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Research Article

Application of jute mattings to control growth of submerged macrophytes in a shallow clear-water pond

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Abstract – The jute mattings of two different densities were tested to control growth of *Elodea canadensis* Michx. and *Myriophyllum spicatum* L. in the Velký Bolevecký pond (West Bohemia, Czechia) during fourteen months. Both jute densities prove to be effective, permeable and stayed intact for one year. Results showed significant interaction among species, jute density and date in both abundance and length of *Elodea* and *Myriophyllum* fragments. When tested separately, we found the significant difference between abundance of *Elodea* and *Myriophyllum* fragments on the jute mattings, among the sites, and in time, but not between the two jute densities. *Elodea* dominated the sites due to spread of fragments from mowing that continued at the pond. However, the fragment length of given species varied between the two jute densities. They might easier root, but it could be also explained by the variability of sampled quadrats. Fragment lengths of *Elodea* and *Myriophyllum* were also changing in time but the length did not significantly differ between the two species or among the sites. Although *Elodea* and *Myriophyllum* dominated the jute mattings by the end, their progress was slower than in control sites.

Keywords: Biomanipulation / jute / *Elodea canadensis* / *Myriophyllum spicatum* / shallow lake

1 Introduction

The European water bodies are affected by many negative factors, such as eutrophication, unsustainable aquaculture management, spread of invasive species and climate change, and this has led to progressive loss of macrophyte species (Hussner, 2012; Jůza *et al.*, 2019; Kosten *et al.*, 2009; Murphy *et al.*, 2018; Rahel and Olden, 2008; Sayer *et al.*, 2008). However, the subsequent restoration and biomanipulation treatments in water bodies have not always meet all expectations, and other problems may arise, for instance, development of extensive homogenized stands of submerged macrophytes that suppress less competitive macrophyte species, impair the multiple uses of surface water for recreation purposes, and could also interfere with a good ecological status of a water body (Hilt *et al.*, 2006; Verhofstad *et al.*, 2017; WFD, 2000).

There are biological, chemical, and mechanical methods to control unwanted macrophyte species (Zehnsdorf *et al.*, 2015). One of the most widely used mechanical methods is harvesting (Bartodziej *et al.*, 2017). On the one hand, it helps to remove nutrients deposited in plant and periphyton biomass, on the other hand, it is relatively expensive, as it must be applied repeatedly, and causes spread of vegetative fragments of species such as *Elodea*. Furthermore, it might negatively affect fish fry, as well as molluscs living on the plant and bottom surface (Hoffmann *et al.*, 2013; Kalff, 2002; Redekop *et al.*, 2016; Zehnsdorf *et al.*, 2015).

Another mechanical approach to macrophyte control is application of benthic barriers but the right choice of the material should be considered. The artificial materials were applied in the past (*e.g.*, polypropylene, polyethylene, and fiberglass; Engel, 1984; Mayer, 1978). However, their use has several disadvantages. They are very difficult to handle in water. The artificial materials are either not permeable or their permeability is limited. This may cause gas evolution and requirement of additional manipulation and/or weighing that makes removal from the habitat difficult. When spaces were made for gas release, macrophytes were reported to grow through (Hofstra and Clayton, 2012). As apparent from gas evolution, the artificial materials also affected physical and chemical conditions of underlying sediment (*e.g.*, increase in NH_4 and decline in dissolved oxygen; Engel, 1984; Ussery *et al.*, 1997). Gunnison and Barko (1992) recommended installation of materials in colder periods of the year, when less

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developed macrophyte stands occurred and decomposition processes were slower. Additionally, subsequent sedimentation on the mattings enabled macrophyte re-colonization and cleaning of mattings was advised (Engel, 1984; Mayer, 1978). The application of artificial mattings also eliminated occurrence of macroinvertebrates that could affect higher trophic levels (Engel, 1984; Ussery *et al.*, 1997). Furthermore, there is an increasing recent awareness of release of microplastics to freshwater ecosystems (Eerkes-Medrano *et al.*, 2015), thus application of such materials seems to be out of date.

