

**STATUS OF ENDANGERED *GRAPHODERUS BILINEATUS* IN SLOVENIA
WITH PROPOSAL OF URGENT CONSERVATION MEASURES**

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Abstract – After the only historical record for *Graphoderus bilineatus* (De Geer, 1774) in Slovenia from Rače, from 1936, the species was rediscovered in 2011 in a gravel pit in Spodnje Krapje by the Mura River. The systematic large-scale survey of *Graphoderus bilineatus* in Slovenia took place between 2008 and 2020 and the species was found only at two locations by the Mura River. In 2017 and 2020, the species was found in Murska šuma near the border with Croatia and Hungary, but its occurrence was not confirmed any more in Spodnje Krapje. The current protection measures are not sufficient for effective long-term conservation of the relict *Graphoderus bilineatus* population in Slovenia, which is on the brink of extinction and urgently needs a detailed action plan.

KEY WORDS: endangered species, Natura 2000, diving beetles, Dytiscinae

Izvleček – STATUS OGROŽENEGA OVRATNIŠKEGA PLAVAČA *GRAPHODERUS BILINEATUS* V SLOVENIJI S PREDLOGOM NUJNIH VARSTVENIH UKREPOV

V Sloveniji je bil za ovratniškega plavača *Graphoderus bilineatus* (De Geer, 1774) znan le en zgodovinski podatek iz Rač iz leta 1936, vrsta pa je bila ponovno odkrita v gramoznici Spodnje Krapje ob reki Muri leta 2011. Sistematična vzorčenja med letoma 2008 in 2020 so vrsto potrdila le na dveh lokacijah v Sloveniji. V letih 2017 in 2020 je bilo potrjeno še drugo najdišče, tokrat v Murski šumi, blizu meje s Hrvaško in Madžarsko, medtem ko prisotnost vrste v Spodnjem Krapju ni bila več potrjena. Trenutni varstveni ukrepi za dolgoročno ohranjanje vrste v Sloveniji ne zadostujejo, saj je ovratniški plavač v Sloveniji na robu izumrtja, zato je nujen podroben akcijski načrt.

KLJUČNE BESEDE: ogrožene vrste, Natura 2000, kozaki, Dytiscinae

Introduction

Graphoderus bilineatus (De Geer, 1774) is a Palearctic species (Boukal *et al.* 2007), distributed from France to Siberia and from Scandinavia to Italy and Romania (Foster 1996). The populations towards northeast (Lundkvist *et al.* 2002, Kalniņš 2006, Przewoźny *et al.* 2014, Kolar & Boukal 2020) and in Southern Europe (Turić *et al.* 2021) are quite stable, but in general the species is rare and with a patchy occurrence (Foster 1996, Hendrich & Balke 2000, 2005, Iversen *et al.* 2013). It is declining in some countries in central Europe (Cuppen *et al.* 2006, Hendrich & Balke 2005) and is considered extinct in some countries in Western Europe, e.g. Belgium (Scheers 2015) and the United Kingdom (Foster 1996). It is one of the two species of diving beetles listed in the Annex II of Habitat Directive (Council Directive 92/43/EEC).

In general, it is an eurytopic and acidophilic species (Koch 1989) that lives in permanent, unshaded, stagnant waters with a sandy or peat bottom (Cuppen *et al.* 2006). Hendrich and Balke (2000) reported the species from shaded standing waters with clear water, in forest bogs, and even in gravel pits. In southern Europe, in Croatia, the species was found mostly on floodplains, in oxbow lakes and canals with standing water and medium-dense vegetation (Temunović *et al.* 2011).

In Slovenia the species is considered rare and endangered (Ambrožič *et al.* 2015a). Before 1950, there was only one known record from Slovenia. A single specimen is stored in the Central Collection of Beetles of Slovenia in the Slovenian Museum of Natural History, was collected in 1936 by Josef Peyer in the area of Rače near Maribor (Drovenik & Pirnat 2003). After 75 years the species was rediscovered in Slovenia in 2011 at the location of Spodnje Krapje by the Mura River (Ambrožič *et al.* 2015a). Following the rediscovery a systematic species survey has taken place in order to reveal species status, distribution and vulnerability in Slovenia.

