

**Within-weed bed architectural adaptation of branching pattern in
Myriophyllum spicatum L.**

Prilagoditve razvejanosti rastlin vrste *Myriophyllum spicatum* L.
v različnih delih sestoja

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Abstract: Regarding architectural adaptations in aquatic plants caused by the velocity of water flow only scarce, older information is available. When studying different *Myriophyllum spicatum* L. specimen architecture in the same water body differences in individual main axes and branching pattern were detected at the upstream and at the downstream end of individual plant beds. Samples from these two locations showed significant differences in architectural composition. At the downstream parts of the water body individual plants were longer and the number of branches was higher, which is contributed to flow velocity.

Keywords: *Myriophyllum spicatum*, architecture of plants, water flow velocity

Povzetek: Večina podatkov o prilagoditvah vodnih rastlin, ki jih povzroča hitrost toka vode, je redkih in zastarelih. Pri proučevanju razrasti različnih primerkov vrste *Myriophyllum spicatum* L. v istem vodnem telesu, smo ugotovili razlike med dolžino glavnega poganjka in vzorci razvejanja rastlin v zgornjem in spodnjem delu sestoja rastlin. V spodnjem delu so bili poganjki daljši, njihova razvejanost pa je večja, kar pripisujemo hitrosti vodnega toka.

Ključne besede: *Myriophyllum spicatum*, razvejanost rastlin, hitrost vodnega toka

Introduction

The effect of water current on aquatic plants has been a topic of interest for many authors. Aspects getting highest attention were *i.a.* occurrence and distribution of species related to water flow conditions, leaf di-/polymorphism or physiological adaptations (nutrients, photosynthesis), and many more (for additional information see Neuhold et al. 2016). As aquatic plant beds form obstacles in

the water channel, water flow increases around the beds, whereas the flow within beds is attenuated to a considerable extent (Sand-Jensen and Mebus 1995, Wenninger and Janauer 1991).

The publications dealing with this topic differ in methods regarding accuracy, spatial dimension of the approach, the measuring devices used, and even in studying either natural weed beds or experimental set-ups (e.g. Wilson 2007). A quite comprehensive picture of the interaction of aquatic

plant beds with water movement and sedimentation processes is given by Madsen et al. (2001).

This phenomenon namely the effect of plant beds on water flow velocity is also documented by other authors (Carter et al. 1988, Marshall and Westlake 1990, Chambers et al. 1991, Machata-Wenninger and Janauer 1991, Sand-Jensen and Mebus 1996, Sand-Jensen and Pedersen 1999). Especially the two last-cited contributions included detail of the flow conditions found upstream, within and downstream of the macrophyte beds.

In the documentation provided in publications listed above the longitudinal form of the studied weed beds can only be delineated indirectly by the shape of the isopleths in successive cross-sections. In the present brief study we were interested in two different weed bed features: (i) describing the general shape of the longitudinal profile of flow velocity developed along the mid-line of the *M. spicatum* beds present in the Wiener-Neustädter-Canal, (ii) assessing architectural differences of *M. spicatum* bed between the upstream end, affected by the direct impact of the flow, and the trailing end of *M. spicatum* bed. (iii) comparing this within-weed bed architectural adaptation of branching pattern and with that in locations with slow and fast flow velocity.

Site and methods

Individual plants (ramets) of a *Myriophyllum spicatum* L. clone were sampled from a historic canal (Wiener Neustädter Canal, WNC) near the towns Laxenburg/Biedermannsdorf. The selected weed bed was located at the coordinates: 48°04'44.79"N / 16°21'29.09"E. The canal is characterised by regulated constant discharge, providing an ideal environment for macrophyte development. Regarding current velocity at this site see Table 1.

Individuals of *M. spicatum* were sampled from the upstream end of the weed bed (N = 4), where the full force of the current acts on the plants. At the downstream end of the weed bed the sampled individuals (N = 4) were sheltered by a protective canopy of stems and branches growing upstream. Axes and branches sampled from the very upstream and the very downstream end were spread on a plastic sheet, straightened, counted and their length was determined with a tape measure. For comparison samples from additional two locations in the same channel, namely a location with fast water flow and one with slow water flow were taken into account (Neuhold et al. 2016).

