



# Small Hydropower Plants' Proliferation Would Negatively Affect Local Herpetofauna

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Hydropower plants (HPPs) have a strong environmental impact on freshwater wetlands. Small diversion HPPs (SDHPPs) with 0.1–10 MW of installed power, redirect water from small mountainous rivers into several-kilometer-long tubes, disrupting complex dynamics of local aquatic food webs and their interactions with neighbor terrestrial food webs. It certainly affects local aquatic communities, but it is often neglected that two highly threatened vertebrate groups—amphibians and reptiles—which live in and around these wetlands, could be affected as well. In the Balkan peninsula, a part of Southeastern Europe, SDHPPs recently became very attractive and profitable for potential investors after they were proclaimed as eligible for subsidies from the national budget. As a result, in year 2020, the maximal projected number of SHPPs in the Balkans increased to 4,556. According to the literature data, ~28% of amphibian species in the Balkan Peninsula use small rivers and streams in the upper parts of watersheds as feeding, breeding and/or nursery habitats. Additionally, 38% of the total number of reptile species in Europe are registered in the hilly/mountainous areas of the peninsula, and 33% of these species strictly need humid habitats. The attempt of this mini-review is to present the facts which show that SHPPs and DSHPPs, in the way they are currently being installed, present harmful energy solution for the biodiversity of the mountain parts of Balkan peninsula, particularly for local amphibian and reptile populations which rely on lotic aquatic ecosystems and/or humid terrestrial habitats.

**Keywords:** small hydropower plants, small diversion hydropower plants, Europe, impact, local biodiversity, Balkan peninsula, herpetofauna

## INTRODUCTION

Alarming trends for climate change presented in 1979 on the First World Climate Conference in Geneva suggested urgent global actions toward minimization of, or a total ban on, fossil fuels consumption (Ripple et al., 2020). The imperative for quick implementation of low-carbon renewables and other cleaner sources of energy, which would replace fossil fuels, put the use of hydropower into focus again (Oud, 2002; Zarfl et al., 2014). Although hydropower has been considered as a “renewable” and “green” source of electricity [see, for example Altinbilek (2004) and Flamos et al. (2011)], it seems that hydropower plants (HPPs throughout the text) have a strong

environmental impact on freshwater wetlands (Bunn and Arthington, 2002; Collen et al., 2014; Wu et al., 2019), additionally strengthened by climate change (Wu et al., 2021). Small hydropower plants (SHPPs) with 0.1–10 MW of installed power, were at the beginning presented as a very “green” and sustainable source of electricity: the general impression was that they had a much lesser negative environmental impact than the large HPPs [see short overview in Couto and Olden (2018)]. However, in reality the situation is quite the opposite (Konak and Sungu-Eryilmaz, 2016; Kelly-Richards et al., 2017). Small hydropower plants are generally established in the upper parts of river watersheds where they disrupt the river continuity (de Paes et al., 2019 and references therein). Despite being numerous, SHPPs contribute minimally to electricity production— $< \sim 2\%$  of the total (Kelly-Richards et al., 2017). Finally, they are often being established in remote areas and thus not easy to supervise or control (Schwartz, 2019). Small diversion HPPs (SDHPPs) which redirect water from small mountainous rivers into several-kilometer-long tubes especially impact local biodiversity (Meyer et al., 2007). In theory, the amount of water that still flows along the riverbed after this intervention should be large enough to keep local life forms at a biological minimum; in practice, water diversion makes parts of the riverbed dry, turning small perennial rivers to intermittent ones both spatially and temporally (Pekel et al., 2016). This not only results in the devastation of parts of the local lotic ecosystem, but also in degradation of the adjacent terrestrial biological community (Zilihona et al., 2004).

The literature describing impacts of energy development on direct wildlife mortality have mostly been focused on fish and bird species (Loss et al., 2019). Moreover, scientific papers related to the impact of SDHPPs on terrestrial vertebrates mainly analyzed birds and mammals [see in: Wu et al. (2019) and references therein, Wu et al. (2021)]. We conducted a search by Google Scholar and have found that this type of studies on amphibians and/or reptiles are relatively rare and mostly local (Benayas et al., 2006; Crnobrnja-Isailović, 2020; Dare et al., 2020 and references therein); however, they all pointed out a conflict between the SDHPP proliferation and the conservation of local amphibian and reptile communities [see in: Popescu et al. (2020)].

## COMMUNITY WEBS IN THE UPPER PARTS OF THE WATERSHEDS

Lotic aquatic systems or, in other words, rivers and streams, have a very complex structure; their most distinctive feature is their water flow (Webster, 1975). In ecosystems of the upper parts of a watershed, nutrient balance depends on stream discharge, and during periods of average flow the ratio of annual nutrient inputs to exports can vary up to three times [see in Molles and Sher (2019)]. Any aggressive change of the water flow dynamics will affect the biodiversity of the rivers and streams by altering specific components of the hydrological regime—baseflow magnitude, flood frequency and size, floodplain inundation, discharge variability; the flow components are rarely impacted independently from one another, ecosystem responses

function in the similar way and, altogether, this complexity is not easy to understand and predict the outcomes (Rolls and Bond, 2017).

