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DISTRIBUTION AND ECOLOGY OF THE PREDATORY KATYDID *SAGA PEDO* (PALLAS, 1771) IN CROATIA WITH THE FIRST RECORD IN THE CONTINENTAL REGION

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Until now, *Saga pedo* (Pallas, 1771) was known to occur in Croatia only in the Mediterranean biogeographical region and on the southern slopes of the Dinaric Alps in the Alpine region. Here we give the first record of the species' presence deep inside what is officially called the Alpine region and in the Peripannonian area in the Continental region of the country. Along with all known specimens and observation records, our results represent the updated distribution of *S. pedo* in Croatia. Some notes on ecology, field observations, and discussion about habitat preferences are also given.

Key words: Orthoptera, Saginae, bush crickets, citizen science, Kalnik Mt, fauna, parthenogenesis, Natura 2000 species

Adžić, K., Deranja, M., Mihaljević, M., Rebrina, F., Skejo, J., Jelić, D., Pavlović, M., Kirin, K. & Tvrtković, N.: Rasprostranjenost i ekologija grabežljivog konjica *Saga pedo* (Pallas, 1771) u Hrvatskoj, s prvim nalazom u kontinentalnoj regiji. Nat. Croat., Vol. 32., No. 1, 35-47, 2023, Zagreb.

Vrsta *Saga pedo* (Pallas, 1771) u Hrvatskoj je do sada poznata isključivo iz mediteranske biogeografske regije i južnih padina Dinarida alpinske regije koji graniče s njom. U ovom radu donosimo prve dokaze prisutnosti vrste duboko u onome što se službeno zove alpinska regija te peripanonskom prostoru u kontinentalnoj regiji Hrvatske. Objedinjujući sve dostupne uzorke i opažanja, u rezultatima prikazujemo upotpunjenu rasprostranjenost vrste *S. pedo* u Hrvatskoj. Također dajemo i podatke o ekologiji, terenska opažanja i raspravu o stanišnim preferencijama ove vrste.

Ključne riječi: ravnokrilci, grabežljivi konjici, konjici, građanska znanost, Kalnik, fauna, partenogeneza, Natura 2000 vrsta

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INTRODUCTION

Predatory katydids of the subfamily Saginae are represented by six species in Europe (Cigliano *et al.*, 2022). Two of them can be found in Croatia: the more common and relatively widely distributed *Saga pedo* (Pallas, 1771), and probably *Saga natoliae* Serville, 1838 reported from the very south of the country by Adamović (1964) - a finding in need of confirmation (Skejo *et al.*, 2018). They are the largest species of Orthoptera in Europe, with individuals of *S. pedo* reaching 75 mm in body length (*S. natoliae* is even larger) (Lemonnier-Darcemont *et al.*, 2016), placing it among the largest insects in Croatia.

The habitat of *S. pedo* in Croatia has been considered to be associated with localities affected by the Mediterranean climate, as its known distribution encompasses only the coastal area of the Mediterranean region and a few islands within it, along with some rare findings at higher altitudes on Mt Učka, Mt Velika Kapela, Mt Velebit, Mt Dinara, and Mt Sniježnica (Krauss, 1879; Bucchich, 1886; Pungur, 1899; Padewieth, 1900; Werner, 1905; Karny, 1907; Kuthy, 1908; Ramme, 1951; Us, 1964; Tvrtković, 1982; Schuster *et al.*, 1998; Bellmann, 2006; Skejo & Rebrina, 2013; Rebrina *et al.*, 2015; Puskás *et al.*, 2018; Skejo *et al.*, 2018; Rebrina & Tvrtković, 2019), landscapes dominated by karst topography (Croatian Geological Survey, 2009). The species inhabits well-preserved open habitats with few or no chemical inputs from agriculture, ranging from dry grasslands, over maquis, to forest edges, and even vineyards and similar cultivated areas, up to altitudes of 1750 m a.s.l. (Lemonnier-Darcemont *et al.*, 2016; Anselmo, 2019). The research methods recommended by Lemonnier-Darcemont *et al.* (2016) for estimating species abundance in a given area are the linear transect and the biocenometer.

