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Catchment area, environmental variables and habitat type as predictors of the distribution and abundance of *Portulaca oleracea* L. in the riparian areas of Serbia

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A B S T R A C T

Portulaca oleracea L. is one of the most widely distributed plant species, invading a host of worldwide regions. Rivers and canals, as corridors connecting neighboring habitats, are known to exhibit high invasion levels. Consequently, the aim of this paper was to show which catchment areas, environmental factors and habitat types can be seen as predictors of the presence of this invasive species in the riparian areas of Serbia. Field research was carried out at 250 field sites, where the cover and abundance of *P. oleracea*, relevant environmental variables and habitat type were recorded. Redundancy analysis (RDA) and response curves fitted using a generalized linear model (GLM) were used to show the relation of the cover of *P. oleracea* and the following variables: catchment area, predominant bank material, elevation, and the total number of invasive species on site. A non-metric multidimensional scaling (NMDS) was used to group sites where *P. oleracea* was found, based on the values of its cover. In general, primarily the rivers in the northern, low-lying part of Serbia can be seen as important corridors of the spread of *P. oleracea*. Its dominance is especially associated with areas draining into the Danube and Sava rivers and field sites characterized by a high pressure of invasive plants. Of the total number of records, the highest number of invaded field sites was recorded along the Danube, Tisa and Zapadna Morava rivers. Regarding the environmental and habitat predictors, the results have shown that the abundance of *P. oleracea* is associated with gravelly and sandy banks and grassland habitat types, primarily anthropogenic herb stands.

Keywords: alien plants, common purslane, invasion corridor, invasive weed, pigweed, riparian habitat.

И З В О Д

Portulaca oleracea L. представља једну од најшире распрострањених биљних врста, која се сматра инвазивном у низу региона широм света. Реке и канали, као коридори који повезују суседна станишта, познати су по високом нивоу инвазије. Имајући то у виду, циљ овог рада био је да се утврди који се сливови, средински фактори и типови станишта могу сматрати показатељима присуства ове инвазивне врсте у рипаријалним областима Србије. Теренска истраживања су обављена на 250 локалитета, где су забележени подаци о бројности и покровности *P. oleracea*, као и релевантни параметри о животној средини и типу станишта. Анализа редундантности (RDA) и генерализовани линеарни модел (GLM) коришћени су како би се приказао однос покровности *P. oleracea* и следећих променљивих: слив, доминантан материјал на обали, надморска висина и укупан број инвазивних врста на локалитету. Неметричко мултидимензионално скалирање (NMDS) коришћено је за груписање локалитета према степену покровности *P. oleracea*. Резултати су показали да се пре свега реке у северном, низијском делу Србије могу сматрати значајним коридорима ширења *P. oleracea*. Доминантно присуство ове врсте везано је за области сливова Дунава и Саве, као и локалитете који се одликују високим притиском инвазивних биљних врста. Од укупног броја налаза ове врсте, највећи број инвадираних локалитета забележен је дуж токова Дунава, Тисе и Западне Мораве. У погледу срединских и станишних показатеља, резултати су показали да је заступљеност *P. oleracea* везана за шљунковите и пешчане обале, као и за травне типове станишта, примарно антропогене групације зељастих врста.

Кључне речи: стране врсте, коридори инвазије, инвазивни корови, тушт, тушт обични, рипаријална станишта.

1. Introduction

Portulaca oleracea L. is an annual succulent herbaceous broadleaf species. There is debate on its origins (Slavnić, 1972; Ocampo and Columbus, 2012); while some consider it to be a cosmopolitan species (Byrne and McAndrews, 1975; Danin and Reyes-Betancourt, 2006), others propose that it originates from India and the Middle East (Alam et al. 2014). Nowadays, it is considered to be one of the most aggressive weeds (Matthews et al., 1993), with a worldwide distribution (Botha, 2001; DiTomasso and Healy, 2007). According to the Global Naturalized Alien Flora (GloNAF) database, it is one of the eleven most widely distributed species, invading a total of 311 regions worldwide, 15 of which are on the European continent (Pyšek et al., 2017). In Serbia, it is considered to be an invasive alien plant species (IASV, 2011; Vrbničanin, 2015; Stojanović and Jovanović, 2018), which spreads very rapidly (especially in the northern Vojvodina region) and forms dense populations, covering large areas (Radak, 2011). It is also considered an invasive weed in some of the neighboring countries, such as Bosnia and Herzegovina (Kovačević and Mitrić, 2013) and Romania (Anastasiu and Negrean, 2005).

