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DITTRICHIA GRAVEOLENS – HOW DOES SOIL SALINITY DETERMINE DISTRIBUTION, MORPHOLOGY, AND REPRODUCTIVE POTENTIAL?

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ABSTRACT

Road salting in winter, which improves the safety of road travel, has a strong impact on species inhabiting road verges, since it creates habitats with increased salinity. Higher levels of soil salinity represent a habitat that can be occupied by plants exhibiting special adaptations and tolerance. As a result, Dittrichia graveolens*, which is indigenous in the Mediterranean area, is moving inland and can be found in several Central European countries. We studied how soil salinity determines the* D. graveolens *plant height, reproductive potential and distribution along the road verge. Plant height was related to soil electrical conductivity (EC) – a measure for salinity. Our results show that the species grows best in soils where the EC ranges from 110 to 170* µS/cm*, while at values less than 100* µS/cm*, no plants were observed.*

Key words: invasive species, road verges, road salting, Slovenia

DITTRICHIA GRAVEOLENS – COME LA SALINITÀ DEL SUOLO DETERMINA DISTRIBUZIONE, MORFOLOGIA E POTENZIALITÀ RIPRODUTTIVA DELLA SPECIE?

SINTESI

La salatura delle strade in inverno, che migliora la sicurezza dei viaggi, ha un forte impatto sulle specie che vivono sui bordi stradali, in quanto crea habitat con salinità elevata. I livelli più alti di salinità del suolo caratterizzano un habitat che può essere occupato da piante che presentano adattamenti e tolleranze speciali. Di conseguenza, Dittrichia graveolens*, pianta indigena nell'area mediterranea, si sta muovendo verso l'interno e può essere trovata in diversi paesi dell'Europa centrale. Gli autori hanno studiato come la salinità del suolo determina l'altezza della pianta di* D. graveolens*, il potenziale riproduttivo e la distribuzione lungo il bordo stradale. L'altezza della pianta è legata alla conduttività elettrica del suolo (CE) – una misura per la salinità. I risultati mostrano che la specie cresce meglio su terreni in cui la CE varia da 110 a 170 µS/cm, mentre dove i valori sono inferiori a 100 µS/cm non sono state osservate piante.*

Parole chiave: specie invasiva, bordi stradali, salatura delle strade, Slovenia

INTRODUCTION

The introductions of the majority of naturalized alien plants to Europe has happened since 1750 (Williamson *et al.*, 2009) and has resulted in the establishment of more than 3700 species, while the current invasion rate is estimated at 6.2 new species per year (Lambdon *et al.*, 2008). These species belong to more than 200 plant families, among which Asteraceae, Poaceae, Rosaceae and Brassicaceae are predominant (*Pyšek et al.*, 2009). These are large families with many species representatives known to be weeds. Approximately one half of naturalized alien plants in Europe are alien plants from another continent (e.g. North and South America, Asia), while the other half is represented by species from another part of Europe, where the plants are native. Many of common agricultural weeds invasive in Europe are also native to the Mediterranean (Pyšek *et al.*, 2009).

There are numerous routes and vectors for alien species introduction; however, we focus here on highways, which represent an opportunity for introduction into a new region and at the same time promote further dispersal with the help of vehicular transportation along road corridors (*Pollnac et al.*, 2012 and references therein). In Central Europe several invasive species are known as "Autobahn-Pflanzen", among them *Dittrichia graveolens* (L.) Greuter (syn. *Inula graveolens* (L.) Desf.), *Senecio inaequidens* DC. and *Atriplex micrantha* Ledeb. – examples of alien plant species which are able to spread rapidly along roads (Heger & Böhmer, 2006). Even though highways are highly disturbed, stressful, and fragmenting structures in the human-dominated landscape, their maintenance results in the creation of road verges – often dry, sunny, nutrient-poor and gravel-like habitats, which are dominated by environmental conditions different from most natural habitats in their vicinity. Additionally, human activities can impact road verges in such way that they represent a new, artificial habitat, one not previously existing. They exhibit altered physical and chemical soil characteristics; for example, texture, compaction, water content, leakage of deicing chemicals causing salinity, nitrogen deposition and pollution (Thompson *et al.*, 1986; Cale & Hobbs, 1991; Truscott *et al.*, 2005). Additionally, they represent highly disturbed habitats for plants because of repeated disturbance from maintenance like mowing, shrub clearing or herbicide application (Gelbard & Belnap, 2003). The use of deicing chemicals has a profound impact on road verge habitats, since it can cause soil salinity and saline spray, directly impacting standing vegetation. Therefore, such habitats can be occupied by plants exhibiting special adaptations or tolerance, among which maritime species are particularly successful (Scott & Davison, 1982). Invasions have been reported for *Spergularia media* and *S. marina* (Kocián, 2015b), *Atriplex micrantha* (Smettan, 2002), the grasses *Puccinellia distans*, *P. maritima*, *P. fasciculata*, *Aster tripolium*, *Plantago maritima* and *P. coronopus* (Scott & Davison, 1982) and many more.

