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Influence of abiotic factors on invasive behaviour of alien species *Elodea nuttallii* in the Drava River (Slovenia)

Zdenka Mazej Grudnik[1]*, Ida Jelenko[1] and Mateja Germ[2]

[1] ERICo Velenje, Environmental Research and Industrial Co-operation Ltd., Koroška 58, 3320 Velenje, Slovenia
[2] Department of Biology, Biotechnical Faculty, University of Ljubljana, Večna pot 111, 1101 Ljubljana, Slovenia

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Abstract – The alien and potentially invasive species *Elodea nuttallii* was observed for the first time in Slovenia's Drava River in 2007, when its huge biomasses were observed at some locations. Changes in biomass of submerged macrophyte communities and abiotic factors such as water temperature, discharge and level were monitored at two impoundments of the Drava River (2009, 2010 and 2011). The correlations between abiotic factors and developed final biomass were assessed to determine if the level of abiotic factors has an impact on the final biomass and invasive behaviour of *E. nuttallii*. The results obtained showed that biomass of E. *nuttallii* was not excessive in 2009 and 2010, while in the year 2011 it developed huge biomass at locations, which were not directly exposed to the main water current. The biomass of *Myriophyllum spicatum* was also higher in 2011 in comparison with 2009 and 2010 but not in such high degree. The key factor for the development of the final biomass of *E. nuttallii* was the water temperatures in winter and spring and also the point at which water temperatures in spring surpassed 10 °C. The invasive behaviour of *E. nuttallii* is expected in the years with higher temperatures in January and March and at the locations which are not directly exposed to the main water current. We assume that continuation of the deposition of silt in the impoundments of the Drava River could contribute to invasive behaviour of species *E. nuttallii* in the years with mild winters and warmer springs.

Key words: Water temperature / discharge / water level / alien species / *Elodea nuttallii* / *Myriophyllum spicatum*

Introduction

Most of the world's rivers have dams and weirs. Information on the quantitative and qualitative effects of these structures on biological communities is crucial for successful management and restoration of stream ecosystems (Mueller *et al*., 2011). Impoundment of a river causes the carrying power of its flow to diminish and deposit of sediments (silt and clay) begins, creating environments that favour development of macrophytes. This can involve invasion of alien plant species, in the present case *Elodea nuttallii* (Planch.) H. St. John, which can form dense stands (Barrat-Segretain, 2001, 2004) with negative consequences on the balance of the rivers' hydrosystems. Senescence of plants of *E. nuttallii* can cause release of nutrients at high levels resulting in oxygen depletion at the end of the growing season. At high densities, *Elodea* plants hinder navigation, shore recreation and reservoir management.

Factors known to influence lake macrophyte colonization patterns and biomass include littoral sediment slopes (Duarte and Kalff, 1986), water clarity (Chambers and Kalff, 1985), and temperature (Svensson and Wigren-Svensson, 1992; Rooney and Kalff, 2000), discharge (Chambers *et al*., 1991; Asaeda *et al*., 2004; Janauer *et al*., 2010), wave action (Olson *et al*., 2012), sediment conditions (Barko *et al*., 1982; Anderson and Kalff, 1988), physical structure (Sculthorpe, 1967) and water regime (Šraj Kržič *et al*., 2007).

Water temperature is an important abiotic factor influencing macrophyte growth and production (Santamaria and VanVierssen, 1997) and can influence species distribution and community structure (Svensson and Wigren-Svensson, 1992; Rooney and Kalff, 2000). A macrophyte community responds to increased temperatures with changes in species composition, increased productivity and accelerated life-cycles (Grace and

*Corresponding author: zdenka.mazej@erico.si

Tilly, 1976; Haag and Gorham, 1977; Svensson and Wigren-Svensson, 1992; Taylor and Helwig, 1995). In one of the very few studies examining the relationship between climate and inter-annual variation in macrophyte communities, Rooney and Kalff (2000) attributed large increases in whole lake macrophyte biomass to higher temperatures in the early growing season (Mckee *et al.*, 2002).

