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Using Geographical Information Systems (GIS) to make an atlas: a proposal to collect, store, map and analyse chorological data for herpetofauna

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Abstract: The best available tools for collecting, storing, managing, mapping and analysing chorological data are the Geographical Information Systems (GIS). GIS have been applied to chorological atlases mainly because of two reasons: ease in building the maps and ability to detect and correct the errors of incorrect locations. The aim of this paper is: 1) to present a GIS-based methodology to collect, store, manage and map chorological data, and 2) to apply this methodology in Salamanca province for updating and analysing the chorological information of the herpetofauna and the species density. All records were located by a GPS. The attributes of each point were collected in a predefined database. Species maps were made automatically using a script programmed into a GIS. During the fieldwork, a total of 1217 points were collected: 602 for 13 amphibian species and 615 for 20 reptile species. The GIS-based methodology applied in the Salamanca province proved to be reliable and fast. The possible geographic and database errors were eliminated.
Key words: chorological atlas, GIS, GPS, herpetofauna, Spain.

Resumen: Utilización de los Sistemas de Información Geográfica (SIG) para construir un atlas: una propuesta para reunir, almacenar, representar y analizar datos corológicos de la herpetofauna. – Los mejores instrumentos disponibles para reunir, almacenar, manipular, y analizar los datos corológicos son los Sistemas de Información Geográfica (SIG). Los SIG han sido aplicados a los atlas corológicos principalmente por dos razones: la facilidad para construir los mapas y la capacidad para detectar y resolver los errores de localizaciones incorrectas. Los objetivos de este trabajo son: 1) presentar una metodología para reunir, almacenar, manipular y representar los datos corológicos con ayuda de un SIG, y 2) aplicar esta metodología en la provincia de Salamanca, con el fin de actualizar y analizar la información corológica de la herpetofauna y la riqueza específica. Todas las citas fueron localizadas con un GPS. Los atributos de cada punto fueron recogidos en una base de datos predefinida dentro del GPS. Los mapas de las especies fueron generados automáticamente con la ayuda de un script programado dentro de un SIG. Durante el trabajo de campo, se tomaron un total de 1217 puntos: 602 para 13 especies de anfibios y 615 para 20 de reptiles. La metodología SIG aplicada en la provincia de Salamanca resultó fiable y rápida. Los posibles errores geográficos y estructurales de la base de datos fueron eliminados.
Palabras clave: atlas corológicos, España, GIS, GPS, herpetofauna.

INTRODUCTION

Conservation is not possible if what and where to conserve is not known (IUCN, 2001). For this reason, distribution atlas or *ad hoc* chorological information have several potential uses, especially in nature conservation and management, such as: (1) education and recreation, (2) documenting distribution and population, (3) documenting and analysing changes in population size and range, (4) providing a framework for survey design, (5) assessing species-environment associations, (6) investigating theoretical aspects of ecology (DONALD & FULLER, 1998), and (7) modelling species distribution (OSBORNE & TIGAR, 1992). Atlases have become an indispensable data source for assessing large-scale patterns of species distribution and distributional change.

The best available tools for collecting, storing, managing, mapping and analysing chorological data are the Geographical Information Systems (GIS). GIS softwares, developed for the first time in the late 1960s (BOSQUE SENDRA, 1997), allow a correct management and manipulation of chorological data (BURROUGH & MCDONNELL, 1998).

Similarly, Global Positioning System (GPS) technology is a necessary device during the process of data collection in the field, at the database creation stage. GPS provides metric precision on positioning the records, so the disturbing location errors are eliminated automatically (see below). The high precision achieved allows the method to work at different scales, which can be changed without problems (PALOMO & ANTÚNEZ, 1992), and detect different ecological patterns (THUILLER *et al.*, 2003). The currently low prices of GPS equipment and the elimination of Selective Availability by the USA Government in May 2000, allowed the spread of GPS use (SILLERO *et al.*, 2002). Nowadays, GPS technology is essential in any chorological project to guarantee data precision and correction.

The location of data collected in the field from topographical maps or GPS should be defined within a determined geographic projection using a particular methodology. The most frequently used cartographic framework, proposed for the first time in the Atlas Florae Europaeae (JALAS & SUONUINEN, 1972), is the Universal Transverse of Mercator (UTM) grid and co-ordinate system. This system allows standardization of surveys, calculation of hypothetical extension ranges of species, and provides a friendly display of maps. The UTM grid is universal as it projects to nearly any zone of the world between 84º N and 80º S, is flexible as it works at different scales, and is easy to understand as it uses a nomenclature-based system to reference data (DEFENSE MAPPING AGENCY, 1989).

