POTENTIAL OF SUBMERGED VEGETATION TO REMOVE NUTRIENTS FROM EUTROPHIC FISHPONDS*

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The possibility to remove nutrients from two eutrophic fishponds in the Czech Republic through harvesting the dominant submerged species, *Ceratophyllum demersum* and *Stuckenia pectinata*, was evaluated. Both plants were sampled in three locations within the fishpond in two-week intervals from late June to late September 2016. In the biomass of both plants nitrogen and phosphorus concentrations were measured and, subsequently, standing stocks of both elements were calculated. The results revealed that the maximum biomass occurred at different times, in June for *S. pectinata* and in July for *C. demersum*. The maximum standing stocks were 3.61 and 7.44 g N m^{-2} and 0.13 and 0.53 g P m^{-2}, respectively·. These values are within the range reported in the literature for the studied species, but they are about one order of magnitude lower when compared to tall emergent species. The total amount of removable nutrients in the monitored fishponds varied between 448 and 842 kg N and between 30.5 and 31.9 kg P.

macrophytes, *Ceratophyllum demersum*, *Stuckenia pectinata*, phosphorus, nitrogen, shallow water

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INTRODUCTION

Eutrophication can be described as excessive input of nutrients into a water body. The major consequence of eutrophication is excessive growth of algae, cyanobacteria, and macrophytes. Cultural eutrophication is the primary problem most surface waters are facing today. It is probably one of the most visible examples of human changes to the biosphere affecting aquatic ecosystems from the Arctic to the Antarctic (Smith, 2003; Smith, Schindler, 2009; Smith et al., 1999). Phosphorus has long been known as a key factor causing eutrophication of freshwaters and many models were developed to predict eutrophication levels based on the phosphorus loading of water bodies (e.g., Vollenweider, 1968; Dillon, Rigler, 1975; Canfield, Bachmann, 1981). However, nitrogen is also an important element in the process of eutrophication and similar models were developed for nitrogen as well (e.g., Canfield, Bachmann, 1981; Reckhow, 1988).

Macrophytes can very effectively take up nutrients and sequester them in the biomass. Floating macrophytes such as water hyacinth (*Eichhornia crassipes*) or duckweeds (Lemnaceae) take up nutrients from the water while emergent macrophytes such as common reed (*Phragmites australis*) or cattails (*Typha* spp.) take up nutrients from the sediments (Vymazal, 1995; Wetzel, 2001). Submersed macrophytes (sometimes referred to as SAV – submerged aquatic vegetation) are able to take up nutrients from both water and sediments (e.g., Bristow, Whitcombe, 1971; Denny, 1972). Despite the reduced structure and extent of the root system of most submersed macrophytes in comparison to emergent macrophytes, the roots of submersed plants possess many of the functional characteristics of emergent ones (Bristow, 1975). It is generally accepted that submersed vegetation obtains

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nutrients largely from sediments (Carignan, Kalff 1979, 1980; Barko, Smart, 1980, 1981); however, there is clear evidence that nutrients can be taken up directly by shoot tissues of submersed macrophytes (e.g., Bristow, Whitcombe, 1971; Denny, 1980; Rattray et al., 1991).

Emergent plants such as common reed, cattails, or reed canary grass are usually evaluated with respect to removal of nutrients from eutrophic waters and less attention has been paid to submerged aquatic vegetation. Although the dry mass of SAV is low relative to emergent species, the potential of SAV to retain notable amounts of nutrients present in aquatic environment has been documented in several studies (Knight et al., 2003; Pietro et al., 2006).

Removal of excessive aquatic vegetation can help reverse the undesirable effects of eutrophication (Carpenter, Adams, 1977; Kuiper et al., 2017). The advantage of using macrophytes for nutrient removal is not only that they have a large capacity to sequester nutrients in the biomass, but also the method is economical and eco-friendly (Dai et al., 2012). Submerged vegetation harvesting (Fig. 1) combines multiple environmental benefits such as excessive nutrient removal, prevention of water re-pollution by plant decomposition (Hu et al., 2010), and improved conditions for recreational use of water bodies (Quilliam et al., 2015).

At the same time, SAV plays a crucial role in shallow lake ecosystems functioning. Submerged vegetation helps improve water quality and provides habitat, refuge and food resource to numerous aquatic organisms (Carpenter, Lodge, 1986).

Significant habitat disturbance can be seen as a major negative effect of macrophyte harvesting. Mechanical mowing can impact trophic interactions such as herbivore pressure on the remaining vegetation and therefore increase the risk of a regime shift to a turbid state (Van Altena et al., 2016). Thus, special attention should be paid to planning the harvest campaign, not only in terms of maximum nutrient removal but also with regard to local habitat requirements, management history, and nutrient loading (Kuiper et al., 2017).