Discharge and water level are also very important factors influencing the distribution and biomass of macrophytes. Plant biomass has been found to be negatively correlated with water depth and discharge (Asaeda *et al.*, 2004). Water movement has a significant effect on macrophyte growth, typically stimulating both abundance and diversity of macrophytes at low to moderate velocities, but reducing growth at higher velocities (Madsen *et al.*, 2001).

E. nuttallii (Planch.) H. St. John (1920) is endemic in North America but an alien species in Europe. It was first observed in the Drava River, Slovenia in 2007 (Király *et al.*, 2007), when huge biomass derived from macrophytes developed at some locations of the Drava River, while prior to this year such phenomenon was not observed (unpublished observation). During the autumn of 2007, shoots from the biomass broke up into numerous short fragments that drifted towards the barriers of hydropower plants, causing blocking of inflow gratings, and leading to economic consequences. In the following year 2008, the final biomass of macrophytes was much lower and did not cause any problems for the power plants. Abiotic factors (water temperature, discharge and water level) in the Drava River differ from year to year as a result of different weather conditions and changes in hydropower plants operation. This could reflect in different distribution and biomass of macrophytes.

In the present paper, a 3-year study (2009–2011) of the community structure and final biomass of aquatic macrophytes is presented. The main goals of the research were: (i) to identify the influence of abiotic factors, such as water temperature, discharge and water level, on the final biomass of the *E. nuttallii*; (ii) to identify factors that trigger the invasive potential of this macrophyte species.

Material and methods

Study site

The Drava River rises in Italy near the Austrian–Italian border; in its middle course it flows through the Northeastern Slovenia. It is a typical fluvio-glacial river; its highest flow occurs in July during the melting of glaciers, when most other rivers are already showing signs of summer drought. Its other high point is in November, when it is filled by autumn rainfall from the broad Alpine hinterland. A chain of hydropower plants built on the Drava River influences the river ecosystem significantly. Their operation results in water level fluctuation and discharge while changes in the latter lead to deposition of silt. Since 2007, a huge biomass of macrophytes clogged gratings on two of the eight Slovenian hydroelectric plants (HPP) on the Drava River, HPP Mariborski otok and HPP Vuhred, causing major problems. As a consequence, detailed surveys of the presence and abundance of macrophytes in these specific impoundments have been completed. The reservoir of the HPP Vuhred, which lies in the upper part of the Drava River, is 13.1 km long. The reservoir of the HPP Mariborski otok is lower in the Drava River chain, located just outside of the city of Maribor. Its impoundment is 15.5 km long. A map of the Drava River with the locations of the hydropower plants HPP Vuhred and HPP Mariborski otok and their impoundments as well as sampling locations is presented in Figure 1.

Field surveys and laboratory work

Field surveys were carried out from boat and by SCUBA divers in August 2009, 2010 and 2011 at two impoundments of the Drava River, HPP Vuhred and HPP Mariborski otok. Both banks of the impoundments were reviewed in detail in terms of macrophyte abundance. *Myriophyllum spicatum* and *E. nuttallii* were present in high abundance; other macrophyte species grew only sporadically. For this reason, our research focused on only those two species. A number of 20 m stretches of the waterline, 35 sites at impoundment HPP Vuhred and 32 at impoundment HPP Mariborski otok were reviewed and six stretches, where macrophytes were commonly present, were chosen at each impoundment for sampling macrophyte biomass in the years 2009, 2010 and 2011. The species abundance in each section was evaluated according to Kohler and Janauer (1995) on a five-level descriptor scale (1 – very rare, 2 – rare, 3 – common, 4 – frequent, 5 – abundant, predominant). The exposure of the sampling location was defined as "open" if it was in the riverbed, exposed to main water current, and "sheltered" in the case of bays or former branches. All plants of *E. nuttallii* and *M. spicatum* were cut from three quadrates (50×50 cm) at each of six stretches leading to a total of 18 samples of both species for each impoundment in 1 year (108 samples in total in 3 years). Then, the lengths of plants were measured using tape meter, stored in plastic mesh bags and transferred to the laboratory, where they were dried at 80 °C to constant weight for biomass measurement. The biomass was expressed in g/dry weight.