Small lotic ecosystems in the upper parts of river sheds support biological communities adapted to fast-flowing and dynamic habitats (see above) and this makes the ecological impact of SHPP (per mega-watt of produced power) much higher than that of large HPP (Lange et al., 2015). These communities could and often do consist of some endemic species (Meyer et al., 2007), so their disruption contradicts both national and international legislation on biodiversity conservation [see in: Crnobrnja-Isailović (2020)]. Life-history traits and ecological characteristics of those species largely determine their response to the change of flow regime and therefore the ways biodiversity patterns are related to flow alteration (Rolls and Bond, 2017). Anthropogenic (intense) changes in the dynamics and structure of those peculiar communities, done on multiple levels of ecological organization, and affecting physical, chemical and biological processes, could devastate their uniqueness and therefore harm local biodiversity (Meyer et al., 2007). For example, as these communities are adjusted to site-specific temporal variability in water flow over fine temporal scales, the flow regulation (reduced flow disturbance frequency) will impact both their persistence and establishment and also of those in nearby terrestrial habitat (Rolls and Bond, 2017). Dynamics of upland lotic ecosystems is also complex, including the top-down impacts related to energy flow linkages (Power and Dietrich, 2002), and their interaction and intertwining with neighbor terrestrial food webs (Progar and Moldenke, 2002); simply put: as edge/area ratios increase upstream, small headwater channels are supposed to be more influenced by nearby terrestrial ecosystems (Power and Dietrich, 2002 and references therein) and therefore also by terrestrial species. SDHPPs installation affects biodiversity of upper parts of river sheds, both aquatic and adjacent terrestrial communities, by diverting river flow, and in the extent depending on the details which ultimately define the ecological impacts of HPP (Couto and Olden, 2018).

## AMPHIBIANS AND REPTILES IN FOOD WEBS

From the aspect of feeding relations, both amphibians and reptiles can generally be categorized as consumers, mostly carnivores, although specific developmental stages of some species are facultative or obligate herbivores (Pough et al., 2004). A statement that many amphibian and reptile species, being of small body size, are mostly positioned in the middle of food webs, has changed following more detailed insight into complexity of feeding relations in the ecosystems (Molles and Sher, 2019). Both of those vertebrate groups can have an important role even on the higher levels of local food webs (Todd et al., 2010). Amphibians mainly predate on small invertebrates and sometimes on vertebrates, at the same time being the prey of larger carnivore species; their larval stages are characterized by complex spatial-temporal feeding dynamics,

which also have a complex impact on food webs in the aquatic ecosystems they inhabit (Hocking and Babbitt, 2014). Depending on their size, reptiles have various positions in food webs (Pough et al., 2004). Reptiles are often direct or indirect terrestrial consumers (feeding on terrestrial insects which in turn prey on aquatic insects), and predators of species that are a part of the freshwater ecosystems: more than 90% of the biomass of freshwater species is regularly being transferred to terrestrial predators and every change in the population dynamics of their prey has an impact on abundance, territoriality, and, in the end, on overall reproductive success of those predator species (Polis et al., 1997).

### CURRENT THREATENING STATUS OF AMPHIBIANS AND REPTILES

The latest summary statistics done for 2020 by the International Union for Nature Conservation (IUCN) reveals that 31% of Red List assessed amphibian species of the world are exposed to certain factors of threat that lead to their rapid extinction (The IUCN Red List of Threatened Species, 2020). Amphibians are the most threatened vertebrate group, while reptiles are third on that list with 18% of threatened species. Recent scientific studies warned that even amphibian species with a large distribution range (and therefore mainly proclaimed as “Least Concern” under IUCN Red List criteria) suffer from anthropogenic

pressure in many countries (Petrovan and Schmidt, 2016). Besides habitat fragmentation and degradation, increased intensity of transportation, deliberate killing or harvesting for sale, or environmental pollution and climate change, there is an additional threat for amphibians and reptiles: the appearance and intensified spread of pathogenic microorganisms which devastate their populations (Pereira et al., 2013; Price et al., 2014; Lorch et al., 2016). Additionally, in many parts of the world, humans have an unfounded negative attitude toward amphibians and reptiles, reflected through persecution of these species, deliberate killing of their individuals and destruction of their habitats (Anthony et al., 2008; Böhm et al., 2013). All these facts indicate that amphibians and reptiles are prone to further decline if intensification of the listed threatening factors continues.

The high vulnerability of amphibians comes from the absence of efficient structures and functions typical for endothermic vertebrates that enable survival in conditions of apparent variation of environmental factors. Many amphibian species have a biphasic life history (aquatic and terrestrial environment) and one of the specific features of their reproductive biology is the necessity to utilize aquatic (freshwater) environments where they lay fertilized eggs or larvae and where embryonic development occurs (Pough et al., 2004). The influence of water regime is significant for amphibians: “the impact of reduced water availability is particularly important in areas that are already under hydrological stress” (Araújo et al., 2006).