Additionally, such habitats are less likely to be dominated by numerous native plants. The combination of a high variety of non-native seeds transported along roads and the presence of road verge habitats sparsely occupied by native species makes road verges into opportunity habitats for alien plants.

We were therefore interested in the occurrence of a plant of southern origin, annual species *Dittrichia graveolens*, which has been spreading along Slovenian highways. It is distributed across the central part of the country where there is a harsher climate, while it does not occur in the coastal region of Slovenia (Frajman & Kaligarič, 2009), where a closely related perennial, *D. viscosa*, can be found native to Istria (Wraber, 1999; Jogan *et al.*, 2001). We hypothesized that *D. graveolens* is not a particularly good competitor, and therefore not present in the sub-Mediterranean region, while at the same time it is tolerant of higher concentrations of salinity, which enables its establishment further north because of winter road maintenance with deicers.

MATERIAL AND METHODS

Study species

Dittrichia graveolens is an annual herbaceous plant in the family Asteraceae. It reaches heights of 10 to 50 cm (own observation). Leaves and stem, as well as the capitulum involucre are densely glandular and hairy. Yellow flowers are female if lingulate and hermaphrodite if tubular (Brullo & de Marco, 2000). In Central Europe the flowering occurs from September to October (Kocián, 2015a). Achenes are 1.8-2 mm long, with a 4 mm pappus (Brullo & de Marco, 2000). It is native to the Mediterranean basin and partly to the Western Atlantic coast and the Middle East (Brullo & de Marco, 2000). It has invaded other European regions and regions of the world with similar climates, including California, Australia and New Zealand (Preston, 2006). In Slovenia it was first observed in 2008 along Highways A1 from Šentilj to Koper and A2 from Karavanke tunnel to Obrežje, with its densest stands on the A1 between Ljubljana and Blagovica, and between Vransko and Slovenske Konjice (Frajman & Kaligarič, 2009). It grows on road verges as well as in the central reserve.

Substrate sampling and salinity measurements

At the end of September and the beginning of October in 2009, we selected parts of Highway A1 (connecting Šentilj and Koper, passing Maribor, Ljubljana) for the collection of plants and substrate samples. The road has two lanes in each direction and a central reserve overgrown by taller vegetation. The first site was located 1 km from the highway service area at Lukovica in the

Fig. 1: Increasing height of** Dittrichia graveolens **individuals away from the road margin at the Lukovica site.
Sl. 1: Višina osebkov vrste** Dittrichia graveolens **narašča z oddaljenostjo od cestnega roba na lokaciji Lukovica.

direction of Trojane. A dense stand of *D. graveolens* plants extended for several kilometers along the entire road verge. The second site was located at the Ravne service area near Kozina. No continuous stands were observed there. Individuals of *D. graveolens* were found in smaller, discrete groups, only occasionally in dense stands along shorter road segments.

Substrate samples were collected directly at the road margin to a maximum of 50 cm away, as the closest sample to the road, and then at distances 100 cm, 120 cm, and 200 cm perpendicularly to the road margin. In this direction, a prominent gradient in plant height was observed (Fig. 1). At both locations, soil samples were collected from plots where *D. graveolens* was present. We collected 1 kg of substrate sample on each site for salinity analysis. For the two control samples, we collected the substrate at Kozina from sites where no *D. graveolens* individuals were sighted.

Samples were sieved to remove larger stones, mixed with deionized water in a ratio of 1:9 and shaken for 1 h. The conductivity of the prepared solution was measured by a portable conductometer MA 5950 (Metrel, Slovenia) at room temperature (20 °C) after the solution had been allowed to settle for 30 min. Conductivity readings were corrected regarding the temperature at which they were taken, if necessary.

For comparison of substrate salinity along the distance away from the road, a Welch-ANOVA was used to test for significant differences, since the results yielded heterogeneous variances according to Levene's test.

Reproductive potential of *D. graveolens*

In evaluating the reproductive potential of *D. graveolens* plants, we recognized three categories of plant height: 1 – from 5 to 15 cm; 2 – from 16 to 25 cm; 3 – larger than 25 cm. The potential reproductive success of *D. graveolens* plants was estimated by counting the number of flower heads per plant in each category. Average seed (achene) number per single flower head was estimated after counting seeds for 50 randomly selected flower heads for each height category, which were collected in Lukovica. The data obtained were used for calculating the total seed number for an individual plant.