The new approach using natural materials, such as coconut fiber and jute mattings, was successfully applied, for example, to limit growth of *Lagarosiphon major* Ridley in Lough Corrib in Ireland (Caffrey *et al.*, 2010), to study effects on *Ceratophyllum demersum* L., *Egeria densa* Planch., *Elodea canadensis* Michx., *Hydrilla verticillate* (L.f.) Royle, *Lagarosiphon major*, and *Potamogeton crispus* L. in an experimental study in New Zealand (Hofstra and Clayton, 2012), and to limit *Najas marina* ssp. *intermedia* (Wolfg. ex Gorski) Casper and *Elodea nuttallii* (Planch.) H.St.John in four lakes in Germany (Hoffmann *et al.*, 2013). The natural materials have considerable advantages as they are easy to work with, permeable and biodegradable (Caffrey *et al.*, 2010; Hoffmann *et al.*, 2013).

Based on these positive results of the mentioned studies, two different jute mattings were applied on sites dominated mainly by *Elodea* and *Myriophyllum* in a shallow Velký Bolevecký pond. The main objective of this study was to determine whether: (i) were jute mattings able to control invasive *Elodea* and *Myriophyllum* and (ii) was a significant difference in abundance and fragment length between *Elodea* and *Myriophyllum*, between two different jute densities and among the study sites during the experiment.

2 Material and methods

2.1 Study site

The Velký Bolevecký pond (hereafter VBP; 49°46′26.5″N, 13°23′50.9″E) is situated near the city Plzeň (West Bohemia, Czechia). After a recent recovery (Jůza *et al.*, 2019), the pond is mainly used for recreational purposes. It has the surface area of 43 ha, mean and maximum depth of 2.1 m and 4.5 m, respectively (Duras and Dziaman, 2010). The basic physico-chemical parameters correspond with its recent oligotrophic state (Tab. 1). The bottom mostly consists of fine-grained muddy sediment, but sandy littoral slopes can be found at some beach shores used for recreation. The VBP has been under restoration and biomanipulation treatments due to eutrophication since 2006, which included direct intervention into the P cycle using Al and Fe coagulants, substantial fish stock reduction, additional stocking with predatory fish, and reintroduction of thirteen native macrophyte species (*e.g.*, *Potamogeton crispus*, *Nuphar lutea* (L.) Sm., *Sagittaria sagittifolia* L., and *Eleocharis acicularis* (L.) Roem. & Schult.; Duras and Dziaman, 2010; Jůza *et al.*, 2019). Nevertheless, positive visible changes in water quality and development of macrophytes have brought a new problem with immense growth of homogenized macrophyte stands. They are currently dominated by *Elodea* and *Myriophyllum*, but *Egeria densa* has started spreading as well. These dense macrophytes can grow up to several meters (Fig. S1). They benefit from their rapid establishment through vegetative reproduction. Alien invasive species *Elodea* and *Egeria* that are native to North and South America, respectively, were possibly introduced to the VBP as unwanted aquarium species. Some species could not be determined to species level during the experiment. For more detailed information about the VBP, its history, management development, monitoring, restoration, and biomanipulation treatments, see Jůza *et al.* (2019).

Table 1. The physico-chemical surface water parameters were measured and analysed bi-weekly from April to September in 2017 and 2018 at the same point at Velký Bolevecký pond. T = temperature, Z_{SD} = transparency, Chl-*a* = chlorophyll *a*, DO = dissolved oxygen, Cond = conductivity, DOC = dissolved organic carbon, TN = total nitrogen, TP = total phosphorus, TDP = total dissolved phosphorus, and ANC = acid neutralization capacity.

Parameters	Median (range)
T (°C)	20.5 (7.3–24.9)
Z_{SD} (m)	3.6 (2.2–4.8)
Chl-*a* ($\mu g\,L^{-1}$)	2.8 (0.5–8.9)
DO (%)	95.5 (77.0–120.0)
Cond ($mS\,m^{-1}$)	40.7 (37.6–45.9)
pH	7.7 (6.3–9.2)
NO_3-N ($mg\,L^{-1}$)	0.10 (0.10–0.36)
NH_4-N ($mg\,L^{-1}$)	0.045 (0.015–0.090)
TN ($mg\,L^{-1}$)	0.6 (0.3–1.3)
TDP ($mg\,L^{-1}$)	0.007 (0.005–0.012)
TP ($mg\,L^{-1}$)	0.018 (0.013–0.032)
ANC-4.5 ($mmol\,L^{-1}$)	0.61 (0.49–0.87)
Ca ($mg\,L^{-1}$)	26.0 (24.0–29.0)

