Updated distribution and biogeography of amphibians and reptiles of Europe

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**Abstract.** A precise knowledge of the spatial distribution of taxa is essential for decision-making processes in land management and biodiversity conservation, both for present and under future global change scenarios. This is a key base for several scientific disciplines (e.g. macro-ecology, biogeography, evolutionary biology, spatial planning, or environmental impact assessment) that rely on species distribution maps. An atlas summarizing the distribution of European amphibians and reptiles with 50 × 50 km resolution maps based on ca. 85 000 grid records was published by the Societas Europaea

Herpetologica (SEH) in 1997. Since then, more detailed species distribution maps covering large parts of Europe became available, while taxonomic progress has led to a plethora of taxonomic changes including new species descriptions. To account for these progresses, we compiled information from different data sources: published in books and websites, ongoing national atlases, personal data kindly provided to the SEH, the 1997 European Atlas, and the Global Biodiversity Information

Facility (GBIF). Databases were homogenised, deleting all information except species names and coordinates, projected to the same coordinate system (WGS84) and transformed into a 50 × 50 km grid. The newly compiled database comprises more than 384 000 grid and locality records distributed across 40 countries. We calculated species richness maps as well as maps of

Corrected Weighted Endemism and defined species distribution types (i.e. groups of species with similar distribution patterns) by hierarchical cluster analysis using Jaccard’s index as association measure. Our analysis serves as a preliminary step towards an interactive, dynamic and online distributed database system (NA2RE system) of the current spatial distribution of European amphibians and reptiles. The NA2RE system will serve as well to monitor potential temporal changes in their distributions. Grid maps of all species are made available along with this paper as a tool for decision-making and conservation-related studies and actions. We also identify taxonomic and geographic gaps of knowledge that need to be filled, and we highlight the need to add temporal and altitudinal data for all records, to allow tracking potential species distribution changes as well as detailed modelling of the impacts of land use and climate change on European amphibians and reptiles.

*Keywords*: biogeography, conservation, distribution atlas, distribution types, endemism, European herpetofauna, IUCN red list, species richness.

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**Introduction**

A good knowledge on the geographical dis- tribution of organisms is pivotal for macro- ecological and evolutionary studies, as well as to inform policy makers in decisions on land management, health, climate change and biodi- versity conservation (Jetz, McPherson and Gu- ralnick, 2011). The availability of reliable maps that depict the historical and current distri- bution of species therefore constitutes an im- portant component in conservation-related re- search. Data on their extent of occurrence are crucial for assigning IUCN threat categories to species (IUCN, 2001). This has for instance been a strategy in the Global Amphibian As- sessment (Stuart et al., 2004) which provided the first comprehensive estimate of threat cat- egories and distribution ranges of amphibians worldwide, a taxon that constitutes an impor- tant model group in conservation biology (e.g. Hopkins, 2007). Furthermore, many amphibian species and at least some groups of reptiles are undergoing severe global declines (Wake and Vredenburgh, 2008; Sinervo et al., 2010; Böhm et al., 2013), making their conservation a prime challenge and gathering data on their current distribution a top research priority.

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In European herpetology, shortly after the *Societas Europaea Herpetologica* (SEH) was established in 1979, it became evident that a comprehensive assessment of the distribution of all European amphibians and reptiles should receive priority, as basic maps where lack- ing. A mapping committee of the SEH was established in 1983, coordinated by a team based at the Muséum National d’Histoire Na- turelle in Paris. From the work of regional and national coordinators, more than 85 000

grid records were collected and shown in maps of 50 × 50 km resolution produced by the Service du Patrimoine Naturel (Paris, France).

This resulted in a distribution atlas published in 1997 (Gasc et al., 1997). This work, which in the following will for brevity be referred to as ‘the 1997 European Atlas’, has subse- quently provided the basis for numerous stud- ies, such as several conservation-oriented mod- elling approaches (e.g. Araújo and Pearson, 2005; Araújo et al., 2005; Araújo, Thuiller and Pearson, 2006; Araújo et al., 2008).

After the publication of the 1997 Euro- pean Atlas, there has been a high intensity of mapping efforts and related research in Eu- rope. Numerous regional and national soci- eties have since then produced detailed am- phibian and reptile distributional information covering large parts of Europe, more detailed and reliable than the 1997 European Atlas. Many of these were published in the form of regional or national atlases (e.g. Bitz et al., 1996; Günther, 1996; Pleguezuelos, 1997; Ca- bela, Grillitsch and Tiedemann, 2001; Hofer, Monney and Dušej, 2001; Pleguezuelos, Lizana and Márquez, 2002; Głowacin´ski and Rafin´ski, 2003; Puky, Schad and Szövenyi, 2006; Sin- daco et al., 2006; Jacob et al., 2007; Lanza et al., 2007; Laufer, Klemens and Sowig, 2007; Proess, 2007; Creemers and van Delft, 2009; Corti et al., 2010; Loureiro et al., 2010). Some of them (e.g. UK, Netherlands, Wallonia, Flan- ders, Switzerland) were published also through publicly available internet resources. Others, like the atlas of Sweden, were published exclu-

sively on the internet. This wealth of novel data claims for an update of the herpetofaunal distri- bution data also at the European level, to quan- tify Europe-wide the improvement in knowl- edge since the previous Atlas, as well as a first step towards tracking potential changes in the distribution of the European herpetofauna in the context of global change.

Novel technologies for mapping species dis- tributions currently available, such as newly de- veloped Geographic Information Systems (Lon- gley et al., 2010) and their extensions, offer the possibility of establishing extensive databases of distribution records, with associated meta- data such as voucher specimen lists or photos. Citizen-science online tools allow contributors entering their observations, and directly link them to analysis tools such as spatial modelling or the production of customised maps. The cur- rent Mapping Committee of the SEH (estab- lished in 2006), together with the SEH Council and some associated fellows, has acknowledged that distribution atlases should be conceived as dynamic tools, implemented in a way that al- lows for continuous updates, extension changes, and customised data extraction while respect- ing the copyright that particular organisations or individuals might hold on parts of the underly- ing data. The goal is to establish a Spatial Data Infrastructure, a system of geographically dis- tributed systems, where the original data remain on the servers controlled by national or regional herpetological societies, and through an online network it is possible to make data queries via the SEH portal (Sillero et al., 2014; see [http://](http://na2re.ismai.pt/) [na2re.ismai.pt](http://na2re.ismai.pt/)). For countries that do not have national databases, the SEH works on establish- ing a connected database linked to an internet portal for data collection.

A dynamic online atlas of European amphib- ians and reptiles based on an underlying dis- tributed database of distribution records repre- sents a major logistic challenge and is time- consuming. However, considering the current conservation crisis faced by many European amphibians and reptiles (Cox, Chanson and Stu-

art, 2006), it is an urgent task to make updated distributional information on these organisms available. The species distribution maps of the 1997 European Atlas (Gasc et al., 1997) have never been made available in GIS format. How- ever useful and original at the time, they are now outdated due to the considerable accumulation of new distribution data, and especially because of the taxonomic progress that resulted in mul- tiple changes of genus-level classification, and a large number of new species descriptions (Spey- broeck, Beukema and Crochet, 2010; Vences et al., 2013). This new taxonomy resulted in many species being split into multiple entities for which the exact distribution limits are poorly known.

The goal of the present study is to provoke and facilitate filling of these gaps by making updated distribution maps for the European her- petofauna available. For this purpose, we have compiled information from a large number of published and partly unpublished mapping ef- forts at a variety of spatial scales and trans-

formed those data into a 50 × 50 km UTM

grid, similar to the one used for the 1997 Eu- ropean Atlas. Based on this new compilation of maps, all of which are made available (see online Supplementary Atlas S1-S5 online), we here (1) identify the major spatial and taxo- nomic gaps in the currently available knowledge in order to identify future research priorities, and (2) analyse patterns of species richness, en- demism and main distribution types (i.e. groups of species with similar distribution patterns) for European amphibians and reptiles.

**Materials and methods**

*Study area*

This compilation included almost the same area as the 1997 European Atlas (Gasc et al., 1997). We used the limits for Europe (see Supplementary fig. S1 online) provided by Geo- commons [(http://geocommons.com/overlays/76975](http://geocommons.com/overlays/76975)). The geographical limits of the previous SEH 1997 European at- las were those defined by Mertens and Wermuth (1960), covering parts or the whole of 45 countries. Partial territo- ries included were: north-western tip of Turkey (European Turkey), territories in the Russian Federation west of the

Urals, north-eastern tip of Azerbaijan, north-western tip of Kazakhstan, Greece minus the Sporades Islands. However, the Geocommons limits do not include parts of Azerbaijan and Kazakhstan, while the Ural limits are defined more pre- cisely. These limits for Europe are widely accepted by many geographical atlases (e.g. Cheers, 2005).

*Taxa*

For historical consistency and to facilitate reading, in this paper we use the traditional term ‘reptiles’ for the para- phyletic group including the vertebrate orders Squamata, Testudines, Crocodylia, and Rhynchocephalia, i.e. Saurop- sida excluding birds (of which only Squamata and Tes- tudines are represented in Europe’s extant fauna). The species-level taxa considered in this compilation were de- termined by the SEH, using Speybroeck, Beukema and Cro- chet (2010) as starting point (see Supplementary Text S1 on- line). In numerous cases, although the species status of two or more related taxa is undisputed, we were unable to assign all available records to a species. This was either because the original databases had been compiled following an outdated taxonomy, or because many records could not be identified up to species level in the field (such as for instance, *Tritu- rus marmoratus* and *T. pygmaeus* in the Iberian Peninsula). In these cases, we merged the respective species into a sin- gle entry in our database, which therefore in several cases represents a simplification of current taxonomy.

The sampling effort was obviously not homogeneous across the whole study area. Some countries have a very good knowledge on the ranges of their species while others have large gaps of chorological information. Although the present compilation is represented at a rather coarse scale

(50 × 50 km grid), gaps in the species distributions are still

observable. Similarly, not all national and regional data sets are fully consistent in their treatment of marine and intro- duced species. Where available, our compilation includes terrestrial as well as marine taxa (i.e. marine turtles). Be- sides native species and populations, a number of national data sets also included introductions, i.e. introduced species from outside Europe as well as introduced populations of European species occurring outside their natural range. In this case our compilation is not fully consistent. For ma- rine turtles, some countries included records on sightings (on coast and ocean) and reproduction places (i.e. Portu- gal and Spain), while other countries only included repro- duction places (i.e. Italy and Balkan countries). In general, we did not include single records of escaped exotic species where there was no indication of naturalised populations. For non exotics, we considered as introduced those cases where the origin of the introduction is well known and can be traced back into recent history, such as the populations of *Discoglossus pictus* in southern France and in Spain (Cat- alonia), but not those cases where ancient introductions are suspected (e.g. various species on Mediterranean islands). In this sense, much of the actual herpetofaunal composition in the Mediterranean is probably related to or at least influ- enced by human activities (Corti et al., 1999).

*Database compilation*

Our goal in compiling updated distribution maps for the Eu- ropean fauna was to cover as many European countries as possible with national atlas data or new personal records. The species data included in these updated maps were ob- tained from different data sources, namely (1) published (in books or websites) or on-going national atlases, (2) per- sonal data kindly provided to the SEH, (3) the 1997 Euro- pean Atlas, and (4) the Global Information Facility (GBIF: [www.gbif.org](http://www.gbif.org/)). Because the GBIF data originate from many different data sources and contain numerous errors and discrepancies, we tried to minimise their use as explained below. However, a few of the national atlas data were di- rectly available only from GBIF (e.g. Denmark and Nor- way) and in these cases, the data were labelled as National Atlas Data rather than as GBIF data. Some countries pro- vided databases used in already published atlases (whole database with temporal data series: e.g. Spain and Portu- gal; simplified database: e.g. The Netherlands) or before publishing as an atlas (e.g. Slovenia and France). For other countries, we digitised the data from published books (e.g. Hungary). We also included large unpublished databases for several countries compiled by some co-authors of this study (e.g. S.L. Kuzmin, P. de Pous). In the case of territories of former Yugoslavia, J. Crnobrnja Isailovic´ and collaborators provided some of the original data used in the 1997 Eu- ropean Atlas. National atlases and personal databases were subsequently merged in one database, which in the follow- ing will be referred to as COUNTRIES. A second database, hereafter named SEH/GBIF database, contained the data of the 1997 European Atlas and GBIF, but only for those coun- tries for which no national atlas data were available. For the final compilation, the same exclusion strategy was also employed at the level of single UTM squares. Whenever a record from the COUNTRIES database was available for a UTM grid (only in personal databases: e.g. S.L. Kuzmin’s personal database) we used that one rather than the dupli- cate record from the SEH/GBIF database. This process was performed using spatial queries in ArcGIS 9.3.

Many original databases contained erroneous records. The databases were therefore reviewed and validated by members of the SEH Council and its Mapping Committee in various rounds. Erroneous records were excluded from the two main databases (COUNTRIES and SEH/GBIF) and stored in a different file. During this revision of the point locality data in the COUNTRIES and SEH/GBIF database, we furthermore flagged introduced species and species loca- tions, and these were transferred to a third database hereafter called INTRODUCED. As such, we never deleted a record: keeping all erroneous records rather than simply deleting them allowed tracking validation errors and makes our de- cisions verifiable. Introduction records were defined using our current knowledge, which is not homogeneous, thus bias may be present for some species and regions.

The three databases were composed by point records. The numerous data (table 1; 30 databases) have been re- ceived in multiple digital formats, with disparate informa- tion and in different spatial resolutions (ranging from point

centroids of 50 × 50 km UTM grid cells to very precise

**Table 1.** List of databases used in this atlas compilation. Resolution, records, and sources refer to data obtained and used for the compilation of the European atlas. References to published atlases are mentioned. Some of these databases included more than one country (e.g. S.L. Kuzmin). See table 2 for number of records per country.

