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Titel | Title

Population dynamics of the European green toad (Bufotes viridis) in an urban environment (Simmeringer Haide, Austria)

verfasst von | submitted by

Marie-Luise Wedenig BSc

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Abstract

The European green toad, *Bufotes viridis,* is often found in urban areas. This pioneer species is highly adaptable and quickly colonizes newly created habitats, e.g. artificially created ponds or gravel pits. Despite its adaptable way of life, the populations of *B. viridis* are declining throughout Austria. This capture-recapture study investigates a population of *B. viridis* in Simmeringer Haide (Vienna, Austria) and compares the results with data from three previous years.

Two artificial breeding sites were investigated, which are typical locations for *B. viridis*: a concrete pool and an artificial rainwater collection basin. Data were collected between March and August 2023, on average twice per week. Capture-recapture data were collected by taking pictures of the toads' individual dorsal pattern and individuals were identified using the semi-automated pattern recognition software IBEIS.

The snout-vent length and body mass of each individual were recorded to calculate the scaled mass index in order to assess the body condition of the population. The exact location and sex were recorded as well. For the analysis of estimated population size, detection probability and apparent survival probability, the Jolly-Seber-Schwarz-Arnason open population model was used.

In this study 650 individuals were captured during the breeding season in 2023, including 581 males and 69 females. A total of 550 toads (85%) were caught for the first time, 100 toads (15%) were recaptures from the previous years. The population size was estimated to be 1883 individuals (CI: 1574-2254) and the calculated scaled mass index was 21.8 (CI: 0.68). The apparent survival probability from 2022 to 2023 was 49% for females (CI: 30-68) and 41% for males (CI: 34-49).

Compared to previous years, the apparent survival probability and the estimated population size increased. Continued long-term monitoring and the expansion of surveys to additional breeding sites and terrestrial habitats are recommended to create a further data basis for the future protection of the green toad and to prevent the disappearance of further green toad populations in Vienna's urban area.

Keywords:
capture-recapture, *Bufotes viridis*, urban area, pattern recognition, population studies, herpetology

Zusammenfassung

Die Wechselkröte, *Bufotes viridis,* ist häufig in städtischen Gebieten anzutreffen. Diese Pionierart ist sehr anpassungsfähig und besiedelt rasch neu geschaffene Lebensräume, z.B. künstlich angelegte Teiche oder Schottergruben. Trotz ihrer anpassungsfähigen Lebensweise ist der Bestand von *B. viridis* in ganz Österreich rückläufig. Die vorliegende Fang-Wiederfang Studie befasst sich mit einer Population von *B. viridis* in der Simmeringer Haide (Wien, Österreich) und vergleicht diese mit den Daten der drei vorangegangenen Jahre.

Es wurden zwei Laichgewässer untersucht, die typische Aufenthaltsorte der Kulturfolgerin *B. viridis* darstellen: ein Betonbecken und ein künstliches Regenwasser-Auffangbecken. Die Daten wurden zwischen März und August 2023 gesammelt, in der Regel zweimal pro Woche. Zur Erfassung der Fang-Wiederfang-Daten wurden Fotos der individuellen Rückenmuster der Kröten aufgenommen und anschließend mit der Mustererkennungs-software IBEIS identifiziert.

Die Körperlänge (snout-vent length) und das Gewicht der Individuen wurden erfasst, um den scaled mass index (SMI) zu berechnen und dadurch mehr über den körperlichen Zustand der Population zu erfahren. Auch der genaue Standort und das Geschlecht wurden dokumentiert. Für die Analyse der geschätzten Populationsgröße, der Wiederfang-wahrscheinlichkeit und der scheinbaren Überlebenswahrscheinlichkeit wurde das offene Populationsmodell nach Jolly-Seber-Schwarz-Arnason verwendet.

In dieser Studie wurden während der Brutsaison 2023 insgesamt 650 Individuen gefangen, davon 581 Männchen und 69 Weibchen. Insgesamt 550 Kröten (85%) wurden zum ersten Mal gefangen, 100 Kröten (15%) waren Wiederfänge aus den Vorjahren. Die Populationsgröße wurde auf 1883 Individuen (KI: 1574-2254) geschätzt und der berechnete SMI betrug 21,8 (KI: 0,68). Die scheinbare Überlebenswahrscheinlichkeit von 2022 auf 2023 betrug 49% für die Weibchen (KI: 30-68) und 41% für die Männchen (KI: 34-49).

Im Vergleich zu den Vorjahren haben sowohl die Überlebenswahrscheinlichkeit als auch die geschätzte Populationsgröße zugenommen. Ein fortgesetztes Langzeitmonitoring und die Ausweitung des Untersuchungsgebietes auf weitere Brutgewässer und terrestrische Lebensräume werden empfohlen, um eine zusätzliche Datengrundlage für den zukünftigen Schutz der Wechselkröte zu schaffen und das Verschwinden weiterer Wechselkröten-Populationen im Wiener Stadtgebiet zu verhindern.

Stichworte:
Fang-Wiederfang, *Bufotes viridis*, Wechselkröte, Stadtgebiet, Mustererkennung, Populationsstudie, Herpetologie

1. Introduction

According to the IUCN Red List, amphibians are the most threatened class of vertebrates worldwide: over 40% of all amphibian species are threatened and the status keeps getting worse (Luedtke et al., 2023). In Austria 21 different amphibian species can be found. All of them are listed on the IUCN Red List of Threatened Species and twelve of them are currently threatened in their populations (Gollmann, 2007).

As threats increase, amphibian populations decline. Natural habitats are being destroyed and reduced in size and cities continue to expand. In urban environments amphibians face particular challenges: habitat fragmentation, isolation, habitat degradation (Kovács & Sas, 2010; Catenazzi, 2015), an increase in impervious surfaces, increased drainage and the loss of natural water bodies are a few of the pressures that amphibians have to deal with. These dangers considerably restrict the ability of amphibians to disperse in urban and suburban landscapes. Due to their special habitat requirements, amphibians are dependent on both aquatic and terrestrial habitats. As amphibians are not particularly mobile, a fragmented and urbanized landscape with physical barriers between breeding sites and terrestrial habitats is a major challenge (Hamer & McDonnell, 2008; Vargová et al., 2023).

This study focuses on *Bufotes viridis* Laurenti, 1768, the European green toad. As a pioneer species, the green toad is highly migratory and has the ability to adapt quickly to new environmental conditions. These attributes allow it to survive in secondary habitats (Brandt & Feuerriegel, 2004). While its primary habitats, mainly steppes and wild floodplains, have been degraded in many regions, *B. viridis* is often found in urban areas (Landler et al., 2023; Vargová et al., 2023; Gruszka et al., 2024; Lemaire et al., 2025).

Bufotes viridis quickly colonizes newly created habitats, e.g. artificially created biotopes, liner pools, concrete pools or gravel ponds as spawning waters and compost heaps, ruins or plywood as hiding places during the day (Cabela et al., 2001; Indermaur et al., 2009). According to Staufer (2018) ruderal areas are also highly important for the survival of the green toad in urban areas. Despite its adaptability, the abundance of *B. viridis* is declining throughout Austria (Umweltdachverband, 2008). Due to the use of aquatic and terrestrial habitats, the green toad has complex habitat requirements. In order to get to their spawning waters or wintering grounds, they must frequently undertake migrations. In large cities such as Vienna, green toads encounter many barriers that make their migrations dangerous (Bülbül & Koç Gür, 2022). One of the most dangerous barriers for amphibians is road traffic — particularly at the beginning of the spawning season, many individuals die within a very short time when crossing roads due to traffic. To reduce the number of roadkills, e.g. speed limits can be set, warning signs and guidance systems can be erected along roads, or alternative spawning waters located in high-quality rural habitats can be provided (Staufer, 2018). Amphibian guidance systems and complete road closures are the most successful ways of preventing the death of green toads and other amphibians (Brzeziński et al., 2012; Rienesl, 2017).

