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Distribution and diversity of amphibians in Albania: new data and foundations of a comprehensive database

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Abstract. Albania is part of the Mediterranean biodiversity hotspot. Yet its amphibian fauna is poorly known due to little scientific exploration during the long political isolation of the country. To fill this gap, we constructed a georeferenced database with occurrences of all known amphibian species based on records from published sources and personal data collected during expeditions to poorly known areas. Our database includes 1097 records of 16 species collected between 1920 and 2017. Based on aggregated records, we analysed richness patterns of amphibians in 10×10 km grid cells as a function of altitude, climate, land cover diversity and distance from the sea. The mean number of species per cell was 1.8 ± 0.11 S.E. (maximum: 10 species) and at least one species occurred in 238 of the 349 cells. Sampling effort was uneven and sampling hotspots were mostly in popular sites of natural heritage. Cells with high amphibian diversity were near the Prokletije Mountains in the North-West, near Lura, Korab and Grammos Mountains and Ohrid and Prespa Lakes in the East, and near Çikës Mountains and in coastal areas of Vlorë in the South-West. General linear models showed that the most important predictors of presence and diversity of amphibian species are land cover diversity and precipitation. Our study presents the largest database of amphibian occurrences in Albania to date that will be useful for biogeographical and ecological studies and for conservation purposes.

Keywords: Balkan Peninsula, BIOCLIM, biogeography, GLMM, range, species richness.

Introduction

Understanding the spatial distribution of biodiversity is one of the principal objectives of ecology (Gaston, 2000). Mapping species distributions and diversity is also a prime objective and tool in conservation (Pimm and Jenkins, 2005). However, the collection of records is often spatially biased, even in Europe (Sillero et al., 2014a).

Globally, amphibians are considered as one of the most threatened taxonomic groups (Gibbons et al., 2000; Alroy, 2015), with almost half of the species are declining (Stuart et al., 2004). The rapid decline of amphibians is explained by several factors such as fragmentation, degradation and complete loss of their habitats, global climate change, rapidly spreading diseases, and synergies between these threats (Cushman, 2006; Sodhi et al., 2008). Rare species with restricted ranges and small populations are more likely to decline and to be affected by extinction risk (Harnik, Simpson and Payne, 2012). Moreover, some amphibian species and endemic phylogenetic lineages are better adapted to past refugial regions and can survive better there than in their current post-glacial ranges (Dufresnes and Perrin, 2015). An understanding of the main drivers of the presence and diversity of amphibians is thus fundamental for the design and implementation of

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conservation measures for declining amphibians.

Albania is located in the western part of the Balkan Peninsula and is part of the Mediterranean hotspot of biodiversity (Myers, 2000; Griffiths, Kryštufek and Reed, 2004). The country covers 28,748 km^2 with an altitudinal range from sea level to 2764 meters. The collection of faunistic data on amphibians started in the early 20th century (Kopstein and Wettstein, 1920; Werner, 1920). This was followed by a long hiatus until the next review on amphibians was published in the mid-nineties (Haxhiu, 1994). However, these data are more restricted than those for reptiles from the same and later period (see Haxhiu, 1998; Jablonski, 2011; Mizsei et al., 2017). After the rapid decline of amphibians came into the spotlight of conservation in the early 1990s and after the former isolationist political system ended in Albania in 1992, the number of records on amphibian species from Albania started to increase again. However, many of these records remained unpublished.

Mainly due to the north-south orientation of Albania, the country covers the ranges of numerous amphibian species occurring in the Balkan Peninsula. Moreover, despite its small area, Albania has high geomorphological heterogeneity and highly varied topography formed by the Hellenides range (e.g. 70% of its terrain is mountainous; fig. 1). These conditions, along with a Mediterranean climate led to the formation of a diverse pool of amphibian species in the Hellenides region where Albania is located (Pabijan et al., 2015). Landscape topography is primarily explained by orogenic processes initiated by the collision of the Adria microplate with the Eurasian plate. During the last stage of the Neotectonic Pliocene-Quaternary period, from the Middle Pleistocene to the present times, local episodes of subsidence induced the formation of graben lakes such as Skadar, Ohrid and Prespa (fig. 1) and the development of Quaternary graben plains (Aliaj, Baldassare and Shkupi, 2001). This land

Figure 1. Geographic map of the study area indicating toponymics mentioned in the text.

evolution, in combination with the later relative stability of the Mediterranean climate resulting from little influence of Pleistocene glaciations, led to allopatric speciation and diversification in several amphibian lineages. There are strong indications that some of these Miocene-Pliocene speciation centres or Pleistocene glacial refugia of amphibians (and other taxa with limited dispersal ability) were located inside or close to the current territory of Albania (Médail and Diadema, 2009). The Western Balkan is home for two endemic species of water frogs (*Pelophylax epeiroticus*, *P. shqipericus*), one endemic brown frog (*Rana graeca*), crested newt (*Triturus macedonicus*) and smooth newt (*Lissotriton graecus*) which are also part of the Albanian amphibian fauna (Sillero et al., 2014a; Pabijan et al., 2015; 2016). However, detailed data on the phylogeography and genetic diversity of amphibian species in Albania are still lacking. Current coastal and freshwater ecosystems include rivers, streams, lakes, swamps, estuaries, lagoons or drainage channels and all these represent suitable habitats for amphibians. To date, 16 species of amphibians have been detected in Albania (Haxhiu, 1994; Szabolcs and Mizsei, 2017). Mainly due to the southern location and the landscape- and habitat-scale heterogeneity of Albania, this number of species is higher than in many other European countries covering a larger area (Haxhiu, 1994). Therefore, this region has central importance in understanding both the past and present patterns of amphibian diversity in Europe, which thus warrants a synthesis and an update of the current knowledge on amphibian species of the country. In addition, the high diversity of habitats in Albania and the synthesised knowledge on the occurrence of amphibian species offer an opportunity to contribute to our understanding of some of the environmental factors influencing the presence/absence and the diversity of amphibian species in a biodiversity hotspot.

In this study we aim to (i) fill gaps in our knowledge on the distribution of amphibian species in Albania by collecting occurrence records from previous literature and supplementing them by our recently collected data into a single georeferenced database, (ii) present up-to-date distribution maps for each species, and (iii) analyse patterns of species diversity in order to find hotspots of amphibian diversity and to identify environmental factors that explain the distribution of amphibians in Albania. This article is complementary to our previous study on the distribution and diversity of reptiles in Albania (Mizsei et al., 2017).

Materials and methods

Data collection and processing

We used five sources of data to populate our database on the occurrences of amphibians in Albania. First, we collected records by searching the primary literature for studies and reports of amphibian species in Albania. Whenever it was possible, we georeferenced published maps in Quantum GIS 1.8.0 using the GDAL plugin (for Bruno, 1989) or used the original coordinates published in the articles (as in Bringsøe, 2011; Jablonski, 2011; Recuero et al., 2012; Pabijan et al., 2015; Szabolcs and Mizsei, 2017). If maps or coordinates were not available (as in Kopstein and Wettstein, 1920; Werner, 1920; Frommhold, 1962; Schneider and Haxhiu, 1994; Haxhiu, 1994, 2000a, 2000b, 2000c, 2000d; Uhrin and Šíbl, 1996; Farkas and Búzás, 1997; Ragghianti et al., 1999; Denoël et al., 2001; Haxhiu and Vrenozi, 2009; Shehu et al., 2009; Oruçi, 2010; Aliko et al., 2012; Guignard et al., 2012; Aliko, Biba and Sula, 2013; Shkurti, 2013; Aliko, Qirjo and Nuna, 2014), we identified localities given in the studies using combinations of Google Earth 7.1.8, Google Maps (http://maps.google.com), the GeoNames database (http://geonames.org) and online searches. When a location could be identified with certainty, we added there a point record. Second, we processed records from the amphibian collection of the Hungarian Natural History Museum (Budapest). Third, we added records from the Global Biodiversity Information Facility (GBIF, http://gbif.org, which includes records from several museums), the iNaturalist (http://inaturalist.org) and the TrekNature (http://treknature.com) databases with the permission of the data providers. Fourth, we obtained records from fellow scientists and citizen herpetologists with extensive knowledge of Albanian amphibians. The internet forum called Fieldherping.eu (http://fieldherping.eu) was a major source to contact these experts. Finally, we added our own unpublished data collected during 21 on-site field expeditions in Albania. Most of these expeditions were conducted as part of studies on the Greek Meadow Viper (*Vipera graeca*, Mizsei et al., 2016), but we also specifically visited areas from where we found no information in the four sources listed above. Most field expeditions took place in the summer months, but some were conducted as early as late April to as late as early October, and one was in the winter. During site visits, we surveyed every habitat suitable for amphibians for at least 30 min and recorded the coordinates of each amphibian found by a GPS device in the field or we assigned one coordinate to multiple individuals if they were close to each other (~50 m). We also recorded roadkills. We stored all records in point shapefiles in a GIS database.

