

Impact of Climate Changes on Aquatic Vegetation of Hydromeliorative Facilities

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ABSTRACT

Distributions of 20 aquatic associations in the Danube-Tisza-Danube hydrosystem were mapped using published data and personal field observations resulting in 562 georeferenced collection sites. The Maxent modeling software was used to estimate the current potential and future distribution of the associations by the year 2050 (2xCO₂ climate conditions, CCM3 model). Based on the Principal Component Analysis (PCA), climate data at the collection sites described climatic preferences of different aquatic associations. The central-eastern part of the investigated area showed the most favorable climatic conditions for aquatic vegetation growth and thus the highest potential for future biodiversity. The stands of *Lemnetum trisulcaae*, *Ceratophyllo-Azolletum filiculoides*, *Najadetum marinae*, *Salvinio natantis-Spirodeletum polyrhizae*, *Elodeetum canadensis* and *Potametum denso-nodosi* associations displayed a marked invasive potential in the forecasted distribution scenarios. The results revealed that the stands of *Nymphaetum albae* and *Nymphaeo albae-Nupharetum luteae subass. nupharetosum* associations are likely to be significantly less abundant in the future. As the key climatic factors used in the analysis were annual mean temperature, as well as mean temperature of the wettest and warmest quartile, the findings suggest that, if adequate protective measures shall not be taken, these provenances could become degraded in the next decade and some could even become extinct at the locations where they presently occur naturally.

Key words: climate change, aquatic vegetation, hydromeliorative facilities, Maxent.

Aquatic macrophytes are a significant component of aquatic ecosystems. Changes in the distribution and composition of phytocenoses are useful indicators of environmental status [Hrivnák et al., 2011]. Most of the aquatic flora, due to the high degree of polymorphism and phenotypic plasticity, as a response to environmental variations, thrives in diverse conditions and has cosmopolitan distribution. Thus, small number of aquatic plants that are less

tolerant to environmental variations, through their presence and relative abundance, serve as reliable habitat quality indicators [Lacoul, Freedman, 2006].

Light intensity, temperature, water flow rate, substrate type, sediment, and nutrient concentrations are important factors affecting the growth of macrophyte vegetation [Hughes, 2000; Scott et al., 2002; Parmesan, Yohe, 2003; Madsen et al., 2006; Nikolić et al., 2007; Grin-

berga, Sprinĝe, 2008; Nikolić et al., 2009; Hrivnák et al., 2009; Radulović et al., 2010; Janauer et al., 2010; Džigurski et al., 2014]. However, due to its many direct and indirect effects on physical, chemical, biological, metabolic, and physiological characteristics of aquatic ecosystems, temperature remains the predominant factor. Consequently, effects of temperature and climate changes on aquatic plants and their communities are the subject of a growing number of studies [Parmesan, Yohe, 2003; Burnett, 2007; Grinberga, Sprinĝe, 2008].

Intensive macrophyte growth starts when water temperature reaches 8–10 °C, whereby higher air temperatures enable more rapid increases [Scott et al., 2002; Madsen et al., 2006; Grinberga, Sprinĝe, 2008]. Under moderate continental climatic conditions, occurrence of macrophytes is governed by their resistance to low temperatures. Thus, meteorological conditions have decisive effects on aquatic vegetations, as summer droughts result in low water levels that favor macrophyte overgrowth [Abou-Hamdan et al., 2005; Sender, 2009]. Climate change forecast scenarios suggest that shallower aquatic ecosystems thriving in temperate climate are more likely to be significantly eroded [Nikolić et al., 2011]. Thus, it is evident that future climate changes could cause change in vegetation distributions [Kelly, Goulden, 2008].

Previous studies have modeled future species distribution at both regional and local scale in order to raise awareness of the high risk of species extinction in the next century [Erasmus et al., 2002; Thuiller, 2004; Scheldeman et al., 2007].

Predictive modeling of species geographic distributions based on the environmental conditions of specific geographic sites has previously yielded valuable information in diversity studies [Skov, 2000; Vargas et al., 2004]. These studies allow us to understand the distribution of specific taxa [Hijmans, Spooner, 2001], help to define their diversity and collection gaps [Scheldeman et al., 2007], and assist in understanding climatic adaptation mechanisms [Berger et al., 2003; Van Zonneveld et al., 2009]. Moreover, findings of such studies have potential application in invasive species management [Ward, 2007; Giovanelli et al., 2007] and help determine conservation areas [Bystriakova

et al., 2003; Chen, Junfeng, 2007]. Species distribution modeling combines species locality data with environmental variables to create a model of species requirements for the examined parameters [Anderson et al., 2003].

The Climate Envelope Modeling (CEM) is a useful tool for rapid assessment of the potential impacts of climate change on the distribution of species and ecosystems. It uses the documented geographic distribution of a species as a basis for predicting its potential occurrence [Van Zonneveld et al., 2009]. Furthermore, Geographical Information System (GIS) provides a visual representation of species distribution and habitat status and therefore has important use in biogeography.

The aim of the research presented here was to demonstrate the current and potential distribution of 20 aquatic vegetation communities and to predict the impact of climatic factors on their distribution by the year 2050. Particular emphasis was given to associations with significant deviations from the distribution, as these species provide reliable information on the impact of climate change on aquatic vegetation. Moreover, the aim of our study was to identify the areas of high present and potential future diversity, as well as determine climatic preferences of aquatic associations.

MATERIALS AND METHODS

Study area. The Danube-Tisza-Danube hydrosystem (Hs DTD) is the central part of the European inland waterway Rhine-Main-Danube, and is one of the largest hydrosystems in Europe as well as one of the most important in the world (Fig. 1). Hs DTD is located in the Vojvodina Province, Serbia (44°39'15.04" and 46°10'11.32" north latitude to the 18°50'15.00" and 21°33'27.82" east longitude). It is a versatile, anthropogenic hydrosystem that regulates waterways in Vojvodina region. Its canal network connects 80 residential locations, allows drainage of excess water and irrigation of agricultural land, provides water supply to urban and industry sectors, as well as fisheries, facilitates water transport, accepts and removes waste water, and provides excellent facilities for recreation, sport and tourism. The total length of all 19 Hs DTD channels is 930 km,