Materials and methods

The systematic surveys of *Graphoderus bilineatus* in Slovenia took place between 2008 and 2020 (Vrezec *et al.* 2008, 2011, 2012, 2017a, 2017b, 2020, Ambrožič *et al.* 2014, 2015a, 2015b). Altogether, 268 sites were sampled using two methodological approaches, bottle trap and net sampling (Vrezec *et al.* 2011). In the bottle traps (see Ambrožič *et al.* 2015a for details), we used various baits (canned cat food, pieces of trout) as attractants. The trap was sunk to the bottom of the water body among vegetation. We set 10 to 20 traps at each location. Sampling lasted from one to two nights. With net sampling we sampled between aquatic vegetation or along the bottom by counting two to five swings at ten to thirteen microlocations in the water body and recording the catch for each microlocation (Koese & Cuppen 2006, Kalman *et al.* 2008). We sampled mainly smaller water bodies that were overgrown with aquatic and riparian vegetation. Identification to species level was performed in the laboratory (Freude *et al.* 1971, Friday 1988, Hájek 2009).

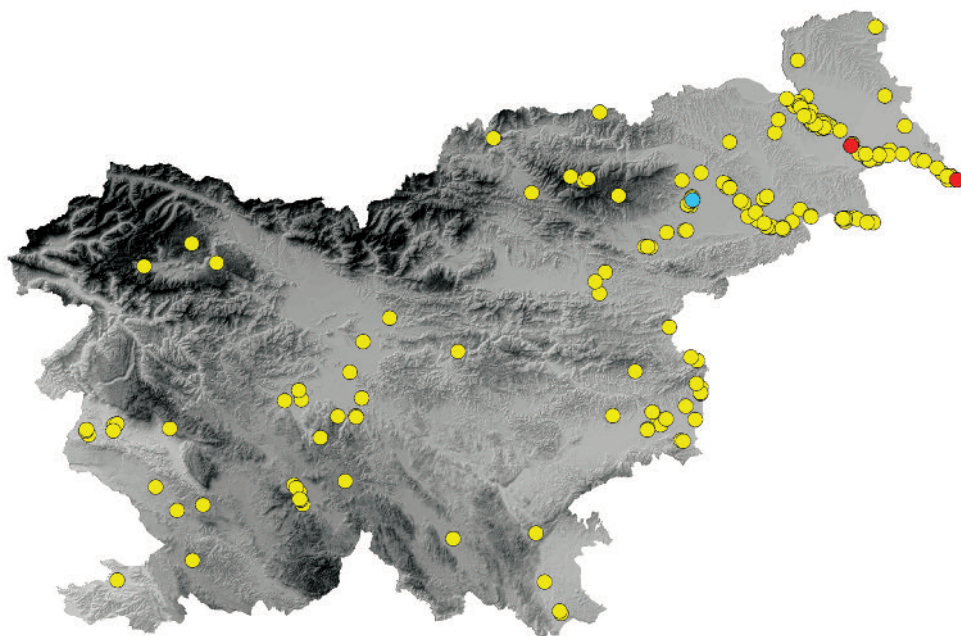


Figure 1: Map of the historical (before 1950, blue dot) and recent (after 2010, red dots) records of *Graphoderus bilineatus* in Slovenia. The systematic surveys of the species in Slovenia took place between 2008 and 2020 using two sampling methods on 268 sampling sites (yellow dots).

Slika 1: Karta zgodovinske (pred letom 1950, modra pika) in recentne razširjenosti (po letu 2010, rdeči piki) ovratniškega plavača *Graphoderus bilineatus* v Sloveniji. Sistematični popisi so potekali med letoma 2008 in 2020 z dvema metodama vzorčenja na 268 vzorčnih mestih (rumene pike).

All sampling of protected species was performed with the licence of the Environmental Agency of the Republic of Slovenia No. 35601-150 / 2006-6, No. 35601-75/2012-8 and No. 35601-40/2017-4) issued to the National Institute of Biology.