Portulaca oleracea is characterized by a prolonged flowering period (from July until the first frosts; Radak, 2011) and seed germination ability for up to 40 years (Egley, 1974), which further enables its invasion. Additionally, under favorable conditions, it can also propagate vegetatively, via its stem fragments (Botha, 2001; DiTomasso and Healy, 2007). *P. oleracea* is a mesophyte species, favoring light and warm sites (Vrbničanin, 2015) and a strong competitor (Botha, 2001; Kovačević and Mitrić, 2013). Additionally, it has been shown that this weed species contains some bioactive substances (e.g. vitamin C) (Mladenović et al., 2018). In addition to its presence in agricultural areas (Radak, 2011, Vrbničanin, 2015), in Vojvodina this invasive alien species (IAS) is also found in the weed communities of gardens and parks, and on waste deposits. It is also common along transport networks (Radak, 2011). Similar habitat affinities of *P. oleracea* have been recorded by DiTomasso and Healy (2007) in North America.

It is well known that corridors which connect adjoining habitats, *i.e.*, rivers, canals and roads, can be critical in the spread of IAS (Pattison et al., 2017, Follak et al., 2018). European riparian habitats exhibit high levels of plant invasion (Chytrý et al., 2009), and similar data has recently been evidenced in Serbia (Anđelković, 2019). Given that there is already some knowledge on the prevalence of *P. oleracea* along transport networks in Vojvodina (Radak, 2011), the aim of this study was to show how common *P. oleracea* is in the riparian areas of Serbia and which environmental factors favor its establishment and dominance in these habitat types.

2. Materials and methods

2.1. Field research

The presence of *P. oleracea* was studied at 250 riparian field sites, distributed along 39 rivers and 6 canal sections of the Danube-Tisa-Danube system of canals (Anđelković, 2019; Anđelković et al. 2022). The studied rivers were selected with the aim of encompassing nine catchment areas (CAs) in Serbia and thereby ensuring the best geographical coverage of the study area. At each field site, a 100 m long transect was set up on the banks of the river/canal, parallel to its course (Aguiar et al., 2001, 2005), where the cover and abundance of the riparian vegetation was recorded, following the van der Maarel scale (1979). Along the same section of the river, relevant environmental variables were recorded, and habitat types were determined following the EUNIS habitat type classification system (Davies et al., 2004, 2012).

2.2. Data analysis

Redundancy analyses (RDA) were performed in this study to observe the correlation of the cover of *P. oleracea* with the catchment area and predominant bank material as explanatory variables. Two response curves of *P. oleracea* on the elevation gradient and the total IAS number on site, fitted using the generalized additive model (GAM), were also shown. A non-metric multidimensional scaling (NMDS) diagram representing the grouping of sites where *P. oleracea* was found, based on the values of *P. oleracea* cover, was also shown. All of the analyses were performed in Canoco 5.0 (Ter Braak and Šmilauer, 2012).

3. Results and discussions

Portulaca oleracea was recorded along a total of 33 field sites, with the highest number of field sites recorded along the Danube (eight), Tisa (five) and Zapadna Morava (five) rivers (Figure 1, Table 1).

When discussing the invasibility of certain field sites, in addition to the presence/absence of alien species, it is also important to consider their abundance, *i.e.*, their cover or biomass (Aguiar et al., 2001). Consequently, although the target species was observed at a relatively small subsection of the study area, it is important to point out that at two field sites (along the Sava and Tisa rivers) it reached a cover of > 60 % (Table 1).

The redundancy analysis (RDA) where *P. oleracea* cover was observed in relation to the catchment area (K, S1-S9) was statistically significant (F=3.3, P=0.006). As shown in Figure 2, the highest *P. oleracea* cover was recorded along the rivers belonging to the Danube (S1) and Sava (S2) CAs, and the lowest along the DTD canal system (K), followed by the CAs of the Južna Morava (S7) and Timok (S9) rivers, while no records of this species were found in the CAs of the Kolubara (S3), Drina (S4) and Beli Drim (S8) rivers.

