

## Reproductive ecology of Anuran Amphibians: Effects of internal and external factors

G. A. Ivanov<sup>1✉</sup>, M. V. Yermokhin<sup>1</sup>, V. V. Tabachishin<sup>1</sup>, V. G. Tabachishin<sup>2</sup>

<sup>1</sup> Saratov State University

83 Astrakhanskaya St., Saratov 410012, Russia

<sup>2</sup> Saratov Branch of A. N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences

24 Rabochaya St., Saratov 410028, Russia

### Article info

#### Review

<https://doi.org/10.18500/1814-6090-2023-23-1-2-3-26>

EDN: XXKIUN

Received December 17, 2023,  
revised January 23, 2023,  
accepted January 23, 2023,  
published June 30, 2023

**Abstract.** This research paper examines the influence of internal factors (female body weight, body condition) and external ecological factors on the reproductive parameters of females, as well as on the reproductive ecology of adult individuals of anuran amphibians. Among the most significant reproductive characteristics of females are the number of eggs in a clutch, the proportion of reproductive products to female body weight (contribution to reproduction), and the average weight of eggs. The body weight of the female and the ecological (meteorological) conditions of her activity during the year preceding spawning, as well as the hibernation conditions, have the greatest impact on the quantitative expression of these parameters. The proportion of reproductive products to female body weight in anuran amphibians usually ranges from 13 to 30%. Climate warming can directly affect the reproductive parameters of females, the survival of metamorphs, and the phenology of the spawning period.

**Keywords:** anuran amphibians, reproductive parameters, contribution to reproduction, climate change, reproductive phenology

This is an open access article distributed under the terms of Creative Commons Attribution 4.0 International License (CC-BY 4.0)

**For citation:** Ivanov G. A., Yermokhin M. V., Tabachishin V. V., Tabachishin V. G. Reproductive ecology of Anuran Amphibians: Effects of internal and external factors. *Current Studies in Herpetology*, 2023, vol. 23, iss. 1–2, pp. 3–26 (in Russian). <https://doi.org/10.18500/1814-6090-2023-23-1-2-3-26>, EDN: XXKIUN

### REFERENCES

- Bobretsov A. V., Bykhovets N. M., Kochanov S. K., Petrov A. N. Distribution and morphometric features of the common toad *Bufo bufo* L. (Bufonidae, Amphibia) in the North-East of the European part of Russia. *Current Studies in Herpetology*, 2022, vol. 22, iss. 1–2, pp. 3–16 (in Russian). <https://doi.org/10.18500/1814-6090-2022-22-1-2-3-16>
- Yermokhin M. V., Tabachishin V. G. Reproductive parameters of females *Pelobates fuscus* (Laurenti, 1768) as functions of size and weight characteristics. *Current Studies in Herpetology*, 2011, vol. 11, iss. 1–2, pp. 28–39 (in Russian).
- Yermokhin M. V., Tabachishin V. G. An abnormally early hibernation ending of the Red-bellied toad (*Bombina bombina*) (Discoglossidae, Anura) in the populations of the Medveditsa river valley (Saratov region). *Povelzhskiy Journal of Ecology*, 2021, no. 1, pp. 89–96 (in Russian). <https://doi.org/10.35885/1684-7318-2021-1-89-96>
- Yermokhin M. V., Tabachishin V. G. Phenological changes in the wintering end date of *Pelophylax ridibundus* (Pallas, 1771) (Ranidae, Anura) in the Medveditsa river valley (Saratov region) under conditions of climate transformation. *Povelzhskiy Journal of Ecology*, 2022 a, no. 4, pp. 474–482 (in Russian). <https://doi.org/10.35885/1684-7318-2022-4-474-482>
- Yermokhin M. V., Tabachishin V. G. False spring in the spawning migrations of Spadefoot toads (*Pelobates*, Anura): Distribution in the European Russia and the phenomenon scale in 2020. *Povelzhskiy Journal of Ecology*, 2022 b, no. 1, pp. 3–16 (in Russian). <https://doi.org/10.35885/1684-7318-2022-1-3-16>
- Yermokhin M. V., Tabachishin V. G., Ivanov G. A. Comparative analysis of body condition indexes efficiency of *Pelobates fuscus* toadlets. *Current Studies in Herpetology*, 2014, vol. 14, iss. 3–4, pp. 92–102 (in Russian).
- Yermokhin M. V., Tabachishin V. G., Ivanov G. A., Rybal'chenko D. A. Reproductive parameters of *Bombina bombina* and *Pelophylax ridibundus* (Amphibia, Anura) females as functions of their size and weight characteristics. *Current Studies in Herpetology*, 2016, vol. 16, iss. 1–2, pp. 3–13 (in Russian). <https://doi.org/10.18500/1814-6090-2016-16-1-2-3-13>
- Kutenev A. P. Dynamics of size of liver, fat bodies and gonads in grass frogs (*Rana temporaria*) and moor frog (*R. arvalis*) frogs. In: *Ekologiya nazemnykh pozvonoch-*

✉ Corresponding author. Department of Animal Morphology and Ecology, Saratov State University, Russia.

ORCID and e-mail addresses: Gleb A. Ivanov: [yermokhinmv@yandex.ru](mailto:yermokhinmv@yandex.ru); Mikhail V. Yermokhin: <https://orcid.org/0000-0001-6377-6816>, [yermokhinmv@yandex.ru](mailto:yermokhinmv@yandex.ru); Vasiliy V. Tabachishin: [tabachishinvg@sevin.ru](mailto:tabachishinvg@sevin.ru); Vasily G. Tabachishin: <https://orcid.org/0000-0002-9001-1488>, [tabachishinvg@sevin.ru](mailto:tabachishinvg@sevin.ru).

