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Seasonal Changes of Body Condition in a Population of Fire Salamanders (Salamandra salamandra) in Vienna

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Abstract

During the ongoing global amphibian extinction crisis even widely distributed species like the fire salamander may rapidly decline due to various threats. While this deterioration of the conservation status is expected to proceed in the future and even increase due to the intensifying impacts of climate change, monitoring and understanding natural developments in healthy fire salamander populations becomes urgent. During this study, a population of fire salamanders at Wilhelminenberg, located in Vienna, was monitored to assess the body condition and spatial distribution of adult individuals throughout one year. Between November 2023 and October 2024, out of 378 total captures 284 different individuals were identified. The fluctuation of the body condition throughout the year showed a distinct pattern for the sexes. The body condition of adult males was highest during summer, most likely caused by the favorable food availability during the previous months. Increased mating efforts in fall might explain the decrease in body condition during fall reaching its lowest point in winter. For females, the body condition increased throughout the pregnancy in winter and decreased in spring after the larvae were deposited. The distance of individuals to the breeding stream throughout the year showed the trend of a sex-independent fluctuation. The tendency of higher fire salamander activity closer to the stream during the breeding season might be due to females depositing larvae and males increasing their chance of mating.

Introduction

Compared to the average over the past ten million years, the global rate of species extinction has accelerated by at least tens to hundreds of times (IPBES, 2019). Overall estimates across a wide range of species groups conclude that a proportion of around 25% of species is threatened by extinction according to IUCN Red List criteria (IPBES, 2019). In vertebrates, at least 680 species have been driven to extinction since 1500 (IPBES, 2019). Among vertebrates worldwide, amphibians have been identified as the most threatened class, with over 40% of species at risk of becoming extinct (Luedtke et al., 2023; IUCN SSC, 2024). This development can be caused by the sensitivity of amphibians to disturbances within ecosystems, as they function as excellent indicators of the quality of their environment (Vié et al., 2009). Amphibians are affected by changes in their terrestrial and aquatic environment, such as habitat loss or degradation and pollution (Luedtke et al., 2023; Womack et al., 2022; Egea-Serrano et al., 2012), as they often depend on both habitats during their life cycle (IUCN SSC, 2024). According to the Red List Index, amphibians are among the three most rapidly declining taxonomic groups (Secretariat of the Convention on Biological Diversity, 2020) with habitat loss and degradation, climate change effects, and diseases being the main threats (Luedtke et al., 2023). The primary threat for amphibians is increasingly shifting from diseases toward the impact of climate change (Luedtke et al., 2023). As strong responses to climate change are likely among amphibians (Buckley et al., 2012), their capability to adapt their behavior and phenotype to changing phenological conditions needs further assessment (Radchuk et al., 2019). Adaptations, such as shifts in body size (for example: Caruso et al., 2014; Bucciarelli et al., 2020; Hernández-Pacheco et al., 2021) have already been observed in different amphibian species. Smaller body size and lower body condition can affect fitness due to decreased population growth rates, viability, and fecundity, especially in females (Hernández-Pacheco et al., 2021; Reading, 2007). Among amphibians, Caudata (salamanders and newts) are most threatened as their extinction risk was constantly higher than those of Anura (frogs and toads) (Luedtke et al., 2023).

The deterioration in status can also be observed in widespread species such as the fire salamander (*Salamandra salamandra*). Between the previous IUCN Red List assessment from 2022 (IUCN SSC,

2022) and the latest assessment published in 2023 (IUCN SSC, 2023), the classification of this salamander species changed from 'Least Concern' to 'Vulnerable'. This evaluation reflects the continuous decrease in numbers of this widely distributed species and integrates the intensity of future threats. In the latest assessment, the updated classification is reasoned by the projected population decline which was estimated to be higher than 30% within the next 21 to 45 years. Threats such as habitat loss (IUCN SSC, 2023), habitat fragmentation (IUCN SSC, 2023), pollution of breeding sites by agrochemicals (IUCN SSC, 2023), and infectious diseases, such as chytridiomycosis (Bosch and Martínez-Solano, 2006; Spitzen-van der Sluijs et al., 2016; Lötters et al., 2020) were identified to cause this decline in abundance. Especially the spread of the chytridiomycosis pathogen *Batrachochytrium salamandrivorans* led to the collapse of fire salamander populations in Europe (Spitzen-van der Sluijs et al., 2016; Lötters et al., 2020).

Based on these concerning developments and increasing threats, an effective long-term monitoring of the health status in fire salamanders is necessary. Body condition, commonly defined as the accumulation of energy reserves in the body (for example: Labocha et al., 2014; Peig and Green, 2009), is assumed to indicate the health of individuals (Peig and Green, 2009). Gaining a deeper understanding of the dynamics of body condition and its monitoring are essential tools for establishing baseline knowledge and detecting changes within populations at an early stage. Indices like the Scaled Mass Index (SMI) by Peig and Green (2009), using a combination of body weight and body length for its calculation, are important indicators of physical condition (Stevenson and Woods, 2006; Peig and Green, 2009). Therefore, the SMI can be used to assess the body condition within a population, as well as the seasonal change in body condition (Najbar et al., 2019).
General concerns about the informative value of body condition indices were discussed (Wilder et al., 2016). In the case of amphibians, including salamanders, the reliability of the SMI as a measure of energy storage as well as a predictor of fat, protein, or lean mass content, was assessed in a controlled feeding experiment by MacCracken and Stebbings (2012). Further, the SMI was already used in different studies as an indicator of body condition in salamanders (for example: Rosa et al., 2021; Bodinof Jachowski et al., 2024), including fire salamanders (Mayerhofer, 2013; Najbar et al., 2019). In contrast to indices calculated with the residuals of ordinary least square (OLS) regression of the body weight on body length, the SMI allows the comparison populations if the same reference values (L_0 and B) are used (Peig and Green, 2009).
Body fat is important during the hibernation process, within which energy is used to survive unfavorable conditions (Roots, 2006; Reading, 2007). As a result of climate change, milder winters are expected in Europe (Ranasinghe, 2021), causing an increased metabolic rate in amphibians during winter and resulting in poor body condition (Reading, 2007). Fire salamanders are internally fertilizing salamanders with embryos developing in the female's uterus until a varying number of developed larvae are deposited in the breeding waters (Greven and Guex, 1994). An increased SMI in females can therefore indicate higher fitness if the increase in body weight is caused by the larvae they carry. A study on the body condition of adult female fire salamanders contrasted three populations in the Vienna Woods and found differences in the average body length as well as varying body condition indices (SMI) (Mayerhofer, 2013). In Poland, a study focused on the seasonal change in body condition of adult male fire salamanders found a fluctuating pattern of the SMI (Najbar et al., 2019). The highest SMI was reached in early summer, whereas it was lowest during winter.

The quality of the habitat influences the development of fire salamanders (Sinsch, 2024). Therefore, a deeper understanding of the habitat use and requirements of fire salamanders is necessary to designing effective conservation measures. Monitoring the movement behavior of individuals across different life stages and throughout the year provides important insights about essential habitat requirements and their association to specific phases of life. This knowledge is particularly crucial in

the context of intensifying climate change and ongoing habitat degradation, as it establishes baseline knowledge necessary for tracking future changes. Fire salamanders are biphasic, depending on both aquatic and terrestrial habitat during their life cycle (Oswald et al., 2022). Aquatic breeding sites are essential for reproduction as females deposit their larvae in streams or ponds (Steinfartz et al., 2007). A study from Italy discovered male fire salamanders also chose microhabitats closer to the breeding site during breeding, suggesting that this behavior was caused by males actively looking for females to mate with (Manenti et al., 2017). In the Vienna Woods, research on the demography and spatial movement patterns of fire salamanders was conducted using a capture-recapture approach (Burgstaller et al., 2021). Burgstaller et al. (2021) found that recapture rates within years were lower than recapture rates between years, which may indicate seasonal movements.

Our study examined, whether seasonal variation in body condition and distance to the breeding stream differ between the sexes in adult fire salamanders. In addition, we investigated whether there are differences in the distance to the breeding stream depending on sex, season, or body condition. We expected the development of the SMI through the season for mature male individuals to be similar to the findings of Najbar et al. (2019). For females, we predicted a differing pattern due to the gain in body mass during the winter. In line with the results of Manenti et al. (2017), we expected an increased sex-independent activity closer to the stream during breeding.

Standardized sampled long-term data are essential for evidence-based assessments on the extent of declining trends (Seyring et al., 2024) and comparisons of study results between areas (IUCN SSC, 2024). A standardized methodology allows a better evaluation of the impact of conservation actions. Therefore, this study is an approach to standardize the monitoring of adult fire salamanders and establish a procedure that enables long-term monitoring and comparison between different populations.

