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Mikołaj Kaczmarski, Łukasz Dylewski, Tomasz Maliński, Piotr Tryjanowski*

Among the trees: shade promotes the growth and higher survival of juvenile toads

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Abstract: Vegetation, including trees, significantly shapes microhabitats for amphibians due to the leaf litter input, providing stable shelter, creating a microclimate or indirectly through trophic interactions. It is known that some species can survive in a highly modified urban environment. Species associated with open space can find stable habitats in urban and human-transformed areas, but is the impact of shading (presence of canopy cover) significant in their case? We focus on the effect of solar exposure on the growth rate of juvenile green toads *Bufotes viridis* in fruit and canopy manipulation treatments. The main aim of the study was to examine the selected habitat traits promoting post-metamorphic growth of the green toad in semi-open enclosures. We investigated differences between exposure/land cover variants, i.e., sunny site (open area with direct solar exposure) and shadow site (shady site with a tree canopy cover). Using imitation fruits and real cherry plum *Prunus cerasifera* fruits (non-native tree species), we checked whether amphibian growth is related to the additional structure that fruit lying on the ground created (a more heterogeneous surface structure) or to a trophic character (additional food source due to attracting invertebrates). We conducted a 40-day rearing experiment in three variants with two replications in semi-open enclosures with 20 juvenile toads each. We found differences in snout-vent length and body mass index investigated due to site exposure during post-metamorphic growth. The survival rate of juvenile toads in the shaded site was higher than in sunny sites. We demonstrated a positive effect of the tree's shade, regardless of the fleshy fruit's presence on the ground. Toads benefit from developing at sites with reduced solar exposure (i.e., with a tree canopy), resulting in intensive growth and higher survival rate. Thus, there is an opportunity for planners and urban authorities to manage habitats for amphibian conservation purposes by creating a shaded zone, even for open habitat species, especially in transformed areas such as cities. Our results indicate that the beneficial effect of the lying fruit on the growth of juveniles is limited to specific conditions, and understanding this requires further research.

Keywords: *Bufotes viridis*, growth rate, *Prunus*, survival pattern, tree canopy, urban ecology

Addresses: M. Kaczmarski, Ł. Dylewski, P. Tryjanowski, Department of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71c, PL 60-625, Poznań, Poland;
MK https://orcid.org/0000-0002-3341-0933, e-mail: traszka.com@gmail.com;
ŁD https://orcid.org/0000-0002-1370-7625, e-mail: lukasz.dylewski@up.poznan.pl;
PT https://orcid.org/0000-0002-8358-0797, e-mail: piotr.tryjanowski@gmail.com
T. Maliński, Department of Botany and Forest Habitats, Poznań University of Life Sciences, Poznań, Poland; https://orcid.org/0000-0001-5311-4421, e-mail: tomasz.malinski@up.poznan.pl
* corresponding author

Introduction

Amphibians have been heavily affected by habitat alteration, and urbanization appears to be a global trend that threatens them on a large scale (Nowakowski et al., 2018; Pyron, 2018). It is known that urbanized areas with a mosaic of lethal and suboptimal habitats constitute a harsh habitat for most amphibian species, and only some generalists can fully use the available niches and maintain sustainable populations in the long term (Hamer & McDonnell, 2008; Nowakowski et al., 2018). Nevertheless, amphibians still occur in many urban habitats like ponds, small lakes, river valleys, or artificial water bodies, and amphibian communities in urban areas may be similar to those outside the cities and frequently have a significant biodiversity value (Kaczmarski et al., 2020; Konowalik et al., 2020). Regardless of the origin and utility functions, such urban sites often have a significant conservation value and are biodiversity refuges in urban ecosystems (Hamer, 2022; Hamer & McDonnell, 2008; Holtmann et al., 2017). However, progressive urbanization transforms habitats into increasingly unfavourable conditions, driving many species of amphibians towards a widespread decline mainly due to habitat loss or degradation, fragmentation, isolation or direct mortality (Baillie et al., 2004; Hamer & McDonnell, 2008). Consequently, many amphibian populations in urban areas become small, burdened with inbreeding, and more exposed to the risk of extinction (Hamer & McDonnell, 2008; Nowakowski et al., 2018; Pyron, 2018; but see Jehle et al., 2023).