Resolution Records Sources Published atlases

NATIONAL DATABASES

Austria 5 × 5 km 14 136 digitised from Atlas Cabela, Grillitsch and

Tiedemann, 2001

Bosnia and Herzegovina 10 × 10 km 152 provided by D. Dobrnjic´ and

E. Tanovic´

Brussels 10 × 10 km 59 provided by Natagora Weiserbs and Jacob, 2005 Bulgaria 10 × 10 km 3170 digitised from website [http://www.oocities.org/](http://www.oocities.org/herpetology_bg/)

[herpetology\_bg/](http://www.oocities.org/herpetology_bg/)

Estonia 10 × 10 km 2872 provided by Riinu Rannap

Flanders 5 × 5 km 38 945 provided by Natuurpunt-Hyla Bauwens and Claus, 1996

France 50 × 50 km 11 071 provided by Service du

Patrimoine Naturel (Muséum

National d’Histoire Naturelle)

Lescure and De Massary,

2012

Germany 10 × 10 km 31 065 digitised from Atlas Günther, 1996 Greece exact coordinates 9893 provided by P. Lymberakis Valakos et al., 2008 Hungary 10 × 10 km 13 582 digitised from Atlas Puky, Schad and

Szövenyi, 2006

Italy 50 × 50 km 4292 provided by SHI (Societas Herpetologica Italica) data

through R. Sindaco Luxembourg exact coordinates 10 642 provided by Musée National

d’Histoire Naturelle du Luxembourg

Malta 50 × 50 km 37 compiled by Claudia Corti

Sindaco et al., 2006

Proess, 2003, 2007

Poland 10 × 10 km 15 502 digitised from Atlas Głowacin´ski and Rafin´ski,

2003

Portugal 10 × 10 km 17 431 provided by A. Loureiro Loureiro et al., 2010 Romania exact coordinates 5454 provided by D. Coga˘lniceanu Coga˘lniceanu et al.,

2013a, 2013b

Slovenia 10 × 10 km 3414 provided by Societas Slovenica Herpetologica

Spain 10 × 10 km 68 618 provided by Sociedad Herpetológica Española

Sweden exact coordinates 30 778 obtained from GBIF

Switzerland 10 × 10 km 5705 provided by Koordinationsstelle für Amphibien- und Reptilienschutz in der Schweiz

(KARCH)

Pleguezuelos, Lizana and Márquez, 2002, updated

until 2005

Meyer et al., 2009

The Netherlands 10 × 10 km 8061 provided by RAVON Creemers and van Delft,

2009

UK + Ireland 10 × 10 km 20 289 digitised from Atlas Arnold, 2005

Ukraine 10 × 10 km 1162 digitised from Atlas Kypnjehko and Bepbec, 1999

Wallonia 4 × 4 km 7269 provided by Raînne-Natagora Jacob et al., 2007

PERSONAL DATABASES

1. Crnobrnja-Isailovic´,
   1. Dobrnjic´,
   2. Tanovic´, Idriz Haxhiu

50 × 50 km 1128

P. de Pous Several 10 405

1. Jablonski 50 × 50 km 685

S.L. Kuzmin 1! 17 865 Kuzmin, 2013

**Table 1.** (Continued.)

Resolution Records Sources Published atlases

CONTINENTAL DATABASES

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Europe | 50 × 50 km | 12 155 | SEH | Gasc et al., 1997 |
| GBIF | Several | 18 772 | GBIF |  |

TOTAL 384 609

GPS point locality records). Therefore, the databases were homogenised, deleting all other information except species names, coordinates, and data source, and projected to the same coordinate system (WGS84).

*Map production*

As an atlas is usually the representation of the species’ distributions by uniform units (Sillero, Celaya and Martín- Alfageme, 2005; Loureiro and Sillero, 2010), record points were transformed into a grid. We used the official UTM

grid of 50 × 50 km, that it is freely available from the Eu-

ropean Environment Agency (<http://www.eea.europa.eu/>).

This grid is based on the one used for the European Atlas of Flora, the first biological distribution atlas for Europe (Jalas and Suonuinen, 1972). It includes 4524 land squares. There- fore, each point database (COUNTRIES, SEH/GBIF, and INTRODUCED) was transformed to a grid file, by spatially overlapping with the 50 × 50 km UTM grid. This transfor-

mation from the point databases (e.g. GPS points, as well as centroids of grids of 1 × 1 km, 4 × 4 km, 5 × 5 km, 10 × 10 km, and 50 × 50 km squares) to a grid database was performed by a set of GIS scripts for ArcGIS 9.3 (see

Supplementary table S1 online) in which for each species, each grid was assigned 0 for absence or 1 for presence.

The species maps (see example in fig. 1; all maps are provided online in Supplementary Atlases S1 and S2, and the corresponding GIS files in Supplementary Atlases S3 and S4; species codes are provided in Supplementary At- las S5) were created automatically by overlapping the three grid files (COUNTRIES, SEH/GBIF, and INTRODUCED),

using a script written in the R language (R 2.15, R Develop- ment Core Team, 2012). The script (included online in Sup- plementary Text S2) looked sequentially for each species in the three grids, representing them with different colours. The resulting maps were exported to images in .jpg format. Species richness maps for amphibians and reptiles were cal- culated by the sum of all species present in each grid cell. We then compared species richness maps with those based entirely on the original data of the 1997 European Atlas, and for each grid cell we subtracted the old from the new number of species occurring therein. The resulting value was subse- quently represented on the same grid to indicate areas of increased vs. decreased quantity of recorded species. For a better cartographical representation, all maps are shown in the Albers Conical projection for Europe. This projection (EPSG code: 9822; [http://spatialreference.org/ref/sr-org/44/](http://spatialreference.org/ref/sr-org/44/html/) [html/](http://spatialreference.org/ref/sr-org/44/html/)) reduces cartographical distortions of Europe, by a better adjustment to the central meridian (Greenwich) and both standard parallels.

*Biogeographical analyses*

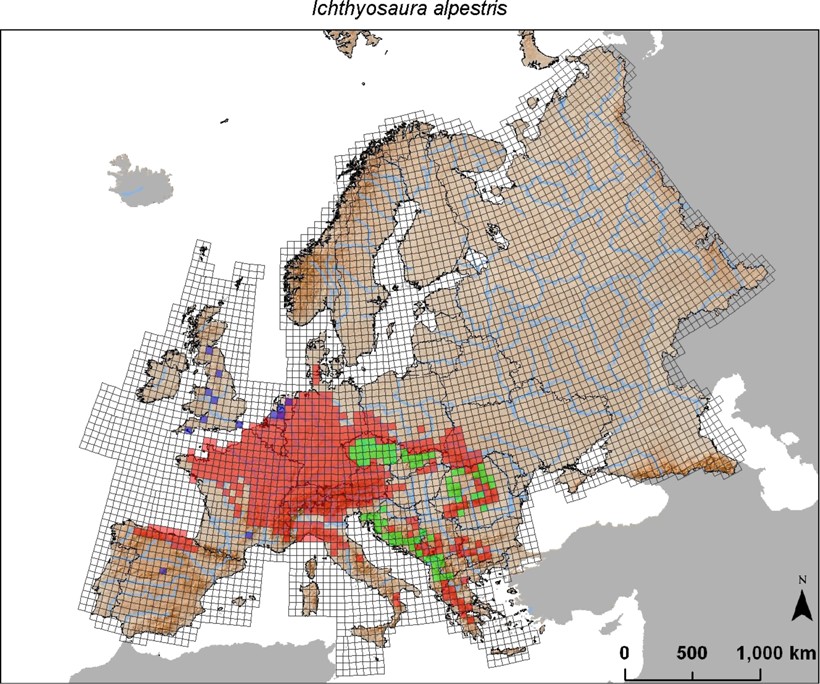
The coarse 50 × 50 km occurrence data were not suitable for sophisticated analyses (e.g. calculation of ecological niche models; Sillero, 2011), and these were not the main

goal of this compilation. We therefore did not apply any methods based on environmental niche modelling which at this level had already been carried out by Araújo, Thuiller and Pearson (2006) and Araújo et al. (2008). Instead, we used a number of descriptive statistics to visualise general biogeographic patterns. Besides calculating species rich- ness, we also used clustering analysis to define chorotypes and applied a measure of regional endemism. Chorotypes were defined by Baroni-Urbani, Ruffo and Vigna Taglianti (1978) as clusters of species with statistically similar distri- butions for a specific area. However, Vigna-Taglianti et al. (1999) stated that to define chorotypes the whole species’ distribution should be used. In fact, Vigna-Taglianti et al. (1999) proposed a standard classification of chorotypes us- ing several groups of animals (e.g. beetles, amphibians, and reptiles). Nevertheless, the term chorotypes has been widely used when applied to the herpetofauna of certain regions (e.g. Corti et al., 1991, 1997; Olivero, Real and Márquez, 2011; Sillero et al., 2009, and reference therein). Our in- tention here was not to establish a standard classification of biogeographical regions for the European amphibians and reptiles, but to classify species by their distribution simi- larity using the current available knowledge. Notwithstand- ing this, and for avoiding misunderstandings, we will use the term distribution type instead of chorotype, proposed by Baroni-Urbani and Collinwood (1976) and Baroni-Urbani and Collinwood (1977). In these two works, distribution types were calculated using incomplete species’ distribu- tions.

Identification of the main distribution types of amphib- ians and reptiles in Europe was carried out following Sillero et al. (2009). The merged species distribution files (COUN- TRIES and SEH/GBIF) were transformed into two separate data matrices for amphibians and reptiles, respectively (.csv format) and analysed using the R 2.15 software (R Devel- opment Core Team, 2012). Distribution types were deter- mined by a Hierarchical Cluster Analysis using Jaccard’s bi- nary index and UPGMA as clustering method (Sillero et al., 2009), which is a measure of similarities among species dis- tributions. This analysis was performed using the function “vegdist” of the R package “vegan” (Oksanen et al., 2012),

which computes the Jaccard’s index as 2*B* = *(*1 + *B)*,

where *B* represents Bray-Curtis dissimilarity. The Bray-



**Figure 1.** Example of species distribution map (*Ichthyosaura alpestris*) showing, in different colours, records corresponding to the COUNTRIES (red), SEH/GBIF (green) and INTRODUCED (purple) databases used in this study. Brown colours represent higher elevations. We used the official UTM grid of 50 × 50 km from the European Environmental Agency

([www.eea.europa.eu/](http://www.eea.europa.eu/)). COUNTRIES database included data from published or on-going national atlases, and from personal

data kindly provided to the SEH. SEH/GBIF included data from the 1997 European Atlas and the Global Information Facility (GBIF: [www.gbif.org](http://www.gbif.org/)). We only included data from SEH/GBIF when data from COUNTRIES database were not available. Datasets for introduced species were not available in all countries.

Curtis dissimilarity is calculated as *(a* + *b* − 2*j)/(a* + *b)*, where *a* and *b* are the numbers of species on compared squares, and *j* is the number of species in both squares com-

pared. The Jaccard’s index is 1 when species composition is identical between squares and 0 when two squares have no species in common. According to the values of Jaccard’s in- dex, the species were clustered into a dissimilarity tree, and the branches with a minimum of at least three species and splitting off the basal polytomy of this tree were defined as the main distribution types.

Using occurrence data of amphibians and reptiles, we separately calculated for the two groups the Corrected Weighted Endemism index (CWE) (Crisp et al., 2001). For calculating this index, the species are weighted by the in- verse of their cell ranges so that species with narrow ranges are assigned relatively high weights, while species with broader ranges are assigned progressively lower weights

(Laffan and Crisp, 2003). The sum of the weighted values for a given cell (weighted endemism) is then divided by the number of species occurring in the cell. This correction for the cell species richness ensures that CWE values high- light areas with a high proportion of endemic species but not necessarily high in richness (Crisp et al., 2001; Laffan and Crisp, 2003; Laffan, Ramp and Roger, 2012). We calculated CWE using the “endemicity tools” extension for ArcView

3.2 (Danho, 2003), and performed computations at the cell level (radius = 1), excluding empty grid cells from analysis. Single cell calculations provide the maximum resolution for

the analysis at the expense of artefacts occurring in poorly sampled cells (Laffan and Crisp, 2003). We assumed that herpetological explorations in Europe have been intensive enough to allow calculations at single-cell level (see below for a discussion of this assumption; see also Ficetola et al., 2013).

**Results and discussion**

*Database compilation*

The COUNTRIES database includes a total of

cludes 15 485 records; and the INTRODUCED database includes 4310 records. Our compila- tion thus totals 384 609 entries from 28 national and personal databases, plus the original SEH and GBIF databases (table 1). The Spanish Her- petological Society provided the largest amount of records (68 618; updated until 2005; table 2). Other countries, like Portugal and Luxembourg also provided their entire database, with data about locality, author, and date. Records with a

high spatial resolution (table 1) were also avail- able for instance in Flanders (5 × 5 km), Wal- lonia (4 × 4 km), and Portugal (GPS points). Table 1 details the characteristics of the dif-

ferent databases that were used in this study. The final number of records per species repre-

sented in the 50 × 50 km grids (total: 48 440 occurrence records at the 50 × 50 km grid level) is lower than in the sum of the three

databases (COUNTRIES, SEH/GBIF, INTRO-

DUCED) due to record duplications caused by the reduction in the spatial resolution of the UTM squares (e.g. from GPS points in the Por- tuguese database to the final 50 × 50 km UTM square).

Overall, 218 taxa were mapped (73 species of amphibians and 145 of reptiles; table 3), in- cluding 13 amphibian and 18 reptile species that were not represented in the 1997 European At- las (Gasc et al., 1997). However, as the study area is slightly different, 18 species from the eastern edges of the area covered by the 1997 European Atlas were not mapped in our compi- lation (see Study Area section). Therefore, and considering also taxonomical changes, our com- pilation includes 31 newly mapped species (ta- ble 3). We merged 46 taxa with others in the same species-level map (usually not more than 2-3 species per map) when their taxonomic sta- tus and/or their precise distribution boundaries were insufficiently known to warrant plotting

**Table 2.** Point records per country from the three main databases (COUNTRIES, SEH/GBIF, and INTRODUCED) of this compilation, for amphibians and reptiles, and for both groups together. See table 1 for number of records per national and personal databases.

and reptiles

Albania 163 852 1015

Andorra 12 23 35

Austria 8365 5872 14 237

Belgium∗ 40 413 4251 44 664

Bosnia and 177 312 489

Herzegovina

Bulgaria 1108 2565 3673

Belarus 1258 195 1453

Croatia 471 1924 2395

Czech Republic 648 436 1084

Denmark 3695 1452 5147

Estonia 2525 480 3005

Finland 1845 2264 4109

F.Y.R. of Macedonia 74 201 275

France 6865 5881 12 746

Georgia 742 18 760

Germany 24 380 11 116 35 496

Greece 1430 11 367 12 797

Hungary 8227 3738 11 965

Ireland 459 530 989

Italy 1583 2736 4319

Latvia 368 63 431

Liechtenstein 8 5 13

Lithuania 432 90 522

Luxembourg 9539 1054 10 593

Malta 8 32 40

Moldova 356 72 428

Montenegro 94 228 322

Netherlands 6249 2012 8261

Norway 6958 3359 10 317

Poland 11 264 4127 15 391

Portugal 8054 9101 17 155

Romania 3084 4470 7554

Russia 14 315 2695 17 010

Serbia 493 721 1214

Slovakia 1694 641 2335

Slovenia 1522 1489 3011

Spain 27 797 41 059 68 856

Sweden 26 562 4253 30 815

Switzerland 3015 2464 5479

Ukraine 4031 881 4912

United Kingdom 10 880 8417 19 297

TOTAL 241 163 143 446 384 609

∗ Belgium data was composed by three different databases: Flanders, Wallonia, and Brussels.

them on separate maps (see section on taxo- nomic gaps of knowledge below and table 3).