Methods

Study species

The fire salamander (*Salamandra salamandra*) is the largest Salamandridae in Europe, where it is widely distributed. This species inhabits moist mixed deciduous forests, most of which are dominated by Eurasian beech (*Fagus sylvatica*) (Alcobendas et al., 1996; Meikl et al., 2010). Mosses, as well as leaf litter, are used for foraging small invertebrates and are therefore essential habitat structures (Bogaerts et al., 2021). Frost-proof shelters, such as micromammal caves, hiding places in rotting deadwood and under stones, are necessary for surviving dry periods and overwintering if temperatures fall below activity levels. Anthropogenic structures such as basements and bunkers can also be used throughout the year to withstand unpreferred weather conditions or for breeding purposes (Bogaerts et al., 2021). Fire salamanders are larviparous, the fertilized eggs develop in the uterus of the female. In early spring, usually between March and May, pregnant females deposit their larvae mainly in clean, fish-free streams but also in shallow ponds (Steinfartz et al., 2007). Commonly, fire salamanders are described as nocturnal, but diurnal activity can be observed as well. The activity is influenced by different weather conditions like air temperature, precipitation and air humidity (Bogaerts et al., 2021).

Study site

The project area of this study was the "Wilhelminenberg", a region in the north-western part of Vienna (WGS84, 48.221°N, 16.280°E, 361 m a.s.l). It is located central-east within the geographic range of the fire salamander (*Salamandra salamandra*) in Europe but close to the distribution gap of the Viennese basin. The study site itself is located close to an urban settlement.
The forest is dominated by beech trees (*Fagus sylvatica*) in different age classes but an undergrowth of young beech trees is missing. The northwestern part of the area also includes ashes (*Fraxinus excelsior*) close to the stream while the eastern part consists of more oaks (*Quercus robur*), European red pines (*Pinus sylvestris*), and birch trees (*Betula pendula*) closer to the stream. The whole area provides a high amount of deadwood in different states of decomposition. Due to the absence of forest management practices, such as the removal of dead trees, a constant accumulation of dead wood is ensured. A breeding stream (Anderbach) crosses the area in the northern part of the study site (Figure 1). Due to the restricted access to the property of the Research Institute of Wildlife Ecology (FIWI) only little anthropogenic disturbance influences the fire salamander population within the project area.

Data collection along transects

The data sampling was conducted from November 2023 to October 2024. During this period the whole seasonal cycle was covered. Evenly distributed throughout the study site, four representative plots were established at a distance of about 180 m to each other (Figure 1). For orientation, the transects were marked with barrier tape around trees. The data collection was conducted by monitoring along the adjacent pair of line transects within each plot. Two line transects, belonging to an adjacent pair, were 10 meters apart from each other and 5 meters away from the border of the plot. While monitoring only individuals within the plots were documented as found on the transect. The length of the plots ranged from 160 m to 180 m, while the width was always 20 m, resulting in an area of approximately 3.600 m^2 which was covered in total. The sampling order of the plots and transects, as well as the direction of sampling (uphill vs. downhill), was chosen randomly for each sampling occasion.

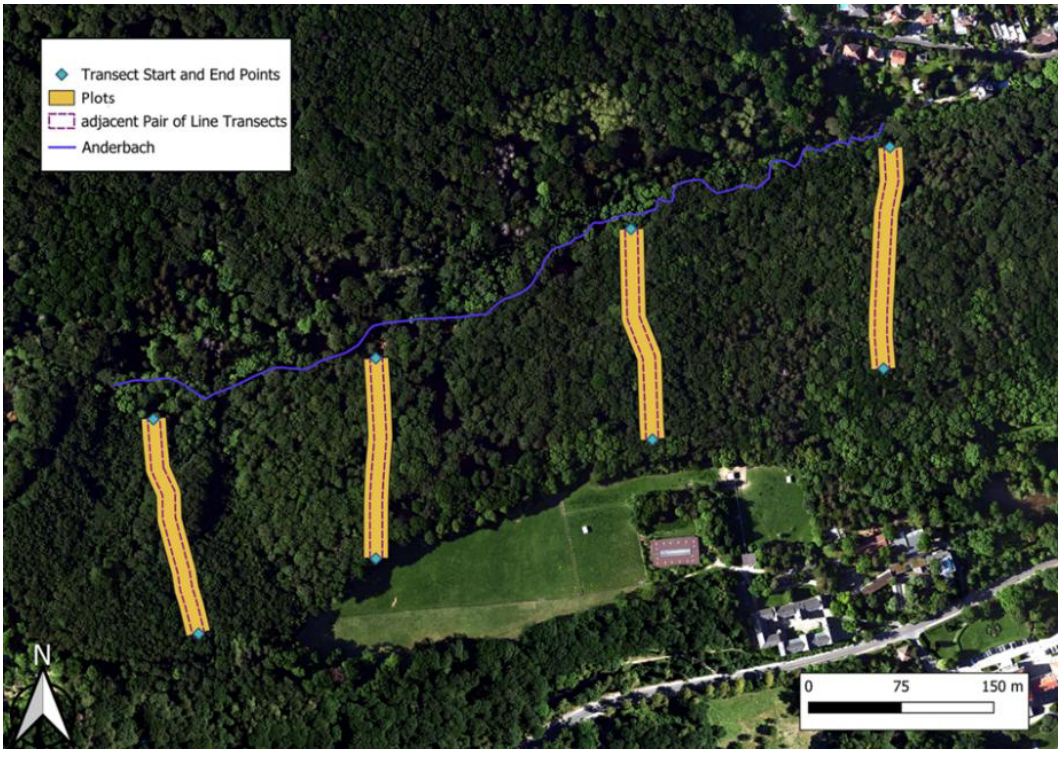

Figure 1: Location of the plots within the study area.
Background image: Geoland Basemap Orthofoto (URL: https://www.basemap.at/wmts/1.0.0/WMTSCapabilities.xml)

Data collection took place at varying times of the day and night during suitable weather conditions. Those include air temperatures above 3 °C and air humidity above 70 % at least part of the sampling occasion (Bogaerts et al., 2021). Weather data were obtained hourly from the ZAMG (Geosphere Austria) from the weather station "Jubiläumswarte", which is located about 1 kilometer west of the study area. For each fire salamander found, the local surface temperature of the microhabitat was measured using a Bosch UniversalTemp infrared thermometer.
During the fieldwork checking potential shelters, such as micromammal caves, underneath leaf litter, under logs, and stones, was avoided to minimize the disturbance on the individuals because stress could influence the body condition. Only presence data were collected by documenting the GPS location of the fire salamanders found, using an Etrex 30 GPS tracker (accuracy 2 - 4 m).
When a fire salamander was found a strict hygiene protocol was followed. Each individual was only touched wearing nitrile gloves and the handling was kept to a minimum.
The body mass was determined by weighing the fire salamanders in a plastic container on a digital pocket scale (precision 0.01g). It was essential to place the scale on a flat and solid underground to guarantee the correct functioning of the scale in the field. The empty container was weighed by themselves first to set the scale to zero if the weight of 107 g was displayed correctly. In case the scale did not work properly, it was placed on a flatter and more solid underground.
The unique dorsal pattern was photographed using a waterproof Nikon COOLPIX camera and used for further individual identification. For later measurement of the body length, the bottom of the plastic container was covered with laminated scaled paper as a reference beforehand.
The sex of all individuals was determined by the shape of the cloaca (Feldmann and Klewen, 1981). As described, reliable sexing is only possible for individuals with a total body length of at least 14 cm (Bogaerts et al., 2021), therefore individuals with a shorter total body length were classified as "juveniles". If uncertain, the sex of the individual was classified as "N.A.".
Right after the procedure was finished, individuals were then released at the location where they were captured. The handling of the fire salamanders took a maximum of two minutes per individual. All materials touched by the fire salamander were disinfected and the nitrile gloves were changed.

Identification and body length determination

Using the unique dorsal color pattern of adult fire salamanders (Bogaerts et al., 2021), individuals were identified and visually compared to all the photos previously taken. Visual comparison was conducted manually.

The linear body measurement was digitally determined from the dorsal photos taken on scaled paper. Two versions of linear measures of size were measured. The body length (bl) was defined as the length from the tip of the snout to the tapering of the tail (Figure 2). The total body length (tbl) was measured from the tip of the snout to the end of the tail. In some cases, it was not possible to measure the total body length because part of the tail was not visible or bent upwards. For the measurement, the program ImageJ and the "Segmented Line" tool (Figure 2) were used (Margenau et al., 2018). In preparation, five 1 cm reference lines on the scaled paper were measured in pixels. It was ensured that those reference lines were clearly visible, isometric and close to the individual. From those samples, the average amount of pixels was estimated and set as scale. The final measurement was taken along the spine. The whole procedure was repeated for each photo analyzed.