Survival in an urban area is often associated with remnants of near-natural habitats, even relatively small habitat patches (Kaczmarski & Kaczmarek, 2016; Kiss et al., 2021). Population persistence decreases in isolated patches, and the risk of stochastic processes significantly increases, so such places require special attention and proper management to stop negative processes (Lambert & Donihue, 2020). From a broader perspective, most species require high connectivity within a stable green and blue infrastructure network to persist (Löfvenhaft et al., 2004). The critical landscape features are linear shrub strips, extensive water networks, and woodland areas (Ficetola & De Bernardi, 2004). As far as we know, vegetation, including trees, significantly shapes microhabitats for amphibians due to the leaf litter input, providing stable shelter or creating a microclimate (Burrow & Maerz, 2022; Shoo et al., 2011; Skelly et al., 2014; Stephens et al., 2013; Stoler & Relyea, 2021). In this context, tree species composition, or canopy cover by itself close to amphibian breeding ponds, may affect species differently; for instance, some of the recommendations indicate the beneficial effect of selective removal of shoreline trees to improve thermal conditions in the reservoir (Skelly et al., 2014). The issue of reducing the tree cover and creating open space close to breeding sites to improve mating and development conditions for amphibian larvae is an interesting issue that has been tested mainly in forest areas. Thus, it is worth considering how these recommendations and experiences can be transferred to urban areas. This issue is of particular importance because removing trees is treated as a negative trend in green spaces, e.g. due to the need to adapt cities to climate change and the undisputed role of trees in lowering air temperature and reducing the heat island effect (Kronenberg, 2012; Ziter et al., 2019). It seems that understanding the issue of the impact of shading (presence of canopy cover) on amphibians is crucial in the context of species preferring open areas because some of them find stable habitats in urban and human-transformed areas.

A species that meets the above criteria and, in our opinion, requires a study to understand better which factors influence its success in urban areas of Central Europe is the European green toad *Bufotes viridis* Laurenti, 1768 (hereinafter green toads). This typical pioneer species prefer open landscapes, can live in very large populations even in heavily transformed areas within the cities and is an excellent example of an urban adapter (Ensabella et al., 2003; Kaczmarski et al., 2019a; Mazgajska & Mazgajski, 2020; Sistani et al., 2021). The green toad is a strictly protected species in Poland that generally maintains a stable population trend at a national level (Pabijan & Ogielska, 2019). However, this toad is losing many breeding sites and is disappearing from urban areas, notably when its populations are not recognized and appropriately managed (Kaczmarek et al., 2015; Mazgajska & Mazgajski, 2020). Despite its widely-known high level ability to adapt to human-altered habitats, some records indicated declines in some parts of its range (IUCN, 2018).

Previous research indicated that cherry plum *Prunus cerasifera* Ehrh. fruits lying on the ground in experimental conditions in a partly shaded site have a supporting effect on the growth of juvenile green toads, possibly due to the attracted insects that are then eaten by the toads (Kaczmarski et al., 2019b). *Prunus cerasifera* is a non-native tree species, kenophyte, that was initially a cultivated plant and nowadays has entered the landscape to various habitats. This species grows well and spreads mainly in habitats transformed by humans, such as roadsides or wastelands, within cities and the agricultural landscape (Tokarska-Guzik et al., 2012; Dylewski et al., 2022). It is observed that *P. cerasifera* can gradually expand its habitat range and colonize more natural areas (Czortek et al., 2023). Under favourable conditions, it produces abundant fruit, which falls to

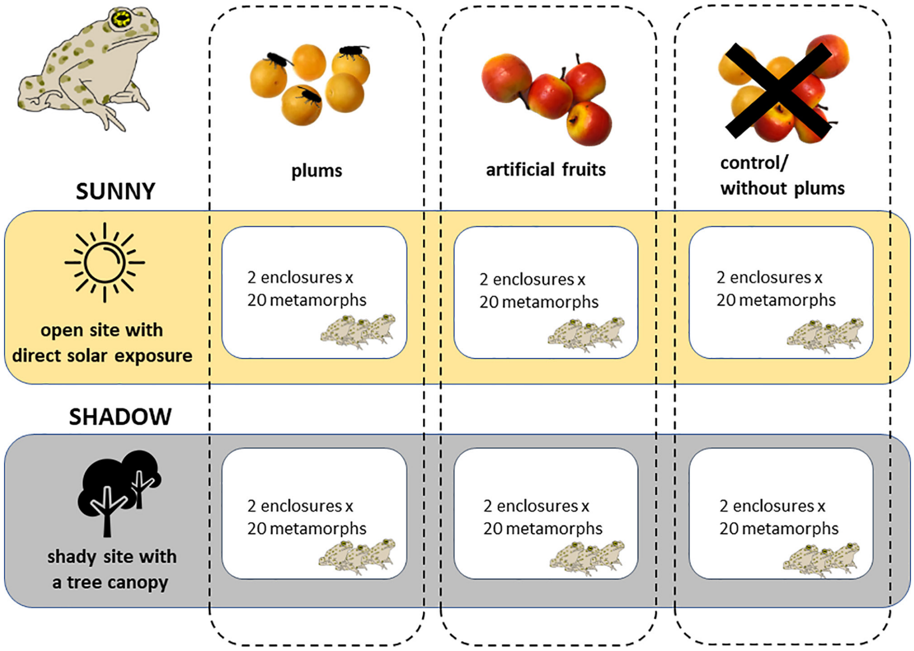

Fig. 1. The experimental setup: two different extreme variants of exposure – 1. sunny site (open site with direct solar exposure) vs – 2. shadow site (shady site with a tree canopy cover) and three experimental treatments: 1: real plum, 2: artificial fruit, 3: control/without plums