**Table 3.** Total number of records (50 × 50 km UTM squares) per species for this compilation and the 1997 European atlas. COUNTRIES, INTRODUCED and SEH/GBIF corresponds to the record numbers per species of each database included in this compilation, and ‘All data’ summarises the total number of records. Atlas 1997 corresponds to the 1997 European atlas. Difference is the subtraction between this compilation and the 1997 European atlas. Species are listed alphabetically according to current classification, separately for Amphibia,

Testudines, and Squamata. Species endemic to Europe are marked with an asterisk (∗). Numbers in parentheses refer to species complexes which subsume species either not considered as

valid (Speybroeck, Beukema and Crochet, 2010) or for which distribution records cannot be unambiguously assigned in the available databases (see footnotes for detailed explanations). The second column summarises the global extinction risk status of each species according to the IUCN red list (IUCN, 2012), according to IUCN categories (IUCN, 2001): DD, Data Deficient; LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; CR, Critically Endangered (dashes indicate species that have not yet been evaluated by IUCN at a global level). Status in parentheses refers to cases where confirmation is necessary due to taxonomic uncertainties.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| AMPHIBIANS |  |  |  |  |  |  |  |  |
| *Alytes cisternasii*∗ | NT | 93 | 0 | 0 | 93 | *Alytes cisternasii* | 76 | 17 |
| *Alytes dickhilleni*∗ | VU | 20 | 0 | 0 | 20 | *Alytes obstetricans* (partim) |  | 20 |
| *Alytes muletensis*∗ | VU | 2 | 1 | 0 | 3 | *Alytes muletensis* | 1 | 2 |
| *Alytes obstetricans*∗ | LC | 466 | 11 | 0 | 477 | *Alytes obstetricans* (partim) | 448 | 29 |
| *Bombina bombina* | LC | 783 | 0 | 155 | 938 | *Bombina bombina* | 701 | 237 |
| *Bombina variegata*∗ (14) | LC | 525 | 3 | 95 | 621 | *Bombina variegata* | 570 | 51 |
| *Bufo boulengeri* | LC | 18 | 0 | 0 | 18 | *Bufo viridis* (partim) |  | 18 |
| *Bufo bufo* | LC | 2254 | 0 | 359 | 2613 | *Bufo bufo* | 2059 | 554 |
| *Bufo calamita*∗ | LC | 963 | 4 | 28 | 996 | *Bufo calamita* | 782 | 214 |
| *Bufo viridis* complex (11) | LC | 1332 | 0 | 230 | 1562 | *Bufo viridis* (partim) | 1266 | 296 |
| *Calotriton arnoldi*∗ | CR | 1 | 0 | 0 | 1 | *Euproctus asper* (partim) |  | 1 |
| *Calotriton asper*∗ | NT | 28 | 0 | 0 | 28 | *Euproctus asper* (partim) | 25 | 3 |
| *Chioglossa lusitanica*∗ | VU | 40 | 0 | 0 | 40 | *Chioglossa lusitanica* | 38 | 2 |
| *Discoglossus galganoi*∗ (5) | LC | 210 | 0 | 0 | 210 | *Discoglossus galganoi* | 157 | 53 |
| *Discoglossus montalentii*∗ | NT | 7 | 0 | 0 | 7 | *Discoglossus montalentii* | 5 | 2 |
| *Discoglossus pictus* | LC | 19 | 14 | 0 | 33 | *Discoglossus pictus* | 21 | 12 |
| *Discoglossus sardus*∗ | LC | 26 | 0 | 0 | 26 | *Discoglossus sardus* | 30 | −4 |
| *Euproctus montanus*∗ | LC | 9 | 0 | 0 | 9 | *Euproctus montanus* | 6 | 3 |
| *Euproctus platycephalus*∗ | EN | 8 | 0 | 0 | 8 | *Euproctus platycephalus* | 13 | −5 |
| *Hyla arborea* complex (2) | LC | 1117 | 0 | 123 | 1240 | *Hyla arborea* (partim) | 1213 | 27 |
| *Hyla intermedia*∗ | LC | 134 | 0 | 0 | 134 | *Hyla arborea* (partim) |  | 134 |
| *Hyla meridionalis* | LC | 200 | 1 | 0 | 201 | *Hyla meridionalis* | 137 | 64 |
| *Hyla sarda*∗ | LC | 28 | 0 | 0 | 28 | *Hyla arborea* (partim) |  | 28 |
| *Ichthyosaura alpestris*∗ | LC | 513 | 13 | 75 | 601 | *Triturus alpestris* | 556 | 45 |
| *Lissotriton boscai*∗ | LC | 119 | 0 | 0 | 119 | *Triturus boscai* | 110 | 9 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Lissotriton helveticus*∗ | LC | 545 | 1 | 1 | 546 | *Triturus helveticus* | 486 | 60 |
| *Lissotriton italicus*∗ | LC | 39 | 0 | 0 | 39 | *Triturus italicus* | 31 | 8 |
| *Lissotriton montandoni*∗ | LC | 44 | 0 | 16 | 60 | *Triturus montandoni* | 56 | 4 |
| *Lissotriton vulgaris* | LC | 1691 | 0 | 289 | 1980 | *Triturus vulgaris* | 1460 | 520 |
| *Lithobates catesbeianus* | LC | 0 | 47 | 0 | 47 | *Rana catesbeiana* | 18 | 29 |
| *Lyciasalamandra helverseni*∗ | VU | 3 | 0 | 0 | 3 | *Mertensiella luschani* (partim) |  | 3 |
| *Ommatotriton vittatus* | LC | 30 | 0 | 0 | 30 | *Triturus vittatus* | 0 | 30 |
| *Pelobates cultripes*∗ | NT | 253 | 0 | 0 | 253 | *Pelobates cultripes* | 197 | 56 |
| *Pelobates fuscus* | LC | 432 | 0 | 388 | 770 | *Pelobates fuscus* | 852 | −82 |
| *Pelobates syriacus* | LC | 35 | 0 | 9 | 44 | *Pelobates syriacus* | 79 | −35 |
| *Pelodytes caucasicus* | NT | 27 | 0 | 0 | 27 | *Pelodytes caucasicus* | 0 | 27 |
| *Pelodytes* sp.∗ (10) | (LC) | 383 | 0 | 0 | 383 | *Pelodytes punctatus* | 270 | 113 |
| *Pelophylax cretensis*∗ | EN | 8 | 0 | 0 | 8 | (not included) |  | 8 |
| *Pelophylax epeiroticus*∗ | VU | 11 | 0 | 0 | 11 | *Rana epeirotica* | 11 | 0 |
| *Pelophylax* kl. *esculentus*/*lessonae*∗ (1) | LC | 1304 | 3 | 104 | 1411 | *Rana kl. esculenta* + *Rana lessonae* | 1874 | −463 |
| *Pelophylax* kl. *grafi*∗ | NT | 11 | 1 | 0 | 12 |  |  | 12 |
| *Pelophylax perezi*∗ | LC | 306 | 0 | 0 | 605 | *Rana perezi* | 295 | 11 |
| *Pelophylax ridibundus*/*bedriagae* (12) | LC | 1405 | 43 | 157 |  | *Rana ridibunda* (partim) and *Rana balcanica* | 1169 | 436 |
| *Pelophylax shqipericus*∗ | EN | 2 | 0 | 0 | 2 | *Rana shqiperica* | 6 | −4 |
| *Pleurodeles waltl* | NT | 166 | 0 | 0 | 166 | *Pleurodeles waltl* | 132 | 34 |
| *Proteus anguinus*∗ | VU | 8 | 1 | 12 | 22 | *Proteus anguinus* | 23 | −1 |
| *Rana arvalis* | LC | 1254 | 0 | 310 | 1564 | *Rana arvalis* | 1147 | 417 |
| *Rana dalmatina* | LC | 613 | 1 | 106 | 720 | *Rana dalmatina* | 685 | 35 |
| *Rana graeca*∗ | LC | 65 | 0 | 0 | 65 | *Rana graeca* | 82 | −17 |
| *Rana iberica*∗ | NT | 78 | 0 | 0 | 78 | *Rana iberica* | 63 | 15 |
| *Rana italica*∗ | LC | 67 | 0 | 0 | 67 | *Rana italica* | 51 | 16 |
| *Rana latastei*∗ | VU | 29 | 0 | 0 | 29 | *Rana latastei* | 25 | 4 |
| *Rana macrocnemis* | (LC) | 67 | 0 | 2 | 69 | *Rana macrocnemis* | 2 | 67 |
| *Rana pyrenaica*∗ | EN | 5 | 0 | 0 | 5 | *Rana temporaria* (partim) |  | 5 |
| *Rana temporaria* | LC | 1979 | 0 | 366 | 2345 | *Rana temporaria* (partim) | 1782 | 563 |
| *Salamandra atra*∗ | LC | 62 | 0 | 7 | 69 | *Salamandra atra* | 63 | 6 |
| *Salamandra corsica*∗ | LC | 7 | 0 | 0 | 7 | *Salamandra salamandra* (partim) |  | 7 |
| *Salamandra lanzai*∗ | VU | 4 | 0 | 0 | 4 | *Salamandra lanzai* | 3 | 1 |
| *Salamandra salamandra*∗ | LC | 833 | 0 | 80 | 913 | *Salamandra salamandra* (partim) | 854 | 59 |
| *Salamandrella keyserlingii* | LC | 55 | 0 | 21 | 66 | *Salamandrella keyserlingii* | 22 | 44 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Salamandrina perspicillata*/*terdigitata* | LC | 58 | 0 | 0 | 58 | *Salamandrina terdigitata* | 41 | 17 |
| *Speleomantes ambrosii*∗ | NT | 1 | 0 | 0 | 1 | *Speleomantes ambrosii* (partim) | 15 | −14 |
| *Speleomantes flavus*∗ | VU | 2 | 0 | 0 | 2 | *Speleomantes flavus* | 2 | 0 |
| *Speleomantes genei*∗ | VU | 2 | 0 | 0 | 2 | *Speleomantes genei* | 2 | 0 |
| *Speleomantes imperialis*∗ | NT | 4 | 0 | 0 | 4 | *Speleomantes imperialis* | 3 | 1 |
| *Speleomantes italicus*∗ | NT | 16 | 0 | 0 | 16 | *Speleomantes italicus* | 8 | 8 |
| *Speleomantes sarrabusesis*∗ | VU | 1 | 0 | 0 | 1 | (not included) |  | 1 |
| *Speleomantes strinatii*∗ | NT | 13 | 2 | 0 | 15 | *Speleomantes ambrosii* (partim) |  | 15 |
| *Speleomantes supramontis*∗ | EN | 4 | 0 | 0 | 4 | *Speleomantes supramontis* | 4 | 0 |
| *Triturus cristatus* complex∗ (20) | LC | 1368 | 0 | 182 | 1550 | *Triturus cristatus* superspecies (partim) | 1209 | 341 |
| *Triturus marmoratus*/*pygmaeus*∗ (4) | LC/NT | 332 | 0 | 0 | 332 | *Triturus marmoratus* | 284 | 48 |
| *Xenopus laevis* | LC | 0 | 7 | 0 | 7 | (not included) |  | 7 |
| REPTILES (TESTUDINES) |  |  |  |  |  |  |  |  |
| *Caretta caretta* | EN | 235 | 0 | 0 | 235 | *Caretta caretta* | 27 | 208 |
| *Chelonia mydas* | EN | 40 | 0 | 0 | 40 | *Chelonia mydas* | 0 | 40 |
| *Dermochelys coriacea* | CR | 297 | 0 | 0 | 297 | *Dermochelys coriacea* | 0 | 297 |
| *Emys orbicularis* (17) | NT | 776 | 1 | 318 | 1095 | *Emys orbicularis* | 786 | 309 |
| *Eretmochelys imbricata* | CR | 12 | 0 | 0 | 12 | *Eretmochelys imbricata* | 0 | 12 |
| *Lepidochelys kempii* | CR | 43 | 0 | 0 | 43 | *Lepidochelys kempii* | 0 | 43 |
| (not included) |  |  |  |  |  | *Lepidochelys olivacea* | 0 | 0 |
| *Mauremys caspica* | – | 0 | 0 | 8 | 8 | *Mauremys caspica* (partim) | 96 | −88 |
| *Mauremys leprosa* | – | 198 | 2 | 0 | 200 | *Mauremys leprosa* | 134 | 66 |
| *Mauremys rivulata* | – | 85 | 0 | 6 | 91 | *Mauremys caspica* (partim) |  | 91 |
| *Testudo graeca* | VU | 91 | 2 | 31 | 124 | *Testudo graeca* | 127 | −3 |
| *Testudo hermanni*∗ | NT | 230 | 6 | 20 | 256 | *Testudo hermanni* | 223 | 33 |
| *Testudo marginata*∗ | LC | 36 | 6 | 0 | 36 | *Testudo marginata* | 62 | −26 |
| *Trachemys scripta* (13) | LC | 0 | 396 | 0 | 396 |  |  | 396 |
| REPTILES (SQUAMATA) |  |  |  |  |  |  |  |  |
| *Ablepharus kitaibelii* | LC | 121 | 0 | 15 | 136 | *Ablepharus kitaibelii* | 109 | 27 |
| *Acanthodactylus erythrurus* | LC | 156 | 0 | 0 | 156 | *Acanthodactylus erythrurus* | 110 | 46 |
| (not included) |  |  |  |  |  | *Agkistrodon halys* | 2 | −2 |
| *Algyroides fitzingeri*∗ | LC | 27 | 0 | 0 | 27 | *Algyroides fitzingeri* | 22 | 5 |
| *Algyroides marchi*∗ | EN | 5 | 0 | 0 | 5 | *Algyroides marchi* | 6 | −1 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Algyroides moreoticus*∗ | NT | 20 | 0 | 0 | 20 | *Algyroides moreoticus* | 19 | 1 |
| *Algyroides nigropunctatus*∗ | LC | 55 | 0 | 0 | 55 | *Algyroides nigropunctatus* | 57 | −2 |
| *Alsophylax pipiens* | LC | 0 | 0 | 1 | 1 | *Alsophylax pipiens* | 1 | 0 |
| *Anguis cephallonica*∗ | NT | 11 | 0 | 0 | 11 | *Anguis cephallonicus* | 14 | −3 |
| *Anguis* sp. (7) | (LC) | 1355 | 2 | 463 | 1820 | *Anguis fragilis* | 1701 | 119 |
| *Archaeolacerta bedriagae*∗ | NT | 14 | 0 | 0 | 14 | *Lacerta bedriagae* | 12 | 2 |
| *Blanus cinereus*/*mariae*∗ (6) | (LC) | 174 | 0 | 0 | 174 | *Blanus cinereus* | 118 | 56 |
| *Chalcides bedriagai*∗ | NT | 168 | 0 | 0 | 168 | *Chalcides bedriagae* | 123 | 45 |
| *Chalcides chalcides* | LC | 121 | 0 | 0 | 121 | *Chalcides chalcides* | 91 | 30 |
| *Chalcides ocellatus* | – | 70 | 1 | 0 | 71 | *Chalcides ocellatus* | 57 | 14 |
| *Chalcides striatus*∗ | LC | 246 | 0 | 0 | 246 | *Chalcides striatus* | 201 | 45 |
| *Chamaeleo africanus* |  | 0 | 1 | 0 | 1 |  |  | 1 |
| *Chamaeleo chamaeleon* | LC | 34 | 6 | 0 | 40 | *Chamaeleo chamaeleon* | 24 | 16 |
| *Coronella austriaca* | – | 1003 | 1 | 219 | 1223 | *Coronella austriaca* | 1042 | 181 |
| *Coronella girondica* | LC | 368 | 0 | 0 | 368 | *Coronella girondica* | 276 | 92 |
| *Cyrtopodion caspium* | – | 0 | 0 | 2 | 2 | *Cyrtodactylus caspius* | 5 | −3 |
| *Mediodactylus russowi* (not included) | – |  |  |  |  | *Cyrtodactylus russowi* | 1 | −1 |
| *Dalmatolacerta oxycephala*∗ | LC | 22 | 0 | 0 | 22 | *Lacerta oxycephala* | 22 | 0 |
| *Darevskia armenaica* | – | 0 | 0 | 1 | 1 | *Lacerta armenaica* | 1 | 0 |
| *Darevskia caucasica* | – | 0 | 0 | 27 | 27 | *Lacerta caucasica* | 28 | −1 |
| *Darevskia derjugini* | – | 0 | 0 | 5 | 5 | *Lacerta derjugini* | 5 | 0 |
| *Darevskia lindholmi*∗ | – | 6 | 0 | 7 | 13 | *Lacerta saxicola* |  | 6 |
| *Darevskia praticola* | NT | 32 | 0 | 46 | 78 | *Lacerta praticola* | 36 | 42 |
| *Darevskia rudis* (not included) | – | 0 | 0 | 8 | 8 | *Lacerta rudis* | 9 | −1 |
| *Darevskia saxicola* | – | 0 | 0 | 16 | 16 | *Lacerta saxicola* | 5 | 11 |
| *Dinarolacerta montenegrina*∗ | LC | 0 | 0 | 1 | 1 | *Lacerta mosorensis* (partim) |  | 1 |
| *Dinarolacerta mosorensis*∗ | VU | 0 | 0 | 13 | 13 | *Lacerta mosorensis* (partim) | 11 | 2 |
| *Dolichophis caspius* | – | 177 | 0 | 120 | 297 | *Coluber caspius* | 246 | 51 |
| *Dolichophis schmidti* | – | 0 | 0 | 2 | 2 | *Coluber schmidti* | 8 | −6 |
| *Eirenis collaris* | – | 0 | 0 | 10 | 10 | *Eirenis collaris* | 14 | −4 |
| *Eirenis modestus* | LC | 0 | 0 | 6 | 6 | *Eirenis modestus* | 0 | 6 |
| *Elaphe dione* | – | 2 | 0 | 44 | 46 | *Elaphe dione* | 36 | 10 |
| *Elaphe quatuorlineata*∗ | NT | 156 | 0 | 3 | 159 | *Elaphe quatuorlineata* (partim) | 220 | −61 |
| *Elaphe sauromates* | – | 50 | 0 | 0 | 50 | *Elaphe quatuorlineata* (partim) |  | 50 |
| *Eremias arguta* | – | 32 | 0 | 101 | 133 | *Eremias arguta* | 120 | −61 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Eremias velox* | – | 0 | 0 | 43 | 43 | *Eremias velox* | 26 | 17 |
| *Eryx jaculus* | – | 46 | 0 | 13 | 59 | *Eryx jaculus* | 56 | 3 |
| *Eryx miliaris* | – | 0 | 0 | 16 | 16 | *Eryx miliaris* | 18 | −2 |
| *Eumeces schneiderii* | – | 0 | 0 | 2 | 2 | *Eumeces schneiderii* | 6 | −4 |
| *Euleptes europaea* | NT | 44 | 0 | 0 | 44 | *Phyllodactylus europaeus* | 29 | 15 |
| *Hellenolacerta graeca*∗ | NT | 13 | 0 | 0 | 13 | *Lacerta graeca* | 11 | 2 |
| *Hemidactylus turcicus* | LC | 346 | 12 | 0 | 358 | *Hemidactylus turcicus* | 237 | 121 |
| *Hemorrhois algirus* | – | 0 | 2 | 0 | 2 | *Coluber algirus* | 1 | 1 |
| *Hemorrhois hippocrepis* | LC | 167 | 0 | 0 | 167 | *Coluber hippocrepis* | 142 | 25 |
| *Hemorrhois ravergieri* | – | 0 | 0 | 7 | 7 | *Coluber ravergeri* | 9 | −2 |
| *Hierophis gemonensis*∗ | LC | 78 | 0 | 0 | 78 | *Hierophis gemonensis* | 53 | 25 |
| *Hierophis viridiflavus*∗ | LC | 374 | 1 | 0 | 375 | *Coluber viridiflavus* | 311 | 64 |
| *Iberolacerta aranica*∗ | EN | 2 | 0 | 0 | 2 | *Lacerta bonnali* (partim) |  | 2 |
| *Iberolacerta aurelioi*∗ | EN | 2 | 0 | 0 | 2 | *Lacerta bonnali* (partim) |  | 2 |
| *Iberolacerta bonnali*∗ | NT | 6 | 0 | 0 | 6 | *Lacerta bonnali* (partim) | 7 | −1 |
| *Iberolacerta cyreni*∗ | EN | 5 | 0 | 0 | 5 | *Lacerta bonnali* (partim) |  | 5 |
| *Iberolacerta galani*∗ | NT | 2 | 0 | 0 | 2 | *Lacerta bonnali* (partim) |  | 2 |
| *Iberolacerta horvathi*∗ | NT | 11 | 0 | 0 | 11 | *Lacerta horvathi* | 18 | −7 |
| *Iberolacerta martinezricai*∗ | CR | 1 | 0 | 0 | 1 | *Lacerta bonnali* (partim) |  | 1 |
| *Iberolacerta monticola*∗ | VU | 21 | 0 | 0 | 21 | *Lacerta monticola* (partim) | 23 | −2 |
| *Lacerta agilis* | LC | 808 | 2 | 375 | 1185 | *Lacerta agilis* | 1172 | −13 |
| *Lacerta bilineata*∗ | LC | 415 | 0 | 0 | 415 | *Lacerta viridis* (partim) |  | 415 |
| *Lacerta schreiberi*∗ | NT | 94 | 0 | 0 | 94 | *Lacerta schreiberi* | 80 | 14 |
| *Lacerta strigata* | LC | 0 | 0 | 50 | 50 | *Lacerta strigata* | 18 | 32 |
| *Lacerta trilineata* | LC | 126 | 0 | 9 | 135 | *Lacerta trilineata* | 107 | 28 |
| *Lacerta viridis* | LC | 297 | 6 | 68 | 371 | *Lacerta viridis* (partim) | 746 | −375 |
| *Laudakia caucasia* | – | 0 | 0 | 4 | 4 | *Laudakia caucasia* | 5 | −1 |
| *Laudakia stellio* | LC | 3 | 5 | 0 | 8 | *Laudakia stellio* | 18 | −10 |
| *Macroprotodon brevis* | NT | 113 | 0 | 0 | 113 | *Macroprotodon cucullatus* (partim) |  | 113 |
| *Macroprotodon cucullatus* (15) | (LC) | 9 | 0 | 0 | 9 | *Macroprotodon cucullatus* (partim) | 90 | −81 |
| *Macrovipera lebetina* | – | 0 | 0 | 4 | 4 | *Macrovipera lebetina* | 7 | −3 |
| *Macrovipera schweizeri*∗ | EN | 1 | 0 | 0 | 1 | *Macrovipera schweizeri* | 1 | 0 |
| *Malpolon insignitus* | – | 103 | 0 | 56 | 159 | *Malpolon monspessulanus* (partim) |  | 159 |
| *Malpolon monspessulanus* | LC | 280 | 0 | 0 | 280 | *Malpolon monspessulanus* (partim) | 361 | −81 |
| *Mediodactylus kotschyi* | LC | 106 | 4 | 2 | 112 | *Cyrtodactylus kotschyi* | 112 | 0 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Montivipera xanthina* | LC | 3 | 0 | 0 | 3 | *Vipera xanthina* | 1 | 2 |
| *Natrix maura* | LC | 461 | 1 | 0 | 462 | *Natrix maura* | 413 | 49 |
| *Natrix natrix* | LC | 1613 | 4 | 509 | 2126 | *Natrix natrix* | 1967 | 159 |
| *Natrix tessellata* | LC | 347 | 1 | 172 | 520 | *Natrix tessellata* | 452 | 68 |
| *Ophiomorus punctatissimus* | LC | 12 | 0 | 0 | 12 | *Ophiomorus punctatissimus* | 18 | −6 |
| *Ophisops elegans* | – | 11 | 0 | 3 | 14 | *Ophisops elegans* | 7 | 7 |
| *Phrynocephalus guttatus* | – | 0 | 0 | 26 | 26 | *Phrynocephalus guttatus* | 32 | −6 |
| *Phrynocephalus helioscopus* | LC | 0 | 0 | 5 | 5 | *Phrynocephalus helioscopus* | 8 | −3 |
| *Phrynocephalus mystaceus* | – | 0 | 0 | 19 | 19 | *Phrynocephalus mystaceus* | 24 | −5 |
| *Platyceps collaris* | – | 0 | 0 | 3 | 3 | *Coluber rubriceps* | 4 | −1 |
| *Platyceps najadum* | LC | 92 | 0 | 14 | 106 | *Coluber najadum* | 76 | 30 |
| *Podarcis bocagei*∗ | LC | 36 | 0 | 0 | 36 | *Podarcis bocagei* (partim) | 78 | −42 |
| *Podarcis carbonelli*∗ | EN | 18 | 0 | 0 | 18 | *Podarcis bocagei* (partim) |  | 18 |
| *Podarcis cretensis*∗ | EN | 6 | 0 | 0 | 6 | *Podarcis erhardii* (partim) |  | 6 |
| *Podarcis erhardii*∗ | LC | 57 | 0 | 0 | 65 | *Podarcis erhardii* (partim) | 62 | 3 |
| *Podarcis filfolensis*∗ | LC | 5 | 0 | 0 | 5 | *Podarcis filfolensis* | 1 | 4 |
| *Podarcis gaigeae*∗ | VU | 3 | 0 | 0 | 3 | *Podarcis erhardii* (partim) |  | 3 |
| *Podarcis hispanicus* complex (3) | (LC) | 282 | 0 | 0 | 282 | *Podarcis hispanica* | 244 | 38 |
| *Podarcis levendis*∗ | VU | 1 | 0 | 0 | 1 | *Podarcis erhardii* (partim) |  | 1 |
| *Podarcis lilfordi*∗ | EN | 8 | 0 | 0 | 8 | *Podarcis lilfordi* | 3 | 5 |
| *Podarcis melisellensis*∗ | LC | 36 | 0 | 0 | 36 | *Podarcis melisellensis* | 36 | 0 |
| *Podarcis milensis*∗ | VU | 4 | 0 | 0 | 4 | *Podarcis milensis* | 4 | 0 |
| *Podarcis muralis* | LC | 702 | 13 | 29 | 744 | *Podarcis muralis* | 665 | 79 |
| *Podarcis peloponnesiacus*∗ | LC | 16 | 0 | 0 | 16 | *Podarcis peloponnesiaca* | 14 | 2 |
| *Podarcis pityusensis*∗ | NT | 3 | 6 | 0 | 9 | *Podarcis pityusensis* | 4 | 5 |
| *Podarcis raffonei*∗ | CR | 3 | 0 | 0 | 3 | *Podarcis wagleriana* (partim) |  | 3 |
| *Podarcis siculus*∗ | LC | 182 | 9 | 0 | 191 | *Podarcis sicula* | 158 | 33 |
| *Podarcis tauricus* | LC | 140 | 0 | 22 | 162 | *Podarcis taurica* | 163 | −1 |
| *Podarcis tiliguerta*∗ | LC | 30 | 0 | 0 | 30 | *Podarcis tiliguerta* | 23 | 7 |
| *Podarcis waglerianus*∗ | LC | 18 | 0 | 0 | 18 | *Podarcis wagleriana* (partim) | 18 | 0 |
| *Psammodromus algirus* | LC | 255 | 0 | 0 | 255 | *Psammodromus algirus* | 219 | 36 |
| *Psammodromus hispanicus*∗ (19) | LC | 236 | 0 | 0 | 236 | *Psammodromus hispanicus* | 181 | 55 |
| *Pseudopus apodus* | – | 94 | 0 | 35 | 129 | *Pseudopus apodus* | 22 | 107 |
| *Rhinechis scalaris*∗ | LC | 279 |  | 0 | 279 | *Elaphe scalaris* | 236 | 43 |
| *Scelarcis perspicillata* | LC | 0 | 2 | 0 | 2 | *Podarcis perspicillata* | 2 | 0 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | IUCN  status | COUNTRIES | INTRODUCED | SEH/GBIF | All data | Species name as in Atlas 1997 | Atlas 1997 | Difference |
| *Tarentola mauritanica* | LC | 401 | 27 | 0 | 433 | *Tarentola mauritanica* | 270 | 163 |
| *Teira dugesii* | LC | 0 | 1 | 0 | 1 | (not included) |  | 1 |
| *Telescopus fallax* | LC | 98 | 0 | 13 | 111 | *Telescopus fallax* | 104 | 7 |
| *Timon lepidus*∗ | NT | 325 | 0 | 0 | 325 | *Lacerta lepida* | 284 | 41 |
| *Trapelus agilis* | – | 0 | 0 | 5 | 5 | *Trapelus sanguinolentus* | 0 | 5 |
| *Typhlops vermicularis* | – | 64 | 0 | 9 | 73 | *Typhlops vermicularis* | 82 | −9 |
| *Vipera ammodytes* | LC | 225 | 0 | 28 | 253 | *Vipera ammodytes* | 224 | 29 |
| *Vipera aspis*∗ | LC | 359 | 0 | 0 | 359 | *Vipera aspis* | 311 | 48 |
| *Vipera berus* | LC | 944 | 0 | 462 | 1406 | *Vipera berus* | 1325 | 81 |
| *Vipera dinniki* | – | 0 | 0 | 5 | 5 | *Vipera dinniki* | 5 | 0 |
| *Vipera kaznakovi* | – | 0 | 0 | 12 | 12 | *Vipera kaznakovi* | 12 | 0 |
| *Vipera latastei* | VU | 182 | 0 | 0 | 182 | *Vipera latasti* | 142 | 40 |
| merged with *V. berus* |  |  |  |  |  | *Vipera nikolskii* | 9 | −9 |
| *Vipera seoanei*∗ | LC | 50 | 0 | 0 | 50 | *Vipera seoanei* | 40 | 10 |
| *Vipera ursinii*/*renardi* (9) | VU | 49 | 0 | 0 | 49 | *Vipera ursinii* | 172 | −123 |
| *Zamenis hohenackeri* | – | 0 | 0 | 5 | 5 | *Elaphe hohenackeri* | 5 | 0 |
| *Zamenis longissimus*/*lineatus* (8) | (LC) | 513 | 0 | 76 | 589 | *Elaphe longissima* | 487 | 102 |
| *Zamenis situla* | LC | 128 | 0 | 0 | 128 | *Elaphe situla* | 100 | 28 |
| *Zootoca vivipara* | LC | 1091 | 0 | 470 | 1561 | *Lacerta vivipara* | 1403 | 158 |
| TOTAL |  | 41 465 | 123 | 9463 | 48 440 |  | 41 540 | 6900 |