For species treatment, we used the most up-to-date nomenclature and taxonomy by Sillero et al. (2014a), Speybroeck et al. (2016), and by Dufresnes et al. (2017) for *Pelophylax* water frogs with the cross-check of Frost (2017). Three species from the latter genus (*P. epeiroticus*, *P. kurtmuelleri* and *P. shqipericus*) are difficult to identify based on external morphological characters because they occur sympatrically and are known to hybridise with each other. Although most of the *Pelophylax* species can be identified acoustically (Schneider and Haxhiu, 1994; Lukanov, Tzankov and Simeonovska-Nikolova, 2015), we did not have this information in most cases, thus we merged these three species into *Pelophylax* spp. to avoid the possibility of sampling bias to any of the three species (see e.g. Mester et al., 2015). Recent taxonomical work suggested that two species of the genus *Bufotes* occur in Albania (formerly *Bufo*, Özdemir et al., 2014). Because we could not identify these species in the field, we merged them under the name *B. viridis/variabilis*. We used the names *L. graecus* instead of *L. vulgaris* and *Pelophylax kurtmuelleri* instead of *P. ridibundus* because recent molecular analyses supported the species status of these Balkan lineages (Pabijan et al., 2016, Dufresnes et al., 2017).

For spatial visualisation and analyses, we aggregated point records into a 10 × 10-km grid ($n = 349$ cells covering Albania) provided by the European Environmental Agency (EEA, http:/eea.europa.eu/data-and-maps/data/eea-reference-grids) in ETRS89 Lamberth Azimuthal Equal Area projection (EPSG: 3035). This resolution fitted well with our records and was amenable for further spatial analyses, whereas coarser resolutions (e.g. 50 × 50 km) may have led to less informative results. Our database is easily joined to those of other countries by aggregating them to EEA grids. To identify the elevation of the localities to produce the altitudinal ranges of the species, we used the Shuttle Radar Topographic Mission (SRTM) 90-m Digital Elevation Database 4.1 (Jarvis et al., 2008). We also noted the year for every record.

Spatial analyses

Spatial autocorrelation among the records and bias due to spatially uneven sampling are common biases in point occurrence data (Rocchini et al., 2011). We tested for spatial autocorrelation in the number of records per cell using the Global Moran's I spatial statistic. This statistic tests the null hypothesis that the occurrence records are evenly distributed against the alternative hypothesis that the records are spatially either clustered ($Z > 0$) or dispersed ($Z < 0$). To analyse patterns in sampling bias, we used the Getis Ord Gi* spatial statistic (Ord and Getis, 1995), which informs whether sampling effort is significantly lower (GiZ score < -1.96, coldspot of sampling) or higher (GiZ score > 1.96, hotspot of sampling) than expected by chance. We used ESRI ArcGIS 10.0 in these analyses.

We calculated Shannon diversity for each 10 × 10 km cell and then visualised the occurrences of the species within the cells using the R package 'vegan' (Oksanen et al., 2016). Additionally, we calculated the Extent of Occurrence (EOO) for each species by fitting a Minimum Convex Polygon to their point records and then dissected it with the territory of Albania to obtain the Albanian range of each species. We chose to estimate EOO to ensure compatibility with the measures used in the Red Listing process of the International Union for the Conservation of Nature (IUCN) and with our previous work on reptiles of Albania (Mizsei et al., 2017).

Environmental data and linear modeling

We obtained information on several variables to model the effects of environmental factors on amphibian presence/absence and diversity (table 1). First, we obtained data on 19 climatic variables (Bioclim) from the WorldClim database (Hijmans et al., 2005). We then applied a principal component analysis using the R package 'cluster' to extract four principal components for the climatic variables (Maechler et al., 2016), which explained 99% of the total variance. Second, we measured habitat diversity by calculating the Shannon-diversity of CORINE Land Cover (CLC 2006 ver. 17, 250 m resolution; European Environmental Agency, 2007) classes in each cell using the LecoS 1.9.8 plugin in QGIS (Jung, 2012). This index thus incorporates both habitat heterogeneity (e.g. landscape architecture) and anthropogenic pressure (e.g. agricultural or urban land use). Third, we measured elevation and altitudinal variation within the cells by calculating the mean and standard deviation (S.D.) of altitude within each 10 × 10 km cell based on grid values from the Shuttle Radar Topographic Mission (SRTM) 90-m Digital Elevation Database 4.1 (Jarvis et al., 2008) using Zonal Statistics in QGIS 2.12. Finally, we calculated the distance between the centroid of each cell and the closest point to the sea shore using the NNJoin 1.2.2 plugin in QGIS.

To evaluate the effects of environmental variables on amphibian presence/absence, we applied a model selection approach by fitting generalized linear mixed models (GLMM) with binomial error distribution (Pinheiro and Bates, 2000) using the 'lme4' R package (Bates et al., 2015). We ran models for all possible combinations of the environmental variables. To evaluate the relation between Shannon diversity of amphibians and environmental predictors, we fitted a GLMM using the Markov chain Monte Carlo (MCMC) routine of the 'MCMCglmm' R package with its default parameters (Hadfield, 2010). Model fitting and selection were performed in the 'MuMIn' R package (Barton, 2011). To control for spatial autocorrelation, we specified cell ID as a random factor, and to control for sampling bias, we included GiZ scores as a random factor in both GLMMs. To minimise the influence of phylogenetic relatedness of the species, we included species ID nested in taxonomic order as an additional random factor in the GLMM.

After model selection, we calculated the relative importance of environmental predictors using model-comparison techniques in an information-theoretic framework (Burnham and Anderson, 2002). In the first step, we obtained the values of Akaike's information criterion corrected for small sample sizes (AICc), which is a metric of the trade-off between the goodness of fit of the model and its complexity, thus, it functions as a measure of information entropy. Next, we assessed the corresponding Akaike weight (ω) of each model, which represents the relative likelihood of a model. In the third step, we selected models with substantial support by considering models with AICc differences of <2 from the best (lowest AICc) model (Burnham and Anderson, 2002). Finally, we calculated model-averaged parameter estimates (θ) and unconditional standard errors that controlled for model uncertainty (SEu; Burnham and Anderson,

Table 1. Environmental variables used in this study.

Predictor	Description	Data source
BIO PC1	"Temperature" principal component BIO1 = Annual Mean Temperature BIO6 = Min Temperature of Coldest Month BIO11 = Mean Temperature of Coldest Quarter	Hijmans et al., 2005
BIO PC2	"Precipitation" principal component BIO12 = Annual Precipitation BIO16 = Precipitation of Wettest Quarter BIO19 = Precipitation of Coldest Quarter	Hijmans et al., 2005
BIO PC3	"Temperature variation" principal component BIO2 = Mean Diurnal Range (Mean of monthly (max temp-min temp) BIO4 = Temperature Seasonality (standard deviation*100) BIO7 = Temperature Annual Range (BIO5-BIO6))	Hijmans et al., 2005
BIO PC4	"Precipitation variation" principal component BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO15 = Precipitation Seasonality (Coefficient of Variation)	Hijmans et al., 2005
CORINE DIV	Shannon diversity of CORINE Land cover in 10 × 10 km cells	European Environment Agency
ALT MEAN	Mean of altitude values in 10 × 10 km cells, calculated from the SRTM near 90 m data	CGIA-CSI
ALT SD	Standard deviation of altitude values in 10 × 10 km cells, calculated from the SRTM near 90 m data	CGIA-CSI
SEA DIST	Min distance of 10 × 10 km cells centroids from sea coast	present study

2002) of each variable by the sums of their Akaike weights across all models with substantial support containing the given predictor. For all analyses, we used the R 3.3.2 statistical computing environment (R Core Team, 2016).