These cartographic rules, and the use of GIS and GPS, have been widely applied in herpetological work in Europe (e.g. ARNOLD, 1995) and especially in the USA (e.g. USGS, 1999; DANIEL & EDMOND, 2004). In the Iberian Peninsula, these cartographic rules have been in use since their introduction but as GIS and GPS have only recently become available there are several examples of atlases without GIS applications: 1) in the first atlas of Portugal (CRESPO & OLIVEIRA, 1989), the maps were made by hand drafting; 2) in the first atlas of the Iberian Peninsula (PLEGUEZUELOS, 1997), the maps were made automatically, but without the help of GIS (MARTÍNEZ-RICA, 1997); 3) in the third atlas of Portugal (GODINHO *et al.*, 1999), only the cartography and a few analyses were produced with GIS assistance; 4) in the latest atlas of Spain (PLEGUEZUELOS *et al.*, 2002) a small part of the project was carried out under

GIS control: the search of location errors in the database and the production of maps (SILLERO *et al.*, 2002). Some field records were collected by GPS, but the point coordinates were transformed to UTM grid system by hand. The newest Portuguese atlas (LOUREIRO *et al.*, 2004), currently in preparation, will be the first project totally managed and controlled by a GIS in the Iberian Peninsula, from the database creation (CELAYA *et al.*, 2004) to the cartographic output. All data from the field are collected by GPS.

GIS has been applied to the chorological atlases mainly for two reasons: ease in building the maps and ability to detect and correct the errors included in the database. These errors are usually of two kinds: species misidentification and incorrect locations. The former could only be prevented by increasing rigour when accepting chorological information. To prevent the latter, it is necessary to design a solid and dependable database. Otherwise, complex problems may occur, such as: 1) often, neither volunteers nor experts know the precise geographic position of the location where they are surveying; 2) when an area of certain size is surveyed by grids, it is easy for the researcher to cross the square limits without realizing it; thus, it often happens that, when checking a distribution database with GIS, the locality where the sample was recorded does not match its UTM co-ordinate and vice versa; 3) using grids geo-referenced with different co-ordinate systems or datums may produce a dislocation of records (records would be assigned to neighbouring squares) changing their real geographic reference, and 4) data duplication in the database.

All these problems could be solved using a GPS, which allows the sampler to convert the datums, to know the exact geographic position in any moment, and with the help of GIS, to get additional information, such as locality and other geographical data. The database should permit the automatic introduction of data and the detection of duplicate data related to the sample point. Thus, to avoid or minimise this type of mistakes in similar projects, it is essential to design carefully the methodology before starting to collect and store data. At this point, it is obvious that a basic knowledge of cartography concepts, GPS and GIS use are required to ensure the success of the project.

The aims of this paper are: 1) to present a GIS-based methodology to collect, store, manage and map chorological data, and 2) to apply this methodology to the province of Salamanca, for updating the chorological information about the distribution of amphibians, reptiles and species density.

We considered Salamanca province to be a good study area to test the suitability of GIS to make an atlas because the available data are from several origins (e.g. VERICAD, 1979; PÉREZ-MELLADO, 1983) and different scales (e.g. ZAMARREÑO *et al.*, 1992; GÓMEZ-CANTARINO & LIZANA, 2000). Other provinces in Spain have not the same diversity of information. This paper describes the first attempt to collect data on species distribution in Spain that uses a GIS for management of data and map representation.