Figure 2: Example of the measurement of the body length using ImageJ and the "segmented line" tool.

Body condition (SMI)

The Scaled Mass Index (SMI) by Peig and Green (2009) is calculated by using the body mass (M_i) and the linear body measurement (L_i) for a certain individual (i). The body length L_i is standardized to a reference value (L_0), such as the mean body length. The scaling exponent (B) equals the slope of the linear regression of the log-transformed M_i on the log-transformed L_i.

$$SMI_i = M_i(L_0/L_i)^B$$

For the calculation only the first capture of each individual was used to avoid a biased impact of repeatedly captured individuals. Further, only individuals found on the transects were considered in the analysis.
In this study, L_0, the arithmetic mean of the body length (bl) equaled 105.84 mm while the scaling exponent B equaled 2.81. To avoid sex-related bias in comparisons, L_0 and B were calculated using a sub-dataset consisting of all females found (n = 131) and 131 randomly chosen males as well as all 29 juveniles.

Data preparation for spatial analysis

For the distance analysis, the location of the Anderbach was obtained from the MKZ_34_1 map from the official website of the city of Vienna
(Stadtvermessung der Stadt Wien: https://www.wien.gv.at/ma41datenviewer/public/start.aspx). QGIS (Desktop LTR 3.34.4) was used to combine the capture locations of individuals and the location of the breeding stream in one project. The shortest distance to the stream was determined by the "Shortest line between features" tool with the point layer of the fire salamander locations being the input layer and the line layer of the stream being the destination layer. As a method, the "Distance to the Nearest Point on feature" was used. Only individuals found on transects were considered for this analysis to avoid a bias.

Statistical analysis

All calculations were performed using R (version 4.4.0, R Core Team 2024). The seasonal change in body condition, expressed as SMI, was analyzed using general linear mixed models (GLMMs), with the package "glmmTMB" and then visualized with "ggeffects". Based on the results of the study by Najbar et al. (2019), a fluctuating pattern was assumed for the change of the SMI throughout the seasons. Therefore, the date of the sampling occasions was sine- and cosine-transformed, because the development of body condition was expected to follow patterns similar to those functions. The SMI calculated with the body length was set as response variable, while the sine-transformed capture day, cosine-transformed capture day, the sex, the interaction between sex and the sine-transformed capture day as well as the interaction between sex and the cosine-transformed capture day were fixed effects. In this model, the random effect was the transect on which the individual was found. The model was built using a Gaussian error distribution. The residual plots were produced with the "DHARMa" package and visually checked for fulfilling the normality assumption. For fixed effects with significant influence on the SMI effect sizes were quantified using the "effsize" package. Graphical visualizations were created by using the package "ggplot2".

For the analysis of seasonal changes within the spatial distribution pattern, GLMMs were run with the "glmmTMB" package. In preparation, the date of the sampling occasions was sine- and cosine-transformed because the distance to the stream throughout the seasons was expected to follow patterns similar to those functions. Within the GLMMs, the distance to the stream was the response variable. The sine- and cosine-transformed days of capture, body mass, sex (adult females vs. adult males), and the SMI were used as fixed explanatory variables. The transect on which the individuals were captured was used as random effect. As a result of the distance to the stream not being normally distributed, a log link function of the gamma family was used in the modeling. The residual plots were produced with the "DHARMa" package and visually checked for fulfilling the normality assumption. Using the "effsize" package, effect sizes were calculated for fixed effects with significant influence on the distance. Graphical visualizations were generated by using the "ggplot2" package.

Results

In total 284 different fire salamanders (females n = 94, males n = 147, juveniles n = 30, N.A. = 13) were identified within 378 captures during 32 capture occasions.
The first adult females depositing their larvae were observed on the 11th of February.

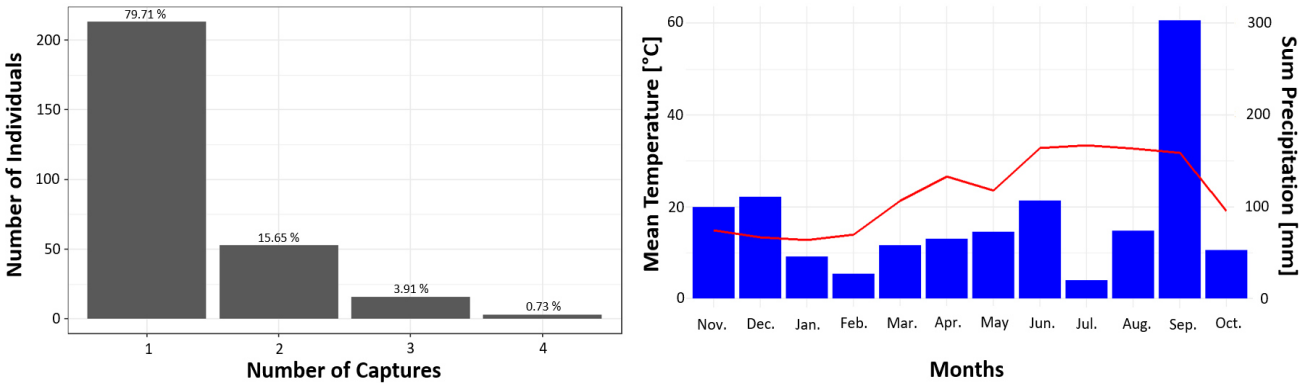

Figure 3: The left panel displays how many individuals were captured a certain number of times during this study.
The right panel shows the precipitation sum (blue bars) and the mean temperature (red line) for each month during the time of this study. The weather data was obtained from the official GeoSphere Austria website for the weather station "Jubiläumswarte".

Body length

According to the Shapiro-Wilk test, the body length was not normally distributed for adult females (Shapiro-Wilk test, bl: W = 0.9693, p = 0.02732, n = 93). In contrast, the same test showed a normal distribution for the total body length of adult females (tbl: W = 0.985, p-value = 0.3905, n = 90) as well as the bl and tbl of adult males (Shapiro-Wilk test, bl: W = 0.99018, p = 0.3815, n = 150, tbl: W = 0.99124, p-value = 0.5034, n = 146). For both sexes, the histograms, and QQ-Plots showed a normal distribution regarding the body length and total body length.

Table 1: Characteristics of the linear measures of size for both sexes. Values in the same row with identical superscripts are not significantly different.

	adult females	adult males
bl [mm]		
mean ± sd	111.39 ± 9.55[a]	110.01 ± 8.71[a]
range	86 to 133	88 to 137
sample size	n = 93	n = 150
tbl [mm]		
mean ± sd	182.11 ± 16.74[a]	181.12 ± 15.28[a]
range	143 to 225	140 to 224
sample size	n = 90	n = 146

Body mass (weight)

The Shapiro-Wilk test indicated no normal distribution of body mass for adult females (Shapiro-Wilk test, W = 0.96738, p-value = 0.0199, n = 93). In contrast, the test was normally distributed for males (Shapiro-Wilk test, W = 0.98341, p-value = 0.06805, n = 150).
Still, the histograms and QQ-Plots for adult females and males appear to be normally distributed.

Table 2: Characteristics of the body mass for the different subgroups. Values in the same row with different superscripts are significantly different.

	adult females	adult males
body mass [g]		
mean ± sd	40.64 ± 10.39[a]	31.56 ± 5.71[b]
range	17.6 to 83.5	20.9 to 45.8
sample size	n = 93	n = 150

Length and body mass were significantly correlated (Spearman correlation, bl: S = 709549, ρ = 0.7884403, p < 0.001, tbl: S = 779856, ρ = 0.745692, p < 0.001) for all individual (Figure 4).