Results

Species distributions

We collected a total of $N = 1097$ occurrence records of amphibians. The earliest records were from 1920, and the rate of collection was low until the mid-20th century (fig. 2). After 1962, the number of records increased, with one large peak in 1994 (Haxhiu, 1994). More than half ($N = 555$ or 50.6%) of the total number of records ($N = 1097$) are new, i.e., published here for the first time, while the other half ($N = 542$) were published previously in other articles (table 2, fig. 3a). Of the new records, we collected a total of $N = 482$ records during field expeditions, $N = 18$ from the museum collection, $N = 8$ from internet sources and $N = 47$ records from personal communication. The number of records ranged from a minimum of three (*Pelobates syriacus*) to a maximum of 339 (*Pelophylax* spp.). For most species, half or nearly half of the records are new, and we added at least one new record for all species (except *P. syriacus*) (table 2). *P. syriacus* was the rarest species, present in only one grid cell, while *Pelophylax* spp. was the most widely distributed, present in 181 grid cells. At least one species of amphibian occurred in 238 of the 349 grid cells covering Albania. Estimates of the EOO revealed that many species with only a few records had much larger possible ranges than expected. For instance, *L. graecus* was present in 47 or *R. graeca* in 43 cells, however, their EOO was close to the total area of the country.

Amphibian diversity patterns

The distribution of Moran's I spatial statistics showed that overall sampling effort was spatially clustered ($Z = 4.064$, $P < 0.0001$). Although Getis Ord Gi* statistics did not reveal coldspots of sampling effort, sampling hotspots were found (fig. 3b), mostly in the Prokletije Mountains (Mts.), the vicinity of Ohrid and

Table 2. List of amphibian species in Albania with their number of records (i.e. coordinates), extent of occurrence (EOO) and distribution type.

Species	Total records	Published records	New records	N of presence 10 × 10 km cells	EOO (km^2)	Distribution type
Bombina variegata	136	46	90	67	24457	Southern-European
Bufo bufo	70	27	43	50	25977	European
Bufotes viridis/variabilis	96	36	60	53	25945	Turano-Europeo-Mediterranean
Hyla arborea	48	26	22	33	21559	Europeo-Mediterranean
Ichthyosaura alpestris	63	43	20	31	12047	European
Lissotriton graecus	55	34	21	47	25065	European
Pelobates syriacus	3	3	0	1	1	Eastern-Mediterranean
Pelophylax spp.	399	221	178	181	26010	Eurasian
*Pelophylax epeiroticus**	8	5	3	6	597	Eastern-Mediterranean
*Pelophylax kurtmuelleri**	59	54	5	41	23735	Eastern-Mediterranean
*Pelophylax shqipericus**	25	21	5	19	7028	Eastern-Mediterranean
Rana dalmatina	54	28	27	35	22938	Southern-European
Rana graeca	69	16	53	43	23250	Eastern-Mediterranean
Rana temporaria	16	15	1	14	6536	European
Salamandra atra	6	2	4	3	335	Central-European
Salamandra salamandra	42	31	11	40	24424	Europeo-Mediterranean
Triturus macedonicus	39	14	25	29	21279	Eastern-Mediterranean
Total	1097	539	558	238		

*We merged the three *Pelophylax* species in the analyses. Details about their records are only given here.

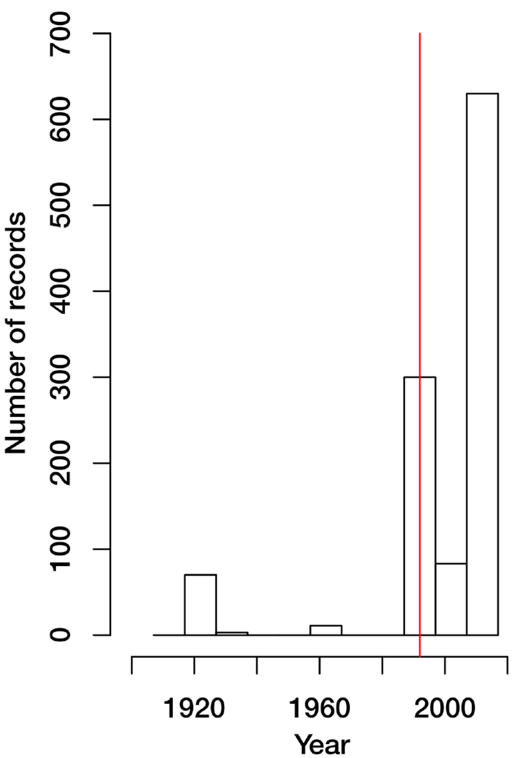

Figure 2. Number of records by year of publication (published sources) or year of data collection (unpublished sources). The red vertical line indicates the year when the former isolationist political system ended in Albania (1991).

Prespa Lakes, Pindos Mts., coastal regions near Vlorë and around Butrint Lake in the South (fig. 1, fig. 3c).

The mean number of species per cell was 1.8 ± 0.11 (S.E.), with a maximum of $N = 10$ in two cells. Cells with high amphibian diversity were in Prokletije Mts., Lura and Korab Mts., in the vicinity of Ohrid and Prespa Lakes, Grammos Mts., Çikës Mts. and coastal regions near Vlorë (fig. 1, fig. 3c). Distribution maps of amphibians of Albania are presented in the online supplementary materials (figs S1-S14 and shapefile).

Most amphibians had a large altitudinal range between 0 and 1500 m above sea level, with the exception of a few, mostly mountain-dwelling species (e.g. *Ichthyosaura alpestris*, *Salamandra atra*, *Rana temporaria*) which had lower sample sizes and/or narrower ranges (fig. 4). GLMM models showed that the most important predictors for amphibian presence and diversity were land cover diversity (CORINE DIV) and precipitation (BIO PC2), whereas temperature