**FIGURE 1 |** Maximal projected number of SHPPs per country (Schwartz, 2020) on the territory included in this review. Arabic and Roman numbers represent amphibian species listed in **Table 1** and reptile species listed in Discussion, respectively, per country (source: Speybroeck et al., 2016). AL, Albania; BA, Bosnia and Herzegovina; BG, Bulgaria; GR, Greece; HR, Croatia; ME, Montenegro; MK, North Macedonia; RS, Serbia; SL, Slovenia.

Reptiles have evolved toward independence from the aquatic environment; however, their extinction risk factors are similar with those of amphibians (Gibbons et al., 2000). Reptiles are also victims of rapid environmental change, although less so than amphibians. Humidity apparently influences different aspects of reptile biology and ecology [see Daltry et al. (1998), Le Galliard et al. (2012); and Garcia-Porta et al. (2019)]. For example, reproductive output, population growth and survival of some viper species are highly negatively impacted by prolonged drought (Smith et al., 2019). Drought was there defined as inadequate precipitation in terrestrial ecosystems over the years, which depletes the moisture of the soil and thus impacts all organisms interacting with the reptile capital breeder through the local food web. For Europe, modeling revealed an expected decline in species' richness in those parts where, on an annual level, precipitation will significantly decrease and the air temperature significantly increase (Araújo et al., 2006).

## HERPETOFAUNA AND SDHPPs IN THE BALKANS, SOUTHEASTERN EUROPE

According to Speybroeck et al. (2016), amphibian species present in the Balkans make up 39% of the total number of amphibian species in Europe. Combining national amphibian species lists of Balkan countries (Heathcote and Wilkinson, 2015) and data on species biology and ecology (Arnold and Ovenden, 2002) revealed that 29 species inhabit hilly/mountainous areas of the Balkan Peninsula. Among them, ~28% use small rivers and streams in the upper parts of watersheds as feeding, breeding and/or nursery habitats (Arnold and Ovenden, 2002; Crnobrnja-Isailović, 2020). Also, 88% of these are proclaimed Least Concern (non-threatened) by IUCN RL criteria, due to the large distribution area and the absence of evidence on any rapid population decline. As an example, a short overview in Republic of Serbia revealed that more amphibian species than had

**TABLE 1** | List of amphibian species inhabiting hilly/mountain areas of the Balkan Peninsula.

	Genus	Species	Common name	IUCN Global Red List status	Recorded in lentic habitats	Recorded in lotic habitats
1	<i>Proteus</i>	<i>anguinus</i>	Olm	VU	Subterranean	Subterranean
2	<b><i>Ichthyosaura</i></b>	<b><i>alpestris</i></b>	<b>Alpine newt</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
3	<i>Lyciasalamandra</i>	<i>helverseni</i>	The Karpathos Lycian salamander	VU	N	N
4	<i>Lyciasalamandra</i>	<i>luschani</i>	Lycian salamander	EN	N	N
5	<i>Lissotriton</i>	<i>vulgaris</i>	Smooth newt	LC	Y	N
6	<i>Salamandra</i>	<i>atra</i>	Alpine salamander	LC	N	N
7	<b><i>Salamandra</i></b>	<b><i>salamandra</i></b>	<b>Fire salamander</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
8	<i>Triturus</i>	<i>camifex</i>	Italian crested newt	LC	Y	N
9	<b><i>Triturus</i></b>	<b><i>cristatus</i></b>	<b>Northern crested newt</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
10	<i>Triturus</i>	<i>ivanbureschi</i>	Buresch's crested newt	NA	Y	N
11	<i>Triturus</i>	<i>macedonicus</i>	Macedonian crested newt	NA	Y	N
12	<b><i>Bombina</i></b>	<b><i>variegata</i></b>	<b>Yellow-bellied toad</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
13	<b><i>Bufo</i></b>	<b><i>bufo</i></b>	<b>Common toad</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
14	<i>Bufo</i>	<i>variabilis</i>	Variable green toad	NA	Y	N
15	<i>Bufo</i>	<i>viridis</i>	Green toad	LC	Y	N
16	<i>Hyla</i>	<i>arborea</i>	Common tree frog	LC	Y	N
17	<i>Hyla</i>	<i>orientalis</i>	Oriental tree frog	NA	Y	N
18	<i>Phelophylax</i>	<i>bedriagae</i>	Levant water frog	LC	Y	N
19	<i>Phelophylax</i>	<i>cerigensis</i>	Carpathos frog	EN	Y	N
20	<i>Phelophylax</i>	<i>cretensis</i>	Cretan frog	EN	Y	N
21	<i>Phelophylax</i>	<i>epeiroticus</i>	Epirus water frog	VU	Y	N
22	<i>Phelophylax</i>	<i>kl. esculentus</i>	Edible frog	LC	Y	N
23	<i>Phelophylax</i>	<i>kurtmuelleri</i>	Balkan water frog	LC	Y	N
24	<i>Phelophylax</i>	<i>shqjpericus</i>	Albanian water frog	EN	Y	N
25	<i>Phelophylax</i>	<i>ridibundus</i>	Marsh frog	LC	Y	N
26	<b><i>Rana</i></b>	<b><i>dalmatina</i></b>	<b>Agile frog</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>
27	<b><i>Rana</i></b>	<b><i>graeca</i></b>	<b>Greek stream frog</b>	<b>LC</b>	N	<b>Y</b>
28	<b><i>Rana</i></b>	<b><i>latastei</i></b>	<b>Italian agile frog</b>	<b>VU</b>	<b>Y</b>	<b>Y</b>
29	<b><i>Rana</i></b>	<b><i>temporaria</i></b>	<b>European common frog</b>	<b>LC</b>	<b>Y</b>	<b>Y</b>

