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Atlas of the amphibians and reptiles of northern Morocco: updated distribution and patterns of habitat selection

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Observational data collected from bibliography and during herpetological surveys in northern Morocco between 1989 and 2014 were plotted to generate updated distribution maps of amphibians and reptiles using a UTM 5 x 5 km grid system. Eleven amphibians and 53 reptiles were observed, including three amphibians and nine reptiles endemic to Morocco. In both taxonomic groups, three distinct species categories were identified in the area: widely distributed species, species restricted to particular environmental characteristics, and species with small and / or fragmented distributions. For total species richness, 10 areas of high diversity were identified. These areas were common to all taxonomic groups and correspond roughly to Mediterranean-type habitats. Amphibians constitute a relatively homogeneous group according to their habitat selection patterns while reptiles can be grouped in three assemblages: 1) generalist species with broad distributions in northern Morocco; 2) species occupying Mediterranean environments, generally abundant in the north-western region; and 3) species that occupy arid habitats, frequently found in the eastern region. The topographic complexity of northern Morocco apparently creates micro-environmental conditions for each group and is related to high levels of species diversity observed: 78% and 52% of the total number of amphibians and reptiles of Morocco, respectively. These findings strengthen the status of northern Morocco as a priority area for herpetofauna conservation at the national level.

Key words: conservation; habitat selection; herpetofauna; priority area; species richness.

Atlas de los anfibios y reptiles del norte de Marruecos: actualización de la distribución y los patrones de selección de hábitat. Recopilamos datos observaciones obtenidos tanto de la literatura como de muestreos herpetológicos realizados en el norte de Marruecos entre 1989 y 2014 para generar mapas de distribución actualizados, empleando una cuadrícula UTM de 5 x 5 km, de las especies de anfibios y reptiles. Observamos 11 anfibios y 53 reptiles, incluyendo tres especies de anfibios y nueve de reptiles endémicos de Marruecos. Para ambos grupos taxonómicos identificamos tres tipos de especies en la zona: especies de amplia distribución, especies restringidas a unas

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condiciones ambientales particulares, y especies con áreas de distribución pequeñas y / o fragmentadas. Para la riqueza total de especies identificamos 10 áreas de elevada diversidad, las cuales fueron comunes a todos los grupos taxonómicos y correspondieron generalmente a ambientes mediterráneos. Los anfibios constituyen un grupo homogéneo de acuerdo a la selección de su hábitat, mientras que los reptiles se pueden agrupar en tres tipos: 1) especies generalistas de amplia distribución en Marruecos; 2) especies presentes en ambientes mediterráneos, generalmente abundantes en la región noroccidental; y 3) especies que ocupan ambientes áridos y que aparecen frecuentemente en la región oriental. La compleja topografía del norte de Marruecos parece crear condiciones micro-ambientales para cada grupo y está en relación con la elevada diversidad observada, que abarca respectivamente el 78% y el 52% del número total de especies de anfibios y reptiles presentes en Marruecos. Estos hallazgos refuerzan la importancia del norte de Marruecos como un área prioritaria para la conservación de la herpetofauna a nivel nacional.

Key words: áreas prioritarias; conservación; herpetofauna; riqueza de especies; selección de hábitat.

Atlas des amphibiens et reptiles du nord du Maroc: actualisation de la distribution et les patrons de sélection de l'habitat. Les données d'observation recueillies de la bibliographie et lors de prospections herpétologiques réalisées dans le nord du Maroc entre 1989 et 2014, nous ont permis d'actualiser les cartes de distribution des amphibiens et des reptiles de cette région en utilisant un système de grille UTM 5 x 5 km. Onze amphibiens et 53 reptiles ont été observés, dont trois et neuf endémiques marocains, respectivement. Pour les deux groupes taxonomiques, trois catégories distinctes ont été identifiées dans la région: les espèces largement répandues, les espèces inféodées à des caractéristiques environnementales particulières et celles à distribution réduite et / ou fragmentées. Concernant la richesse en espèces, 10 zones de grande diversité ont été identifiées. Ces zones sont communes à tous les groupes taxonomiques et correspondent en général aux habitats de type méditerranéen. Selon leurs modèles de sélection des habitats, les amphibiens forment un groupe relativement homogène, tandis que les reptiles forment trois groupes distincts: 1) les espèces généralistes, présentant une ample répartition au nord du Maroc; 2) les espèces occupant les milieux méditerranéens; généralement abondantes dans les régions du nord-ouest, et 3) les espèces qui occupant les habitats arides, fréquents dans l'Oriental. La complexité orographique du nord marocain crée apparemment des conditions micro-environnementales pour chaque groupe et est liée à l'importante diversité spécifique observée: 78% et 52% du nombre total des amphibiens et des reptiles du Maroc, respectivement. Ces résultats renforcent le statut du nord du Maroc en tant que zone prioritaire pour la conservation de l'herpétofaune au niveau national.

