



URBAN POPULATION OF THE GROUND BEETLE *CARABUS VARIOLOSUS NODULOSUS* (COLEOPTERA: CARABIDAE) IN LJUBLJANA CITY (CENTRAL SLOVENIA)

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Abstract – A population of the endangered ground beetle *Carabus variolosus nodulosus* Creutzer, 1799 was discovered in Landscape Park Tivoli, Rožnik and Šišenski hrib in the city center of Ljubljana. In the park area we recorded 12,275 meters of flowing water. In 2012 and 2014, we confirmed the species at 24 out of 48 sampling sites (50%). The estimated minimal number of adult beetles in 2014 ranged from 2295 to 5715. Based on the data collected, we zoned the area with the highest densities. Guidelines for the management of the area are also given in order to maintain or even improve the status of the ground beetle population in Ljubljana. Ljubljana holds the only urban population of the species known so far, which might represent a unique evolutionary significant unit, although its share in the total population in Slovenia is estimated at only 0.02%.

KEYWORDS: city park, urban environment, Natura 2000, zonation, riparian habitat

Izvleček – URBANA POPULACIJA MOČVIRSKEGA KREŠIČA *CARABUS VARIOLOSUS NODULOSUS* (COLEOPTERA: CARABIDAE) V LJUBLJANI

V Krajinškem parku Tivoli, Rožnik in Šišenski hrib v mestnem središču Ljubljane je bila odkrita populacija ogroženega močvirskega krešiča *Carabus variolosus nodulosus* Creutzer, 1799. Na območju parka smo popisali 12.275 metrov tekočih voda. V letih 2012 in 2014 smo močvirskega krešiča potrdili na 24 točkah od 48 vzorčnih mest (50 %). Ocenjeno minimalno število odraslih hroščev v letu 2014 je bilo med 2295 in 5715. Glede na zbrane podatke smo naredili conacijo območja z največjimi gostotami. Podane so tudi smernice za gospodarjenje z

območjem, da bi ohranili ali celo izboljšali stanje populacije močvirskega krešiča v Ljubljani, ki je do sedaj edina znana urbana populacija vrste in morda predstavlja celo edinstveno evolucijsko pomembno enoto, čeprav šteje po oceni le 0,02 % celotne populacije v Sloveniji.

KLJUČNE BESEDE: mestni park, urbano okolje, Natura 2000, conacija, mokrotni habitat

Introduction

Green spaces in urban environments have a positive impact on the quality of life of residents (Adler & Tanner 2013), but at the same time, from the point of view of biodiversity conservation, they are special habitats due to a different type of management, which can have a high conservation value. However, it is important to note that larger patches of green areas (> 50 ha), habitat corridors and suitable management are needed to preserve area-sensitive species within urban areas (Beninde *et al.* 2015). In the city of Ljubljana, one of the most important green islands is the Landscape Park Tivoli, Rožnik and Šišenski hrib. The long-term vision of the City of Ljubljana in Environmental Protection Program for the City of Ljubljana envisages sustainable growth and continuous improvement of the quality of life through the constant pursuit of a clean, safe and friendly environment for all people and the preservation and creation of new green spaces with unique biodiversity (Jazbinšek Seršen *et al.* 2014). The Landscape Park Tivoli, Rožnik and Šišenski hrib, located near the city center, is visited by more than 1,700,000 people per year (Smrekar *et al.* 2011) and is a key area for the implementation of this vision.

Surveys of the beetle fauna in the areas of Landscape Park Tivoli, Rožnik and Šišenski hrib have confirmed the presence of some species listed in the European Habitats Directive (Council Directive 92/43/EEC): *Carabus variolosus*, *Lucanus cervus* and *Osmoderma eremita* (Vrezec *et al.* 2013), while only historical data are known for *Cerambyx cerdo*, *Rosalia alpina* and *Morimus funereus* (Breljih *et al.* 2006).