- nykh [Ecology of Terrestrial Vertebrates]. Petrozavodsk, Institute of Biology, Karelian Research Center, USSR Academy of Sciences Publ., 1991, pp. 14–24 (in Russian).
- Kutakov A. P. *Ekologija travianoi liagushki (Rana temporaria L., 1758) na Severo-Zapade Rossii* [Ecology of Grass Frog (*Rana temporaria* L., 1758) in the North-West of Russia]. Petrozavodsk, Petrozavodsk State University Publ., 2009. 140 p. (in Russian).
- Lyapkov S. M. *Population Ecology of Moor (Rana arvalis) and Common (Rana temporaria) Frogs. Geographic Variation in Age Composition, Postmetamorphic Growth, Size and Reproductive Characteristics*. Moscow, KMK Scientific Press, 2021. 219 p. (in Russian).
- Fominykh A. S., Lyapkov S. M. The formation of new characteristics in life cycle of the marsh frog (*Rana ridibunda*) in thermal pond conditions. *Zhurnal obshchei biologii*, 2011, vol. 72, no. 6, pp. 403–421 (in Russian).
- Cherdantseva E. M., Cherdantsev V. G., Lyapkov S. M. The influence of egg size on the intensity and duration of *Rana arvalis* metamorph development in an experiment performed in a spawning water body. *Zoologicheskii zhurnal*, 2007, vol. 86, no. 3, pp. 329–339 (in Russian).
- Alford R. A. Declines and the global status of amphibians. In: Sparling D. W., Linder G., Bishop C. A., Krest S., eds. *Ecotoxicology of Amphibians and Reptiles*. Boca Raton, CRC Press, 2010, pp. 13–46.
- Altweig R. Multistage density dependence in an amphibian. *Oecologia*, 2003, vol. 136, iss. 1, pp. 46–50. <https://doi.org/10.1007/s00442-003-1248-x>
- Altweig R., Reyer H.-U. Patterns of natural selection on size at metamorphosis in water frogs. *Evolution*, 2003, vol. 57, iss. 4, pp. 872–882. [https://doi.org/10.1554/0014-3820\(2003\)057\[0872:PONSOS\]2.0.CO;2](https://doi.org/10.1554/0014-3820(2003)057[0872:PONSOS]2.0.CO;2)
- Arnfield H., Grant R., Monk C., Uller T. Factors influencing the timing of spring migration in common toads (*Bufo bufo*): Timing of spring migration in toads. *Journal of Zoology*, 2012, vol. 288, iss. 2, pp. 112–118. <https://doi.org/10.1111/j.1469-7998.2012.00933.x>
- Beattie R. C. The date of spawning in populations of the common frog (*Rana temporaria*) from different altitudes in northern England. *Journal of Zoology*, 1985, vol. 205, iss. 1, pp. 137–154. <https://doi.org/10.1111/j.1469-7998.1985.tb05618.x>
- Beck C. W., Congdon J. D. Effects of individual variation in age and size at metamorphosis on growth and survivorship of southern toad (*Bufo terrestris*) metamorphs. *Canadian Journal of Zoology*, 1999, vol. 77, no. 6, pp. 944–951. <https://doi.org/10.1139/z99-041>
- Beebee T. J. Geographical variations in breeding activity patterns of the natterjack toad *Bufo calamita* in Britain. *Journal of Zoology*, 1985, vol. 205, iss. 1, pp. 1–8. <https://doi.org/10.1111/j.1469-7998.1985.tb05608.x>
- Bennett A. M., Murray D. L. Maternal body condition influences magnitude of anti-predator response in offspring. *Proceedings of the Royal Society B: Biological Sciences*, 2014, vol. 281, iss. 1794, article no. 20141806. <https://doi.org/10.1098/rspb.2014.1806>
- Berger L. Principles of studies of European water frogs. *Acta Zoologica Cracoviensia*, 1988, vol. 31, pp. 563–580.
- Berven K. A. Factors affecting population fluctuations in larval and adult stages of the wood frog (*Rana sylvatica*). *Ecology*, 1990, vol. 71, iss. 4, pp. 1599–1608. <https://doi.org/10.2307/1938295>
- Berven K. A. Density dependence in the terrestrial stage of wood frogs: Evidence from a 21-year population study. *Copeia*, 2009, vol. 2009, iss. 2, pp. 328–338. <https://doi.org/10.1643/CH-08-052>
- Berven K. A., Gill D. E. Interpreting geographic variation in life-history traits. *American Zoologist*, 1983, vol. 23, iss. 1, pp. 85–97. <https://doi.org/10.1093/icb/23.1.85>
- Blaustein A. R., Belden L. K., Olson D. H. Amphibian phenology and climate change. *Conservation Biology*, 2002, vol. 16, iss. 6, pp. 1454–1455. <https://doi.org/10.1046/j.1523-1739.2002.t01-1-02109.x>
- Blaustein A. R., Han B., Fasy B., Romansic J., Scheessele E. A., Anthony R. G., Marco A., Chivers D. P., Belden L. K., Kiesecker J. M., Garcia T., Lizana M., Kats L. B. Variable breeding phenology affects the exposure of amphibian embryos to ultraviolet radiation and optical characteristics of natural waters protect amphibians from UV-B in the US Pacific Northwest: Comment. *Ecology*, 2004, vol. 85, iss. 6, pp. 1747–1754.
- Blaustein A. R., Searle C., Bancroft B. A., Lawler J. Amphibian population declines and climate change. In: Beever E. A., Belant J. L., eds. *Ecological Consequences of Climate Change: Mechanisms, Conservation, and Management*. Boca Raton, London, New York, CRC Press, 2011, pp. 29–53.
- Bouchard S. S., O’Leary C. J., Wargelin L. J., Charbonnier J. F., Warkentin K. M. Post-metamorphic carry-over effects of larval digestive plasticity. *Functional Ecology*, 2016, vol. 30, iss. 3, pp. 379–388. <https://doi.org/10.1111/1365-2435.12501>
- Boyd C. E., Goodyear C. P. Somatic and gametic dry matter and protein in gravid female of several amphibian species. *Comparative Biochemistry and Physiology. Part A: Physiology*, 1971, vol. 40, iss. 3, pp. 771–775. [https://doi.org/10.1016/0300-9629\(71\)90262-3](https://doi.org/10.1016/0300-9629(71)90262-3)
- Brannelly L. A., Webb R. J., Jiang Z., Berger L., Skerratt L. F., Grogan L. F. Declining amphibians might be evolving increased reproductive effort in the face of devastating disease. *Evolution*, 2021, vol. 75, iss. 10, pp. 2555–2567. <https://doi.org/10.1111/evo.14327>
- Brizzi R., Corti C. Reproductive cycles of the European amphibians: A brief history of studies on the role of exogenous and endogenous factors. *Herpetologia Bonnensis II: Proceedings of the 13th Congress of the Societas Europaea Herpetologica*. Bonn, Societas Europaea Herpetologica, 2006, pp. 27–30.
- Buchholz D. R., Hayes T. B., Gatten R. E. Jr. Evolutionary patterns of diversity in spadefoot toad metamorphosis (Anura: Pelobatidae). *Copeia*, 2002, vol. 2002, iss. 1, pp. 180–189.