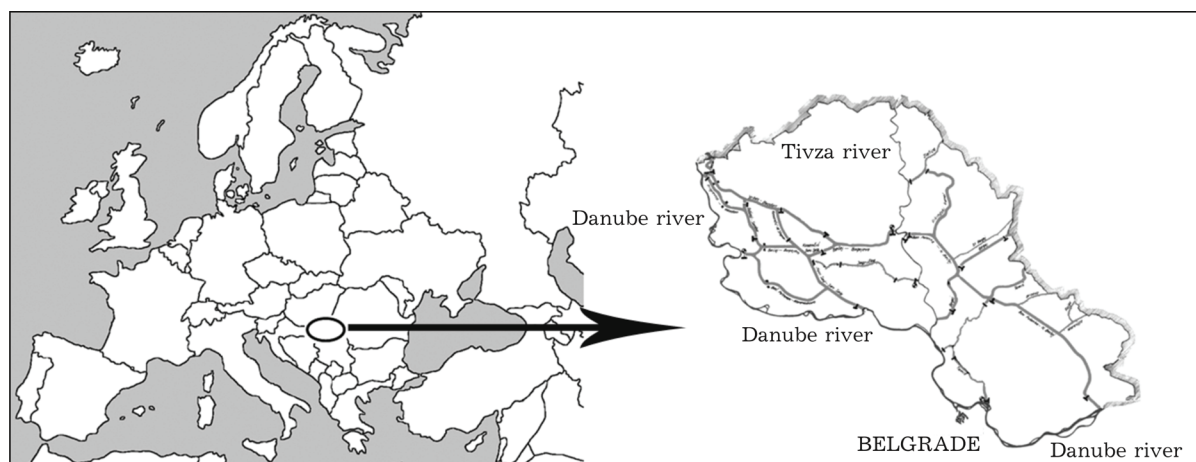


Fig. 1. Study area: The Danube – Tisza – Danube hydrosystem

of which 600 km are navigable [Lazić, 2006]. Vojvodina is characterized by moderate continental climate. It is a part of the Pannonian Basin and is mostly surrounded by mountains (the Carpathians, the Alps and Dinarides). The greater openness of the area to the north and west allows air currents and weather changes in these parts to significantly affect the climatic conditions of Vojvodina region. Combined with large annual fluctuations in air temperature, these factors result in a greater degree of continental climate characteristics expression in Vojvodina than would be attributed to its general geographical location. The average annual temperature in this region is 11.0 °C, with the mean annual temperature gradient increasing from the northwest (10.7 °C) to southeast (11.7 °C). In Vojvodina, average summer temperatures are between 21 and 23 °C, average winter temperature is 2 °C and spring and fall are rather short [Katić et al., 1979; Lalić et al., 2011].

Long-term studies of aquatic vegetation of Hs DTD in Vojvodina Province (Serbia) were conducted in the vegetative period between 2004 and 2009, by applying the Braun-Blanquet method. The syntaxonomic survey was made according to Chytrý [2011].

For the purpose of spatial analysis presented in this work, all data points were entered into the Geographic Information System DIVA-GIS 5.2 software [Hijmans et al., 2005].

Using the BIOCLIM model [Busby, 1991], 2.5 arc-minutes resolution WorldClim climate data set [Hijmans et al., 2005], potential areas of distribution of each association were mode-

led, based on climatic preferences. In this study, all 19 BIOCLIM climatic parameters were used. These variables are derived from the monthly temperature and rainfall values and represent annual trends, seasonality and extreme or limiting environmental factors. The Maxent modeling software [Phillips et al., 2006, 2008] was used to predict potential associations distribution as well as future distribution for the year 2050 (2xCO₂ climate conditions, CCM3 model). Calibration (training) data was generated by randomly selecting 75 % of the occurrence records. Modeling was performed using default settings for control parameters (maximum number of iterations = 500, convergence threshold = 10⁻⁵, regularization multiplier = 1.0, maximum number of background points = 10 000). Moreover, the “area under the receiver operating curve” (AUC) index was used to assess the model performance, as it provides a single measure of overall accuracy that is not dependent upon a particular threshold. AUC scores greater than 0.50 are thus taken to indicate that a model performs better than it could be ascribed to random chance only; poorly if 0.60 < AUC < 0.70, it is deemed acceptable if 0.70 < AUC < 0.80; good if 0.80 < AUC < 0.90; and excellent if AUC > 0.90 [Araújo et al., 2005]. The spatial analysis yielded 20 maps (one for each aquatic association) that, combined, indicated modeled potential and future species diversity.

Principal Component Analysis (PCA) was carried out on all 19 climatic parameters, applying a varimax normalized rotation using

STATISTICA for Windows version 10.0 [2011]. Each association was represented in DivaGis and total of 19 BIOCLIM variables were generated for each investigated locality on the basis of the WorldClim data set. PCA summarized 19 BIOCLIM variables and produced principal factors and factor scores. Only factors with eigenvalues superior or equal to one were used. The arithmetic average of the factor scores for each association was taken as the indicator of each association's climatic preferences. Representation of variation around the centroid, in order to give an indication of the adaptability of each association for each climatic principal component, was achieved using standard deviation of factor scores [Scheldeman et al., 2007].

RESULTS AND DISCUSSION

Syntaxonomic survey and short descriptions of studied aquatic vegetation

- Class: Lemnetea de Bolós et Masclans 1955
 Alliance: *Lemnion minoris* de Bolós et Masclans 1955
 Ass. *Lemnetum trisulcae* Den Hartog 1963
 Ass. *Lemno-Spirodeletum polyrhizae* Koch 1954
 Ass. *Lemnetum gibbae* Miyawaki et J. Tüxen 1960
 Ass. *Salvinio natantis-Spirodeletum polyrhizae* Slavnić 1956
 Ass. *Ceratophyllo-Azolletum filiculoides* Nedelcu 1967
 Alliance: *Utricularion vulgaris* Passarge 1964
 Ass. *Lemno-Utricularietum* Soó 1947
 Alliance: *Hydrocharition morsus-ranae* (Passarge 1964) Westhoff et den Held 1969
 Ass. *Hydrocharitetum morsus-ranae* Van Langendonck 1935
 Ass. *Ceratophylletum demersi* Corillion 1957
 Class: Potametea Klika in Klika et Novák 1941
 Alliance: *Nymphaeion albae* Oberdorfer 1957
 Ass. *Nymphaeo albae-Nupharetum luteae* Nowiński 1927
 Ass. *Nymphaeo albae-Nupharetum luteae* Nowiński 1927 subass. *nupharetosum*
 Ass. *Nymphaeetum albae* Vollmar 1947
 Ass. *Trapetum natantis* Kárpáti 1963

- Ass. *Nymphoidetum peltatae* Bellot 1951
 Alliance: *Potamion* Miljan 1933
 Ass. *Potametum lucentis* Hueck 1931
 Ass. *Elodeetum canadensis* Nedelcu 1967
 Ass. *Elodeetum nuttallii* Ciocârlan et al. 1997
 Ass. *Potamo pectinati-Myriophylletum spicati* Rivas Goday 1964
 Ass. *Potametum denso-nodosi* de Bolós 1957
 Ass. *Najadetum marinae* Fukarek 1961
 Ass. *Najadetum minoris* Ubrizsy 1961

Lemnetum trisulcae is submerged, bare-rooted, association. In the studied area, it is sporadically developed near the shore, in places where the water is mesotrophic to eutrophic, warm, does not exceed 1 m in depth, and the waterbed is mostly muddy. In addition to the edicator *Lemna trisulca* L., floating *Lemna minor* L. and *Hydrocharis morsus-ranae* L., as well as submerged *Ceratophyllum demersum* L., also contribute to the physiognomic character of these floristically poor stands.