In the present study, we investigated the distribution and abundance of the population of *Carabus variolosus* in the area of the Landscape Park Tivoli, Rožnik and Šišenski hrib. In Slovenia and Ljubljana, the subspecies *Carabus variolosus nodulosus* Creutzer, 1799 lives, which according to some authors even has species status (Turin *et al.* 2003), while the genetic structure of populations in Slovenia is even more complex, as shown by a recent molecular study (Mossakowski *et al.* 2020). This is probably a consequence of the extremely low dispersal of the species with low genetic heterozygosity of populations and high diversification among populations as a whole (Matern *et al.* 2009). This means that most populations of *Carabus variolosus* are isolated, demographically independent, and even evolve independently. Therefore, isolated and viable populations of the species are particularly worthy of protection due to their unique genetic structure (Matern *et al.* 2009), which may even function as evolutionary significant units.

The ground beetle *Carabus variolosus* inhabits very wet and swampy banks of forest streams, which are usually covered with stands of swampy deciduous forests, especially black alder (*Alnus glutinosa*), *Equiseto-Fraxinetum*, *Carici-Fraxinetum* and forest stands of beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*) (Drovenik & Pirnat 2003, Müller-Kroehling 2006, Vrezec *et al.* 2007). Adult beetles live for two to three years, have a low dispersal power and live in relatively small populations limited to suitable habitat (Matern *et al.* 2007a, 2009). Because the beetle is strongly tied to wet environments, its reproduction is limited to very moist habitats, increasing its sensitivity to encroachment into swampy and shaded environments of forest streams. The species is also affected by habitat fragmentation, which breaks links between isolated subpopulations (Müller-Kroehling 2006). In Slovenia, this species is still widespread, but according to the results of the population monitoring at selected sample sites between 2007–2020, it is locally declining (Vrezec *et al.* 2020).

The aim of the present study was to study the only known urban population of *Carabus variolosus* and to give guidelines for improvement of the management of the area for the conservation of the species in the Landscape Park Tivoli, Rožnik and Šišenski hrib in Ljubljana city.

Material and Methods

Study area

The Landscape Park Tivoli, Rožnik and Šišenski hrib is located in the center of the city of Ljubljana and covers an area of 459 ha, including the city park Tivoli and the Rožnik and Šišenski hrib park forests. The area was declared a landscape park by decree in 1984, both for natural and cultural aspects. Within the Landscape Park there are other, special protected areas: the nature reserves Mali Rožnik (Figure 1) and Mostec, a natural monument in the area below Turn, a horticultural monument city park Tivoli and several natural values and cultural heritage sites (Smrekar *et al.* 2011).

The largest central part of the Landscape Park (288 ha) is a varied forest area with five peaks (Šišenski hrib, Rožnik, Cankarjev vrh, Tivoljski vrh and Debeli hrib). Forest covers 341 ha or 74% of the area (Smrekar *et al.* 2011), with the main forest communities being acidophilous *Pineto-Vaccinetum austroalpinum*, *Alnetum glutinosae* and *Querceto-Castanetum* (Kermavnar 2015). The area was never completely deforested in the past, although at least in the 15th century part of the area was covered with vineyards (Smrekar *et al.* 2011). The forests are covering the major part of the area at least from 18th century on, although it seems that this forest fragment is isolated from the nearby continuous forests at least for 300 years (Figure 2). As late as the end of the 19th century, the forests of the park were inhabited by true forest bird specialists such as the Capercaillie (*Tetrao urogallus*) and the Ural Owl (*Strix uralensis*) (Schulz 1895), indicating the presence of primeval forest stands in the park. Both species have disappeared from the Park's forests to date (Tome *et al.* 2013), but forest cover has remained unchanged for at least the last 100 years (Smrekar *et al.* 2011). In the Ljubljana urban forest, the economic use of timber



Figure 1: Example of a swampy bank of a forest stream in the area of the Landscape Park Tivoli, Rožnik and Šišenski hrib in the area of Mali Rožnik as a habitat for *Carabus variolosus* (Photo: Irena Bertoncelj).