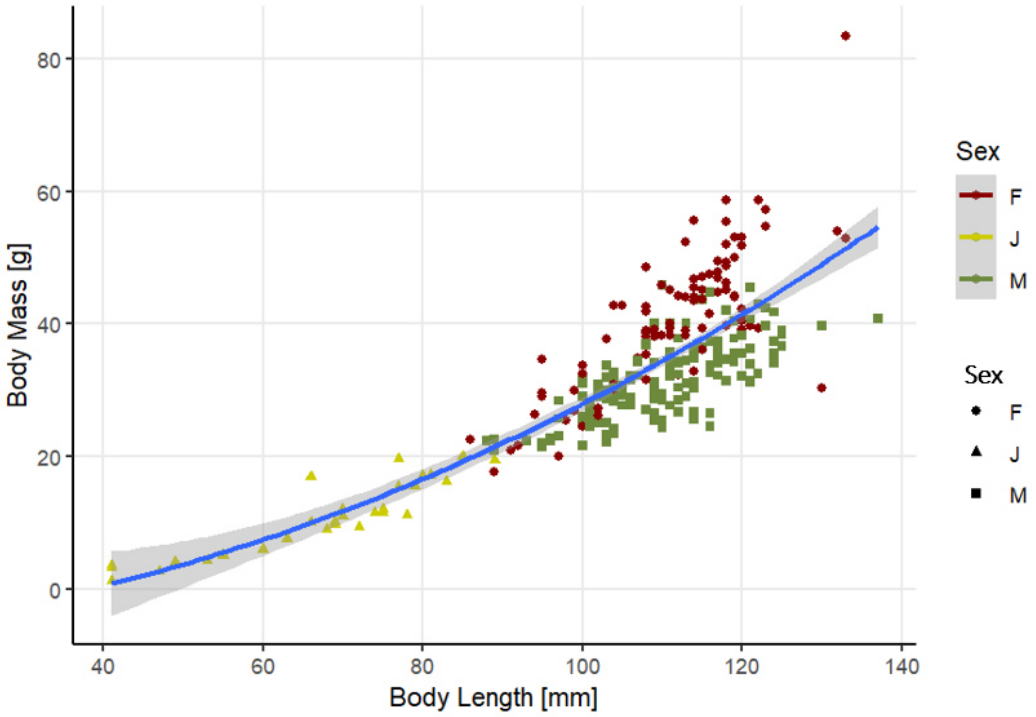

Figure 4: Body mass as a function of the body length. The regression line (blue) was plotted using stat_smooth(method = "lm", formula= (y ~ x + I(x^2)) and the confidence interval is displayed as shaded area.

Body condition - Scaled Mass Index (SMI)

According to the Shapiro-Wilk test, the SMI of all individuals was not normally distributed (Shapiro-Wilk test, bl: W = 0.98871, p-value = 0.05397, tbl: W = 0.95175, p-value < 0.001).

Therefore, the Kruskal-Wallis test was used to test for differences between the sexes. The result was significant for both linear measures of size (Kruskal-Wallis test, bl: chi-squared = 75.526, df = 1, p-value < 0.001, tbl: chi-squared = 67.714, df = 1, p-value < 0.001). Consequently, the Dunn's test was performed using the Bonferroni method and showed a highly significant difference between the SMI of adult females and adult males (bl: p = 3.61e-18, tbl: p < 0.001). The Cohen's d revealed a large effect size (d estimate = -1.38, 95 % confidence interval: -1.67 to - 1.09) for the sex. Therefore, the sex explained a high amount of variation in the SMI.

Table 3: Characteristics of the SMI calculated with the linear size measures (bl and tbl) for both sexes. Values in the same row with different superscripts are significantly different.

	adult females	**adult males**
SMI (with bl)		
mean ± sd	34.78 ± 5.21[a]	28.41 ± 4.21[b]
range	17.06 to 46.87	19.01 to 41.10
b_{SMA}	2.81	2.81
L_0	105.84	105.84
sample size	n = 93	n = 150
SMI (with tbl)		
mean ± sd	34.65 ± 6.30[a]	27.78 ± 4.77[b]
range	19.54 to 51.46	20.14 to 46.14
b_{SMA}	2.68	2.68
L_0	172.13	172.13
sample size	n = 90	n = 146

Seasonal aspect

The seasonal change in body condition showed a different pattern for adult female than for male fire salamanders (Figure 5). This finding is consistent with the GLMMs which returned significant results for a sex difference of the SMI (p < 0.001, z-value = 10.12) and for the SMI following a sex-dependent seasonal fluctuation pattern related to the cosine function (p = 0.00102, z-value = 3.29). The predicted body condition (SMI) of adult female fire salamanders was highest during winter, whereas the SMI of adult males was highest during summer (Figure 5).

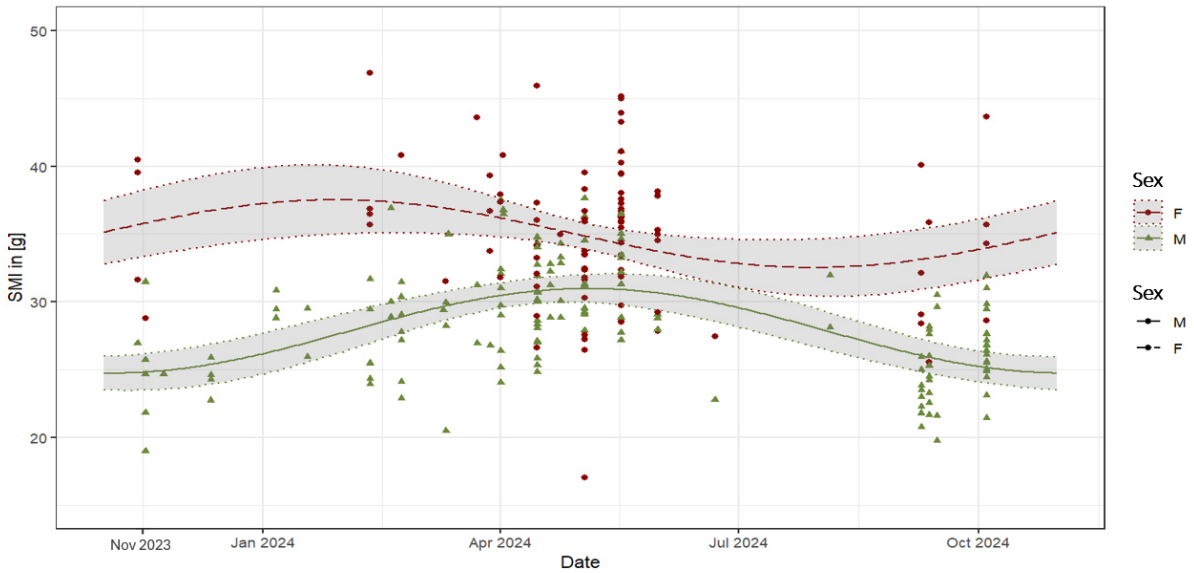

Figure 5: Seasonal change of SMI by day of the year for adult female and adult male individuals compared. The confidence interval is displayed as shaded area.

Spatial aspect

By visual inspection, the distance to the stream throughout the year fluctuated similarly for both sexes. The GLMMs performed showed a sex-independent significance for the cosine-transformed days ($p = 0.0376$, z-value = 2.044) and the sine-transformed days ($p = 0.0278$, z-value = 1.942). Adult fire salamanders were found further away from the stream during late summer than in early spring. No significance was found for the SMI, sex, bl, and body mass. The effect size for the cosine-transformed days of the year (eta-squared = 0.098) and the sine-transformed days of the year (eta-squared = 0.0124) on the distance, both indicate a small impact of this variable.

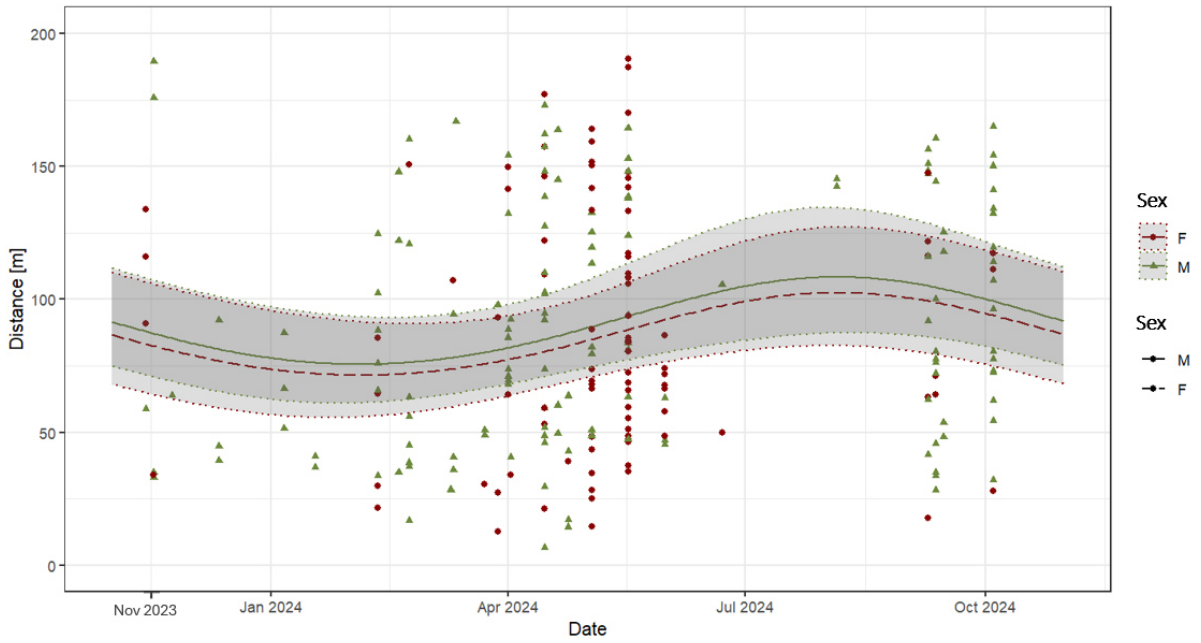

Figure 6: Seasonal change in distance to the stream by day of the year for adult female and adult male individuals. The confidence interval is displayed as shaded area.