Lemno-Spirodeletum polyrhizae is a floating, bare-rooted phytocenosis, usually forming a broad, several hundred meters long belt, in hypertrophic shallow waters, alongside semiaquatic vegetation. Water currents often tear parts of these stands, dispersing phytocenosis fragments into deeper waters. Its main contributors are *Lemna minor* and *Spirodela polyrhiza* (L.) Schleid, along with *Ceratophyllum demersum*, *Lemna gibba* L. and *Salvinia natans* (L.) Allioni.

Lemnetum gibbae is characterized by fragmented development, thus forming small islands in close proximity to the canal banks. The parts of the canal where the water is warm, the depth does not exceed 0.5 m, and the current is calm, provide optimal conditions for its development. In addition to the edicator, *Lemna minor*, *Ceratophyllum demersum*, *Salvinia natans* and *Spirodela polyrhiza* also contribute to the physiognomic character of this phytocenosis

Salvinio natantis-Spirodeletum polyrhizae forms a long belt along the semiaquatic vegetation. Warm and sunny places, shielded from the wind, where the water is shallow, calm and eutrophic are conducive to its development. Under favorable temperature and light regimen, these stands sometimes cover

almost the entire canal width. Along with the edificators, *Lemna minor* and *Ceratophyllum demersum* are also common in these stands.

Ceratophyllo-Azolletum filiculoides typically forms islands or narrow belts along the emerged vegetation. These communities are most abundant in quiet wind-protected places along the canal banks, close to reclamation facilities, in water depths of up to 0.5 m. The basic physiognomic character of these floristically poor stands provide *Azolla filiculoides* Lam. and *Ceratophyllum demersum*, as well as *Lemna minor*, *Lemna gibba* and *Spirodela polyrrhiza*.

Lemno-Utricularietum, in the studied ecosystem, developed directly along the reed beds and between their sparse stands. *Utricularia vulgaris* L., *Lemna minor*, *Ceratophyllum demersum* and *Myriophyllum spicatum* L. form these floristically poor stands.

Hydrocharitetum morsus-ranae is of the floating, bare-rooted vegetation type. However, in very shallow waters (not exceeding 0.3 m in depth), rooting of *Hydrocharis morsus-ranae* species occasionally occurs. Shallow and warm waters, flowing slowly over a muddy waterbed, are most conducive for the development of these stands, which typically form small islands 2-3 m in diameter, creating a mosaic with other floating phytocenoses. Along with the edificators, these stands are dominated by *Lemna minor*, *Spirodela polyrrhiza* and *Ceratophyllum demersum*.

Ceratophylletum demersi is a submerged bare-rooted association that develops in highly eutrophic, deeper canal waters, where it sometimes forms lush "underwater meadows". Less frequently, in canal sections where the current is slightly faster and floating vegetation less developed, it forms a narrow band alongside emerged vegetation. *Ceratophyllum demersum*, as well as *Myriophyllum spicatum*, *Lemna minor* and *Spirodela polyrrhiza*, contribute to the physiognomic character of these stands.

Nymphaeo albae-Nupharetum luteae is the most developed and the most stable floating rooted vegetation, which in the studied area forms either a narrow belt bordering the emerged vegetation, or a very wide one that extends towards the canal middle. Optimum development of these stands favors moderately eutrophic waters, of 1-2.5 m depth. These floristically rich stands are dominated by *Nu-*

phar luteum (L.) Sm. and *Nymphaea alba* L., although *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Salvinia natans*, *Hydrocharis morsus-ranae* and *Vallisneria spiralis* L. also show a strong presence.

Nymphaeo albae-Nupharetum luteae subass. nupharetosum is present in deeper waters (typically exceeding 2 m), is moderately rich in organic and mineral matter, and can tolerate small water ripples. Towards the canal banks, stands of this subassociation are often the last belt of floating vegetation. Their physiognomic, floristic and cenotic character derives from the edificator *Nuphar luteum*, while the association subedificator, *Nymphaea alba*, was noted in only one locality. *Lemna minor*, *Spirodela polyrrhiza* and *Ceratophyllum demersum* are present in almost all studied associations.

Nymphaeetum albae in the studied area developed at the depth of 0.5-2 m, on the canal section that is a natural depression and is used as a pond. This section is characterized by a wide waterbed, weak current, negligible water level fluctuations and mesotrophic status. In addition to the floating edificators of this association, submerged *Ceratophyllum demersum* and *Myriophyllum spicatum* are also abundant.

Trapetum natantis is the dominant floating vegetation in the DTD canal network. Thermophilic stands are developed in the central, deeper parts of the canal (cca. 3 m), characterized by frequent water level fluctuations, as well as in shallower sections, where the water has eutrophic status [Džigurski et al., 2013]. *Trapa natans* L. predominates its floristic composition, along with *Hydrocharis morsus-ranae*, *Spirodela polyrrhiza*, *Ceratophyllum demersum* and *Myriophyllum spicatum*.

Nymphoidetum peltatae develops optimally in eutrophic, slow-flowing, 0.5-2.5 m deep waters. In addition to the edificator, which provides the main character to these stands, *Trapa natans*, *Hydrocharis morsus-ranae*, *Ceratophyllum demersum*, *Vallisneria spiralis*, *Lemna minor*, *Spirodela polyrrhiza* and *Salvinia natans* contribute to their heterogenous structure.

Potametum lucentis is a submerged rooted community, developed on a muddy waterbed, in the deeper canal sections (up to 3 m). While it thrives in warm and slow waters, it

also tolerates water current effects. In the studied canal network, these stands are characterized by fragmented development, in the form of islands. The floristic composition is dominated by *Potamogeton lucens* L. and *Myriophyllum spicatum*, along with significant representation of *P. pectinatus* L., *Ceratophyllum demersum*, *Lemna minor*, *P. fluitans* Roth., *P. crispus* L. and *Spirodela polyrrhiza*.

Elodeetum canadensis is a submerged rooted phytocenosis, developed mostly in the shallower, calmer canal sections and bays, in close proximity to the emerged vegetation. In summer, the time of intensive development, the stands develop in water depths of 1–1.5 m, where they form islands several meters in diameter. The dominant *Elodea canadensis* Rich. provides the basic physiognomic character, while the presence of *Ceratophyllum demersum*, *Lemna minor* and *Spirodela polyrrhiza* is sporadic.

