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First record of stone moroko (*Pseudorasbora parva*), an invasive alien fish species, in water bodies of urban green areas in Poland

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Abstract. Invasive alien species are currently a major ecological problem. One such species is stone moroko, *Pseudorasbora parva* (Gobionidae), which has only been found to date in natural or agricultural water bodies (lakes, rivers and streams, carp ponds). Therefore, the current study is the first description of stone moroko in urban green areas (Warsaw, Poland). The fish were caught with a hydrobiological net. Four catches were conducted in ponds located in Morskie Oko Park (pond 1) and the Saxon Garden (pond 2) – two in fall and two in the spring, while two spring catches were conducted in Dolinka Służewska Park (stream). The population in pond 2 apparently survived the winter, and the fish caught in June displayed visible signs of sexual dimorphism and were significantly larger (average body mass: 1648 ± 1123 mg; range: 460–6090 mg) than those caught in the pond in the two fall samplings (404 ± 122 mg; 154–729 mg). After recording substantial numbers of specimens in the fall, no fish were caught in pond 1 during either of the spring catches, while only a few moroko were caught in the stream in April (1212 ± 869 mg; 454–2901 mg) and none were caught in June. Throughout the study, 59 specimens were caught in pond 1, 74 in pond 2, and 7 in the stream.

Keywords: city parks, ichthyofauna, invasive species, overwintering, urban areas

In Poland, invasive alien species (IAS) of fishes are spreading at an alarming rate, threatening native populations in a variety of ways (i.e., through competition within trophic niches, predation of eggs/larvae, pathogen transmission) (Witkowski and Grabowska 2012). This is why they need to be monitored carefully, as such efforts may later permit assessing their influence on local ecosystems and, consequently, to allow proper countermeasures to be implemented. One such species is the stone moroko, *Pseudorasbora parva* (Temminck and Schlegel, 1842), which is a relatively diminutive (6–10 cm total length range) Asian gudgeon that originates from rather small overgrown water bodies (channels, pools, lakes) in Japan, Korea, Russia, Mongolia, and China (Pinder 2005, Czerniejewski et al. 2019). It is currently considered a pest species in Europe that is known to transfer infectious diseases (Kirczuk et al. 2021) and to significantly alter the natural food supply for other fish species (Musil et al. 2015). Reports of its presence in Polish waters are quite ambiguous, as Traczuk et al. (2024) identified stone moroko in

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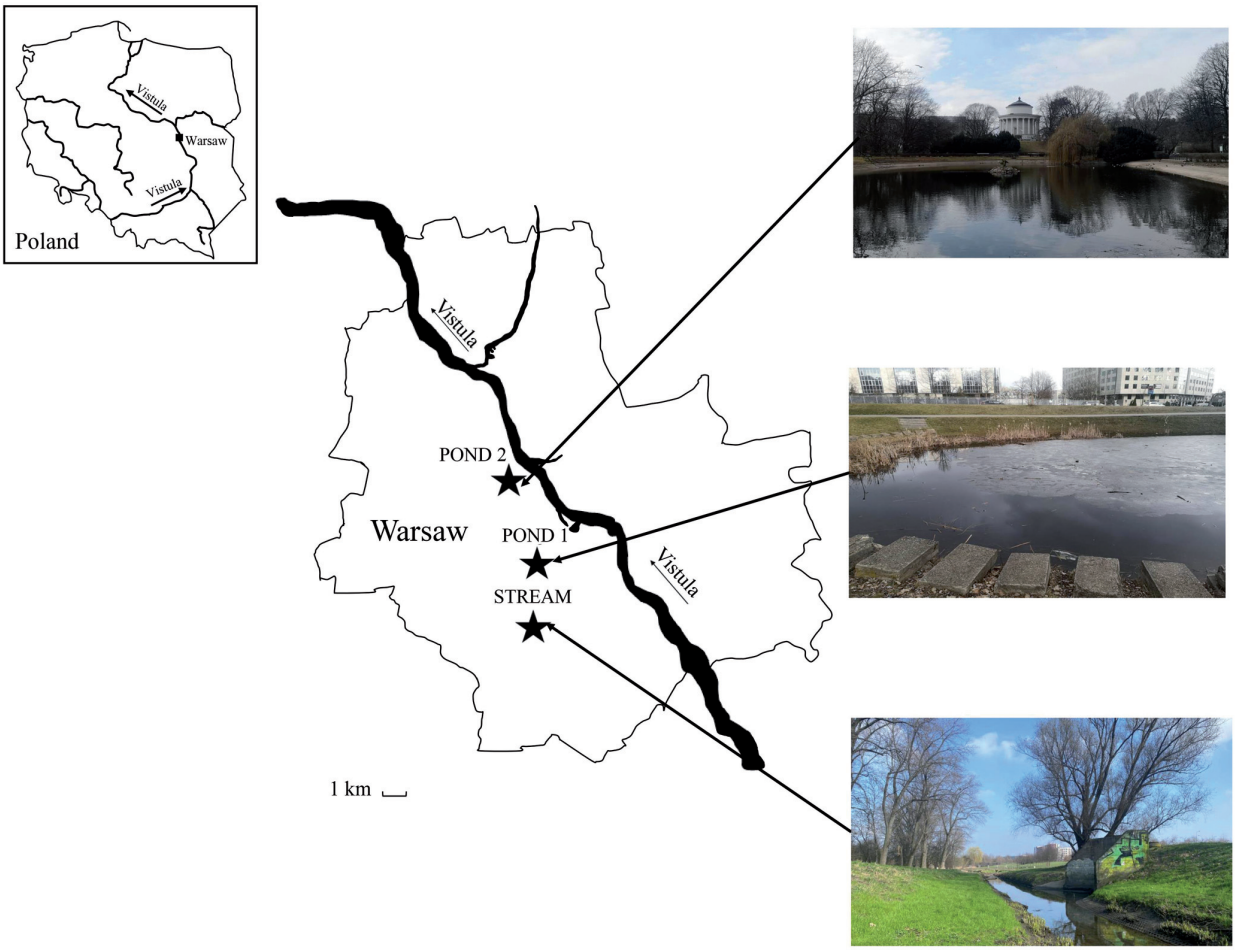