Results and discussion

In the 12-year period we sampled 268 sites altogether, while *Graphoderus bilineatus* was found in only two locations (0.7%) in Slovenia (Figure 1). At Spodnje Krapje location the species was found at two sampling events in 2011 (Ambrožič *et al.* 2015a), but afterwards the species was not found again although the site was regularly sampled (13 surveys in seven different years in the period 2012-2020). However, a second location for this species was confirmed, in the lower part of the Mura region, near the border with Croatia and Hungary in 2017 (12. 5. 2017, leg. Špela Ambrožič Ergaver, coll. Vrezec) and 2020 (21. 5. 2020, leg. Špela Ambrožič Ergaver, Urška Ratajč,

Matic Gabor, coll. Vrezec). A total of two individuals were caught in the traps at Črni jarek in the area of Murska šuma in the old riverbed of the Ledava River (Figure 1).

Our findings indicate great rarity and vulnerability of the *Graphoderus bilineatus* population in Slovenia. The only known recent location for the species is in the Mura river basin, which is probably the last area where this species survived in Slovenia, since analysis showed that it had disappeared from the Drava river basin with 90% probability (Ratajc 2017). Main habitats for this species in Slovenia are oxbows, abandoned gravel pits and old riverbeds. It is difficult to speculate about specific habitat requirements of the species here, however, the two recent locations both have clear water and a substantial shallow water area with rich riparian vegetation. We have not detected any major changes to habitat quality at Spodnje Krapje (Figure 2) in terms of water chemistry or aquatic vegetation. Only certain anthropogenic disturbances were noticed (e.g. logging and an increase in non-native fish abundances) and the species had apparently disappeared from this location. *Graphoderus bilineatus*



Figure 2: An abandoned gravel pit in the Siget gravel system, Spodnje Krapje by the river Mura, in which *Graphoderus bilineatus* was first rediscovered in Slovenia in 2011, but its occurrence was not confirmed after 2011 (Photo: Ivan Ergaver).

Slika 2: Opuščena gramoznica v sistemu Siget, Spodnje Krapje ob reki Muri, v kateri smo leta 2011 v Sloveniji prvič odkrili ovratniškega plavača *Graphoderus bilineatus*, pri kasnejših popisih pa vrsta ni bila več potrjena (Foto: Ivan Ergaver).



Figure 3: The second recent location for *Graphoderus bilineatus* is in the old riverbed of Ledava River in Murska šuma. The species was found here in the years 2017 and 2020 and probably represents the relict remnants of the population in Slovenia (Photo: Špela Ambrožič Ergaver).

Slika 3: Stara struga reke Ledave v Murski šumi je druga recentna lokacija za ovratniškega plavača *Graphoderus bilineatus*. Vrsta je bila tu najdena v letih 2017 in 2020 in verjetno predstavlja reliktni ostanek populacije v Sloveniji (Foto: Špela Ambrožič Ergaver).

continued inhabiting the pond in Črni jarek (Figure 3) even though the meadows around the pond were turned into pastures and fields in the years after the first record of the species. Since this water body is relatively small, the negative effects of increasing nutrient loads are to be expected in the future years. Additionally, grazing of the cattle presents a disturbance to the riparian vegetation, which could lead to lower water beetle diversity (Gioria *et al.* 2010, Ambrožič *et al.* 2018).

Graphoderus bilineatus is more widespread and abundant in some countries neighbouring Slovenia. In Hungary there are strong populations in the floodplains of the rivers Bodrog, Tisza and Drava (Kalman *et al.* 2007, 2008, 2011, Soós *et al.* 2008) and in Croatia in the lowland part of the Drava and Sava rivers (Temunović *et al.* 2011, Turić *et al.* 2021). In Italy, the species is rare and declining, since it is still

present only at one out of 15 historical sites, in the lake of Pratignano (Fanano, Modena) within the Parco dell'Alto Appennino Modenese in Emilia-Romagna (Boscari *et al.* 2020). To our knowledge, there are no known recent populations in southern parts of Austria, which could suggest that the population along the Mura River is only a small isolated remnant of the former population and a possible relict population.

According to our results, *Graphoderus bilineatus* is extremely rare in Slovenia and thus extremely vulnerable. A change of species' status in the national Red List of endangered species has already been suggested (Ambrožič *et al.* 2015a), however, recent studies suggest that the species is at the brink of extinction in Slovenia. It is necessary to establish strict protection of the areas where the species still occurs in order to conserve the population in Slovenia. Given the current knowledge, it is necessary to designate the areas of the old Ledava riverbed and gravel pit in Krapje as natural reserves excluding management for fishing, agricultural or other human activities and to dedicate it exclusively to strict nature protection. The area is located in the Natura 2000 area of Mura (SI3000215), but the current protection measures in the area are not sufficient for effective long-term conservation of the species, which is one of the most endangered beetle species in Slovenia and needs strict conservation management with the highest level of conservation concern. A detailed action plan for *Graphoderus bilineatus* is needed, which should include, among other administrative and technical requirements, the following categories:

(1) Genetic analysis of relict population. To our knowledge, there are no other historical or recent data (from Austria or Croatia) (Temunović *et al.* 2011) in Mura River region, which might suggest that the remnant population in Slovenia is a possible relict population.