MATERIALS AND METHODS

Study area

The province of Salamanca is located in central western Spain on the semiarid Meseta (central-Iberian plateau). With an area of 12 500 km^2, it is basically a plain with an average altitude of 700-900 m. The monotonous smoothness of the plains are disrupted to the south by the mountains of the Sistema Central and to the northwest by the Arribes canyon excavated by the Duero river, where altitude decreases to 112 m. The climate is typically Mediterranean (low precipitation, with an average of 400 mm throughout the year and summer drought) with continental shade (cold temperatures in winter). These general characteristics of the climate are modified by the relief to the south and northwest. Thus, three main ecosystems can be distinguished in the province: 1) the dominant plains, subdivided in two groups considering geological and economical factors, i.e. the cereal fields to the north-east located over the outer limit of the Duero sedimentary basin which provides the deepest soils in the province, and the "dehesa", consisting of large livestock exploitations interspersed with more or less dense sets of Mediterranean oak (*Quercus ilex*) trees that grow in shallow and stony soils where granite rocks do not outcrop; 2) the Arribes canyon, which is the smallest area, with a very abrupt relief that has restricted land exploitation, and a typical Mediterranean microclimate that provides mild temperatures in winter, and 3) the southern mountainous area has an average altitude of 900-950 m at its base and reaches 2425 m at the Calvitero peak, the summit of the province. The precipitation in the sierras increases with altitude and the average exceeds 700 mm per year; the land is covered by the densest forests in the province composed of oaks (*Quercus pyrenaica*) and chestnuts (*Castanea satyva*).

Published data

Different studies have been made about herpetofauna chorology in Salamanca but only one atlas has been published (PÉREZ-MELLADO, 1983). Some works present data for specific species (BUENO, 1991; ZAMARREÑO *et al.*, 1992; GÓMEZ-CANTARINO & LIZANA, 2000; ARRIBAS, 2005; MERCHÁN *et al.*, 2005) and others for particular regions (GISBERT *et al.*, 1986; CIUDAD *et al.*, 1987; LIZANA *et al.*, 1991; BUENO, 1996; MORALES *et al.*, 1997; POLLO *et al.*, 1998; MERCHÁN *et al.*, 2002). Some studies present data from neighbouring UTM squares from the bordering provinces (POLLO *et al.*, 1988; GARCÍA-JIMÉNEZ & PRIETO-MARTÍN, 1992), while others are more general, with broader objectives or larger study areas (BOSCÁ, 1877; KLEMMER, 1957; PALAUS & SCHMIDTLER, 1969; PALAUS, 1974; POZUELO, 1974; GISBERT & GARCÍA-PEREA, 1986; REY *et al.*, 1994). The oldest studies present data without specific geographic references (MARTÍNEZ-RICA, 1979; VERICAD, 1979). The Spanish atlas of 2002 (PLEGUEZUELOS *et al.*, 2002) contains many new records from several authors which had not been published before. Excepting the Spanish atlas and the work of MERCHÁN *et al.* (2005), the aforementioned chorological references were made without GIS assistance.

Fieldwork

Data were collected during 2002. Amphibians were surveyed using dip-netting, egg search on water vegetation and margins, refuge search, night search for calls and raining-night search by car for migrating individuals on roads (GENT & GIBSON, 1986; HEYER *et al.*, 1994). Reptiles were searched using visual encounter surveys and refuge search (TELLERÍA, 1996).

Survey duration, for both amphibians and reptiles, was 90 min with one observer and 45 min with two observers. Terrestrial habitats were surveyed for reptiles and rivers for amphibians, turtles and snakes. Reproductive ponds of amphibians were surveyed throughout their whole perimeter or, when the ponds were very large, for a maximum of 10 minutes. Night searches by car had no time limit.

Each UTM square of 10 x 10 km was surveyed a minimum of six times with a representation of all present habitats. From a total of 170 UTM squares of 10 x 10 km of the Salamanca province, 53 squares were surveyed to test the GPS and database suitability. They corresponded to the mountains of the Sistema Central and the neighbouring area to the north. The area comprising the 53 squares was steeper than the rest, which could lead to difficulties for the GPS to record the locations, and represented 31.8% of the study area. Within the 53 UTM squares of 10 x 10 km, 474 squares of 1 x 1 km were surveyed, representing 3.7% of the study area.

One data point was recorded for each individual or group of individuals surveyed. Each survey was defined with one initial and final point. Data location co-ordinates were collected by a Corvallis Microtechnology MARCH-II GPS, which had a predefined customisable database. Several variables were included in the database, such as specific name, sex, age, activity, survey type and survey identification name. The values of the variables were previously defined, and only one value could be chosen for each variable. These values could only be modified during database edition, before the point was collected by the GPS. Information about habitat and weather was also included in the database following the same procedure, and recorded for each geographic point. Thus, all the data needed for the study (the geographic and ecological information) were exclusively recorded by the GPS. Data points were downloaded to GPS software PC-GPS 2.7 (CMT, 2001) and exported to ArcView 3.2 GIS (ESRI, 2000a) in shapefile format. All points were collected using the UTM co-ordinate system and the European Datum of 1950.