Figure 1. Locations of sampling stations in Warsaw: Morskie Oko Park (natural pond 1), Saxon Garden (artificial pond 2) and Dolinka Służewska Park (stream).

only two of 535 Polish lakes studied, while Szlakowski et al. (2019) recorded the occurrence of stone moroko at as many as 117 river sites (7% of the locations studied). Nevertheless, it has also been discovered in other natural water bodies (Czerniejewski et al. 2019), including reservoirs heated by power plant water outflow (Kapusta et al. 2008, 2014, Záhorská et al. 2013, 2014) and carp ponds and adjacent watercourses (Witkowski 2009, Bojarski et al. 2022). However, no scientific reports have surfaced to date regarding its presence in urban green areas. The present study reports the first such occurrences, with the identification of stone moroko in three different locations in Warsaw, Poland from October 2020 to June 2021.

The field study was conducted in selected water bodies of three municipal green spaces in Warsaw, Poland: Morskie Oko Park (pond 1), the Saxon Garden (pond 2), and Dolinka Służewska Park (stream). The sites were selected based on reports from members of the public. The fish were caught along the entire edges of ponds 1 and 2. A spot near a rainwater drain was selected as the catch site on the stream as indicated by reports from members of the public. The locations are presented in Fig. 1, and the exact coordinates are given in Table 1. Pond 1 (area ~700 m^2, depth ~2 m) is a semi-natural pond with a muddy bottom and minor surface water inflows. It is connected by groundwater with the nearby Łazienki Park. Pond 2 is an entirely artificial, concrete reservoir (area ~2500 m^2, depth ~1.5 m) without any aquatic vegetation or surface water inflow, but it has both inlet and outlet pipes that are used only when it is being emptied to be cleaned and then refilled. The

Table 1
Number and body parameters of stone moroko caught, including information about the locations sampled (coordinates, water parameters) at different sampling times