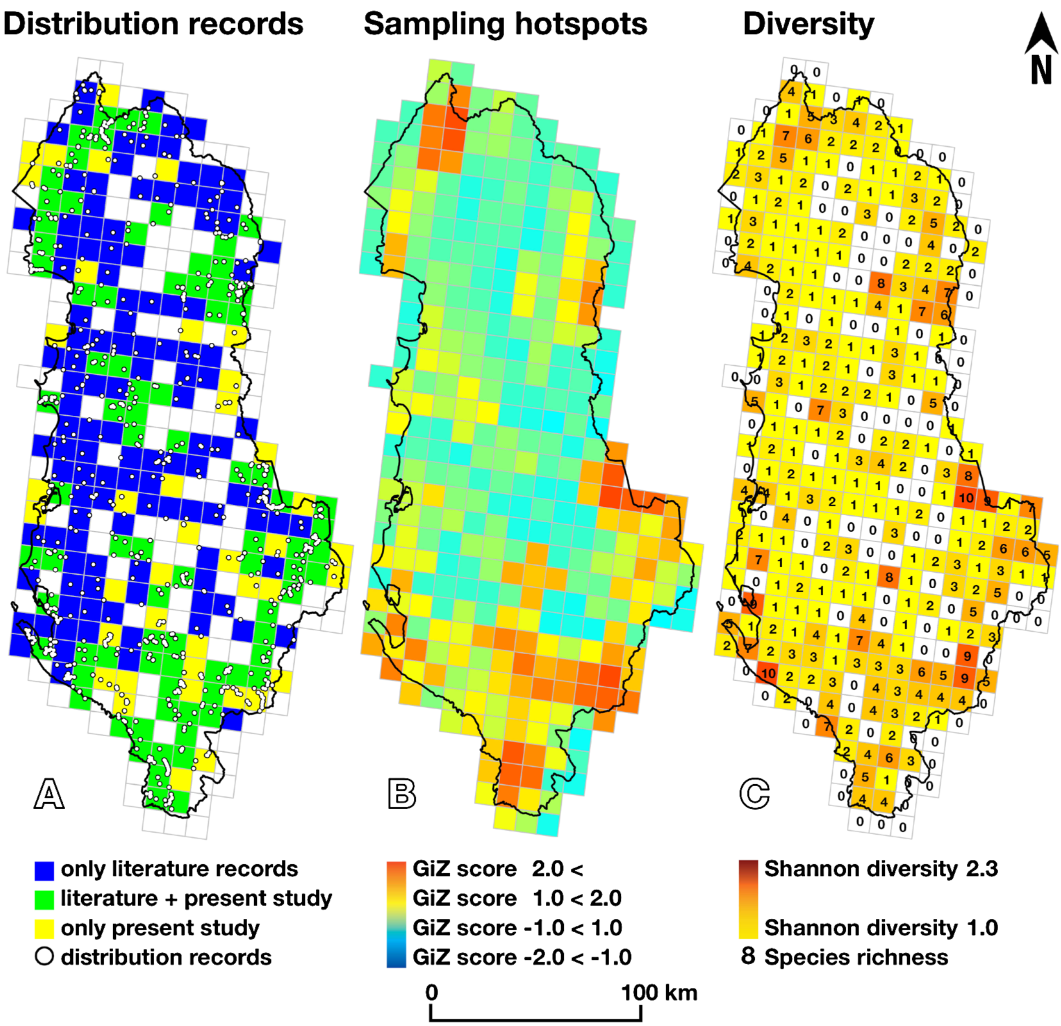

Figure 3. Sources of occurrence records of amphibian species used in the present study (A), sampling hotspots (GiZ score > 1.0) and coldspots (GiZ score < −1.0) (B), and amphibian species richness (numbers) and Shannon diversity index (shading) (C) in Albania on a 10 × 10 km grid. We used 10 × 10 km grid system provided by the European Environmental Agency (EEA) in ETRS89 Lamberth Azimuthal Equal Area projection (EPSG: 3035).

variation (BIO PC3) was important for amphibian presence only (table 3). Each of these variables was part of at least one of the best models for presence and diversity (table 4). Model-averaged parameter estimates suggested that CORINE DIV (land cover diversity), BIO PC2 (precipitation) and BIO PC3 (temperature variation) significantly influenced amphibian presence, whereas diversity was influenced only by CORINE DIV (table 5). The effect of CORINE DIV was positive for both presence and diversity, whereas that of BIO PC2 was negative for presence (table 5, fig. 5).

Discussion

Our study presents a spatially explicit database containing the largest amount of amphibian records from Albania to date and a fine-scale analysis of patterns of amphibian occurrence

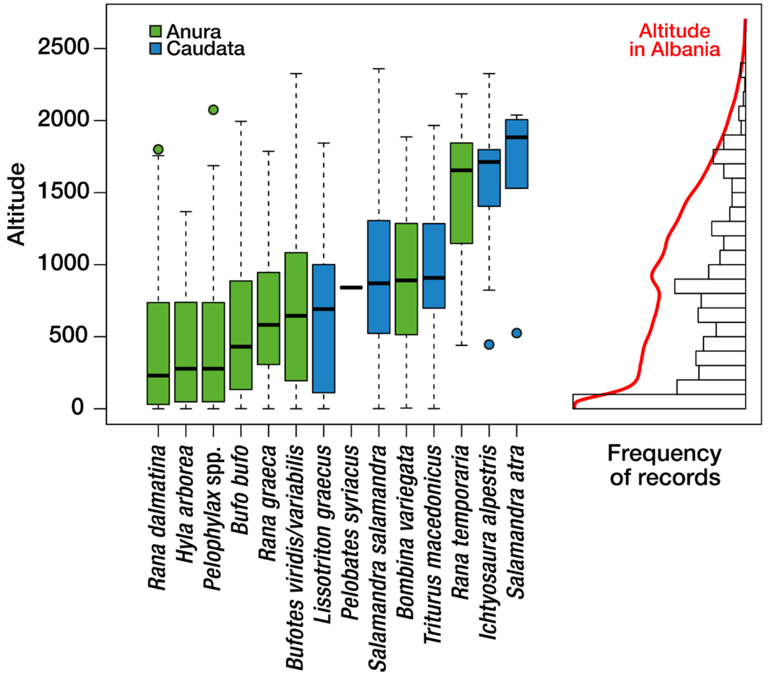

Figure 4. Altitudinal distribution of amphibian species and frequency of occurrence records by altitude in Albania. Box-and-whiskers plots show the median (horizontal line), the 25th and 75th percentile (bottom and top of box, respectively), minimum and maximum values (lower and upper whiskers, respectively) and outliers (circles). The red line is the frequency distribution of altitudinal values in Albania.

Table 3. The importance of predictors in the GLMM model for presence/absence and for Shannon diversity of amphibians in Albania. See table 1 for the description of the variables.

Presence		Shannon diversity	
Predictor	Importance	Predictor	Importance
CORINE DIV	1.000	CORINE DIV	1.000
BIO PC2	0.903	BIO PC2	0.427
BIO PC3	0.756	BIO PC4	0.291
BIO PC1	0.217	ALT SD	0.181
SEA DIST	0.204	ALT MEAN	0.087
ALT SD	0.122	BIO PC3	0.069
ALT MEAN	0.095	SEA DIST	0.000
BIO PC4	0.000	BIO PC1	0.000

and diversity involving all known species in the country.

The relatively low species richness in many cells indicates that most of the country is still data deficient (fig. 3b, fig. 6). Amphibian biodiversity hotspots were found where sampling effort was higher than average (i.e. in protected areas or popular tourist destinations such as Theth and Prespa National Parks, Butrint World Heritage Site). These results are similar to those found by Cogălniceanu et al. (2013) for Romania, a country also characterized by uneven sampling mainly due to high altitudinal complexity and uneven road density. Because amphibian species richness per cell was relatively low in our study (1.8), rare species had a large impact on the designation of amphibian hotspots. Such species included *P. syriacus*, which reaches its westernmost distribution in a single cell in the South-East (Szabolcs and Mizsei, 2017), and three montane species *I. alpestris*, *R. temporaria* and *S. atra* with restricted altitudinal distributions (table 1; fig. 4). These results imply that the low number of records for some rare species will not easily be expanded by further sampling due to biogeographic constraints that determine the ranges of these species. Although we found no evidence of sampling coldspots, and the altitudinal distribution of records corresponded well with the frequency distribution of altitude (fig. 4), it was clear from the generally low species richness that there is a need to add more data on the occurrences of species other than these rare specialists. Therefore, further mapping should focus also on filling the gaps in the ranges of widespread species.

The temporal distribution of our records showed that data collection was almost halted during the Communist era (1946-1992), then restarted during the 1990s, and more recently it has yielded an unprecedented amount of records. This corresponds to the abandonment of the political and economic isolation of the previous regime, which also resulted in higher standards of living and a dynamically growing GDP (http://imf.org). However, economic development also leads to the abandonment of traditional land uses and an increasing rate of habitat alterations, both of which usually have a negative impact on amphibian diversity (Scribner et al., 2001; Hartel et al., 2009). Examples are shown by an increasing number of road constructions and large-scale hydropower projects for example in the valleys of Vjosë or Valbona rivers (Freyhof, 2010; http://balkanrivers.net), which may lead to the devastation of important wetland habitats (Cushman, 2006).