2.2 Jute experiment

Three sites dominated by *Elodea* and *Myriophyllum* were selected in less recreationally used parts of the VBP on April 27, 2017 (I, II and III; Fig. 1). Macrophyte occurrence, average cover and length at the selected sites are showed in Table 2. Three belts (2 × 12 m) were marked with floats at each site. The macrophyte taxonomic composition, coverage (%) and average length (cm) were estimated within each belt that was divided into three parts (2 × 4 m).

The selected sites were mown by a harvester on May 15, 2017. Subsequently, the two jute belts of lower ($305\,g\,m^{-2}$, hereafter L) and higher density ($365\,g\,m^{-2}$, hereafter H) of the size 1.9 × 12 m were placed on stubbles on May 17. The jute mattings were placed at the depth of 2 m, anchored to the sediment with stainless steel hooks and unreeled towards the center of the VBP. The cobble stones were used as additional weight. Next to the mattings were placed control plots without the jute mattings. The jute mattings and controls were left 2–3 m apart (Fig. 1).

During the experiment abundance and average length (cm) of plant fragments (from cutting) as well as macrophytes rooting on and/or growing through the jute matting were counted and measured by a scuba diver in the first half of every month during June–August 2017. However, abundance of

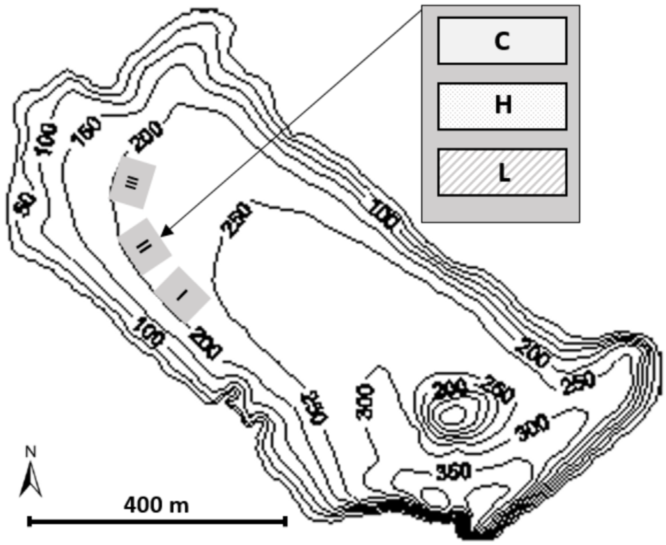

Fig. 1. The bathymetric map (depth in centimetres) of the Velký Bolevecký pond with the position of the studied sites (I, II and III) and in detail a triplicate of plots covered with either lower (L = 305 g m^{-2}) or higher density (H = 365 g m^{-2}) jute mattings, and a control (C = uncovered plot).

macrophytes on the jute mattings increased so the measurements continued in three 1 × 1 m randomly placed quadrats at each jute matting from September 2017 to May 2018. The coverage (%) and average length (cm) of macrophyte species were noted in controls from June 2017 to May 2018.

The jute condition was also recorded by the scuba diver from June 2017 to August 2018. The scales were modified from Caffrey *et al.* (2010) and Hoffmann *et al.* (2013): (i) jute natural disintegration (0 = no sign of degradation, 1 = disintegrates on contact, 2 = partially degraded, 3 = completely degraded); (ii) visible changes in the sediment color beneath the jute (0 = no visible changes, 1 = slight change in color, 2 = considerable change in color); (iii) the visible amount of gas evolution and accumulation beneath the jute (0 = almost none: no visible gas bubbles/no buckling in the jute, 1 = some: low emissions of gas/little buckling in the jute, 2 = high: frequent gas emissions/increased buckling, 3 = very high: large and frequent gas emissions/affected areas are floating); and (iv) sedimentation on the jute (0 = no sign of sedimentation, 1 = partially covered, 2 = still visible, 3 = completely covered). Additionally, sedimentation thickness was measured (cm).