Slika 1: Primer zamočvirjene brežine gozdnega potoka na območju Krajinskega parka Tivoli, Rožnik in Šišenski hrib v predelu Malega Rožnika kot življenjskega prostora močvirskega krešiča *Carabus variolosus* (Foto: Irena Bertoncelj).

is low, and social and regulatory functions, including biodiversity conservation, are more important (Smrekar *et al.* 2011).

In the eastern part of the park there is the 43 ha large city park Tivoli, which is an example of designed nature and was declared as city park already in 1814 (Smrekar *et al.* 2011). On the western side of Šišenski hrib is the only large flat area within Landscape Park. Lake Koseze is located there and south of it are the only large non-forested areas of the park. The Landscape Park is completely surrounded by built-up areas from three directions (north, south and east). Only on the western side is the area connected to the wider hinterland of the hills of Polhov Gradec, but this ecological corridor is interrupted by the western part of the Ljubljana bypass (Smrekar *et al.* 2011).

Larger watercourses in the area are the Mostec stream, which flows into Lake Koseze, and Pržanec and Glinščica streams on the edge of the park (Figure 3). Higher parts of the area consist of mechanically less resistant permocarbonate shales, sandstones and conglomerates, so smaller streams have carved deep and steep ravines. Due to the small catchment areas, Rožnik watercourses usually dry up during the summer months (Smrekar *et al.* 2011). During sampling of fish and crayfish in Mostec, Glinščica, Pržanec, Lake Koseze and Tivoli ponds, Bertok and Podgornik (2004) found that only Mostec stream is preserved in a more or less natural form, while the other water bodies are anthropogenically modified and impoverished.



Figure 2: Comparison of maps of the area of the Landscape Park Tivoli, Rožnik and Šišenski hrib and nearby surrounding from years 1763 (above; Josephinische Landesaufnahme 1763–1787 für das Gebiet der Republik Slowenien) and 2015 (below).

Slika 2: Primerjava kart območja Krajinskega parka Tivoli, Rožnik and Šišenski hrib in bližnje okolice med letoma 1763 (zgoraj; Josephinische Landesaufnahme 1763–1787 für das Gebiet der Republik Slowenien) in 2015 (spodaj).

As part of this research, we sampled the central forested part of the landscape park between Tivoli and Večna pot.

Field sampling

We mapped all streams, their tributaries, springs and standing waters. During the fieldwork we used GPS to record the route and waypoints, which were processed using ArcGIS (ESRI). This allowed us to estimate the size of *Carabus variolosus* habitat in the area.

Beetles were sampled in 2012 and 2014 during the spring peak of adult activity between May and June. We used pitfall traps (diameter of 10 cm) placed directly adjacent to streams, not more than 0.5 m from the water line, and left open for seven days, when they were collected (Vrezec *et al.* 2009). The traps contained a smaller amount of wine vinegar as bait and a number of structures (pebbles, pieces of bark, and twigs) to prevent drowning of captured animals. Five traps were set at each site for a total distance of 25 meters along the stream. At 40 sampling sites 200 pitfall traps were set in total. Fieldwork was conducted under a permit from Slovenian Environment Agency No. 35601-75/2012-8.

Data analysis

Systematic sampling at a large number of sampling sites allowed us to calculate relative abundances of beetles (Krebs 1999). Systematically collected data and calculated relative abundances are particularly important for quantitative assessment of the importance of the local population at the national level, as they show how important the area is compared to other areas sampled using the same method (Vrezec & Kapla 2007). Relative abundances do not represent the true absolute values of population densities, but they allow effective comparisons between areas, i.e. they indicate the population core areas with higher densities (Sutherland 2000, Vrezec *et al.* 2005, 2012). For sampling with traps, the sampling unit was the trapping night, i.e. the catch of 10 traps in one night. The relative abundance (RA) was therefore calculated as follows:

$$RA = \text{No. individuals} \times 10 / [\text{No. traps} \times \text{No. nights}]$$