As its common name suggests, animals of this species are obligate predators that feed on other insects, Orthoptera likely being its main prey (Anselmo, 2019). However, observation of an *S. pedo* nymph feeding on nectar was made by Peter F. McGrath (2020), indicating that this species could be opportunistic to some extent in its feeding habits, at least in some stages of development. *Saga pedo* is an interesting species when it comes to its genetics and reproduction. It has a pentaploid karyotype and reproduces by thelytoky (parthenogenesis in which only females are produced from unfertilized eggs), which likely enabled the species to be distributed over and colonize such a wide distribution range, especially when compared to its sexed congeners (Dutrillaux *et al.*, 2009). Historical records and descriptions of *S. pedo* males do exist (e. g. in Padewieth, 1900; Ramme, 1951, Baur *et al.*, 2006; photographs of male available at Orthoptera.ch (2023)) but are questioned by Lemonnier-Darcemont *et al.* (2016). Recent studies proved the hybridization of *S. pedo* with other congeners in captivity, making this an interesting subject for future research (Lemonnier-Darcemont & Darcemont 2007).

Even though *S. pedo* can be found across Europe and parts of western Asia (Cigliano *et al.*, 2022; introduction to the USA reported by Cantrall, 1972), it is not a common species due to its low population density and cryptic behavior (Holuša *et al.*, 2013; Lemonnier-Darcemont *et al.*, 2016, Anselmo, 2022). *Saga pedo* is the only species of Orthoptera strictly protected by law in Croatia (NN 144/13, 73/16) and is listed in Natura 2000 Annex IV of the Habitats Directive. By IUCN criteria it is globally assessed as a vulnerable (VU) species (in need of assessment update) and as least concern (LC) in Europe, with trends of decreasing population sizes and population fragmentation being the main threats for the species (Baillie & Groombridge, 1996; Hochkirch *et al.*, 2016).

This paper aims to gather all available records of *S. pedo* in Croatia, including literature data, citizen science observations and new unpublished records, with the goal of providing an updated account of the distribution of the species in the country. Habitat preference is gathered from localities with confirmed species presence.

MATERIAL AND METHODS

Institutional abbreviations used in this paper:

HPM—Croatian Natural History Museum, Zagreb, Croatia;

PMF—University of Zagreb, Faculty of Science, Department of Biology, Entomology Collection, Zagreb, Croatia;

HNHM—Hungarian Natural History Museum, Budapest, Hungary;

NHMW—Natural History Museum, Vienna, Austria;

cGS—collection of Gergely Szövényi.

Museum specimens deposited in the Croatian Natural History Museum (HPM) were examined by Fran Rebrina and Josip Skejo. Field observations made by the authors were collected independently, through an extended period of fieldwork in Croatia not specifically focused on *S. pedo*. Specimens collected during fieldwork by Maks Deranja, Maja Mihaljević, Marko Pavlović, and Karmela Adžić (2020–2021) are deposited in the PMF collection (research permit ID: UP/I-612-07/20-33/27, 515-05-2-1-20-2; UP/I-612-07/21-48/70, 517-10). Specimen identification follows the species' original description (Pallas, 1771) and *Saga* Charpentier, 1825 species key provided by Lemonnier-Darcemont *et al.* (2016).

Additionally, social media platforms were examined for citizen science observations, namely (1) iNaturalist (www.inaturalist.org) by filtering observations of the species in the country with research grade, all observations confirmed by the authors; (2) Observation.org was examined by the authors, only observations supported by specimen photographs were considered, excluding duplicate observations; (3) Facebook group "Koji je ovo pauk/kukac?" (eng. "What spider/insect is this?") where an observation of *S. pedo* made by Kristina Kirin was uploaded, other observations from Facebook are not included in the paper due to technical issues connected to linking references from the platform (links sometimes change with updates causing old ones to become inaccessible); (4) Biologer.hr observations of *S. pedo* confirmed as valid observations on the platform and by the authors; and (5) other citizen science sources—public forum (akvarij.net) and local online news portal (tportal.hr)—with species records gathered individually by the authors.

All observations collected are shown on a map made in QGIS version 3.28.1-Firenze to visualize the species' distribution in Croatia (Fig. 1). The map of biogeographical regions was downloaded from European Environment Agency (EEA, 2016). Habitat photographs were taken by the authors during their individual field researches (Fig. 2). Altogether 94 observations of *S. pedo* are reported for Croatia in this paper: 35 gathered from literature data, 41 new records (author's observations and other unpublished records, including specimens from HPM), and 18 citizen science observations (Tab. 1, Fig. 1). All the observations were annotated with the altitude of the locality.