		Body parameters (mean ± standard deviation)				Water parameters		
Date of catch	N	BW (mg)	TL (mm)	BH (mm)	CF	Temperature (°C)	pH	Conductivity (μS cm^{-1})
Morskie Oko Park (POND 1); pond coordinates: 52°12'27.3"N, 21°01'38.3"E								
22.10.2020*	34	702.0^{AB} ± 260.2 (252-1403; 638)	46.80^{AB} ± 5.46 (34.55-57.58; 46.18)	7.80^{B} ± 1.07 (5.35-10.05; 7.93)	0.66^{BC} ± 0.06 (0.50-0.80; 0.64)	10.9	8.57	463
14.12.2020	25	757.7^{AB} ± 430.5 (373-1994; 575)	45.92^{ABC} ± 7.76 (37.47-65.80; 42.57)	8.12^{B} ± 1.56 (6.12-11.71; 7.61)	0.72^{AB} ± 0.06 (0.63-0.84; 0.72)	2.5	8.38	397
24.03.2021	0	–	–	–	–	3.6	6.72	272
06.06.2021**	0	–	–	–	–	24.4	8.50	688
Saxon Garden (POND 2); pond coordinates: 52°14'28.5"N, 21°00'30.3"E								
22.10.2020	36	389.2^{C} ± 124.5 (154-729; 377)	39.81^{C} ± 4.19 (27.94-48.01; 40.58)	6.34^{C} ± 0.73 (4.53-8.44; 6.26)	0.60^{C} ± 0.07 (0.45-0.75; 0.59)	11.6	9.53	444
14.12.2020	12	449.3^{BC} ± 110.7 (302-703; 447)	40.83^{BC} ± 3.71 (33.52-44.95; 41.94)	6.76^{BC} ± 0.75 (5.34-7.94; 6.72)	0.65^{BC} ± 0.08 (0.56-0.80; 0.63)	2.0	10.02	420
24.03.2021	5	547.6^{ABC} ± 223.4 (332-900; 534)	45.14^{ABC} ± 5.54 (37.93-53.05; 45.55)	7.48^{ABC} ± 1.05 (6.45-8.83; 7.03)	0.58^{BC} ± 0.10 (0.43-0.70; 0.60)	5.0	10.46	397
06.06.2021	21	1647.6^{A} ± 1122.7 (460-6090; 1500)	51.64^{A} ± 7.10 (38.01-67.90; 52.60)	12.06^{A} ± 1.89 (7.87-17.78; 12.00)	1.08^{A} ± 0.22 (0.84-1.95; 1.02)	24.8	10.20	484
	12♂	1469.2^{ABC} ± 394.5 (460-1860; 1540)	51.98^{ABC} ± 5.24 (38.01-57.99; 53.47)	11.61^{ABC} ± 1.35 (7.87-13.00; 11.97)	1.01^{ABC} ± 0.09 (0.84-1.14; 1.02)			
	9♀	1885.6^{ABC} ± 1681.1 (600-6090; 1360)	51.18^{ABC} ± 9.37 (38.37-67.90; 49.06)	12.66^{ABC} ± 2.39 (9.73-17.78; 13.06)	1.18^{ABC} ± 0.30 (0.97-1.94; 1.09)			
Dolinka Służewska Park (STREAM); rainwater inflow coordinates: 52°10'04.7"N, 21°01'55.5"E								
12.04.2021***	7	1212.3^{AB} ± 869.0 (454-2901; 938)	53.14^{ABC} ± 10.06 (40.23-69.16; 49.06)	9.85^{AB} ± 2.62 (7.28-14.44; 8.83)	0.71^{ABC} ± 0.11 (0.59-0.88; 0.70)	9.3	8.50	753
06.06.2021	0	–	–	–	–	21.3	8.65	1036

BW – body weight, TL – total length, BH – body height, CF – condition factor. Other fish species caught (and released): * 2 × *Carassius carassius*, 3 × *Tinca tinca*; ** 5 × *Carassius carassius*; *** 6 × *Alburnus alburnus*, 5 × *Pungitius puntigius*, 3 × *Gasetrosteus aculeatus*. Body parameter values are means ± standard deviation and values in parentheses are ranges and medians. Different superscript letters indicate statistically significant differences among groups ($P < 0.05$)

outflows from this pond lead to rainwater runoff connected to other reservoirs in Warsaw. Lastly, Służewiecki Stream flows eastward from Szczęśliwice through Służewiec and Wilanów and then flows into Lake Wilanowskie. The stream possesses a few smaller tributaries and also drains rainwater. Its depth at one particular rainwater inflow in Dolinka Służewiecka Park, which was the third area studied, was 0.5–1.5 m with a sandy bottom free of aquatic vegetation.

On October 22 and December 14, 2020, two fall catches were conducted to assess the presence of stone moroko in ponds 1 and 2. Due to the presence of a thick layer of ice from January to February 2021, no winter catches were performed in these two locations until March 24, 2021. It was at that time that new information was obtained about the presence of stone moroko at a specific location in the stream, which was first investigated on April 12, 2021. Finally, one late spring catch was conducted at all three locations on June 6, 2021.

The fish were caught with a hydrobiological net (Caperlan PRF 240 R) with a mesh diameter of 2 mm. Specimens of native fish species caught were released immediately, while stone moroko specimens were euthanized with 0.05% MS-222 (Sigma-Aldrich, Germany), then weighed (body weight, BW; ± 0.1 mg) and measured (total length,

TL, and body height, BH; ± 0.01 mm). Fulton's condition factor (CF) was calculated with the following formula: $CF = 100 \times BM \times TL^{-3}$. Basic water parameters (temperature, pH, conductivity) were also recorded during the catches with an electronic device (GroLine Waterproof pH Meter; Hanna Instruments, Poland). Morphometric data was analyzed statistically (Statistica 13, StatSoft, Poland) with the non-parametric Kruskal-Wallis test to check for significant differences ($P < 0.05$) among fish groups caught in the water bodies studied at different times.