Discussion

In line with our predictions, the development of the SMI in adult female fire salamanders throughout the year followed a different pattern compared to that of adult males. For adult males, the SMI was highest during summer and lowest in winter. For females, we observed the lowest SMI in summer which then increased over the winter months until early spring.

The seasonal change observed for the distance to the stream seemed sex-independent and might indicate a movement pattern, that needs to be further studied.

Our findings did not provide any evidence for a sexual dimorphism in body length in the fire salamander population studied. Instead, significant sex differences in weight and SMI were found.

Seasonal aspect

Compared to other studies (Najbar et al., 2019; Juszczyk (1987) and Zakrzewski (2007) quoted by Najbar et al., 2019), the seasonal change in body condition, expressed as SMI, showed a similar pattern for adult male fire salamanders.
Even though the development of the SMI for adult female fire salamanders throughout the year could not be compared to other studies, it is consistent with our expectations.
Kiss et al., 2021 assessed the body condition of fire salamanders during spring/summer (March to June) and fall (July to November) calculating the residuals of the linear regression between the logarithms of individual body weight and body length. Consistent with our results the study found a higher body condition for male individuals in spring/summer than in fall. For females, the body condition between spring/summer and fall was not substantially different, which supports our findings.
For mature males, the increased mating effort (Thiesmeier, 2004) after the dry summer period could explain the decrease in body condition (Najbar et al., 2019). The mating season for fire salamanders is prolonged, lasting from spring to fall (Thiesmeier and Günther, 1996) while pausing during hot and dry weather conditions in summer (Vörös et al., 2010 quoted by Kiss et al., 2021). During our study, potential matings and increased mating efforts for males, such as `rival combats` (Bogaerts et al., 2021; Penner et al., 2022), have only been observed in fall. While monitoring the accesses of a hibernation shelter used by fire salamanders in Vienna, Leeb (2013) also found sex differences in activity. During winter male individuals left the burrow more often and were involved in interactions more often than females. This higher activity level of males could be a reason for their further decrease in body condition in fall and could be linked to the mating system (Leeb, 2013). It seems reasonable that mature males invest more energy into mating efforts and the search for potential food sources even if the weather conditions are not favorable. During spring, warmer temperatures lead to better food availability in the forest as insect abundance increases (Crowley et al., 2023) and terrestrial mollusks and earthworms emerge during more frequent rainy conditions. These better food availabilities support an increase in body condition until the dry period in summer (Najbar et al., 2019; Reading, 2007).

In contrast, the pattern in body condition observed in adult female fire salamanders seems to be characterized by the pregnancy of an uncertain number of individuals. The increase of the SMI in females during fall can be explained by the additional resources accumulated to provide for their unborn offspring. In lecithotroph viviparous species, such as *S. salamandra*, females provide yolk for their embryos, which nourishes them throughout the pregnancy (Greven and Guex, 1994). The average SMI of the females then further increases during the winter due to the developing larvae carried by pregnant females. Under these circumstances, a more active behavior, as it was observed in males (Schulte et al., 2007), might be too energy inefficient. Consequently, pregnant females may leave their hibernation shelters only if weather conditions are more favorable to increase the chance of finding food.

Spatial aspect

Our results show a significant sex-independent correlation between the distance to the breeding stream and the cosine-transformed as well as the sine-transformed days of the year. The shorter distance to the Anderbach in early spring could indicate that not only pregnant female fire salamanders that have to deposit their larvae move towards the breeding stream in early spring. Instead, adult individuals might move closer to the stream in general, as Manenti et al. (2017) already reported. For adult males, this possible migration pattern could be explained by them trying to mate with females that return from the larviposition (Manenti et al., 2017). In our study, a further distance to the stream during summer was also observed to be sex-independent. Perhaps there is no incentive for fire salamanders to cluster at the stream. Instead, reducing the density of individuals by dispersing further away could make it easier to find food and shelter.

Since the effect size for cosine- and sine-transformed days only have a small impact on the variance, other parameters might be more relevant. Possible alternative explanations for the observed spatial pattern could be linked to the specific relief of our study site (Figure A1 and Figure A2 of Appendix). Better hibernation shelters may be located closer to the stream (Thiesmeier and Günther, 1996), the food availability closer to the stream could be higher during breeding season (Manenti et al., 2017) or the microclimate differs on a local scale resulting in different regional activity periods throughout the year.

To assess whether supporting evidence for the observation of this study can also be found during other years and within different populations further research is needed. A capture-recapture approach or long-term tracking could give a deeper insight into the movement behavior of fire salamanders.

Body length

Regarding the total body length, adult females at Wilhelminenberg were on average longer than female individuals studied by Najbar et al. (2019) in Poland and around the same length as the individuals from the Vienna Woods studied by Martina Mayerhofer in 2012 and 2013 The mean total body length of male adults was higher than the mean total body length found in Poland. At the same time, the range was smaller but covered higher total body lengths.
According to Sinsch (2024), over 90% of the final body size in adult fire salamanders is gained before reaching sexual maturity. Therefore, the habitat quality affecting larvae and juveniles can potentially influence the growth rates and impact adult body sizes (Sinsch, 2024). For example, exposure to non-lethal heavy metal pollution in breeding streams was identified as the main environmental driver in the variation in adult size during a German study (Sinsch, 2024). Negative correlations between body size and population size have also been observed. This relationship may be a regulatory mechanism in population dynamics (Unglaub et al., 2018).

Table 4: Comparison of the total body length (tbl) between different studies regions.

	Szydlik 2025 Wilhelminenberg	**Mayerhofer 2013 Maurer Wald**	**Mayerhofer 2013 Moosgraben**	**Mayerhofer 2013 Neuwaldegg**	**Najbar et al. 2019 Poland**
tbl [mm] adult females					
mean ± sd	182.11 ± 16.74	190.3 ± 1.93	177.9 ± 1.41	181.7 ± 1.93	148.5 ± -
range	143 to 225	-	-	-	94 to 205
sample size	n = 90	n = 60	n = 140	n = 55	n = 786
tbl [mm] adult males					
mean ± sd	181.12 ± 15.28	-	-	-	147 ± -
range	140 to 224	-	-	-	97 to 210
sample size	n = 146	-	-	-	n = 774

From the data of this study, a significant sex difference in the average measure of size (bl and tbl) in adult fire salamanders was not observed. The absence of sexual dimorphism in body size was already described in fire salamanders during previous studies (Sinsch, 2024; Reinhard et al., 2015). In contrast, other studies reported sexual size dimorphism (SSD) (Najbar et al., 2019; Labus et al., 2013). A significant sex difference in body length can be potentially explained by females displaying a positive relationship between body size and fecundity (Shine, 1979; Salthe, 1969). Within 79 salamander species reviewed, Shine (1979) estimated female-biased SSD in 61 %, while male-biased SSD was only found in 19 % and 20 % did not express any SSD. In a study review on sexual dimorphism within *Salamandra*, *Lyciasalamandra*, *Mertiensiella* and *Chioglossa* with large sample sizes, Reinhard et al. (2015) reported a lack of SSD among the family of *Salamandridae*, referring to it as a "lineage-specific pattern". For anurans, variation in SSD between populations could also be explained by differences in age structures between the sexes (Monnet and Cherry, 2002). Varying results between different fire salamander populations were seen as indicators for possible influences of environmental parameters, such as altitude and habitat quality (Kiss et al., 2021). Reinhard et al. (2015) state the sexual dimorphism, among the salamander species reviewed in their research, is influenced by the combined effects of diverse selection pressures. So far, the drivers causing the high intraspecific variation in phenotypes of *Salamandra salamandra* are not fully understood (Alarcón-Ríos et al., 2020).

Body mass (weight)

For adult female fire salamanders from this study, the range of the body mass as well as its mean were higher than the body mass of females from the Vienna Woods studied by Martina Mayerhofer in 2012 and 2013 and from Poland studied by Najbar et al. from 2004 to 2016. The average body mass of male adults from the Wilhelminenberg was higher than in Poland while the range was smaller but covered higher body masses.
Dobson (1992) described two explanations for differences in structural size. Either, differences in body size are caused by plasticity in structural growth or due to increased body condition, as more energy reserves are stored (Dobson, 1992). Regarding mean total body lengths from our study being mostly longer compared to Najbar et al. (2019) and Mayerhofer (2013), higher mean body masses might be related to plasticity in growth rates. In some cases, like in comparison to female fire salamanders from Maurer Wald with longer mean total body lengths but lower mean body mass, a higher body condition could also be an explanation.