No plots were checked in December 2017, February, and March 2018 due to the occurrence of thick ice cover.

2.3 Water analyses

Two water samples were randomly taken by a syringe under each jute matting and filtered *in situ* using 0.45 μm nylon syringe filters on August 8, 2017, as at the sites were visible changes in sediment color and gas evolution. The samples were transported to the accredited laboratories of the Vltava River Authority, Plzeň, Czech Republic, the same day and tested for $N\text{-}NO_2$, $N\text{-}NO_3$, $N\text{-}NH_4$, and total dissolved phosphorus (TDP).

The concentrations of TDP were assessed using inductively-coupled plasma spectrometry (Agilent 8800 ICP-QQQ; EN ISO 17294-2, 2004). Spectrophotometry and ion liquid chromatography were used for $N\text{-}NO_2$, $N\text{-}NO_3$ and $N\text{-}NH_4$ analysis (Shimadzu UV-1650PC; ISO 7150-1, 1994; Dionex ICS-1000; EN ISO 10304-1, 2009).

2.4 Statistical analyses

To reveal the effect of different jute density among sites and over time on abundance and length of macrophyte shoots/fragments, as well as effect of different jute density among sites and over time on the selected water quality parameters, sedimentation thickness, generalized linear model with gaussian distribution were applied. The final model was determined by sequential deletion of the last explanatory significant explanatory parameters (or interaction terms) from the full model. The significance of parameters was evaluated using Chi-tests from analysis of deviance. The final model included only parameters with significant *p*-values. Post-hoc Tukey tests were performed to investigate differences among treatments. In addition generalized linear model with quasi-binomial distribution (quasi-binomial distribution that accounts for data overdispersion were applied to compare macrophyte cover among control sites; Zuur *et al.*, 2009). Further steps followed the same protocol as in previous analysis except for *F*-tests used to evaluate parameter significance. All analysis were done in R 4.0.1 (R Core Team, 2021).

3 Results

In total, six macrophytes occurred at the studied plots during our surveys. Apart from both dominants, *Elodea* and *Myriophyllum*, *Batrachium* sp., *Chara* sp., *Egeria densa*, and *Potamogeton crispus* also increased their abundances at the sites.

The abundance of fragments of *Elodea* prevailed on the jute mattings, regardless of jute density (Fig. 2). These were mostly remaining cuttings from the mowing and only a few pieces of *Elodea* and *Myriophyllum* grew directly from the sediment through the jute mattings during the experiment (Tab. 3). Although *Elodea* gained foothold on the mattings, its extent was not as big as in control sites (Figs. S2 and S3).

On the jute mattings, a significant difference was among species, material and date in both abundance and length of *Elodea* and *Myriophyllum* fragments (Tab. 4, Fig. 2). When tested separately, significant difference was found in the number of fragments between *Elodea* and *Myriophyllum*, among the sites I, II and III, and during the time, but not between the material L and H. Nevertheless, the macrophyte fragment length significantly differed between material L and H during the time, but not between *Elodea* and *Myriophyllum*, and among the sites (Tab. 4).

On control sites, the significant difference was detected in the macrophyte cover between *Elodea* and *Myriophyllum* (Tab. 5; Fig. S3). The macrophyte cover did not significantly change over the course of time and among the sites I, II and III. Similarly to the macrophyte cover, there was a significant difference in shoot length between *Elodea* and *Myriophyllum*, and the

Table 2. The macrophyte average (AVG) cover and length at the selected sites before the jute mattings were placed in April 27, 2017.