Elodeetum nuttallii is formed on the muddy waterbed, in shallow canal sections and bays, alongside semiaquatic vegetation, in places where the water flow is slow. Eutrophic waters provide favorable conditions for the development of this stand. By its synmorphology and synecology, this community is very similar to the ass. ***Elodeetum canadensis***, with the exception that ***Elodeetum nuttallii*** stands tolerate water salinity, and their distribution is thus conditioned by the composition of the surrounding land. While the edificator *Elodea nuttallii* (Planch.) H. St. John determines the primary physiognomic character of these stands, *Potamogeton crispus*, *Ceratophyllum demersum*, *Lemna minor*, *Trapa natans* and *Spirodela polyrrhiza* are noteworthy contributors as well.

Potamo pectinati–Myriophylletum spicati belongs to the submerged rooted aquatic vegetation type. While the stands are typically formed in deeper waters (exceeding 3 m), on the canal sections where the water flow is slower, they tolerate the influence of the water currents. In the studied area, these stands usually form a 10 m-long belt alongside emerged vegetation, and rarely create smaller islands in the canal middle. To this community characterized by heterogeneous floristic composition, in addition to the edificators *Potamogeton pectinatus* and *Myriophyllum spicatum*, sporadically contribute *P. crispus*, *Lemna mi-*

nor, *Ceratophyllum demersum* and *Spirodela polyrrhiza*.

Potametum denso-nodosi in the studied area developed in the central, deepest canal sections (3–3.5 m), where the influence of water currents is significant. On some sections, the stands extend across the entire canal width. In the floristic composition, *Potamogeton fluitans* predominates, though the presence of *Myriophyllum spicatum*, *Najas marina* L., *Lemna minor*, *Ceratophyllum demersum* and *Ranunculus circinatus* L. is also significant.

Najadetum marinae is a submerged rooted community that, in the studied region, developed a few meters away from the canal banks, in deeper waters (up to 2 m). The proliferation of this phytocenosis along the canal banks bordering Slatina pastures is caused by the adaptation of the edificator *Najas marina* to the increased water salinity. In this floristically very poor community, the edificator is only occasionally accompanied by *Ceratophyllum demersum* and *Trapa natans*.

Najadetum minoris is rare in the studied ecosystem and forms small islands in somewhat deeper canal network sections, on muddy waterbeds, alongside emerged vegetation [Ljevnaić-Mašić, 2010]. Its floristic and physiognomic character is primarily influenced by the edificator *Najas minor* All., even though *Myriophyllum spicatum*, *Potamogeton crispus* and *Ceratophyllum demersum* are also prominent.

Future state of climate in the studied area.

Based on the climatic scenario produced by the CCM3 model, in 2050 the climate in the studied region will be characterized by an increase in both minimum and maximum temperature values, as well as a reduction in precipitation (Table 1). In 2050 minimum temperature values will increase by an average of 2.5 °C in comparison to the current climate. The most significant increase in the minimum temperature is expected for April (3.0 °C), October (2.9 °C) and May (2.88 °C). According to the climatic scenario, in 2050 the maximum temperature is also expected to increase by an average of 2.56 °C. The greatest increase is expected for March (3.35 °C), July (3.24 °C) and May (3.23 °C). As noted above, a considerable reduction in precipitation is also expected in 2050. The obtained data indicate that the most significant reduction is expected in August

T a b l e 1

Monthly values of temperature and precipitation for current and future climate extracted from the investigation localities

Month	Current climate			Future climate (CCM3 model)		
	T_{\min}	T_{\max}	P_{rec}	T_{\min}	T_{\max}	P_{rec}
I	-3.23	2.96	38.47	-1.54	3.94	35.44
II	-2.28	5.43	40.46	0.07	7.20	35.24
III	1.40	11.41	37.46	4.02	14.76	40.03
IV	5.95	17.04	49.02	8.96	19.73	52.38
V	10.60	22.18	64.35	13.48	25.41	69.34
VI	13.73	25.33	78.42	16.36	28.30	75.60
VII	15.06	27.94	58.80	17.86	31.18	51.83
VIII	14.69	27.86	52.50	17.20	30.68	25.51
IX	11.17	24.14	43.10	13.40	26.88	24.63
X	6.67	17.73	43.26	9.57	20.76	53.02
XI	2.44	9.52	53.61	4.73	11.61	48.01
XII	-0.79	5.03	51.80	1.20	6.85	67.99
	$\bar{x} = 6.28$	$\bar{x} = 16.38$	$\Sigma 611.25$	$\bar{x} = 8.78$	$\bar{x} = 18.94$	$\Sigma 579.02$

(26.99 mm), September (18.47 mm) and December (16.19 mm), while a minimal increase is noted for March (2.57 mm), April (3.36 mm), May (4.99 mm) and October (9.76 mm). The expected average annual precipitation for 2050 is 579.02 mm, corresponding to a reduction of 32.23 mm compared to the current values.

Effects of climate change on aquatic vegetation. The final dataset included 562 records representing all 20 aquatic associations (Table 2). *Hydrocharitetum-morsus ranae*, *Ceratophylletum demersi* and *Trapetum natantis* were the commonly recorded associations, whereas *Lemno-Utricularietum* and *Ceratophyllo-*

T a b l e 2

The list of all associations, training and test AUC values for current modeling

Associations	AUC _{training}	AUC _{test}
<i>Ceratophylletum demersi</i>	0.928	0.907
<i>Ceratophyllo-Azolletum filiculoides</i>	0.958	0.993
<i>Elodeetum canadensis</i>	0.886	0.835
<i>Elodeetum nuttallii</i>	0.939	0.966
<i>Hydrocharitetum-morsus ranae</i>	0.931	0.900
<i>Lemnetum gibbae</i>	0.946	0.962
<i>Lemnetum trisulcae</i>	0.941	0.928
<i>Lemno-Spirodeletum polyrhizae</i>	0.923	0.877
<i>Lemno-Utricularietum</i>	0.985	0.991
<i>Najadetum marinae</i>	0.974	0.978
<i>Najadetum minoris</i>	0.980	0.990
<i>Nymphaeetum albae</i>	0.998	0.995
<i>Nymphaeo albae-Nupharetum luteae</i>	0.979	0.976
<i>Nymphaeo albae-Nupharetum luteae subass. nupharetosum</i>	0.988	0.989
<i>Nymphoidetum peltatae</i>	0.983	0.971
<i>Potametum denso-nodosi</i>	0.948	0.918
<i>Potametum lucentis</i>	0.858	0.825
<i>Potamo pectinati-Myriophylletum spicati</i>	0.944	0.902
<i>Salvinio natantis-Spirodeletum polyrhizae</i>	0.946	0.858
<i>Trapetum natantis</i>	0.929	0.886