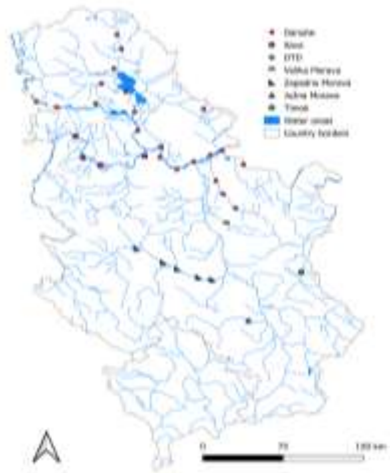

Figure 1. Map of Serbia showing the riparian locations within the catchment areas where *Portulaca oleracea* L. was recorded

Table 1.
Distribution records of *Portulaca oleracea* L. in the riparian areas of Serbia

Catchment	River	Field site	Latitude (N)	Longitude (E)	Altitude (m)	Cover value*
Danube	Danube	Bačko Novo Selo	45.28553	19.13801	78	5
Danube	Danube	Belegiš	45.02389	20.35358	76.5	3
Danube	Danube	Vinča	44.76903	20.61883	85	3
Danube	Danube	Kovin – Malo Bavanište	44.7272	21.01936	78	5
Danube	Danube	Banatska Palanka	45.23423	19.38094	80	7
Danube	Danube	Dubovac	44.7886	21.21354	67	5
Danube	Danube	Orešac	44.65544	20.81957	74	3
Danube	Danube	Vinci	44.69891	21.60446	75.5	3
Danube	Jegrička	Temerin	45.46717	19.91363	74	2
Danube	Mlava	Šetonje	44.28263	21.50939	168	2
Danube	Mlava	Trnovče	44.4181	21.36512	111	3
Danube	Mlava	Malo Crniće	44.54442	21.27925	99	3
Danube	Nera	Stara Palanka	44.83296	21.35471	81	5
Danube	Rojga	Plandište	45.22851	21.136	88	3
Danube	Tamiš	Pančevo	44.87067	20.6322	77	3
Danube	Tisa	Ada	45.7992	20.1478	79	9
Danube	Tisa	Bečej	45.60952	20.05795	83	5
Danube	Tisa	Most ZR – Žabalj	45.39332	20.2053	88	5
Danube	Tisa	Titel	45.19945	20.31182	78	5
Danube	Tisa	Senta	45.93447	20.09149	80	1
Sava	Sava	Provo	44.68979	19.90944	87	3
Sava	Sava	Sremska Mitrovica	44.96155	19.61317	87	8
Sava	Sava	Šabac	44.76147	19.70679	85	3
Sava	Topčiderska reka	Topčiderski park	44.77875	20.43954	86	2
Velika Morava	Resava	Plažane	44.1349	21.40171	164	5
Zapadna Morava	Zapadna Morava	Čukojevac	43.70642	20.82893	184	2
Zapadna Morava	Zapadna Morava	Oplanići	43.76628	20.6646	203	3
Zapadna Morava	Zapadna Morava	Čačak	43.89853	20.35025	238	1
Zapadna Morava	Zapadna Morava	Kukljin	43.60239	21.23356	146	3
Zapadna Morava	Zapadna Morava	Medveđa	43.6252	21.07417	167	1
Južna Morava	Toplica	Vlahovo	43.21112	21.64783	235	3
Timok	Beli Timok	Debelica	43.66593	22.26557	187	2
DTD	Novi Sad – Savino Selo	Novi Sad	45.27422	19.84918	82	1

* following the van der Maarel (1979) scale.