Fig. 1. Harvesting of submerged vegetation in a fishpond
photo by J. Vymazal

The objectives of this study were to evaluate (*i*) the seasonal growth of *Ceratophyllum demersum* and *Stuckenia pectinata* in two fishponds in the Czech Republic, (*ii*) the amount of nitrogen and phosphorus in the aboveground biomass of both species, and (*iii*) the optimum time for harvest in order to remove maximum amounts of nitrogen and phosphorus. We hypothesised that both species have different seasonal growth pattern, and the period of maximum biomass will differ and therefore, the harvesting time in order to optimise removal of nutrients will differ.

Stuckenia pectinata (L.) Börner (formerly *Potamogeton pectinatus* L.) is a submersed aquatic macrophyte with parvopotamid growth (Hogeweg, Brenkert, 1969). It is cosmopolitan in its distribution and can be found in various environments, such as alkaline fresh and brackish waters, standing and running waters, and in waters of different trophic status (Howard-Williams, 1978; Van Wijk, 1988). *S. pectinata* tends to be very abundant in areas where it occurs (Howard-Williams, 1978). *S. pectinata* is morphologically very variable. The shoots can grow up to 2 m in length and usually produce many side-branches. Sometimes, especially at the end of the growing season, the branching is concentrated in the upper part of the shoots, thus forming densely-leaved brushes at the water surface (Van Wijk, 1988).

Ceratophyllum demersum L. is a cosmopolitan plant species growing in a wide range of habitats. It is quite frequently found in eutrophic waters and it is a useful indicator of high nutrient availability (Best, Visser, 1987; Wells et al., 1997; Eller et al., 2015). In Central Europe, *C. demersum* represents a main component of aquatic vegetation in eutrophic ponds in agricultural landscapes (Hyldgaard et al., 2014; Pelechaty et al., 2014). The plant is clonal, forming only rhizomes and a floating mat submerged below the water surface (Nagengast, Gabka, 2017). *C. demersum* is a nitrophilous macrophyte, which can tolerate high nitrogen concentration and exhibits very good removal of nitrogen from the water column (Tracy et al., 2003; Gao et al., 2009).

MATERIAL AND METHODS

Site description

Two fishponds (Rod and Malý Dubovec) were selected in South Bohemia, Czech Republic, according to

Table 1. General characteristics of studied fishponds

	Rod fishpond	Malý Dubovec fishpond
Average depth	0.7 m	1.5 m
Total area	30.904 ha	8.789 ha
Littoral area	7.720 ha	2.765 ha
SAV coverage area	22 743 ha	6.024 ha
Dominant vegetation	*Ceratophyllum demersum*	*Stuckenia pectinata*

SAV = submerged aquatic vegetation

the historically well-documented presence of species of interest, i.e., *Stuckenia pectinata* and *Ceratophyllum demersum*.

Rod fishpond is located within Protected Landscape Area and it is a part of a larger fishpond system traditionally used for carp (*Cyprinus carpio*) production. *C. demersum* stands have been historically prevalent in submerged vegetation complex; however, small patches of *S. pectinata* can be found sparsely. The average depth of the fishpond is 0.7 m and the total area is nearly 31 ha; it is classified as a medium-sized fishpond. Along the inlet, a large littoral area is overgrown mainly by *Phragmites australis* and *Typha* spp., followed by a sedge meadow in the area above the regular water level. Rod fishpond is currently classified as a pond with hypertrophic water status. Since 2014, it has been a subject to biomanipulation experiment when fish stock was cut to minimum by replacing carp with a small number of generational tench (*Tinca tinca*) and perch (*Perca fluviatilis*) fishes. The main incentive for such a dramatic fish stock reduction was to provide suitable conditions for the development of zooplankton, benthos and macrophytes in order to increase feeding opportunities for wetland birds of the Ramsar site, Biosphere reserve and Landscape Protected Area Třeboňsko. To sum up, high stock of carp results in decline of aquatic vegetation, which represents a main source for waterfowl nutrition.