Area	Material	Species	AVG cover (%)	AVG Length (cm)
	A	*E. canadensis*	45	30
	A	*M. spicatum*	52	160
I	A	*Bratrachium* sp.	3	40
	B	*E. canadensis*	30	30
	B	*M. spicatum*	65	160
	A	*E. canadensis*	45	30
	A	*M. spicatum*	55	160
II	B	*E. canadensis*	34	30
	B	*M. spicatum*	61	160
	B	*Chara* sp.	5	50
	A	*E. canadensis*	40	30
III	A	*M. spicatum*	60	160
	B	*E. canadensis*	55	30
	B	*M. spicatum*	45	160

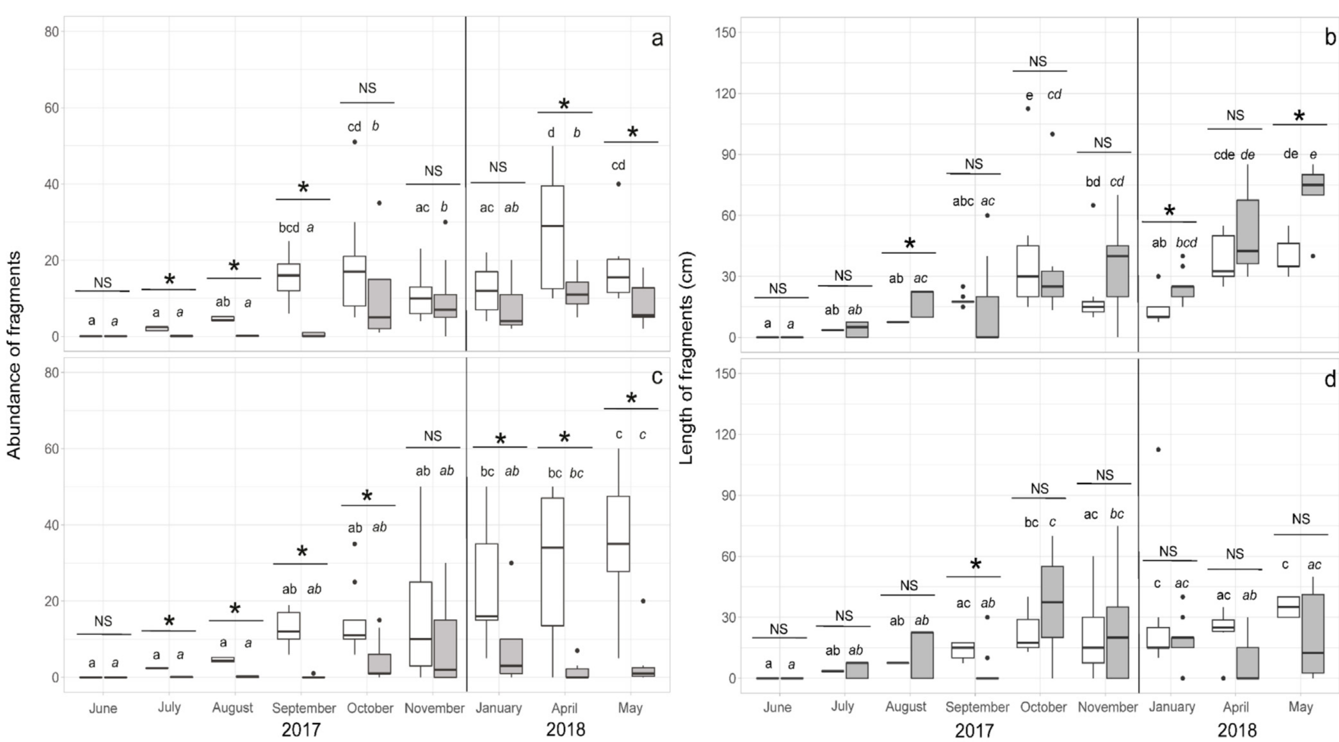

Fig. 2. Abundance (left) and length (right) of fragments on L (a, b) and H (c, d) jute matting during time. Open and grey boxplots denote to *Elodea canadensis* and *Myriophyllum spicatum*, respectively. Significant differences between the species at given month are marked by asterisk, non-significant ones by 'NS'. Different letters denote significant difference ($p < 0.05$) among months in either species (*Elodea canadensis* = small letters, *Myriophyllum spicatum* = small letters in italics). Box limits correspond to upper and lower quartiles, horizontal bar to the median, and points show outliers outside the 1.5 times interquartile range among species.

length also differed over time and within the sites I, II and III (Tab. 5, Fig. S4).