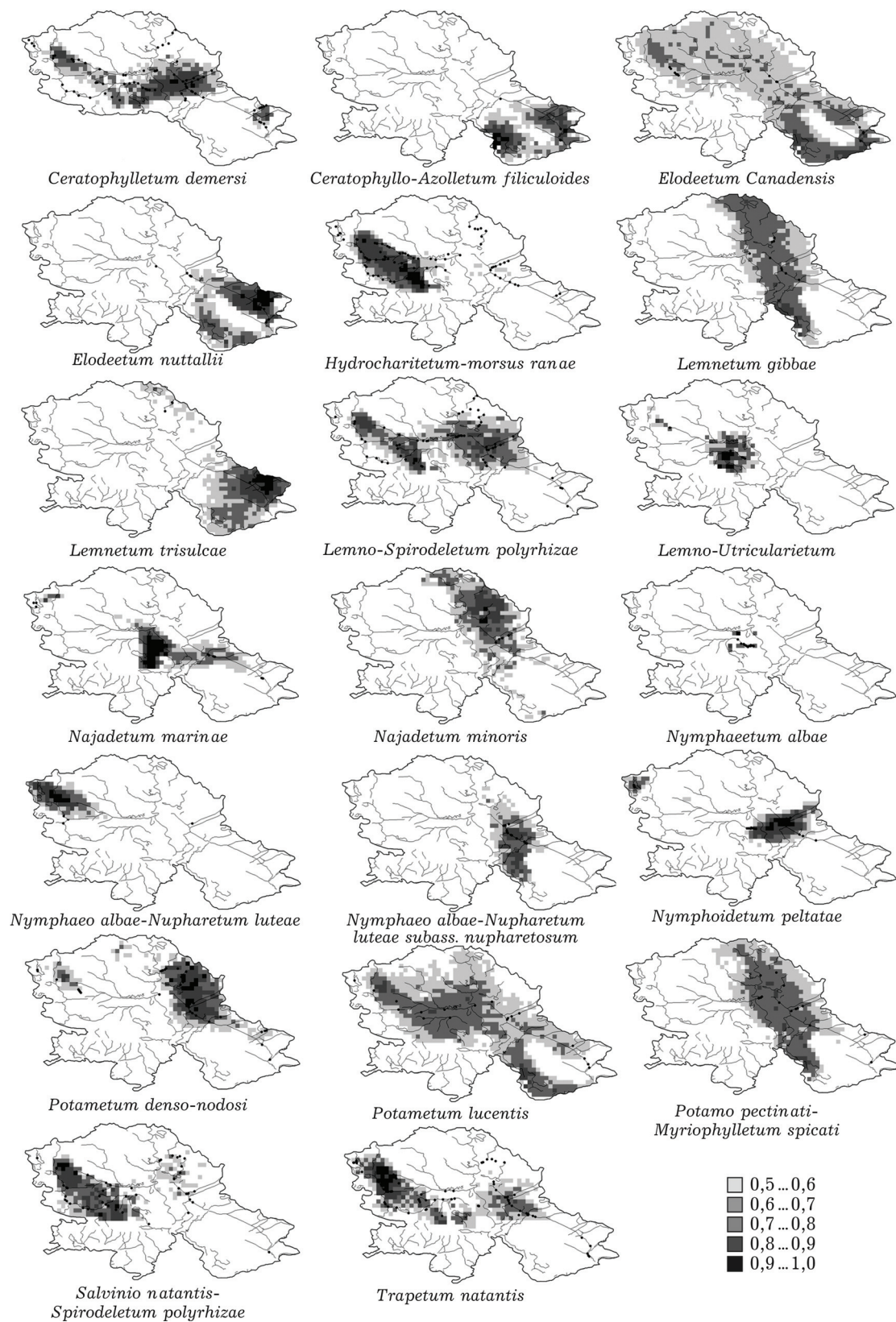


Fig. 2. Collection sites and potential distribution of aquatic associations. Different shades of gray represent the probability of occurrence percentage

Azolletum filiculoides were the least abundant.

The AUC training values for current potential distribution ranged from 0.858 to 0.998, whilst test AUC values were in 0.825–0.995 range.

The climate envelopes developed for each association show that they could potentially occur in several other aquatic ecosystems (Fig. 2). However, potential association distribution for *Ceratophylletum demersi*, *Lemno–Spirodeletum polyrhizae*, *Najadetum marinae*, *Nymphoidetum peltatae*, *Potametum denso-nodosi* and *Salvinio natantis–Spirodeletum polyrhizae* remained unchanged compared to the current status.

Moreover, although *Hydrocharitetum-morsus ranae*, *Lemno–Spirodeletum polyrhizae*, *Trapetum natantis* presently exist in the north part of the investigated area, the potential distribution map did not indicate their presence in this area. The findings suggest that almost the entire investigated area is suitable for *Elodeetum canadensis*, whereas *Elodeetum nuttallii*, *Lemnetum trisulcae*, *Ceratophyllo–Azolletum filiculoides* and *Potametum lucentis* favor southern region. The suitable areas for *Lemno–Utricularietum*, *Nymphaeo albae–Nupharetum luteae*, *Nymphaeo albae–Nupharetum luteae* subass. *nupharetosum*, and especially for *Nymphaeetum albae* are very small compared to other associations.

The climate in several parts of the investigated area was predicted to become more suitable for some associations in 2050 and less suitable for others (Fig. 3). Future distributions of *Ceratophylletum demersi*, *Hydrocharitetum-morsus ranae*, *Lemno–Spirodeletum polyrhizae*, *Nymphaeo albae–Nupharetum luteae*, *Nymphoidetum peltatae* and *Trapetum natantis* were found to be very similar to their current and potential distribution. *Lemnetum trisulcae*, *Ceratophyllo–Azolletum filiculoides*, *Najadetum marinae*, *Salvinio natantis–Spirodeletum polyrhizae*, *Elodeetum canadensis* and *Potametum denso-nodosi* showed a potential invasive distribution pattern in the predicted scenario. The results revealed that population of other investigated associations, especially *Nymphaeetum albae* and *Nymphaeo albae–Nupharetum luteae* subass. *nuphare-*

tosum is likely to be significantly depleted in the future.

The sum of the modeled potential and future distribution maps of 20 associations resulted in the maps indicating the modeled association diversity (Fig. 4). The findings suggest that central-eastern part of the investigated area has the highest potential (14–17 associations) as well as future diversity. According to the future predicted scenario, northern and southern parts of the investigated area will show less diversity (with only 1–3 associations), compared to their current potential (3–9 associations).

PCA indicated three factors of total variance (Table 3). The first factor could explain 43.09 % of the observed variance. It was defined by the annual precipitation, precipitation of wettest and driest month and precipitation in the wettest, driest, warmest and coldest quarter. The second factor explained 37.93 % of the observed variance due to mean monthly temperature range, temperature seasonality, maximum temperature in the warmest and coldest months, annual range of temperature, mean temperature in the driest quarter and precipitation seasonality. Finally, the third factor explained 15.70 % of the observed variance and showed a positive correlation with the annual mean temperature, as well as the mean temperature for the wettest and warmest quarter. Combined, these three factors accounted for 96.72 % of total variance.