1. *Pelophylax* kl. *esculentus*/*lessonae* includes records of *P. lessonae*, *P*. kl. *esculentus*, as well as *bergeri* as subspecies of *P. lessonae*, and the hemiclone kl. *hispanicus*.
2. *Hyla arborea* complex includes records of *H. arborea*, *H. molleri*, and *H. orientalis*, which are currently not accepted at species level by the SEH.
3. *Podarcis hispanicus* complex includes *P. hispanicus* sensu lato, *P. liolepis*, *P. vaucheri* and several yet undescribed candidate species; the precise distribution areas of these taxa remain to be elucidated.
4. *Triturus marmoratus*/*pygmaeus* includes records of *T. marmoratus* and *T. pygmaeus* due to uncertain identification to species level of numerous records especially from Portugal which are based on larvae.
5. *Discoglossus galganoi* contains *D. jeanneae* which is currently not accepted at species level by the SEH.
6. *Blanus cinereus*/*mariae* includes records of *B. cinereus* and *B. mariae* which due to their morphological similarity are not distinguished in the available databases.
7. *Anguis* sp. includes *A. colchica*, *A. graeca*, *A. fragililis*; the distinction of these three taxa at the species level as well as their precise distribution areas require confirmation by additional study.
8. *Zamenis longissimus*/*lineatus* includes records of *Z. longissimus* and *Z. lineatus*; records of these species are not unambiguously distinguished in the databases available to us.
9. *Vipera ursinii*/*renardi* includes records of *V. ursinii* and *V. renardi* which is currently not accepted at species level by the SEH.
10. *Pelodytes* sp. includes records of *P. ibericus*, *P. punctatus*, and two undescribed candidate species of the Iberian Peninsula; the distribution area and taxonomy of these taxa require more study.
11. *Bufo viridis* complex includes *balearicus* and *variabilis*, which are currently not accepted at species level by the SEH.
12. *Pelophylax ridibundus* includes *kurtmuelleri* (= *Rana balcanica*) which is not accepted at species level by the SEH.
13. Records of *Trachemys scripta* might also include records of introduced specimens of other species of *Trachemys* or related genera (e.g. *Chrysemys picta*).
14. *Bombina variegata* includes *B. pachypus* which is treated as a subspecies of *B. variegata*.
15. *Macropotodon cucullatus* refers to the Balearic populations.
16. *Pelophylax bedriagae* includes *P. cerigensis* which is not recognized as a species by the SEH.
17. *Emys orbicularis* includes *Emys trinacris*. The latter is currently not accepted at species level by the SEH.
18. *Bufo boulengeri* includes *siculus*. The latter is currently not accepted at species level by the SEH.
19. *Psammodromus hispanicus* includes *P. ewardsianus*, *P. hispanicus*, and *P. occidentalis*, which are currently not accepted at species level by the SEH.
20. *Triturus cristatus complex* includes *T. karelinii*, *T. arntzeni*, *T. carnifex*, *T. cristatus*, *T. dobrogicus*, and *T. macedonicus*; records of these species are not unambiguously distinguished in the databases available to us.