(2) Exploration of species reintroduction possibilities (source population, captive breeding, release techniques) at the areas of previous (i.e. Rače ponds) and recent occurrences (Mura river). The current population is extremely small and probably facing extinction due to an extremely fragmented habitat with low metapopulation capacity (Hanski & Ovaskainen 2002). As observed at the location in Krapje, local extinction events are still ongoing and their prevention should therefore be a priority.

(3) Revitalization of water bodies. To promote recolonization and to enable a successful reintroduction we need to establish a suitable habitat for *Graphoderus bilineatus*. Thus, we propose the construction of water bodies with the following properties:

- a. The total surface area of the water body should be medium-sized (e.g. at least 8,000 m²; Cuppen *et al.* 2006), because medium-sized water bodies were found to support the richest water beetle communities (Lundkvist *et al.* 2001).
- b. The greater part of the basin of the water body should be at least 1 m deep (and the central part of the water basin at least 1.5 m) (Cuppen *et al.* 2006, Hendrich & Balke 2000).
- c. Shading of the water body was found to negatively correlate with the abundance of *Graphoderus bilineatus* (Turić *et al.* 2021), therefore the water body should not be completely shaded (Cuppen *et al.* 2006). Only part of the bank should be

overgrown with deciduous trees or shrubs (depending on the existing situation at the site of the intervention), and most of the bank should be overgrown with herbaceous vegetation (wetland vegetation with species such as *Carex*, *Schoenoplectus*, *Sphagnum*) (Hendrich & Balke 2000).

- d. The bottom of the water basin, with the exception of the central deepest part, should be overgrown with submerged macrophytes (*Utricularia*, *Ceratophyllum*, *Hottonia*, *Potamogeton*) (Hendrich & Balke 2000). In general, dense vegetation can represent a good shelter and oviposition sites for the beetles (Gioria *et al.* 2010). Even though different diving beetle species have specific habitat requirements, many studies found that rich aquatic macrophyte and riparian vegetation is positively influencing water beetle diversity and abundance (Gioria *et al.* 2011, Ambrožič *et al.* 2018). The presence of *Graphoderus bilineatus* positively correlates with species richness of water beetle communities (Turić *et al.* 2021).
- e. It must be ensured that the water is present permanently, at least in a part of the established water body, because permanent water can support richer and more diverse assemblages (Gioria *et al.* 2010, Kolar & Boukal 2020, Turić *et al.* 2021).
- f. Anthropogenic disturbances were found to have significant negative effects on the abundance of *Graphoderus bilineatus* (Turić *et al.* 2021). Access to the water body should therefore be limited. It is also very important to prevent the release of non-native fish species (eg. *Lepomis gibbosus*, *Amerius melas*, *Pseudorasbora parva*), which negatively affect water beetle populations (Åbjörnsson *et al.* 1997, Hendrich & Balke 2000, Dudgeon *et al.* 2006).
- g. Moderate nutrient loaded water bodies were found to support richest macrophyte communities, and consequently higher water beetle diversity (Ambrožič *et al.* 2018). Following the water body establishment, it is therefore necessary to monitor water beetle populations and basic physical and chemical parameters in the area of both the newly established water body and the selected already existing water bodies in the reserve.

(4) National management plan for the network of water bodies in accordance with the requirements of the species.

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financer: Dravske elektrarne Maribor d.o.o.) and Life + LIVEDRIVA: Restoration of the river ecosystem of the lowland part of the Drava in Slovenia (leading partner: DOPPS - BirdLife Slovenia). We are grateful to our co-workers in the field: Ivan Ergaver, Martin Vernik, Matic Gabor, dr. Dejan Bordjan and dr. Alja Pirnat. We thank Martin Vernik for useful guidance in preparing the article.

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