Our analysis of the data currently available showed that the diversity of land cover was the most important factor affecting both the occurrence and the diversity of amphibian species in Albania. These results agree well with those of several previous landscape-scale studies (e.g. Van Buskirk, 2005; Denoël and Ficetola, 2008; Hartel et al., 2009; Vági et al., 2013; Tsianou et al., 2016) and can be explained by two mutually non-exclusive hypotheses. First, most amphibians are characterised by a complex life cycle and they use different environments during their larval and adult life, thus, most species require complex habitats. Second, those species which use aquatic habitats even as adults can mainly spread along aquatic habitats (Ficetola and De Bernardi, 2004), thus their occurrence is primarily related to local hydrological factors and to a lesser extent to climate or land use and they can occur under various climatic conditions and land use types. Indeed, in our study, the species with the largest amount of records were *Pelophylax* spp. and *Bombina variegata* (table 2). Both of these anurans are associated with freshwater habitats mostly year-round (Arnold and Ovenden, 2002). The relatively large number of records for these two species can also be explained by their high detectability: these anurans are frequent in several types of waters due to their wide ecological tolerance, are often active in daylight, and calling males can be easily detected acoustically even in the hottest summer months due to their prolonged breeding season (Arnold and Ovenden, 2002). All these factors can lead to sampling bias in mapping surveys (Cogălniceanu et al., 2013).

In contrast, other amphibians are mostly terrestrial throughout the year, are often active only in rainy and moist weather, mainly at night, thus are more difficult to detect in the field. These terrestrial, but still widespread species can be characterized by large, countrywide EOO values and often by wide altitudinal ranges, even if they were detected only in a small fraction of cells. Species in this group included *Bufo bufo*, *B. viridis/variabilis*, *Hyla arborea*, *L. graecus*, *Rana dalmatina* and *T. macedonicus* (table 2). Two other species, *R. graeca* and *Salamandra salamandra* also showed large EOO. Although EOO and, in general, species ranges are typically explained by a complex set of factors, the large EOO for these species is likely related to the fact that these species are mostly associated to mountain habitats (Bruno, 1989; Haxhiu, 1994), and can thus be widespread in Albania (table 2). Adequate sampling of these species requires surveys during the breeding season in spring, when most amphibians stay in and around water bodies. The detection probability of individuals in various life stages can be further increased by a combination of newt traps, dip-netting and visual or acoustic surveys (Ficetola and De Bernardi, 2004; Van Buskirk, 2005; Mattfeldt, 2007; Vági et al., 2013; Mester et al., 2015).

Table 4. Parameter estimates and AIC values of the best GLMM models and the models with substantial support (ΔAICc < 2) fitted on the presence and Shannon diversity of amphibians in Albania.

Variable	Model	CORINE DIV	BIO PC2	BIO PC3	BIO PC1	SEA DIST	ALT SD	ALT MEAN	BIO PC4	df	AICc	ΔAICc
Presence	1	1.37504	−0.08859	−0.10412						8	2890.266	0.000
	2	1.29567	−0.08835							7	2891.487	1.222
	3	1.38543	−0.09603	−0.10198			0.00052			9	2891.656	1.391
	4	1.37858	−0.14665		0.08909	−0.00001				9	2891.834	1.568
	5	1.38769	−0.08935	−0.10471	0.01423					9	2891.945	1.679
	6	1.35787		−0.10515						7	2892.121	1.856
	7	1.38320	−0.08723	−0.10331				0.00006		9	2892.161	1.896
	8	1.37949	−0.08434	−0.11082		0.00000				9	2892.204	1.939
Diversity	1	0.31683								4	632.902	0.000
	2	0.31918	−0.02937							5	633.056	0.154
	3	0.32254							−0.04277	5	633.357	0.455
	4	0.32408	−0.03133						−0.04564	6	633.641	0.739
	5	0.29448	−0.03213				0.00037			6	634.041	1.139
	6	0.32376						0.00008		5	634.095	1.193
	7	0.29240					0.00032			5	634.563	1.661
	8	0.33340		−0.02531						5	634.663	1.761

Table 5. Model averaged parameter estimates of GLMMs fitted on the presence and Shannon diversity of amphibians in Albania. Significant parameter estimates are indicated in bold.

Response	Main effect	Estimate	S.E.	z value	*P*
Presence	(Intercept)	−5.172	0.804	6.428	0.000
	CORINE DIV	**1.367**	**0.227**	**6.015**	**0.000**
	BIO PC2	**−0.096**	**0.046**	**2.093**	**0.036**
	BIO PC3	−0.105	0.053	1.982	0.047
	BIO PC1	0.053	0.049	1.072	0.284
	SEA DIST	0.000	0.000	0.766	0.444
	ALT SD	0.001	0.000	1.109	0.267
	ALT MEAN	0.000	0.000	0.326	0.745
	BIO PC4	0.000	0.000	−0.191	0.848
Response	**Main effect**	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	***P***
Diversity	(Intercept)	0.224	−0.636	1.001	0.558
	CORINE DIV	**0.325**	**0.175**	**0.495**	**0.001**
	BIO PC2	−0.048	−0.101	0.004	0.078
	BIO PC4	−0.056	−0.145	0.028	0.228
	ALT SD	0.000	−0.001	0.001	0.772
	ALT MEAN	0.000	−0.001	0.000	0.606
	BIO PC3	−0.001	−0.069	0.063	0.962
	SEA DIST	0.000	0.000	0.000	0.474
	BIO PC1	0.037	−0.046	0.108	0.302

We did not distinguish between the three *Pelophylax* species occurring in Albania, as they are hard to identify based only on morphological characters. *Pelophylax kurtmuelleri* is capable of hybridisation with the two other species (Schneider and Haxhiu, 1994; Ragghianti et al., 1999, 2004) which also makes their identification difficult. *Pelophylax epeiroticus* is found between the extreme south-western Albania to southern Greece along the Ionian Coast and is genetically related to *P. kurtmuelleri* and *ridibundus* (Lymberakis et al., 2007). *Pelophylax*

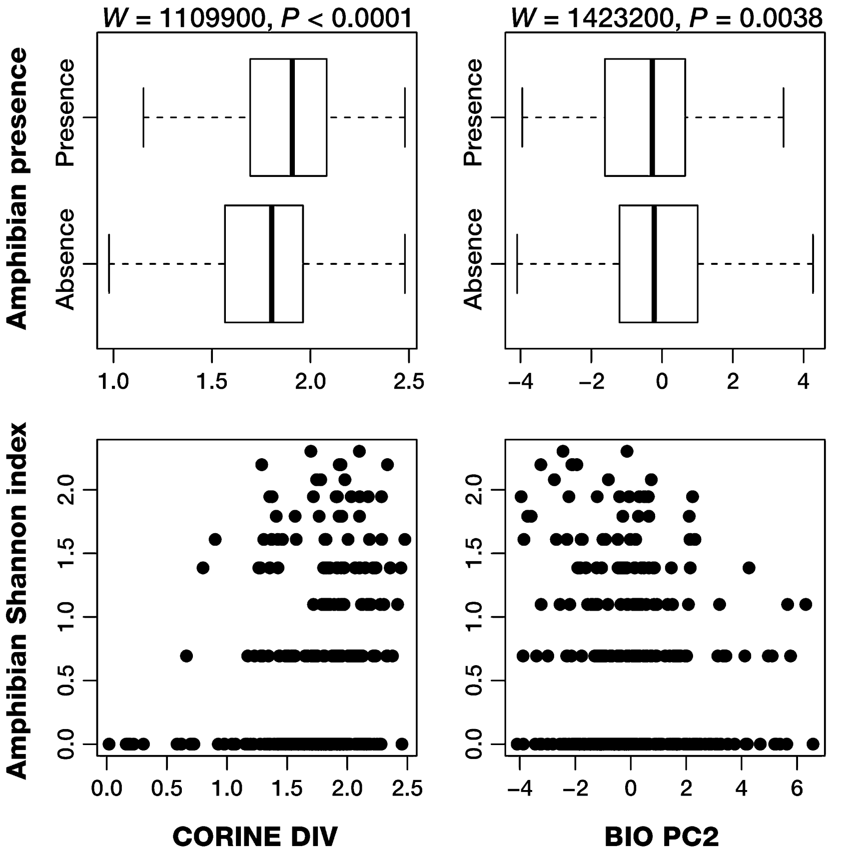

Figure 5. Species presence and Shannon diversity index as a function of the most important predictors identified by GLMM model selection (for abbreviations, see table 1).

