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Aquatic hibernation of Fire Salamanders (*Salamandra salamandra*): A mini review and new observations

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Amphibians are globally endangered, and one of the most important factors contributing to their decline is habitat loss due to human activity (e.g., Schmidt et al. 2002, Cushman 2006). Breeding habitats such as ponds are usually well known at least for common species of amphibians and terrestrial habitat preferences are also a subject of investigation (e.g., Babik & Rafinski 2001, Romano et al. 2018). However, knowledge about amphibian wintering sites, even of well-studied European species, is still greatly limited (Denton & Beebee 1993, Balogová & Uhrin 2014, Balogová et al. 2017). Therefore, even discrete reports are important to identify their preferences regarding this part of their lifecycle.

The European Fire Salamander (*Salamandra salamandra*) is a widely distributed species of tailed amphibian in Southern, Western and Central Europe (e.g., Speybroeck et al. 2016). In Poland, it reaches its northeastern border of distribution (Speybroeck et al. 2016). Generally, Fire Salamanders are highly terrestrial amphibians – apart from females giving birth to fully-developed larvae in brooks and pools, adult individuals of this species are known to have a strictly terrestrial lifestyle (Juszczyk 1987, Zakrzewski 2007). Due to their advanced adaptations to that effect, Fire Salamanders are less capable of handling the challenges of aquatic environments. While they can swim through shallow, stagnant water, they are not able to dive and usually drown in deep water (Juszczyk 1987). Terrestriality also extends to their wintering behaviour, and the most common hibernation sites include most often burrows excavated either by themselves or by rodents, cavities under roots of trees and rocks, inside dead wood and leaf litter (Juszczyk 1987, Schlüpmann 2008), in caves and artificial galleries (Schlüpmann 2008, Balogová & Uhrin 2014, Balogová et al. 2017), or shelters under man-made structures and debris (Schlüpmann 2008). Often these winter quarters are rather wet, sometimes even partially submerged, or suffused by a more or less constant trickle of water, assuring the high levels of humidity Fire Salamanders require for their survival. It is for these reasons that Fire Salamanders are commonly observed wintering in old mines, galleries and caves near bodies of stagnant water (Feldmann 1967, Kabisch 1971, Baumgart 1981, Schlüpmann 2008, Balogová & Uhrin 2014), and sometimes these pools are used as breeding habitats into which the females release their larvae (Kabisch 1971, Schlüpmann 2008, Manenti et al. 2009, Balogová & Uhrin 2014, Balogová et al. 2017). However, adult individuals have never been observed swimming or diving in these habitats (Kabisch 1971, Balogová & Uhrin 2014) and seemed to actively avoid the water (Feldmann 1967, Baumgart 1981).

At the end of November 2016, I received information about adult Fire Salamanders being observed inside a spring pool located northeast of the town of Nowy Targ in the Gorce Mountains (part of the Carpathian Mountains), southern Poland. The spring in question is located on a south-facing slope in a deep valley at 870 m above sea level, on a privately owned clearing in mixed spruce-fir-beech forest. It has been modified to enhance water collection – the banks were reinforced with stones and the whole spring is enclosed in a wood and polystyrene shed to provide access to it during winter (Fig. 1C). A plastic tube was installed under one of the banks in order to channel water out of the spring pool. This site has been known to me as a Fire Salamander breeding site for 20 years (B. Zając, unpubl. data). Since female Fire Salamanders in the Polish Carpathians usually give birth to larvae between April and June (Zakrzewski 2007) I decided to investigate this unusual allegation further. During the 2016/2017 winter season I visited the site three times (on 28 November, 30 December and on 9 January). I used a thermometer (±1.5°C accuracy) to measure air and water temperature. During the first visit, I observed one adult Fire Salamander in the

spring pool (at an air temperature of 0°C with snowfall). The salamander was moving inside the pool with its head protruding from the water surface, but it did not try to leave it. During the second visit, with temperatures around -5°C and a thick snow cover (around 0.5 m), I observed two adult individuals in the water in a crevice under the stony bank. I also observed overwintering Fire Salamander larvae presumably from the same year. The adult individuals were mostly stationary and exhibited only little movement, while the larvae were actively swimming in the pool. During the third visit, the air temperature measured -12.0°C. No adult fire salamanders were observed in the visible part of the pool, but at least six individuals were located in a crevice, four of them with their heads protrud-