Key words: conservation; herpétofaune; richesse spécifique; sélection d'habitat; zone prioritaire.

Northern Morocco is located in the Mediterranean Basin hotspot, one of 34 global areas simultaneously gathering high biodiversity and high levels of threat (MYERS *et al.*, 2000; MITTERMEIER *et al.*, 2004). Northern Morocco also concentrates a large portion of the terrestrial biodiversity in the Mediterranean Basin and amphibians and reptiles constitute a major component of such diversity, especially in the western Mediterranean and north Africa (BONS & GENIEZ, 1996; SCHLEICH *et al.*,

1996; GENIEZ *et al*., 2004). The region is also characterised by a high proportion of endemic species (SCHLEICH *et al*., 1996; MARTÍNEZ-FREIRÍA *et al*., 2013) and by the presence of relict elements of Palearctic fauna (BONS & GENIEZ, 1996). The high richness in northern Morocco has been associated with the presence of Rif and Atlas Mountains, which divide the country into several bioclimatic regions of Mediterranean type (MÉDAIL & QUÉZEL, 1999), characterised by hot and dry summers and cold and wet winters. The prevailing conditions allow for distinguishing at least three climatic regions: an Atlantic climate attenuated by moisture from the ocean in the western area, a mountain climate in the main summits, and a continental climate, more or less arid, inland and in the Oriental region (SOBRINO & RAISSOUNI, 2000). This geographical diversity also allowed the allopatric speciation of several species (e.g. BROWN *et al*., 2002; FRITZ *et al*., 2005; RECUERO *et al*., 2007). Moreover, phylogenetic analyses over the past decade have identified a large number of genetic lineages within Moroccan herpetofauna, sometimes leading to the description of several new species or species complexes (e.g. HARRIS *et al*., 2003; PERERA *et al*., 2007; CARRANZA *et al*., 2008; PINHO *et al*., 2008; FONSECA *et al*., 2008, 2009; VELO-ANTÓN *et al*., 2012).

Atlases of species distribution are essential sources of data to evaluate large-scale patterns of species geographical ranges and changes in their distribution in space and time (SILLERO *et al*., 2005). These atlases can also be used, among other subjects, for clarifying the spatial distribution of species and determining the geography of population distribution, documenting and analysing changes in population size and range, providing framework data for survey designs, evaluating habitats occupied by species and communities, and for ecological modelling of species distribution (e.g. ANDERSON *et al*., 2002; HIRZEL *et al*., 2002). The most frequently used system in biodiversity distribution atlases in the Western Mediterranean is based on the UTM (Universal Transverse Mercator) coordinate system, and it has been used in many cases in the Iberian Peninsula (e.g. PLEGUEZUELOS *et al*., 2002; AYLLÓN *et al*., 2002-2003; SILLERO *et al*., 2005; SOARES *et al*., 2005) and Morocco (e.g. FAHD & PLEGUEZUELOS, 1996, 2001; BELQAT & ADLER, 2001; BENNAS *et al*., 2001; EL HAISSOUFI *et al*., 2010).