Nine species (six amphibians and three rep- tiles) represented more than 10 000 records in the whole compiled point databases, cor- responding in almost all cases to the most widespread species in Europe. From lesser (11 696) to larger (31 638), these were: *Zootoca vivipara*, *Anguis* sp., *Ichthyosaura alpestris*, *Natrix natrix*, *Triturus cristatus* complex, *Pelo- phylax* kl. *esculentus*/*lessonae*, *Lissotriton vul- garis*, *Rana temporaria*, and *Bufo bufo*. In the opposite extreme, there were 41 species (13 amphibians and 28 reptiles) with less than 10 records. These species corresponded to en- demisms of mainland Europe (e.g. *Iberolacerta aranica*) and of the Mediterranean islands (e.g. *Podarcis filfolensis*). However, and particularly for the most widespread taxa, the higher num- ber of records also correspond to species present in distribution atlases with a high resolution,

* 1. a high number of records. In relation with the whole database in grid format (table 3), 16 species included more than 1000 records (i.e. present in more than 1000 grid cells), three of them with more than 2000 (i.e., *Natrix na- trix*, *Rana temporaria*, *Bufo bufo*). All these, again, were species widespread in Europe. On the other hand, 59 species were present in less than 10 cells, many of them endemisms (e.g. *Podarcis levendis*), but others were marginal species with their main distribution range out- side the study area (e.g. *Eirenis modestus*).

The increment in distribution knowledge was considerable (4224 new grid records, 19.6%). Although the taxa entities are not completely congruent, 44 (8.3%) taxa presented less records than in the 1997 European Atlas; 17 (7.8%) the same number; and 152 (69.7%) more records (table 3). The extremes are *Pelophylax* kl. *escu- lentus*/*lessonae* with a loss of 463 records, and *Rana temporaria* with a gain of 563 records. The reasons for the changes in the number of grid cells per species are manifold. Increases are usually due to an improved mapping intensity and coverage, whereas decreases are often ex- plained by changes in taxonomy such as split- ting of previously widespread species into dif-

ferent species, or redefinitions of taxa with cor- responding reduction of their actual ranges, but also because of the low number of recent data for some countries devoid of distribution atlas programs (see table 1).

Patterns of species richness were different in amphibians and reptiles as we will fur- ther explore in the biogeography section be- low. Species richness of amphibians was high- est in Western-Central Europe, while for rep- tiles the southern peninsulas had the highest concentration of species, in particular Greece (fig. 2), which is in general agreement with anal- yses based on the 1997 European Atlas (Araújo, Thuiller and Pearson, 2006; Araújo et al., 2008) and the Global Amphibian Assessment (e.g. Anthony et al., 2008; Baha el Din et al., 2008). Several countries such as Albania, Bosnia and Herzegovina, Latvia, Lithuania, Ireland, F.Y.R. of Macedonia, Moldova, Montenegro and Ser- bia presented low levels of species richness, mainly due to insufficient coverage, impossibil- ity of digitising chorological information pub- lished in journals, or because database chairs decided not to collaborate in our compilation. No atlases or articles with chorological data are currently available for some of these countries, as far as we know. Calculating species richness for endemic European species only (i.e. exclud- ing all species which have ranges extending out- side the study area) leads to a strong shift of species richness towards Western Europe, re- flecting that the Balkan Peninsula holds many species with ranges extending into the Middle East and Caucasus, and Central Europe holds many widespread species with ranges extend- ing east of the Ural Mountains (fig. 3). Simi- larly, the Caucasus region was not identified as an area of endemism because most of the nu- merous species endemic to the Caucasus Moun- tains are distributed on the southern slopes as well, i.e. outside Europe as we defined it.

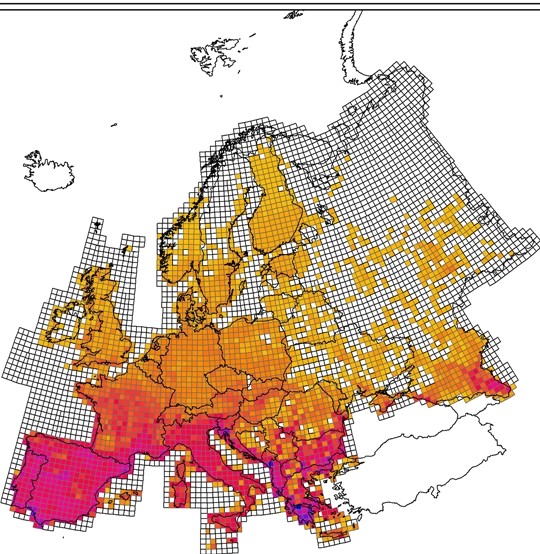
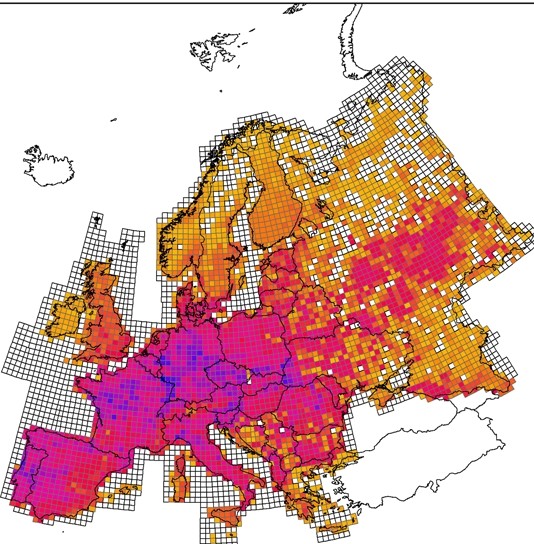
The species richness of European threat- ened amphibians, following the IUCN cat- egories Vulnerable (VU), Endangered (EN), and Critically Endangered (CR), presented a

very patchy distribution (fig. 4): north-western Iberian Peninsula, Po lowland, Sardinia, and western Greek coast were the areas with a higher number of threatened amphibians. On the other hand, threatened reptiles were widespread, especially in the Iberian and Italian peninsulas as well as in Central Europe. These different patterns are due to the species com- position: threatened amphibians were mostly composed by localised endemics (e.g. *Alytes muletensis*) while threatened reptiles included some widespread species (e.g. *Emys orbic- ularis*). However, the European herpetofauna might have a higher level of conservation threat than currently recognised (Denoël, 2012). Fu- ture evaluations such as those provided through herpetological atlases could thus shed light on wider patterns of vulnerability (see e.g. Denoël, 2012).

*Biogeographical analysis*

The analysis of corrected weighted endemism (CWE) highlighted the importance of Mediter- ranean islands as centres of endemism for both amphibians and reptiles (fig. 5). For amphib- ians, highest CWE values were found in Sar- dinia and Corsica, Mallorca, Sicily, and south- ern Aegean islands. In addition, some grid cells on the Balkans and the Western Caucasus stand out with high local endemism values. Reptiles showed an overall similar pattern, but some ar- eas such as Corsica, Sicily and the southern Aegean presented lower CWE values while ad- ditional areas of endemism were identified on smaller Mediterranean islands such as Malta, as well as certain areas in Spain (corresponding to the microendemic *Iberolacerta* species) and the Balkans.

However, these CWE calculations were some- what biased due to our definition of the study area. Because the CWE calculation took the full range size of a species into account, and the full range sizes of some species (104) were not included in the study area (and thus not com- plete in the compilation database used for anal- ysis, especially regarding species distributed in



**Amphib ian richness**

--231

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--456

--897

--1101

-1132

-14

-15

-16 N

-18"

-17 !

0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

**Reptile richness**

-

1 -18

LJ 0 17

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--5687 -222423

--910 -2265

### --1121 -222987

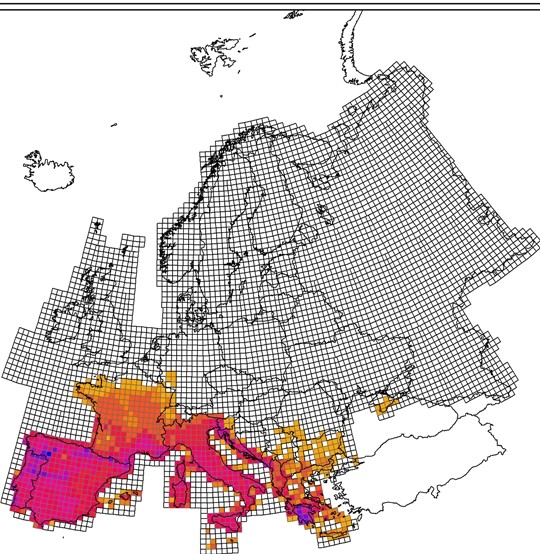
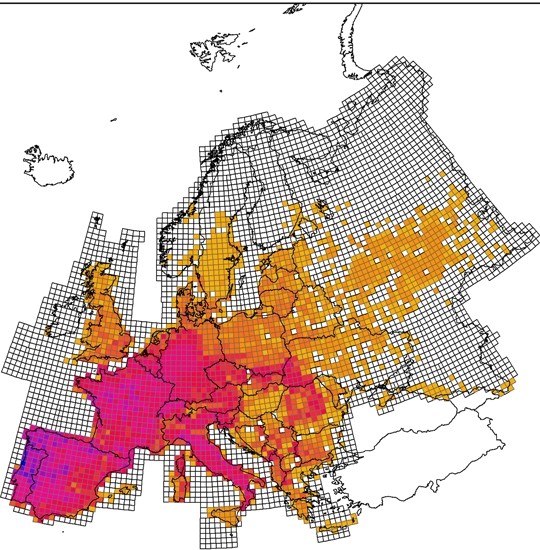
--111345 -333201 N

#### -16 -33"!

0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

**Figure 2.** Maps of Europe showing species richness separately for amphibians and reptiles, based on species distribution maps of all non-introduced species occurring in the study area.



**Amphib ian endemisms**

--231

o

--456

-87

## -9

-10

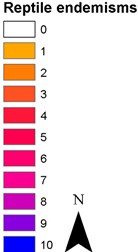
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-13

o 250 500 1,000 km

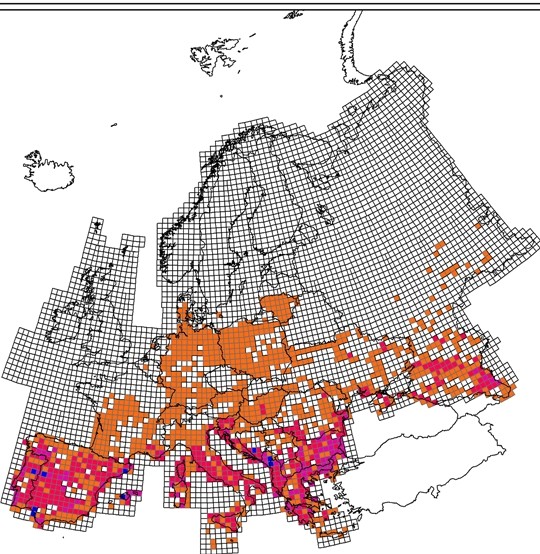
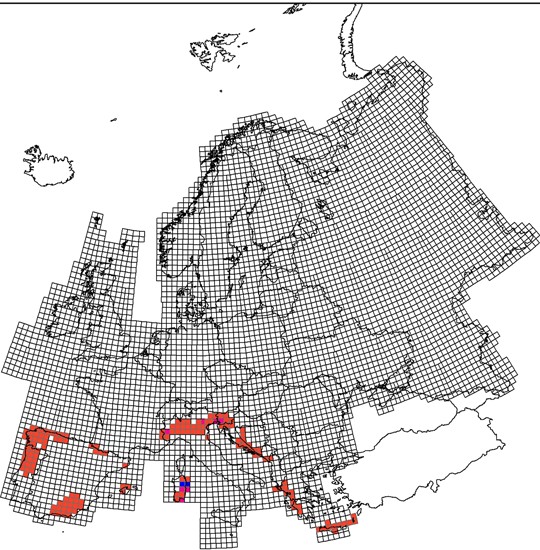
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o 250 500 **1**.ooo km

**1 1 1 1 1 1 1 1 1**

**Figure** 3. Maps of Europe showing species richness based on species distritution maps of European endemie amphibians and reptiles (i.e. including only species whase range does not extend beyond the study area).