In order to learn more about the causes of endangerment and the population status of green toads, regular population surveys are necessary. Population studies help to identify the causes of population declines and to assess the impact of conservation measures on population development (Sterrett et al., 2019). To find out more about the condition and status of individuals within a population, it is important to record body mass and size, in order to calculate the body condition. Body condition can provide information about an animal's nutritional status and energy storage. It can be used to draw conclusions about environmental and anthropogenic impacts on populations and provide information about habitat quality (Landler et al., 2022). Landler et al. (2022) developed a standardized method for analyzing the body condition of green toads, using the scaled mass index (SMI), which was proposed by Peig and Green (2010). As an important part of local biodiversity, the green toad not only fulfills a useful function in ecosystems as part of the food chain, but also plays a crucial role as an indicator of the natural state of its environment and of changes in its habitats (Schaub, 2012).

In Vienna, many populations of green toads have been documented and scientifically monitored at various locations for years (Rienesl, 2017; Sistani et al., 2021; Staufer et al., 2023). Formerly known distribution areas near the Wienerwald and densely developed areas in Floridsdorf, Brigittenau and Erdberg are now considered extinct. The main distribution area of the green toad in Vienna is in the north, northeast and southeast (Rienesl, 2021). The areas of Donaufeld, Rudolf-Bednar-Park (former Nordbahnhof) and Simmeringer Haide are currently well-studied areas with scientific monitoring (Landler, 2021).

The green toad population in the Simmeringer Haide is considered to be very large, but has already lost connectivity with other populations (Rienesl, 2021). Since 2016, Martina Staufer has been managing a local road protection project to rescue green toads from traffic and to document the road mortality of green toads in this heavily fragmented landscape (Staufer, 2022). Additional population studies have been conducted since 2020 as part of master's theses at the BOKU University. Apart from three road signs, there are currently no further conservation measures for this toad population (pers. obs.).

This master's thesis concentrates on the status and trends of the European green toad population at Simmeringer Haide. A focus of this study is how well green toads, as a pioneer species, cope with this urban environment and whether they manage to develop a stable population despite anthropogenic influence. Based on previous studies and master's theses (Hemmerich, 2022; Proksch 2022; Horvath, 2023), the collected data from 2023 were compared with the data from the three previous years (2020-2022).

The aim of this capture-recapture study was to provide additional data to support the future protection of the green toad in Vienna's urban area and to help prevent further population declines.

2. Materials and methods

2.1. Study species

The European green toad is characterized by its distinctive green and white spotted dorsal pattern (Figure 1). The average snout-vent length of adults is between 60 and 75 mm, whereby females are 5-10 mm larger than males. Adult males weigh between 20 and 40 g, adult females between 35 and 55 g (Günther & Podloucky, 1996).

Figure 1: Female and male green toad in mating position (amplexus) at Simmeringer Haide. Picture: Wedenig

From the end of March to July, *B. viridis* can be found at breeding waters. Good weather conditions for green toad activity are warm and humid days and nights - when temperatures continue to rise, the activity of the amphibians also increases and is particularly high on nights with temperatures above 15 °C (Staufer, 2018; Staufer, 2022). From dusk, males sit at the spawning waters and try to attract the females with their high-pitched trilling calls, which can be heard up to 500 m away (Rienesl, 2021). While females stay for a few days at breeding sites and leave immediately after spawning, males stay for an average of three weeks. After the breeding season, they return to their wintering grounds, where they hibernate from September onwards (Stöck et al., 2008; Rienesl, 2021).

The area of distribution of *B. viridis* extends from eastern France to south-west Asia and from southern Sweden to North Africa. In Austria *B. viridis* can be found in all federal states, with the exception of Vorarlberg, with a main occurrence in eastern Austria (Cabela et al., 2001; Rienesl, 2017). In Austria, the green toad is classified as 'vulnerable' (VU) (Gollmann, 2007) and listed in the Vienna Nature Conservation Ordinance as a species of priority importance and as a strictly protected species with habitat protection throughout the city (Wiener Naturschutzverordnung, 2024). As an Annex IV species of the Fauna-Flora-Habitats Directive, *B. viridis* is also considered a strictly protected and endangered species of community interest throughout the European Union (Council Directive 92/43/EEC, 1992).

2.2. Investigation site

The research area, Simmeringer Haide (Figure 2), is located in the 11th district of Vienna, Austria (48.169157, 16.447231, 150 m a.s.l.) (Staufer, 2018).

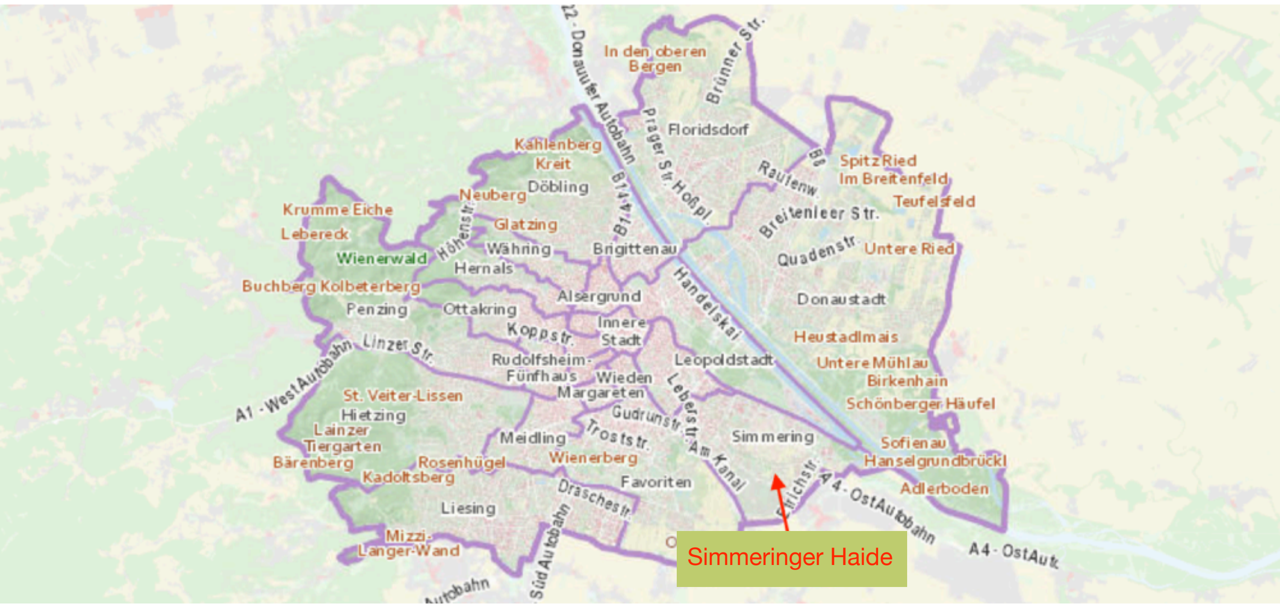


Figure 2: The research area Simmeringer Haide. (ViennaGIS 2023, edited)

Simmeringer Haide is a mixture of residential area, industrial area and greenhouse agriculture, which takes up the largest part of this region (Figure 3). The mainly pannonian-continental climate is characterized by strong temperature differences and summers with low precipitation. The study area contains several breeding sites for amphibians and in particular for *B. viridis*. This study concentrates on two artificial breeding sites, a concrete pool and a rainwater collection basin.