Water temperature, water level (expressed as altitude and used as a surrogate of water depth) and discharge in the Drava River were measured continuously on every half an hour, by Dravske elektrarne Maribor, using a Piezoresistive submersible sensor – (Rittmeyer, MPISTRN.005) and a Level and Position Transducer (Rittmeyer, GP3S). Averages of water temperature, discharge and water level were calculated for each month from January to August for all 3 years. The start of the growing season for macrophytes was taken as the day when the water temperature reached 10 °C (Kunii, 1984). The number

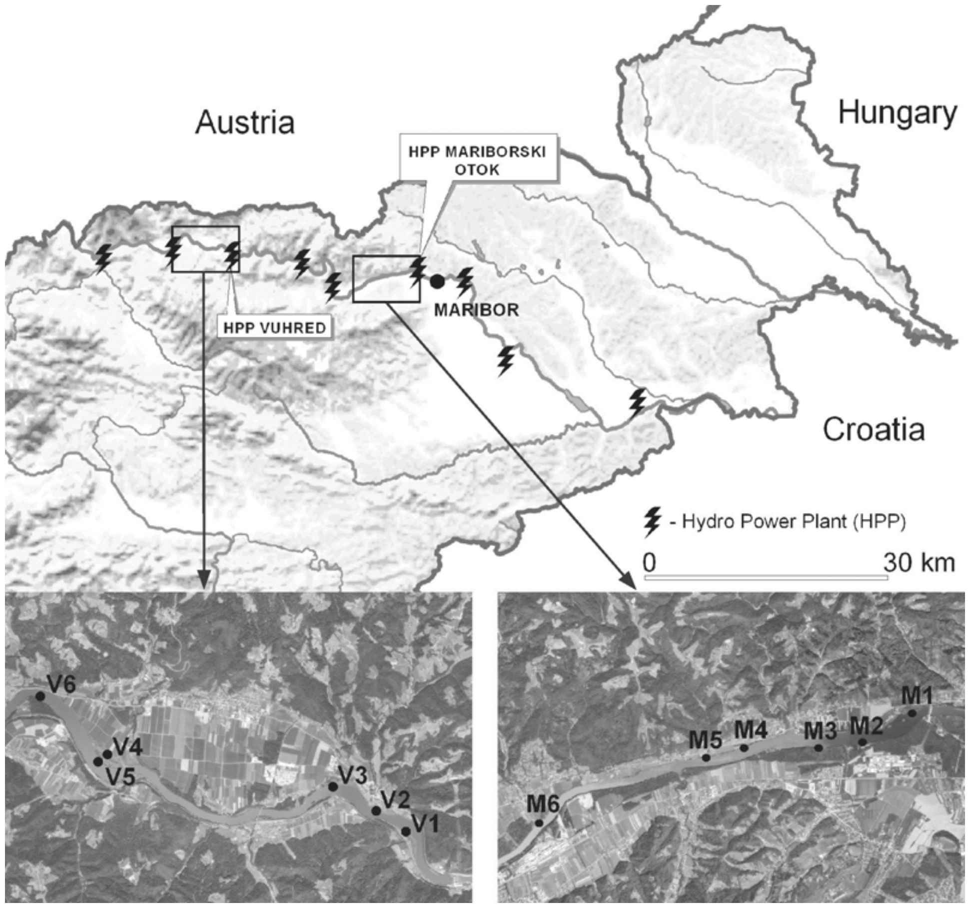

Fig. 1. Map of NE Slovenia with the Drava River and the positions of the hydropower plants HPP Vuhred and HPP Mariborski otok, their impoundments and sampling locations (HPP Mariborski otok: M1–M6; HPP Vuhred: V1–V6).

of days when water temperature was $>10\,^{\circ}$C, from January 1 to the day of sampling (August 25), corresponds to the length of the vegetation period of macrophytes.