Table 5: Comparison of the total body weight between different studies and regions.

	Szydlik 2025 Wilhelminenberg	**Mayerhofer 2013 Maurer Wald**	**Mayerhofer 2013 Moosgraben**	**Mayerhofer 2013 Neuwaldegg**	**Najbar et al. 2019 Poland**
body mass [g] adult females					
mean ± sd	40.64 ± 10.39	37.9 ± 1.12	35.3 ± 0.56	38.3 ± 0.93	20.88 ± -
range	17.6 to 83.5	-	-	-	5.3 to 51.7
sample size	n = 93	n = 60	n = 140	n = 55	n = 902
body mass [g] adult males					
mean ± sd	31.56 ± 5.71	-	-	-	17.68 ± -
range	20.9 to 45.8	-	-	-	5.5 to 42.7
sample size	n = 150	-	-	-	n = 859

In this study, the average body mass in adult females was significantly higher than in adult males. Most likely, this difference is caused by the gain in weight in pregnant female fire salamanders.

Body condition - Scaled Mass Index (SMI)

Sex was identified as the main explanatory variable for the significant difference observed in SMI. Pregnant females with higher reproductive effort could considerably influence this result. During their pregnancy, more nutrition is needed to allow the development of the offspring wherefore weight is gained. For male fire salamanders, there is no need to store this additional energy.
Kiss et al. (2021) found no significant differences in the mean body condition index between adult male and female fire salamanders using the residuals of a linear regression between the log-transformed body mass and body length.

Conclusions and further perspectives

Our study revealed sex-dependent fluctuations in body condition (SMI) for the fire salamander population at Wilhelminenberg throughout the year. Our findings for male individuals are consistent with the results of Najbar et al. (2019). No comparable literature was found for the seasonal change of the SMI observed in females, but the pattern appears plausible. The variation in distance to the stream was sex-independent and may follow a seasonal pattern influenced by periodic movement habits. Further investigation is needed to assess whether a seasonal movement pattern can be concluded. Manenti et al. (2017) already observed a higher activity in adult fire salamanders of both sexes closer to the breeding site during early spring, suggesting this could be due to males trying to increase their chances of mating.

Compared to similar studies, the lack of sexual size dimorphism and the existence of sex-dependent body conditions within the population we investigated highlight the variation that can occur between fire salamander populations. Gaining knowledge about the range of intraspecific variability in amphibian species is important as it can facilitate the understanding of demographic resilience and evolutionary potentials of populations, improving management and conservation actions (Schlippe Justicia et al., 2023).

As underlying causes for variations between populations and seasonal patterns remain unclear, standardized long-term studies comparing different populations should be conducted. This allows the assessment of the consistency in seasonal changes in body condition, especially in adult females. For the investigation of the existence of seasonal movement patterns in fire salamanders and identification of underlying causes, additional variables such as the location of hibernation shelters may be beneficial. Tracking the movement of individuals by using specific tracking devices would enable a deeper insight into the behavior of fire salamanders.

Ethics statement

The permission to handle the individuals and sample data was given by the state of Vienna (Magistrat 22 Umweltschutz, from 05.04.2023, permit number: MA22-291870/2023).

Literature

Alarcón-Ríos, L., Nicieza, A. G., Kaliontzopoulou, A., Buckley, D., Velo-Antón, G. (2020). Evolutionary history and not heterochronic modifications associated with viviparity drive head shape differentiation in a reproductive polymorphic species, *Salamandra salamandra*. Evolutionary Biology, 47, 43-55. DOI: 10.1007/s11692-019-09489-3.

Alcobendas, M., Dopazo, H., Alberch, P. (1996). Geographic variation in allozymes of populations of *Salamandra salamandra* (Amphibia: Urodela) exhibiting distinct reproductive modes. *Journal of Evolutionary Biology,* 9(1), 83-102. DOI: 10.1046/j.1420-9101.1996.9010083.x.

Bodinof Jachowski, C. M., Alaasam, V., Blumenthal, A., Davis, A. K., Hopkins, W. A. (2024). The habitat quality paradox: loss of riparian forest cover leads to decreased risk of parasitism and improved body condition in an imperiled amphibian. *Conservation Physiology*, 12(1), coad101. DOI:10.1093/conphys/coad101.

Bogaerts, S., Lötters, S., Spitzen-van der Sluijs, A., Preißler, K., Caspers, B., Oswald, P., Michaels, C. J., ter Meulen, T., Reinhardt, T., Martel, A., Pasmans, F., (2021). EAZA Amphibian Taxon Advisory Group, Best Practice Guidelines (striped) fire salamander, *Salamandra salamandra* (*terrestris*). - First edition. European Association of Zoos and Aquariums, Amsterdam, The Netherlands.

Bosch, J., Martínez-Solano, I. (2006). Chytrid fungus infection related to unusual mortalities of *Salamandra salamandra* and *Bufo bufo* in the Peñalara Natural Park, Spain. *Oryx*, 40(1), 84-89. DOI: 10.1017/S0030605306000093.

Bucciarelli, G. M., Clark, M. A., Delaney, K. S., Riley, S. P. D., Shaffer, H. B., Fisher, R. N., Honeycutt, R., Kats, L. B. (2020). Amphibian responses in the aftermath of extreme climate events. *Scientific Reports*, 10(1), 3409. DOI: 10.1038/s41598-020-60122-2.

Buckley, L. B., Hurlbert, A. H., Jetz, W. (2012). Broad-scale ecological implications of ectothermy and endothermy in changing environments. *Global Ecology and Biogeography*, 21(9), 873–885. DOI: 10.1111/j.1466-8238.2011.00737.x.

Burgstaller, S., Leeb, C., Ringler, M., Gollmann, G. (2021). Demography and spatial activity of fire salamanders, *Salamandra salamandra* (Linnaeus, 1758), in two contrasting habitats in the Vienna Woods. *Herpetozoa*, 34(1), 23-34. DOI: 10.3897/herpetozoa.34.e58496.

Caruso, N. M., Sears, M. W., Adams, D. C., Lips, K. R. (2014). Widespread rapid reductions in body size of adult salamanders in response to climate change. *Global Change Biology*, 20(6), 1751–1759. DOI: 10.1111/gcb.12550.

Crowley, L., Ivison, K., Enston, A., Garrett, D., Sadler, J., Pritchard, J., Mackenzie, A., Hayward, S. (2023). A comparison of sampling methods and temporal patterns of arthropod abundance and diversity in a mature, temperate, Oak woodland. *Acta Oecologica*, 118(3-4), 103873. DOI: 10.1016/j.actao.2022.103873.

Dobson, F. S. (1992). Body mass, structural size, and life history patterns of the Columbian ground squirrel. *American Naturalist*, 140(1):109–125. DOI:10.1086/285405.

Egea-Serrano, A., Relyea, R. A., Tejedo, M., Torralva, M. (2012). Understanding of the impact of chemicals on amphibians: a meta-analytic review. *Ecology and Evolution*, 2(7), 1382-1397. DOI: 10.1002/ece3.249.

Feldmann, R., Klewen, R. (1981). Feuersalamander, *Salamandra salamandra terrestris* Lacépède, 1788. in: Feldmann, R. (Ed.): *Die Amphibien und Reptilien Westfalens* (pp. 30-44). *Abhandlungen des Landesmuseums der Naturkunde Münster*, 43.

Greven, H., Guex, G. D. (1994). Structural and Physiological Aspects of Viviparity in *Salamandra salamandra*. *Mertensiella*, 4, 139-160.

Hernández-Pacheco, R., Plard, F., Grayson, K. L., Steiner, U. K. (2021). Demographic consequences of changing body size in a terrestrial salamander. *Ecology and Evolution*, 11, 174-185. DOI: 10.1002/ece3.6988.

IPBES (2019). Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Brondízio, E. S., Settele, J., Díaz, S., Ngo, H. T. (Eds). IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1.

IUCN SSC Amphibian Specialist Group (2022). *Salamandra salamandra*. The IUCN Red List of Threatened Species 2022: e.T59467A79323745. DOI: 10.2305/IUCN.UK.2022-1.RLTS.T59467A79323745.en.

IUCN SSC Amphibian Specialist Group (2023). *Salamandra salamandra*. *The IUCN Red List of Threatened Species* 2023: e.T59467A219148292. DOI: 10.2305/IUCN.UK.2023-1.RLTS.T59467A219148292.en.