Tab. 1. List of all available records of *Saga pedo* (Pallas, 1771) in Croatia. Table includes literature data, citizen science observations, and new records (author's observations and other unpublished records, including specimens from HPM). Table includes date of observation (= date); name of observer; locality of observation (including height above mean sea level); latitude (= LAT) and longitude (= LON); basis of record (= B) including human observations (O), photography (P), and collected specimens (S); and observation reference and/or validators (= REF/VAL). Coordinates for localities with imprecise information in their reference are indicated by asterisks (*), uncertain year of observation by square brackets ([]), and if information is unknown a question mark is given (?).

DATE	OBSERVER	LOCALITY	LAT	LON	B	REF/VAL
LITERATURE						
[1853]	Mann, J.	*Rijeka (= Fiume), 36 m a.s.l.	45.329819	14.442323	S	Krauss 1879, NHMW
1874, 1877 Jul, Aug	Krauss, H.A.	*Cres Isl, Martinšćica (= Martinschiza), 9 m a.s.l.	44.820525	14.350851	O	Krauss 1879
1874, 1877 Jul, Aug	Krauss, H.A.	*Bakar (= Buccari), 202 m a.s.l.	45.301136	14.553225	O	Krauss 1879
[1879] Jul, Aug	Krauss, H.A.	*Pula–Medulin (= near San Giovanni, Pola–Medolino), 12 m a.s.l.	44.861399	13.869602	O	Krauss 1879
[1879] Jul, Aug	Krauss, H.A.	*Krk Isl (= Veglia), 131 m a.s.l.	45.065002	14.622281	O	Krauss 1879
[1879] Jul, Aug	Krauss, H.A.	*Lošinj Isl (= Lussin), 144 m a.s.l.	44.680646	14.370282	O	Krauss 1879
[1885] Jun	Bucchich, G. (= Bučić)	*Korčula Isl (= Curzola), 213 m a.s.l.	42.940394	16.912958	O	Bucchich 1886
[1899]	Pungur, J.	*Rijeka (= Fiume), 36 m a.s.l.	45.329819	14.442323	S	Pungur 1899, HNHM
[1899]	Pungur, J.	*Senj (= Zengg), 14 m a.s.l.	44.988245	14.903822	S	Pungur 1899, HNHM
1895–1898	Padewieth, M. (= Franjo Dobijaš)	*Novi Vinodolski (= Novi), 36 m a.s.l.	45.128680	14.791270		Padewieth 1900, Ramme 1951
1895–1898	Padewieth, M.	*Senj, 14 m a.s.l.	44.988245	14.903822		Padewieth 1900, Ramme 1951
1900 Aug 9	Padewieth, M.	*Klarićevac, 629 m a.s.l.	45.022510	14.921108	O	Padewieth 1900
1895–1898	Padewieth, M.	*Senj–Sv. Križ, 252 m a.s.l.	44.980416	14.941477		Padewieth 1900
1895–1898	Padewieth, M.	*Sv. Juraj, 20 m a.s.l.	44.927745	14.920596		Padewieth 1900
1895–1898	Padewieth, M.	*Jablanac, 12 m a.s.l.	44.706558	14.898001		Padewieth 1900
[?]	Brunner, C.	*Lošinj Isl, Mali Lošinj, 21 m a.s.l.	44.531156	14.471699		Ramme 1951, Werner 1905
[?]	Werner, F.	*Pelješac (= Sabioncello), 362 m a.s.l.	42.941462	17.388763		Werner 1905
[?]	Werner, F.	*Sinj, 325 m a.s.l.	43.702860	16.637501		Werner 1905
[?]	Werner, FG.	*Pula (= Pola), 3 m a.s.l.	44.867949	13.850561		Werner 1905
[?]	Karny, H.	*Učka (= Mte. Maggiore), 843 m a.s.l.	45.253643	14.198026		Karny 1907