The specific UTM square (10 x 10 and 1 x 1 km) was assigned to each sample point by the Arc-View command “Assign data by location” of the Geoprocessing extension. This GIS function is a spatial join that attributes to a point all the layers that intersect with it. The exact locality of the points was assigned with the same procedure.

Map production

For mapping the species records, an Avenue (ESRI, 2000b) script was used (see Appendix I). The script rationale was simple but effective: it copied (cloned) a point layer and selected only the points belonging to one species. Then, the selected points were drawn to a new layer and exported to a JPEG format file automatically (Fig. 1). The process was repeated until all the species in the list were mapped. Maps were projected in UTM zone 30 N.

Different symbols with different meaning were displayed in the maps: black dots showed new records in both 1 x 1 km and 10 x 10 km UTM grids, black crosses meant new records in the 1 x 1 km UTM grid but not in

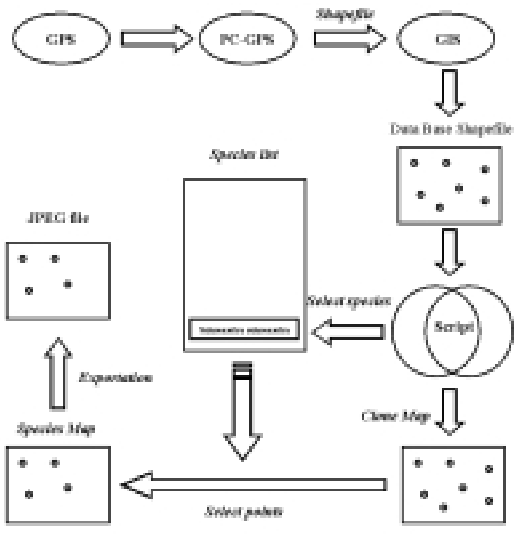


FIGURE 1. Work operating scheme of script to make maps by species.

FIGURA 1. Esquema del funcionamiento del script para hacer los mapas por cada especie.

the 10 x 10 km one, empty circles represented bibliographic records with geographic reference in the 1 x 1 km UTM grid only, and grey squares showed bibliographic records with geographic reference in the 10 x 10 km UTM grid.

For the species density map (Fig. 2), a Select Distinct SQL query was made with an Access database in order to get a unique record for each species and 10 x 10 km UTM square. Then, the Arc-View Summarize function was used to count the number of distinct species for each 10 x 10 km UTM square and the results were saved in a table. This table was joined with the 10 x 10 km UTM grid through a common field (UTM square designation name), to display the specific density map.

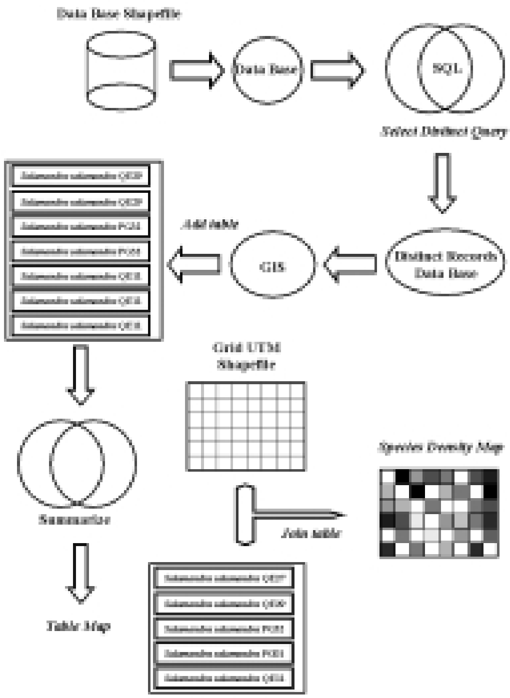


FIGURE 2. Process to make the species density map.

FIGURA 2. Proceso para hacer el mapa de densidad específica.

RESULTS

A total of 1217 records were gathered: 602 for 13 amphibian species and 615 for 20 reptile species (Table 1). At the 1 x 1 UTM resolution scale, from the 1217 records, 215 belonged to 10 x 10 km UTM squares without any previous records (73 for amphibians and 172 for reptiles), and the remaining 1002 were first records for the 1 x 1 km UTM squares but not for the 10 x 10 km ones (529 for amphibians and 473 for reptiles). At the 10 x 10 UTM resolution scale, a total of 473 records were collected: 109 new records (42 for amphibians and 67 for reptiles) and 364 previously known records (196 for amphibians and 166 for reptiles). A total of 695 bibliographic points for amphibians and 1000 for reptiles with 10 x 10 km UTM square references were recorded, and 5096 for amphibians and 2774 for reptiles with 1 x 1 km UTM square references (7870 in total).