Statistics

Data on characteristic parameters of the plant architecture were analysed with SPSS 15.0 for WINDOWS. Normal distribution was tested by applying Kolmogorov-Smirnov, or Shapiro-Wilks tests, respectively. ANOVA was applied to the normally-distributed data together with Duncan Post-Hoc mean separation test, testing for significance between means. Methods followed Untersteiner (2007).

Results

We present a few architectural features of the sampled plants on a percentage basis, as the simplest way of comparison. Since *Myriophyllum* plants had been sampled from other locations in the Wiener-Neustädter-Canal, too (Neuhold et al. 2016), yet growing under considerably different flow conditions, we used the data from the 'up'-location in our sampled weed bed to set the benchmark for comparing common architectural features.

Table 1: Means of flow velocity in the canal cross section free of *Myriophyllum spicatum* growth ("fast" and "slow" water velocity: see Neuhold et al. 2016) and at the location "up" at the beginning of the stand.
Tabela 1: Hitrost vodnega toka na delu kanala brez prisotnosti vrste *Myriophyllum spicatum* (hitra ("fast") in počasna ("slow") hitrost vodnega toka: glej Neuhold in sod. 2016) in na mestu "up" na začetku sestoja

Flow velocity (ms ⁻¹)	fast	up	slow
Mean value	1.44	0.92	0.39
Standard deviation	0.20	0.26	0.05

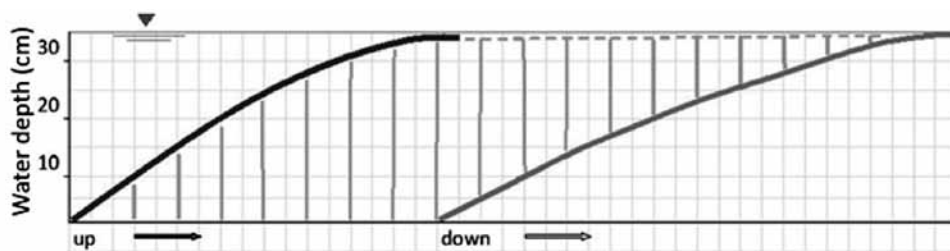


Figure 1: Weed bed of ramets of *Myriophyllum spicatum* - longitudinal section; the beginning of black line indicates sampling point for individual ramets at the upstream end of the weed bed ("up"), while the beginning of dark grey line indicates sampling point for individual ramets at the downstream end of the weed bed ("down"). The presence of plants within the water column is shown by vertical lines. Arrow: water surface indicator.

Slika 1: Sestoj vrste *Myriophyllum spicatum* - vzdolžni presek; začetek črne črte označuje točko vzorčenja posameznih rastlin na začetku sestoja, medtem ko začetek temno sive črte označuje vzorčevalno točko za posamezne rastline na spodnjem delu sestoja. Prisotnost rastlin v vodnem stolpcu je prikazana z navpičnimi črtami. Puščica kaže na vodno gladino.

Figure 1 shows the longitudinal section of a weed bed of *M. spicatum*. Maximum lengths of individuals sampled from the two parts of the weed bed were 90 cm at "up" and 120 cm at "down" location, respectively.

Figure 2 shows the relation of all branches recorded for the sampled ramets to the flow velocity. The branching at 'up' in Fig. 1 is rather similar to that in fast flow and that in 'down' (Fig. 1) is similar to that in slow flowing water ('slow' in Table 1).

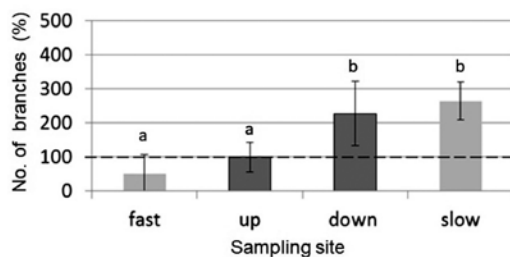


Figure 2: Number of all branches recorded for the sampled ramets. The value 100% relates to the mean number of all branches sampled from ramets at the "up" location. It provides the benchmark for the other locations. "Down" indicates the downstream end of the plant bed. The dark grey bars refer to "up" and "down" sampling locations. Light grey bars: data based on samples from other locations in the same channel, published by Neuhold et al. (2016). "Fast" indicates the same parameter for plants growing in very fast flow, while "slow" the number of branches for plants growing under lower flow velocity. Statistical differences are indicated by different characters.