Figure 3: The research area Simmeringer Haide is characterized by greenhouse agriculture. Picture: Wedenig

The first breeding site used to be a compost dump and is named the concrete pool, because it is encased in concrete. It is about 160 square meters, has little vegetation and up to 20 cm water depth. The concrete pool borders to an agricultural field on one side and is limited by streets and a parking lot on the three other sides (Figure 4). The second breeding site is a rainwater collection basin with almost no vegetation and up to 2 m water depth. It is about 2800 square meters in size and surrounded by an earth wall that the toads must climb up to reach the water surface. The basin is framed by a small strip of gravel, which borders on greenhouses and a road (Figure 5).

Figure 4: The artificial concrete pool as breeding site for *B. viridis*. Picture: Wedenig

Figure 5: The rainwater collection basin as breeding site for *B. viridis*. Picture: Wedenig

The breeding waters are located at a distance of 230 m from each other and connected via a road. In order to record exactly where the individuals were found, a virtual grid was placed over a map section (Google Maps) of the study area. Each basin was divided into four sections (Figure 6).

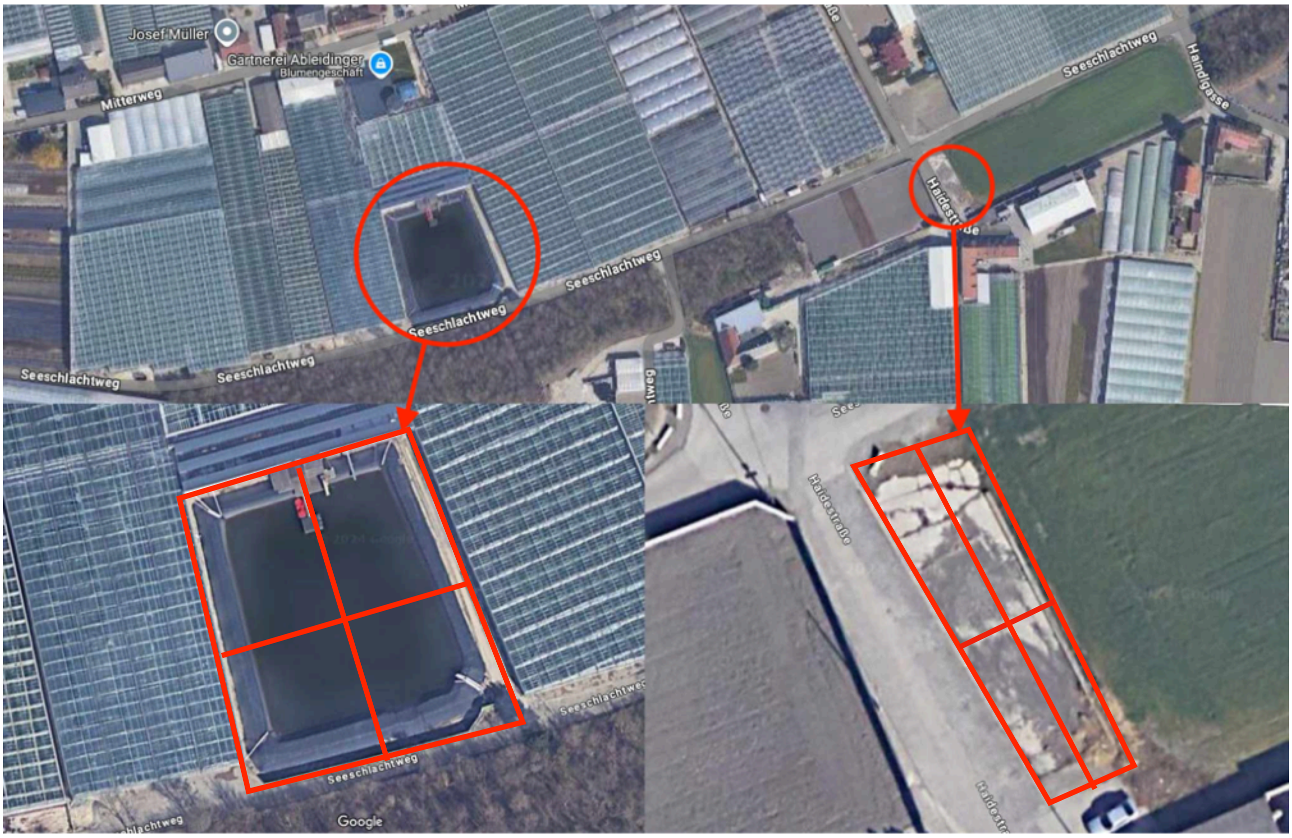


Figure 6: Overview of the study area and the two breeding sites. (Google Maps 2024, edited)

2.3. Data collection

The data collection took place during the breeding season in 2023 from 13 March to 10 August. The study area was visited on average two days a week. Data were collected on a total of 28 days, on four days I received support from fellow students who helped me as part of an internship. The days were selected according to the best weather conditions, i.e. precipitation during the day and warm nights (temperatures above 10 °C). Data recording began at dusk on each day and ended as soon as all observed toads at the breeding sites and the surrounding area had been recorded, which was usually around midnight.

For this capture-recapture study, adult individuals were caught by hand or with a landing net, weighed, measured (snout-vent length) and photographed to record the individual pattern of each toad. For the photographs, each toad was placed in a box with light grey background and extra light, the photographs were taken using a smartphone (Samsung Galaxy S21) (Figure 7). The mass was recorded in grams by using a digital scale (Brifit – KA25/UF200H) and the body length was determined in millimeters using a caliper. Juveniles and dead green toads were collected and recorded as well, if a pattern could still be recognized.

Figure 7: Photobox setup. Picture: Wedenig

In addition, the sex was identified, which can be determined based on body size, presence of red warts (females), brightness of the spot pattern, release calls (males) and the presence of the male's black nuptial pads on their thumb (Figure 8). Each documented green toad was given its own ID. The time and the location where it was found were also recorded. To avoid duplicate data recordings on one day, captured individuals remained in a container until all green toads from one breeding site had been documented (the duration was kept as short as possible). If pairs were found during amplexus they were photographed and immediately released without being measured and weighed (Figure 8).

Figure 8: f.l.t.r.: *Bufotes viridis*; female, male with black nuptial pads, pair in amplexus. Pictures: Wedenig

2.4. Data analysis

2.4.1. Pattern recognition of individuals

Based on their unique, green and white spotted pattern, specimens of *B. viridis* can be identified (Drechsler et al., 2015; Burgstaller et al., 2021; Gruszka et al., 2024). If photographed several times, they can not only be recognized between the different field days, but also over years. In order to process the large number of collected picture data, the pattern recognition software IBEIS, a successor version of HotSpotter, was used (Burgstaller et al., 2021). Before uploading the pictures on IBEIS, the photos were edited with the program Krita (Krita 5.1.5.). Blurred photos were sorted out, selected photos were cropped and rotated all to the same position and the background was cut. After editing, the photos were imported into IBEIS. The program displays image pairs with the highest matching scores, helping to decide whether an individual represents a first capture or a recapture (Figure 9). It also includes a function to recognize double captures on the same day. Each individual was assigned its own ID, a consecutive number since 2020 (starting with BV_SH_3667 in 2023). Despite the high accuracy of the program, the comparisons had to be checked again manually (the first 10 matches of each comparison were checked) and incorrect matches had to be corrected.