To calculate the relative abundance, we only considered the data from the sites where the species was found. For *Carabus variolosus*, reference tables of relative abundances were prepared, which allowed us to determine the rank of local abundances according to the situation in Slovenia. These reference values include data collected during the national population monitoring of the species between 2007 and 2012 (Table 1). The mean value of relative abundance in the area of Landscape Park Tivoli, Rožnik and Šišenski hrib can thus be classified into one of three classes: low density (MIN - values between the minimum and the first quartile (Q_1) of all known relative abundances in Slovenia), medium density (MED - values between the first (Q_1) and the third quartile (Q_3) of all known relative abundances in Slovenia) and high density (MAX - values above the third quartile (Q_3) of all known relative abundances in Slovenia).

Table 1: Reference values of relative abundances (RA [No. of individuals / 10 trap nights]) of ground beetle species *Carabus variolosus nodulosus* in Slovenia determined between 2007 and 2012 (N = 205 locations with confirmed presence of the species; Vrezec & Kapla 2007, Vrezec *et al.* 2012)

Tabela 1: Referenčne vrednosti relativnih gostot (RA [št. osebkov / 10 lovnih noči]) močvirskega krešiča *Carabus variolosus nodulosus* v Sloveniji ugotovljene med letoma 2007 in 2012 (N = 205 lokacij s potrjeno prisotnostjo vrste; Vrezec in Kapla 2007, Vrezec s sod. 2012)

Statistical value	RA
First quartile (Q ₁)	0.67
Median (MED)	1.33
Third quartile (Q ₃)	2.57
Maximum (MAX)	27.67

Using data collected in 2014 (40 sampling sites), we estimated the minimum number of active adults of *Carabus variolosus* based on the total number of caught individuals. The sampling was conducted in one catching session only lasting 7 days and without repeated recaptures. Therefore only minimal possible population estimate can be given. The species is mostly active up to 2 meters from the streambed (Bric 2011). At each site, we covered 25 meters of the stream with five traps, giving us 100 m² of inspected habitat for the species. Based on the number of beetles captured in seven days, we calculated the minimum absolute density (number of specimens / m²). We calculated the average absolute density at all 40 sampling sites, which, according to systematic sampling, should reflect the average density of the species along watercourses in the area in a strip of 2 meters on each side of the stream. Using the measured length of watercourses in the area of Landscape Park, we estimated the total habitat of the species in which we estimated the minimum number of active adult beetles at the time of sampling. Abundance was expressed in the interval calculated based on average density, and the upper limit was expressed as average density with standard deviation added.

The area of Landscape Park was zoned according to habitat availability based on all data collected on the occurrence of *Carabus variolosus*. Zonation was done using a conservative approach and respecting the precautionary principle. The impact zone was estimated to be 25 m on either side of the stream bed. This zone includes a narrow area of activity for the species along the stream where the majority of the population resides (Matern *et al.* 2007b, Bric 2011), and a broader area of impact important for shading the streambed and wet banks (Matern *et al.* 2007b).

The data were processed in MS Excel, and the map views with ArcGis 9.3

Results

Mapping of watercourses in the Landscape Park Tivoli, Rožnik and Šišenski hrib

During the mapping of watercourses, 12,275 meters of flowing waters, 10 standing waters and six springs were recorded in the area of Landscape Park Tivoli, Rožnik



Figure 3: Mapped network of watercourses in the area of the Landscape Park Tivoli, Rožnik and Šišenski hrib – springs (points), running (lines) and standing waters (polygons).

Slika 3: Skartirana mreža vodotokov na območju Krajinskega parka Tivoli, Rožnik in Šišenski hrib – izviri (točke), tekoče (linije) ter stoječe vode (poligoni).

and Šišenski hrib (Figure 3). The longest and most branched is the system of forest streams that flow into the stream in Mostec. The other streams are mostly very short and become channelized once they reach the forest edge. We only mapped the streams during the period of higher water levels, so we did not record which of the streams dried up during the hot summer months.