Tab. 1. Continued

DATE	OBSERVER	LOCALITY	LAT	LON	B	REF/VAL
LITERATURE						
1906 Jul	Horváth	*Novi Vinodolski (= Novi), 36 m a.s.l.	45.128680	14.791270	S	Kuthy 1908, Puskás, Nagy, & Szövényi 2018, HNHM
1963 Jul 4	Us, P.A.	*Cres Isl, Osor, 105 m a.s.l.	44.856922	14.397575	O	Us 1964
1963 Jul 15	Us, P.A.	*Lošinj Ils, near Osor, 1 m a.s.l.	44.692867	14.391621	O	Us 1964
[1982]	Šipoš, V.	*Velebit Mt, Babrovača, 950 m a.s.l.	44.705466	14.959309	S, P	HPM, Tvrtković 1982
1997 Jun 3	[?]	*Cres Isl, Merag–Sv. Vid, 262 m a.s.l.	44.970905	14.447273	O	Schuster *et al.*, 1998
199 Jun 4, 6	[?]	*Cres Isl, Srem, Kapelle and W Ort, 146 m a.s.l.	44.750241	14.442616	O,P	Schuster *et al.*, 1998
1988 Aug 9	Bellman, H.	*Istra, Marčana, 161 m a.s.l.	44.956505	13.955276	O	Bellman 2006
2012 Aug 7	Rebrina, F.	Dinara Mt, near Duler, 1200 m a.s.l.	44.082389	16.358723	S	Skejo & Rebrina 2013
2012 Aug 3	Zadravec, M., Hlavati, D. *et al.*	Dinara Mt, Velika Previja, 1250 m a.s.l.	44.078696	16.359267	O	Rebrina, Skejo, & Tvrtković 2015
2011 Sep 9	Tvrtković, N., M. Vuković	Dinara Mt, SW from Pitomi vrh peak, 1293 m a.s.l.	44.081881	16.350987	P	Rebrina, Skejo, & Tvrtković 2015
2011 Jul 18	Szövényi, G.	Velebit Mt, Upper Libinje, 900–1000 m a.s.l.	44.311	15.562	S	Puskás, Nagy, & Szövényi 2018, No.68: 1♂ [cGS]
2011 Jun 26	Halpern, B.	Velebit Mt, Libinje, 850 m a.s.l.	44.2963	15.5595	S	Puskás, Nagy, & Szövényi 2018, No.69: 1♂ [cGS]
1965 Sep 5–10	J. Fernbach	*Krk Isl (= Krk sziget), Dobrinj, 206 m a.s.l.	45.128856	14.603700	S	Puskás, Nagy, & Szövényi 2018, HNHM
2006 Jun 3	Tvrtković, N.	*Sniježnica Mt, Kuna Konavonska, 700 m a.s.l.	42.559249	18.362224	P	Rebrina, & Tvrtković 2019
2018 Aug 20	Rebrina, F.	Sniježnica Mt, Sv. Ilija peak, 1230 m a.s.l.	42.573996	18.351740	P	Rebrina, & Tvrtković 2019
NEW RECORDS						
1976	Perović, F.	*Istra, Vozilići, 85 m a.s.l.	45.157421	14.163135	S	HPM
1976	Perović, F. & Tvrtković, N.	*Istra, Brseč - Golovik, 226 m a.s.l.	45.190894	14.225697	S	HPM
1976	Vukušić, A.	*Velebit Mt, Gornja Klada, 350 m a.s.l.	44.806677	14.900825	S	HPM
1995 Jun	Tvrtković, N. & Vuković, M.	*Velebit Mt, Sv. Juraj (= Jurjevo) - Oltari, 600 m a.s.l.	44.897695	14.958724	O	authors
2004 Oct 9	Lisičić, D.	Prodol, 394 m a.s.l.	45.280599	14.241467	P	Jelić, D.