Statistical analysis

Data were analysed using the statistical software package Statistica for Windows 7.1. Data on the biomass of the two macrophyte species were not distributed normally (Shapiro–Wilk's test: $d = 0.33$, $P < 0.05$; Lilliefors: $P < 0.01$). Therefore, differences in the influence of exposure of plants to the main water flow on plant biomass of both species were analysed using the Mann–Whitney U test. The Kruskal–Wallis test (ANOVA) was used to test the differences in plant biomass between years. The Spearman correlation coefficient (R) was used to test the correlation between biomass and length of macrophytes. Differences were considered to be statistically significant when $P < 0.05$.

The influence of abiotic factors, such as water temperature, water level and discharge on final plant biomass of *E. nuttallii* was observed trough multivariate analyses. Multivariate analysis was done using Regression Tree Models, which compute good results, even when independent variables are correlated. In this analysis average biomass of macrophytes of a previous year, average monthly water temperatures, average monthly discharges, average monthly water levels, length of the vegetation period, maximum discharge and minimum water level as well as exposure of the sampling location to the main water current were included as independent variables.

Results

Abiotic factors

The greatest differences in water temperature between the years were observed in the early growing season (April, May and June). The average water temperature was almost 4 °C higher in May 2011 than in May 2009 and 3 °C higher than in 2010, respectively (Fig. 2). In the spring of year 2011, the water temperature achieved earlier the value above 10 °C than in the years 2009 and 2010, what can be seen in Figure 3, where detailed analysis of spring temperatures was made. During the period June–July, temperatures were on average higher in years 2010 and 2011 than in 2009, while in August there were no differences between years (Fig. 2).

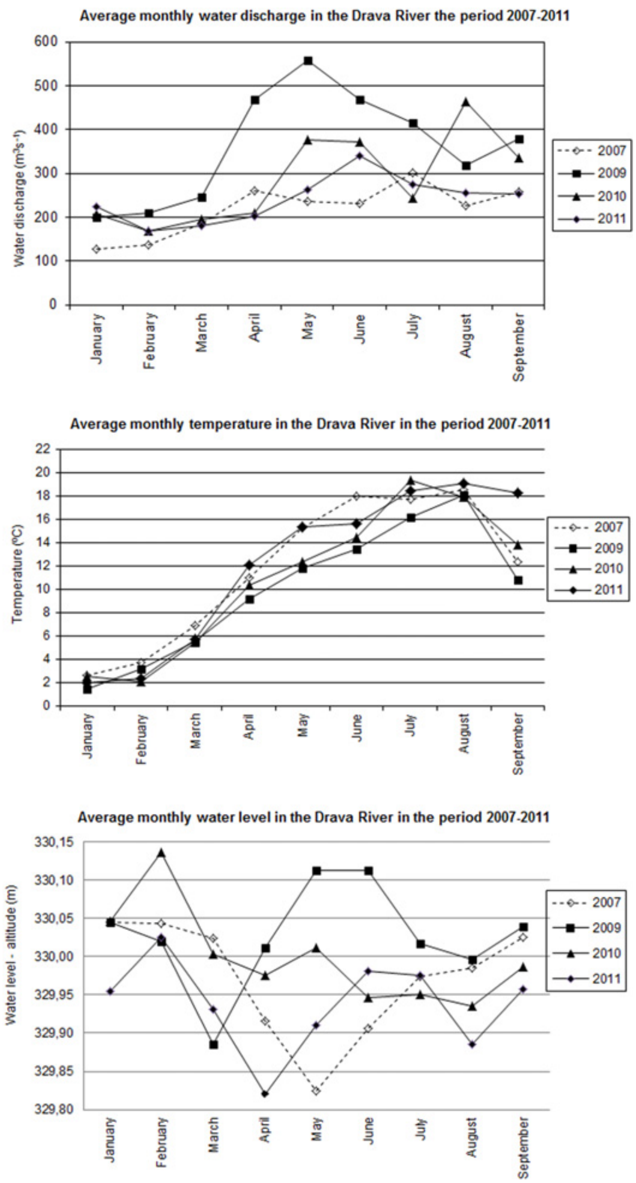

Fig. 2. Average monthly discharge, monthly water temperatures and monthly water level of the Drava River in the period 2007–2011 (data source: Dravske elektrarne Maribor).