The projection of the mean of factor scores (Table 4) for the second and third factors showed that, based on the examined parameters, the *Lemnetum trisulcae* and *Ceratophyllo–Azolletum filiculoides* associations could be clearly separated from other associations along the second axis (Fig. 5). On the other hand, factor 3 clearly separated *Nymphaeo albae–Nupharetum luteae* subass. *nupharetosum* and *Nymphaeetum albae* from other investigated associations.

The standard deviation around the centroid was the highest for *Lemno–Spirodeletum polyrhizae* followed by *Ceratophylletum demersi*, whilst the lowest values were detected for *Nymphaeetum albae*, *Nymphaeo albae–Nupharetum luteae* and *Lemno–Utricularietum*, respectively (see Table 4).

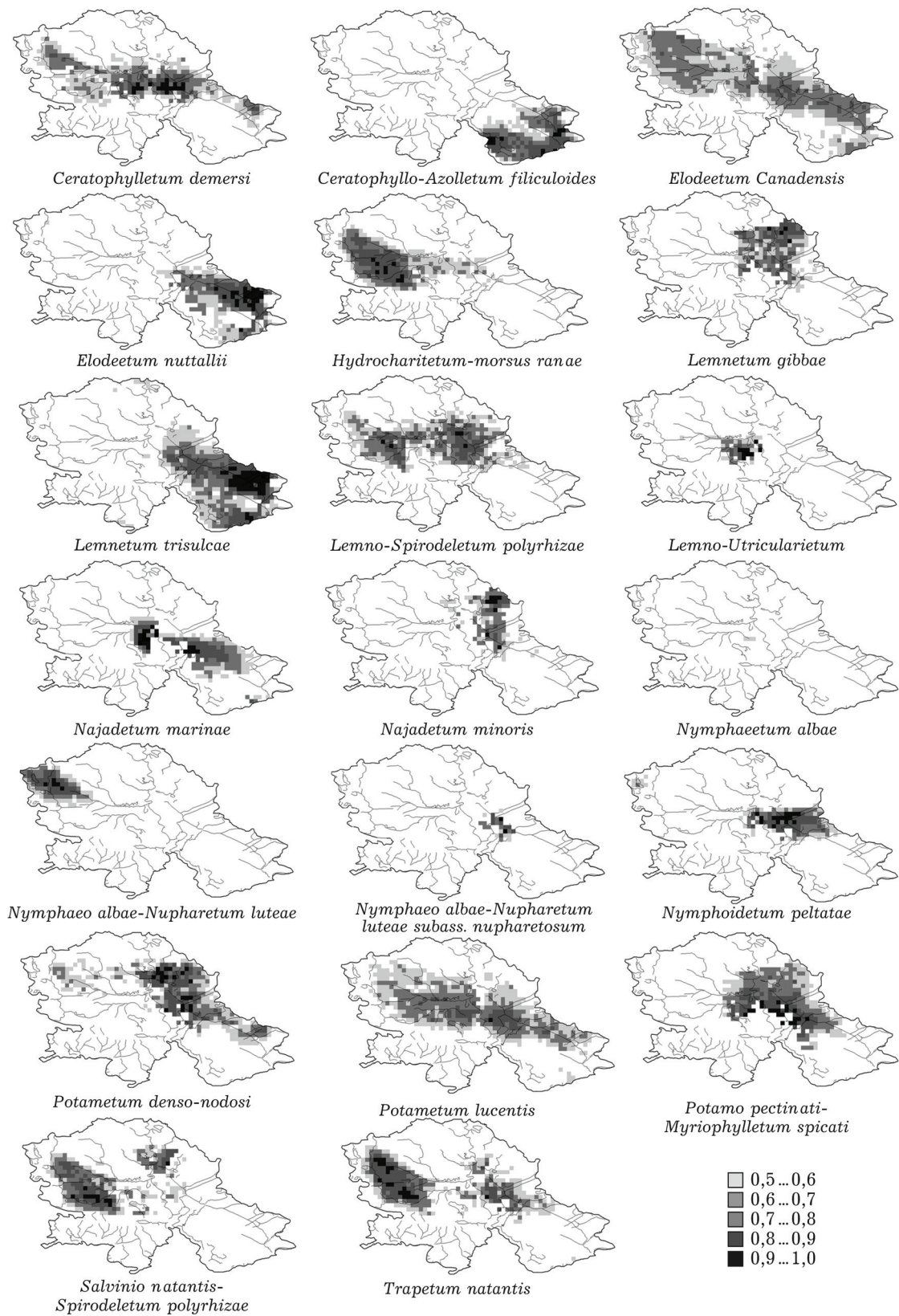


Fig. 3. Prediction of climate change impact on aquatic associations' occurrence. Different shades of gray represent the probability of occurrence percentage

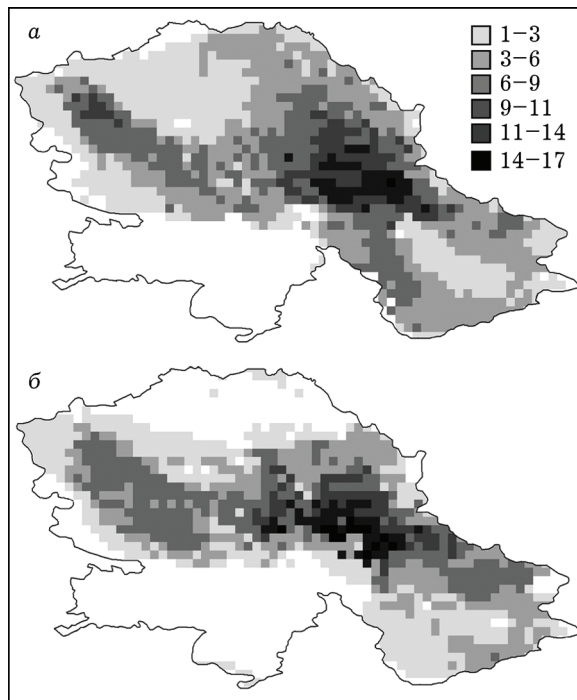


Fig. 4. Aquatic association diversity: a – potential, b – modeled. The darker areas indicate the highest richness (maximum value: 17 associations)

Aquatic macrophytes are an important component of aquatic ecosystems, offering shelter and food for many organisms [Grünberga, Sprinže, 2008]. The species composition and abundance of aquatic plants are controlled by physical, chemical, and biological factors. Although light availability, sediment condition and water flow rate are important factors influencing macrophyte growth in aquatic ecosystems [Vereecken et al., 2006], air temperature remains one of the most important factors influencing plant growth. Changes in macrophyte distribution and composition are reliable indicators of the environmental status and the factors that influence it, and are thus indispensable means of indirect monitoring of ecological conditions in aquatic ecosystems [Parmesan, Yohe, 2003; Lacoul, Freedman, 2006; Stančić, 2010].