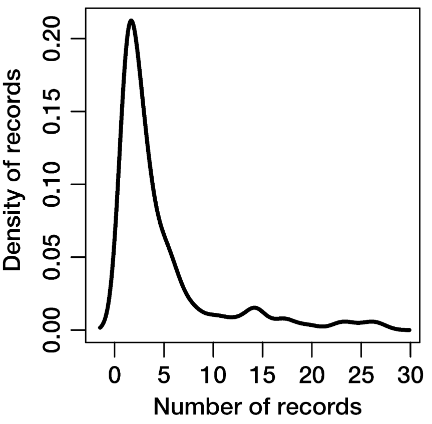

Figure 6. Frequency of the number of amphibian records in 10 × 10 km grid cells.

shqipericus lives in southern Montenegro from Lake Skadar to (probably) Orikum in western Albania along the Adriatic Coast. This species is genetically related to *P. lessonae* (Ragghianti et al., 2004). *Pelophylax kurtmuelleri* has a country-wide distribution and is common in the western and southern Balkans (Dufresnes et al., 2017). The latter species may occur sympatrically with the two former ones, although we found no evidence for habitat overlap between the three species. Little is known about the ecology of the two West Balkan species and their coexistence with *P. kurtmuelleri*, therefore, further research is necessary as both are endemic and highly threatened. The IUCN Red List category of *P. epeiroticus* is Vulnerable (Uzzell, Lymberakis and Haxhiu, 2009) and of *P. shqipericus* is Endangered (Uzzell and Crnobrnja-Isailović, 2009).

Besides habitat alteration (loss, fragmentation, degradation), other threats to amphibians include climate change and spread of diseases. Climate change can alter the amount and distribution of precipitation, which is among the most important factors governing amphibian occurrences (table 5, Rodríguez, Belmontes and Hawkins, 2005; Tsianou et al., 2016). Finally, the chytrid fungus *Batrachochytrium dendrobatidis* (Fisher, Garner and Walker, 2009) has also been detected in eight species of amphibians in Albania (Vojar et al., 2017), although we are not aware of any outbreak of chytridiomycosis in the East Mediterranean. In conclusion, a detailed assessment of the distribution of amphibian species and diversity and an evaluation of the efficiency of protected and properly managed areas is urgently needed in Albania. We hope that our work will be an important starting point toward these aims. To facilitate future work, the spatially explicit database and methodological approaches presented here provide important baseline information. Our results can be integrated into larger databases such as the NA2RE – New Atlas of Amphibians and Reptiles of Europe (Sillero et al., 2014a, 2014b; http://na2re.ismai.pt).

