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Jasmina ŠINŽAR-SEKULIĆ*, Aljoša TANASKOVIĆ**

A b s t r a c t. − This study presents the results of the preliminary analysis of the production potential of two macrophyte species in the Danube reservoirs: the indigenous water chestnut *Trapa natans* and the introduced knotgrass *Paspalum paspalodes*. These species spread rapidly in the Danube after the construction of two hydroelectric power plants Đerdap I and II and subsequent formation of reservoirs, since natural characteristics of the Danube watercourse in the length of 250 km were significantly changed and became favorable for macrophyte development. Besides a fundamental role played in the nutrient retention, a huge amount of biomass produced by *Trapa natans* and *Paspalum paspalodes* could be used for the production of biofuel, and as food for livestock.

Keywords: Danube, invasive species, *Trapa natans*, *Paspalum paspalodes*, production

INTRODUCTION

Freshwater habitats – ecological significance and threat factors

Fresh waters and adjacent wetlands represent one of the most important and most endangered natural resources on our planet [33]. Although they

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make up only 0.01% of the water reserve on Earth and occupy less than 1% of its surface, freshwater habitats support almost 10% of the known species [13]. The primary productivity of wetlands is very high in relation to other natural areas, even agroecosystems that are heavily managed [11]. Fresh waters and adjacent wetlands are especially important for maintaining the level of groundwater. After the melting of snow and excessive rains, wetlands around watercourses absorb additional water and thus play a key role in flood control. They prevent erosion of river banks by stabilizing the soil and sediments on the water edge. Wetlands also participate in the process of self-purification of water that contributes to the improvement of their quality by absorbing nutrients such as nitrogen and phosphorus. Finally, wetlands comprise a sequence of extremely important habitat types inhabited by many important species of plants and animals, particularly waterfowl. Therefore, fresh waters and adjacent wetlands provide a key contribution to the conservation of biodiversity [23].

Today, people use inland waters and wetlands for various activities that lead to degradation of natural habitats, pollution, changes of the flow regime, excessive exploitation of the fish stock, and the spread of invasive species [29]. In addition to direct use of drinking water and irrigation, fresh waters and adjacent wetlands are also used for transport, energy production and waste disposal, as a source of food, raw materials and sites for homes, farms and factories [29]. In addition to the direct economic benefits, it is estimated that fresh waters and adjacent wetlands provide about 20% of all ecosystem services on our planet [10].

However, in order to achieve some of the benefits, such as irrigation or electricity production, people build dams that change the natural hydrological regime of watercourses [25]. Dams represent transversal obstacles that prevent any kind of exchange along watercourses [35], which leads to a significant negative impact on aquatic ecosystems, primarily their fragmentation [17]. Other than changes in the flow regime, dams also affect the transport of sediments, and change the chemistry and temperature of water. In other words, dams interfere with natural dynamic processes and affect the ecological integrity of the ecosystem [22]. One of the most obvious changes occurring after the construction of the dam and the subsequent formation of accumulations is the permanent destruction of the affected terrestrial ecosystems [22]. As follows, some unique types of habitats, as well as complete populations of endangered plant and animal species can disappear. Moreover, after filling up the accumulation, the lotic ecosystems are replaced by lentic ones, and the circulation of the water mass in the accumulation replaces the normal river flow [22].

Another significant consequence of the ecosystem disturbance caused by dam construction is the emergence and spread of invasive species [21]. Invasive species are distinguished by rapid expansion and the establishment of densely and more or less pure populations in large parts of different areas of the world [12]. They represent a serious problem at all levels, from local to global, both for autochthonous vegetation, and agriculture, water management, forestry, as well as urban and rural ruderal communities [28]. Most of the authors define invasive species as deliberately or accidentally introduced organisms whose historical development is not related to the territory to which they are entered, and whose invasiveness is the consequence of the absence of competitors [20]. However, some of the authors still consider that native species can become invasive after major exogenous changes in the environment (e.g. eutrophication, loss or addition of top predators, changes in the fire regime) which alter the competition mode by redistributing the selective pressures [31]. Namely, according to Valéry et al. [31], from an ecological point of view, an invasive species is always alien to its novel environment as a result of either a change of the environment (introduced species) or a change in the environment (native species).