No new records were collected for *Hyla meridionalis*, *Anguis fragilis*, *Iberolacerta martinezricai*, *Coronella austriaca* and *Hemorrhois hippocrepis*. Thus, maps for these species are not presented here because they were published in other works (PLEGUEZUELOS *et al.*, 2002; MERCHÁN *et al.,* 2005). The remaining species are displayed in maps (Fig. 3). However, records from all species were used to calculate the specific density maps for amphibians, reptiles and both taxonomic groups together (Fig. 4).

DISCUSSION

GIS implementation

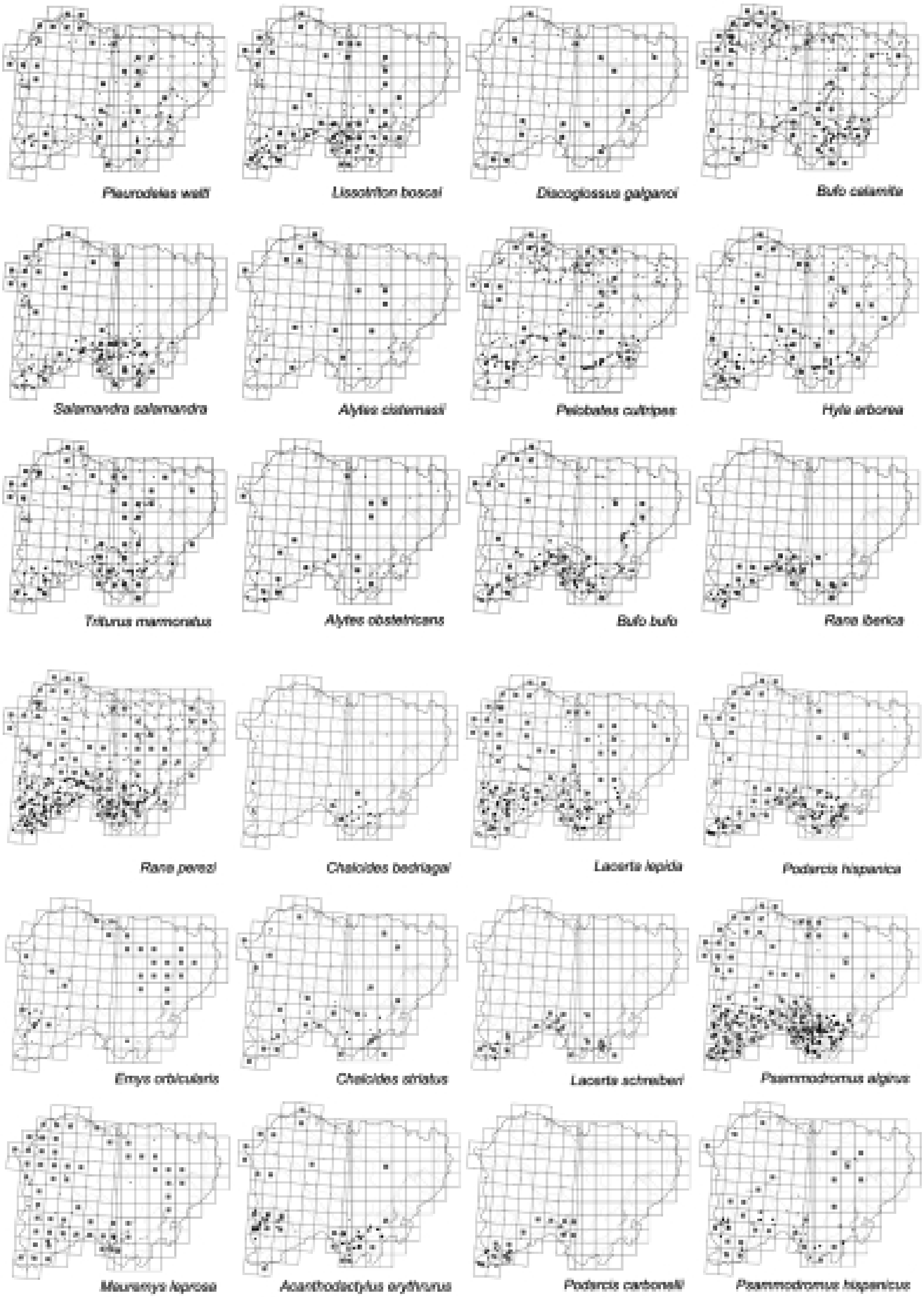
The GIS methodology developed for the Salamanca province proved reliable and fast. The possible geographic and database errors presented in the introduction were eliminated: 1) the exact coordinates and UTM square of points in each record were known in real time