Figure 9: IBEIS photo comparison, a recapture was detected. Pictures: Wedenig

2.4.2. Population estimation and apparent survival probability

The data collected during the fieldwork were documented in Microsoft Excel (Excel Online). For the statistical capture-recapture analysis the openCR package (Efford, 2020) of the statistical program R was used (R Core Team, 2020). For estimated population size (Super N), detection probability (p) and apparent survival probability (phi), the Jolly-Seber-Schwarz-Arnason (JSSA) model (Schwarz & Arnason, 2013) was used, because it is an open population model which allows the modeling of gains and losses between sampling occasions.

The estimated population size was calculated for 2023 and compared with three previous years. Apparent survival probabilities were estimated for year-to-year intervals since 2020. Different models were evaluated and compared by using Akaike's Information Criterion (AIC) (Akaike, 2011). The best model with a dAIC value of 0 was used. Figures were created with Microsoft Excel 2025.

2.4.3. Scaled mass index (SMI)

To determine the condition of individuals, the scaled mass index (SMI) was used (Peig & Green, 2010). Landler et al. (2023) suggest using 3 as a scaling coefficient for calculating the SMI of *B. viridis* and so the following formula was applied:

$$SMI = m \times (60/L)^3$$

m is the individual mass in g, 60 is the reference length in mm, L is the individual SVL in mm and 3 is the scaling coefficient used for green toad populations.

3. Results

3.1. Total counts

From 13 March to 10 August, data were collected from 1019 toads, including males, females, juveniles and dead toads. After sorting out juveniles (SVL < 50 mm) and dead toads (2 recordings), 967 data recordings were left, of which 317 were recaptures during 2023. Therefore the picture comparison identified 650 individuals, including 581 males and 69 females. When collecting data throughout the year, peaks occurred on 17 April (140 toads), 19 April (115 toads) and 17 May (87 toads). Until the end of March and since the end of June, fewer than 20 toads were consistently found on each occasion (Figure 10).

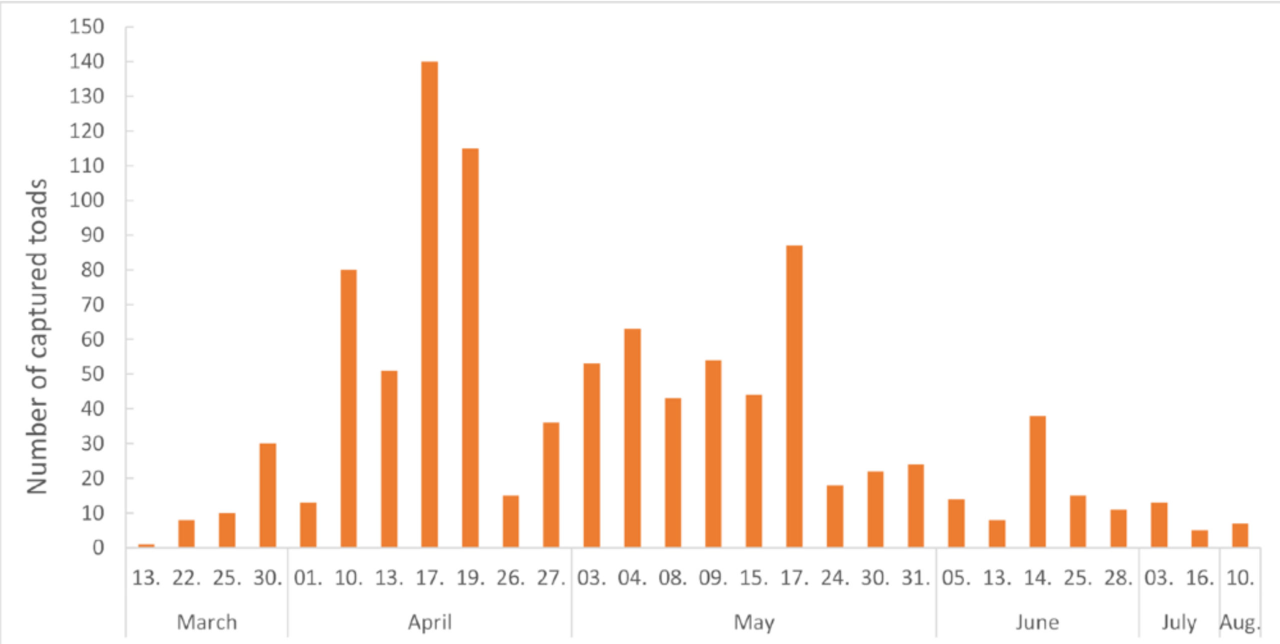


Figure 10: Number of captured toads at each field day during 2023.

3.2. Population estimation and apparent survival probability

The AIC model evaluation revealed two models with a dAIC value less than 2 (Table 1). The best model was used for the further results. Here the detection probability (p) and the apparent survival probability (phi) depended on time (non-linear time-dependent) and sex, the population size estimation (N) depended on time (Table 1).

Table 1: Model based AIC evaluation of the best 5 population models (p = detection probability, phi = apparent survival probability, N = population size estimation, t = non-linear time-dependent)

model	AIC	dAIC
p~t + sex phi~t + sex N~t	**32855.58**	**0**
p~t + sex phi~t N~t	**32856.19**	**0.524**
p~t + sex phi~t + sex N~t + sex	32855.58	2.000
p~t + sex phi~t N~t + sex	32856.19	2.524
p~t + sex phi~sex N~t	32905.27	49.516

The population size was estimated to be 1883 individuals (CI: 1574-2254) (Figure 11). The apparent survival probability from 2022 to 2023 was 49% for females (CI: 30-68) and 41% for males (CI: 34-49) (Figure 12). The detection probability in 2023 was 0.3% for females (CI: 0.2-0.5) and 3.3% for males (CI: 3.0-3.7) (Table A1).

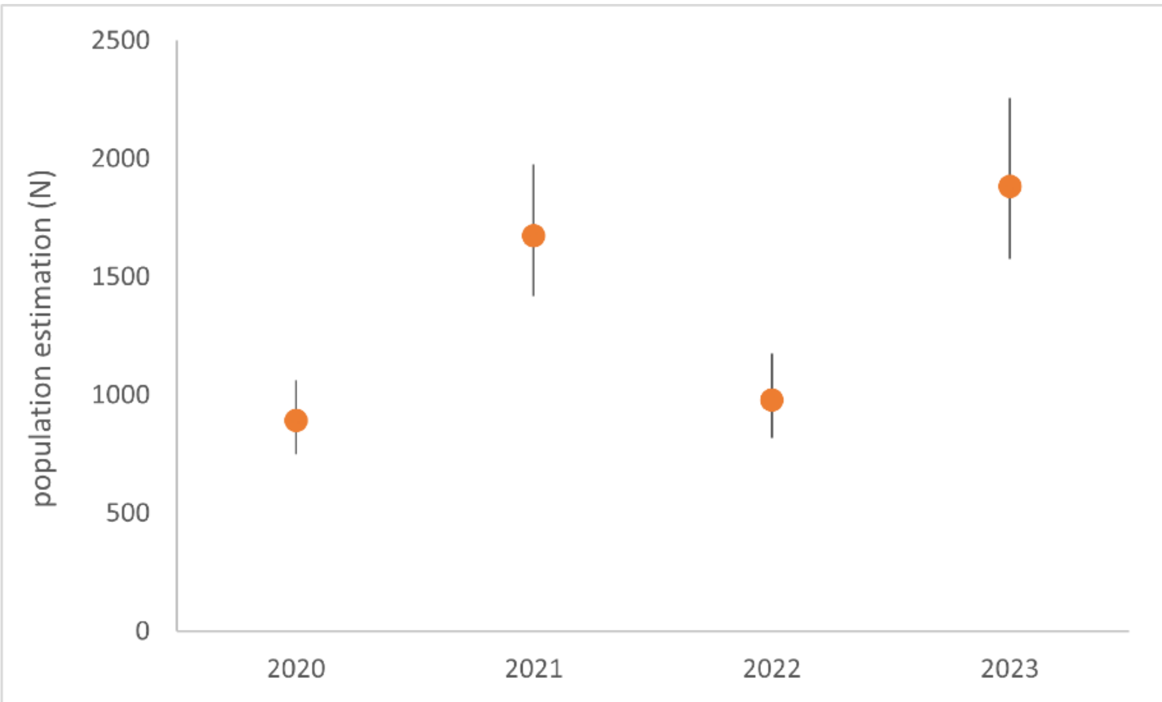


Figure 11: Population size estimation (N) compared to three previous years. Confidence intervals are shown as whiskers.