- Bull E. Dispersal of newly metamorphosed and juvenile Western toads (*Anaxyrus boreas*) in Northeastern Oregon, USA. *Herpetological Conservation and Biology*, 2009, vol. 4, iss. 2, pp. 236–247.
- Cabrera-Guzmán E., Crossland M. R., Brown G. P., Shine R. Larger body size at metamorphosis enhances survival, growth and performance of young cane toads (*Rhinella marina*). *PLoS ONE*, 2013, vol. 8, article no. e70121. <https://doi.org/10.1371/journal.pone.0070121>
- Cadeddu G., Castellano S. Factors affecting variation in the reproductive investment of female treefrogs, *Hyla intermedia*. *Zoology*, 2012, vol. 115, iss. 6, pp. 372–378. <https://doi.org/10.1016/j.zool.2012.04.006>
- Cahill A. E., Aiello-Lammens M. E., Fisher-Reid M. C., Hua X., Karanewsky C. J., Yeong Ryu H., Sbeglia G. C., Spagnolo F., Waldron J. B., Warsi O., Wiens J. J. How does climate change cause extinction? *Proceedings of the Royal Society B : Biological Sciences*, 2012, vol. 280, iss. 1750, article no. 20121890. <https://doi.org/10.1098/rspb.2012.1890>
- Camargo A., Naya D. E., Canavero A., Rosa da I., Maneyro R. Seasonal activity and body size-fecundity relationship in a population of *Physalaemus gracilis* (Boulenger, 1883) (Anura, Leptodactylidae) from Uruguay. *Annales Zoologici Fennici*, 2005, vol. 42, no. 5, pp. 513–521.
- Castellano S., Cucco M., Giacoma C. Reproductive investment of female green toads (*Bufo viridis*). *Copeia*, 2004, vol. 2004, no. 3, pp. 659–664. <https://doi.org/10.1643/CE-03-182R2>
- Cayuela H., Arsovski D., Bonnaire E., Duguet R., Joly P., Besnard A. The impact of severe drought on survival, fecundity, and population persistence in an endangered amphibian. *Ecosphere*, 2016, vol. 7, iss. 2, pp. e01246. <https://doi.org/10.1002/ecs2.1246>
- Chelgren N. D., Rosenberg D. K., Heppell S. S., Gitelman A. I. Carryover aquatic effects on survival of metamorphic frogs during pond emigration. *Ecological Applications*, 2006, vol. 16, iss. 1, pp. 250–261. <https://doi.org/10.1890/04-0329>
- Chen W., Zhang L., Lu X. Higher prehibernation energy storage in anurans from cold environment: A case study on a temperate frog *Rana chensinensis* along broad latitudinal and altitudinal gradients. *Annales Zoologici Fennici*, 2011, vol. 48, no. 4, pp. 214–220. <https://doi.org/10.5735/086.048.0402>
- Cogălniceanu D., Miaud C. Variation in life history traits in *Bombina bombina* from the lower Danube floodplain. *Amphibia-Reptilia*, 2004, vol. 25, iss. 1, pp. 115–119. <https://doi.org/10.1163/156853804322992896>
- Corn P. S. Amphibian breeding and climate change: Importance of snow in the Mountains. *Conservation Biology*, 2003, vol. 17, iss. 2, pp. 622–625. <https://doi.org/10.1046/j.1523-1739.2003.02111.x>
- Corn P. S. Climate change and amphibians. *Animal Biodiversity and Conservation*, 2005, vol. 28, iss. 1, pp. 59–67. <https://doi.org/10.32800/abc.2005.28.0059>
- Corn P. S., Muths E. Variable breeding phenology affects the exposure of amphibian embryos to ultraviolet radiation. *Ecology*, 2002, vol. 83, iss. 11, pp. 2958–2963. [https://doi.org/10.1890/0012-9658\(2002\)083\[2958:VBPA\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2002)083[2958:VBPA]2.0.CO;2)
- Crucitti P. A review of phenological patterns of amphibians and reptiles in Central Mediterranean ecoregion. *Phenology and Climate Change*. Rijeka, Croatia, University Campus STEP Ri Slavka Krautzeka, 2012, pp. 35–52.
- Crump M. L. Energy accumulation and amphibian metamorphosis. *Oecologia*, 1981, vol. 49, iss. 2, pp. 167–169. <https://doi.org/10.1007/BF00349184>
- Cummins C. P. Temporal and spatial variation in egg size and fecundity in *Rana temporaria*. *Journal of Animal Ecology*, 1986, vol. 55, iss. 1, pp. 303–316.
- Cummins C. P. UV-B radiation, climate change and frogs – the importance of phenology. *Annales Zoologici Fennici*, 2003, vol. 40, iss. 1, pp. 61–67.
- Diaz-Paniagua C. Variability in timing of larval season in an amphibian community in SW Spain. *Ecography*, 1992, vol. 15, iss. 3, pp. 267–272.
- Drakulić S., Feldhaar H., Lisičić D., Miočić M., Cizelj I., Seiler M., Spatz T., Rödel M.-O. Population-specific effects of developmental temperature on body condition and jumping performance of a widespread European frog. *Ecology and Evolution*, 2016, vol. 6, iss. 10, pp. 3115–3128. <https://doi.org/10.1002/ece3.2113>
- Džukić G., Beškov V., Sidorovska V., Cogălniceanu D., Kalezić L. Historical and contemporary ranges of the spadefoot toads *Pelobates* spp. (Amphibia: Anura) in the Balkan Peninsula. *Acta Zoologica Cracoviensia*, 2005, vol. 48, no. 1–2, pp. 1–9.
- Earl J. E., Whiteman H. H. Are commonly used fitness predictors accurate? A meta-analysis of amphibian size and age at metamorphosis. *Copeia*, 2015, vol. 103, iss. 2, pp. 297–309. <https://doi.org/10.1643/CH-14-128>
- Ficetola G. F., Bernardi de F. Offspring size and survival in the frog *Rana latastei*: From among-population to within-clutch variation. *Biological Journal of the Linnean Society*, 2009, vol. 97, iss. 4, pp. 845–853. <https://doi.org/10.1111/j.1095-8312.2009.01229.x>
- Ficetola G. F., Maiorano L. Contrasting effects of temperature and precipitation change on amphibian phenology, abundance and performance. *Oecologia*, 2016, vol. 181, iss. 3, pp. 683–693. <https://doi.org/10.1007/s00442-016-3610-9>
- Fitzpatrick L. C. Life history patterns of storage and utilisation of lipids for energy in amphibians. *American Zoologist*, 1976, vol. 16, iss. 4, pp. 725–732. <https://doi.org/10.1093/icb/16.4.725>
- Galloy V., Denoël M. Detrimental effect of temperature increase on the fitness of an amphibian (*Lissotriton helveticus*). *Acta Oecologica*, 2010, vol. 36, iss. 2, pp. 179–183. <https://doi.org/10.1016/j.actao.2009.12.002>
- Gibbons M. M., McCarthy T. K. The reproductive output of frogs *Rana temporaria* (L.) with particular reference to body size and age. *Journal of Zoology*, 1986, vol. 209, iss. 4, pp. 579–593. <https://doi.org/10.1111/j.1469-7998.1986.tb03613.x>