A distribution atlas of the herpetofauna of Morocco was published in the mid-1990s (BONS & GENIEZ, 1996), and there have also been some publications focusing on partial regions of the country, such as the Rif's mountains (FAHD & PLEGUEZUELOS, 1996, 2001) or the southern region (GENIEZ *et al*., 2004). However, there are still many knowledge gaps in distribution patterns, especially in poorly sampled and inaccessible regions, such as the Algerian-Moroccan frontier regions and the highest Rif and Atlas Mountains. Furthermore, since the seminal work of BONS & GENIEZ (1996), there have been profound changes in the taxonomic status of multiple species (e.g. WADE, 2001; CARRANZA *et al*., 2004, 2006, 2008; GARCIA-PORTA *et al*., 2012; METALLINOU *et al*., 2012) and many works have collected additional distribution data for several species (e.g. IN DEN BOSCH, 2005; HARRIS *et al*., 2008, 2010; BARATA *et al*., 2011; DE POUS *et al*., 2012; BEUKEMA *et al*.,

2013). As such, the present work aims to: 1) revise the taxonomic list of amphibians and reptiles present in northern Morocco; 2) update the knowledge on the spatial distribution of amphibians and reptiles in northern Morocco at the 5 x 5 km UTM grid scale; 3) identify areas of high amphibian and reptile species richness; and 4) identify preliminary relationships between species distribution and habitat variability. Ultimately, we expect to provide a framework basis for the definition of conservation strategies for these two taxonomic groups in northern Morocco.

Materials and Methods

Study area

The study area is located in northern Morocco and covers approximately 53 013 km^2. It is bordered by the Mediterranean Sea to the north, Algeria to the east, the Atlantic Ocean to the west, and minimum latitude of N 33.389 degrees (datum WGS 1984) to the south (Fig. 1). The maximum altitude is 2548 m at Jbel Tazekka. The climate is mainly of Mediterranean type and it is characterised by high levels of precipitation and drainage, with an average annual rainfall and soil drainage above 1100 mm. The high plains of eastern Morocco exhibit a hot and dry climate. Coastal areas experience moderate rainfall levels and temperature is milder in comparison with inland areas that exhibit a continental-type climate.

Limestone formations are relatively common in northern Tingitana Peninsula and east of the central Rif. To the east, the terrain becomes high and steep, with climbs reaching elevations of 1700 m (Jbel Tazaout), 1928 m (Jbel Kelti), 2050 m (Jbel Tissouka) and 2170 m (Jbel Bouhalla, Jbel Lexhab and Jbel Lakraa). Sebou landscape is characterised by low altitude and mostly flat areas. Mountains of Beni Snassen have rock formations of limestone and can reach an altitude of 1530 m. The north of Morocco is considered very rich and diverse in vegetation cover (Benabid, 1982; Valdés *et al*., 2002; Valdés, 2013). Major plant formations are generally of thermo-Mediterranean type (Sauvage, 1961), occurring in the Tingitana peninsula, the western and central Rif, Jbel Tazekka, Debdou and Beni Snassen mountains, but have been degraded in some areas and transformed into croplands and pastures in other places like the Gharb Basin and the eastern Rif.

Taxonomic species list

Since the publication of the lists developed by Bons (1972), Mellado & Dakki (1988), Bons & Geniez (1996), Schleich *et al*. (1996) and Geniez *et al*. (2004), changes in species status have not ceased to modify the list and taxonomy of amphibians and reptiles of Morocco. In this study, we used the most updated and most complete taxonomic species data. For amphibians, we adopted the work of Beukema *et al*. (2013), except for *Bufo spinosus* (Garcia-Porta *et al*., 2012; Recuero *et al*., 2012; Arntzen *et al*., 2013) and for the genus *Discoglossus* (Vences *et al*., 2014), for which *D. scovazzi* was separated from *D. pictus*. For reptiles, we took into account the following taxonomical considerations: we used *Timon tangitanus* –separated from *Timon pater*–, *Scelarcis perspicillata* and *Podarcis vaucheri* based on the revision of the phylogeny of Eurasian *Lacerta* by Arnold *et al*. (2007), discarded *Acanthodactylus lineomacula-*