the ground, constituting an attractive food source for many animals, especially in urban areas. In the current research, we decided to determine the impact of other factors in the fruit manipulation treatment, i.e. site exposures to solar radiation, which would better reflect the habitat requirements of the study toad species in real urban settings. To verify the strength of the exposition effect, we decided to test two extreme sun exposure variants: sunny site (open area with direct solar exposure) vs shaded site (with a tree canopy cover). Furthermore, to check whether the factor supporting the faster growth of the toad is the insects attracted by fruit or the mere presence of a more heterogeneous structure of the ground surface (i.e. when the fruit is lying on it), we additionally tested a treatment with imitation (artificial) fruit. Thus, we tested three treatments of fruits lying on the ground: 1: real plums, 2: artificial fruit, 3: control/without fruit, under two exposure conditions (shaded vs sunny sites) to investigate the effect of fleshy fruit on toads' growth (Fig. 1).

Methods

The experiment was performed in July-August 2019 at the two exposure/land cover variants: 1) sunny open site (open area with direct solar exposure, hereafter: sunny site, 52°25'38.3"N, 16°53'38.4"E) and 2) shaded site (shady site with a tree canopy cover, hereafter: shadow site 52°25'40.7"N, 16°53'49.2"E) at the Dendrological Garden, Poznań University of Life Sciences. The shadow site was located inside an extensively used park dominated by tree species native to NW Poland, including Scots pine *Pinus sylvestris*, silver birch *Betula pendula*, Norway maple *Acer platanoides*, and a few non-native tree species: black locust *Robinia pseudoacacia* and Douglas fir *Pseudotsuga menziesii*. At the ground level, well-developed litter with elements of deadwood dominated. The sunny site was located on the edge of extensively used meadows, on an educational garden and experimental plots near a few old trees: a black locust and the sycamore maple *Acer pseudoplatanus*. Herbaceous and grassy vegetation dominated at the ground level and was mowed at least once a year. Three treatments, two with fruit, characterized by a more heterogeneous surface structure (1. plums, 2. artificial fruit), and one homogeneous surface without any fruits (3. controls), replicated twice and were evenly distributed in both exposure/land cover variants, were used in the study (Fig. 1). In line with a previous study, we used the cherry plum (also commonly known as the myrobalan plum, Fig. 2), as a fleshy fruit lying on the ground (Kaczmarski et al., 2019b). Artificial fruits were purchased from a commercial supplier offering decorative items, while the myrobalan plums were collected near the study sites.

Acquisition and rearing of animals

We used freshly metamorphosed individuals of the green toad as model species. Juvenile toads were collected near natal water bodies on the same day (July 19) during post-metamorphic dispersion. All individuals originated from a city centre population living in a fountain and a small patch of a green area (52°24'04.7"N, 16°54'54.9"E; more details: Kaczmarski et al., 2019b; Zawadzki et al., 2017).

We adopted an experimental design from a previous study (for more details, see: Kaczmarski et al., 2019b). However, we have made some modifications to the earlier research protocol. We changed the location of the experimental setup from a partly shaded site to the two extreme solar exposure variants mentioned above (shaded, with tree canopy vs sunny open site with direct solar exposure). Compared to the previous experiment, we reduced the group size from 30 to 20 individuals due to the species conservation status and the decline described above to maintain the number of replications in all treatments and, due to not significantly increasing the number of animals used in the research. Consequently, we also decided to reduce the surface covered with fruit from 0.5 m^2 to 0.25 m^2 (Fig. 2). After capture, the animals were randomly assigned to one of the experimental groups, with 20 juveniles per enclosure with the following dimensions: 1 × 1 × 0.5 m. Next, the toads were acclimatized for seven days (ending July 26), and after this time, fruit (real plums or artificial fruit) were placed in the enclosures. The experimental objects: plums (fleshy fruit) or artificial fruit, were located in the central part of the enclosure and covered an area of about 0.25 m^2 (Fig. 2), while control treatments were left without any fruits. Each enclosure contained layers of soil a few centimetres deep, an artificial hiding place (plastic stands), and one shallow bowl with water so all animals could rehydrate freely. Irrespective, enclosures were sprinkled with water every second day due to the risk of excessive drying of the animals due to the drought prevailing during the experiment. Regular irrigation of enclosures initiated seed bank germination and herbaceous vegetation growth within a few days. According to Kaczmarski et al. (2019b), experiment groups were fed every two days with various live insects from a commercial supplier, such as small crickets, *Acyrthosiphon pisum*, *Callosobruchus* spp., and *Shelfordella lateralis*. The distance between each enclosure was not less than 1 m. Each enclosure was covered with a mesh that protected the amphibians from predators such as birds and feral cats but allowed invertebrates (mostly flying