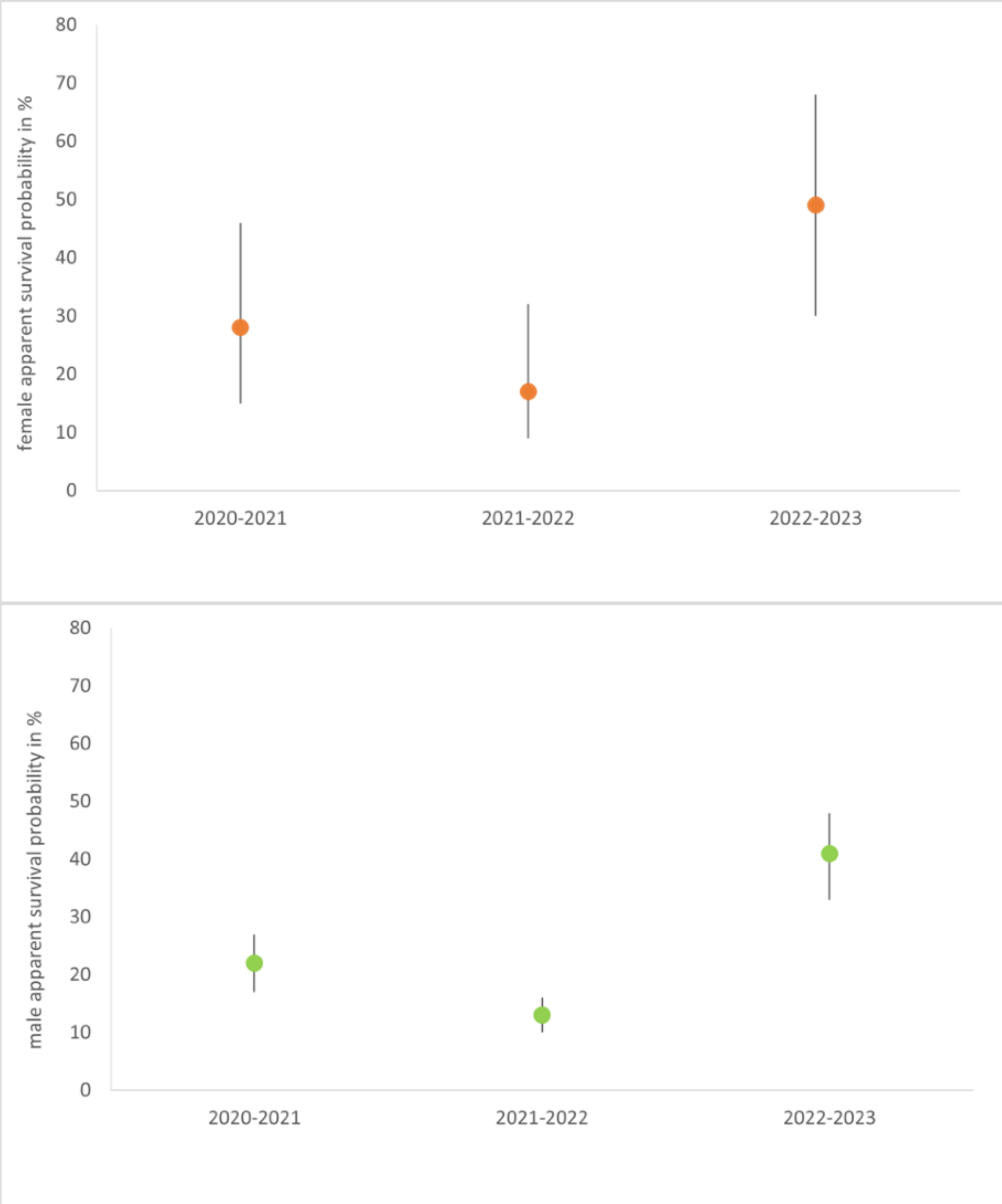


Figure 12: Apparent survival probability (phi) for females (upper figure) and males (lower figure) compared with the previous intervals. Confidence intervals are shown as whiskers.

3.3. Capture-recapture

Since the beginning of data recording in 2020, 2109 individuals have been caught. In 2023, 13 individuals from 2020 were detected again and only five of them were captured each year from 2020 to 2023. Out of the 650 individuals found in 2023, 550 toads (85%) were caught for the first time, 100 toads (15%) were recaptures from the previous years.

In 2023 recaptures were found at each occasion, from 25 March onwards. Especially at the peak-days there were many individuals caught for the first time (Figure 13).