TABLE 1. Number of records by species, referenced to 10 x 10 km and 1 x 1 km UTM grids.

TABLA 1. Número de registros por especies, refererenciados a las cuadrículas UTM 10 x 10 km y 1 x 1 km.

	New records for UTM 10 x 10 km squares	New records for UTM 1 x 1 km squares	Total
Amphibians			
Pleurodeles waltl	13	13	26
Salamandra salamandra	3	52	55
Triturus marmoratus	3	45	48
Lissotriton boscai	7	45	52
Alytes cisternasii	4	0	4
Alytes obstetricans	3	4	7
Discoglossus galganoi	0	2	2
Pelobates cultripes	11	59	70
Bufo bufo	14	47	61
Bufo calamita	1	42	43
Hyla arborea	12	41	53
Rana iberica	0	11	11
Rana perezi	2	168	170
Reptiles			
Emys orbicularis	2	6	8
Mauremys leprosa	0	7	7
Tarentola mauritanica	0	8	8
Chalcides bedriagai	9	7	16
Chalcides striatus	8	5	13
Acanthodactylus erythrurus	11	39	50
Lacerta lepida	24	79	103
Lacerta schreiberi	0	15	15
Podarcis carbonelli	0	17	17
Podarcis hispanica	6	69	75
Psammodromus algirus	34	157	191
Psammodromus hispanicus	17	10	27
Blanus cinereus	17	17	34
Rhinechis scalaris	3	5	8
Coronella girondica	3	1	4
Malpolon monspessulanus	3	9	12
Macroprotodon brevis	1	0	1
Natrix maura	1	19	20
Natrix natrix	2	2	4
Vipera latastei	1	1	2
Total	215	1002	1217

during the survey (if a GPS with map function was available) or later in the laboratory by applying a spatial join; 2) the digital data could be represented in any co-ordinate system without errors and in multiple modes of representation; 3) there were no typographic or other management errors, because all the data were collected into the GPS through a predefined customizable database; 4) data duplication was not possible


Pleurodeles waltl
Lissotriton boscai
Discoglossus galganoi
Bufo calamita
Salamandra salamandra
Alytes cisternasii
Pelobates cultripes
Hyla arborea
Triturus marmoratus
Alytes obstetricans
Bufo bufo
Rana iberica
Rana perezi
Chalcides bedriagai
Lacerta lepida
Podarcis hispanica
Emys orbicularis
Chalcides striatus
Lacerta schreiberi
Psammodromus algirus
Mauremys leprosa
Acanthodactylus erythrurus
Podarcis carbonelli
Psammodromus hispanicus