Tab. 1. Continued

DATE	OBSERVER	LOCALITY	LAT	LON	B	REF/VAL
NEW RECORDS						
2004	Schweiger, M.	Krk Isl, E from Stara Baška, 56 m a.s.l.	44.972563	14.759419	P	Jelić, D.
2004	Schweiger, M.	Krk Isl, W plateau, 384 m a.s.l.	44.994657	14.739174	P	Jelić, D.
2006 Jul 31	Kirin, T.	Brgudac, 747 m a.s.l.	45.380726	14.14079	P	Jelić, D.
2006 Sep 9	Kip, S.	*Istra, Skitača, 418 m a.s.l.	44.982486	14.144825	P	Tvrtković, N.
2006	Jelić, D.	Brač Isl, above Pučišć, 220 m a.s.l.	43.334999	16.699346	S	PMF
2008 Jul 15	Velan, S	*Hvar Isl, 129 m a.s.l.	43.154165	16.652716	P	Jelić, D.
2008 Aug	Schweiger, M.	Krk Isl, 193 m a.s.l.	45.039002	14.644376	P	Jelić, D.
2008	Peranić, I.	Velebit Mt, Krasno, 833 m a.s.l.	44.825069	15.048564	P	Jelić, D.
2008	Peranić, I.	*Kamešnica Mt, 1000 m a.s.l.	43.734481	16.795780	P	Jelić, D.
2009 Aug	Schweiger, M.	Pag Isl, 11 m a.s.l.	44.32046	15.205832	P	Jelić, D.
2009 Aug	Schweiger, M.	Pag Isl, 18 m a.s.l.	44.392396	15.110841	P	Jelić, D.
2010 Jul	Schweiger, M.	Pakoštane, 34 m a.s.l.	43.932185	15.484713	P	Jelić, D.
2010 Aug 17	Jelić, D.	Velebit Mt, Veliki Štirovac, 1180 m a.s.l.	44.324566	15.556824	O	observer
2010 Sep 15	Jelić, D.	Velebit Mt, Veliki Štirovac, 1100 m a.s.l.	44.326356	15.555223	O	observer
2013 Aug 2	Čupić, I. & Rebrina, F.	*Cres Isl, Predošćica, 370 m a.s.l.	45.041887	14.371625	S	observers
2014 Aug 1–2	Tvrtković, N. & Skejo, J.	Troglav Mt, Vrdovo, E from Bitelić mountain lodge, 995 m a.s.l.	43.859678	16.643566	O	observers
2015 Jul 22	Skejo, J., Tvrtković, N., & Hristov, H.G.	Mala Kapela Mt, Ljubovo, 930 m a.s.l.	44.647414	15.569586	O	observers
2018 Jul 14	Barosso, F.	Kistanje, 240 m a.s.l.	43.99030	15.97802	O	Jelić, D.
2018 Jul 23	Jelić, D.	Miljacka, 251 m a.s.l.	44.00401	16.03773	O	observer
2020 Jun 12	Adžić, K., Deranja, M., & Pavlović, M.	Vis Isl, Tito's caves, 452 m a.s.l.	43.037457	16.121906	P	observers
2020 Jun 12	Adžić, K., Deranja, M., & Pavlović, M.	Vis Isl, near Sv. Duh church, 541 m a.s.l.	43.035388	16.115129	P	observers
2020 Jun 18	Adžić, K., Deranja, M., & Pavlović, M.	Korčula Isl, Kom, 512 m a.s.l.	42.945768	17.005849	P	observers
2020 Jul 31	Adžić, K., Deranja, M., & Pavlović, M.	Vis Isl, Tito's caves, 452 m a.s.l.	43.037457	16.121906	P, S	PMF

Tab. 1. Continued

DATE	OBSERVER	LOCALITY	LAT	LON	B	REF/VAL
NEW RECORDS						
2021 Jun 9	Mihaljević, M., Deranja, M., & Adžić, K.	Kornat Isl, above Vrulje, 150 m a.s.l.	43.816225	15.313115	P, S	PMF
2021 Jul 15–19	Tumbrinck, J., Tumbrinck, J., Tumbrinck, K., & Skejo, J.	Troglav Mt, Velika Greda, 802 m a.s.l.	43.823635	16.649487	O	observers
2021 Aug 6	Horvat, L.	Žuljane, 200 m a.s.l.	42.885833	17.456367	P	http://orthoptera.speciesfile.org/Common/specimen/ShowSpecimen.aspx?Router=NewPage
2021 Aug 11	Medak, K. & Baćić, J.	Istra, Ližnjan, 5 m a.s.l.	44.823472	13.976722	P	Rebrina, F.
2021 Aug	Jelić, D.	Lisac Mt, 1151 m a.s.l.	44.31585	16.07645	O	observer
2021	Jelić, D.	Lička Plješevica Mt, Mazin, 1106 m a.s.l.	44.40043	16.03611	O	observer
2022 Jun 7	Mihaljević, M., Deranja, M., & Adžić, K.	S slopes of Obruč Mt, 568 m a.s.l.	45.414890	14.485134	P	observers
2022 Jul 1–5	Deranja, M., Jelić, D., Adžić, K., & Maksimović, I.	Puljane, 244 m a.s.l.	43.989918	16.046206	P	observers
2022 Jul 2	Jelić, D.	Miljacka, 252 m a.s.l.	44.00406	16.03812	O	observers
2022 Jul	Phangurha, J.	Puljane, 245 m a.s.l.	43.988058	16.046737	P	authors
2022 Aug 21	Crnković, R.	Turanj, Crni Krug viewpoint, 123 m a.s.l.	43.9800	15.4168	O	authors
[?]	Budinski, I.	*Učka Mt, 843 m a.s.l.	45.253643	14.198026	P	Tvrtković, N.
[?]	Budinski, I.	*Ćićarija Mt, Brest, 679 m a.s.l.	45.455416	14.005314	P	Tvrtković, N.
CITIZEN SCIENCE						
2008 Jul 15		*Rijeka, 324 m a.s.l.	45.329819	14.442323	P	forum akvarij.net
2013 Sep	Perko, I.	*Istra, Donišnica, 9 m a.s.l.	45.066364	14.057554	O	https://www.tportal.hr/vijesti/clanak/krakata-zvijer-iz-raske-doline-20130909
2014 May 28	Benschop, A.	near Novi Vinodolski, 357 m a.s.l.	45.1479	14.8239	P	https://observation.org/observation/85840049/
2015 Jul 27	Meier, N.R.	Istra, near Čabrunići, 232 m a.s.l.	45.0254	13.8744	O	https://observation.org/observation/116627805/

