation of aquatic invertebrate communities in raised bog landscapes. PhD Thesis. Radboud University, Nijmegen, pp 63–86

van Kleef HH, van Duinen GJA, Verberk WCEP, Leuven RS, van der Velde G, Esselink H (2012) Moorland pools as refugia for endangered species characteristic of raised bog gradients. J Nat Conserv 20:255–263

Verberk WCEP, Leuven RSEW, Van Duinen GA, Esselink H (2010) Loss of environmental heterogeneity and aquatic macroinvertebrate diversity following large-scale restoration management. Basic Appl Ecol 11:440–449

Ventė L. http://www.aukstumala.lt/atsisiusti/

Жилинский ДЮ (2013) Динамика растительного покрова нарушенных болотных экосистем под влиянием вторичного заболачивания (на примере болота « Докудовское »). Весці НАН Беларуси. Серия Биологических Наук. 2:15–23