The maximum difference between the lowest and highest water level was <35 cm and it is clear that a small increase in water level leads to a strong increase from <200 to >500 $m^3.s^{-1}$ in the discharge. Discharge was substantially higher in 2009 than in 2010 and 2011. Differences were greatest early in the growing season (April and May) and in July. Differences between years 2009 and 2010 were apparent in May and August, while discharge was the lowest in 2011 (Fig. 2).

In parallel with the rates of discharge, the level of water was, on average, highest in 2009 and lowest in 2011. The water level was particularly low in April and May 2011 (Fig. 2).

Because macrophytes developed huge unmeasured biomass in the year 2007, the levels of water temperature,

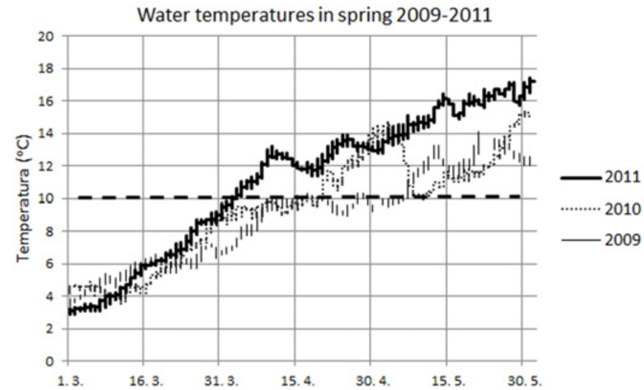

Fig. 3. Water temperature pattern in spring months March, April and May in 2009, 2010 and 2011.

water level and water discharge in this year are also presented in Figure 2. It is clear that conditions in this year were similar than in 2011.

Macrophyte composition and biomass

The presence and abundance of species *M. spicatum* and *E. nuttallii* at sampling locations in the years 2009, 2010 and 2011 are presented in Table 1. At the sampling locations the sediment was mostly mud. *M. spicatum* was present at almost all locations studied, while *E. nuttallii* did not prefer locations, which were directly exposed to main water current. The Mann–Whitney U test showed that the level of biomass of *E. nuttallii* was dependent on exposure of plants to the main water current ($Z = 2.56$; $P < 0.05$); *E. nuttallii* was more commonly found (30 versus 7) in sheltered areas, where the water current was diminished. In contrast, the level of biomass of *M. spicatum* was not significantly dependent on exposure ($Z = -1.88$; $P = 0.06$), but the species was found more frequently in the areas exposed to the main water current (62 versus 6).

While abundance of *M. spicatum* was similar in 3 years, the abundance of *E. nuttallii* increased at some locations in 2011 (Table 1). The average harvest plant biomass of both species at sampling locations was higher in 2011 than either 2009 or 2010 (Fig. 4). It differed significantly between the 3 years (Kruskal–Wallis test: *E. nuttallii:* $H_{(2,37)} = 27.86$; $P < 0.01$; *M. spicatum:* $H_{(2,68)} = 42.17$; $P < 0.01$). The increase in biomass was much more significant in the case of *E. nuttallii* (Fig. 4).

Length of plants

Greater biomass of plants was more likely to be a consequence of greater length than of greater density, expressed as the number of stems per unit area. A strong correlation was found between biomass and length: $R = 0.86$ ($n = 105$; $P < 0.0001$). *E. nuttallii* reached its maximum length of 40 cm in 2009, 70 cm in 2010 and up

Table 1. The spatial distribution and abundance of macrophytes on sampling locations in the two impoundments of the Drava River (HPP Mariborski otok: M1–M6; HPP Vuhred: V1–V6) in the years 2009, 2010 and 2011. Abundance in each section was evaluated according to Kohler and Janauer (1995) on a five-level descriptor scale (1 – very rare, 2 – rare, 3 – common, 4 – frequent, 5 – abundant, predominant).