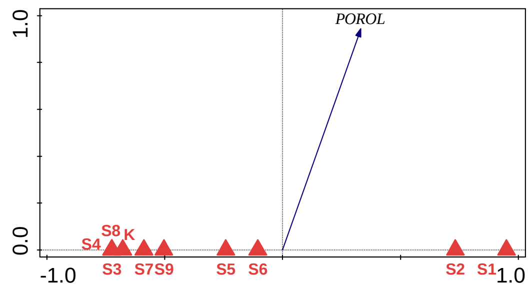

Figure 2. RDA showing the relation of *P. oleracea* cover and the catchment area (S1 – Danube CA; S2 – Sava CA; S3 – Kolubara CA; S4 – Drina CA; S5 – Velika Morava CA; S6 – Zapadna Morava CA; S7 – Južna Morava CA; S8 – Beli Drim CA; S9 – Timok CA; K – DTD canal system)

Five groups of sampling sites can be observed in the NMDS diagram (Figure 3), arranged along the first axis, based on the value of the cover of *P. oleracea*. The group on the very left side of the diagram is characterized by the highest values of the studied species cover in the range of 7–9, following van der Maarel (1979) (the rivers Danube and Tisa from the Danube CA (S1) and the river Sava (Sava CA) are included here). All members of the second group are characterized by the *P. oleracea* cover value of 5; here, sampling sites are mostly from the Danube CA (S1) (the rivers Danube, Nera and Tisa) and only one is from the Velika Morava CA (S5) – the river Resava. The third group, the largest one, is characterized by sites where *P. oleracea* cover was 3, of which many are located within the Danube CA (S1): the Danube, Mlava, Tamiš and Rojga rivers. This group also consists of the field sites located along the Sava, Zapadna Morava and Toplica rivers. The fourth group is variable considering CAs and it comprises five field sites from the Danube (S1), Sava (S2), Zapadna Morava (S6) and Timok (S9) catchment areas, which are characterized by the *P. oleracea* cover of 2. The last group is made up of field sites where *P. oleracea* cover is 1, found along the course of two rivers: the Tisa and Zapadna Morava, and also one field site located along the Novi Sad – Savino Selo canal section (K4) of the DTD hydrosystem.

The high association of the presence (and cover) of *P. oleracea* in the Danube and Sava CAs (Figure 2) is unsurprising, given its established presence and aggressive spread in the Vojvodina province (Radak, 2011) and the agricultural areas of the Srem and Mačva regions (as seen in Vrbničanin, 2015). Its predominant presence along the watercourses of these CAs is also supported by global tendencies for the relative richness of naturalized alien and invasive plant species to be positively correlated with anthropogenic pressures (*i.e.*, population density and proportion of agricultural land, Essl et al., 2019), which are both characteristic of the Vojvodina and Mačva regions. Additionally, the destruction and fragmentation of natural habitats, and anthropogenic disturbances, characteristic of these areas of intensive agriculture are also known to favor the invasion of plant species with a wide ecological valence (Marvier et al., 2004), such as *P. oleracea*. However, the fact that it was recorded along only one canal section (Novi Sad – Savino Selo, Figure 3), and with a low cover (1), was highly unexpected, especially given that the canals of the DTD hydrosystem are surrounded by agricultural land and that this invasive weed species is known to favor such intensively irrigated areas with fertile soils (DiTomasso and Healy, 2007; Vrbničanin, 2015). Furthermore, as *P. oleracea* is considered to be an invasive archeophyte, its presence should therefore be more strongly affected by agriculture as an invasion pathway, thus warranting further investigation into the causes of such a deviation from general invasion tendencies recorded for invasive archeophytes (Chytrý et al., 2008a, 2009; Tyšer et al., 2019).