Tab. 1. Continued

DATE	OBSERVER	LOCALITY	LAT	LON	B	REF/VAL
CITIZEN SCIENCE						
2016 Jun 24	Rutschmann, F.	Istra, Koromačno, 436 m a.s.l.	44.9874	14.1393	O	https://observation.org/observation/120338598/
2017 Apr 15	Mandl, N.	Krk Isl, Baška, 355 m a.s.l.	44.983122	14.765049	P	https://www.inaturalist.org/observations/95910891
2017 Jul 3	mnauky	Krk Isl, Baška, 329 m a.s.l.	44.966532	14.718821	P	https://www.inaturalist.org/observations/22768676
2018 May 21	Koren, T.	Vis Isl, 426 m a.s.l.	43.0539	16.1113	P	Biologer.hr
2018 Jun 23	Sehnal, M.	Cres Isl, 501 m a.s.l.	45.064872	14.359251	P	https://www.inaturalist.org/observations/47968533
2018 Jul 10	Koren, T.	Udbina, 890 m a.s.l.	44.5598	15.8300	P	Biologer.hr
2018 Jul 11	Tavić, A.	Istra, Koromačno, 24 m a.s.l.	44.968947	14.100027	P	https://www.inaturalist.org/observations/14255607
2018 Aug 25	Verheij, M.G.W.	Brištane, 145 m a.s.l.	43.886919	15.981717	P	https://www.inaturalist.org/observations/99215683
2019 Aug 4	Dender, D.	Cres Isl, near Vransko lake, 318 m a.s.l.	44.831427	14.370483	P	Biologer.hr
2020 May 21	Kanski, D.	Split, 74 m a.s.l.	43.515367	16.456675	P	https://www.inaturalist.org/observations/47592889
2021 Sep 23	potoftea	*surroundings of Šibenik (locality obscured), 280 m a.s.l.	43.927381	16.103769	P	https://www.inaturalist.org/observations/95938497
2022 Jul 8	Puille, L.	Velika Kapela Mt, Breze, 705 m a.s.l.	45.164606	14.849224	P	https://www.inaturalist.org/observations/132656329
2022 Aug 21	Kirin, K.	Kalnik Mt, 591 m a.s.l.	46.13135	16.454917	P	https://www.facebook.com/groups/pauci.i.kukci/posts/3126161577633108/
2022 Sep 15	Kranželić, D.	SW of Knin, 325 m a.s.l.	44.005346	16.160219	P	Biologer.hr

RESULTS

The observation of *S. pedo* at the highest altitude is from Mt Dinara, SW from Pitomi vrh at 1293 m a.s.l. (Rebrina *et al.*, 2015). In the northern part of the distribution, the highest altitude confirmed observation is 747 m a.s.l. on Mt Učka, Brgudac (obs. Jelić, D.).

Observed habitats of *S. pedo* in Croatia vary depending on the biogeographical region, but generally are open rocky grasslands (Fig. 2) or garrigue and maquis habitats with little to no forest coverage. Although generally considered to be limited to areas with a Mediterranean climate, there are findings of *S. pedo* relatively deep in the Dinaric karst mountain chains (Ljubovo, Mt Mala Kapela, Udbina, Mt Lička Plješivica) and one very isolated observation in the Peripannonian area of the Continental region, on an isolated karst mountain. All the observations, except for Mt Kalnik, are within the Dinaric karst area.