In the area of Šiška on the Pod hribom road, where the hilly part steeply turns into a plain, we recorded six springs, all of which are canalized. Of the 10 standing waters, six are in the area of Ljubljana ZOO. The largest standing water is Lake Koseze, which has a naturally constructed bank. In its immediate vicinity, on the southern edge, there is also a small marshy water body. Tivoli Pond, which was emptied and restored in 2011, has a paved bank. As a standing water body, we also studied and sampled Mali Rožnik, the area of natural value of national importance.

Survey of *Carabus variolosus*

In 2012, we confirmed *Carabus variolosus* at four of eight sampling sites (50%) and in 2014 at 20 of 40 sampling sites (50%) (Figure 4). During systematic sampling

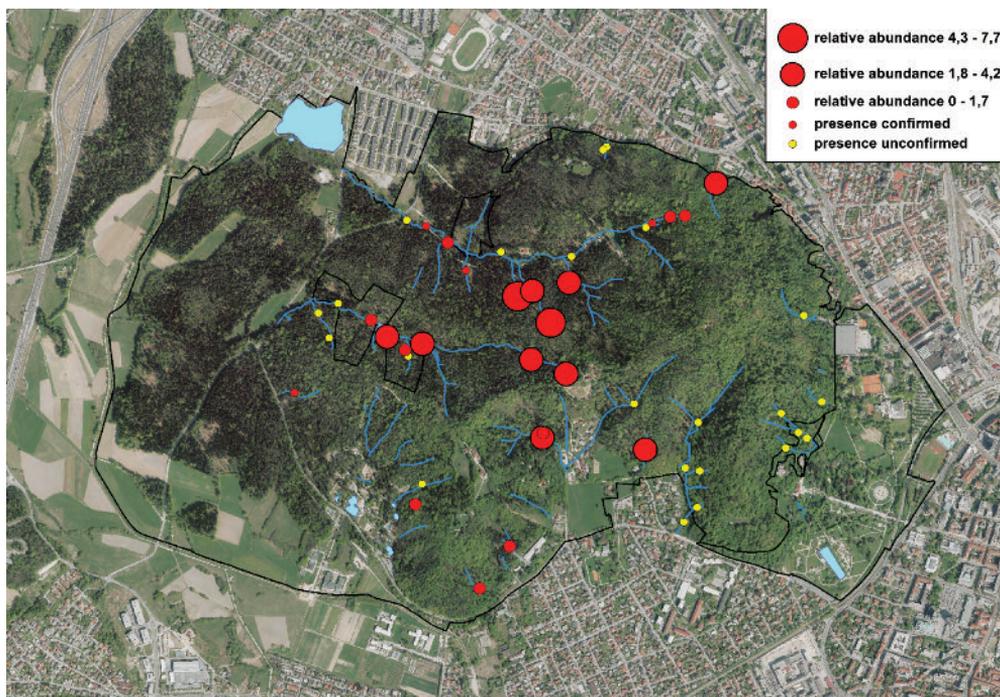


Figure 4: The presence and relative abundance of *Carabus variolosus nodulosus* in the area of the Landscape Park Tivoli, Rožnik and Šišenski hrib was established in 2012 and 2014, and the display also includes random finds. The results of the sampling in 2012 and random finds are shown only by the presence or absence of the species. Relative abundances are shown only for systematic sampling performed in 2014.

Slika 4: Prisotnost ter relativna gostota močvirskega krešiča *Carabus variolosus nodulosus* na območju Krajinskega parka Tivoli, Rožnik in Šišenski hrib ugotovljena v letih 2012 in 2014, prikaz pa vključuje tudi naključne najdbe. Rezultati vzorčenja v 2012 ter naključne najdbe so prikazani le s prisotnostjo oziroma odsotnostjo vrste. Relativne gostote so prikazane samo za sistematično vzorčenje izvedeno v letu 2014.

in 2014, we captured 186 specimens in 1,400 trapping nights, of which 97 were females and 89 males (the ratio of females to males was 1.1:1.0).