- Gibbs J. P., Breisch A. R. Climate warming and calling phenology of frogs near Ithaca, New York, 1900–1999. *Conservation Biology*, 2001, vol. 15, iss. 4, pp. 1175–1178. <https://doi.org/10.1046/j.1523-1739.2001.0150041175.x>
- Goater C. P. Growth and survival of postmetamorphic toads: Interactions among larval history, density, and parasitism. *Ecology*, 1994, vol. 75, iss. 8, pp. 2264–2274.
- Gomez-Mestre I., Tejedo M., Marangoni F. Extreme reduction in body size and reproductive output associated with sandy substrates in two anuran species. *Amphibia-Reptilia*, 2008, vol. 29, iss. 4, pp. 541–553. <https://doi.org/10.1163/156853808786230370>
- Grafe T. U., Schmuck R., Linsenmair K. E. Reproductive energetics of the African reed frogs, *Hyperolius viridiflavus* and *Hyperolius marmoratus*. *Physiological Zoology*, 1992, vol. 65, no. 1, pp. 153–171. <https://doi.org/10.1086/physzool.65.1.30158244>
- Gramapurohit N. P., Shanbhad B. A., Saidapur S. K. Pattern of growth and utilization of abdominal fat bodies during larval development and metamorphosis in five South Indian anurans. *Current Science*, 1998, vol. 75, iss. 11, pp. 1188–1192.
- Grant R. A., Chadwick E. A., Halliday T. The lunar cycle: A cue for amphibian reproductive phenology? *Animal Behavior*, 2009, vol. 78, iss. 2, pp. 349–357. <https://doi.org/10.1016/j.anbehav.2009.05.007>
- Gray M. J., Smith L. M. Influence of land use on postmetamorphic body size of playa lake amphibians. *Journal of Wildlife Management*, 2005, vol. 69, iss. 2, pp. 515–524. [https://doi.org/10.2193/0022-541X\(2005\)069\[0515:IOLUOP\]2.0.CO;2](https://doi.org/10.2193/0022-541X(2005)069[0515:IOLUOP]2.0.CO;2)
- Green D. M. Implications of female body-size variation for the reproductive ecology of an anuran amphibian. *Ethology, Ecology and Evolution*, 2015, vol. 27, iss. 2, pp. 173–184. <https://doi.org/10.1080/03949370.2014.915430>
- Green D. M., Middleton J. Body size varies with abundance, not climate, in an amphibian population. *Ecography*, 2013, vol. 36, iss. 8, pp. 947–955. <https://doi.org/10.1111/j.1600-0587.2013.00063.x>
- Gunzburger M. S. Reproductive ecology of the green treefrog (*Hyla cinerea*) in Northwestern Florida. *American Midland Naturalist*, 2006, vol. 155, iss. 2, pp. 321–328. [https://doi.org/10.1674/0003-0031\(2006\)155\[321:REOTGT\]2.0.CO;2](https://doi.org/10.1674/0003-0031(2006)155[321:REOTGT]2.0.CO;2)
- Harper E. B., Semlitsch R. D. Density dependence in the terrestrial life history stage of two anurans. *Oecologia*, 2007, vol. 153, iss. 4, pp. 879–889. <https://doi.org/10.1007/s00442-007-0796-x>
- Hartel T. Weather conditions, breeding date and population fluctuation in *Rana dalmatina* from Central Romania. *Herpetological Journal*, 2008, vol. 18, iss. 1, pp. 40–44.
- Hartel T., Sas I., Pernetta A., Geltsch I. C. The reproductive dynamics of temperate amphibians: A review. *North-Western Journal of Zoology*, 2007, vol. 3, no. 2, pp. 127–145.