From the authors' fieldwork observations, the species was more common earlier in the season in the period of May - June, while specimens are still nymphs and are active during the daytime. Later in the season the species turns to crepuscular or nocturnal activity, correlating to a rise in daily temperatures. Specimens are adults in this period, utilizing shrubbery in their habitat to find cover, which makes them very hard to spot. During this period most success at finding specimens was observed during the evening, and specimens were especially easy to spot and confirm on roads (obs. Jelić, Deranja & Adžić in Puljane; Tvrtković & Perović in Istria; Tvrtković & Vuković above Sv. Juraj, Mt Velebit). Adults were also observed ovipositing in this period, during night surveys in July in Puljane. The species is confirmed only on larger islands (Fig. 1), the smallest being Kornat with an area of 32.44 km^2.

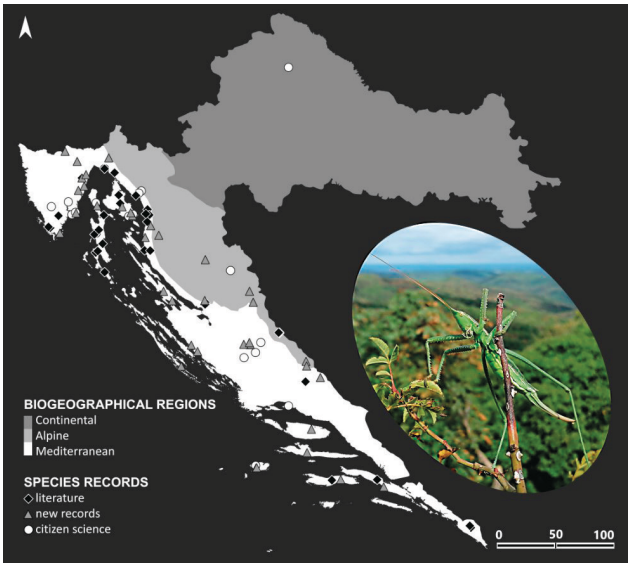

Fig. 1. Findings of *Saga pedo* (Pallas, 1771) in Croatia, divided according to the basis of the record into literature data (all published records), citizen science, and new records (unpublished records and observations made by the authors). Biogeographical region boundaries are indicated on the map, following EEA (2016) geospatial data. North is indicated by the arrow; scale bar is in kilometers. The photograph of the *S. pedo* specimen is from Mt Kalnik in the Continental region, the most isolated find of the species in Croatia (photograph: Kristina Kirin).

Our records of the *S. pedo* were not necessarily restricted to habitats rich in other Orthoptera species, though some localities like Ljubovo—where it was found among 38 other species—do represent such habitats. The largest number of observed (but undocumented) specimens was reported by Padewieth (1900) who saw around 100 specimens running from an outbreak of wildfire in Klaićevac. He also reports being rather unsuccessful at capturing them on the occasion, catching only about 30 specimens.

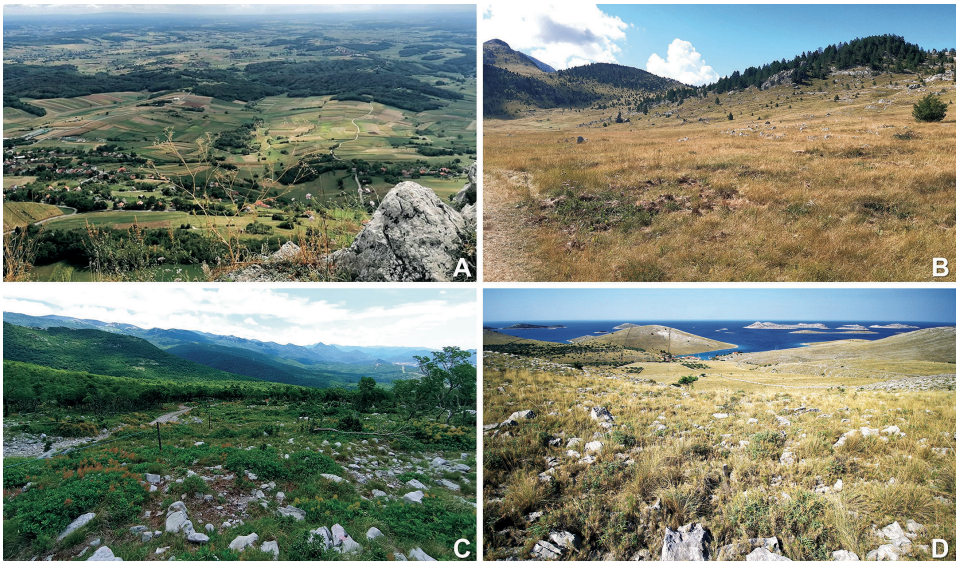

Fig. 2. Different habitats where *Saga pedo* (Pallas, 1771) is found in Croatia. Photographs represent habitats on the mainland, view from Mt Kalnik in the Pannonian lowland (**A**; photographed by K. Kirin); Duler meadow on Mt Dinara on the border of the Alpine region (**B**; photographed by N. Kasalo); on the S slopes of Mt Obruč in the Mediterranean region (**C**; photographed by M. Deranja); and habitat on islands of the Mediterranean region on Kornat (**D**; photographed by K. Adžić).