A total of 140 stone moroko were caught in the water bodies studied (59 specimens in pond 1, 74 in pond 2, and 7 in the stream) along with a few specimens of crucian carp, *Carassius carassius* (L.), and tench, *Tinca tinca* (L.), in pond 1 and specimens of bleak, *Alburnus alburnus* (L.), ninespine stickleback, *Pungitius pungitius* (L.), and three-spined stickleback, *Gasterosteus aculeatus* L., in the stream. No fishes other than stone moroko were caught in pond 2. Exactly half of all the specimens sampled were caught in October in ponds 1 and 2. The BW (range: 252–1403 mg), TL (34.55–57.57 mm), and BH (5.35–10.05 mm) of stone moroko caught in pond 1 were all significantly higher than those from pond 2 (154–729 mg, 27.94–48.01 mm, 4.53–8.44 mm, respectively; Table 1). However, the body parameters of the fish caught in the two ponds during the second catch (December) were not statistically different from each other or from those in either of the October catches, although, notably, a few much larger fish were caught in pond 1 (Table 1). After the winter, dead stone moroko were noted in pond 1, while a few living specimens were observed in pond 2 (332–900 mg) and in the stream (454–2901 mg), and their parameters did not differ from the parameters of the fish caught in December in either of the ponds (most likely due to the low sample number, which affected the statistical analysis). In June, stone moroko was only caught in pond 2, but these fish had clear external features of sexual dimorphism and their four body parameters (BW: 460–6090 mg, TL: 38.01–67.90 mm, BH: 7.87–17.78 mm, CF: 0.84–1.95) were all statistically significantly higher than those of specimens caught before the winter in that same pond (Table 1). Finally, the pH values recorded in pond 2 throughout the study were notably higher (+1.5) in comparison with those in pond 1 and the stream.

Stone moroko possesses traits that determine its profound invasive potential, such as high environmental plasticity (Kapusta et al. 2014, Záhorská et al. 2014) and outstanding reproductive potential (Záhorská et al. 2013, Kirczuk et al. 2021). Therefore, several cautious conclusions can be drawn from the results of the current study. The size and notable sexual dimorphism of stone moroko specimens caught in June in pond 2 suggested that this type of urban environment (high pH) was more favorable for the species, while much smaller and less alkaline pond 1 may not facilitate its survival over winter, although other factors (elimination by birds or anglers) should not be excluded. Interestingly, there was a total absence of vegetation in pond 2, which is unlike the densely overgrown habitats usually preferred by stone moroko (Kapusta et al. 2008). Nevertheless, not only did this population survive the winter, it also apparently achieved sexual maturity quickly, with males displaying visible coloration. Even though the number of fish sampled was low, the size of the females caught in June (mean BM of 1.89 ± 1.68 g) was nearly identical to that of females from the spawning population in the Wardynka River (1.85 ± 1.66 g), which was studied in-depth by Kirczuk et al. (2021), and somewhat comparable, although smaller, to various yearly catches of spawning females (means ranging 2.42–6.38 g) from the heated Lake Licheńskie (Záhorská et al. 2014). Furthermore, the fish were of a comparable size to those from the population in the Ciemięga River (2.2 ± 1.3 g) (Rechulicz 2019). However, it is currently unknown whether or not these fish and/or their progeny survive the emptying of this pond and establish themselves downstream from the water outflow.

Meanwhile, due to limited data, it is uncertain whether or not flowing waters, such as the stream, could be favorable habitats for the establishment of stone moroko populations, although the native fish species noted may certainly present at least some level of competition in pond 1 (Rechulicz 2019).

Notably, the origin of stone moroko is unknown, but since this particular location is directly adjacent to rainwater runoff, which means multiple invasion routes are possible. In contrast, the two ponds studied did not have distinct water inflows (in the case of pond 1 there is only groundwater and minor surface waters, while in pond 2 there is a closed drain pipe), which implies that some sort of carriers contributed to the appearance of stone moroko in them. Unfortunately, the question of whether they were introduced deliberately by irresponsible aquarists (Witkowski and Grabowska 2012) or randomly through egg dispersal by birds (Hirsch et al. 2018) will likely remain unanswered.

In summary, stone moroko seems able to adapt to conditions in urban water bodies in Poland and is likely to continue expanding its range if no action is taken, especially since climate change is predicted to further improve already favorable conditions for its establishment (Artaev 2023). Thus, raising public awareness in highly urbanized areas is essential for the early detection and control of this IAS, as it would be feasible to introduce control measures, such as regular environmental monitoring or inspections of urban sewage systems. Remedial actions are necessary for invasive alien species because they negatively affect biodiversity by displacing native species and causing environmental transformation.

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