Our findings indicate that *Lemno-Utricularietum* and *Ceratophyllo-Azolletum filiculoides* associations are least abundant and should, therefore, be regarded as rare. On the other hand, *Hydrocharitetum-morsus ranae*,

T a b l e 3

Factor loadings, eigenvalues and percentages of variance for the first three components, resulting from the PCA analysis of 19 bioclimatic parameters

Climatic parameters	Factor 1	Factor 2	Factor 3
BIO1 = Annual mean temperature	0.196588	0.616587	0.757564*
BIO2 = Monthly mean temperature	0.279127	-0.937597*	-0.132095
BIO3 = Isothermality	0.647843	-0.685665	-0.235632
BIO4 = Temperature seasonality	-0.308263	-0.926889*	0.089621
BIO5 = Max temperature of the warmest month	0.367280	-0.844610*	0.278855
BIO6 = Max temperature of the coldest month	0.627330	0.707453*	0.192376
BIO7 = Annual range of temperature	-0.228034	-0.955362*	0.022270
BIO8 = Mean temperature of the wettest quarter	-0.134763	0.028363	0.979808*
BIO9 = Mean temperature of the driest quarter	0.172444	0.934790*	0.260943
BIO10 = Mean temperature of the warmest quarter	-0.142800	-0.145263	0.974766*
BIO11 = Mean temperature of the coldest quarter	0.388454	0.653534	0.611485
BIO12 = Annual precipitation	0.963534*	-0.235933	-0.080818
BIO13 = Precipitation of the wettest month	0.921801*	0.327723	-0.163183
BIO14 = Precipitation of the driest month	0.967066*	-0.143375	-0.007636
BIO15 = Precipitation seasonality	-0.522217	0.825457*	-0.001094
BIO16 = Precipitation of the wettest quarter	0.857235*	0.480493	0.023009
BIO17 = Precipitation of the driest quarter	0.973647*	-0.184853	0.067210
BIO18 = Precipitation of the warmest quarter	0.928705*	0.295699	-0.152098
BIO19 = Precipitation of the coldest quarter	0.971670*	-0.049983	0.168960
Eigenvalue	8.19	7.21	2.98
Percentage of total variance	43.09	37.93	15.70

N o t e. The most significant factor loadings are printed in bold.

T a b l e 4

Mean and standard deviation of the mean factor scores for each association

Associations	Factor 1		Factor 2		Factor 3	
	Mean	SD	Mean	SD	Mean	SD
<i>Ceratophylletum demersi</i>	-0.020	1.043	-0.063	0.973	0.046	1.055
<i>Ceratophyllo-Azolletum filiculoides</i>	1.346	0.596	-1.704	0.293	-0.434	1.382
<i>Elodeetum Canadensis</i>	0.366	1.210	-0.263	0.890	-0.415	0.847
<i>Elodeetum nuttallii</i>	0.827	1.087	-1.518	0.230	0.033	1.193
<i>Hydrocharitetum-morsus ranae</i>	0.147	0.784	0.463	1.020	-0.183	0.860
<i>Lemnetum gibbae</i>	-0.761	0.785	-0.500	0.263	0.518	1.009
<i>Lemnetum trisulcae</i>	-0.119	2.070	-1.437	0.106	-1.036	0.614
<i>Lemno-Spirodeletum polyrhizae</i>	-0.262	1.046	0.043	1.037	-0.107	1.001
<i>Lemno-Utricularietum</i>	-0.144	0.219	0.888	0.335	0.756	0.720
<i>Najadetum marinae</i>	0.241	0.952	-0.159	0.721	0.857	1.083
<i>Najadetum minoris</i>	-0.828	0.487	-0.582	0.064	0.318	0.650
<i>Nymphaeetum albae</i>	-0.214	0.114	0.780	0.194	1.248	0.073
<i>Nymphaeo albae-Nupharetum luteae</i>	0.429	0.281	0.627	0.508	-0.598	0.309
<i>Nymphaeo albae-Nupharetum luteae</i> subass. <i>Nupharetosum</i>	-0.229	0.412	-0.767	0.056	1.322	0.440
<i>Nymphoidetum peltatae</i>	-0.145	0.437	-0.118	0.735	0.702	0.880
<i>Potametum denso-nodosi</i>	-0.442	1.197	-0.403	0.895	-0.372	0.989
<i>Potametum lucentis</i>	0.217	1.105	-0.158	0.967	-0.029	0.812
<i>Potamo pectinati-Myriophylletum spicati</i>	-0.691	1.109	-0.438	0.350	0.125	0.931
<i>Salvinio natantis-Spirodeletum polyrhizae</i>	-0.030	0.865	0.327	1.105	-0.224	0.946
<i>Trapetum natantis</i>	0.207	0.950	0.173	1.067	-0.020	0.927

Ceratophylletum demersi and *Trapetum natantis* were the most commonly recorded associations.

Model performance was generally high, since “excellent” AUC values were obtained.

The climate envelope modeling, developed for 20 aquatic associations, showed that, in addition to the areas where natural populations have been recorded, most associations could potentially occur in several other aquatic eco-

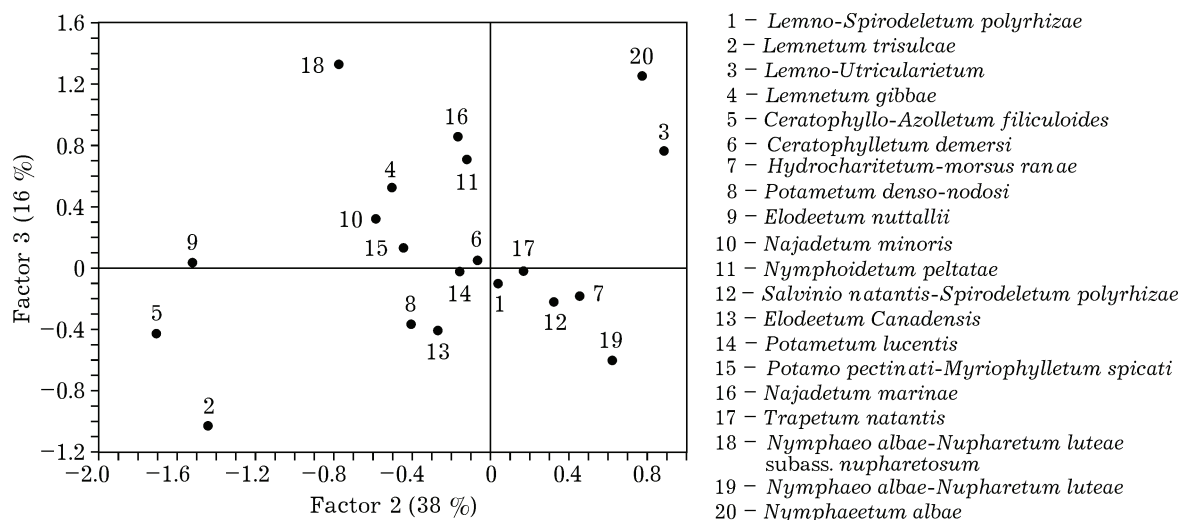


Fig. 5. Distribution of the association centroid for the second and third PCA axes

systems. New suitable areas were identified for *Elodeetum canadensis*, *Elodeetum nuttallii*, *Lemnetum trisulcae*, *Ceratophyllo–Azolletum filiculoides* and *Potametum lucentis*. In general, the new areas found suitable for expansion of the recorded associations had similar climatic conditions to that of the investigated area.