**Amphibian richness**

--o21

-3

N

**A**

0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

**Reptile richness**

-21

C-J o3

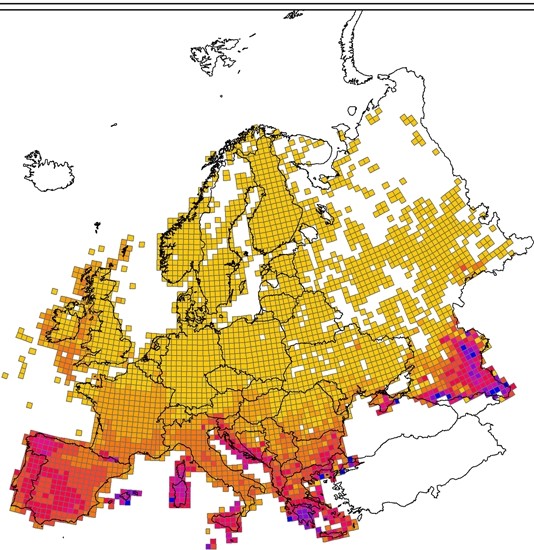
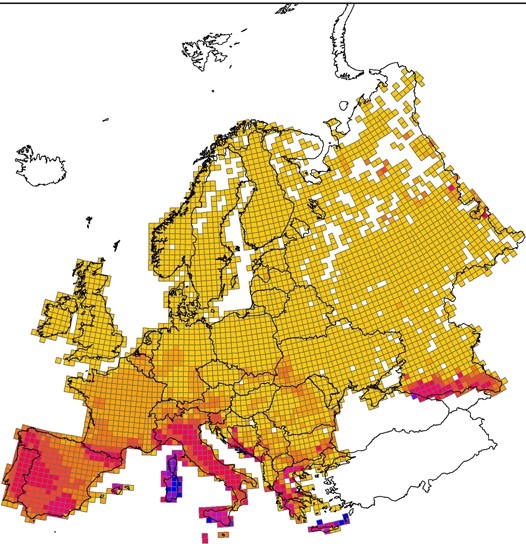
-4 **A**

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0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

**Figure 4.** Maps of Europe showing species richness based on species distribution maps of European threatened amphibians and reptiles, including the IUCN categories Vulnerable, Endangered, and Critically Endangered.



**CWE Amphibians**

**D** o.ooo - 0.012

-0.013 - 0.028

-0.029 - 0.048

-0.049 - 0.069

-0.070 - 0.098

-0.099 - 0.145

-0.146 - 0.211

-0.212 - 0.308

-0.309 - 0.491

-0.492 - 0.750

0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

N

**Á**

**CWE Reptiles**

-0.000 - 0.013

-0.014 - 0.029

-0.030 - 0.048

-0.049 - 0.067

-0.068 - 0.089

-0.090 - 0.117

-0.118- 0.152

-0.153- 0.203

-0.204 - 0.285

-0.286 - 0.429

0 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

N

##### Á

**Figure 5.** Maps of Europe showing Corrected Weighted Endemism (CWE) based on species distribution maps of European endemie amphibians and reptiles.

the Balkan Peninsula or widespread in Central Europe), it is possible that CWE values in the eastern part of Europe were slightly inflated. In other words, many species occur in just a small part of the study area and thus appear to be range-restricted and micro-endemic, while in fact they have wide ranges extending further east outside our study area. This phenomenon is inversely analogous to the species richness pat- terns of endemic European amphibians, where the same artefacts lead to inflated species rich- ness values in Western Europe. These prob- lems call for caution in interpreting the biogeo- graphic analysis of our data, but do not invali- date the observed general patterns. Furthermore, from the point of view of conservation priori- ties, the observed patterns of Europe-endemic species richness are highly relevant since they highlight the importance of specific areas (es- pecially the Mediterranean islands), where the survival of a large number of European en- demics fully depends on European conservation efforts.

Nine and 13 main distribution types were identified for amphibians (named CA1-CA9; table 4 and online Supplementary fig. S2) and reptiles respectively (named CR1-CR13; table 5 and online Supplementary fig. S3). Many species that formed clusters of only one member, corresponding mainly to regional en- demics, were not assigned to a distribution type number and are not further considered here. In the following, we will briefly charac- terise distribution types and mention one rep- resentative species for each. Amphibian distri- bution types can be characterised as follows (table 4 and online Supplementary fig. S2): CA1, species distributed in the Iberian Penin- sula and western France (e.g. *Hyla meridio- nalis*); CA2, western European species (e.g. *Alytes obstetricans*); CA3, species widespread in Europe (e.g. *Bufo bufo*); CA4, Pyrenaean species (e.g. *Calotriton asper*); CA5 and CA6, species distributed in Corsica, Sardinia, and the southern Mediterranean coast (e.g. *Euproctus platycephalus*, CA5; and *Discoglossus sardus*, CA6); CA7, species from the Italian Penin-

**Table 4.** Amphibian species grouped by main distribution types. See the dendrogram in online Supplementary fig. S1. Distribution types were named with codes following Baroni-Urbani and Collingwood (1976) and Baroni-Urbani and Collingwood (1977).

**Distribution type CA1**

*Alytes cisternasii Chioglossa lusitanica Discoglossus galganoi Hyla meridionalis Lissotriton boscai Pelobates cultripes Pelodytes* sp.

*Pelophylax perezi Pleurodeles waltl Rana iberica*

*Triturus marmoratus*/*pygmaeus*

**Distribution type CA2**

*Alytes obstetricans Bombina variegata Bufo calamita*

*Hyla arborea* complex *Ichthyosaura alpestris Lissotriton helveticus Salamandra salamandra Rana dalmatina*

**Distribution type CA3**

*Bombina bombina Bufo bufo*

*Bufo viridis*

*Lissotriton montandoni Lissotriton vulgaris Pelobates fuscus*

*Pelophylax* kl. *esculentus*/*lessonae Pelophylax ridibundus*

*Rana arvalis Rana temporaria*

*Triturus cristatus* complex

**Distribution type CA4**

*Calotriton asper Pelophylax* kl. *grafi Rana pyrenaica*

**Distribution type CA5**

*Discoglossus sardus Euproctus montanus Hyla sarda Discoglossus montalenti Salamandra corsica*

**Distribution type CA6**

*Euproctus platycephalus Speleomantes flavus Speleomantes supramontis*

**Distribution type CA7**

*Hyla intermedia Rana italica Salamandrina*

*perspicillata*/*terdigitata Speleomantes italicus Lissotriton italicus*

**Distribution type CA8**

*Ommatotriton vittatus Pelodytes caucasicus Rana camerani*

**Distribution type CA9**

*Proteus anguinus Rana latastei Salamandra atra*

**Table 5.** Reptile species grouped by main distribution types. See dendrogram in online Supplementary fig. S2. Distribution types were named with codes following Baroni-Urbani and Collingwood (1976) and Baroni-Urbani and Collingwood (1977).

**Distribution type CR1**

*Ablepharus kitaibelii Darevskia praticola Dolichophis caspius Elaphe sauromates Lacerta viridis Montivipera xanthina Natrix tessellata Ophisops elegans Podarcis tauricus Testudo graeca Vipera ammodytes*

**Distribution type CR2**

*Acanthodactylus erythrurus Blanus* sp.

*Chalcides bedriagae Chalcides striatus Chamaeleo chamaeleon Coronella girondica Hemidactylus turcicus Hemorrhois hippocrepis Macroprotodon brevis Malpolon monspessulanus Mauremys leprosa*

*Natrix maura*

**Distribution type CR4**

*Algyroides moreoticus Anguis cephalonica Eryx jaculus Hellenolacerta graeca Hierophis gemonensis Lacerta trilineata Malpolon insignitus Mauremys rivulata Mediodactylus kotschyi*

*Ophiomorus punctatissimus Platyceps najadum Podarcis erhardii*

*Podarcis peloponnesiacus Pseudopus apodus Telescopus fallax*

*Testudo marginata Typhlops vermicularis Zamenis situla*

**Distribution type CR5**

*Algyroides nigropunctatus Dalmatolacerta oxycephalus Dinarolacerta mosorensis*

*Podarcis melisellensis*

**Distribution type CR6**

**Distribution type CR8**

*Darevskia caucasica Eirenis collaris Eirenis modestus Hemorrhois ravergieri Laudakia caucasia*

**Distribution type CR9**

*Darevskia derjurgini Darevskia saxicola Vipera kaznakovi*

**Distribution type CR10**

*Dolichophis schmidtii Eumeces schneiderii Macrovipera lebetina Mauremys caspica*

**Distribution type CR11**

*Elaphe dione Eremias arguta Eremias velox Eryx miliaris Lacerta strigata*

*Phrynocephalus guttatus*

*Phrynocephalus mystaceus*

*Podarcis hispanicus* complex

*Trapelus agilis*

*Psammodromus algirus*

*Psammodromus hispanicus* complex

*Rhinechis scalaris Tarentola mauritanica Timon lepidus*

*Vipera latastei*

**Distribution type CR3**

*Algyroides fitzingeri Archaeolacerta bedriagae Euleptes europea Podarcis tiliguerta*

*Anguis* sp.

*Coronella austriaca Emys orbicularis Lacerta agilis Natrix natrix Vipera berus Zootoca vivipara*

**Distribution type CR7**

*Chalcides chalcides Elaphe quatorlineata Hierophis viridiflavus Lacerta bilineata Podarcis muralis Podarcis sicula Testudo hermanni Vipera aspis*

*Zamenis longissimus*/*lineatus*

*Vipera ursinii*/*renardi*

**Distribution type CR12**

*Iberolacerta aranica Iberolacerta aurelioi Iberolacerta bonnali*

**Distribution type CR13**

*Iberolacerta galani Iberolacerta martinezricai Iberolacerta monticola Lacerta schreiberi Podarcis bocagei Podarcis carbonelli Vipera seoanei*

sula (e.g. *Hyla intermedia*); CA8, Caucasian species (e.g. *Pelodytes caucasicus*); and CA9, alpine and dinaric species (e.g. *Salamandra atra*). In the case of reptiles (table 5 and on- line Supplementary fig. S3): CR1, species dis- tributed along the Italian and Balkan Penin- sulas as well as south-eastern Europe (e.g. *Natrix tessellata*); CR2 grouped species dis- tributed along the western-southern Mediter-

ranean countries (e.g. *Malpolon monspessu- lanus*); CR3, Corsican and Sardinian species (e.g. *Archaeolacerta bedriagae*); CR4, species from the Balkan Peninsula and Eastern Eu- rope (e.g. *Malpolon insignitus*); CR5, species from the eastern Adriatic coast (e.g. *Podarcis melisellensis*); CR6, widespread in all of Eu- rope (e.g. *Anguis* sp.); CR7, western-central Eu- ropean species (e.g. *Vipera aspis*); CR8, CR9,

and CR10, Caucasian species (e.g. *Darevskia caucasica*, CR8; *Vipera kaznakovi*, CR9; *Mau- remys caspica*, CR10); CR11, South-eastern European species (e.g. *Eremias velox*); CR12, species from the Central Pyrenees (e.g. *Ibero- lacerta bonnali*); and CR13, species occurring in the north-western Iberian Peninsula (e.g. *La- certa schreiberi*).

These distribution types were partly but not fully congruent with those published for a more limited study area (i.e. the Iberian Peninsula; Sillero et al., 2009). The discordances can be explained by a higher number of species in- cluded in the present analysis, a larger size of the study area, and a different spatial resolution of the grid. As Europe holds more species and is considerably larger than the Iberian Peninsula, the resulting main distribution types at least partially included the Iberian distribution types. The definition and interpretation of distribution types is always relative and strongly depends on the study area.

The distribution types defined in this work for European amphibians and reptiles are not in full agreement with previous biogeographical clas- sifications, because our classification was based on the distribution of species (always incom- plete) and not on environmental data (Bunce et al., 2002) or distribution data from herpetolog- ical guide books (e.g. range polygons on con- tinental maps; Rueda, Rodríguez and Hawkins, 2010). Bunce et al. (2002) defined 59 environ- mental classes based in a grid square of 0.5 min (i.e. ca. 55 km). As Bunce et al. (2002) did not provide a hierarchical tree of environmental classes, only some of these classes had corre- spondence with our distribution types (e.g. CR6 and CR13). Rueda, Rodríguez and Hawkins (2010) identified respectively seven and eight biogeographical regions for amphibians and reptiles in Europe. In the case of amphibians, Rueda, Rodríguez and Hawkins (2010) clus- tered the distribution types CA8 and CA9 in one single region. In reptiles, the distribution types

including species for the three Mediterranean peninsulas (CR4 and CR7) are also considered by Rueda, Rodríguez and Hawkins (2010). No widespread species (e.g. *Bufo bufo* or *Vipera berus*) fit in any of the regions identified by Bunce et al. (2002) or Rueda, Rodríguez and Hawkins (2010).

*Taxonomic and mapping gaps of knowledge*

About ten species-level units in our analysis are characterised by taxonomic uncertainty or by difficulties in species identification; some of these are (or might be) composed of dif- ferent taxa (see footnotes in table 3). Particu- lar taxonomic efforts are needed to clarify both the status and the precise distribution limits of the *Bufo viridis* complex (*balearicus*, *vari- abilis*, *viridis*), the *Hyla arborea* complex (*H. arborea*, *H. molleri*, and *H. orientalis*), Iberian *Pelodytes* (*P. ibericus*, *P. punctatus*, and two yet undescribed candidate species), the *Anguis fragilis* complex (*A. colchica*, *A. graeca*, *A. fragilis*), and the *Podarcis hispanicus* complex (*P. hispanicus* sensu lato, *P. liolepis*, *P. vaucheri* and several undescribed candidate species). Fur- thermore, in the following species complexes, the precise distribution ranges of each species need to be determined (preferably using ge- netic methods; Joger et al., 2007) and the avail- able records (and new future records) need to be refined to distinguish between the dif- ferent species: *Triturus marmoratus*/*pygmaeus*, *Triturus carnifex*/*cristatus*/*dobrogicus*/*karelinii*/ *macedonicus*, *Blanus cinereus*/*mariae*, *Psam- modromus hispanicus* complex (*P. edward- sianus*, *P. hispanicus*, and *P. occidentalis*), *Vipera ursinii*/*renardi*, and *Zamenis longis- simus*/*lineatus*. This list of taxa in need of tax- onomic and distributional revision is clearly not exhaustive and was driven by the particu- lar problems that we have identified while as- sembling the distributional data sets. It is clear that taxonomic revision is also needed in other species of European amphibians and reptiles, especially those in south-eastern Europe. In- deed, even for the most studied complexes, such

as the crested newts (Wielstra and Arntzen, 2011), reliably attributing all grid cells to ei- ther of the newly recognized species within the limits of distribution of the entire complex turned out to be impossible. The issues identi- fied here are particularly pressing, because they often concern widespread species where clari- fication of the exact distribution boundaries re- quires intensive sampling.