IUCN SSC Amphibian Specialist Group (2024). Amphibian conservation action plan: A status review and roadmap for global amphibian conservation. Wren, S., Borzée. A., Marcec-Greaves, R., Angulo, A. (Eds.). IUCN SSC Occasional Paper, No 57. Gland, Switzerland. *IUCN*. DOI: 10.2305/QWVH2717.

Juszczyk, W. (1987). Płazy i gady krajowe. PWN, Warszawa.

Kiss, I., Hamer, A., Vörös, J. (2021). Life history modelling reveals trends in fitness and apparent survival of an isolated *Salamandra salamandra* population in an urbanised landscape. *European Journal of Wildlife Research*, 67(1). DOI: 10.1007/s10344-021-01521-2**.**

Labocha, M. K., Schutz, H., Hayes, J.P. (2014). Which body condition index is best? *Oikos*, 123(1), 111-119. DOI: 10.1111/j.1600-0706.2013.00755.x.

Labus, N., Cvijanović, M., Vukov, T. (2013). Sexual size and shape dimorphism in *Salamandra salamandra* (Amphibia, Caudata, Salamandridae) from the central Balkans. *Archives of Biological Sciences*, 65(3), 969-975. DOI: 10.2298/ABS1303969L.

Leeb, C. (2013). Mass hibernation and notes on the winter activity of fire salamanders (*Salamandra salamandra*) in the Maurer Wald (Vienna, Austria). Master Thesis, University of Vienna, Vienna.

Lötters, S., Wagner, N., Albaladejo, G., Böning, P., Dalbeck, L., Düssel, H., Feldmeier, S., Guschal, M., Kirst, K., Ohlhoff, D., Preissler, K., Reinhardt, T., Schlüpmann, M., Schulte, U., Schulz, V., Steinfartz, S., Twietmeyer, S., Veith, M., Vences, M., Wegge, J. (2020). The amphibian pathogen *Batrachochytrium salamandrivorans* in the hotspot of its European invasive range: past–present–future. *Salamandra*, 56(3), 173-188.

Luedtke, J. A., Chanson, J., Neam, K. *et al.* (2023). Ongoing declines for the world's amphibians in the face of emerging threats. *Nature,* 622(1), 308-314. DOI: 10.1038/s41586-023-06578-4.

MacCracken, J. G., Stebbings, J. L. (2012). Test of a body condition index with amphibians. *Journal of Herpetology*, 46(3), 346-350. DOI: 10.2307/23326905.

Manenti, R., Conti, A., Pennati, R. (2017). Fire salamander (*Salamandra salamandra*) males' activity during breeding season: effects of microhabitat features and body size. *Acta Herpetologica*, 12(1), 29-36. DOI: 10.13128/Acta_Herpetol-18115.

Margenau, E., Spaid, S., Rucker L., Jacobsen C., Brown D. (2018). Modified salamander stick to facilitate accurate measurement of small individuals. *Herpetological Review*, 49(2), 243-246.

Mayerhofer, M. (2013). Life-history variation in fire salamanders (*Salamandra salamandra*, Linnaeus, 1758) in the Vienna Woods. Master Thesis, University of Vienna, Vienna.

Meikl, M., Reinthaler-Lottermoser, U., Weinke, E., Schwarzenbacher, R. (2010). Collection of Fire Salamander (*Salamandra salamandra*) and Alpine Salamander (*Salamandra atra*) distribution data in Austria using a new, community-based approach. *eco.mont*, 2(1), 59-65.

Najbar, A., Konowalik, A., Halupka, K., Najbar, B., Ogielska, M. (2019). Body size and life history traits of the fire salamander (*Salamandra salamandra*) from Poland. *Amphibia-Reptilia*, 41(1), 1-12. DOI: 10.1163/15685381-20191135.

Oswald, P., Schulte, L., Tunnat, B., Caspers, B. (2023). Population monitoring of European fire salamanders (Salamandra salamandra) with a new photo-recognition software. *Salamandra*, 59(2), 179–197.

Peig, J., Green, A. J. (2009). New perspectives for estimating body condition from mass/length data: the scaled mass index as an alternative method. *Oikos*, 118(12), 1883-1891. DOI: 10.1111/j.1600-0706.2009.17643.x.

Penner, J., Werning, H., Dubberke, V., Patanant, K., Rödel, M. O., Encke, B. (2022). Machbarkeitsstudie zur Ex-situ-Erhaltungszucht des Feuersalamanders (Salamandra salamandra) – das Beispiel Bayern. Version 1 vom 8.2.2022. DOI: 10.5281/zenodo.7665268.

R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Radchuk, V., Reed, T., Teplitsky, C., van de Pol, M., Charmantier, A., Hassall, C., Adamík, P., Adriaensen, F., Ahola, M., Arcese, P., Avilés, J., Balbontín, J., Berg, K., Borras, A., Burthe, S., Jean, C., Dehnhard, N., Lope, F., Dhondt, A., Kramer-Schadt, S. (2019). Adaptive responses of animals to climate change are most likely insufficient. *Nature Communications*, 10(1), 3109. DOI: 10.1038/s41467-019-10924-4.

Ranasinghe, R., Ruane A. C., Vautard, R., Arnell, N., Coppola, E., Cruz, F. A., Dessai, S., Islam, A. S., Rahimi, M., Ruiz Carrascal, D., Sillmann, J., Sylla, M. B., Tebaldi, C., Wang, W., Zaaboul, R. (2021). Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (Eds.)]. *Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA, 1767-1926, DOI: 10.1017/9781009157896.014.

Reading, C. J. (2007). Linking global warming to amphibian declines through its effect on female body condition and survivorship. *Oecologia*, 151(1), 125-31. DOI: 10.1007/s00442-006-0558-1.

Reinhard, S., Renner, S., Kupfer, A. (2015). Sexual dimorphism and age of Mediterranean salamanders. *Zoology*, 118(1), 19-26. DOI: 10.1016/j.zool.2014.08.002.

Roots, C. (2006). Hibernation. Westport, CT: Greenwood Publishing Group.

Rosa, G., Costa, A., Renet, J., Roner, L., Salvidio, S. (2021). Energy storage in salamanders' tails: the role of sex and ecology. *The Science of Nature*, 108, 27. DOI: 10.1007/s00114-021-01741-1.

Salthe, S. N. (1969). Reproductive modes and the number of sizes of ova in the urodeles. *American Midland Naturalist*, 81(2), 467-490. DOI: 10.2307/2423983.

Schlippe Justicia, L., Mayer, M., Lorioux-Chevalier, U., Dittrich, C., Rojas, B., Chouteau, M. (2023). Intraspecific divergence of sexual size dimorphism and reproductive strategies in a polytypic poison frog. *Evolutionary Ecology*, 38(1-2). DOI: 10.1007/s10682-023-10280-2.

Schulte, U., Küsters, D., Steinfartz, S. (2007). A PIT tag based analysis of annual movement patterns of adult fire salamanders (Salamandra salamandra) in a Middle European habitat. *Amphibia-Reptilia*. 28(4), 531-536. DOI: 10.1163/156853807782152543.

Secretariat of the Convention on Biological Diversity (2020). Global Biodiversity Outlook 5. Montreal. ISBN: 9789292256883.

Seyring, M., Barth, B., Bolte, L., Geiger, A., Grimm-Seyfarth, A., Günther, A., Bertram, S., Kasperidus, H., Langbehn, T., Lueg, H., Henle, K. (2024). Establishing standardized methods for analysing abundance trends of amphibians as a model group to assess the loss of biodiversity Empfehlungen zur Etablierung von Standardmethoden zur Ermittlung von Bestandstrends bei Amphibien als Modellgruppe für Biodiversitätsverlust. 90-113 in: Neue Methoden der Feldherpetologie (*Mertensiella* 32). Chimaira, Salzhemmendorf.

Shine, R. (1979). Sexual selection and sexual dimorphism in the amphibia. *Copeia*, 1979, 297-306.

Sinsch, U. (2024). Environmental Drivers of Local Demography and Size Plasticity in Fire Salamanders (*Salamandra salamandra*). *Animals*, 14(19), 2869. DOI: 10.3390/ ani14192869.

Spitzen-van der Sluijs, A., Martel, A. ,Asselberghs, J., Bales, E. K., Beukema, W., Bletz, M. C., Dalbeck, L., Goverse, E., Kerres, A., Kinet, T., Kirst, K., Laudelout, A., Marin da Fonte, L.F., Nöllert, A., Ohlhoff, D., Sabino-Pinto, J., Schmidt, B. R., Speybroeck, J., Spikmans, F., Steinfartz, S., Veith, M., Vences, M., Wagner, N., Pasmans, F., Lötters, S. (2016). Expanding Distribution of Lethal Amphibian Fungus *Batrachochytrium salamandrivorans* in Europe. *Emerging Infectious Diseases*, 22(7), 1286-8. DOI: 10.3201/eid2207.160109. Epub 2016 Jul 15.