In 2014, we calculated the relative abundance of captured beetles for each sample site where the presence of the species was confirmed. The median relative abundance of *Carabus variolosus* in Landscape Park Tivoli, Rožnik and Šišenski hrib was 2.57 (MIN -MAX: 0.29 - 7.71), which is slightly higher than the median relative abundance for Slovenia. However, at 45% of the sample sites we confirmed the abundances belonging to the upper quartile of the abundances found so far in Slovenia. The highest abundances of *Carabus variolosus* were found in the upper reaches of the tributaries of the streams in Mostec and in Mali Rožnik. The species was not found in the streams in the eastern part of Landscape Park (Figure 4).

The narrower habitat of the species is a 4-meter strip along streams covering an area of 49,100 m² in Landscape Park Tivoli, Rožnik and Šišenski hrib. Based on systematic sampling, we estimated that in a 4-meter strip along streams the minimal density of active adult beetles in 2014 was at least 4.67 ± 6.97 individuals / 100 m². This means that the population of the species in 2014 in the area of Landscape Park Tivoli, Rožnik and Šišenski hrib numbered at least 2295 to 5715 adult beetles.

Zonation of the area for *Carabus variolosus* conservation

Based on all collected data and taking into account the precautionary principle, we zoned the area Landscape Park Tivoli, Rožnik and Šišenski hrib according to the availability of *Carabus variolosus* habitat (Figure 5). In zoning, we took into account all collected data on the presence or absence of the species. The habitat zone of *Carabus variolosus* in Landscape Park consists of all streams and their tributaries where the presence of this species has been confirmed and where the presence of this species is most likely according to the data collected. The watercourses in the western part of the park proved to be important for the conservation of *Carabus variolosus* (Figure 5).



Figure 5: Zonation of the Landscape Park Tivoli, Rožnik and Šišenski hrib area in according to the habitat of the ground beetle *Carabus variolosus* (red areas).

Slika 5: Conacija območja Krajinskega parka Tivoli, Rožnik in Šišenski hrib glede na življenjski prostor močvirskega krešiča *Carabus variolosus* (rdeče površine).

Discussion

The importance of the *Carabus variolosus* population in Landscape Park Tivoli, Rožnik and Šišenski hrib is relatively low at the national level, as the park population has been estimated at only 0.02% of the total Slovenian population of this species (Vrezec *et al.* 2012), or at least 5,000 active adult beetles. This estimation should be improved in future studies using more accurate capture-mark-recapture method (Matern *et al.* 2007a). Nevertheless, up to our knowledge this is the only known urban population of the species so far, even at the European level, where it is considered a rare stenotopic species of smaller, mostly montane streams, marshes and swamps (Turin *et al.* 2003). The population in Europe appears to be severely depleted, as the species is considered extinct in Belgium, France, Italy, Switzerland and northern Germany, while it is considered critically endangered in the rest of its range in Germany, Austria and the Balkans (Turin *et al.* 2003). In this respect, the urban population in Ljubljana is a unique exception that requires stricter protection. Due to previous deforestation and recent heavy urbanisation it is now an isolated population remnant for at least 300 years (Figure 1). However, historical isolation processes are still unexplored. In respect to the species genetic differentiation (Matern *et al.* 2009) the described unique urban population might hold specific genetic structure as an evolutionary significant unit, and strict conservation measures are needed to prevent its extinction. Further genetic study of this unique urban population are highly needed.

In this study, streams and their headwaters in the area of Mostec, Mali Rožnik, around Ljubljana ZOO and below Cankarjev vrh proved to be particularly important for the species. Flowing water is the key, but not standing water. The latter is probably also the result of major encroachments on standing water in this area. The area of city park Tivoli is less important for *Carabus variolosus*.