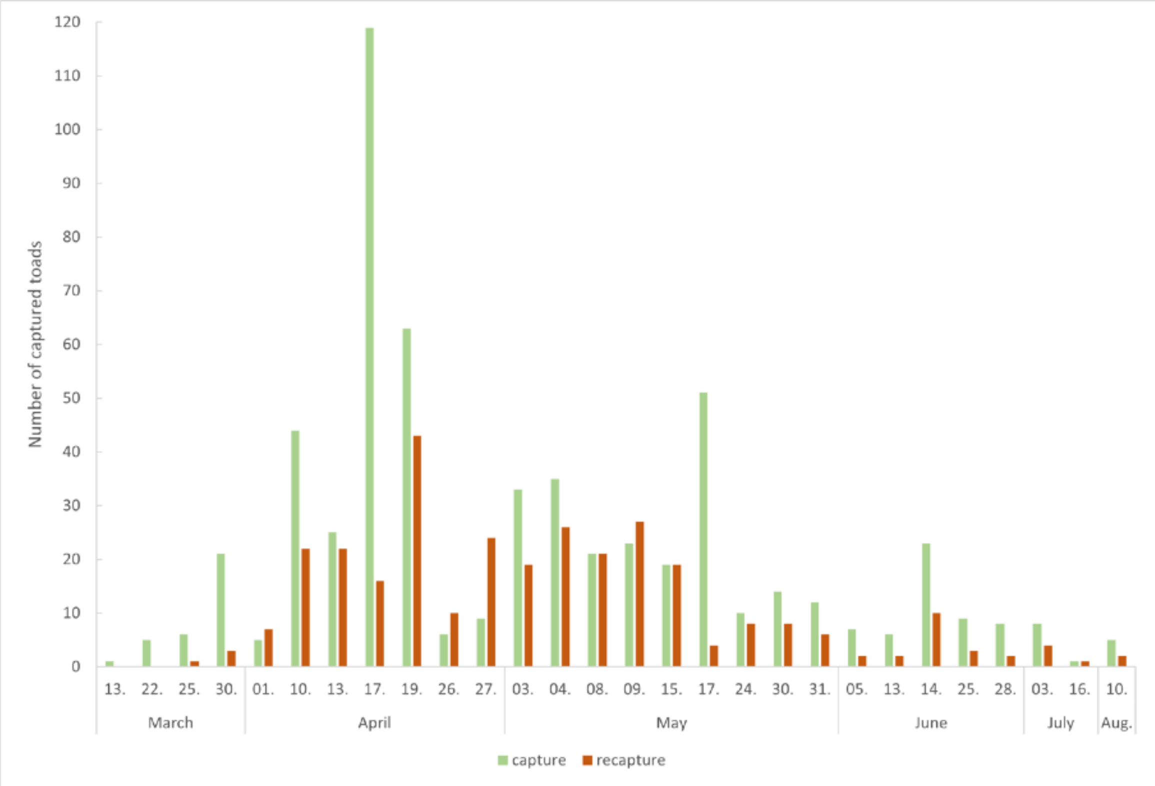


Figure 13: Number of captured toads for the first time (‚capture‘) and recaptures including previous years (‚recapture‘) at each field day during 2023.

3.4. Body condition (SMI)

The average mass of the female green toads was 26.29 g (CI: 2.7) and 21.41 g (CI: 0.31) for males, whereas the mass of the females was more distributed than the mass of the males. Body mass above 25 g was observed in 55% of females and 37% of males (Figure 14). The snout-vent length was almost the same for both sexes: 62.8 mm (CI: 2.26) for females and 61.82 mm (CI: 0.29) for males. The SVL of the females was more distributed as well. Most of the male toads had a SVL between 59 and 62 mm, a size above 65 mm was observed in 23%, whereas a total of 44% of females were larger than 65 mm (Figure 15).

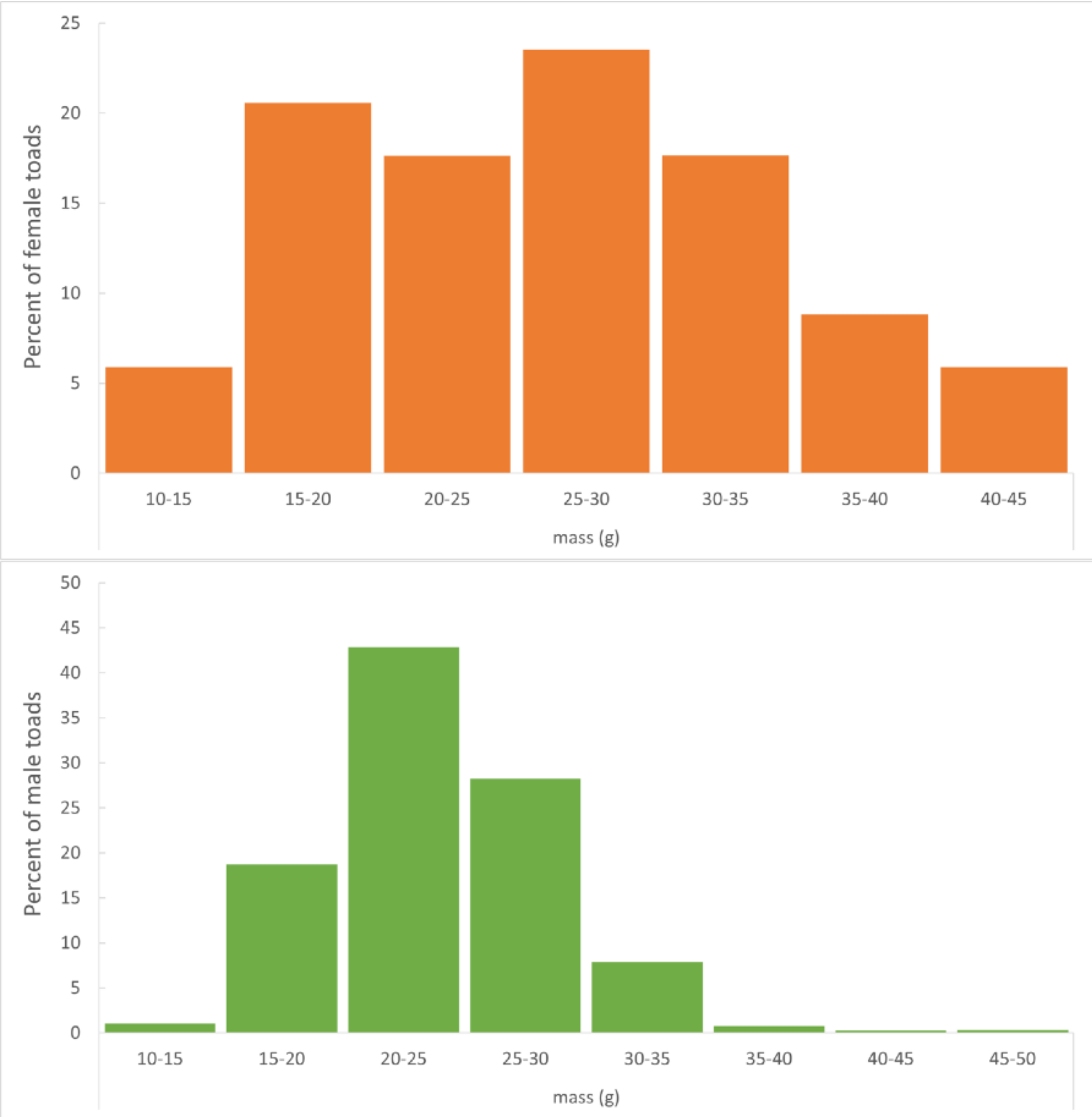
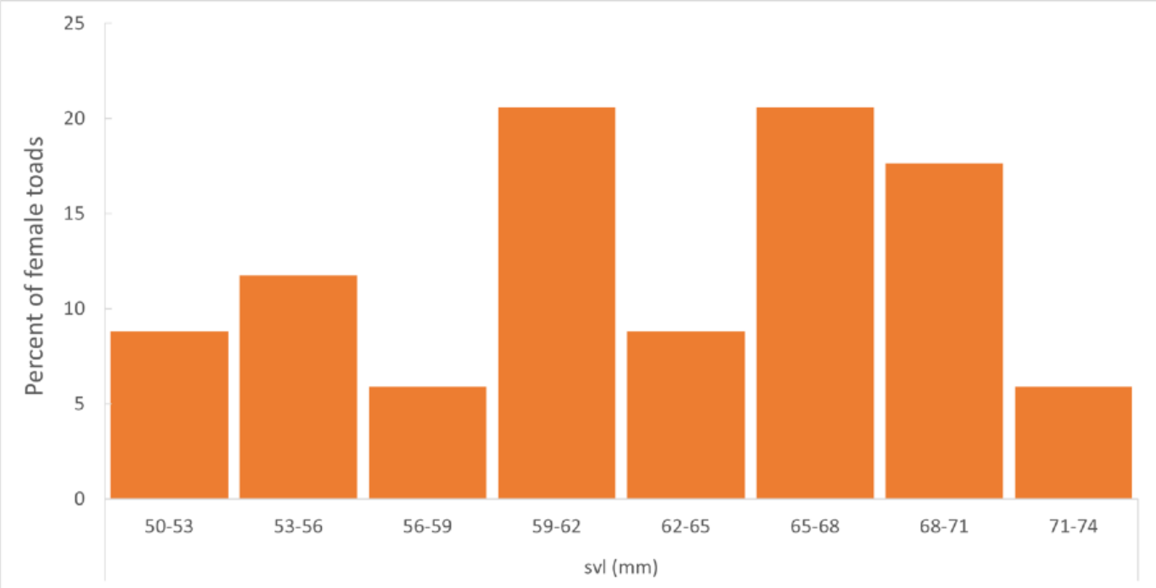


Figure 14: Body mass (g) distribution for females (upper figure) and males (lower figure) in 2023.