Steinfartz, S, Weitere, M, Tautz, D. (2007). Tracing the first step to speciation: ecological and genetic differentiation of a salamander population in a small forest. *Molecular Ecology*, 16(21), 4550-4561. DOI: 10.1111/j.1365-294X.2007.03490.x.

Stevenson, R. D., Woods, W. A. (2006). Condition indices for conservation: new uses for evolving tools. *Integratve and Comparatve Biology*, 46(6), 1169-1190. DOI: 10.1093/icb/icl052.

Thiesmeier, B. (2004). Der Feuersalamander (p. 192). Bielefeld: Laurenti-Verlag. ISBN: 978-3-933066-21-3.

Thiesmeier, B., Günther, R. (1996). Feuersalamander – *Salamandra salamandra* (Linnaeus, 1758). 82-104 in: Günther, R.(Ed.): *Die Amphibien und Reptilien Deutschlands*. Fischer, Jena.

Unglaub, B. Steinfartz, S. Kühne, D. Haas, A. Schmidt, B. (2018). The relationships between habitat suitability, population size and body condition in a pond-breeding amphibian. *Basic and Applied Ecology*, 27. DOI: 10.1016/j.baae.2018.01.002.

Vié, J. C., Hilton-Taylor, C., Stuart, S. N. (Eds.) (2009). Wildlife in a Changing World – An Analysis of the 2008 IUCN Red List of Threatened Species. Gland, Switzerland. *IUCN*, 180 pages. ISBN: 978-2-8317-1063-1.

Vörös, J., Dankovics, R., Harmos, K., Dobay, G., Kiss, I. (2010). A foltos szalamandra (Salamandra salamandra) előfordulása és természetvédelmi helyzete Magyarországon. *Állattani Közlemények*, 95(1), 121-149.

While, G. M., Uller, T. (2014). Quo vadis amphibia? Global warming and breeding phenology in frogs, toads and salamanders. *Ecography*, 37(10), 921-929. DOI: 10.1111/ecog.00521.

Wilder, S. M., Raubenheimer, D., Simpson, S. J. (2016). Moving beyond body condition indices as an estimate of fitness in ecological and evolutionary studies. *Functional Ecology*, 30(1), 108-115. DOI: 10.1111/1365-2435.12460.

Womack, M., Steigerwald, E., Blackburn, D., Cannatella, D., Catenazzi, A., Che, J., Koo, M., Ron, S., Spencer, C., Vredenburg, V., Tarvin, R. (2022). State of the Amphibia 2020: A Review of Five Years of Amphibian Research and Existing Resources. *Ichthyology & Herpetology*, 110(4). DOI: 10.1643/h2022005.

Zakrzewski, M. (2007). Salamandra plamista. Rozmieszczenie, biologia i zagrozenia. Wydawnictwo Naukowe Akademii Pedagogicznej, Kraków.

Appendix

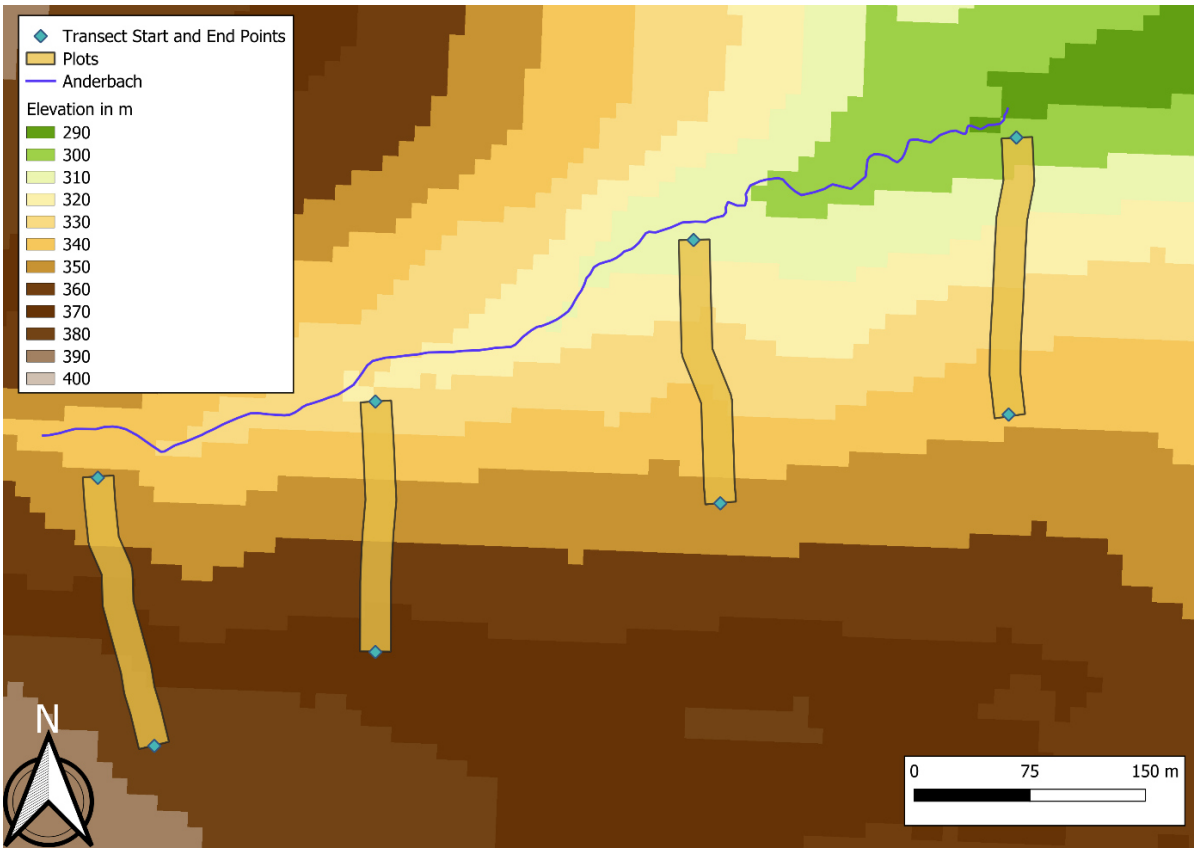

Figure A1: Reclassified elevation lines within the study site. The original contour lines were Open Government Data contour lines provided by the GeoServer Web Map Service: https://data.wien.gv.at/daten/geo?version=1.3.0&

Figure A2: The terrain at the study site. The "Geoland Basemap Gelände" from the WMTS server https://maps.wien.gv.at/basemap/1.0.0/WMTSCapabilities.xml was used as background.

Zusammenfassung

Im Zuge des derzeitigen weltweiten Amphibiensterbens können selbst weit verbreitete Arten wie der Feuersalamander aufgrund verschiedener Bedrohungen stark abnehmen. Während sich der Erhaltungszustand voraussichtlich weiter verschlechtern und durch die zunehmenden Auswirkungen des Klimawandels noch verschärfen wird, ist ein umfassendes Monitoring sowie ein tiefergehendes Verständnis der natürlichen Entwicklungen innerhalb gesunder Feuersalamanderpopulationen dringend erforderlich. Im Rahmen dieser Studie wurde eine Population von Feuersalamandern am Wilhelminenberg in Wien beobachtet, um die Körperkondition und die räumliche Verteilung der adulten Individuen über ein Jahr hinweg zu verfolgen. Zwischen November 2023 und Oktober 2024 wurden von den insgesamt 378 gefangenen Tieren 284 unterschiedliche Individuen identifiziert. Die Fluktuation der Körperkondition über das Jahr hinweg zeigte bei den Geschlechtern ein unterschiedliches Muster. Die Körperkondition der adulten Männchen war im Sommer am höchsten, was wahrscheinlich auf das günstige Nahrungsangebot in den vorangegangenen Monaten zurückzuführen ist. Die verstärkten Paarungsbemühungen im Herbst könnten die Abnahme der Körperkondition im Herbst erklären, die im Winter ihren Tiefpunkt erreichte. Bei den Weibchen stieg während der Schwangerschaft im Winter die Körperkondition an und nahm im Frühjahr nach dem Absetzen der Larven ab. Die Entfernung der Individuen zum Laichgewässer zeigte im Jahresverlauf den Trend einer geschlechtsunabhängigen Fluktuation. Die tendenziell höhere Aktivität der Feuersalamander in der Nähe des Baches während der Brutzeit könnte darin begründet sein, dass die Weibchen ihre Larven absetzen und die Männchen ihre Chancen auf eine potentielle Paarung erhöhen.

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