Slika 2: Število stranskih poganjkov pri vzorčenih posameznih rastlinah. Vrednost 100 % se nanaša na povprečno število vseh poganjkov na začetku sestoja – "up". Vse ostale vrednosti so % glede na referenčne vrednosti na začetku sestoja. "Down" označuje lokacijo na koncu sestoja. Temno sivi stolpci se nanašajo na lokacije za vzorčenje na začetku in koncu sestoja. Svetlo sivi stolpci označujejo sestoje, ki so se razvili na lokacijah z hitrim ("fast") oziroma počasnim ("slow") tokom (Neuhold et al. 2016). Statistično značilne razlike so označene z različnimi črkami.

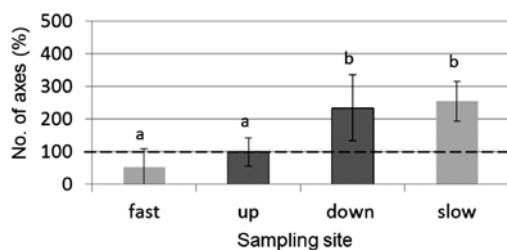


Figure 3: Number of terminal axes (as % of benchmark “up”) in plants with no furcation. Detailed legend: see Fig. 2.

Slika 3: Število glavnih osi (% glede na referenčne vrednosti na začetku sestoja – “up”) pri rastlinah, ki nimajo stranskih poganjkov. Podrobna legenda: glej sliko 2.

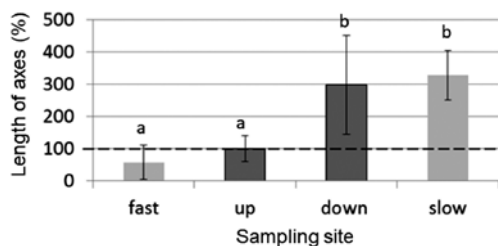


Figure 4: Length of terminal axes (as % of benchmark “up”). Detailed legend: see Fig. 2.

Slika 4: Dolžina glavnega poganjka (% glede na referenčne vrednosti na začetku sestoja – “up”). Podrobna legenda: glej sliko 2.

Aside from just looking at the total set of sampled ramets and their branches we also checked the group of ‘terminal axes’, i.e. axes which had not developed any additional branching (‘branches without furcation’). Fig. 3 and Fig. 4 show the number and length of terminal axes, respectively.

The difference of the means between ramets from “up” and “down” locations is smaller for all branches (Fig. 2), than that of the terminal axes (Fig. 3).

Discussion

During our work with *Myriophyllum spicatum* in the Wiener Neustädter Canal, we noticed a marked difference in the longitudinal composition of the weed beds. At the upstream end the axes and branches showed a quite compact arrangement, forming the main body of the plant bed. Close to the middle part of the bed the ramets lifted from

the sediment, forming the trailing and waving axes of the downstream end. This triggered our interest in looking for architectural differences, and a related environmental parameter causing this variation.

The graphs and tables show clear and significant differences in the architecture between samples from the upper, and from the lower end of the weed bed, respectively. It is striking to see that in the trailing axes (i) the number of all branches of ramets, (ii) the number of ‘terminal’ (not branched) axes, and (iii) the length of the terminal axes always reach higher values than those recorded for the samples from the upstream end of the weed beds.

As regards the longitudinal mid-line section of the weed bed, ramets at the upstream end receive full light intensity over their whole length, whereas ramets following downstream reach full light only with their uppermost branches. The trailing ramets start their upward growth at

the canal bottom covered by the thickest layer of ramets located upstream, which results in maximum light attenuation. Further downstream the shading canopy gets less dense and the trailing ramets finally reach up to full light conditions with a longer part of their stems and branches near the water surface.