		M1	M2	M3	M4	M5	M6	V1	V2	V3	V4	V5	V6
2009	*E. nuttallii*	4	3	1	3	3	4	2	0	2	0	0	0
	M. spicatum	1	1	2	2	0	2	3	3	2	3	3	3
2010	*E. nuttallii*	4	2	3	2	3	4	0	0	2	0	0	0
	M. spicatum	1	1	2	3	0	2	3	3	2	4	3	3
2011	*E. nuttallii*	5	3	3	2	5	5	0	0	4	0	0	0
	M. spicatum	0	2	2	3	0	2	3	3	2	4	3	3

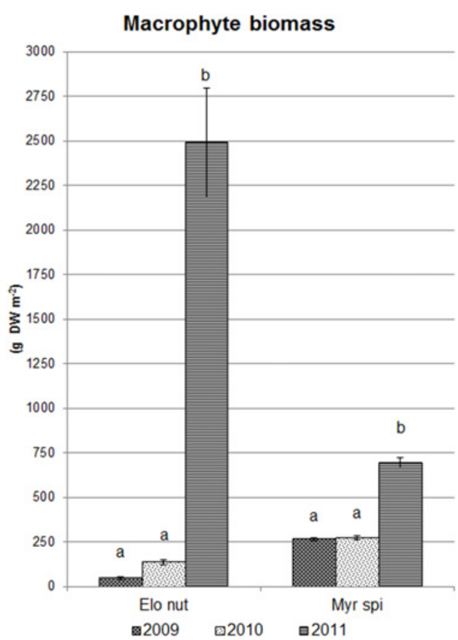

Fig. 4. Dry biomass (DW) of macrophytes in the Drava River in years 2009, 2010 and 2011. Error bars indicate the standard errors. Different letters indicate significant statistical differences in the biomass of both species amongst years (Mann–Whitney *U* Test).

to 300 cm in 2011. Specimens of *M. spicatum* reached a maximum length of 150 cm in 2009 and 2010 and up to 200 cm in 2011. The length of plants of both species, especially *E. nuttallii*, in 2011 exceeded the depth of the water, and upper parts of the plants were found to be floating on the water surface.

Influence of temperature, water level and discharge on final biomass of *E. nuttallii*

A Regression Tree model revealed that the main influence on the final biomass of *E. nuttallii* had the average water temperature in March (T_{Mar}; Fig. 5). It states that when T_{March} was higher than 5.6 °C then *E. nuttallii* grew in the extreme extent. On the other hand, when T_{March} was lower than above stated, an additional variable influenced the growth of this macrophyte species, *i.e.*, the average water temperature in January (T_{January}). Temperatures above 2 °C favour the growth of *E. nuttallii* in the following spring. Third variable that also determined the final biomass of *E. nuttallii* was the exposure of the sampling location. The Regression Tree model showed that *E. nuttallii* grew intensively in sheltered locations (Fig. 5), as it was also determined by basic statistic (see chapter 3.2). All three mentioned variables had important influence on the invasive behaviour on *E. nuttallii*.