- Hartmann M. T., Hartmann P. A., Haddad C. F. Reproductive modes and fecundity of an assemblage of anuran amphibians in the Atlantic rainforest, Brazil. *Iheringia. Série Zoologia*, 2010, vol. 100, no. 3, pp. 207–215. <https://doi.org/10.1590/S0073-47212010000300004>
- Hocking D. J., Rittenhouse T. A. G., Rothermel B. B., Johnson J. R., Conner C. A., Harper E. B., Semlitsch R. D. Breeding and recruitment phenology of amphibians in Missouri oak-hickory forests. *The American Midland Naturalist*, 2008, vol. 160, no. 1, pp. 41–60. [https://doi.org/10.1674/0003-0031\(2008\)160\[41:BARPOA\]2.0.CO;2](https://doi.org/10.1674/0003-0031(2008)160[41:BARPOA]2.0.CO;2)
- Iela L., Milone M., Caliendo M. F., Rastogi R. K., Chieffi G. Role of lipids in the physiology of the testis of *Rana esculenta*: Annual changes in the lipid and protein content of the liver, fat body, testis and plasma. *Bulletino di zoologia*, 1979, vol. 46, iss. 1–2, pp. 11–16. <https://doi.org/10.1080/11250007909440272>
- Indermauer L., Schmidt B. R., Tockner K., Schaub M. Spatial variation in abiotic and biotic factors in a floodplain determine anuran body size and growth rate at metamorphosis. *Oecologia*, 2010, vol. 163, iss. 3, pp. 637–649. <https://doi.org/10.1007/s00442-010-1586-4>
- Jaafer I. H., Ismail A., Kurais A.-R. Correlations of reproductive parameters of two tropical frogs from Malaysia. *Asiatic Herpetological Research*, 1999, vol. 8, iss. 1, pp. 48–52.
- Jahn K. Der Einfluß von Körpergröße, Körpermasse und Alter auf die Laichmasse von *Pelobates fuscus* – Weibchen. *Zeitschrift für Feldherpetologie*, 1998, Bd. 5, no. 1, S. 71–80.
- Jakob C., Poizat G., Veith M., Seitz A., Crivelli A. J. Breeding phenology and larval distribution of amphibians in a Mediterranean pond network with unpredictable hydrology. *Hydrobiologia*, 2003, vol. 499, no. 1–3, pp. 51–61. <https://doi.org/10.1023/A:1026343618150>
- Jönsson K. I., Herczeg G., O’Hara R. B., Söderman F., Schure ter A. F. H., Larsson P., Merilä J. Sexual patterns of prebreeding energy reserves in the common frog *Rana temporaria* along a latitudinal gradient. *Ecography*, 2009, vol. 32, iss. 5, pp. 831–839. <https://doi.org/10.1111/j.1600-0587.2009.05352.x>
- Jørgensen C. B. Ovarian cycle in a temperate zone frog, *Rana temporaria*, with special reference to factors determining number of size of eggs. *Journal of Zoology*, 1981, vol. 195, iss. 4, pp. 449–458. <https://doi.org/10.1111/j.1469-7998.1981.tb03477.x>
- Kanamadi R. D., Saidapur S. K., Bhuttewadkar N. U., Yamakanamaradi S. M. Annual changes in the fat body of the male toad, *Bufo melanostictus* (Schn.) inhabiting the tropical zone of South India. *Proceedings of the Indian National Science Academy*, 1989, vol. 55, no. 4, pp. 261–264.
- Kaplan R. H. Developmental plasticity and maternal effects of reproductive characteristics in the frog, *Bombina orientalis*. *Oecologia*, 1987, vol. 71, iss. 2, pp. 273–279. <https://doi.org/10.1007/BF00377295>
- Klaus S. P., Lougheed S. C. Changes in breeding phenology of Eastern Ontario frogs over four decades. *Ecology and Evolution*, 2013, vol. 3, iss. 4, pp. 835–845. <https://doi.org/10.1002/ece3.501>