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Amphibia-Reptilia

Distribution and diversity of amphibians in Albania

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Supplementary Materials

Figures S1-S14: Distribution maps of amphibians in Albania

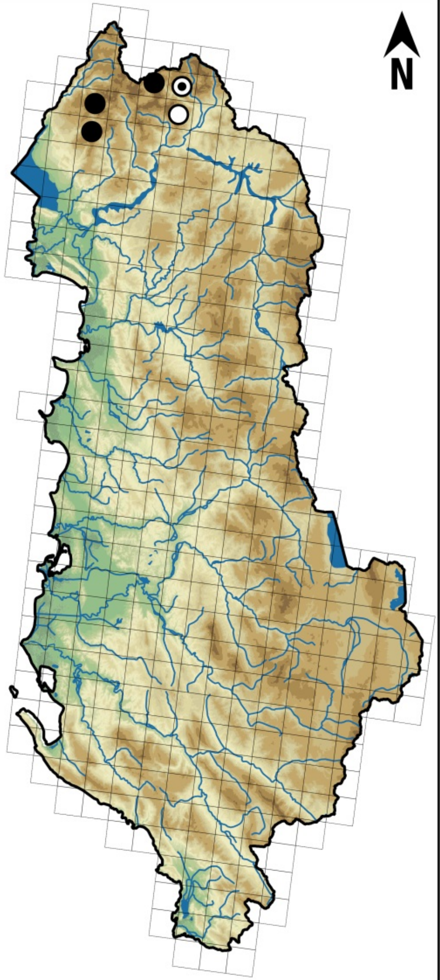

Fig. S01. *Salamandra atra*

literature records
literature + new records
new records
0 50 km

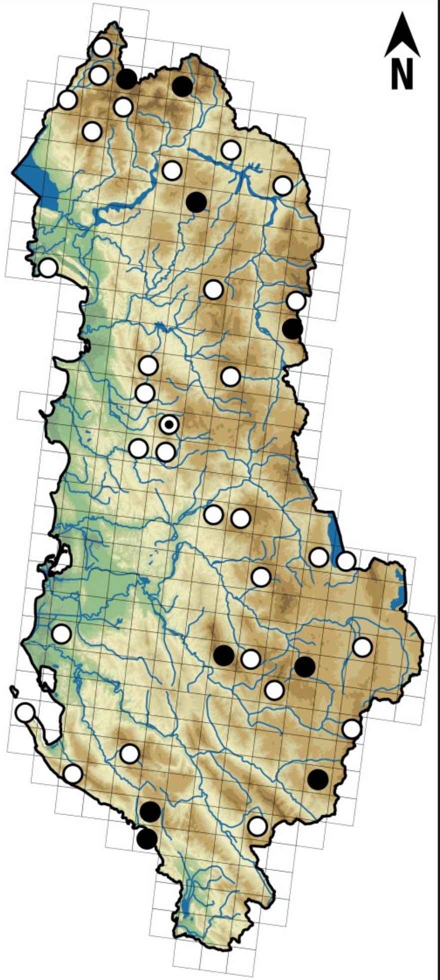

Fig. S02. *Salamandra salamandra*

literature records
literature + new records
new records
0 50 km

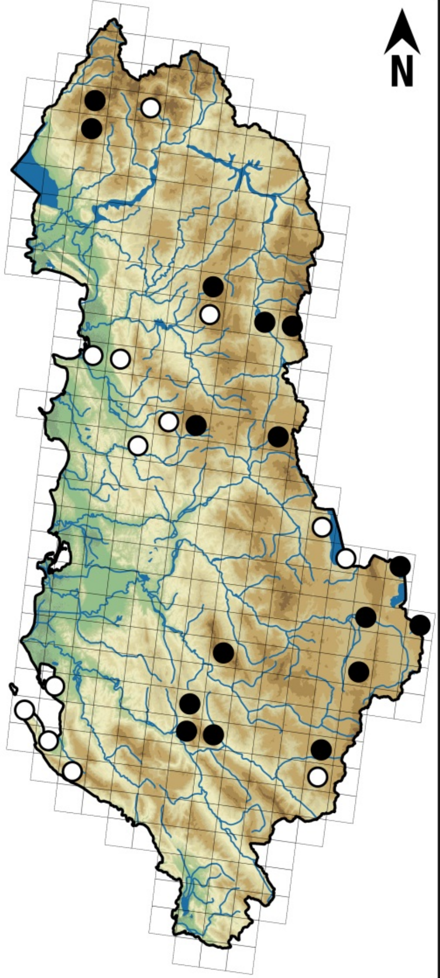

Fig. S03. *Triturus macedonicus*

literature records
literature + new records
new records
0 50 km

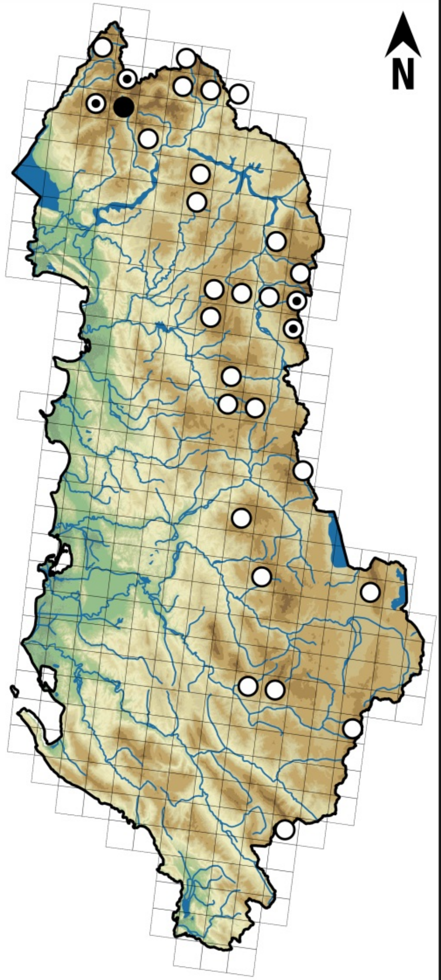

Fig. S04. *Ichthyosaura alpestris*

literature records
literature + new records
new records
0 50 km

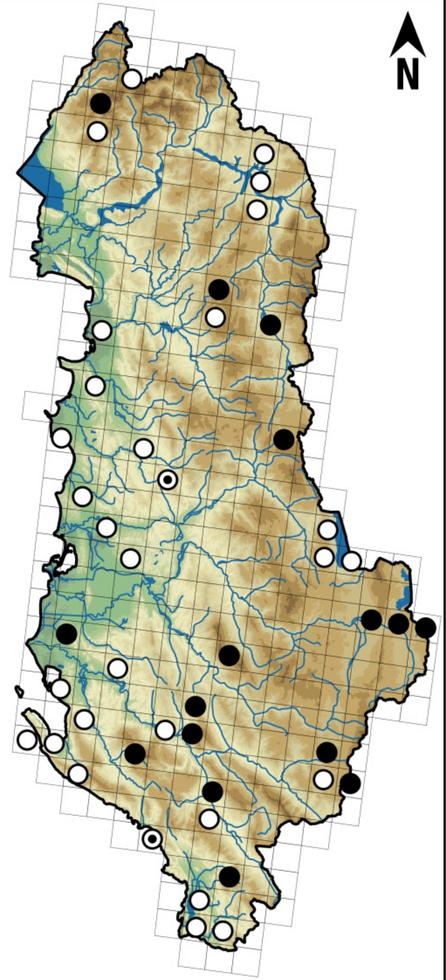

Fig. S05. *Lissotriton graecus*

literature records
literature + new records
new records
0 50 km

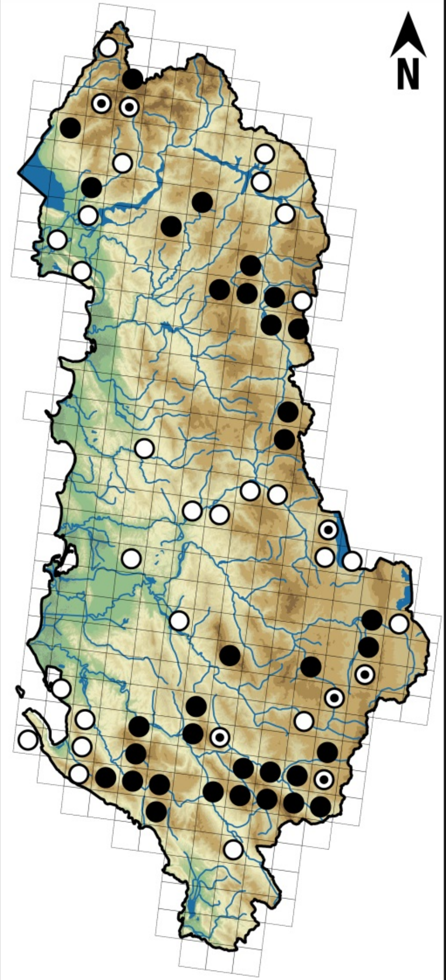

Fig. S06. *Bombina variegata*

literature records
literature + new records
new records
0 50 km