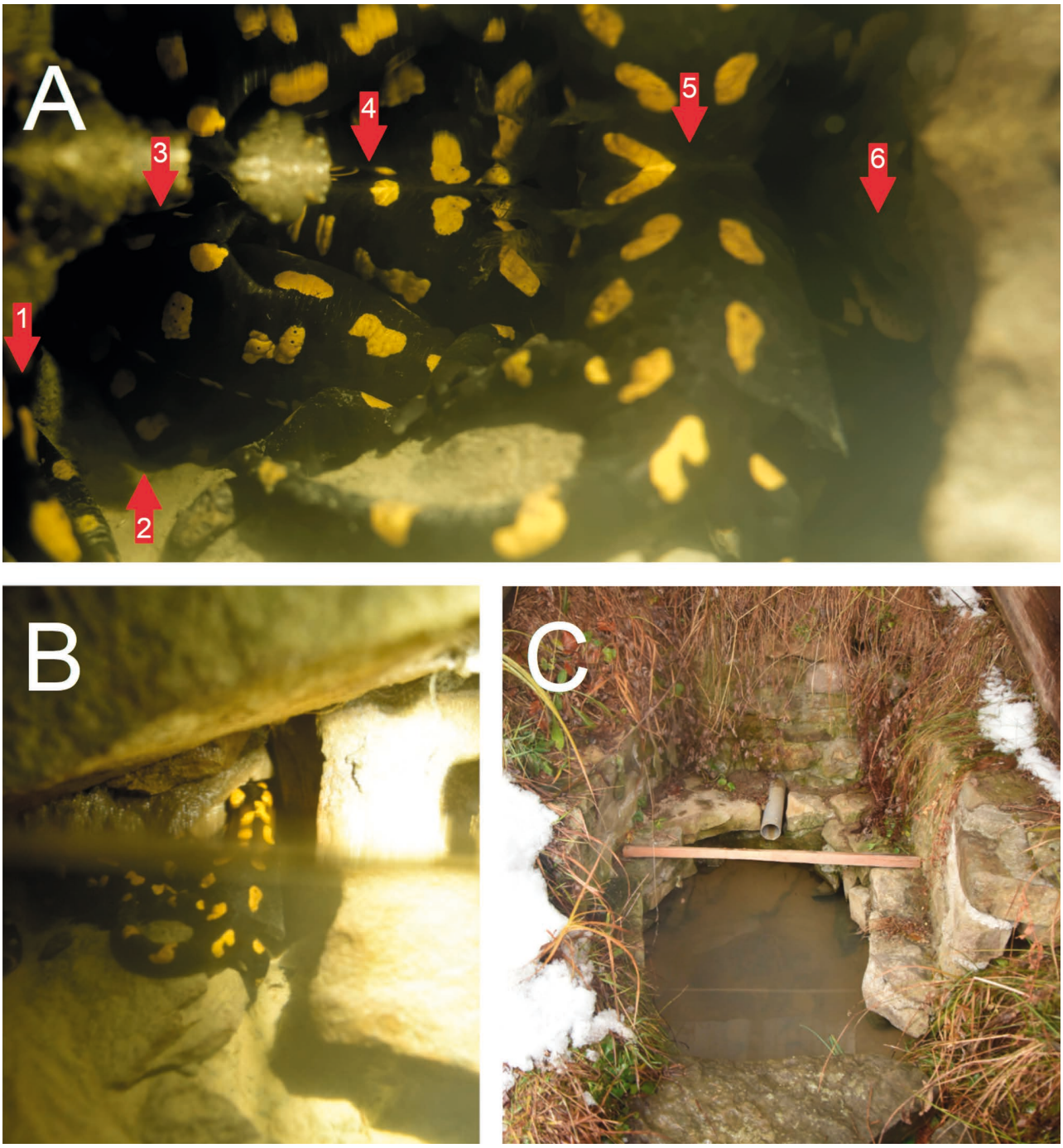

Figure 1. Adult Fire Salamanders, *Salamandra s. salamandra*, overwintering in a spring: (A) underwater view; arrows point out individuals; (B) one of the individuals protruding its head above the water; (C) overwintering habitat. The crevice where overwintering individuals were observed is located under the stony edge, partially obscured by a wooden board.

ing from the water surface (Figs 1A, B). Few larval salamanders were observed in the visible part of the pool. The air temperature was -5.1°C and the water temperature in the spring was 4.6°C. The adult and larval salamanders were immobile.