- Koskela P., Pasanen S. The reproductive biology of the female common frog, *Rana temporaria* L., in northern Finland. *Aquilo, Series Zoologica*, 1975, vol. 16, no. 1, pp. 1–12.
- Kuramoto M. Correlations of quantitative parameters of fecundity in amphibians. *Evolution*, 1978, vol. 32, iss. 2, pp. 287–296. <https://doi.org/10.1111/j.1558-5646.1978.tb00644.x>
- Kusano T., Miura T., Terui S., Maruyama K. Factors affecting the breeding activity of the Japanese common toad, *Bufo japonicus formosus* (Amphibia: Bufonidae) with special reference to the lunar cycle. *Current Herpetology*, 2015, vol. 34, no. 2, pp. 101–111. <https://doi.org/10.5358/hsj.34.101>
- Lai S.-J., Kam Y.-C., Lin Y.-S. Elevational variation in reproductive and life history traits of Sauter's frog *Rana sauteri* Boulenger, 1909 in Taiwan. *Zoological Studies*, 2003, vol. 42, no. 1, pp. 193–202.
- Lardner B., Loman J. Growth or reproduction? Resource allocation by female frogs *Rana temporaria*. *Oecologia*, 2003, vol. 137, iss. 4, pp. 541–546. <https://doi.org/10.1007/s00442-003-1390-5>
- Lavergne S., Mouquet N., Thuiller W., Ronce O. Biodiversity and climate change: Integrating evolutionary and ecological responses of species and communities. *Annual Review of Ecology, Evolution, and Systematics*, 2010, vol. 41, iss. 1, pp. 321–350. <https://doi.org/10.1146/annurev-ecolsys-102209-144628>
- Leary C. J., Jessop T. S., Garcia A. M., Knapp R. Steroid hormone profiles and relative body condition of calling and satellite toads: Implications for proximate regulation of behavior in anurans. *Behavioural Ecology*, 2004, vol. 15, iss. 2, pp. 313–320. <https://doi.org/10.1093/beheco/arh015>
- Liao W. B., Luo Y., Lou S. L., Lu D., Jehle R. Geographic variation in life-history traits: Growth season affects age structure, egg size and clutch size in Andrew's toad (*Bufo andrewsi*). *Frontiers in Zoology*, 2016, vol. 13, iss. 6, article no. 6. <https://doi.org/10.1186/s12983-016-0138-0>
- Liedtke H. C., Müller H., Hafner J., Nagel P., Loader S. P. Interspecific patterns for egg and clutch sizes of African Bufonidae (Amphibia: Anura). *Zoologischer Anzeiger – A Journal of Comparative Zoology*, 2014, vol. 253, iss. 4, pp. 309–315. <https://doi.org/10.1016/j.jcz.2014.02.003>
- Lips K. Reproductive trade-offs and bet-hedging in *Hyla calypsa*, a Neotropical treefrog. *Oecologia*, 2001, vol. 128, iss. 4, pp. 509–518. <https://doi.org/10.1007/s004420100687>
- Loman J. Early metamorphosis in common frog *Rana temporaria* tadpoles at risk of drying: An experimental demonstration. *Amphibia-Reptilia*, 1999, vol. 20, iss. 4, pp. 421–430.
- Loman J. Local variation in *Rana temporaria* egg and clutch size: Adaptation to pond drying? *Alytes*, 2001, vol. 19, no. 1, pp. 45–52.
- Loman J. Temperature, genetic and hydroperiod effects on metamorphosis of brown frogs *Rana arvalis* and *R. temporaria* in the field. *Journal of Zoology*, 2002, vol. 258, iss. 1, pp. 115–129.
- Loman J. Primary and secondary phenology. Does it pay a frog to spawn early? *Journal of Zoology*, 2009, vol. 279, iss. 1, pp. 64–70. <https://doi.org/10.1111/j.1469-7998.2009.00589.x>
- Loumbourdis N. S., Kyriakopoulou-Sklavounou P. Reproductive and lipid cycles in the male frog *Rana ridibunda* in Northern Greece. *Comparative Biochemistry and Physiology. Part A: Physiology*, 1991, vol. 99, iss. 4, pp. 577–583. [https://doi.org/10.1016/0300-9629\(91\)90133-W](https://doi.org/10.1016/0300-9629(91)90133-W)
- Lyapkov S. M., Kornilova M. B., Severtsov A. S. Variation structure of the reproductive characteristics in *Rana temporaria* and their relationship with size and age of the frog. *Entomological Review*, 2002, vol. 82, suppl. 2, pp. 275–289.
- Méndez-Tepepa M., Morales-Cruz C., García-Nieto E., Anaya-Hernández A. A review of the reproductive system in anuran amphibians. *Zoological Letters*, 2023, vol. 9, iss. 1, article no. 3. <https://doi.org/10.1186/s40851-023-00201-0>
- Middleton J., Green D. M. Adult age-structure variability in an amphibian in relation to population decline. *Herpetologica*, 2015, vol. 71, iss. 3, pp. 190–195. <https://doi.org/10.1655/HERPETOLOGICA-D-14-00074>
- Mirabile M., Melletti M., Venchi A., Bologna M. A. The reproduction of the Apennine yellow-bellied toad (*Bombina pachypus*) in central Italy. *Amphibia-Reptilia*, 2009, vol. 30, iss. 3, pp. 303–312. <https://doi.org/10.1163/156853809788795100>
- Mitchell J. C., Pague C. A. Filling gaps in life-history data: Clutch sizes for 21 species of north American anurans. *Herpetological Conservation and Biology*, 2014, vol. 9, iss. 3, pp. 495–501.
- Morey S. V. Pool duration influences age and body mass at metamorphosis in the western spadefoot toad: Implications for vernal pool conservation. In: Witham C. W., Bauder E. T., Belk D., Ferren W. R. Jr., Ornduff R., eds. *Ecology, Conservation, and Management of Vernal Pool Ecosystems: Proceedings from a 1996 Conference*. Sacramento, California Native Plant Society, 1998, pp. 86–91.
- Morrison C., Hero J.-M. Geographic variation in life-history characteristics of amphibians: A review. *Journal of Animal Ecology*, 2003, vol. 72, iss. 2, pp. 270–279. <https://doi.org/10.1046/j.1365-2656.2003.00696.x>
- Ogielska M., Kotusz A. Pattern and rate of ovary differentiation with reference to somatic development in anuran amphibians. *Journal of Morphology*, 2004, vol. 259, iss. 1, pp. 41–54. <https://doi.org/10.1002/jmor.10162>
- Orizaola G., Laurila A. Intraspecific variation of temperature-induced effects on metamorphosis in the pool frog (*Rana lessonae*). *Canadian Journal of Zoology*, 2009, vol. 87, no. 7, pp. 581–588. <https://doi.org/10.1139/Z09-04>