Fig. 2. Top of the panel – one of the semi-open enclosures during the second experimental week (treatment in the shadow site with real plums). Bottom of the panel – decomposing/rotten fruit of the cherry plum *Prunus cerasifera* (non-native tree species, commonly known as the myrobalan plum) and fruit fly *Drosophila* sp. sitting on plums during the experiment

insects, ants and snails) to get in. Therefore, during the experiment, the juvenile toads could freely forage on invertebrates attracted by decomposing fleshy fruit entering our semi-open enclosures through the upper part (Fig. 2).

Morphometric measurements

Throughout the experiment, snout-vent length (SVL) was measured to the nearest 0.01 mm with a digital calliper, and body mass was recorded to the nearest 0.01 g with portable electronic scales. These are standard measurements performed when studying amphibians, including toads. The same observer measured and recorded both parameters during the whole experiment. Measurements were carried out seven times, every seven days on average (± 1 day), for 44 days, between 10.00 and 12.00, and were conducted on all individuals from all enclosures/treatments. The body mass index (BMI) was calculated according to the following equation: (body mass (g)/ SVL^2 (mm) ×1000 (Labocha et al., 2014)).

Data processing and statistical analysis

For analyses, we used the mean value of body mass, SVL, and BMI for each enclosure for each measurement period. One of our enclosures (a control group) was excluded from the statistical analyses because the wall was damaged, and all the toads escaped. Consequently, the numbers of replications were not equal along the experimental gradient.

Mixed models were used to test the effects of exposure (sunny and shadow) and treatments (control, artificial fruit, real plums) on the body mass index, body mass, and SVL. Time (days of the experiment) was a continuous variable. Moreover, the quadratic terms for time allow for a non-linear relationship in each model, as supported by the improvement of the model AICc score (BMI AICc = −6.69; body mass AICc = −11.61; SVL AICc = −4.19). In addition, the following interactions were added to each model: time × exposure and time × treatments. Each model used the enclosures' ID and time as random factors.

Survival analyses were applied to test the effect of the study treatment on toads' mortality. The interval for obtaining estimates was seven days from the start to the end of the experiment. We used Cox's proportional hazards model to determine how the different factors (exposure and treatments) affected the probability of toads' survival (Cox, 1972). First, we developed a full model examining the effects of exposure and variant of their interaction: exposure x treatments, on the probability of toads' survival. Additionally, the two Cox's models explore the effects of exposure on the probability of toads' survival by treatments separately.

The mixed models were carried out in R 4.0.0 (R Core Team, 2020), and the survival analysis was carried out in survival packages (Therneau, 2021). Models' validation were carried out using the DHARMa package (Hartig, 2017). The graphical visualizations were performed in the ggplot2 packages (Wickham, 2016).

Results

Morphometric measurements

We determined a significant non-linear relationship between time and three tested parameters: BMI, body mass and SVL ($p<0.05$, Table 1). We found significant differences between exposure (shadow vs sunny sites) for SVL ($p=0.017$, Table 1, Fig. 3a) and BMI ($p=0.025$, Table 1, Fig. 3c) and weakly significant differences in body mass ($p=0.057$, Table 1, Fig. 3b). The values were lower in sunny enclosures site than in shaded enclosures site in all tested parameters (BMI, SVL, body mass, Fig. 3). Moreover, in the case of body mass, we found that the interaction time × exposure was significant ($p=0.004$, Table 1, Fig. 4), whereas, in the sunny site, the body mass growth rate increased less than in the shadow site.