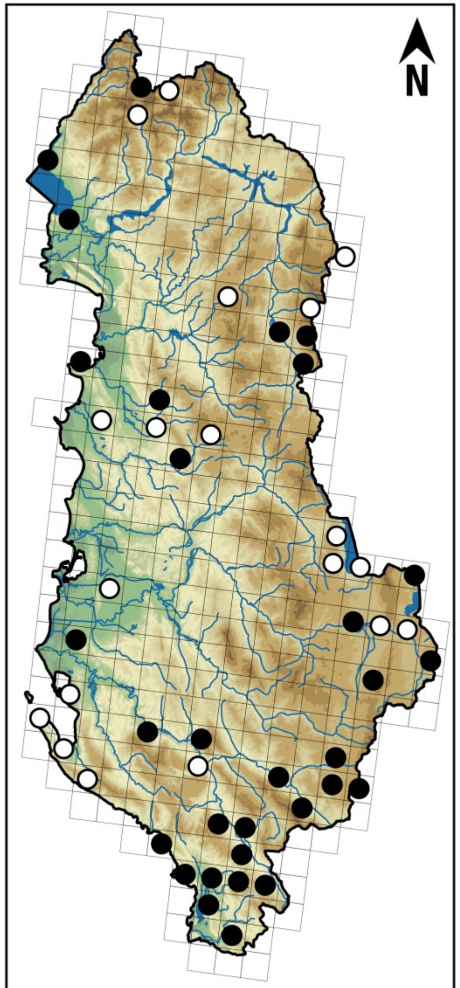

Fig. S07. *Bufo bufo*

literature records
literature + new records
new records
0 50 km

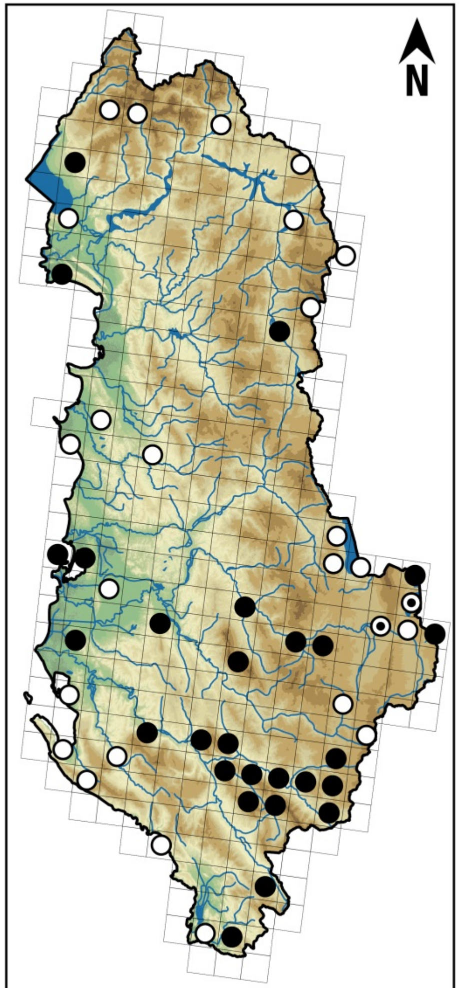

Fig. S08. *Bufotes viridis/variabilis*

literature records
literature + new records
new records
0 50 km

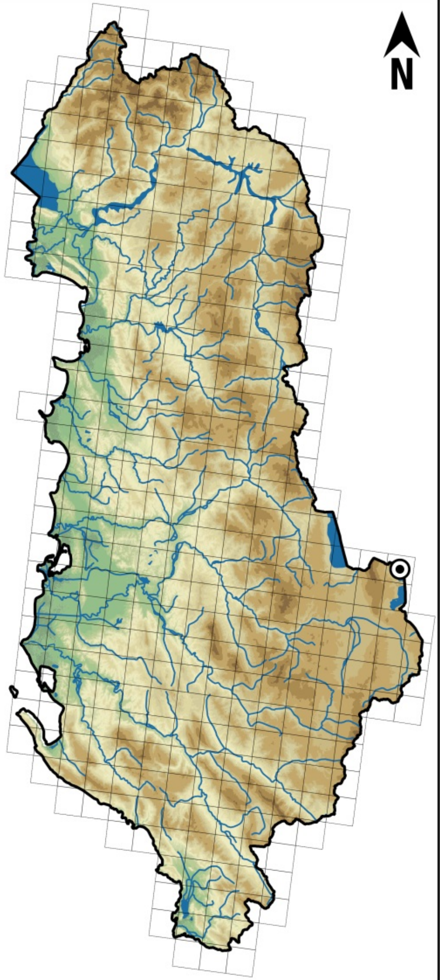

Fig. S09. *Pelobates syriacus*

◯ literature records
⦿ literature + new records
● new records
0 50 km

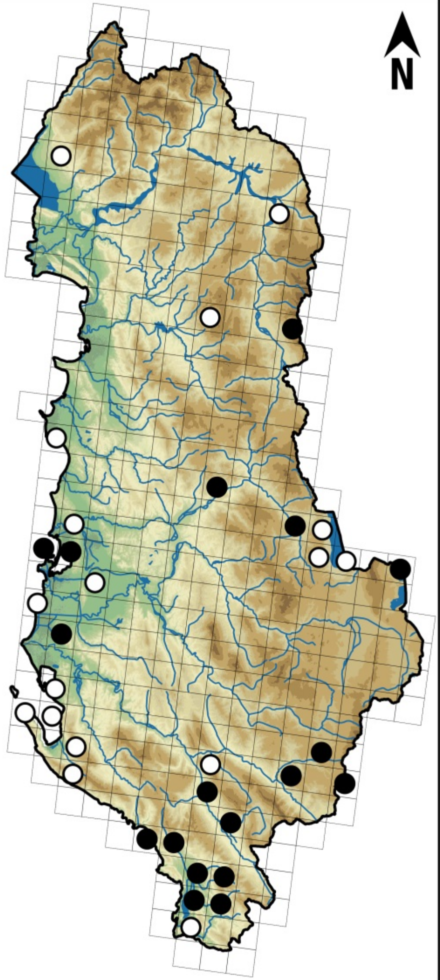

Fig. S10. *Rana dalmatina*

◯ literature records
⦿ literature + new records
● new records
0 50 km

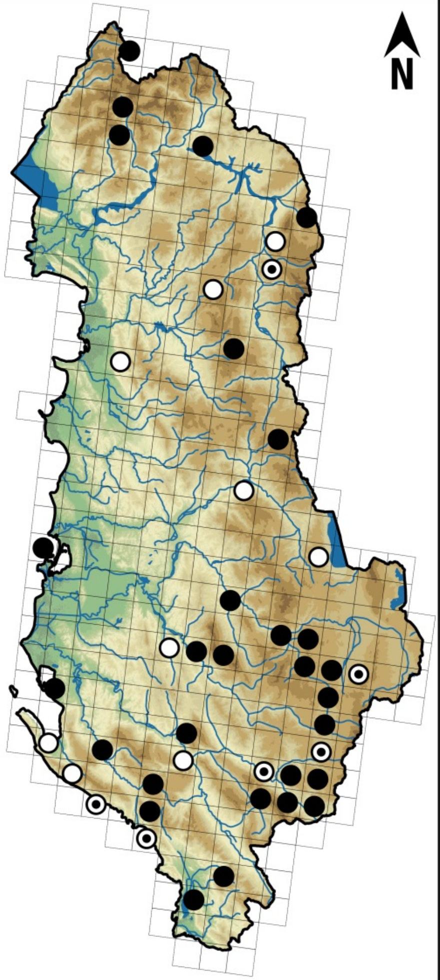

Fig. S11. *Rana graeca*

◯ literature records
⦿ literature + new records
● new records
0 50 km

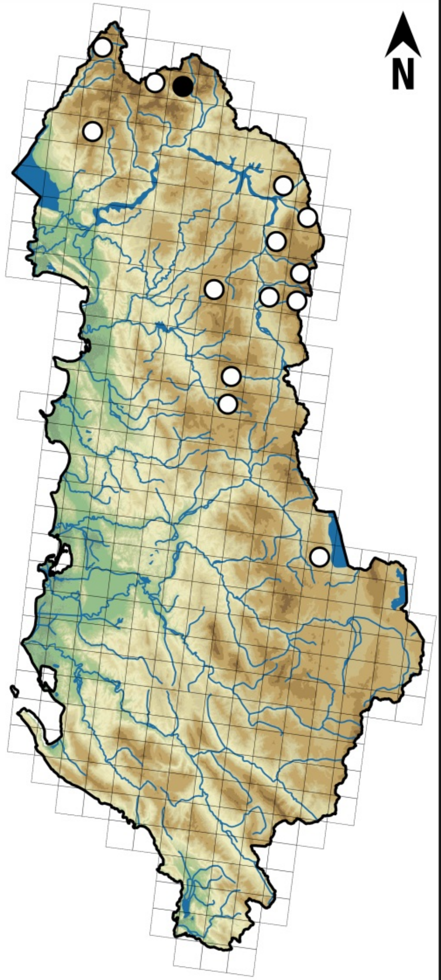

Fig. S12. *Rana temporaria*

◯ literature records
⦿ literature + new records
● new records
0 50 km

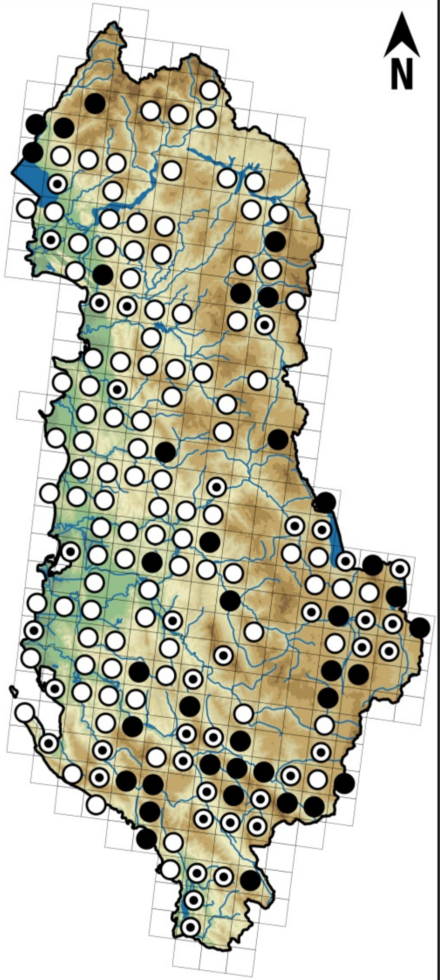

Fig. S13. *Pelophylax* spp.

literature records
literature + new records
new records
0 50 km

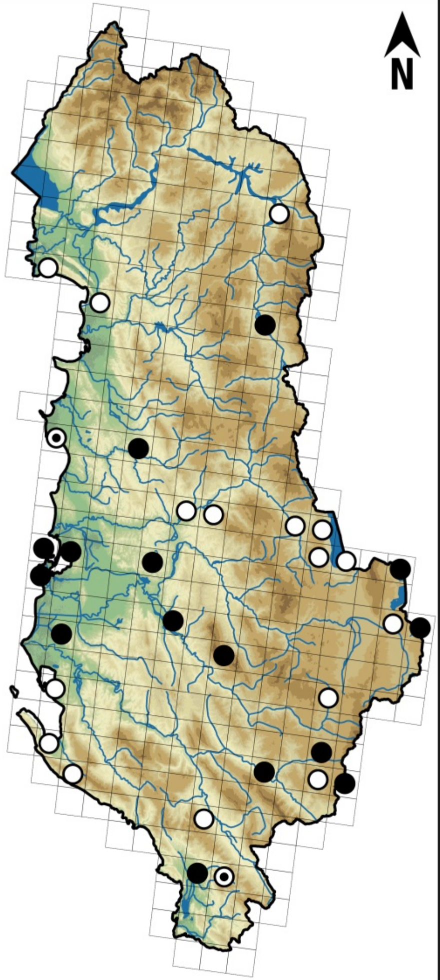

Fig. S14 *Hyla arborea*

literature records
literature + new records
new records
0 50 km