The absence of herbivorous fish during the first year of the experiment (2014) allowed the presence of large zooplanktonic filtrators (*Daphnia*) together with a large colony forming cyanobacteria (*Aphanizomenon flos-aquae*) able to withstand predation pressure of the filtrators. The fishpond system exhibited long-term durability in terms of clear water state with numerous oxygen deficit events. The next year (2015), explosive growth of *Ceratophyllum demersum* was observed along with the presence of large filtrators. A notable portion of nutrients was retained in the plant biomass and the water transparency remained high. In hypertrophic ponds, such a state is called secondary oligothrophy (Pechar et al., 2017). The resulting conditions attracted a large number of aquatic birds. The 2016 season followed the same pattern as the preceding year, and by the end of June, *C. demersum* occupied nearly the whole open water area. However, uncontrollable predation of invasive topmouth gudgeon (*Pseudorasbora parva*) on large zooplankton had shifted the system towards a turbid phytoplankton dominated state in mid-July. An immense amount of plant biomass then resulted in significant oscillations of hydrochemical parameters and the absence of waterfowl species (Pechar et al., 2017).

Malý Dubovec fishpond is a historical fishpond currently used for carp fry production. This fishpond is part of a small-scale protected area with no proximity of intensive production areas. Historically, the vegetation was dominated by *Potamogetoneto natantis–Nymphaeetum candidae* Hejný 1948 community (Hejny, Husak, 1978). In the 1970's, the pond was colonised mostly by *Elodeetum canadensis* Eggler 1933 community with dominance of *Elodea canadensis* Michx. (Pokorny et al., 1984). At present, the pond has a well-developed littoral zone and typical submerged vegetation is represented by dense *S. pectinata* stands during early summer. Later in the season, the vegetation is characterised by *Najas marina*, *C. demersum*, *Myriophyllum spicatum* and, closer to the shoreline, also by *Potamogeton lucens*. The average depth of the fishpond is 1.5 m and the total area reaches only 8.8 ha; it is classified as a small-sized fishpond. The bottom is formed mainly by gravel-sand fraction with an overlying layer of decomposed organic material. The fishpond is saturated by eutrophic water from a large protected fishpond area upstream. During the field campaign, the fishpond maintained fairly good water transparency levels and the fish stock did not trigger any significant changes in the system. At the end of the growing season of *Stuckenia pectinate* oxygen deficits were regularly recorded at the bottom.

Both experimental sites are found in a region characterised by temperate climate, with average precipitation of 660 mm and average temperature of 7.1°C. The both ponds are supplied with minimum amount of water just enough to compensate for evaporation. Therefore, water flow rate is very low. The major characteristics of the studied fishponds are shown in Table 1.

Biomass evaluation

The evaluation of the aboveground biomass of both submerged macrophytes was carried out in 2016 using a quantitative rotary sampler for submersed aquatic macrophytes (Howard-Williams, Longman, 1976). This sampling method is a boat-based alternative to the diver quadrat method. Although the diver quadrat method is the most precise among the SAV sampling methods (Madsen, Wersal, 2012), it could not be performed due to high safety and expertise requirements (Johnson, Newman, 2011). The rotary sampler is composed of two blades placed at the base of a 2 m central rod with a pointed tip at its lower end that is further secured with a circular plate so the tip would not sink too deep and the blades would revolve right above the bottom surface. Furthermore, horizontal collecting hooks for catching the cut material are placed above the cutting blades. Once the sampler is placed, it is operated by a handle at the top that allows to spin the mechanism and to cut macrophyte biomass above the bottom line. This implies that only biomass above bottom line was sampled (excluding roots). The values obtained with this sampler are very close to those obtained by manual cutting underwater (Howard-Williams, Longman, 1976).

In order to achieve precision regarding standing stock estimates, systematic mapping of the whole area of the ponds was also conducted at vegetation peaks of *S. pectinata* (late June) at Malý Dubovec fishpond and of *C. demersum* (late July) at Rod fishpond. This was done by visual methods using GPS positioning to locate vegetation clusters.

In both fishponds, three permanent sampling points were set and secured with anchored marker buoys in random positions, where the biomass was regularly collected during the vegetation period (June–September). At each sampling point, a radius was set where the single sampling campaigns rotated along the central point in order to avoid harvesting the same sampling spot more times. Altogether, six sampling campaigns were performed in both fishponds during 2016. First campaign took place in June and the last in September, so that vegetation peaks of both species would be covered.

After the collection, samples were hung to drain overnight in perforated dark bags, which allowed the intercepted water to run down until the next day when samples were weighed to obtain fresh biomass weight. Then plant dry biomass was determined by drying the samples at 60°C to a constant weight.

Chemical and statistical analyses

Later, the dry shoots were ground using the cutting mill Pulverisette 15 (Fritsch, Idar-Oberstein, Germany) and analysed for nitrogen and phosphorus. Total nitrogen was measured directly using the Primacs SNC analyses (Skalar, Breda, The Netherlands). Phosphorus was analysed following the $HNO_3/HClO_4$ digestion method of Sommer, Nelson (1972). NIST 1547 Peach Leaves were used as the standard (National Institute of Standards and Technology, Gaithersburg, USA). Statistically significant differences were determined at the $P < 0.05$ level by paired Student's *t*-tests and analysis of variance (ANOVA).