Species list made following: Adrović (2015), Crnobrnja-Isailović and Paunović (2015), Crnobrnja-Isailović et al. (2018), Čirović (2015), Haxhiu (2015), Jovanović and Jelić (2015), Sotiropoulos and Lymberakis (2015), Stanković et al. (2015), Sterijovski (2015), Tzankov and Popgeorgiev (2015). Information on use of lentic or/and lotic habitats followed Arnold and Ovenden (2002) and Crnobrnja-Isailović (2020).

IUCN, International Union for Conservation of Nature; LC, least concern; VU, vulnerable; EN, endangered; NA, not Assessed. Bolded are species known for inhabiting lotic, or lentic and lotic aquatic ecosystems.

previously been known have recently been recorded spawning in small mountain rivers and streams (Crnobrnja-Isailović, 2020). One earlier study, conducted in 2003 to check the status of 53 crested newt breeding sites (ponds, pools, ditches, channels, lakes, etc.) recorded some 20–30 years ago, showed that ~40% of those lentic aquatic habitats, originally suitable for crested newt reproduction (and for many other local amphibian species, too), had become inappropriate for this purpose (Crnobrnja-Isailović et al., 2005). This mostly occurred because these aquatic habitats had been turned into fishponds or drained by landowners and then transformed into orchards or potato fields. Another issue is the ongoing climate change and expected natural drying up of a number of amphibian reproductive sites in the region, as well as aridification of some humid terrestrial habitats suitable for certain reptile species (Araújo et al., 2006).

Additionally, 38% of the total number of reptile species in Europe are registered in the hilly and mountainous areas of the Balkan Peninsula (Speybroeck et al., 2016); 33% of these species strictly need humid habitats (Arnold and Ovenden, 2002), and 50% of them are Least Concern.

## DISCUSSION

Hudjek et al. (2020) reviewed the distribution and trends of HPPs (including SDHPPs) in selected countries of the Balkan Peninsula; they revealed an unsatisfactory level of national monitoring programs. It was reflected in the lack of necessary monitoring data, in a very low number of monitoring stations and reference stations near HPPs and outside the affected river section, respectively, and in the absence of recent data on ecological impacts by small HPPs. It led to a conclusion that hydropower projects in the region can generate environmentally friendly electricity only if they are installed in the right places and with applying adequate mitigation measures. In somewhat earlier report, Schwartz (2020) counted 4,556 possible SHPPs in the region, summarizing existing, plus under construction and planned SHPPs (see **Figure 1**). Installation of SDHPPs in the Balkan Peninsula flourished after investors were proclaimed eligible for subsidies from the national budget (Hudjek et al., 2020). The symposium organized in 2019 in Serbia by the national Academy of Science and Arts (Anđelković, 2020) showed a discordance in statements about the impact of SHPPs on the environment between two groups of experts—hydrological engineers (Dimitrijević, 2020; Djordjević, 2020), forestry engineers (Ristić et al., 2020), and biologists (Crnobrnja-Isailović, 2020; Simonović, 2020) vs. mechanical and civil engineers (Božić and Petković, 2020; Karamarković et al., 2020; Stevović, 2020). Studies on S(D)HPPs controversies based on the experiences from Turkey (Konak and Sungu-Eryilmaz, 2016) presented the same issues as noted in the Balkans: the land use change, cumulative impacts, and affected populations are largely overlooked in the process of installing SDHPPs. In other words, a deep conflict between scientific knowledge and profit was described here. The issue of invasion of SDHPPs throughout the Balkans is another warning example of “bad practice,” or the paradox of ignoring

biodiversity conservation while applying theoretically sustainable practices—already presented, in general, by Kelly-Richards et al. (2017).