Production potential of macrophytes

Aquatic plants that are also denoted as aquatic macrophytes, are species that permanently or occasionally inhabit the aquatic environment. Among them, "true" hydrophytes, submerged or floating ones, live in permanently water bodies, while the others known as helophytes are more amphibious and can tolerate seasonal drying [20]. In lowland freshwater habitats of the temperate zone these plans are essential for the structure and functioning of ecosystems, as well as for maintaining their stability [14]. Namely, as the most important primary producers of these ecosystems, aquatic plants provide food for herbivores, habitat and shelter for periphyton, zooplankton, as well as various species of invertebrates and vertebrates. In addition, these plants are a key participant in biogeochemical cycles, and significantly affect the hydrology and sedimentation in aquatic ecosystems [7].

Macrophytic vegetation provides the greatest contribution to the primary production in shallow water bodies (up to ten meters deep, or less, depending on the transparency) [8]. The amount of produced biomass depends primarily on the environmental characteristics of the water body (climate, hydrology, type of substrate, nutrient content), but also on the ecological characteristics of the plants themselves [11]. It has been estimated that the annual net primary productivity of submerse macrophyte communities in eutrophic lakes ranges from 4 to 7 t/ha, while in oligotrophic ones this value is 1 t/ha; for current waters of temperate zone, the estimated values of the annual net primary productivity have been in the range from 1 to 6 t/ha [26]. On the other hand, the more productive helophytes and their communities in the wetlands of the temperate zone can reach productivity of 20 to 46 t/ha per year [26].

Formation of Danube reservoirs and spread of macrophytes

The construction of hydroelectric power plants and consequent formation of Danube reservoirs Đerdap I and II, along with the Gabčikovo Dam downstream of Bratislava, represent the main hydro engineering operations on the whole watercourse of the Danube [19]. The Đerdap reservoir is one of the largest accumulations in Europe that was formed in 1972 after the construction of the hydroelectric power plant Đerdap I on the 943th kilometer of the Danube. The second hydroelectric power plant, Đerdap II, was built on the 863rd kilometer of the Danube. It was finished in 1984, forming the reservoir between two dams that serves principally for smoothing the peak flow operation [30].

After the formation of the Danube reservoirs and the slowdown of the river course, shallow littoral zones were flooded and the sedimentation process was accelerated. These changes resulted in habitat alterations, that is, the formation of new lentic types that are suitable for the development of macrophytic vegetation (Stevanović et al., 2003). There are no reliable data when macrophytes emerged in the Danube reservoirs, but it can be assumed that the colonization had started as early as the first ten years after their formation. Despite the frequent and irregular changes of the water regime of the reservoirs (e.g. sudden lowering of the water level), the macrophyte expansion was so fast and efficient that, currently, 46 years after the construction of the Đerdap I dam, macrophytic vegetation inhabits narrow or broader zones, in the length of over 150 km of the upstream watercourse [27].

Rapid expansion was especially pronounced for two macrophyte species, the indigenous water chestnut *Trapa natans* L. and the introduced knotgrass *Paspalum paspalodes* (Michx.) Scribner. This paper presents the results of the preliminary analysis of the production potential of these two species in the Danube reservoirs.

MATERIAL AND METHODS

The first survey of flora and vegetation of macrophytes in the Danube reservoirs was initiated in 1999, which was followed by their continuous monitoring that lasts to the present day. Field investigations were carried out from the boat using the standard method of transects and transversal profiles. The plant material was collected with the aid of the gear that was especially made for this purpose [3]. Geographical positioning in the field was done with the eTrex Vista C GPS device. Moreover, the monitoring of macrophytes in the Danube reservoirs included their field mapping. In order to map macrophytes and macrophytic vegetation, historical satellite images available through Google Earth software were also used.

As part of the study of flora and vegetation of macrophytes in the Danube reservoirs, determination of the production potential of the dominant species, which included *T. natans* and *P. paspalodes*, was carried out. The production potential of macrophytes was determined with the harvesting method that uses the annual maximum biomass as a measure of production [34]. For *T. natans*, the total biomass was measured, while for *P. paspalodes* only the biomass of the above-ground parts was determined. The plant material was sampled once a month during two vegetation seasons. The samples were taken in triplicate with a frame of 0.25 m^2 randomly positioned at each of the analyzed stands. After sampling, the plant material was washed to remove peryphyton, dried at 105°C for 24 hours, i.e. to a constant mass, and then measured to determine the dry weight value of biomass [15].

All collected data on macrophytic flora and vegetation in the Danube reservoirs, including the values of their biomass, were integrated in the GIS database which was used to calculate the production potential of the investigated species, as well as to prepare the appropriate thematic maps. The GIS database was made using QGIS 2.18 software.