In the urban forest of Landscape Park Tivoli, Rožnik and Šišenski hrib ecological and social functions (recreation, education) are emphasized for the benefit of citizens. The importance of the wood-producing function of the forest is low, but present (Smrekar *et al.* 2011). In order to preserve the biodiversity of the park, logging should be limited to the most urgent protection and remediation measures. This is especially true for cutting trees along forest streams, where increased thinning can cause accelerated drying of streams and marshy portions along them, negatively affecting the population of *Carabus variolosus*. Clearcuts along streams are particularly unfavorable.

For the long-term conservation of the natural network of watercourses with its associated biodiversity, which is unique to urban forests, we propose the following management guidelines that will help conserve the *Carabus variolosus* population (adapted according to Matern *et al.* (2007b) proposal):

- (1) A prohibition on logging and other forestry activities in the immediate vicinity of forest streams defined by a 50 m impact zone from the streams;
- (2) A ban on regulation and rapid drainage of streams in the area of Landscape Park Tivoli, Rožnik and Šišenski hrib, which would lead to drying of the riparian

zone, as well as regulation of banks within zones that could significantly affect or even destroy *Carabus variolosus* habitat;

(3) Maintaining the natural dynamics of the watercourse with occasional flooding, which maintains soil moisture with increased bank sedimentation, which also contributes to reduced overgrowth of the bank with scrub (the measure also increases the retention time of water in the park area, which is important due to the reduction in water overflow during heavy rains, which is critical to limiting erosion and flooding (Adler & Tanner 2013), as the park is surrounded by predominantly urbanized areas);

(4) Avoiding the planting of non-native conifers, especially Norway spruce, in close proximity to the streams, as these contribute significantly to the acidification of the substrate and thus the water;

(5) Leaving fallen logs, especially of softwood species, along streams that serve as overwintering structures for the beetle.

In the urban environment, the potential for introduction of non-native species is greater than elsewhere and increases significantly with distance from stores selling such live animals (Chucholl 2014), which is particularly evident for aquatic species. The likelihood of live animals being released increases with their accessibility to humans and with the population density of people in a given area, which is highest in an urban environment. In the case of the watercourses in the Landscape Park Tivoli, Rožnik and Šišenski hrib, as well as in the wider area of Ljubljana, the risk of introduction of non-native aquatic species is particularly high. From the perspective of streams, which are the habitat of *Carabus variolosus*, it is important to highlight the risk of introduction of non-native crayfish species, which have been shown to have impacts on hydrology and biodiversity (Souty-Grosset *et al.* 2006; Vrezec & Brancelj 2012). Impacts on biodiversity are reflected in both disease transmission and extinction of some aquatic species due to increased predation, such as hygrophilous beetles (Casale & Busato 2008). Among the latter, the Red Swamp Crayfish *Procambarus clarkii* is particularly dangerous, for which we also record cases of releases into the environment in Slovenia (Govedič 2018). No alien crayfish species have yet been recorded in the wider Ljubljana area, but due to the free availability of live crayfish in stores in Ljubljana (Vrezec & Brancelj 2012), the risk of introduction is high. Successful introduction of predatory alien species may destroy the only known urban population of *Carabus variolosus*, despite strict conservation measures to protect its habitat.

The results of this and some previous studies on the biodiversity of the Landscape Park Tivoli, Rožnik and Šišenski hrib (e.g. Mihelič 2005; Tome *et al.* 2013; Vrezec *et al.* 2013) show quite high diversity. This state of biodiversity is unique in European urban forests, so this is content that should be better exploited in Ljubljana in terms of promotion and education. Due to the large number of visitors on the one hand and the interesting biodiversity on the other hand, Landscape Park Tivoli, Rožnik and Šišenski hrib allow a large part of the city population to have direct contact with the specifics of the Natura 2000 network. As such, it can serve both as an educational and tourist facility and as an example of good practice in the conservation of endangered species at the European level.

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