RESULTS

Observation on sites with *D. graveolens* stands showed that plant height and plant density increase with distance from the road margin. Differences were also observed in the abundance of *D. graveolens* plants between the Lukovica and Kozina locations. Additionally, as expected, those sites without *D. graveolens* in Kozina showed the lowest salinity values.

The salinity of the substrate at Lukovica changed significantly within the 2 m distance next to the road (Welch ANOVA at $p>0.05$; Fig. 2), because of lower salinity figures at a distance of 1 m. However, if we exclude those measurements within 50 cm of the road, an increase in salinity was observed from 1 m to 2 m away from the road margin – in the same direction as plant size increased. Up to 50 cm away, individual plants were 5 to 15 cm tall; from 1 to 1.5 m distance from the road, plants reached 10 to 30 cm of height,

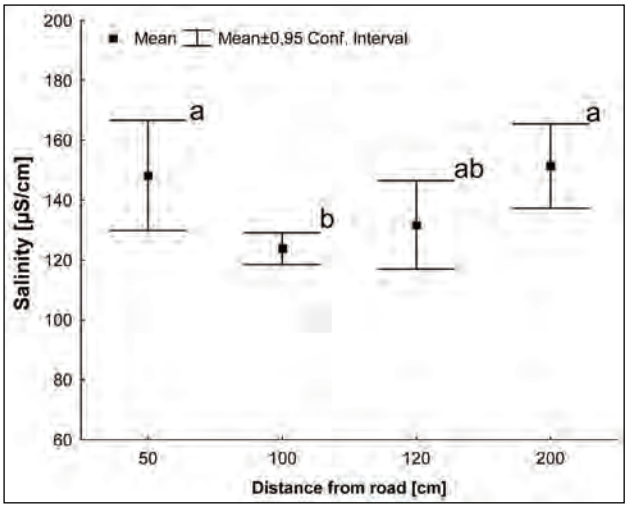

Fig. 2: Mean salinity values of the substrate away from the road margin were significantly different within the 2 m distance (Welch ANOVA, $p<0.05$) at the Lukovica location. Different letters indicate significantly different means.
Sl. 2: Srednje vrednosti slanosti substrata so se statistično značilno (Welcheva ANOVA, $p<0,05$) razlikovale z oddaljenostjo od cestnega roba znotraj razdalje 2 m na lokaciji Lukovica. Različne črke označujejo statistično značilno različne srednje vrednosti.

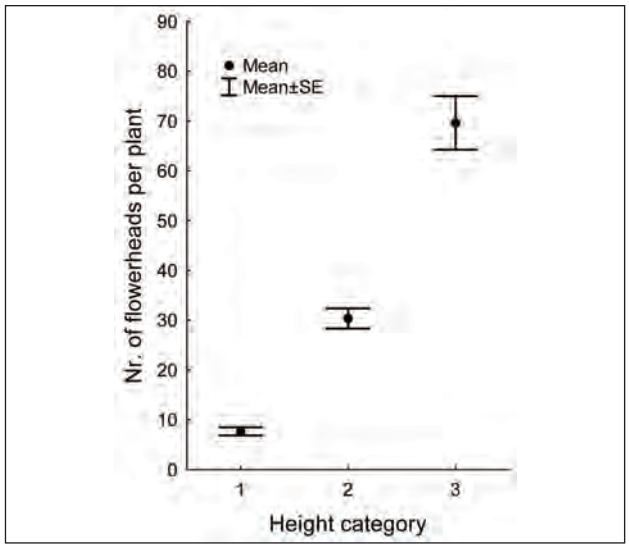

Fig. 3: Reproductive potential of** D. graveolens **plants, collected in Lukovica, from different height categories (1: 5–15 cm; 2: 16–25 cm; 3: >25 cm) measured through the number of flower heads per single plant.
Sl. 3: Reproduktivni potencial** D. graveolens **na lokaciji Lukovica izmerjen kot število koškov na posamezno rastlino, ki so pripadale trem velikostnim razredom (1: 5–15 cm; 2: 16–25 cm; 3: >25 cm).

and more than 2 m away, some individuals were taller than 40 cm. Plants grew in soils with salinity from 110 to 237 µS/cm at both locations. Average soil salinity on two sites in Kozina without *D. graveolens* plants was 97 and 82 µS/cm.