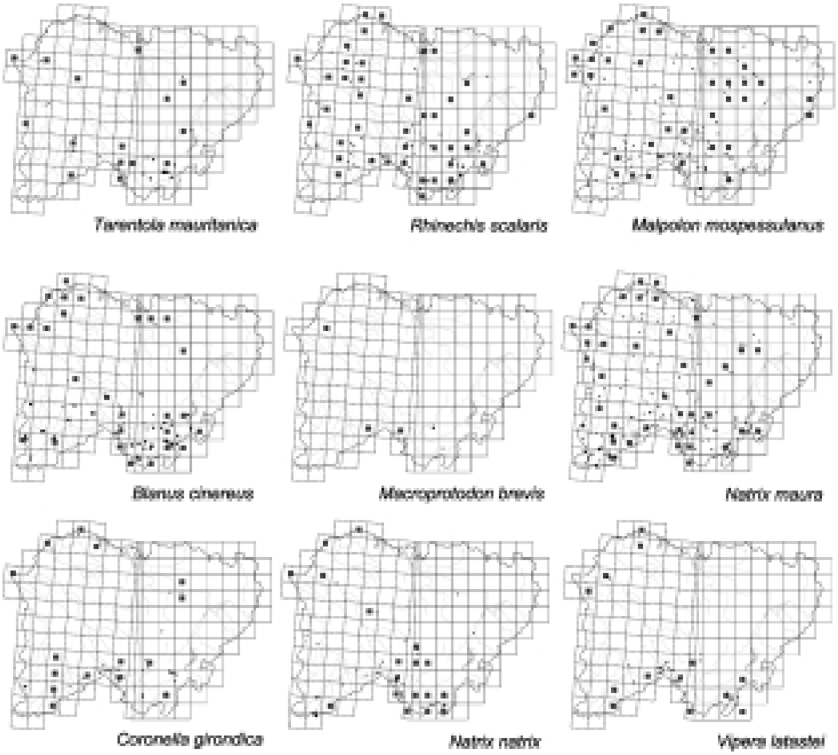


FIGURE 3. Amphibian and reptile distribution maps in the province of Salamanca (Spain). Black dots represent new records in both 1 x 1 km and 10 x 10 km UTM grids; black crosses, new records in the 1 x 1 km UTM grid but not in the 10 x 10 km one; empty circles, bibliographic records with geographic reference in the 1 x 1 km UTM grid only; and grey squares, bibliographic records with geographic reference in the 10 x 10 km UTM grid.

FIGURA 3. Mapas de distribución de anfibios y reptiles en la provincia de Salamanca (España). Los puntos negros representan nuevas citas en mallas UTM de 1 x 1 km y de 10 x 10 km; las cruces negras, nuevas citas en la malla UTM de 1 x 1 km pero no en la de 10 x 10 km; los circulos vacíos, citas bibliográficas con localización geográfica en la malla de 1 x 1 km; y los cuadrados grises, citas bibliográficas con localización geográfica únicamente en la malla de 10 x 10 km.

because each point was unique and independent. The whole working process, from field collection to map representation, was under the same system and database, so the probability of mistakes was reduced.

There are more advantages associated with the use of GIS in this atlas. The raw data could be used by other researchers because data are in a convertible digital format, and the exact locality of each species point is perfectly known. As the precision of the data is high, it is possible to work at several scales, allowing tests of ecological hypothesis and detection of different ecological patterns. Results such as species area calculation, number of points by species or altitudinal distribution, for example, can easily be obtained (these variables were difficult to calculate from analogical data). Thus, the possibility of working with these data is very wide, especially when more data, such as bioclimatic information, are added, increasing the number of possible derived works. Also, from the species density map, it is possible to

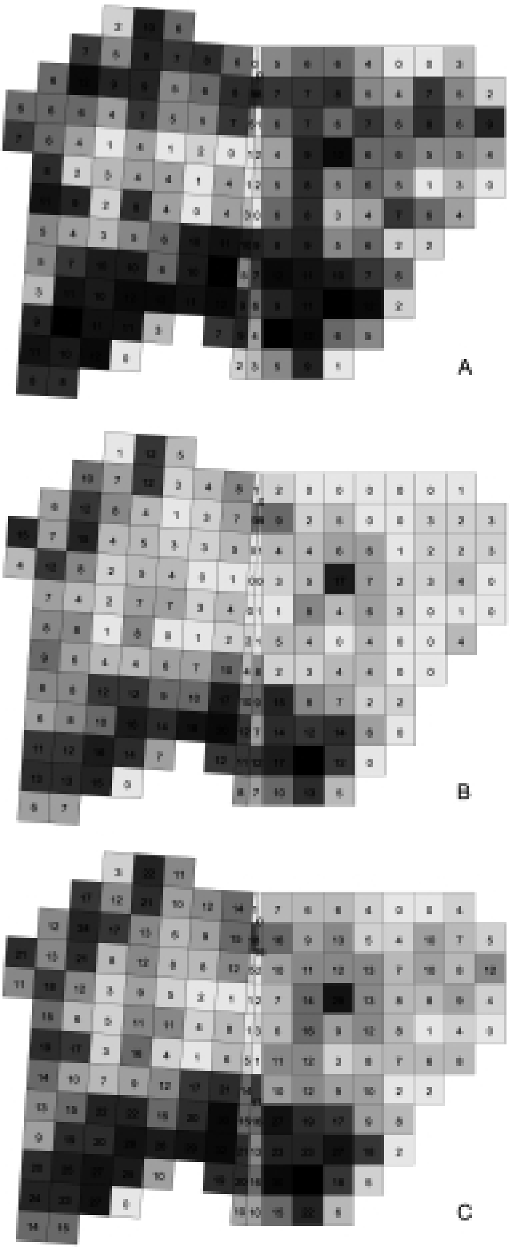


FIGURE 4. (A) Species density maps of amphibians. (B) Species density maps of reptiles. (C) Species density maps of amphibians and reptiles together.