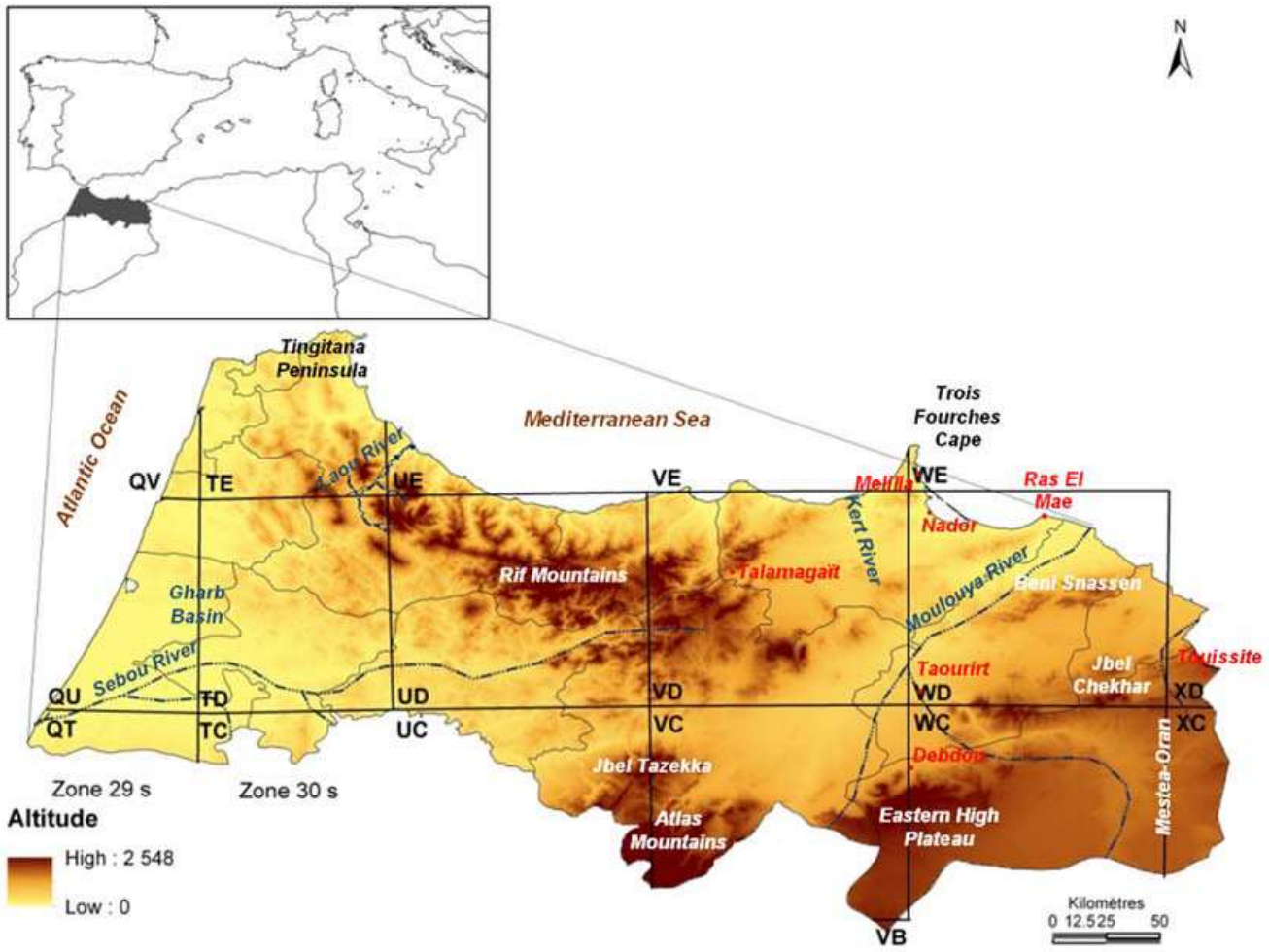

Figure 1: Location of the study area, altitudinal variation and identification of the main toponims cited in the text.

tus, which was lumped into *Acanthodactylus erythrurus* following FONSECA *et al*. (2009), used *Agama impalearis* after BROWN *et al*. (2002), considered *Trapelus boehmei* based on WAGNER *et al*. (2011), used *Uromastyx nigriventris* following the genetic analyses of HARRIS *et al*. (2007) and WILMS *et al*. (2007), considered *Stenodactylus mauritanicus* after METALLINOU *et al*. (2012) and METALLINOU & CROCHET (2013), used *Hyalosaurus koellikeri* based on MACEY *et al*. (1999), followed for *Macroprotodon* snakes the works of WADE (2001) and CARRANZA *et al*. (2004), separating *M. cucullatus* from *M. brevis* and *M. abubakeri*, considered *Malpolon insignitus* after CARRANZA *et al*. (2006), and used *Hemorrhois hippocrepis* based on NAGY *et al*. (2004) and *Daboia mauritanica* following LENK *et al*. (2001).