- Orizaola G., Dahl E., Nicieza A. G., Laurila A. Larval life history and anti-predator strategies are affected by breeding phenology in an amphibian. *Oecologia*, 2012, vol. 171, iss. 4, pp. 873–881. <https://doi.org/10.1007/s00442-012-2456-z>
- Pacifici M., Foden W. B., Visconti P., Watson J. E. M., Butchart S. H. M., Kovacs K. M., Schefers B. R., Hole D. G., Martin T. G., Akçakaya H. R., Corlett R. T., Huntley B., Bickford D., Carr J. A., Hoffmann A. A., Midgley G. F., Pearce-Kelly P., Pearson R. G., Williams S. E., Willis S. G., Young B., Rondinini C. Assessing species vulnerability to climate change. *Nature Climate Change*, 2015, vol. 5, iss. 3, pp. 215–224. <https://doi.org/10.1038/nclimate2448>
- Parmesan C. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics*, 2006, vol. 37, iss. 1, pp. 637–669. <https://doi.org/10.1146/annurev.ecolsys.37.091305.110100>
- Paton P. W., Crouch W. B. Using the phenology of pond-breeding amphibians to develop conservation strategies. *Conservation Biology*, 2002, vol. 16, no. 1, pp. 194–204.
- Ponsero A., Joly P. Clutch size, egg survival and migration distance in the agile frog (*Rana dalmatina*) in a floodplain. *Archiv fur Hydrobiologie*, 1998, Bd. 142, no. 3, S. 343–352.
- Prado C. P. A., Haddad C. F. B. Size-fecundity relationships and reproductive investment in female frogs in the Pantanal, South-Western Brazil. *Herpetological Journal*, 2005, vol. 15, iss. 3, pp. 181–189.
- Pramoda S., Saidapur S. K. Annual changes in the somatic weight, hypophyseal gonadotrophs, ovary, oviduct and abdominal fat bodies in the Indian bull frog, *Rana tigerina*. *Proceedings of the Indian National Science Academy*, 1984, vol. 50, no. 5, pp. 490–499.
- Rafińska A. Reproductive biology of the fire-bellied toads, *Bombina bombina* and *B. variegata* (Anura: Discoglossidae): Egg size, clutch size and larval period length differences. *Biological Journal of the Linnean Society*, 1991, vol. 43, iss. 3, pp. 191–210. <https://doi.org/10.1111/j.1095-8312.1991.tb00593.x>
- Räsänen K., Laurila A., Merilä J. Maternal investment in egg size: Environment and population-specific effects on offspring performance. *Oecologia*, 2005, vol. 142, iss. 4, pp. 546–553. <https://doi.org/10.1007/s00442-004-1762-5>
- Räsänen K., Söderman F., Laurila A., Merilä J. Geographic variation in maternal investment: Acidity affects egg size and fecundity in *Rana arvalis*. *Ecology*, 2008, vol. 89, iss. 9, pp. 2553–2562. <https://doi.org/10.1890/07-0168.1>
- Reading C. J. Egg production in the Common toad, *Bufo bufo*. *Journal of Zoology*, 1986, vol. 208, iss. 1, pp. 99–107. <https://doi.org/10.1111/j.1469-7998.1986.tb04712.x>
- Reading C. J. Linking global warming to amphibian declines through its effects on female body condition and survivorship. *Oecologia*, 2007, vol. 151, no. 1, pp. 125–131. <https://doi.org/10.1007/s00442-006-0558-1>
- Reading C. J., Clarke R. T. The effects of density, rainfall and environmental temperature on body condition and fecundity in the common toad, *Bufo bufo*. *Oecologia*, 1995, vol. 102, iss. 4, pp. 453–459. <https://doi.org/10.1007/BF00341357>
- Reading C. J., Jofre G. M. Declining common toad body size correlated with climate warming. *Biological Journal of the Linnean Society*, 2021, vol. 134, iss. 3, pp. 577–586. <https://doi.org/10.1093/biolinnean/blab101>
- Richter-Boix A., Llorente G. A., Montori A. Breeding phenology of an amphibian community in a Mediterranean area. *Amphibia-Reptilia*, 2006a, vol. 27, iss. 4, pp. 549–559. <https://doi.org/10.1163/156853806778877149>
- Richter-Boix A., Llorente G. A., Montori A. A comparative analysis of the adaptive developmental plasticity hypothesis in six Mediterranean anuran species along a pond permanency gradient. *Evolutionary Ecology Research*, 2006b, vol. 8, iss. 6, pp. 1139–1154.
- Richter-Boix A., Llorente G. A., Montori A. Effects of phenotypic plasticity on post-metamorphic traits during pre-metamorphic stages in the anuran *Pelodytes punctatus*. *Evolutionary Ecology Research*, 2006c, vol. 8, iss. 2, pp. 309–320.
- Rowland F. E., Schyling E. S., Freidenburg L. K., Urban M. C., Richardson J. L., Arietta A. Z. A., Rodrigues S. B., Rubinstein A. D., Benard M. F., Skelly D. K. Asynchrony, density dependence, and persistence in an amphibian. *Ecology*, 2022, vol. 103, iss. 7, pp. e3696. <https://doi.org/10.1002/ecy.3696>
- Ryan T. J., Winne C. T. Effects of hydroperiod on metamorphosis in *Rana sphenocephala*. *American Midland Naturalist*, 2001, vol. 145, iss. 1, pp. 46–53. [https://doi.org/10.1674/0003-0031\(2001\)145\[0046:EOHOMI\]2.0.CO;2](https://doi.org/10.1674/0003-0031(2001)145[0046:EOHOMI]2.0.CO;2)
- Ryser J. Weight loss, reproductive output, and the cost of reproduction in the common frog, *Rana temporaria*. *Oecologia*, 1989, vol. 78, iss. 2, pp. 264–268. <https://doi.org/10.1007/BF00377165>
- Salvidio S. Stability and annual return rates in amphibian populations. *Amphibia-Reptilia*, 2011, vol. 32, iss. 1, pp. 119–124. <https://doi.org/10.1163/017353710X541887>
- Schmidt B. R., Anholt B. R. Analysis of survival probabilities of female common toads, *Bufo bufo*. *Amphibia-Reptilia*, 1999, vol. 20, iss. 1, pp. 97–108. <https://doi.org/10.1163/156853899X00114>
- Scott D. E., Casey E. D., Donovan M. D., Lynch T. K. Amphibian lipid levels at metamorphosis correlate to post-metamorphic terrestrial survival. *Oecologia*, 2007, vol. 153, iss. 3, pp. 521–532. <https://doi.org/10.1007/s00442-007-0755-6>
- Scott W. A., Pithart D., Adamson J. K. Long-term United Kingdom trends in the breeding phenology of the common frog, *Rana temporaria*. *Journal of Herpetology*, 2008, vol. 42, iss. 1, pp. 89–96. <https://doi.org/10.1670/07-022.1>
- Semlitch R. D. Differentiating migration and dispersal processes for pond-breeding amphibians. *Journal*