Based on the recent findings, the currently known *S. pedo* population is divided into minimally 11 disjunct subpopulations within Croatia: mainland population, Mt Kalnik isolated population, and island populations (isolated on nine islands). The species has severely fragmented populations in Europe (Hochkirch *et al.*, 2016) which poses additional constraints on its adaptive potential.

DISCUSSION

Only in the recent decade has it become standard to give precise localities including coordinates of the observation. This makes certain old records unreliable, e. g. a finding from Mt Učka (= Mte. Maggiore) made by Karny (1907) or findings attributed to the largest nearby city, e. g. Rijeka (= Fiume) listed as a locality by Pungur (1899), both examples covering large potential areas of observation.

The finding of *S. pedo* from Mt Kalnik needs further research. As observation was uploaded to Facebook by Kristina Kirin at the end of the species' activity period, it was not possible to organize additional fieldwork at the locality within the same season.

The possibility of *S. pedo* being accidentally introduced is unlikely given the fact that the finding site is far from inhabited areas, which is why this observation is considered valid. The southern side of Mt Kalnik has xerothermic limestone rocky meadows bordered with shrubs of pubescent oak (*Quercus pubescens* Willd.) and flowering ash (*Fraxinus ornus* L.) woodland (Vukelić *et al.*, 2008), probably similar to habitats on Villany Hills in Southern Hungary and to some other isolated European northwestern locations of *S. pedo* populations (Nagy & Nagy, 2000; Kenyeres *et al.*, 2002; Krištin & Kańuch, 2007). We consider it an isolated subpopulation.

From our fieldwork observations it can be inferred that *S. pedo* is not restricted to habitats rich in other Orthoptera as main food resources. In fact, on islands such as Kornat, the species was found exclusively in habitats with a low Orthoptera diversity (Fig. 2C), but was absent from microhabitats preferred by most other species of Orthoptera, e. g. in proximity to water sources. *Saga pedo* was only confirmed on larger islands in Croatia (Tab. 1, Fig. 1) and it is possible that habitat size and quality are the main factors determining habitat selection in the species. The species was not found on islands smaller than 30 km^2, which indicates that it cannot survive in smaller isolated areas with constant natural or human habitat change pressure without potential microrefugia, but this cannot be confirmed without additional research.

Our findings on the change in activity period during the day and night correspond to the records of Lemonnier-Darcemont *et al.* (2016). We estimated population size in the area with the linear transect method, 10, 20, and 40 m long transects, at 6 localities near Puljane in July. We consider the method to be unsuccessful in our case as we were able to detect only a single specimen, despite conducting transect reearch during the evening when specimens are easier to detect. *Saga pedo* individuals were seen in relatively large numbers on the road during the night, which is recognized as a potential roadkill threat to the species by Lemonnier-Darcemont *et al.* (2016). It remains unclear why are there no more records of *S. pedo* roadkill in areas where the species is found. Given the unique morphological appearance of *S. pedo* it can easily be identified among other Orthoptera roadkill in Croatia (authors' observations), making this an important source of information which should be employed in future research aiming to detect the species' presence on new localities.

Future research on *S. pedo* in Croatia should be focused on discovering new localities where the species is present or confirming its presence in underexplored areas such as Mt Kalnik, Mt Dilj and Mt Papuk in the Peripannonian area, the southern slopes of Mt Mala Kapela in Lika region (officially named Alpine region), southern slopes in the middle parts of the Mt Velebit, inland Dalmatia, and the southernmost part of the country (see area without data Fig. 1). Additional research into the ecology of the species is needed for a better understanding of its behavior, threats, and population trends.

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AUTHORS' CONTRIBUTION

The idea for the paper came from Karmela Adžić, Maks Deranja, Maja Mihaljević, and Josip Skejo. All the authors have contributed to the paper with their fieldwork observations and new records of *S. pedo*. The first version of the paper was written by Karmela Adžić and Maks Deranja. All the authors were included in the writing process and have contributed to the final version of the manuscript.

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