RESULTS AND DISCUSSION

During the field investigations of the Danube reservoirs, over 100 macrophyte species were recorded so far, which were not known at the Danube before the construction of the hydroelectric power plants Iron Gate I and II. It was also noted that the dense populations of *Trapa natans* and *Paspalum paspalodes* covered large areas along the shallow sublittoral of reservoirs, flooded river islands, mouth of tributaries and forelands along the embankments. The largest areas covered by their stands were found in the following sections of the Danube watercourse (Fig. 1, A–F): Smederevska ada, Malo Bavanište – the mouth of the river Nera, Zatonje – the mouth of the river Pek, Brnjica – Dobra (Đerdap I reservoir), Korbovo – Vajuga, Ljubičevac – Brza Palanka (Đerdap II reservoir).

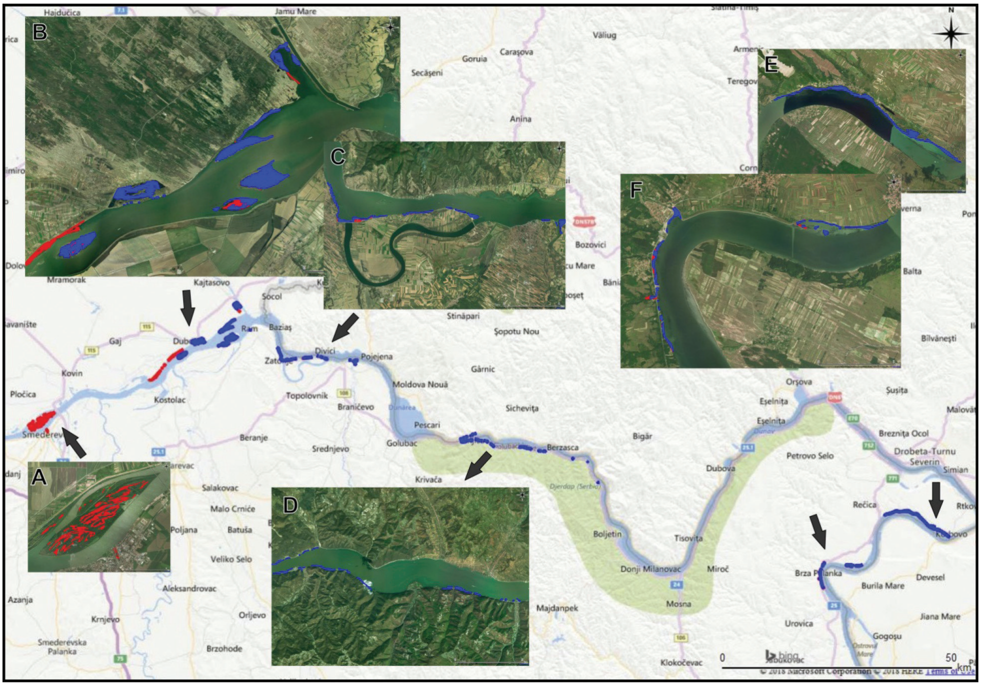

Fig. 1. Investigated section of the Danube: Smederevska ada (A), Malo Bavanište – the mouth of the river Nera (B), Zatonje – the mouth of the river Pek (C), Brnjica – Dobra (D), Korbovo – Vajuga (E), Ljubičevac – Brza Palanka (F)

The results of the preliminary analysis of the production potential of *T. natans* and *P. paspalodes* in the Danube reservoirs showed that both species reached their average annual maximum biomass in August. The average annual maximum biomass for *T. natans* and *P. paspalodes* was 3.63 t/ha and 12.71 t/ha, respectively. The area of occupancy and the production of biomass of both species in the analyzed sections of the Danube watercourse, as well as their totals are given in Table 1. Namely, the stand of *T. natans* in the Danube reservoirs covered 461,6736 ha and produced 1675,0 t of the biomass, while *P. paspalodes* stands covered 191,0321 ha and produced 2427,13 t of the biomass.

T. natans is an annual floating-leaved macrophyte native to Serbia that occurs in stagnant and slow running, usually eutrophic water basins; it is particularly well-developed in warm ponds and oxbow lakes that during floods or high water levels have a direct connection with the river itself [18]. This was probably the main route for the spread of this species in the Danube reservoirs.