- of Wildlife Management, 2008, vol. 72, iss. 1, pp. 260–267. <https://doi.org/10.2193/2007-082>
- Seymour R. S. Energy metabolism of dormant Spadefoot toads (*Scaphiopus*). *Copeia*, 1973, vol. 1973, iss. 3, pp. 435–445.
- Shirose L. J., Brooks R. J. Age structure, mortality, and longevity in syntopic populations of three species of ranid frogs in central Ontario. *Canadian Journal of Zoology*, 1995, vol. 73, no. 10, pp. 1878–1886. <https://doi.org/10.1139/z95-220>
- Smith C. L. Seasonal changes in blood sugar, fat bodies, liver glycogen and gonads in the common frog, *Rana temporaria*. *Journal of Experimental Biology*, 1950, vol. 26, iss. 4, pp. 412–429. <https://doi.org/10.1242/jeb.26.4.412>
- Smith D. C. Adult recruitment in chorus frogs: Effects of size and date at metamorphosis. *Ecology*, 1987, vol. 68, iss. 2, pp. 344–350.
- Sparks T., Tryjanowski P., Cooke A., Crick H., Kuzniak S. Vertebrate phenology at similar latitudes: Temperature responses differ between Poland and the United Kingdom. *Climate Research*, 2007, vol. 34, iss. 2, pp. 93–98. <https://nora.nerc.ac.uk/id/eprint/679>
- Stuart S. N., Chanson J. S., Cox N. A., Young B. E., Rodrigues A. S. L., Fischman D. L., Waller R. W. Status and trends of amphibian declines and extinctions worldwide. *Science*, 2004, vol. 306, no. 5702, pp. 1783–1786. <https://doi.org/10.1126/science.1103538>
- Tabachishin V. G., Yermokhin M. V. New data on the distribution of Pallas's spadefoot toad (*Pelobates vespertinus* (Pallas, 1771)) and fire-bellied toad (*Bombina bombina* L., 1761) (Anura, Amphibia) on the territory of the Saratov region and adjacent territories. *Current Studies in Herpetology*, 2021, vol. 21, iss. 3–4, pp. 138–143. <https://doi.org/10.18500/1814-6090-2021-21-3-4-138-143>
- Terhivuo J. Phenology of spawning for the common frog (*Rana temporaria* L.) in Finland from 1846 to 1986. *Annales Zoologici Fennici*, 1988, vol. 25, no. 2, pp. 165–175.
- Todd B. D., Scott D. E., Pechmann J. H. K., Gibbons J. W. Climate change correlates with rapid delays and advancements in reproductive timing in an amphibian community. *Proceedings of the Royal Society B: Biological Sciences*, 2011, vol. 278, iss. 1715, pp. 2191–2197. <https://doi.org/10.1098/rspb.2010.1768>
- Tomavsević N., Cvetković D., Aleksić I., Crnobrana-Isailović J. Effect of climatic conditions on post-hibernation body condition and reproductive traits of *Bufo bufo* females. *Archives of Biological Sciences*, 2007, vol. 59, no. 3, pp. 51–52. <https://doi.org/10.2298/ABS070351PT>
- Tryjanowski P., Rybacki M., Sparks T. Changes in the first spawning dates of common frogs and common toads in Western Poland in 1978–2002. *Annales Zoologici Fennici*, 2003, vol. 40, no. 6, pp. 459–464.
- Unglaub B., Steinfartz S., Drechsler A., Schmidt B. R. Linking habitat suitability to demography in a pond-breeding amphibian. *Frontiers in Zoology*, 2015, vol. 12, article no. 9. <https://doi.org/10.1186/s12983-015-0103-3>
- Valenzuela-Sánchez A., Cunningham A. A., Soto-Azat C. Geographic body size variation in ectotherms: Effects of seasonality on an anuran from the southern temperate forest. *Frontiers in Zoology*, 2015, vol. 12, article number 37. <https://doi.org/10.1186/s12983-015-0132-y>
- Vasseur D. A., DeLong J. P., Gilbert B., Greig H. S., Harley C. D. G., McCann K. S., Savage V., Tunney T. D., O'Connor M. I. Increased temperature variation poses a greater risk to species than climate warming. *Proceedings of the Royal Society B: Biological Sciences*, 2014, vol. 281, iss. 1779, article no. 20132612. <https://doi.org/10.1098/rspb.2013.2612>
- Vignoli L., D'Amen M., Rocca F. D., Bologna M. A., Luiselli L. Contrasted influences of moon phases on the reproduction and movement patterns of four amphibian species inhabiting different habitats in Central Italy. *Amphibia-Reptilia*, 2014, vol. 35, iss. 2, pp. 247–254.
- Vonesh J. R., Warkentin K. M. Opposite shifts in size at metamorphosis in response to larval and metamorph predators. *Ecology*, 2006, vol. 87, iss. 3, pp. 556–562. <https://doi.org/10.1890/05-0930>
- Walpole A. A., Bowman J., Tozer D. C., Badzinski D. S. Community-level response to climate change: Shifts in anuran calling phenology. *Herpetological Conservation and Biology*, 2012, vol. 7, iss. 2, pp. 249–257.
- Weddeling K., Bosbach G., Hachtel M., Sander U., Schmidt P., Tarkhnishvili D. Egg size versus clutch size: Variation and trade-off in reproductive output of *Rana dalmatina* and *R. temporaria* in a pond near Bonn (Germany). Anajeva N., Tsinenko O., eds. *Herpetologia Petropolitana: Proceedings of the 12th Ordinary General Meeting of the Societas Europaea Herpetologica*. Saint Petersburg, Societas Europaea Herpetologica, 2005, pp. 238–240.
- Womack M. C., Steigerwald E., Blackburn D. C., Cannatella D. C., Catenazzi A., Che J., Koo M. S., McGuire J. A., Ron S. R., Spencer C. L., Vredenburg V. T., Tarvin R. D. State of the amphibia 2020: A review of five years of amphibian research and existing resources. *Ichthyology & Herpetology*, 2022, vol. 110, iss. 4, pp. 638–661. <https://doi.org/10.1643/h2022005>
- Yermokhin M. V., Tabachishin V. G. False spring in the spawning migrations of Spadefoot toads (*Pelobates*, Anura): Distribution in European Russia and the phenomenon scale in 2020. *Biology Bulletin*, 2022 a, vol. 49, no. 10, pp. 1883–1889. <https://doi.org/10.1134/S1062359022100235>
- Yermokhin M. V., Tabachishin V. G. False spring in the Southeastern European Russia and anomalies of the phenology of spawning migrations of the Pallas' spadefoot toad *Pelobates vespertinus* (Pelobatidae, Amphibia). *Russian Journal of Herpetology*, 2022 b, vol. 29, no. 4, pp. 206–214. <https://doi.org/10.30906/1026-2296-2022-29-4-206-214>