Subtracting the number of species (amphib- ians and reptiles merged) for each grid cell in the 1997 European Atlas from the respective value in our compilation yields a pattern reflect- ing the overall increased coverage and mapping intensity, especially in Western and Central Eu- rope (fig. 6). However, in the new compilation a lower overall number of species per grid cell is present in some countries. This counter-intuitive pattern is partly explained by the fact that for some areas the 1997 European Atlas was based on expert opinion about the occurrence of a species in a grid cell (Gasc et al., 1997), and underlying records were not available any more for the new national atlases. Contemporary re- gional and national atlases, on the contrary, typ- ically only take fully documented records into account. Moreover, we mainly compiled pub- lished data. Therefore, our compilation lacks all chorological information in personal databases or journals not available to us. For those coun- tries where new national mapping data exist we excluded the SEH/GBIF database records from our compilation, therefore for countries such as Greece and Ukraine the current compilation contains fewer grid cell records which however are better documented than those in the 1997 European Atlas. In general, south-eastern Eu- rope concentrates a high species richness espe- cially of reptiles, but many countries in this area lack national atlases. Future efforts should be targeted to encourage and support national map- ping efforts in this region. In addition, a Euro- pean initiative might be useful to set up a map- ping campaign to fill in these crucial distribu- tional gaps.

**Conclusions and future tasks: the distributed database network system**

Distribution maps are ephemeral products in constant need for updating. Therefore, the most important part of a chorological atlas is its database, which should be operative for a long time. For this reason, the SEH Mapping Com- mittee decided to implement a system of dis- tributed online databases, as this is the only so- lution to avoid problems of data duplication and actualisation, and to ensure that the owners of each sub-database maintain the control over its administration. The first prototype of this sys- tem is ready (see Sillero et al., 2014). In the near future, we hope the system might connect the databases of each European country.

An important future aspect will be to stan- dardise the date of each record in each of the national databases as well as in the SEH database (see also Denoël, 2012). At present, precise dates of observation are provided for each record in some of the databases, but com- pletely lacking in others. Furthermore, histori- cal records often lack any precise date. A sys- tem of minimum date (at least year) for each record needs to be implemented to allow query- ing the databases for possible changes in species range, e.g. in the context of both climate change and land cover use, and accurate dates would even allow evaluating phenological changes. This would imply to have multiple records for each cell grids when data are available for sev- eral years for instance.

One major problem cannot be solved by the distributed database system, namely the lack of funding and personnel in many countries to set up a national database, collect mapping data, validate each record, and feed them into the system. It therefore will be important to activate also other sources from which these data could be obtained. Distribution mapping and species monitoring are research fields with a well-developed tradition of citizen science contribution. In many countries of central and northern Europe, the bulk of amphibian and reptile distribution data are collected by volun-

Amphibian richness

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--9

--10CJ 3

CJ 4

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CJ -3 -10

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CJ -1 -12 CJ o -13 N

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O 250 500 1,000 km

**1 1 1 1 1 1 1 1 1**

Reptile richness

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--11 011

--1o c:J 12

--8

--9 013

-14

-7 -15

c:J .s -16

D.s -11

0-4 -18

-20

LJ -3 -19

D-2

LJ -1 -21

CJo -22

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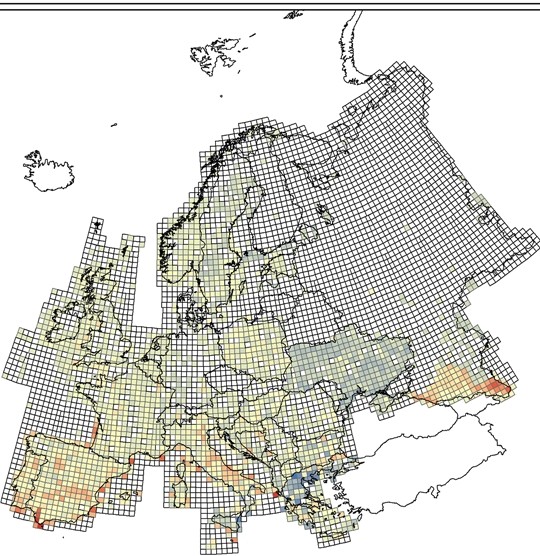
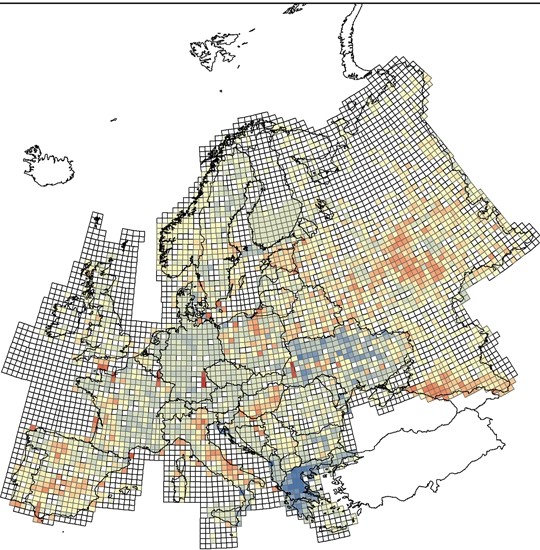
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**1 1 1 1 1 1 1 1 1**

Figure 6. Differences in species richness of all non-introduced species of European amphibians and reptiles between this compilation and the 1997 European Atlas (Gasc et al" 1997).

teers, many of which do not hold biology de- grees and are not professionally working as her- petologists. We feel that activating such vol- unteering work especially in southern coun- tries, and among tourists visiting these coun- tries, should be an important resource to fill mapping gaps (Bonardi et al., 2011). Provid- ing a common platform to enter such observa- tions, accompanied by photographic documen- tation, will be a step to achieve this goal, if coupled with a functional and robust validation procedure. Such an online platform for enter- ing data will be provided by the SEH on- line database system. However, major chal- lenges remain, such as integration with other systems like iNaturalist ([www.inaturalist.org](http://www.inaturalist.org/)), [Observado.org](http://Observado.org/) ([www.observado.org](http://www.observado.org/)), or Tel- mee ([www.telmee.nl](http://www.telmee.nl/)), the feedback of the cen- trally collected data into the national databases, and especially, the review and scientific valida- tion process before the contributed data are in- cluded in these databases (Boakes et al., 2010; Bonter and Cooper, 2012; Ficetola et al., 2013). An important point is also that each national or local database should use the same taxonomic list. Finally, there is a large variation of resolu- tion between distribution atlases: although some use point coordinates, others provide only large

areas. At the current stage, the grid size resolu- tion of 50 × 50 km reduces this problem, but in the long term, the realisation of more detailed

maps would require the centralization of highly detailed data from each database.

In summary, the data presented here pro- vide a first, tentative step towards an interac- tive, dynamic and distributed database of the spatial distribution of European amphibians and reptiles. The grid maps of all species made available along with this paper will facilitate conservation-related studies and actions, and will inform and guide further activities to im- prove and complete the database. However, it should be kept in mind that they are currently dependent on availability of digital databases, and not only on species presence or even on current knowledge on species distribution. Find-

ing ways to gather all species occurrence data available in Europe is a major challenge for the future. Integrating the temporal dimension and measures of spatial uncertainty to all point records in the original databases is another nec- essary improvement to allow detailed modelling of the impacts of land use and climate change, and we call for concerted and varied efforts to fill the geographic and taxonomic gaps identi- fied.

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**References**

Anthony, B., Arntzen, J.W., Baha el Din, S., Böhme,

W., Coga˘lniceanu, D., Crnobrnja-Isailovic´, J., Crochet, P.-A., Corti, C., Griffiths, R., Kaneko, Y., Kuzmin, S., Lau, M.W.N., Li, P., Lymberakis, P., Marquez, R., Pa- penfuss, T., Pleguezuelos, J.M., Rastegar, N., Schmidt, B., Slimani, T., Sparreboom, M., Ugurtas, I., Werner, Y., Xie, F. (2008): Amphibians of the Palearctic realm. In: Threatened Amphibians of the World, p. 106-111. Stuart, S.N., Hoffmann, M., Chanson, J.S., Cox, N.A., Berridge, R.J., Ramani, P., Young, B.E., Eds, Lynx, Barcelona.

Araújo, M.B., Pearson, R.G. (2005): Equilibrium of species’ distributions with climate. Ecography **5**: 693-695.

Araújo, M.B., Thuiller, W., Williams, P.H., Reginster, I. (2005): Downscaling European species atlas distribu- tions to a finer resolution: implications for conservation planning. Glob. Ecol. Biogeogr. **1**: 17-30.

Araújo, M.B., Thuiller, W., Pearson, R.G. (2006): Climate warming and the decline of amphibians and reptiles in Europe. J. Biogeogr. **33**: 1712-1728.

Araújo, M.B., Nogués-Bravo, D., Valdes, P.J., Rahbek, C. (2008): Quaternary climate changes explain diversity among reptiles and amphibians. Ecography **31**: 8-15.

Arnold, H.R. (1995): Atlas of amphibians and reptiles in Britain. ITE research publication no. 10, London, HMSO.

Baha el Din, S., Böhme, W., Corti, C., Crnobrnja-Isailovic´, J., Lymberakis, P., Marquez, M., Miaud, C., Slimani, T., Ugurtas, I., Werner, Y. (2008): The status and dis- tribution of amphibians in the Mediterranean Basin. In: Threatened Amphibians of the World, p. 113. Stuart, S.N., Hoffmann, M., Chanson, J.S., Cox, N.A., Berridge, R.J., Ramani, P., Young, B.E., Eds, Lynx, Barcelona.

Baroni-Urbani, C., Collingwood, C.A. (1976): A numerical analysis of the distribution of British Formicidae (Hy- menoptera, Aculeata). Verhandl. Naturf. Ges. Basel **85**: 51-91.

Baroni-Urbani, C., Collingwood, C.A. (1977): The zoo- geography of ants (Hymenoptera, Formicidae) in North- ern Europe. Acta Zool. Fennica **152**: 2-34.

Baroni-Urbani, C., Ruffo, S., Vigna Taglianti, A. (1978): Materiali per uma biogeografia italiana fondata se alcuni generi di coleotteri cicindelidi, carabidi, e crisomelidi. Estr. Mem. Soc. Ent. Ital. **56**: 35-92.

Bauwens, D., Claus, K. (1996): Verspreiding van Amfi- bieën en Reptielen in Vlaanderen. De Wielewaal Natu- urvereniging, Turnhout, Belgium.

Bitz, A., Fischer, K., Simon, L., Thiele, R., Veith, M., Eds (1996): Die Amphibien und Reptilien in Rheinland- Pfalz. GNOR, Nassau, Germany.

Boakes, E.H., McGowan, P.J.K., Fuller, R.A., Ding, C.Q.,

Clark, N.E., O’Connor, K., Mace, G.M. (2010): Dis- torted views of biodiversity: spatial and temporal bias in species occurrence data. PLoS Biology **8**: e1000385.

Böhm, M., Collen, B., Baillie, J.E.M., Bowles, P., Chan-

son, J., Cox, N., Hammerson, G., Hoffmann, M., Liv-

ingstone, S.R., Ram, M., Rhodin, A.G.J., Stuart, S.N., van Dijk, P.P., Young, B.E., Afuang, L.E., Aghasyan,

A., García, A., Aguilar, C., Ajtic, R., Akarsu, F., Alen-

car, L.R.V., Allison, A., Ananjeva, N., Anderson, S., An- drén, C., Ariano-Sánchez, D., Arredondo, J.C., Auliya, M., Austin, C.C., Avci, A., Baker, P.J., Barreto-Lima,

A.F., Barrio-Amorós, C.L., Basu, D., Bates, M.F., Batis- tella, A., Bauer, A., Bennett, D., Böhme, W., Broadley, D., Brown, R., Burgess, J., Captain, A., Carreira, S., Castañeda, M.D.R., Castro, F., Catenazzi, A., Cedeño- Vázquez, J.R., Chapple, D.G., Cheylan, M., Cisneros- Heredia, D.F., Cogalniceanu, D., Cogger, H., Corti, C., Costa, G.C., Couper, P.J., Courtney, T., Crnobrnja- Isailovic, J., Crochet, P.-A., Crother, B., Cruz, F., Dal- try, J.C., Daniels, R.J.R., Das, I., de Silva, A., Dies-

mos, A.C., Dirksen, L., Doan, T.M., Dodd, C.K., Doody, J.S., Dorcas, M.E., Duarte de Barros Filho, J., Egan, V.T., El Mouden, E.H., Embert, D., Espinoza, R.E., Fal- labrino, A., Feng, X., Feng, Z.-J., Fitzgerald, L., Flores- Villela, O., França, F.G.R., Frost, D., Gadsden, H., Gam-

ble, T., Ganesh, S.R., Garcia, M.A., García-Pérez, J.E., Gatus, J., Gaulke, M., Geniez, P., Georges, A., Ger- lach, J., Goldberg, S., Gonzalez, J.-C.T., Gower, D.J., Grant, T., Greenbaum, E., Grieco, C., Guo, P., Hamilton, A.M., Hare, K., Hedges, S.B., Heideman, N., Hilton- Taylor, C., Hitchmough, R., Hollingsworth, B., Hutchin- son, M., Ineich, I., Iverson, J., Jaksic, F.M., Jenkins, R., Joger, U., Jose, R., Kaska, Y., Kaya, U., Keogh,

J.S., Köhler, G., Kuchling, G., Kumlutas¸, Y., Kwet, A., La Marca, E., Lamar, W., Lane, A., Lardner, B., Latta, C., Latta, G., Lau, M., Lavin, P., Lawson, D., LeBre- ton, M., Lehr, E., Limpus, D., Lipczynski, N., Lobo, A.S., López-Luna, M.A., Luiselli, L., Lukoschek, V., Lundberg, M., Lymberakis, P., Macey, R., Magnusson, W.E., Mahler, D.L., Malhotra, A., Mariaux, J., Maritz, B., Marques, O.A.V., Márquez, R., Martins, M., Master- son, G., Mateo, J.A., Mathew, R., Mathews, N., Mayer, G., McCranie, J.R., Measey, G.J., Mendoza-Quijano, F., Menegon, M., Métrailler, S., Milton, D.A., Mont- gomery, C., Morato, S.A.A., Mott, T., Muñoz-Alonso, A., Murphy, J., Nguyen, T.Q., Nilson, G., Nogueira, C., Núñez, H., Orlov, N., Ota, H., Ottenwalder, J., Pa- penfuss, T., Pasachnik, S., Passos, P., Pauwels, O.S.G., Pérez-Buitrago, N., Pérez-Mellado, V., Pianka, E.R., Pleguezuelos, J., Pollock, C., Ponce-Campos, P., Powell, R., Pupin, F., Quintero Díaz, G.E., Radder, R., Ramer, J., Rasmussen, A.R., Raxworthy, C., Reynolds, R., Rich- man, N., Rico, E.L., Riservato, E., Rivas, G., da Rocha, P.L.B., Rödel, M.-O., Rodríguez Schettino, L., Roosen- burg, W.M., Ross, J.P., Sadek, R., Sanders, K., Santos- Barrera, G., Schleich, H.H., Schmidt, B.R., Schmitz, A., Sharifi, M., Shea, G., Shi, H.-T., Shine, R., Sindaco, R., Slimani, T., Somaweera, R., Spawls, S., Stafford, P., Stuebing, R., Sweet, S., Sy, E., Temple, H.J., Tognelli, M.F., Tolley, K., Tolson, P.J., Tuniyev, B., Tuniyev, S., Üzüm, N., van Buurt, G., Van Sluys, M., Velasco, A., Vences, M., Veselý, M., Vinke, S., Vinke, T., Vogel, G., Vogrin, M., Vogt, R.C., Wearn, O.R., Werner, Y.L., Whiting, M.J., Wiewandt, T., Wilkinson, J., Wilson, B., Wren, S., Zamin, T., Zhou, K., Zug, G. (2013): The con- servation status of the world’s reptiles. Biol. Conserv. **157**: 372-385.