Even without numerous SDHPPs, the Balkan populations of some of the most widespread European amphibian species would be prone to local declines [see in Jovanović and Crnobrnja-Isailović (2019)]; moreover, their future in the region would not be bright if the mitigation of climate change fails (Jovanović et al., 2020). For those amphibian species that use both lotic and lentic waters for spawning (see **Table 1**), we expect that the decline of lentic breeding sites due to climate change will further increase the use of lotic ones. Huge number of SDHPPs in the hilly/mountainous parts (see projections in **Figure 1**) would not obviously support the survival of local amphibian populations which depend on rivers and streams. Proliferation of SDHPPs in the Balkans would also harm local populations of certain reptile species, by depleting soil moisture in the terrestrial habitats adjacent to the affected mountain rivers. For example, the local populations of *Vipera berus* (I<sup>1</sup>) would decline if the proliferation of SDHPPs continues, as humid terrestrial habitats nearby the upper parts of watersheds are suitable habitats for them (Arnold and Ovenden, 2002; Speybroeck et al., 2016). The same would also apply for other reptile species in the region which favor humid habitats [*Algyroides moreoticus* (II), *Zootoca vivipara* (III), *Iberolacerta horvathi* (IV), *Dinarolacerta mosorensis* (V), *Darevskia praticola* (VI), *Hellenolacerta graeca* (VII), *Anguis fragilis* (VIII), *Elaphe quatuorlineata* (IX)] or lotic aquatic habitats [*Natrix natrix* (X), *N. tessellata* (XI)] (Arnold and Ovenden, 2002).

In conclusion, our statement is that further proliferation of SDHPPs all over the Balkan Peninsula would negatively impact local herpetofauna, particularly those species which are directly or indirectly dependent on the lotic ecosystems in the hilly/mountainous regions. Existing policies and regulations generally appear to underestimate these impacts (see in Couto and Olden, 2018), but scientific interest on issue of non-sustainability of S(D)HPPs increases. The most of possibly affected amphibian and reptile species in the region are widespread (Arnold and Ovenden, 2002; Speybroeck et al., 2016; **Table 1** and references therein) and further proliferation of SDHPPs would negatively affect many of their local populations. Consequently, this would disturb many local biological communities which is a very high price for a negligible amount of produced electricity.

## AUTHOR CONTRIBUTIONS

JC-I generated the idea and wrote the first draft of the manuscript. BJ, MI, JĆ, and TČ summarized collected data on amphibian and reptile species. All authors were involved in collecting appropriate literature, extracting relevant data, commented on the first draft of the manuscript, corrected the draft, and approved the final version.

<sup>1</sup>Roman letter identifies reptile species on **Figure 1**.