Table 1. Results of mixed models for SVL, body mass, and BMI of the green toads *Bufotes viridis*. Statistically significant results are marked in bold

	F	df	P
SVL			
Time	1.06	1,4.48	0.354
Time²	**8.12**	**1,4.00**	**0.046**
Exposure	**7.16**	**1,8.97**	**0.025**
Treatments	0.06	2,8.97	0.945
Time × Exposure	1.13	1,51.00	0.292
Time × Treatments	1.88	1,51.00	0.163
Body mass			
Time	1.24	1,4.59	0.319
Time²	**32.91**	**1,4.00**	**0.005**
Exposure	4.67	1,9.57	0.057
Treatments	0.15	2,9.57	0.857
Time × Exposure	**9.31**	**1,51.00**	**0.004**
Time × Treatments	2.21	2,51.00	0.119
BMI			
Time	5.73	1,4.24	0.071
Time²	**12.24**	**1,4.00**	**0.025**
Exposure	**7.02**	**1,15.92**	**0.017**
Treatments	0.40	2,15.92	0.677
Time × Exposure	0.60	1,51.00	0.442
Time × Treatments	1.78	2,51.00	0.178

SVL – snout-vent length; BMI – body mass index; Time – experiment time; Exposure variants – shady or open/solar exposure site; Treatments: plums, artificial fruits, controls.

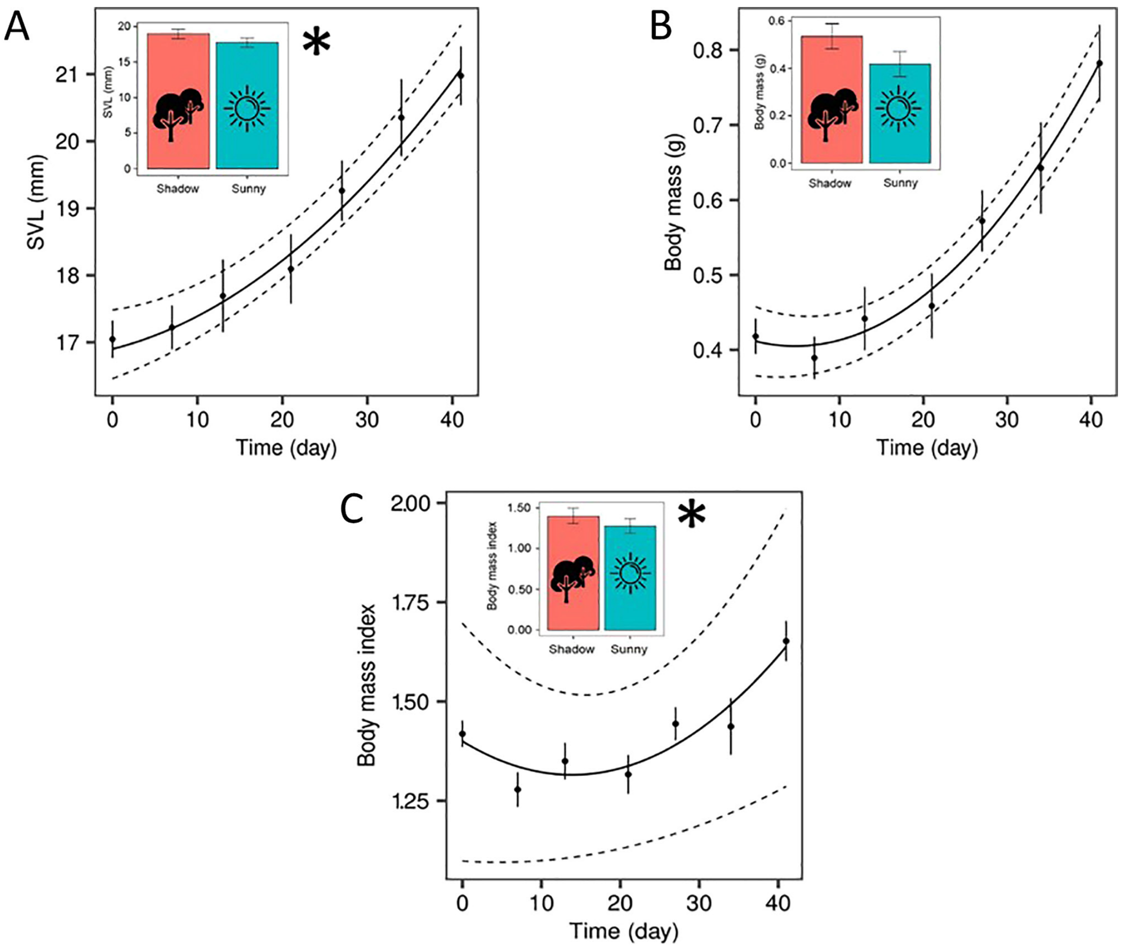

Fig. 3. Plots present the average value for the day for: (A) SVL, (B) body mass, (C) body mass index of juvenile toads during the experiment. Exposure variants: sunny site (open site with direct solar exposure) and shadow site (shady site with a tree canopy cover). Black line - fitted line; dashed line – 95%CI. An asterisk indicates statistically significant differences