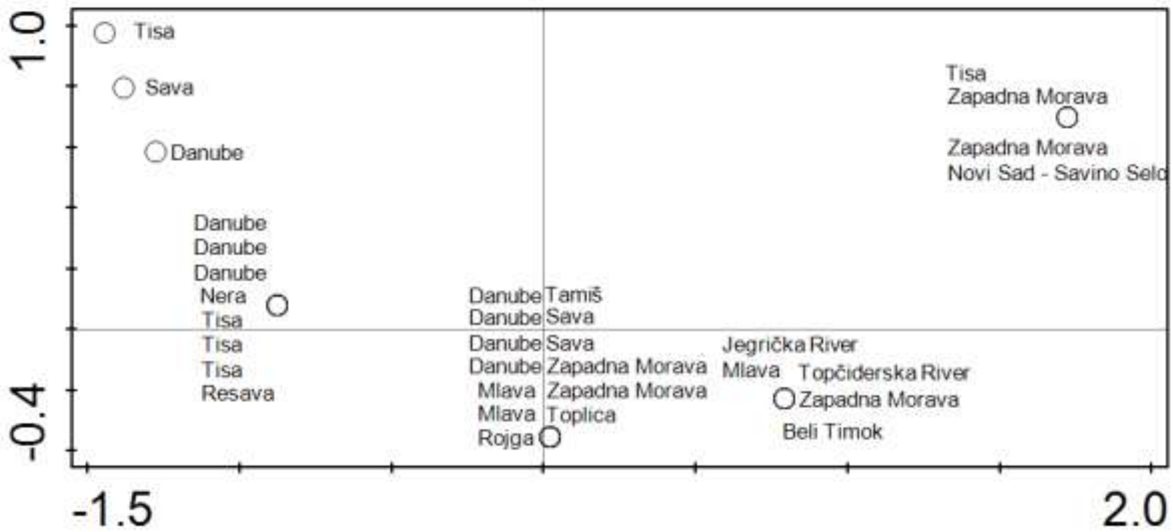

Figure 3. NMDS diagram representing the grouping of sites where *P. oleracea* was found, based on its cover values

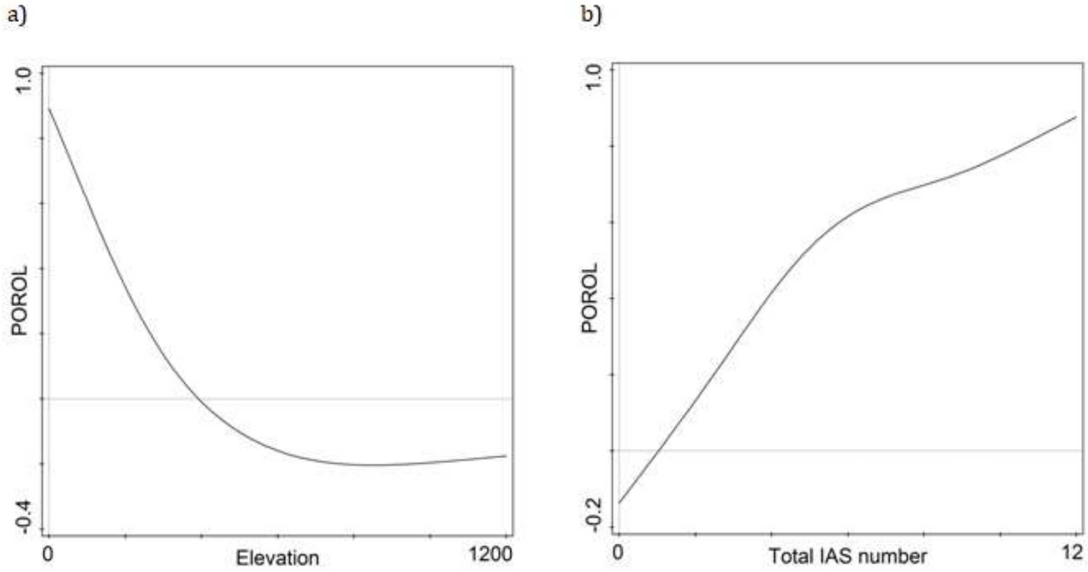

Figure 4. Response curves of *P. oleracea* cover in relation to altitude **(a)** and the total number of IAS on site **(b)**

It is known that predominant bank material is one of the best predictors of riparian plant communities (Engelhardt et al., 2015). Considering the river- and canal-bank material substrate on which *P. oleracea* was recorded, the only statistically significant positive correlation was observed when *P. oleracea* cover was tested in relation to gravel and sand ($F=6.2$, $P=0.018$), as the dominant bank material (ordination diagram not shown). These results go fully in line with the previous knowledge of the affinity of this species for light and sandy soils (Vrbničanin, 2015) and gravely substrate (Kovačević and Mitrić, 2013). Such proclivity for these substrates is enabled by its drought tolerance (DiTomasso and Healy, 2007).