RESULTS

Biomass

The aboveground biomass of *C. demersum* and *S. pectinata* exhibited different seasonal patterns. *C. demersum* biomass in Rod fishpond increased until July 7, 2016 when it reached is maximum of 96 g m^{-2}. After that, the biomass steadily decreased until the end of September (Fig. 2). On the other hand, the maximum biomass of *S. pectinata* in Malý Dubovec fishpond occurred during the first sampling on June 20,

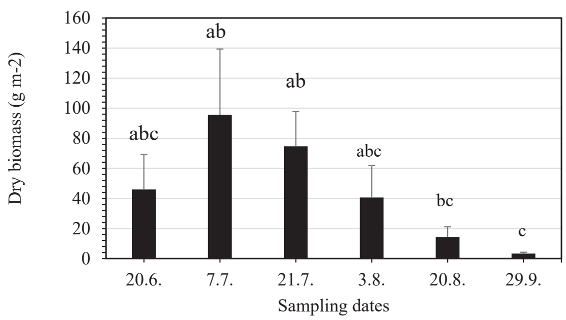

Fig. 2. Average aboveground biomass of *Ceratophyllum demersum* in Rod fishpond during the period June–September 2016
bars represent standard deviation (n = 3), different letters indicate significant difference at α = 0.05 between the means

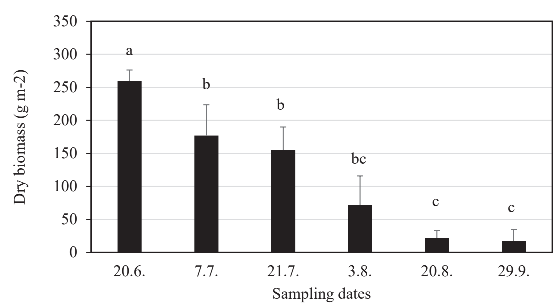

Fig. 3. Average aboveground biomass of *Stuckenia pectinata* in Malý Dubovec fishpond during the period June–September 2016
bars represent standard deviation (n = 3), different letters indicate significant difference at α = 0.05 between the means

2016 and after that it steadily decreased until the end of September (Fig. 3).

Nutrient concentrations in the biomass

Nitrogen concentrations in *C. demersum* aboveground biomass were stable during the studied period and varied only between 3.54% dry matter (DM) and 4.03% DM (both observed in July). There was no statistical difference between sampling dates. The concentrations of nitrogen in *S. pectinata* increased throughout the studied period and varied between 2.52% DM in July and 3.47% DM in September (Fig. 4).

Concentrations of phosphorus varied insignificantly throughout the monitored period between June and September 2016 (Fig. 5). Phosphorus concentration in *C. demersum* varied between 0.27% DM in August and 0.35% DM at the end of July, while in *S. pectinata* the highest phosphorus concentration was recorded in September (0.30% DM) and the lowest one in early August (0.18% DM).

Nutrient standing stocks

Standing stocks of nitrogen in *C. demersum* in Rod fishpond and in *S. pectinata* in Malý Dubovec fishponds followed the biomass pattern (Fig. 6). This is quite a common observation as biomass is the major factor affecting standing stock (Richardson, Vymazal, 2001). The highest nitrogen standing stock in *C. demersum* Rod fishpond amounted to 3.61 g N m^{-2} on July 7, 2016, while the highest N standing stock in *S. pectinata* in Malý Dubovec fishpond amounted to 7.44 g N m^{-2} during the first sampling in June.

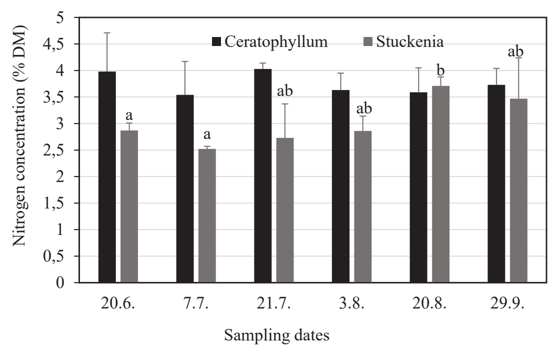

Fig. 4. Nitrogen concentrations in *Ceratophyllum demersum* in Rod fishpond and *Stuckenia pectinata* in Malý Dubovec fishpond during the period June–September 2016
bars represent standard deviation (n = 3), different letters indicate significant difference at α = 0.05 between the means, there was no significant difference for Ceratophyllum