Although indigenous, finding itself in a new environment free from selective pressures [31], *T. natans* has occupied an extremely large area of the Dan-

Table 1. The area of occupancy and the production of *Trapa natans* and *Paspalum paspalodes* in the investigated sections of the Danube reservoirs

Section	***Trapa natans***		***Paspalum paspalodes***	
	Area (ha)	**Production (t)**	**Area (ha)**	**Production (t)**
Smederevska ada			91,7195	1165,33
Malo Bavanište – the Nera mouth	214,8134	779, 34	90,3895	1148,44
Zatonje – the Pek mouth	4,8838	62,05	41,5522	150,75
Brnjica – Dobra	31,8041	115,39		
Korbovo – Vajuga	96,8849	351,50		
Ljubičevac – Brza Palanka	18,9054	68,89	4,0393	51,32
TOTAL	461,6736	1675,0	191,0321	2427,13

ube reservoirs over the past 45 years. The annual maximum biomass of this species, as in the case of the investigated area, is usually reached in late summer, when its dense floating rosettes often completely cover the water surface [6]. According to Pierobon et al. [24], the vast development of floating rosettes by *T. natans* represents a typical strategy of invasive macrophyte species that exclude other primary producers through the competition for light. The average maximum biomass of *T. natans* that was obtained in this study (3.63 t/ha) is consistent with the literature values. In the water bodies of the temperate zone with the optimal temperature and light conditions during the growth season, biomass peaks of this species can reach up to 5 t/ha [24].

Unlike *T. natans*, the other investigated plant, *Paspalum paspalodes*, is an alien species belonging to the life form of rhizomatous emergent tussock grasses [28]. Despite its neotropical origin [9], this invasive species is increasing its distribution in Europe [2]. Namely, *P. paspalodes* is a strong competitor that spreads very quickly by rhizomes and stolons, and distinguishes itself by high growth rates and the production of large amounts of biomass; due to those characteristics, this species rapidly overrun new aquatic and waterlogged habitats [1].

P. paspalodes was first recorded in Serbia at the end of the 20th century [4,5]. Successively, it was also found at many locations along the Danube, especially on the stretch between Belgrade and the Đerdap I dam [28]. This invasive species also has a serious negative impact on the environment in the "Iron Gate" Natural Park in Romania [16].

As for production, as in the case of *T. natans,* the obtained average maximum biomass of *P. paspalodes* in this study (12.71 t/ha) is consistent with the literature values, which are in the range from 8.5 to 34 t/ha [32].

In addition to negative effects of an extensive invasion of newly formed habitats in the Danube reservoirs by the analyzed species, their presence may serve as an adequate substitution for the lost flooded zones given that it is today a spawning place for fishes, as well as a feeding and nesting site for waterfowl. Moreover, besides nutrient retention, their biomass could be used for the production of biofuels, and as food for livestock. Hence, monitoring of the floristic diversity, dynamics and production potential of macrophytes and macrophytic vegetation in Danube reservoirs is the most important task in the protection of all resources in this region.

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ПРЕЛИМИНАРНО ИСТРАЖИВАЊЕ ПРОИЗВОДЊЕ МАКРОФИТА У ДУНАВСКИМ РЕЗЕРВОАРИМА – СТУДИЈА СЛУЧАЈА ДВЕ ИНВАЗИВНЕ БИЉНЕ ВРСТЕ – ИЗВОРНЕ *TRAPA NATANS* И УВЕЗЕНЕ *PASPALUM PASPALODES*

Јасмина ШИНЖАР-СЕКУЛИЋ, Аљоша ТАНАСКОВИЋ

Р е з и м е

Студија доноси резултате прелиминарне анализе потенцијала продукције две врсте макрофита у резервоарима Дунава – домаћег воденог кестена *Trapa natans* и интродукованог дивљег троскота *Paspalum paspalodes*. Те врсте су се брзо рашириле на Дунаву након изградње две хидроелектране Ђердап I и Ђердап II и накнадног формирања резервоара, будући да су природне карактеристике тока Дунава у дужини од 250 km биле знатно измењене и постале погодне за развој макрофита. Поред основне улоге коју имају у задржавању нутријената, велике количине биомасе коју стварају *Trapa natans* и *Paspalum paspalodes* могу бити коришћене за производњу биогорива и као сточна храна.

Кључне речи: Дунав, инвазивне врсте, *Trapa natans*, *Paspalum paspalodes*, продукција