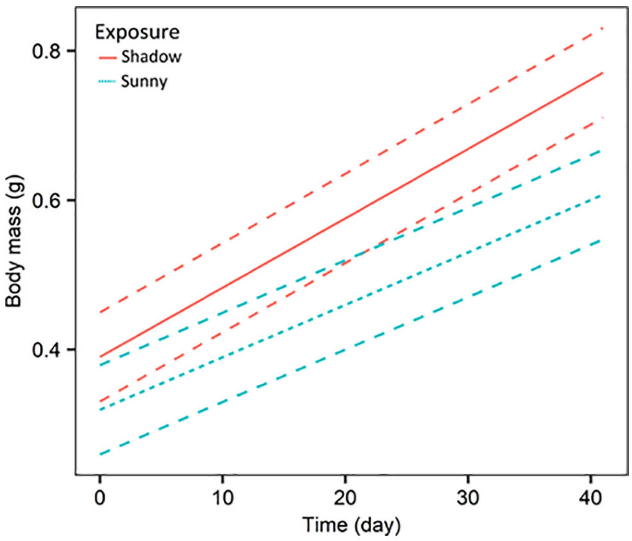

Fig. 4. Plot representing the body mass of juvenile toads during the experiment. Exposure variants: sunny site (open site with direct solar exposure) represented by a blue dotted line, and shadow site (shady site with a tree canopy cover) represented by a red solid line. Dashed line – 95%CI

Juvenile survival

The Cox's proportional hazard analysis for the full model was significant overall (χ^2=24.92, df=5, p<0.001), with exposure (χ^2 = 12.21, df=1, p<0.001), treatments (χ^2=10.19, df=2, p=0.006), except for interaction (χ^2=4.38, df=2, p=0.111) significantly influencing the probability of juveniles' survival (Fig. 5a). In separate models, treatments' effect did not differ in the shadow site (χ^2=0.20, df=2, p=0.910; Fig. 5b) but did so in the sunny site (χ^2=15.04, df=2, p<0.001; Fig. 5c). The probability of survival in the sunny site enclosure was significantly different between control and artificial fruit treatments (p<0.01) and between control and real plums (p>0.01), where the probability of survival was lower for the control treatment compared to the two others (Fig. 5c). No significant differences were found between an artificial fruit and a real plum (p>0.05) in the sunny site exposure (Fig. 5c).