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## REFERENCES

- Adrović, A. (2015). "Status of amphibians in Bosnia and Herzegovina," in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 62–66.
- Altinbilek, H. (2004). Hydropower for sustainable development. *Int. J. Hydropower Dams* 11, 65–69.
- Andelković, M. (2020). *Environmental Impact of Small Hydropower Plants*. Belgrade: Serbian Academy of Sciences and Arts, Scientific Meetings, Book CLXXXVII, Department of Chemical and Biological Studies, Book 17 (In Serbian, with summaries in English).
- Anthony, B., Arntzen, J. W., Baha El Din, S., Böhme, W., Cogalniceanu, D., and Crnobrnja-Isailovic, J. (2008). "Amphibians of the palaeartic realm", in *Threatened Amphibians of the World*, eds S. N. Stuart, M. Hoffmann, J. S. Chanson, N. A. Cox, R. J. Berridge, P. Ramani, et al. (Barcelona: Lynx Edicions, with IUCN - The World Conservation Union, Conservation International and NatureServe), 106–113.
- Araújo, M. B., Thuiller, W., and Pearson, R.G. (2006). Climate warming and the decline of amphibians and reptiles in Europe. *J. Biogeogr.* 33, 1712–1728. doi: 10.1111/j.1365-2699.2006.01482.x
- Arnold, E. N., and Ovenden, D. W. (2002). *Reptiles and Amphibians of Europe*. Princeton; Oxford: Princeton University Press.
- Benayas, J. M. R., De La Montaña, E., Belliure, J., and Eekhout, X. R. (2006). Identifying areas of high herpetofauna diversity that are threatened by planned infrastructure projects in Spain. *J. Environ. Manag.* 79, 279–289. doi: 10.1016/j.jenvman.2005.07.006
- Böhm, M., Collen, B., Baillie, J. E. M., Bowles, P., Chanson, J., Cox, N., et al. (2013). The conservation status of the world's reptiles. *Biol. Conserv.* 157, 372–385. doi: 10.1016/j.biocon.2012.07.015
- Bunn, S. E., and Arthington, A. R. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environ. Manag.* 30, 492–507. doi: 10.1007/s00267-002-2737-0
- Ćirović, R. (2015). "Amphibian declines and conservation in Montenegro," in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 56–61.
- Collen, B., Whitton, F., Dyer, E. E., Baillie, J. E. M., Cumberlidge, N., Darwall, W. R. T., et al. (2014). Global patterns of freshwater species diversity, threat and endemism. *Global Ecol. Biogeogr.* 23, 40–51. doi: 10.1111/geb.12096
- Couto, T. B. A., and Olden, J. D. (2018). Global proliferation of small hydropower plants science and policy. A review. *Front. Ecol. Environ.* 16, 91–100. doi: 10.1002/fee.1746
- Crnobrnja-Isailović, J. (2020). "The impact of diversion small hydropower plants on local amphibian and reptile populations," in *Environmental Impact of Small Hydropower Plants*, ed M. Andelković (Belgrade: Serbian Academy of Sciences and Arts), 191–207 (In Serbian, with summary in English).
- Crnobrnja-Isailović, J., Aleksić, I., and Arntzen, J. W. (2005). The Status of great crested newt breeding sites in Serbia. *Froglog* 67, 2–3. <https://www.iucn-amphibians.org/resources/froglog/froglog/archives/froglog-69/>.
- Crnobrnja-Isailović, J., and Paunović, M. (2015). "Conservation and Decline of European Amphibians: The Republic of Serbia," in *Amphibian Biology, Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 45–55.
- Crnobrnja-Isailović, J., Polović, L., Ljubisavljević, K., Cadenović, N., Cubrić, T., and Haxhiu, I. (2018). "Diversity and conservation status of batrachofauna and herpetofauna in the lake Skadar region," in *The Handbook of Environmental Chemistry*, Vol. XX. The Skadar/Shkodra Lake Environment, eds V. Pešić, G. Karaman, and A. Kostianoy (Heidelberg: Springer-Verlag GmbH), 383–414. doi: 10.1007/978-3-642-01825-2\_252
- Daltry, J. C., Ross, T., Thorpe, R. S., and Wuster, W. (1998). Evidence that humidity influences snake activity patterns: a field study of the Malayan pit viper *Calloselasma rhodostoma*. *Ecography* 21, 25–34. doi: 10.1111/j.1600-0587.1998.tb00391.x
- Dare, G. C., Murray, R. G., Courcelles, D. M. M., Malt, J. M., and Palen, W. J. (2020). Run-of-river dams as a barrier to the movement of a stream-dwelling amphibian. *Ecosphere* 11:e03207. doi: 10.1002/ecs2.3207
- de Paes, R. P., Costa, V. A. F., and dos Santos Fernandes, W. (2019). Effects of small hydropower plants in cascade arrangement on the discharge cyclic patterns. *Braz. J. Water Res.* 24:e33. doi: 10.1590/2318-0331.241920180140
- Dimitrijević, V. (2020). "The impact of mini hydropower plants on water system, design and construction requirements," in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 21–41. (In Serbian, with summary in English).
- Djordjević, B. V. (2020). "Assessing the energy related, environmental and economic impacts of small-scale hydroelectric power plants," in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 67–91. (In Serbian, with summary in English).
- Flamos, A., Georgalis, P., Doukas, H., and Karakosta, C. (2011). Hydro energy: techno-economic and social aspects within new climate regime. *Int. J. Renew. Energy Technol.* 2, 32–52. doi: 10.1504/IJRET.2011.037980
- García-Porta, J., Irisarri, I., Kirchner, M., Rodríguez, A., Kirchner, S., Brown, J. L., et al. (2019). Environmental temperatures shape thermal physiology as well as diversification and genome-wide substitution rates in lizards. *Nat. Commun.* 10, 1–12. doi: 10.1038/s41467-019-11943-x
- Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlmann, K. A., Tuberville, T. D., Metts, B. S., et al. (2000). The global decline of reptiles, Déjà vu amphibians. *Bioscience* 50, 653–666. doi: 10.1641/0006-3568(2000)050[0653:TGDORD]2.0.CO;2
- Haxhiu, I. (2015). "Amphibians of Albania," in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 74–79. Available online at: [http://www.herpconbio.org/contents\\_vol9\\_issue1.html](http://www.herpconbio.org/contents_vol9_issue1.html)