Bonardi, A., Manenti, R., Corbetta, A., Ferri, V., Fiacchini, D., Giovine, G., Macchi, S., Romanazzi, E., Soccini, C., Bottoni, L., Padoa Schioppa, E., Ficetola, G.F. (2011): Usefulness of volunteer data to measure the large scale decline of “common” toad populations. Biol. Conserv. **144**: 2328-2334.

Bonter, D.N., Cooper, C.B. (2012): Data validation in cit- izen science: a case study from Project FeederWatch. Front Ecol. Environ. **10**: 305-309.

Bunce, R.H., Carey, P., Elena-Rossello, R., Orr, J., Watkins, J., Fuller, R. (2002): A comparison of different biogeo- graphical classifications of Europe, Great Britain and Spain. J. Environ. Managem. **2**: 121-134.

Cabela, A., Grillitsch, H., Tiedemann, F. (2001): Atlas zur Verbreitung und Ökologie der Amphibien und Rep- tilien in Österreich: Auswertung der herpetofaunistis- chen Datenbank der herpetologischen Sammlung des naturhistorischen Museums in Wien. Umweltbunde- samt, Vienna, Austria.

Cheers, C. (2005): Geographica – The Complete Illustrated Atlas of the World. Random House, Australia.

Coga˘lniceanu, D., Szekely, P., Samoila˘, C., Iosif, R., Tudor, M., Pla˘ias¸u, R., Sta˘nescu, F., Rozylowicz, L. (2013a): Diversity and distribution of amphibians in Romania. ZooKeys **296**: 35-57.

Coga˘lniceanu, D., Rozylowicz, L., Székely, P., Samoila˘, C., Sta˘nescu, F., Tudor, M., Székely, D., Iosif, R. (2013b): Diversity and distribution of reptiles in Roma- nia. ZooKeys **341**: 49-76.

Corti, C., Nistri, A., Poggesi, M., Vanni, S. (1991): Biogeo- graphical analysis of the Tuscan herpetofauna (Central Italy). Rev. Esp. Herp. **5** [1990]: 51-75.

Corti, C., Lo Cascio, P., Vanni, S., Turrisi, G.F., Vaccaro, A. (1997): Amphibians and Reptiles of the circumsicilian islands: new data and some considerations. Boll. Mus. Reg. Sci. Nat. Torino **15** (1): 179-211.

Corti, C., Masseti, M., Delfino, M., Perez-Mellado, V. (1999): Man and herpetofauna of the Mediterranean is- lands. Rev. Esp. Herp. **13**: 83-100.

Corti, C., Capula, M., Luiselli, L., Sindaco, R., Razzetti, E., Eds (2010): Fauna d’Italia, Vol. XLV, Reptilia. Calderini, Bologna, Italy.

Cox, N., Chanson, J., Stuart, S. (2006): The Status and Dis- tribution of Reptiles and Amphibians of the Mediter- ranean Basin. Gland, Switzerland and IUCN, Cam- bridge, UK.

Creemers, R.C.M., van Delft, J.J.C.W., Eds (2009): De Amfibieën en Reptielen van Nederland. – Nederlandse Fauna. Nationaal Natuurhistorisch Museum Naturalis, European Invertebrate Survey – Leiden, Netherlands.

Crisp, M.D., Laffan, S., Linder, H.Ü., Monro, A. (2001): Endemism in the Australian flora. J. Biogeogr. **28**: 183- 198.

Danho, N. (2003): Endemicity tools. ESRI Support. [http://](http://arcscripts.esri.com/details.asp?dbid=14537) [arcscripts.esri.com/details.asp?dbid=14537](http://arcscripts.esri.com/details.asp?dbid=14537) (accessed: November 2012).

Denoël, M. (2012): Newt decline in Western Europe: high- lights from relative distribution changes within guilds. Biodivers. Conserv. **21**: 2887-2898.

Ficetola, G.F., Bonardi, A., Sindaco, R., Padoa-Schioppa,

1. (2013): Estimating patterns of reptile biodiversity in remote regions. J. Biogeogr. **40**: 1202-1211.

Gasc, J.-P., Cabela, A., Crnobrnja-Isailovic´, J., Dolmen, D., Grossenbacher, K., Haffner, P., Lescure, J., Martens, H., Martínez-Rica, J.P., Maurin, H., Oliveira, M.E., Sofi- anidou, T.S., Veith, M., Zuiderwijk, A. (1997): Atlas of Amphibians and Reptiles in Europe. Societas Eu- ropaea Herpetologica and Muséum national d’Histoire naturelle, Paris.

Głowacin´ski, Z., Rafin´ski, J., Eds (2003): Atlas płazów i

gadów Polski. Status – Rozmieszczenie – Ochrona. In- spekcja Ochrony S´ rodowiska, Instytut Ochrony Przy- rody PAN, Warszawa-Kraków, Poland.

Günther, R., Ed. (1996): Die Amphibien und Reptilien Deutschlands. Gustav Fischer Verlag, Jena.

Hofer, U., Monney, J.-C., Dušej, G. (2001): Die Reptilien der Schweiz: Verbreitung, Lebensräume, Schutz / Les Reptiles de Suisse: Répartition, Habitats, Protection / I Rettili della Svizzera: Distribuzione, Habitat, Pro- tezione. Birkhäuser, Basel.

Hopkins, W.A. (2007): Amphibians as models for studying environmental change. Ilar. J. **48**: 270-277.

IUCN (International World Conservation Union) (2001): IUCN red list categories. Version 3.1. Species Survival Commission, IUCN, Gland, Switzerland, and Cam- bridge, United Kingdom.

IUCN (International World Conservation Union) (2012): The IUCN Red List of Threatened Species. Ver- sion 2012.2. [http://www.iucnredlist.org](http://www.iucnredlist.org/). Downloaded on 17 October 2012.

Jacob, J.-P., Percsy, C., de Wavrin, H., Graitson, E., Kinet, T., Denoël, M., Paquay, M., Percsy, N., Remacle, A.

(2007): Amphibiens et Reptiles de Wallonie. Série Faune – Flore – Habitats no 2. Aves – Raînne et Direction Générale des Ressources naturelles et de

l’Environnement, Ministère de la Région wallonne, Na- mur, Belgium.

Jalas, J., Suonuinen, J. (1972): Atlas Florae Europaea. Dis- tribution of Vascular Plants in Europe, Vol. 1: Pterido- phyta. (T. C. for Mapping the Flora of Europe and Soci- etas Biologica Fennica Vanamo, Ed.). Helsinki, Finland. Jetz, W., McPherson, J.M., Guralnick, R.P. (2011): Integrat- ing biodiversity distribution knowledge: toward a global

map of life. Trends. Ecol. Evol. **27**: 151-159.

Joger, U., Fritz, U., Guicking, D., Kalyabina-Hauf, S., Nagy, Z.T., Wink, M. (2007): Phylogeography of west- ern Palaearctic reptiles – Spatial and temporal speciation patterns. Zoolr. Anz. **246**: 293-313.

Kuzmin, S.L. (2013): The Amphibians of the Former Soviet Union. Pensoft Publisher, Sofia and Moscow.

Kypnjehko, B.E., Bepbec, H.T. (1999): Amphibians and Reptiles of Ukraine. Genesa, Kiev.

Laffan, S.W., Crisp, M.D. (2003): Assessing endemism at multiple spatial scales, with an example from the Australian vascular flora. J. Biogeogr. **30**: 511-520.

Laffan, S.W., Ramp, D., Roger, E. (2012): Using endemism to assess representation of protected areas – the family Myrtaceae in the Greater Blue Mountains World Her- itage Area. J. Biogeogr. **40**: 570-578.

Lanza, B., Andreone, F., Bologna, M.A., Corti, C., Razzetti, E., Eds (2007): Fauna d’Italia, Vol. XLII, Amphibia. Calderini, Bologna, Italy.

Laufer, H., Klemens, F., Sowig, P., Eds (2007): Die Amphi- bien und Reptilien Baden-Württembergs. Ulmer Verlag, Stuttgart.

Lescure, J., de Massary, J.C., Eds (2013): Atlas des Amphi- biens et Reptiles de France. Muséum National d’Histoire Naturelle. Biotope Eds, Paris.

Longley, P.A., Goodchild, M.F., Maguire, D.J., Rhind, D.W. (2010): Geographical Information Systems and Science, 3rd Edition. John Wiley, New York.

Loureiro, A., Ferrand, N., Carretero, M.A., Paulo, O. (2010): Atlas dos Anfíbios e Répteis de Portugal. Sfera do Caos, Lisboa.

Loureiro, A., Sillero, N. (2010): Metodologia. In: Atlas dos anfíbios e répteis de Portugal, p. 66-74. Loureiro, A., Ferrand, N., Carretero, M.A., Paulo, O., Eds, Esfera do Caos, Lisboa.

Mertens, R., Wermuth, H. (1960): Die Amphibien und Reptilien Europas. (Dritte Liste, nach dem Stand vom 1. Januar 1960). Frankfurt am Main, Verlag Waldemar Kramer.

Meyer, A., Zumbach, S., Schmidt, B., Monney, J.-C. (2009): Les Amphibiens et les Reptiles de Suisse Bern, Switzer- land. Haupt Verlag.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O’Hara, R.B., Simpson, G.L., Solymos,

P., Stevens, M.H.H., Wagner, H. (2012): vegan: Commu- nity Ecology Package. R package version 2.0-5. [http://](http://CRAN.R-project.org/package%3Dvegan) [CRAN.R-project.org/package=vegan](http://CRAN.R-project.org/package%3Dvegan)

Olivero, J., Real, R., Márquez, A.L. (2011): Fuzzy chorotypes as a conceptual tool to improve insight into biogeographic patterns. Systc. Biol. **60**: 645-660.

Pleguezuelos, J.M., Ed. (1997): Distribución y Biogeografía de los Anfibios y Reptiles en España y Portugal. Asociación Herpetológica Española – Universidad de Granada, Spain.

Pleguezuelos, J.M., Márquez, R., Lizana, M., Eds (2002): Atlas y Libro Rojo de los Anfibios y Reptiles de

España. Dirección General de la Conservación de la naturaleza-Asociación Herpetológica Española (2a im- presión). Madrid, Spain.

Proess, R., Ed. (2003): Verbreitungsatlas der Amphibien des Grossherzogtums Luxemburg. Ferantia 37, Travaux Scientifiques du Musée national d’Histoire naturelle, Luxembourg.

Proess, R., Ed. (2007): Verbreitungsatlas der Reptilien des Großherzogtums Luxemburg. Ferantia 37, Travaux Sci- entifiques du Musée national d’histoire naturelle, Lux- embourg.

Puky, M., Schad, P., Szövenyi, G. (2006): Herpetological atlas of Hungary/Magyarorszag herpetologiai atlasza. IUCN SSC Hungary.

R Development Core Team (2012): R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3- 900051-07-0, URL <http://www.R-project.org/>.

Rueda, M., Rodríguez, M.A., Hawkins, B.A. (2010): To- wards a biogeographic regionalization of the European biota. J. Biogeogr. **11**: 2067-2076.

Sillero, N. (2011): What does ecological modelling model? A proposed classification of ecological niche models based on their underlying methods. Ecol. Model. **222**: 1343-1346.

Sillero, N., Celaya, L., Martín-Alfageme, S. (2005): Using GIS to make an atlas: A proposal to collect, store, map and analyse chorological data for herpetofauna. Rev. Esp. Herpetol. **19**: 87-101.

Sillero, N., Brito, J.C., Toxopeus, B., Skidmore, A.K. (2009): Biogeographical patterns derived from remote sensing variables: the amphibians and reptiles of the Iberian Peninsula. Amphibia-Reptilia **30**: 185-206.

Sillero, N., Amaro, M., Sousa, F., Sousa, P., Gonçalves- Seco, L. (2014): Distributed database system of the new atlas of amphibians and reptiles in Europe: the NA2RE project. Amphibia-Reptilia **35**: 33-39.

Sindaco, R., Doria, G., Razzetti, E., Bernini, F., Eds (2006): Atlante degli Anfibi e dei Rettili d’Italia/Atlas of Italian Amphibians and Reptiles. Societas Herpetologica Ital- ica. Edizioni Polistampa, Firenze, Italy.

Sinervo, B., Méndez-de-la-Cruz, F., Miles, D.B., Heulin, B., Bastiaans, E., Villagrán-Santa Cruz, M., Lara-Resendiz, R., Martínez-Méndez, N., Calderón-Espinosa, M.L., Meza-Lázaro, R.N., Gadsden, H., Avila, L.J., Morando, M., De la Riva, I.J., Victoriano Sepulveda, P., Rocha, C.F., Ibargüengoytía, N., Aguilar Puntriano, C., Massot, M., Lepetz, V., Oksanen, T.A., Chapple, D.G., Bauer,

A.M., Branch, W.R., Clobert, J., Sites, J.W. Jr. (2010): Erosion of lizard diversity by climate change and altered thermal niches. Science **328**: 894-899.

Speybroeck, J., Beukema, W., Crochet, P.A. (2010): A tenta- tive species list of the European herpetofauna (Amphibia and Reptilia): an update. Zootaxa **2492**: 1-27.

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Ro-

drigues, A.S.L., Fischman, D.L., Waller, R.W. (2004): Status and trends of amphibian declines and extinctions worldwide. Science **306**: 1783-1786.

Valakos, E., Pafilis, P., Sotiropoulos, K., Lymberakis, P., Maragou, P., Foufopoulos, J. (2008): The Amphibians and Reptiles of Greece. Edition Chimaira, Frankfurt am Main.

Vences, M., Guayasamin, J.M., Miralles, A., de la Riva, I. (2013): To name or not to name: Criteria to promote economy of change in Linnaean classification schemes. Zootaxa **3636**: 201-244.

Vigna Taglianti, A., Audisio, P., Biondi, M., Bologna, M.A., Carpaneto, G.M., De Biase, A., Fattorini, S., Piattella, E., Sindaco, R., Venchi, A., Zapparoli, M. (1999): A pro- posal for a chorotype classification of the Near East fauna, in the framework of the Western Palearctic region. Biogeographia **20**: 31-59.

Wake, D.B., Vredenburg, V.T. (2008): Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proc. Natl. Acad. Sci. USA **105**: 11466- 11473.

Weiserbs, A., Jacob, J.P. (2005): Amphibiens et Reptiles de la Région de Bruxelles-Capitale. Aves & Institut Bruxel- lois pour la Gestion de l’Environnement, Bruxelles, Bel- gium.

Wielstra, B., Arntzen, J.W. (2011): Unraveling the rapid ra- diation of crested newts (*Triturus cristatus* superspecies) using complete mitogenomic sequences. BMC Evol. Biol. **11**: 162.