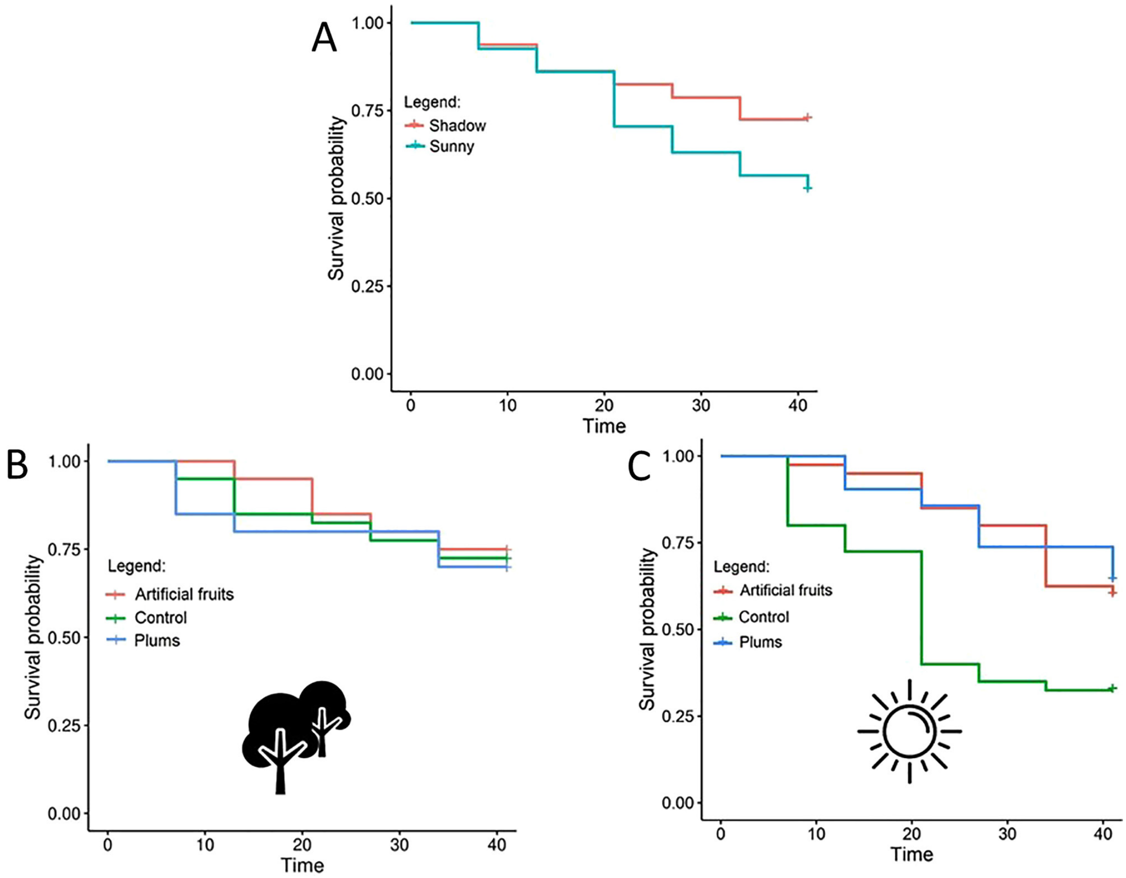

Fig. 5. Juvenile toads survival probability in the experimental exposure: plot A – compared shadow site vs sunny site - significant differences $p<0.001$; plot B – shadow site, results divided into experimental treatments, no significant difference $p>0.05$; plot C – sunny site, results divided into experimental treatments, significant differences $p<0.001$.

Discussion

The solar exposure of the experimental enclosures is the factor influencing two analyzed toads' body characteristics, i.e., SVL and BMI (Table 1, Fig. 3). More precisely, we detected that a shaded site (with a tree canopy) is more favourable to the growth of juvenile green toads. Furthermore, the exposure also significantly impacted individuals' survival, being higher in the shadow site (Fig. 5a). This is consistent with our hypothesis that the growth effect varies between the exposure/land cover variants, i.e., shadow site (shady with a tree canopy) and sunny sites (with direct solar exposure). We interpret the obtained result in the context of stress-related response to high insolation and higher temperatures in the area with limited canopy cover, without any tall vegetation (Shoo et al., 2011). We also assume that the effectiveness and intensity of foraging may be higher in humid conditions under the tree canopy. Unfortunately, we did not control the temperature and humidity during the research, thus we do not know the exact difference in conditions on the ground surface between the sites. Our results are consistent with the literature data, which indicate that plants can strongly affect the thermal and hydric environments experienced by terrestrial amphibians by limiting solar exposure (Burrow & Maerz, 2022). Generally, amphibians are characterized by low skin resistance to water loss, which differs between species and in terms of realized niche/ecological habitat (aquatic, terrestrial and arboreal specializations) (Young et al., 2005). Adult green toads prefer warm and open habitats with direct solar exposure, but their ability to survive depends on the size of the body (Kuzmin, 2001). We can assume that for juveniles whose weight fluctuates around 0.3 g, direct solar exposure to the surface of the habitat represents a high-risk factor. At the same time, such conditions are not lethal to adult toads because with increasing body size, the resistance of amphibians to drying increases (Tracy et al., 2010). Body size has a weak effect on absolute dehydration tolerance; nevertheless, it takes longer for bigger individuals to reach a critical level of dehydration because they possess richer water reserves (Newman & Dunham, 1994). Therefore, due to desiccation risk, the solar exposure habitat without a sufficient canopy cover is not favourable to growth during post-metamorphosis, even though such open areas may be preferential to adult individuals (Kuzmin, 2001). Our result emphasizes the role of vegetation shading the ground surface as a factor favouring the development of juvenile green toads.