The calculated scaled mass index (SMI) was 21.8 (CI: 0.68) for the population in 2023. Small fluctuations were observed between sampling occasions until the end of May, whereas greater variability and a slight increase in SMI occurred toward the end of the breeding season (Figure 16).



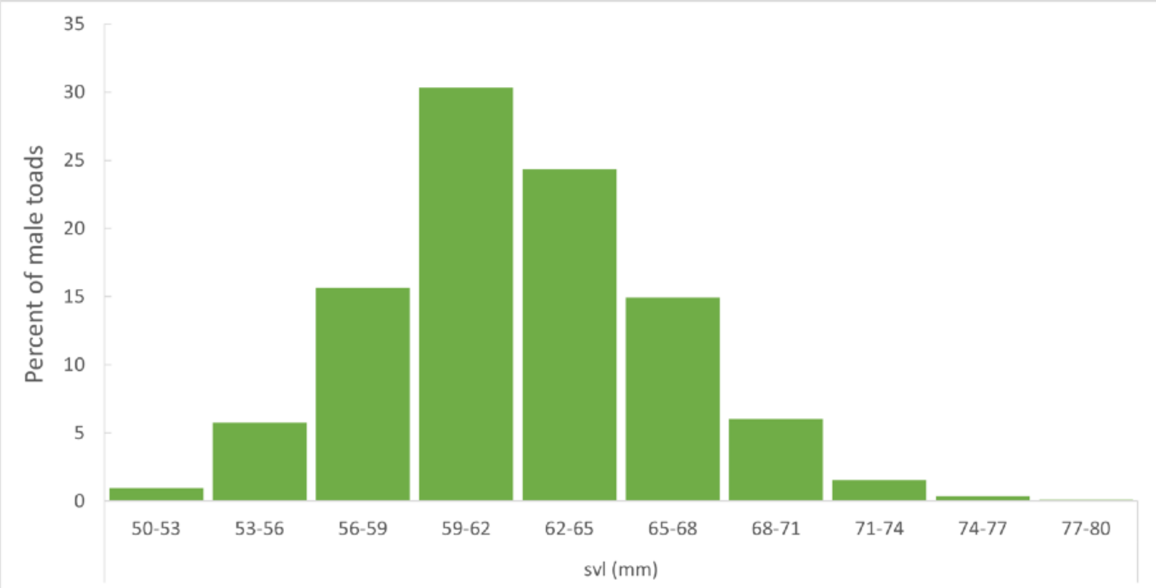


Figure 15: Body size (snout-vent length in mm) distribution for females (upper figure) and males (lower figure) in 2023.

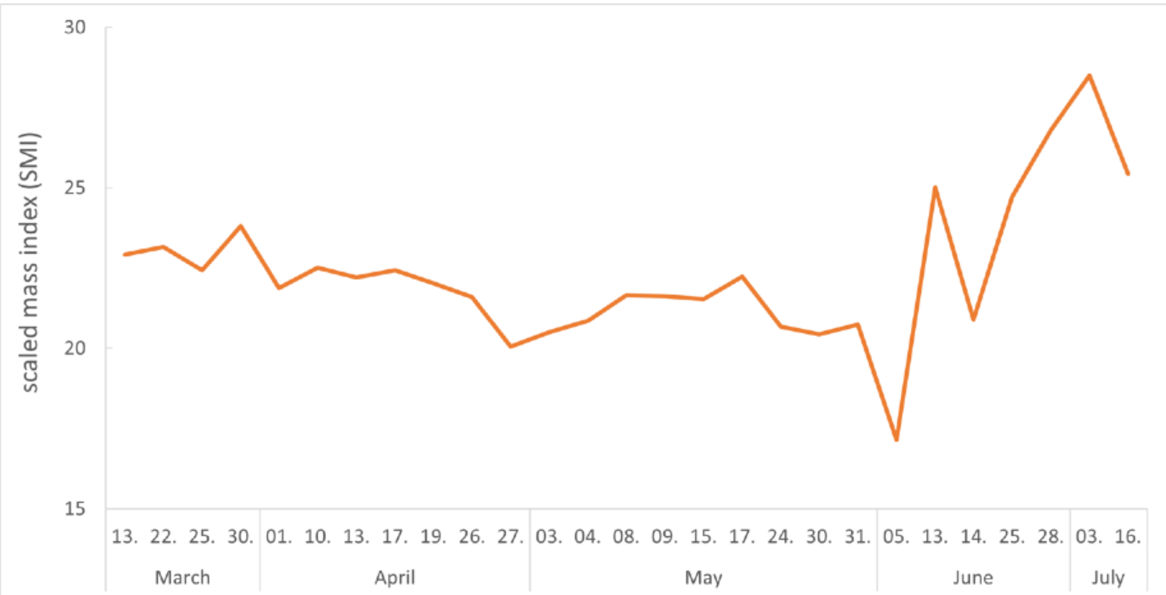


Figure 16: The scaled mass index (SMI) of the population as mean on each field day in 2023.

3.5. Migration between breeding sites

A total of 264 data records were collected at the concrete pool, 671 at the rainwater basin and 32 data were collected in the surrounding area or on the street. Out of the 650 identified individuals, two were observed changing breeding sites once (Table 2). All other recaptured individuals during 2023 showed a high degree of site fidelity during the study and remained at their breeding location.

Table 2: The individuals BV_SH_3679 and BV_SH_3691 changed breeding site.

ID	rainwater basin	concrete pool
BV_SH_3679	30.03.2023	16.07.2023
BV_SH_3691	30.03.2023	10.08.2023

3.6. Further observations

At the beginning of data collection, the concrete pool was dried out and the rainwater basin had a low water level (about 2 m below the top of the wall). During the first five field days, green toads were only found at the rainwater basin. On the sixth field day, 10 April, the concrete pool was filled with water for the first time and as a result, green toads appeared at this breeding site.

The first calling males were heard on 10 April on both breeding sites. Spawn was seen for the first time at 19 April on both breeding sites, juveniles were found on 13 June (concrete pool) and on 16 July (rainwater basin). Since the 18th field day (24 May) to the end of the field work, the water level of the rainwater basin was so low that the water surface could barely be reached with the landing net.

Mallards were frequently observed and black-headed gulls and a hedgehog were observed rarely. As the concrete pool was right next to the road and not fenced, garbage was often found and bicycle tracks were discovered in the pool.

4. Discussion

The study showed a population size estimation of 1883 individuals for *B. viridis* in 2023, indicating an increase compared to previous years. This population is not only estimated to be larger than in the past three years but also relatively large compared to other populations in Vienna and Austria (Wappl & Heyer, 2016; Sistani, 2021; Amon, 2022; Horvath, 2023). The survival rate from 2022 to 2023 also showed an increase compared to the previous two intervals.