Discussion

The abiotic factors, temperature, water level and discharge in the Drava River during the years 2009–2011 varied markedly. The lowest water level and discharge were in the spring 2011, time at which the average temperatures were higher than in 2009 and 2010. This resulted in the highest final biomass of macrophytes in 2011. That macrophyte community responds to increased temperatures with increased productivity and accelerated life-cycles have been reported elsewhere (Grace and Tilly, 1976; Haag and Gorham, 1977; Barko *et al.*, 1982; Svensson and Wigren-Svensson, 1992; Taylor and Helwig, 1995; Rooney and Kalff, 2000). When compared to 2009 and 2010, there was much higher increase in the plant biomass of *E. nuttallii* than that of *M. spicatum* in 2011. Perhaps on account of lower water temperatures, connected with higher water level in the spring of 2009 and 2010, *E. nuttallii* failed to develop its biomass to a high degree. *M. spicatum* was also observed in faster flowing waters (Butcher, 1933; Bernez *et al.*, 2004; Hrivnák *et al.*, 2006), while *E. nuttallii* is known to have low resistance to turbulence-induced mechanical stress (Ellawala *et al.*, 2011). Multivariate analysis shows that the key factor for the developing of final biomass of *E. nuttallii* was the temperature in winter and early spring and also the level of exposure to main water flow. Indeed, higher temperature of the water in winter and spring is important for the more intense biomass development of *E. nuttallii* as it has already been reported (Kunii, 1981; Hamabata, 1997; Rooney and Kalff, 2000). Hamabata (1997) discovered that a mild winter with a minimum monthly temperature above 8 °C favoured the growth of overwintering plants of *E. nuttallii* from which new shoots are produced vegetatively in temperate regions. Shoot elongation of this

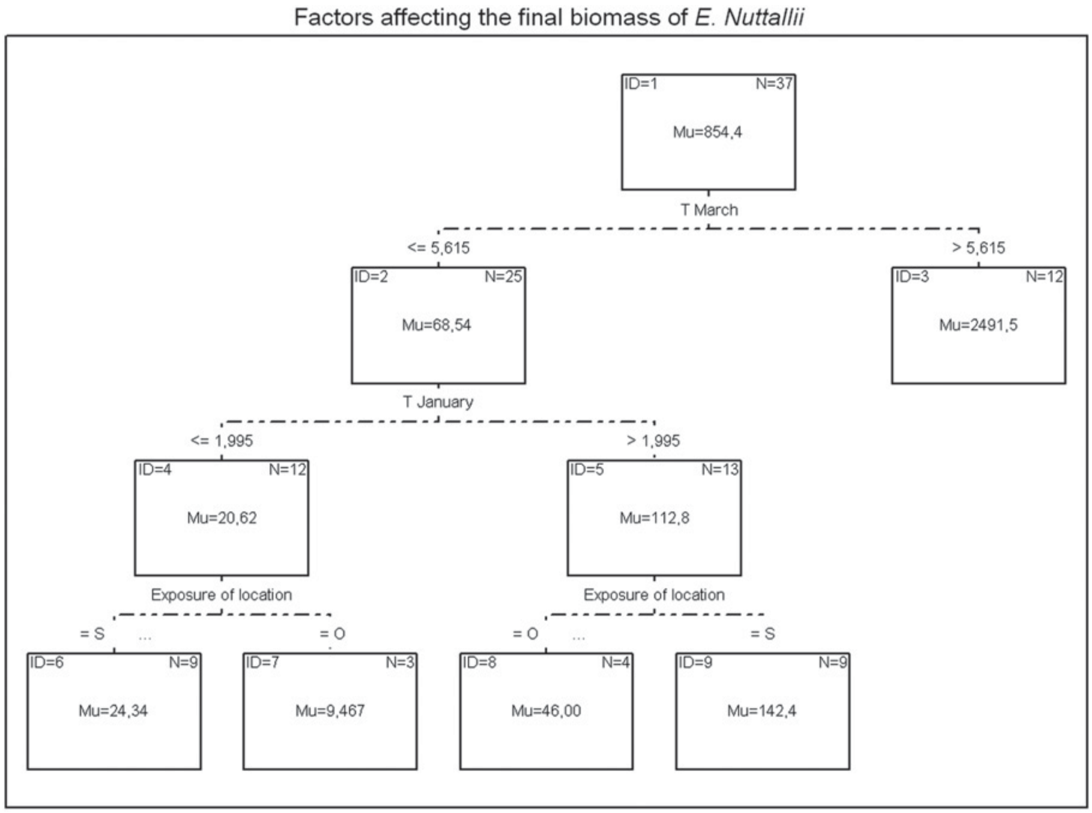

Fig. 5. A Regression Tree model (multivariate analysis) of the influence of the average monthly water temperatures, water levels and discharge in the Drava River in 2009, 2010 and 2011 on the final biomass of *E. nuttallii*. (Mu: average biomass in g per dry weight; o: open; s: sheltered).