Knowledge about the impacts of various stress factors on the larval forms of amphibians is growing. Still, it lacks research concentrating on the effects of habitat changes on juveniles, i.e., individuals after metamorphosis, particularly in terrestrial habitats (deMaynadier & Hunter, 1999; Petrovan & Schmidt, 2019). While sunny breeding sites are considered beneficial for amphibians, especially in the temperate climate zone, larger-scale felling can negatively affect survival in terrestrial habitats (Skelly et al., 2014). As far as we know, the effect of the canopy cover on amphibians has been tested on larvae developing in water bodies of varying exposure or during field studies based on changes in the land cover caused by industrial logging (Burrow & Maerz, 2022; Skelly et al., 2014; Skelly et al., 2005). Thus, most field-based studies investigating the effect of canopy cover on amphibian populations mainly concern issues related to woodland management and the impact of logging on individual species, including their behaviour and habitat preferences (Vuorio et al., 2015). Sometimes, slight changes in the habitat, such as a change in the canopy cover, may cause a decline in the amphibian population, mainly due to a drastic reduction in the recruitment of young amphibians to the breeding population (Bodinof Jachowski & Hopkins, 2018). With progressing urbanization, there is an opportunity to transfer existing knowledge on the impact of forest management on amphibians to urbanized areas, particularly in creating a favourable habitat near water reservoirs. Our research shows that the difference in exposure alone affects the growth of amphibians, which could have further consequences. Reduced juvenile growth dynamics at direct solar exposure sites may negatively affect the overwintering of toads because smaller specimens have a lower survival rate during hibernation (Sinsch & Schäfer, 2016), and they are also more susceptible to diseases (Smith et al., 2022). Thus, differences in the canopy cover shift the recruitment probability of the young generation into the reproductive population. Therefore, our results are significant because they can help create an amphibian-friendly landscape or inform the planning of urban habitat management and identify resources or key microhabitat characteristics essential for this process, which is a considerable challenge to protect this animal group (Guderyahn et al., 2016; Holtmann et al., 2017; Mathwin et al., 2020). Based on our results, we believe it is worth paying attention to the risk of reducing natural shrub and woody vegetation observed close to natural habitats and urbanized areas (Andrew & Slater, 2014; Conway, 2016; Kronenberg, 2012). Such practices may impact the reduced ecosystem services and threaten populations of species considered urban adapters, such as the green toad, through overexposure to solar radiation and, consequently, lead to overheating of habitats, and hence growth limitation because of thermal stress or direct mortality.

In our earlier study, metamorphs of the green toads with access to fleshy fruit (plums) lying on the ground achieved a higher growth rate than the control (Kaczmarski et al., 2019b). In the current study, we did not find any differences in the growth rate of individuals within the three experiment variants: plums, artificial fruit, and controls. Hence, we cannot confirm the hypothesis that the observed growth effect is related to the additional structure that the fruits create or the indirect influence of the fruits themselves. We interpreted those unexpected differences in the development of amphibians based on the changes in experimental conditions and the effect of a dry year (ongoing drought). More precisely, in the current experimental setup, we decided to change the location of the enclosures, moving them from a partially shaded site to two extremes: sunny versus shaded exposition, which changed the conditions. Moreover, due to the group size reduction from 30 to 20 individuals compared to the previous experiment, we decided also to reduce the surface covered with fruit from 0.5 m^2 to 0.25 m^2. Finally, this study was conducted during the year subsequent to ongoing drought (Ionita et al., 2021). This phenomenon substantially impacts ecosystems and may contribute to the further decline in the number of insects noted in Europe (Hallmann et al., 2017). This affects amphibians as predators, possibly modifying their activity and food-base availability. Interestingly, in the sunny sites variant, individuals from the control group, without any surface structure, showed the lowest survival (Fig. 5c). Thus, it may be a premise for further research on the role of the structure formed by fruit or other objects on the soil surface. Growth rates and survival were higher in the shaded site than in the direct solar exposure site. Also, we found that body mass rate is related to the exposure in time (Fig. 4). Obtained result confirms the role of shade rather than indirect trophic interactions. However, we realize that adding artificial prey items in our experimental setups may also have reduced the benefit of the fruit-attracting invertebrate prey. Therefore, our results indicate that the beneficial effect of fruit lying on the growth of juveniles is limited to specific conditions and understanding this requires further research.

Conclusion

The positive effect of the shade created by the tree was identified, regardless of fleshy fruit acting as an insect attractant. Juvenile green toads have a more intense growth rate at shadow sites with reduced solar exposure. In the shadow site, animals also had higher survival rates, similar to the sunny site with surface structures created by fruits (real and artificial) but not in control. Thus, juvenile toads benefit from tree canopy protection through ground shading and a more heterogeneous habitat structure. We conclude there is an opportunity for planners and urban authorities to manage habitats for amphibian conservation purposes by creating a shaded zone near breeding sites, even for open habitat species, especially in transformed areas such as cities. Finally, the beneficial effect of decomposing fleshy fruit lying on the ground on the growth of juveniles is limited to specific conditions.

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Author contributions

MK: contributions to concept/design, acquisition of data, data analysis/interpretation, drafting and critical revision of the manuscript, and approval of the article; ŁD: data analysis/interpretation, drafting and critical revision of the manuscript, and approval of the article; TM: fieldwork, critical revision of the manuscript, and approval of the article; PT: contributions to concept/design, critical revision of the manuscript, and approval of the article.

Ethics statement

This research complied with the current laws in Poland and was performed with appropriate collection and research permits (from the Regional Director of Environmental Protection: WPN-II.6401.223.2019.AG). We followed all applicable institutional and national guidelines for the care and use of animals. Moreover, the Polish Laboratory Animal Science Association trained the principal investigator (MK).

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