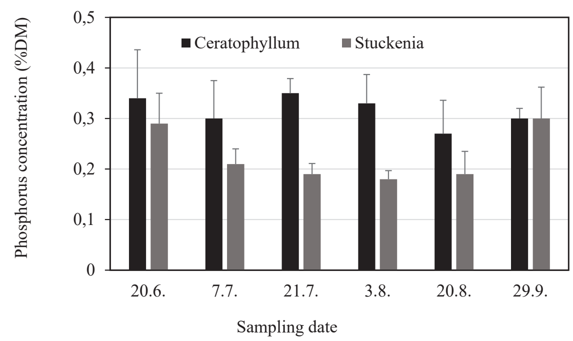

Fig. 5. Phosphorus concentrations in *Ceratophyllum demersum* in Rod fishpond and *Stuckenia pectinata* in Malý Dubovec fishpond during the period June–September 2016
bars represent standard deviation (n = 3), there was no significant difference among samplings for both plants

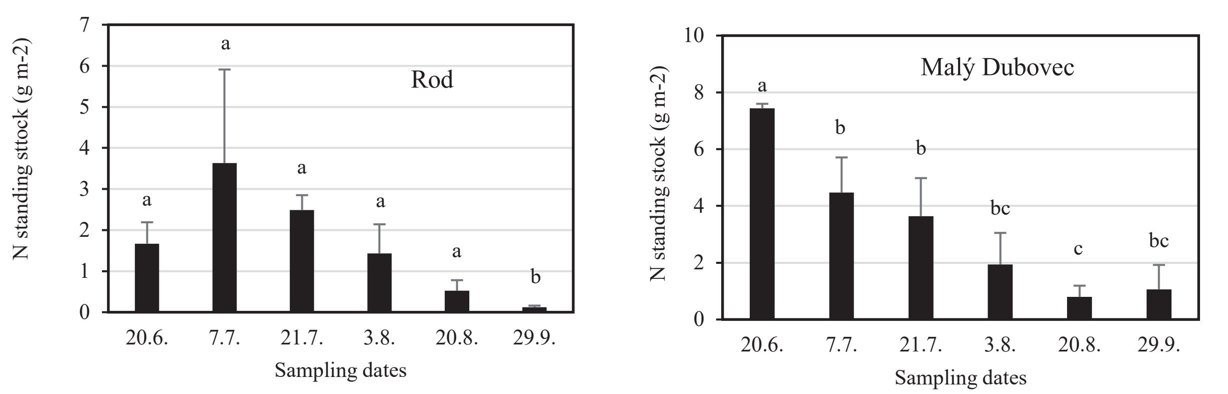

Fig. 6. Nitrogen standing stock in *Ceratophyllum demersum* in Rod fishpond (left) and in *Stuckenia pectinata* in Malý Dubovec fishpond (right) during the period June–September 2016
bars represent standard deviation (n = 3), different letters indicate significant difference at α = 0.05 between the means

Phosphorus standing stock patterns were similar to those of nitrogen in both fishponds (Fig. 7) and were also influenced mostly by the biomass. For *C. demersum*, however, the highest standing stock did not occur at the time of the highest biomass (July 7th) but two weeks later (July 21st). Phosphorus standing stock was higher in *S. pectinata* due to higher biomass of this plant (Figs. 2, 3). The highest standing stock for *S. pectinata* amounted to 0.75 g P m^{-2} in June while *C. demersum* exhibited the highest standing stock of only 0.13 g P m^{-2} on July 21st.

DISCUSSION

Biomass

The maximum aboveground biomass of *C. demersum* (96 g DM m^{-2}) is within the lower end of values reported in the literature (Table 2). The highest biomass of *C. demersum* was reported from Sweden and amounted to 700 g m^{-2} (Forsberg, 1960). However, the maximum biomass found in our study is similar to the values reported by Steffenhagen et al. (2012) from rewetted fens in Germany (90–120 g m^{-2}) and by Greenway, Wooley (2001) from a constructed wetland in Australia (90 g m^{-2}). On the other hand, Pokorny, Rejmankova (1983) reported lower values (51–73 g m^{-2}) from Pavelec fishpond in the same region as our study. The biomass of *Ceratophyllum demersum* in Pavelec fishpond was very low as the small fishpond was covered with duckweed limiting light penetration into the water column. The seasonal pattern was similar to that reported by Nikolic et al. (2007) from Serbia. In that study, the maximum biomass occurred at the end of June and then the biomass steeply decreased.