- Heathvole, H., and Wilkinson, J. (2015). *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*. Exeter: Pelagic Publishing.
- Hocking, D. J., and Babbitt, K. J. (2014). Amphibian contributions to ecosystem services. *Herpetol. Conserv. Biol.* 9, 1–17.
- Hudjek, H., Žganec, K., and Pusch, M. T. (2020). A review of hydropower dams in Southeast Europe – distribution, trends and availability of monitoring data using the example of a multinational Danube catchment subarea. *Renew. Sust. Energy Rev.* 117:109434. doi: 10.1016/j.rser.2019.109434
- Jovanović, B., and Crnobrnja-Isailović, J. (2019). Fluctuations in population abundance in two anurans from Central Serbia. *Herpetozoa* 32, 65–71. doi: 10.3897/herpetozoa.32.e35660
- Jovanović, B., Kessler, E. J., Ilić, M., Corović, J., Tomašević-Kolarov, N., and Phillips, C.A., et al. (2020). Possible implications of weather variation on reproductive phenology of European common toad in southeastern Europe. *Turk. Zool. Derg.* 44, 44–50. doi: 10.3906/zoo-1908-49
- Jovanović, O., and Jelić, D. (2015). “Conservation and declines of amphibians in Croatia,” in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 25–31.
- Karamarković, V., Karamarković, R., Nikolić, M., and Stojić, N. (2020). “The impact of small hydropower plants on the sustainable development of the Republic of Serbia,” in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 43–66. (In Serbian, with summary in English).
- Kelly-Richards, S., Silber-Coats, N., Crootof, A., Tecklin, D., and Bauer, C. (2017). Governing the transition to renewable energy: a review of impacts and policy issues in the small hydropower boom. *Energy Policy* 101, 251–264. doi: 10.1016/j.enpol.2016.11.035
- Konak, N., and Sungu-Eryilmaz, Y. (2016). Does small run-of-river hydro power development in turkey deliver on its sustainability premise? *Soc. Nat. Resour.* 29, 807–821. doi: 10.1080/08941920.2015.1086459
- Lange, K., Meier, P., Trautwein, C., Schmid, M., Robinson, C. T., Weber, C., et al. (2015). Basin-scale effects of small hydropower on biodiversity dynamics. *Front. Ecol. Environ.* 16:1823. doi: 10.1002/fee.1823
- Le Galliard, J. F., Massot, M., Baron, J. P., and Clobert, J. (2012). “Ecological effects of climate change on European reptiles,” in *Conserving Wildlife Populations in a Changing Climate*, eds J. Brodie, E. Post, and D. Doak (Chicago: University of Chicago Press), 179–203.
- Lorch, J. M., Knowles, S., Lankton, J. S., Michell, K., Edwards, J. L., Kapfer, J. M., et al. (2016). Snake fungal disease: an emerging threat to wild snakes. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 371:20150457. doi: 10.1098/rstb.2015.0457
- Loss, S. R., Dorning, M. A., and Diffendorfer, J. E. (2019). Biases in the literature on direct wildlife mortality from energy development. *Bioscience* 69, 348–359. doi: 10.1093/biosci/biz026
- Meyer, J. L., Strayer, D. L., Wallace, J. B., Eggert, S. L., Helfman, G. S., and Leonard, N. E. (2007). The contribution of headwater streams to biodiversity in river networks. *J. Am. Water Resour. Assoc.* 43, 86–103. doi: 10.1111/j.1752-1688.2007.00008.x
- Molles, M. C. Jr., and Sher, A. A. (2019). *Ecology: Concepts and Applications, 8th Edn.* New York, NY: McGraw-Hill Education.
- Oud, E. (2002). The evolving context for hydropower development. *Energy Policy* 30, 1215–1223. doi: 10.1016/S0301-4215(02)00082-4
- Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature* 540, 418–422. doi: 10.1038/nature20584
- Pereira, P. L., Torres, A. M., Soares, D. F., Hijosa-Valsero, M., and Bécáres, E. (2013). Chytridiomycosis: a global threat to amphibians. *Rev. Off. Int. Epizoot.* 32, 857–867. doi: 10.20506/rst.32.2.2210
- Petrovan, S. O., and Schmidt, B. R. (2016). Volunteer conservation action data reveals large-scale and long-term negative population trends of a widespread amphibian, the common toad (*Bufo bufo*). *PLoS ONE* 11:e0161943. doi: 10.1371/journal.pone.0161943
- Polis, G. A., Anderson, W. B., and Holt, R. D. (1997). Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. *Ann. Rev. Ecol. Syst.* 28, 289–316. doi: 10.1146/annurev.ecolsys.28.1.289
- Popescu, V. D., Munshaw, R. G., Shackelford, N., Montesino Pouzols, F., Dubman, E., Gibeau, P., et al. (2020). Quantifying biodiversity trade-offs in the face of widespread renewable and unconventional energy development. *Sci. Rep.* 10:7603. doi: 10.1038/s41598-020-64501-7
- Pough, F. H., Andrews, R. M., Cadle, J. E., Crump, M. L., Savitzky, A. H., and Wells, K. D. (2004). *Herpetology, 3rd Edn.* New York, NY: Prentice Hall
- Power, M. E., and Dietrich, W. E. (2002). Food webs in river networks. *Ecol. Res.* 17, 451–457. doi: 10.1046/j.1440-1703.2002.00503.x
- Price, S. J., Garner, T. W., Nichols, R. A., Balloux, F., Ayres, C., de Alba, A. M. C., et al. (2014). Collapse of amphibian communities due to an introduced Ranavirus. *Curr. Biol.* 24, 2586–2591. doi: 10.1016/j.cub.2014.09.028
- Progar, R. A., and Moldenke, A. R. (2002). Insect production from temporary and perennially flowing headwater streams in western Oregon. *J. Freshwater Ecol.* 17, 391–407. doi: 10.1080/02705060.2002.9663913
- Ripple, W. J., Wolfe, C., Newsome, T. M., Barnard, P., and Moomaw, W. R. (2020). Corrigendum: world scientists’ warning on climate change. *Bioscience* 70, 8–12. doi: 10.1093/biosci/biz152
- Ristić, R., Malušević, I., Polovina, S., Milčanović, V., and Radić, B. (2020). “Small derivate hydropower plants: a negligible contribution to power generation and an imparably adverse environmental impact,” in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 107–133. (In Serbian, with summary in English).
- Rolls, R. J., and Bond, N. R. (2017). “Environmental and ecological effects of flow alteration in surface water ecosystems,” in *Water for the Environment from Policy and Science to Implementation and Management*, eds A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman (Cambridge, MA: Academic Press), 65–82. doi: 10.1016/B978-0-12-803907-6.00004-8
- Schwartz, U. (2019). Hydropower pressure on European rivers: The story in numbers. *FLUVIUS, WWF, RiverWatch, EuroNatur, GEOTA*. Available online at: [https://www.wwf.eu/wwf\\_news/publications/?uNewsID=356638](https://www.wwf.eu/wwf_news/publications/?uNewsID=356638) (accessed December 25, 2020).
- Schwartz, U. (2020). *Hydropower Projects on Balkan Rivers - 2020 Update*. Radolfzell: RiverWatch & EuroNatur. Available online at: [https://balkanrivers.net/uploads/files/3/Balkan\\_HPP\\_Update\\_2020.pdf](https://balkanrivers.net/uploads/files/3/Balkan_HPP_Update_2020.pdf)
- Simonović, P. (2020). “The impact of small derivative hydropower plants on fish species and other aquatic organisms in the mountain river ecosystems of Republic of Serbia,” in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 169–190. (In Serbian, with summary in English).
- Smith, C. F., Schuett, G. W., Reiserer, R. S., Dana, C. E., Collyer, M. L., and Davis, M. A. (2019). Drought-induced suppression of female fecundity in a capital breeder. *Sci. Rep.* 9:15499. doi: 10.1038/s41598-019-51810-9
- Sotiropoulos, K., and Lymberakis, P. (2015). “Declines and conservation of amphibians in Greece,” in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 80–86.
- Speybroeck, J., Beukema, W., Book, B., and Van der Voort, J. (2016). *Field Guide to the Amphibians and Reptiles of Britain and Europe*. London: Bloomsbury Natural History.
- Stanković, D., Lužnik, M., and Pobješaj, K. (2015). “Conservation and declines of amphibians in Slovenia,” in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 32–44.
- Sterijovski, B. (2015). “Conservation and protection status of amphibians in Macedonia,” in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 67–73.
- Stevović, S. (2020). “SHPP construction concept in terms of conflict of interest and synergic solutions,” in *Environmental Impact of Small Hydropower Plants*, ed M. Anđelković (Belgrade: Serbian Academy of Sciences and Arts), 135–168. (In Serbian, with summary in English).
- The IUCN Red List of Threatened Species (2020). *Summary Statistic Tables*. Available online at: <https://www.iucnredlist.org/resources/summary-statistics#Summary%20Tables> (accessed August 8, 2020).