Dittrichia graveolens plants showed high reproductive potential, which increased with the plant's height and differed significantly among height categories (Welch ANOVA, $p<0.05$; Fig. 3). The average number of seeds (achenes) in a single flower head was 30 seeds, and it showed low variability among individuals of different size. According to that, estimated seed production of plants was about 90 seeds per plant in the first and 4380 seeds per plant in the third height category. In relation to distance to the road margin, in its near proximity plants produced on average 500 seeds; however, even at 1 m distance we found plants exhibiting high reproductive potential with more than 2000 seeds per plant.

DISCUSSION

Deicing chemicals, which help to improve road safety, are regularly used on Highway A1 during winter. However, we expected that on road segments toward the south of the country deicing salts would be less frequently used because of the rarer incidence of snowfall and freezing conditions. Even though the sampling was rather simple, our results indicate that the occurrence of *D. graveolens* might be connected to increased soil salinity values. Less densely developed and not continuously occurring *D. graveolens* stands were observed in the southern part of this motorway. On all the sites with *D. graveolens* plants, salinity was higher, while at values below 100 µS/cm, no plants were observed. *Dittrichia graveolens*, besides being halotolerant for soil salinity, has an additional competitive advantage over native plants: it is an annual species, surviving winter as seeds that can avoid the direct negative impact of saline spray, which perennial native species would have to endure.

Additionally, the salinity gradient measured at the road verge corresponds with previous similar reports, showing a sharp decline in soil salinity over the first 2 m distance from salted roads (Thompson *et al.*, 1986). Our results show that the saline opportunity habitat for *D. graveolens* is located only on a narrow strip 1 m or less from the road, up to the distance where the decline in salinity enables the native, more competitive species to begin to dominate the habitat. The rarer occurrence of *D. graveolens* in the southern part of the highway, which lies in a region with a sub-Mediterranean climate, suggests that the establishment of *D. graveolens* in less saline soil is limited because the species is a weak competitor compared to native sub-Mediterranean species and not because of unsuitable climatic conditions. This is furthermore underpinned by numerous records of *D. graveolens* along the roads in those Central European countries (Kocián, 2015a) that have a rather cold climate.

Our results also show that plants 1 m from the road were already 30 cm high, and these were the plants showing the highest seed production. Our previous studies on *Aster squamatus*, we stressed that one characteristic that can be key for successful invasion of alien invasive Asteraceae, especially if they can become established in less productive habitats (including saline or semi-saline habitats), is the late onset of flowering

Fig. 4: Dry fruiting** Dittrichia graveolens **plants at the Kozina location on 25th October 2009.
Sl. 4: Posušene plodeče rastline** D. graveolens **opazovane 25. oktobra 2009 na lokaciji Kozina.

(Šajna *et al.*, 2014; Šajna 2016). *Dittrichia graveolens* starts to flower in September, and flowering lasts until October (Kocián, 2015a).

We observed several dried fruiting plants at full height (Fig. 4). This is an indication that fully developed plants, able to produce seeds, are rarely impacted by mowing during road verge maintenance because mowing happens too early and because larger plants grow in the depression of the road verge, away from the road margin. Location by the road represents immediate potential for seed dispersal via the slipstream of passing vehicles (von der Lippe *et al.*, 2013), while the road corridor functions as a route of secondary dispersal. Such dispersal via traffic, enabling very rapid and often unnoticed invasions, has been recorded for many invasive plant species (von der Lippe & Kowarik, 2007).

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DITTRICHIA GRAVEOLENS – KAKO SLANOST TAL DOLOČA NJENO RAZŠIRJENOST, MORFOLOGIJO IN REPRODUKTIVNI POTENCIAL?

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POVZETEK

Soljenje cest pozimi pripomore k varnosti prometa, a ima močan vpliv na vrste, ki poseljujejo cestne robove. Ustvarja rastišča s slanimi tlemi, ki jih lahko poselijo rastline s posebnimi prilagoditvami in toleranco na slanost. Tak primer je avtohtona mediteranska vrsta Dittrichia graveolens*, ki se ob cestnih robovih seli v osrednjo Evropo in jo najdemo že v mnogih državah. Proučevali smo, kako slanost tal določa višino rastlin* D. graveolens*, njihov reproduktivni potencial in razširjenost ob cestnem robu. Višina rastlin je bila odvisna od električne prevodnosti (EC) tal – merilo za slanost. Naši rezultati kažejo, da vrsta najbolje uspeva v tleh z vrednostmi EC med 110 in 170* µ*S/cm, medtem ko je pri vrednostih pod 100* µ*S/cm nismo opazili. Uspeli smo identificirati tri velikostne razrede, ki se razlikujejo v reproduktivnem potencialu.*

Ključne besede: invazivna vrsta, cestni rob, soljenje cest, Slovenija

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