The number of captured male green toads (581 individuals) was considerably higher than that of females (69 individuals), which aligns with expectations, as males typically dominate breeding sites (Kaczmarski et al., 2019). Males also tend to remain at breeding sites for long periods, often for several consecutive weeks, whereas females typically visit the site once for mating and spawning and depart shortly afterward (Stöck et al., 2009). The lower recapture probability for females at 0.3% can be attributed to their brief, one-time presence at breeding sites. Furthermore, studies on pond-breeding amphibians generally focus on breeding sites, while detecting individuals in their terrestrial habitats is more challenging (Staufer et al., 2023). Males had a higher recapture probability of 3.3%, although this figure was slightly lower compared to previous years. This decline could be explained by the dried out concrete pool at the beginning of the season and the low water level of the rainwater basin from the end of May, which resulted in reduced access to the water surface for the green toads.

Despite the initial lack of water in the concrete pool, only two recaptured individuals were observed to have switched breeding sites. Based on the collected data, green toads occurring in the area of the concrete pool did not use the rainwater basin as an alternative breeding site. These findings suggest either a high site fidelity among *B. viridis* in the study area or the existence of alternative, more suitable breeding sites nearby that were not included in this study. Future research should consider expanding the data collection to include additional breeding sites and increasing the radius of investigation. Including terrestrial habitats, as suggested by Staufer et al. (2023), could also improve the detection of female individuals.

Throughout the breeding season, the number of captured toads varied between the different field days. Distinct peaks occurred in the middle of April and the middle of May, with up to 140 individuals recorded per day, while fewer individuals were found at the beginning and end of the breeding season. Besides the difficulties already mentioned, such as the dried out concrete pool and declining water levels from late May onwards, peaks at this time of the year are consistent with findings from previous years and other literature (Kovacs & Sas, 2010). The secondary peak in May may have been driven by individuals reaching maturity during the season. Males with smaller sizes and lower body condition, therefore younger individuals, are more likely to mate later in the season (Burgstaller et al., 2024).

The female apparent survival probability from 2022 to 2023 was slightly higher (49%, CI: 30-68) compared to males (41%, CI: 34-49), however, confidence intervals overlapped substantially. Male green toads generally have a riskier lifestyle, as their prolonged presence at breeding sites exposes them to predators such as gulls or snakes especially given the limited vegetation and few hiding spots at the investigated breeding sites. In addition, their high pitched mating calls, which can be heard several hundred meters away (Rienesl, 2021), increase their likelihood of being discovered by predators. Compared to the previous years, the apparent survival probability increased considerably (Table A1). One reason for the increase could be that the study area was expanded in 2022 (Horvath, 2023) and 2023, making it possible to recapture more individuals.

The scaled mass index (SMI) showed a slight increase compared to previous years, suggesting a slight improvement in body condition of the individuals. However, body length and weight remained lower compared to other populations in Austria (Wappl & Heyer, 2016; Sistani, 2021; Amon, 2022). This pattern is consistent with a population dominated by young individuals. This assumption is supported by the fact that a large number of new individuals were discovered in 2023 (85%), while only 15% were recaptures from previous years. Staufer (2018) also noted low annual survival rates and limited reproductive success in this population.

There is also the possibility that the diet found in the investigation area is not ideal or that the pesticides potentially used in the greenhouse agriculture, that surround the investigation sites, are harmful to their health. Lemaire et al. (2025) detected mercury contamination in *B. viridis* in Vienna, including individuals from Simmeringer Haide. Breeding waters showed no mercury contamination, which indicates contamination in the diet of *B. viridis,* e.g. contaminated prey. For this reason and because amphibians are particularly vulnerable to chemical pollutants due to their terrestrial and aquatic lifestyle (Croteau et al., 2008), further research is recommended to investigate the effects of other pollutants and pesticides on *B. viridis* in Simmeringer Haide.

Traffic-related mortality is another significant threat to green toads in the investigation area (Landler, 2021; Staufer, 2022). Both breeding sites are situated near roads, and green toads often cross these roads to get to their terrestrial habitats or other breeding areas. For several years now, efforts have been made, especially by Martina Staufer, to prevent the death of many individuals by collecting them at the roadside. Three warning signs were also put up, but some of them are in unsuitable places, where usually no toads are crossing or where they are not visible to car drivers. A simple conservation measure would be to put up more toad warning signs in suitable and clearly visible places. Moreover, the construction of guiding systems along the road or tunnels could lead to safer migration (Rienesl, 2017). More extensive measures like road closures or traffic redirection are almost impossible to implement in this industrial area.

In addition to road traffic and potential dietary contamination, habitat loss and land sealing pose another threat to *B. viridis*. Despite their good adaptability in urban areas (Vargová et al., 2023), habitat loss, fragmentation, and degradation of habitat quality impact their survival (Kovács & Sas, 2010). It is therefore important that future urban landscape planning considers the habitat requirements of *B. viridis* (Landler et al., 2023).

The fact that juveniles were found at both breeding sites indicates high adaptability of *B. viridis* in urban areas despite all adverse circumstances. It is also possible that the high occurrence of greenhouses creates heat islands, which could positively influence the survival rate of juveniles (Burgstaller et al., 2024). Dastansara et al. (2017) showed that higher temperatures have a positive influence on the survival rate and growth rate of larvae of *B. viridis.* Higher temperatures can also cause shorter hibernation periods, which may benefit young toads, as the energy reserves required for survival decrease (Sinsch & Schäfer, 2016).

The *B. viridis* population in Simmeringer Haide is large, well known, and has been scientifically monitored over several years (Staufer, 2018; Hemmerich, 2022; Proksch, 2022; Horvath, 2023; Burgstaller et al., 2024). However, current research is limited to two breeding sites and a short road section. The aim of continued long-term monitoring would be to extend the survey area in the future, but this also depends on the goodwill of the landowners, as most breeding sites are located on private property. Establishing several, well connected breeding sites on public land could further support the population. In order to support the population in the future, more awareness and consideration are required from the public, local residents and farmers. *Bufotes viridis* could be brought more into the spotlight with information campaigns and information signs could be set up.

This and previous studies show that the Simmeringer Haide population of *B. viridis* is large and resilient, but it faces multiple challenges. In order to protect this population in the future and prevent it from disappearing, continued annual monitoring, including more breeding sites and terrestrial habitats, is essential. In-depth studies on local threats, such as pollutant contamination (Lemaire et al., 2025) and road traffic (Staufer, 2022), are recommended to adapt conservation measures to this population.

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6. Appendix

Table A1: The detection probability (p), apparent survival probability (phi) and population estimation (Super N) from 2020-2023 with the lower control limit (lcl) and upper control limit (ucl), separated by sex. (Vienna 2025)

year + sex	estimate.p	lcl.p	ucl.p	estimate .phi	lcl.phi	ucl.phi	estimate.N	lcl.N	ucl.N
2020 female	0.00453	0.00319	0.00644	0.27902	0.15036	0.45836	891.7662	748.6030	1062.308
2021 female	0.00733	0.00517	0.01039	0.17366	0.08718	0.31619	1674.5992	1418.427	1977.037
2022 female	0.00663	0.00463	0.00950	**0.49084**	**0.30016**	**0.68422**	980.2190	817.2706	1175.656
2023 female	**0.00355**	**0.00247**	**0.00508**	NA	NA	NA	**1883.2852**	**1573.514**	**2254.04**
2020 male	0.04226	0.03865	0.04619	0.21781	0.17081	0.27348	891.7662	748.6030	1062.308
2021 male	0.06681	0.06192	0.07205	0.13135	0.10403	0.16453	1674.5992	1418.427	1977.037
2022 male	0.06079	0.05480	0.06739	**0.40956**	**0.33631**	**0.48706**	980.2190	817.2706	1175.656
2023 male	**0.03333**	**0.03013**	**0.03686**	NA	NA	NA	**1883.2852**	**1573.514**	**2254.04**