The maximum biomass of *S. pectinata* (260 g m^{-2}) is similar to values reported by Van Wijk (1988) from the Netherlands and by Van der Valk, Bliss (1971) from Canada (Table 2). The values measured in our study are rather low; however, the biomass values of *S. pectinata* may vary substantially within the habitat as indicated by Royle, King (1991) who measured a wide range of 78–950 g m^{-2} in a lake in Australia.

At Rod fishpond, dominated by *C. demersum*, the highest biomass was reached in early July together with the highest nitrogen standing stock. Although the highest standing stock of phosphorus was recorded two weeks later, its value was still relatively high at the earlier peak biomass. This implies that the ideal time for a harvest efficient in nutrient removal would be mid-summer. This result is in correspondence with maximum potential values for *C. demersum* observed in early July by Steffenhagen et al. (2012). Mid-summer harvest timing is also recommended by Kuiper et al. (2017) in order to avoid triggering a regime shift to a phytoplankton dominated turbid state. Rod is a fishpond with moderate external nutrient loading and removal of large portion of the submerged vegetation could seem beneficial in terms of substantial nutrient impoverishment. However, events that occurred during biomanipulation experiment suggest that this particular system is highly prone to alternative stable states shifts, probably due to high internal nutrient loading. Also, the time lag that can arise between the harvest and undesirable regime shift to a turbid state should not be underestimated when planning long-term SAV harvesting.

Malý Dubovec fishpond dominated by *S. pectinata* reached the maximum standing stock of N and P in late June along with peak biomass. In a temperate and northern boreal climate, the highest biomass is

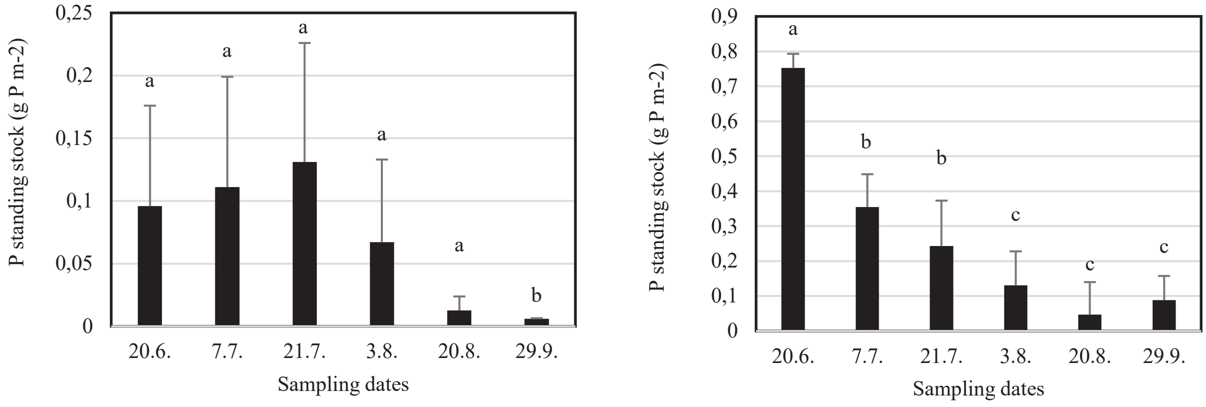

Fig. 7. Phosphorus standing stock in *Ceratophyllum demersum* in Rod fishpond (left) and in *Stuckenia pectinata* in Malý Dubovec fishpond (right) during the period June–September 2016
bars represent standard deviation (n = 3), different letters indicate significant difference at α = 0.05 between the means

Table 2. Maximum aboveground biomass of *Stuckenia pectinata* and *Ceratophyllum demersum* in various habitats

Location	Type of environment	Biomass (g m^{-2})	Reference
Ceratophyllum demersum			
Sweden	lake	500–700	Forsberg (1960)
Serbia	eutrophic lake	22–363	Nikolic et al. (2007)
Alberta, Canada	oxbows	197–269	Van der Valk, Bliss (1971)
Florida, USA	mesocosms	135–184	Dierberg et al. (2002)
Wisconsin, USA	eutrophic lake	151	Smart (1980)
Germany	rewetted fens	90–120	Steffenhagen et al. (2012)
Australia	constructed wetland	90	Greenway, Wooley (2001)
Czech Republic	fishpond	51–73	Pokorny, Rejmankova (1983)
Stuckenia pectinata			
South Africa	saline lake	1952	Howard-Williams (1978)
The Netherlands	brackish waters	92–1070	Van Wijk (1988)
Australia	lake	78–950	Royle, King (1991)
Poland	small water bodies	20–898	Nagengast, Gabka (2017)
France	oligo-mesosaline waters	312–504	Van Wijk (1988(
The Netherlands	running freshwaters	63–306	Van Wijk (1988)
Alberta, Canada	oxbows	91–297	Van der Valk, Bliss (1971)
United Kingdom	running water	120	Westlake (1961)
Finland	mesohaline waters	70–95	Van Wijk (1988)
The Netherlands	freshwater lake	62	Van Wijk (1988)
Sweden;	Baltic Sea estuary	17.5	Kautsky (1987)
Austria	lake	11.1	Schiemer, Prosser (1976)