The jute mattings stayed intact until June 2018 (*i.e.*, 12 months). Even though we did not continue with the macrophyte survey due to loss of both jute plots L and H at the site III (*i.e.*, the floats broke off and the sites were subsequently damaged by the harvester), we continued to check condition of the remaining mattings until August 2018. They started to decompose, lose compactness in June 2018, and did not work as the barrier in August 2019. The changes in sediment color under mattings from light-brown-grey to black-grey were visible at the beginning of the experiment. The minor gas evolution was also mainly visible in the first months, and it did not affect stability or effect of the jute. The changes in sediment and gas evolution could be enhanced by development of filamentous algae, which appeared on the jute in July and

Table 3. Number of plant species that grew through the jute mattings. The sites are present only when at least one macrophyte species occurred. The pieces were counted on the whole mattings from June to August 2017 and then in three randomly placed quadrats.

Area	Material	Repetition	Date 2017	Species	Abundance
I	L	1	July 18	*E. canadensis*	3
I	L	1	July 18	*M. spicatum*	2
I	L	1	August 8	*E. canadensis*	4
I	H	1	July 18	*M. spicatum*	3
I	H	1	August 8	*M. spicatum*	4
I	L	1	September 3	*E. canadensis*	6
I	L	1	October 3	*E. canadensis*	4
I	H	3	October 3	*E. canadensis*	9
I	H	1	October 3	*M. spicatum*	1
I	H	3	October 3	*M. spicatum*	5
II	L	1	September 3	*E. canadensis*	1
II	L	2	September 3	*M. spicatum*	1
II	L	1	October 3	*E. canadensis*	2
II	L	2	October 3	*E. canadensis*	5
II	L	1	October 3	*M. spicatum*	1
II	L	2	October 3	*M. spicatum*	5
II	H	1	October 3	*E. canadensis*	12
II	H	2	October 3	*E. canadensis*	1
II	H	3	October 3	*E. canadensis*	3
II	H	3	October 3	*M. spicatum*	1
III	H	1	September 3	*E. canadensis*	1
III	H	1	September 3	*M. spicatum*	1
III	H	2	October 3	*E. canadensis*	9
III	H	3	November 19	*M. spicatum*	2

Table 4. The surveys of jute mattings. *df* = degrees of freedom, empty space means it was not significant in a final model. The significant results are in bold.

	Abundance of fragments		Length of fragments (cm)	
	df	*p*-value	*df*	*p*-value
Species × Material	1	**0.01**	1	**0.04**
Species × Date	1	<**0.001**	1	0.55
Material × Date	1	0.26	1	<**0.001**
Species × Material × Date	1	**0.01**	1	<**0.001**
Species	1	<**0.001**	1	0.13
Material	1	0.79	1	<**0.001**
Area	2	<**0.001**		
Date	1	<**0.001**	1	<**0.001**

Table 5. The surveys of control plots. *df* = degrees of freedom, empty spaces mean it was not significant in a final model. The significant results are in bold.

	Cover (%)		Length (cm)	
	df	*p*-value	*df*	*p*-value
Area			2	<**0.001**
Species	3	<**0.001**	3	<**0.001**
Date			1	<**0.001**

August 2017, but also later in October and November 2017, and in April and May 2018. The sedimentation on jute mattings was significantly increasing over time (GLM; $\chi_{1,67} = p = < 0.001$; Tab. S1).

There was no variability in N-NO_2 and N-NO_3 (<0.005 mg L^{-1} and <0.02 mg L^{-1}, respectively) and almost no difference in TDP (apart from one exception of 0.017 mg L^{-1} under the material L at the site I, all samples were <0.008 mg L^{-1}) in water samples taken under the materials L and H, and among the sites I, II and III. The N-NH_4 values ranged from 0.04 mg L^{-1} to 0.27 mg L^{-1} (S.D. 0.07 mg L^{-1}) among the materials and sites, and the significant difference was found only in N-NH_4 ($p = 0.0223$) among the sites I, II and III.