- Todd, B. D., Willson, J. D., and Gibbons, J. W. (2010). "The global status of reptiles and the causes of their decline," in *Ecotoxicology of Amphibians and Reptiles, 2nd Edn*, eds D. W. Sparling, C. A. Bishop, and S. Krest (Pensacola, FL: CRC Press), 47–67. doi: 10.1201/EBK1420064162-c3
- Tzankov, N. D., and Popgeorgiev, G. S. (2015). "Conservation and declines of amphibians in Bulgaria," in *Amphibian Biology Vol 11. Part 4. Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey*, eds H. Heathvole, and J. Wilkinson (Exeter: Pelagic Publishing), 131–139.
- Webster, J. R. (1975). *Analysis of potassium and calcium dynamics in stream ecosystems on three southern Appalachian watersheds of contrasting vegetation* (PhD thesis). University of Georgia, Athens, Greece.
- Wu, H., Chen, J., Xu, J., Zeng, G., Sang, L., Liu, Q., et al. (2019). Effects of dam construction on biodiversity: a review. *J. Cleaner Prod.* 221, 480–489. doi: 10.1016/j.jclepro.2019.03.001
- Wu, H., Dai, J., Sun, S., Du, C., Long, Y., Chen, H., et al. (2021). Responses of habitat suitability for migratory birds to increased water level during middle of dry season in the two largest freshwater lake wetlands of China. *Ecol. Indicators* 121:107065. doi: 10.1016/j.ecolind.2020.107065
- Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., and Tockner, K. (2014). A global boom in hydropower dam construction. *Aquat. Sci.* 77, 161–170. doi: 10.1007/s00027-014-0377-0
- Zilihona, I. J. E., Niemela, J., and Nummelin, M. (2004). Effects of a hydropower plant on Coleopteran diversity and abundance in the Udzungwa Mountains, Tanzania. *Biodivers. Conserv.* 13, 1453–1464. doi: 10.1023/B:BIOC.0000021325.90554.0b

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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