usually achieved in the period June–July but at some locations the peak biomass may occur later (Van der Valk, Bliss, 1971; Van Wijk, 1988). To maximise immediate nutrient removal at this locality, harvesting in early summer should be recommended. Yet, the reproductive strategy of *S. pectinata* should be considered when planning the harvest (Kuiper et al., 2017). This plant, unlike *C. demersum*, needs to be allowed to form generative reproductive organs ahead of the harvest so its abundance would not be seriously compromised in the next growing season. Over-harvesting can have grave consequences on trophic cascade, especially when nutrient loading is high (Kuiper et al., 2017). Generally, 50% of the vegetation cover left after harvesting is recommended by Hilt et al. (2006). Although this approach would obviously lower the instant yield of recovered nutrients, it should be perceived as a suitable option for a sustainable long-term management.

Excessive growth of aquatic vegetation set off by eutrophication can be seen as an opportunity to recover nutrients critical in food production while improving the trophic status of numerous water bodies. SAV harvesting represents a perspective contribution to closing the loop of nutrient loss from agricultural land. Still, the risk of ecological damage to other components of aquatic ecosystem is challenging and needs to be examined closely, acknowledging possible impacts over varied timescales (Quilliam et al., 2015). Generally, it is important to keep in mind that the precondition of SAV development is a low feeding pressure of planktonivorous fish (carp, white fish, invasive fish like *Pseudorasbora parva* or carassius). At the same time, long-term fish stock reduction linked with a vigorous growth of SAV results in an acceleration of the lake aging process. Therefore, periodical engagement of a denser carp stock is desirable in order to utilise the accumulated dead plant biomass. In opposite situation, the accumulated plant organic matter may start to decompose anaerobically, inducing release of nutrients, often leaving the environment in hypertrophic conditions.

Nutrients concentrations in the biomass

Concentrations of phosphorus reported in the literature varied between 0.04 and 1.0% DM for *S. pectinata* and between 0.04 and 0.75% DM for *C. demersum*

Table 3. Concentration of phosphorus and nitrogen in aboveground biomass of *S. pectinata* and *C. demersum*. The highest concentrations in bold, the lowest concentrations in bold and italics

Location	Type of habitat	P (% DM)	N (% DM)	Reference
Stuckenia pectinata				
France	oligo-mesosaline waters	0.22–0.35	***0.81***–1.82	Van Wijk (1988)
The Netherlands	brackish waters	0.25–**1.00**	1.06–2.14	Van Wijk (1988)
The Netherlands	freshwater lake	0.15–0.76	1.06–3.05	Van Wijk (1988)
New Jersey, USA	canal, pond, lake	0.20–0.33	1.46–1.98	Riemer, Toth (1968)
Poland	lake	***0.04***	1.61	Bernatowicz (1969)
Czech Republic	small stream	0.82	**4.23**	Dykyjova, Kvet (1982)
Australia	lake	0.12–0.35	1.22–2.61	Royle, King (1991)
India	lake	0.11–0.12	2.20–2.40	Kaul et al. (1980)
Ceratophyllum demersum				
Wisconsin, USA	freshwater lake	0.51–0.75	2.11–**4.43**	Gerloff, Krombholz (1966)
Florida, USA	treatment wetland	0.09–0.43	1.32–3.46	Pietro et al. (2006)
New Jersey, USA	canal, pond, lake	0.42–0.59	3.11–3.97	Riemer, Toth (1968)
South Carolina, USA	pond	0.26		Boyd (1970)
Poland	lake	0.61	2.07	Bernatowicz (1969)
Connecticut, USA	pond	0.24–0.33		Cogwill (1974)
The Netherlands	lake		1.39–3.34	Best (1977)
India	lake	***0.04***–0.05	2.50–2.80	Kaul et al. (1980)
Brazil	tropical lagoon	0.22	2.28	Esteves, Suzuki (2010)
Michigan, USA	lake complex	0.10–0.50	***1.0***–2.5	Hough et al. (1989)
Michigan, USA	lake	0.22	3.04	Spencer, Wetzel (1993)
Australia	constructed wetland	**2.1**	3.40	Greenway, Wooley (2001)
Germany	rewetted fen	0.8–1.2	2.7–3.8.	Steffenhagen et al (2012)
Wisconsin, USA	eutrophic lake	0.8	2.15	Smart (1980)
Florida, USA	mesocosm	0.46–0.54		Dierberg et al. (2002)