4 Discussion

Although the area of each jute barrier was low (24 m^2), our results confirmed suitability of this method to control growth of *Elodea* and *Myriophyllum* for at least one year, regardless of material density. In comparison with control sites, occurrence of target macrophyte species, as well as abundance of fragments and their height was much lower. Similar results were obtained by Hoffmann *et al.* (2013) with jute density of 300 g m^{-2}. Nevertheless, as one year does not seem like a long period, high sedimentation and plant recolonization was also reported after this period, even when artificial materials were used. Moreover, reapplication or additional manipulation and/or cleaning were advised (Engel, 1984). Thus, to prove the effect of jute mattings, a longer study dealing with different species composition, as well as size of barrier is needed.

The use of mowing and jute mattings at the same time is not optimal, but jute mattings could be placed in shallower parts, *i.e.*, those difficult to reach for a harvester, where they should be cleaned from fragments from time to time to prolong efficiency. However, this will increase the cost of the method. The advantage is that, unlike mowing, the jute matting does not support spread of fragments and/or seeds and could be applied in water bodies with early development stages of target species, when harvesting is not yet necessary (Hoffmann *et al.*, 2013).

The relatively small plots in our experiment suffered from enhanced sedimentation and subsequently attachment of fragments from surrounding fully grown vegetation. Thus, the application of jute mattings should be applied to larger areas. Increased sedimentation in time indeed also reported Caffrey *et al.* (2010), when the size of jute mattings ranged from 100–5000 m^2, and Hoffmann *et al.* (2013), with jute size ranging from 150–300 m^2, but the exact values of sedimentation were not given in the studies. In this study, the attachment of fragments was also increased due to material type (*i.e.*, porosity), yet it has a positive effect on permeability, *i.e.*, only slight gas development and release, but no development of reduction processes under the mattings.

Unlike Caffrey *et al.* (2010), we did not see any shoots of desirable native species, such as *Potamogeton crispus*, growing through the mattings, but they were temporary growing for some period on the mattings in our study. This could be caused by use of material of higher density than in their case (*i.e.*, 200 g m^{-2}).

5 Conclusion

Our study confirms suitability of jute mattings to control growth of *Elodea* and *Myriophyllum*. Moreover, jute mattings seem to be a material, which does not affect physico-chemical parameters of the sediment. Nevertheless, other studies with larger jute mattings and their possible reapplication across ecosystems are needed to reveal a real potential of this method.

Author's contribution

KF, JD, and JV designed the experiment. KF, JD and LV conducted the experiment. LV did statistical analysis. KF wrote first draft. All authors provided comments and additional text revisions.

Conflict of interest

Authors declare no conflict of interest.

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Supplementary Material

Table S1. Basic characteristics of the jute sites during the experiment. L = lower and H = higher density of jute matting, NA = missing data due to loss of localities. Degradation: 0 = no sign of degradation, 1 = disintegrates on contact, 2 = partially degraded, 3 = completely degraded; sediment: 0 = no visible changes, 1 = slight change in color, 2 = considerable change in color; gas evolution: 0 = almost none: no visible gas bubbles/no buckling in the matting, 1 = some: low emissions of gas/little buckling in the matting, 2 = high: frequent gas emissions/increased buckling, 3 = very high: large and frequent gas emissions/affected areas are floating; sedimentation: 0 = no sign of sedimentation, 1 = partially covered, 2 = still visible, 3 = completely covered; and sedimentation thickness.

Figure S1. Common macrophyte density in Velký Bolevecký pond.

Figure S2. Jute density and macrophyte species *Elodea canadensis* (top panels) and *Myriophyllum spicatum* (bottom panels) as abundance (a, b) and length (c, d) of fragments during time. Open and grey boxplots denote to low (L) and high (H) density, respectively. Significant differences between the materials at given month are marked by asterisk, non-significant ones by 'NS'. Different letters denote significant difference ($p < 0.05$) between months at given material (L = small letters, H = small letters in italics). Box limits correspond to upper and lower quartiles, horizontal bar to the median, and points show outliers outside the 1.5 times interquartile range among specie.

Figure S3. Macrophyte species cover in the control plots. Different letters denote significant difference ($p < 0.05$).

Figure S4. Macrophyte length among species (A), sites (B), and in time (C) in the control plots. Different letters denote significant difference ($p < 0.05$).

The Supplementary Material is available at https://www.limnology-journal.org/10.1051/limn/2022013/olm.

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