To the best of my knowledge, this is the first substantiated record of aquatically hibernating Fire Salamanders since Fachbach (1972) reported finding at least thirteen adult Fire Salamanders underwater in January in a spring at Glashütten, 1200 m above sea level, Koralpe, Lavanttal Alps, Austria. Here, twelve salamanders had been noted by the landowners when they fetched water from the spring and another salamander was captured at the bottom of an approximately 1-m deep spring box and transported to the laboratory (Fachbach 1972). After performing a series of trials with the wild-caught and additional salamanders in water tanks, Fachbach concluded that adult Fire Salamanders are able to persist underwater and breathe buccopharyngeally in water with a temperature of 12°C or lower, always sitting at the bottom of the tank. Müller & Hellmich (1935) and Hellmich (1936) also mentioned underwater behaviour in the case of adult *S. s. almanzoris* in the Laguna Grande de Gredos, Spain (ca. 2027 m a.s.l.). However, they did not indicate whether their observations referred to wintering individuals. The behaviour of their salamanders was also different from that reported by Fachbach (1972) in that they swam from the bottom to the surface of the lake for breathing and back to the bottom, in a fashion similar to European newts (e.g. *Lissotriton* spp.) (Hellmich 1936, Fachbach 1972). Another incidental observation of Fire Salamanders wintering underwater came from Podhale, a submontane region in the foothills of the Gorce Mountains in Poland, from where Świerad (2003) recorded several adult salamanders wintering in flooded burrows, however he interpreted it as an accidental effect of the water level rising in the ponds nearby rather than a behavioural expression. Unfortunately, Świerad (2003) did not provide any further details regarding the location and time of these observations.

It is not clear what caused the instance of overwintering in an aquatic habitat described here. The salamanders may have been trapped in the spring and forced to overwinter there, but this seems unlikely, as the walls of the spring are scalable and riddled with crevices, and there is also a plastic tube channelling water out of the pool. All these features allow small animals to exit the pool. It also seems unlikely that so many individuals may have gathered in this aquatic habitat in November, as most of the female salamanders in Poland give birth in spring (April–June, Juszczyk 1987). According to the owners of the installation, Fire Salamanders have actually been observed in this springduring winter for many years, and also before the structural changes to enhance water collection were made (M. & F. Cyrwus pers. comm.). This suggests that it may not be an incidental occurrence, but rather a case of local behavioural plasticity of Fire Salamanders. Indeed, unlike many other places, no mines, galleries or caves are present in the surrounding areas. As the local forests are mostly privately owned, the amount of woody debris is very low and, consequently, not many overwintering quarters are available. Also, local climatic conditions may be harsher than usual, as the Gorce Mountains are situated near the northern range limits of this species, and the altitude of the site is also near its upper range limit (usually up to 1000 m above sea level in Poland, Juszczyk 1987, Świerad 2003). In these adverse conditions , springs may offer a preferable overwintering habitat, as their comparatively constant water temperatures prevent them and their immediate surroundings from freezing. However, further visits in December 2017 and 2018 did not yield further information, as no other overwintering Fire Salamanders were detected. This may have been an outcome of changed conditions at the spring, as its water level was significantly lower in 2017 than in the year before. On the other hand, in 2018, the water level had returned to normal, but no Fire Salamanders were observed either; only one individual was found after the winter, in a water-filled barrel that had been sunk into the ground a few metres downhill from the spring. This individual was sitting motionless on the bottom of the barrel and after being moved to the surface and started to move, it was released into the forest (M. & F. Cyrwus pers. comm.).

No additional observations of Fire Salamanders overwintering in aquatic habitats have since been made. Further investigation is needed to confirm whether this phenomenon occurs regularly or if it is a local phenomenon. Since springs are relatively common in this area, searches for other potential wintering sites should be conducted. This may however turn out to be difficult, as non-invasive observations at unmodified springs may be quite impossible, especially under snow cover.

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