(Table 3). Concentrations found in our study (Fig. 5) are within this range but at the lower end as the P concentration in both plants varied only between 0.21 and 0.35% DM, indicating low seasonal variation between June and September. Concentrations of nitrogen reported in the literature varied between 0.81 and 4.23% DM for *S. pectinata* and between 1.0 and 4.43% DM for *C. demersum* (Table 3). Also, nitrogen concentrations in both plants found in our study are within the concentration range reported in the literature; although at the higher end of the reported values. In our study, nitrogen concentration varied between 2.52 and 4.03% DM (Fig. 3). A slight increase in nutrient content of vegetation can be explained by the fact that these species form vegetative reproductive organs at the end of growing season (Smart, 1980).

Nutrient standing stocks

There is limited information in the literature on nutrient standing stocks in *C. demersum* and *S. pectinata*. The available results are summarised in Table 4. Phosphorus standing stock was very low for *C. demersum* but comparable with values reported by Kaul et al. (1980) from India. On the other hand, nitrogen standing stock was comparable with most studies reported in the literature (Table 4), with the exception of an extremely high value reported by Kulshreshtha, Gopal (1982) from India.

The phosphorus standing stock in *S. pectinata* is slightly higher compared to results reported from India (Kaul et al., 1980; Kulshreshtha, Gopal, 1982). The nitrogen standing stock of 7.44 g N m^{-2} is higher than values reported by Kaul et al. (1980) but substantially lower compared to the values reported by Kulshreshtha, Gopal (1982).

The results indicate that it is possible to remove a certain amount of nitrogen and phosphorus by submerged macrophyte harvest. However, both phosphorus and nitrogen standing stocks are about one order of magnitude lower compared to standing stocks for tall emergent species such as *Phragmites australis*,

Table 4. Phosphorus and nitrogen standing stocks reported in the literature for *C. emersum* and *S. pectinata*

	Phosphorus (g m^{-2})	Nitrogen (g m^{-2})	Reference
C. demersum			
Srinagar, India	0.078–0.13	5.24–5.56	Kaul et al. (1980)
Jaipur, India	0.32–2.49	2.65–11.52	Kulshreshtha, Gopal (1982)
Germany	0.80–1.20	2.6–4.2	Steffenhagen et al. (2012)
Florida, USA	0.78		Dierberg et al. (2002)
Australia	1.89	3.06	Greenway, Wooley (2001)
This study	0.13	3.61	
S. pectinata			
Srinagar, India	0.22–0.29	4.37–4.67	Kaul et al. (1980)
Jaipur, India	0.64	23.47	Kulshreshtha, Gopal (1982)
This study	0.75	7.44	

Typha latifolia or *Scirpus lacustris,* which usually vary between 20 and 50 g N m^{-2} and 1 and 5 g P m^{-2} (Vymazal, 1995).

When the area covered by submerged macrophytes at the time of the peak standing stock (Table 1) is taken into consideration, 821 and 448 kg nitrogen can be removed via submerged plants harvesting from Rod and Malý Dubovec fishponds, respectively. The respective values for phosphorus are 29.6 kg and 45 kg. Despite the much smaller pond area of Malý Dubovec fishpond, the total removed phosphorus load is comparable in both fishponds due to substantially higher biomass of *S. pectinata* as comparted to *C. demersum*.

CONCLUSION

The results revealed that *Ceratophyllum demersum* and *Stuckenia pectinata* exhibited different seasonal patterns in terms of their growth dynamics and biomass production. For *S. pectinata*, the highest biomass was recorded in June and then a steep decrease of biomass occurred. *C. demersum* biomass increased from June to July and after that it decreased. The maximum standing stock of phosphorus and nitrogen occurred around peak biomass for both plants. The nitrogen and phosphorus standing stocks were comparable with literature data for the studied species, but the values are about one order of magnitude lower compared to standing stocks in tall emergent species. The total amount of removable nutrients amounted to 821 kg N and 29.6 kg P in Rod fishpond, and 448 kg N and 45 kg P in Malý Dubovec fishpond. Despite this potential, a site-specific approach towards harvest timing and intensity should be applied according to management history, actual nutrient loading, dominant vegetation, and planned use. The results of this study confirmed that fishpond management, with respect to the use of SAV for nutrient removal, is strongly affected by dominant plant species and that it is not possible to create any generalised recommendations.

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