Though *Hydrocharitetum-morsus ranae*, *Lemno–Spirodeletum polyrhizae* and *Trapezium natantis* associations currently thrive in the northern part of the investigated area, the predictions indicate their absence in the future. This phenomenon could be explained by the predicted unfavorable climatic conditions (the area with the lowest average annual temperature in Vojvodina), which are currently largely offset by shallow water rich with nutrients, creating optimal environment for their growth.

The forecast climate for the year 2050 appeared to be more suitable for *Lemnetum trisulcae*, *Ceratophyllo–Azolletum filiculoides*, *Salvinio natantis–Spirodeletum polyrhizae*, *Najadetum marinae*, *Elodeetum canadensis* and *Potametum denso-nodosi*, which showed a potential invasive distribution pattern in the future predicted scenario. High degree of fluctuation of available resources in the ecosystem was identified as the key factor in the invasive pattern [Davis et al., 2000]. In the shallower parts of the canal network and the relatively warmer water rich in nutrients, floating rootless stands of the *Lemnion minoris* alliance (ass. *Lemnetum trisulcae*, ass. *Ceratophyllo–Azolletum filiculoides*, ass. *Salvinio natantis–Spirodeletum polyrhizae*) represent a pioneering type of vegetation. However, under the influence of significant anthropogenic factors, as well as anticipated climate change, this vegetation could find permanent habitat in this area.

In the deeper parts of the central-eastern region, characterized by slightly higher average annual temperature and the presence of saline, stands of *Najadetum marinae* have developed. Climate changes that will result in higher air and water temperatures and increased salinization [Rahel, Olden, 2008] will possibly lead to the significant increase in the distribution range of this halophyte community in 2050. Moreover, marked anthropogenic pollution of this region [Sl. Gl. SRS] is suitable

for the development of thermophilic stands ass. *Elodeetum canadensis* and ass. *Potametum denso-nodosi* [Hrivnák et al., 2011]. It is predicted that climate change will further intensify the eutrophication of ecosystems and will cause overgrowth of the stands of these communities [Bowmer et al., 1995; Dawson, Szoszkiewicz, 1999; Sender, 2009]. Potential distribution range of the *Elodeetum canadensis* association in 2050 is the greatest, and given that the *Elodeetum canadensis* Michx. 1803 was placed by World Conservation Union into the group of invasive plants for the European region [Lacoul, Freedman, 2006], the potential for extensive biodiversity damage is high. However, we posit that the full invasion potential of these stands will be prevented by frequent changes of waterway regimes and navigation, which would serve as a natural eradicator of these phytocenoses.

Our findings suggest that climate change will particularly affect *Nymphaeetum albae* and *Nymphaeo albae–Nupharetum luteae* subass. *nupharetosum*, which will be markedly less abundant in the future. More specifically, in the investigated ecosystem the stands of these communities are often developed alongside those of *Trapezium natantis*. At water depths up to 3m, due to competition for access to natural light, water lilies have biological advantage over *Trapa natans*. Water lilies develop before *T. natans*, and their large leaves reduce the amount of light that penetrates below the water surface, thus hindering the development of *T. natans*. However, at greater depths, *T. natans* predominates and forms its own lush and abundant layer [Džigurski et al., 2013]. Thus, even though the 2050 forecast implies rapid reduction in the *Nymphaeetum albae* and *Nymphaeo albae–Nupharetum luteae* subass. *nupharetosum* distribution ranges, relying on our earlier studies [Džigurski et al., 2010], we believe that their future habitat will be more extensive than predicted by the model.

By applying PCA, we identified climatic conditions governing the distribution of the 20 aquatic associations under investigation. Mean monthly temperature range, temperature seasonality, maximum temperature of the warmest and coldest months, annual range of temperature, mean temperature of the driest quarter and precipitation seasonality factors

allowed for separation between *Lemnetum trisulcae* and *Ceratophyllo-Azolletum filiculoides* from other investigated associations, which is in line with the 2050 forecast that attributes potential invasiveness of these phytocenoses to future climate changes. Annual mean temperature, and mean temperature of the wettest and warmest quarters indicated separation of *Nymphaeo albae-Nupharetum luteae* subass. *nupharetosum* and *Nymphaeetum albae* from other investigated associations, implying that these climatic factors will be responsible for their reduced distribution range in 2050.

The climate of the central-eastern part of the investigated area was found favorable for aquatic vegetation, making this area most suitable for future diversity. The established rich diversity of vegetation is the result of specific and diverse conditions in different parts of the canal network in this area, including intensive anthropogenic impact, high groundwater levels, the presence of saline areas along the canals, as well as climate conditions. In fact, in the last six decades, vegetative period in Serbia has increased by 223 days, and this region is now characterized by one of the longest vegetative periods [Ljevnaić-Mašić, 2010; Radičević et al., 2008].

Very low standard deviation detected for *Nymphaeetum albae*, *Nymphaeo albae-Nupharetum luteae* and *Lemno-Utricularietum* reflects narrow geographic distribution and is directly related to very strict climate adaptations. In contrast, large values for *Lemno-Spirodeletum polyrhizae* and *Ceratophyllum demersi* show very wide range of climatic adaptation levels.

The CEM climate change prediction did not take into account the physical, chemical and biological factors that could influence the species occurrence. Nonetheless, CEM can be considered a useful tool for approximation of the potential impact of climate change on species occurrence [Pearson, Dawson, 2003]. Our study also confirmed that climate has the strong impact on distribution and diversity of aquatic vegetation. Some associations, such as *Lemnetum trisulcae*, *Ceratophyllo-Azolletum filiculoides*, *Najadetum marinae*, *Salvinio nantatis-Spirodeletum polyrhizae*, *Elodeetum canadensis* and *Potametum denso-nodosi*, are

predicted to become more invasive, whereas *Nymphaeetum albae* and *Nymphaeo albae-Nupharetum luteae* subass. *nupharetosum* may not be able to adapt to new climatic conditions. Thus, our findings indicate that, if proper environmental protection measures are not taken, these provenances are likely to become degraded in the next decade, and some could even be extinct at the locations where they presently occur naturally. Hence, our findings are extremely useful for planning management for aquatic ecosystems, biodiversity conservation and natural resources, in line with the European Commission directives [EU Water Framework Directive, Council Directive 2000/60/EC].

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