species began in spring, when the water temperature exceeded about 10 °C (Kunii, 1984). In 2011, the water temperature of the Drava River reached 10 °C at the beginning of the April, earlier in the season than in 2010 (mid-April) and 2009 (beginning of May), so it was presumed that the growth season for macrophytes in the Drava River started earlier in 2011. The earlier start of the vegetation period correlates strongly with plant biomass, as was found by McKee *et al.* (2002). *M. spicatum* is known to tolerate colder water and to grow earlier in the spring (Trebitz *et al.*, 1993; Madsen, 1994), but its biomass was also found to be higher in bodies of warmer water (Olson *et al.*, 2012).

It is possible that *E. nuttallii* outcompeted *M. spicatum* in sheltered locations of the Drava River. We assumed that its relatively lower biomass in comparison to *E. nuttallii* in 2011 could be attributed to the fact that *M. spicatum* grew also in areas in the Drava River exposed to the main water flow, which prevented developing of a large biomass. There were very significant differences, from <200 to >500 $m^3.s^{-1}$ in the level of the discharge and this resulted in strong differences in the river current, which is in fact a major driver for the plant biomass development and the potential removal of submerged plants in rivers by abrasion (Madsen *et al.*, 2001).

E. nuttalii showed its invasive character in the Drava River in warmer year 2011, but only in places, which were not directly exposed to main water flow. The biomass of *E. nuttallii* reached this year a maximum of more than 5000 g dry weight.m^{-2}, which is considerably beyond the figures reported by other researchers. Kunii (1984), Ozimek *et al.* (1990) and Hamabata (1997) reported that the biomass of *E. nuttallii* varied from 500 to 800 g dry weight.m^{-2} in lakes. Hamabata (1997) also reported that, under favourable conditions, *E. nuttallii* tends to form dense pure stands that often reach a height of more than 2 m. In the Drava River, the length of *E. nuttallii* reached as much as 3 m by the end of the season in 2011.

In Slovenia, the alien species *Elodea canadensis* failed to express its invasive character in heterogeneous watercourses with rich macrophyte communities (Kuhar *et al.*, 2010). It is known that *E. canadensis* and *E. nuttallii* have very similar ecological niches and similar biological traits (Herault *et al.*, 2008) and thus we presume that the alien species *E. nuttallii* is unlikely to become invasive in Slovenian watercourses and will not replace native macrophyte species in normal circumstances. Nevertheless, its invasive potential could be expressed under suitable abiotic factors in artificially regulated watercourses and cause economical damage. We assume that continuation of the deposition of silt in the impoundments of the Drava River could contribute to huge expansion of invasive species *E. nuttallii* in years with warmer springs.

Conclusions

1. The levels of temperature in the winter and spring months, together with the values of water level in April, the time of the starting of vegetation period and the level of water discharge in spring months, were the key factors, which could be used as one of the tools for a cautious prediction of the final biomass of macrophytes in August. This would help hydropower plants to define management actions aimed at maintaining uninterrupted operation of hydroelectric power plants without significant economic damage.
2. Multivariate analysis shows that the key factors for the developing of final biomass of *E. nuttallii* were the temperature in winter and early spring and also the level of exposure to main water current. *E. nuttallii* however showed more invasive behaviour in years with higher average water temperatures, lower water level and lower water discharge in spring, but only at places, which were not directly exposed to the main water current.
3. Deposition of silt in the impoundments and warmer years could contribute to huge expansion of invasive species *E. nuttallii* in impoundments of the river Drava, while removal of mud and maintenance of river characteristics of the Drava River would encourage prevalence of native species against alien species.

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