FIGURA 4. (A) Mapa de densidad específica de anfibios. (B) Mapa de densidad específica de reptiles. (C) Mapa de densidad específica de anfibios y reptiles juntos.

make a Gap Analysis study, which is a GIS methodology to identify the differences (gaps) in the distribution of the diversity over spatial areas (SCOTT *et al.*, 1993).

The atlas most similar to the one presented here is the new Herpetofaunal Portuguese Atlas (LOUREIRO *et al.*, 2004), actually under construction, although there are some differences between them. The main one is that the atlas presented here is always under GIS control, from data collection to map representation. This is possible due to the use of GPS, which have the database included inside. Consequently, the process between the collecting of data and their representation in maps is straightforward. The objectives of both atlases are different, and so is the methodology used. The GIS-based methodology is applicable to the management of personal chorological data, and it is not very useful for a national project which has many distinct sources of information in many analogical and digital formats. In the new Portuguese Atlas, field data are introduced in the database through a semi-automatic process, because the GPS used only collects the locality point, and more information could not be added. However, the script for map production is the same as in this paper.

In any chorological project, the most important part is the construction of the database where records are collected, and all efforts have to be directed to make it more efficient and automated. The maps are simply a product of the project and their importance is basically informative. Thus, they should not be the principal objective of the chorological project. The database should not be closed at the end of the project, facilitating the incorporation of more records in the future. Thus, its construction should be reliable, by avoiding all possible errors, and friendly, by allowing other scientists to work with it.

Application to the Salamanca province

The density map of Salamanca exhibited two areas with a large number of species per 10 x 10 km UTM squares: Los Arribes and Southern Mountain Range, where most of the herpetological studies performed by the University of Salamanca have taken place. Nine 10 x 10 km UTM squares had no records of amphibians while 25 squares had none for reptiles (five 10 x 10 km UTM squares lack both amphibians and reptiles). The difference could be explained by the different methodology used to survey each class: raining-night searches by car used for amphibians allowed surveying larger areas in a short time. To determine whether the values in the density map are realistic it is necessary to make more surveys in the squares of low species density, mainly in the areas of north-east and the area between Arribes and the south-west mountains.

No new 10 x 10 km UTM squares were recorded for six species: *Rana iberica*, *Mauremys leprosa*, *Lacerta schreiberi*, *Podarcis carbonelli*, *Discoglossus galganoi*, and *Tarentola mauritanica*. The distribution of 10 species was not enlarged, because only one or two records were collected for each one: *Alytes obstetricans*, *Bufo calamita*, *Rana perezi*, *Emys orbicularis*, *Natrix maura*, *N. natrix*, *Coronella girondica*, *Macroprotodon brevis*, *Rinechis scalaris*, and *Vipera latastei*. The remaining species had more than three records in 10 x 10 km UTM squares.

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APPENDIX I

Avenue script used for mapping the species records.

APÉNDICE I

Script de Avenue utilizado para mapear los registros de cada especie.

```
TheProyect=av.GetProject
TheView=TheProject.FindDoc("View1")
Species=TheView.FindTheme("collected_points.shp")
Grid=TheView.FindTheme("utm_grid.shp")

'Amphibians and reptiles list for Salamanca: only one species is indicated
list = {"Salamandra salamandra"}

for each i in list

        SpecieMap=Species.Clone
        SpecieMap.SetName(i.AsString)
        SpecieMapFtab=SpecieMap.GetFtab
        TheView.AddTheme(SpecieMap)
        consult="([Specie] ="+i.quote+")"
        SpecieMapFtab.SetDefinition(consult)
        SpecieMapFtab.UpdateDefBitmap
        SpecieMap.SetVisible(true)
        Grid.SetVisible(true)
        Species.SetVisible(false)
        TheView.ExportToFile(i.asFileName,"JPEG",{80,80}
        SpecieMap.SetVisible(false)
end
```

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