The response curve fitted with GAM has demonstrated the correlation of *P. oleracea* with altitude (Figure 4a). As seen, the cover of *P. oleracea* decreases with increasing altitude. Prior to the response curve, a RDA was performed ($F=6.5$, $P=0.028$), which confirmed that the negative correlation of *P. oleracea* cover and elevation was statistically significant. This result is fully in line with previous studies (Pyšek et al., 2005; Liendo et al., 2015; Pattison et al., 2017; Essl et al. 2019; Vorstenbosch et al., 2020), which have shown that the richness of naturalized alien plants decreases with increasing altitudes. Similar tendencies for therophyte invasive plants in Serbia (Anđelković, 2019) are now further supported by the correlation of *P. oleracea* abundance and altitude (Figure 4a). Additionally, these results give further support to previous data showing that in Serbia this weed species favors warm habitats of up to 800 m a.s.l. (Vrbničanin, 2015).

Similarly, a response curve based on the GAM model was also used to show the correlation between the cover of *P. oleracea* in riparian areas and the total number of IAS on site. This analysis showed a positive correlation between the cover of *P. oleracea* and the mentioned parameter (Figure 4b). Such results were expected, due to the well-known occurrence of facilitative interactions among the non-native species, which, among other things, potentially promote secondary invasions – a phenomenon known in the invasion biology literature as “invasional meltdown” (Simberloff and Von Holle, 1999).

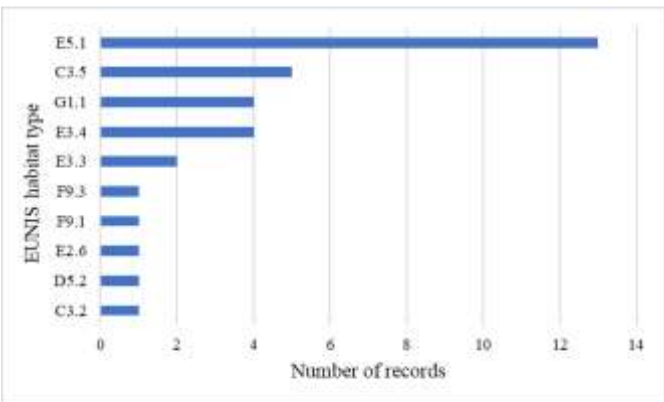

Figure 5. The association of *Portulaca oleracea* L. with different riparian habitat types

When observed at the third level of the EUNIS habitat classification (Davies et al., 2004, 2012), *P. oleracea* was recorded in a total of 10 different habitat types (Figure 5), the majority of which (60.6% of field sites) belong to the E habitat type group (i.e., Grasslands and lands dominated by forbs, mosses or lichens). The habitat types in which *P. oleracea* was most commonly recorded were the anthropogenic herb stands (E5.1; 13 field sites), followed by the C3.5 habitat type (Periodically inundated shores with pioneer and ephemeral vegetation), at five field sites. Its presence was also documented at four field sites represented by riparian woodlands (G1.1 – Riparian and gallery woodland, with dominant *Alnus*, *Betula*, *Populus* or *Salix*) and grasslands (E3.4 – Moist or wet eutrophic and mesotrophic grassland). These findings are in line with the results of the study done by Anđelković (2019), which have shown that these four habitat types stand out with regard to the number of recorded invasive neophytes. The highest cover values (7–9) of the studied species were characteristic of C3.5 and E5.1 habitat types, found along the Danube, Tisa and Sava rivers (data not shown). Such a prevalence of this invasive plant in C3.5 habitat type is not surprising, given that Stanković (2017) has shown that in Ramsar sites of Serbia this habitat type is characterized by high cover values of invasive alien plants, proportional to the natives. Similar results regarding such habitat types exposed to periodic fluctuations in resource availability have been seen previously in works by Chytrý et al. (2008a), Schnitzler et al. (2007) and Richardson et al. (2007). The same is also true of E5.1 habitat type, as such anthropogenic herb stands have been highlighted as habitat types harboring the highest numbers and abundance of IAS (Chytrý et al., 2005, 2008б; Vilà et al., 2007).

4. Conclusions

In conclusion, rivers, especially in the northern, low-lying part of Serbia, can be considered important corridors of the spread of *P. oleracea*. Its dominance is especially prevalent in the areas draining into the Danube and Sava rivers and at those field sites already characterized by a high pressure of invasive plants. Additionally, its abundance was associated with gravelly and sandy banks and grassland habitat types, primarily anthropogenic herb stands.

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Declaration of competing interest

Authors declare no conflicts of interest.

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