The well-known effect of increased growth of internodes and sometimes petioles in low light conditions (Nultsch 2001, p.527) could account for the longer length of the trailing terminal axes. Since higher numbers of ramets with and without branches were also recorded, this could provide an additional indication of a shading effect caused by ramets in the upstream part of the weed bed. In a recent study of shallow Lake Taihu (China) and its regions of turbid and clear water, Guan et al. (2018) showed that *Potamogeton malaiianus* Miq. developed larger shoots, more and longer leaves and more biomass near the water surface. But the leaf morphology of the ‘Bamboo-leaved Pondweed’ is much different from that of *M. spicatum* and in lakes the plants grow quite straight up with elongated lower internodes, whereas in running waters the stems bend in reaction to flow conditions. This causes a close packing of the ramets of submersed species, and in *M. spicatum* sampled in our study, the leaf whorls were not bleached, missing the typical signs of ‘etiolation’.

In general, a marked increase in the intensity of an environmental parameter affects plant growth, as exemplified *i.a.* by Bartélémy and Caraglio (2007; p.390), showing the impact of full light in *Araucaria araucana* (Molina) K. Koch growth, whereas UV radiation is a strong factor scaling down plant size (Caldwell 1968; Caldwell et al. 1982).

The same holds true for the movement of the ambient medium: wind impact shapes alpine vegetation clumps by upwind erosion and downwind regeneration (Costin et al. 2000; p.50). Also strong winds in alpine regions and near sea shores cause stunted growth (Natur erleben 2018) in many plants, and other morphological changes (Wind effect 2018).

Enhanced flow velocities, based on suitable minimum flow conditions, successfully controlled nuisance aquatic plant growth, but the results differed among architectural types, like *Sparganium erectum* L., *Potamogeton crispus*

L. and *Myriophyllum aquaticum* (Vell.) Verdc. (Ochs et al. 2018), with the latter one showing the strongest effect of eradication. Water flow velocity also determined the competitive process between *M. spicatum* and *Elodea nuttallii* (Planch.) H.St. John, revealing a higher sensitivity to flow and turbulence, for the latter (Mazej and Germ 2013). Plant architecture (growth form) also determines water flow within weed beds, as shown by Wolters et al. (2018), who compared *Sparganium emersum* Rehmann, *Potamogeton natans* L. and *Callitriche obtusangula* Le Gall ex Hegelm.

For reaching a final decision between ‘shading of light’ and ‘sheltering from water flow’ as the cause for different architectural forms detected for upstream and downstream ramets the flume-like constant discharge in the Wiener Neustädter Canal provided ideal preconditions.

Along the central line of the weed bed upstream and downstream ramets are significantly different. According to Neuhold et al. (2016) ramets sampled at the ‘fast’ location, as well as ramets at the ‘slow’ location, both taken from the upstream end of their plant stands, were exposed to full light, but experienced very different flow speed. Therefore one can conclude that the internal differences in architectural features of *M. spicatum* weed beds are, at least mainly, caused by different water flow conditions, affecting the individuals at the very upstream end of the weed bed more than those trailing and waving at the very downstream end.

Conclusion

Our results show that *Myriophyllum spicatum* ramets, branched as well as those without additional furcation (‘Terminal axes’), sampled from the upstream, and the downstream end of the same plant bed, respectively, are characterised by statistically significant differences in architectural features. Upstream samples, affected by the full force of the water flow develop an architecture related to that of samples taken from plant beds located in much faster flow sections, whereas architecture of the sheltered downstream samples was closely related to that of samples collected from slower flow passages at a different reach of the canal.

Based on our results testing other common aquatic plant species for the adaptation of architectural features caused by water current impact would deserve progressing in future studies.

Povzetek

Rezultati raziskave kažejo, da so za razvejane kot tudi nerazvejane ramete vrste *Myriophyllum spicatum*, rastoče na začetku in na koncu sestoja,

značilne razlike v zgradbi rastlin. Na rastline na začetku sestoja deluje močan vodni tok, ki se odraža v zgradbi rastline, ki je značilna za predele kanala z hitrim vodnim tokom, medtem ko je bila zgradba rastlin na koncu sestoja podobna zgradbi rastlin, ki uspevajo na območjih s počasnim vodnim tokom.

Rezultati nakazujejo, da bi bilo v prihodnjih študijah potrebno raziskati tudi arhitekturne značilnosti drugih rastlinskih vrst v odvisnosti od vodnega toka.

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