Species observations

Published distributional data were gathered from the following works: BONS & GENIEZ (1996), FAHD & PLEGUEZUELOS (1996, 2001), BROWN *et al*. (2002), DONAIRE-BAROSSO & BOGAERTS (2003), IN DEN BOSCH (2005), FAHD *et al*. (2005, 2007), PIEH (2006), FAHD & MEDIANI (2007), GUZMÁN *et al*. (2007), HARRIS *et al*. (2007, 2008, 2010), CARRANZA *et al*. (2008), FONSECA *et al*. (2008), MEDIANI *et al*. (2009), BARNESTEIN *et al*. (2010, 2012), EL HAMOUMI & HIMMI

(2010), STOETZEL *et al*. (2010), BARATA *et al*. (2011), DE POUS *et al*. (2011a, 2012), DONAIRE *et al*. (2011a,b), ESCORIZA *et al*. (2011), GENIEZ *et al*. (2011), GARCIA-PORTA *et al*. (2012), BEUKEMA *et al*. (2013), DAMAS-MOREIRA *et al*. (2014) and VELO-ANTÓN *et al*. (2014).

We also gathered data collected in the field since 1989 (amphibians), 1996 (saurians and amphisbaenians) or 2001 (snakes) until 2014. Sampling was not uniform across the study area; we focus sampling efforts in regions where previous knowledge about species distribution was rather limited. Sampling was conducted monthly during the whole year and the number of persons varied in each station from two to six. The geographic coordinates of observations collected before 1996 were gathered from maps with a 1:50 000 scale published by the French Institut Géographique National (IGN). Field observations collected after 1996 were georeferenced with a global positioning system (GPS) on the WGS 84 coordinate system.

Distribution atlas, species richness and relationships with land-cover

For each species present in our study area, distribution maps were produced representing all published observations in the earlier documents and our new fieldwork observations over a 5 x 5 km UTM grid cell size (3088 cells in total). Distribution maps combined species for which the distribution limits are not yet clear (*Discoglossus* spp., *Macroprotodon* spp. *and Malpolon* spp.), or species of the same genus for which the number of citations was low (*Saurodactylus* spp.). For rare species (≤ 13

Table 1: Land-cover categories and their availability in the study area, including number of pixels (N) and percentage (%) of occurrence (adapted from BICHERON *et al.*, 2008).

Land-cover category	Code	N	%
Rain-fed croplands	CROP	6690	7.12
Rain-fed shrub or tree crops	SHRU	11	0.01
Mosaic of cropland (50-70%) and vegetation (20-50%)	CRVG	20084	21.437
Mosaic of vegetation (50-70%) and cropland (20-50%)	VGCR	21179	22.53
Closed (> 40%) broad-leaved deciduous forest (> 5 m)	BRFO	658	0.7
Closed (> 40%) needle-leaved evergreen forest	NEFO	379	0.4
Mosaic forest or shrub land / grassland	FOSH	3689	3.93
Closed to open (> 15%) shrub land (< 5 m)	BNSH	5875	6.325
Closed to open (> 15%) broad-leaved deciduous shrub land (< 5 m)	BRSH	2470	2.63
Sparse (< 15%) vegetation	VEGE	7304	7.877
Sparse (< 15%) grassland	GRAS	7416	7.89
Artificial surfaces and associated areas (> 50%)	URBA	628	0.67
Bare areas	BARE	9396	10
Consolidated bare areas	CONS	7744	8.24
Water bodies	WATE	464	0.549

observations) in the study area and also in Morocco, we provide the coordinates in 1 x 1 km, whenever possible. These species include *Chalcides ebneri*, *Chalcides mauritanicus*, *Chalcides parallelus*, *Psammodromus microdactylus*, *Psammodromus blanci*, *Ophisops occidentalis*, *T. pater* and *Eryx jaculus*. We exclude from this list those species considered rare in our study but abundant in their distribution areas in Morocco (see BONS & GENIEZ, 1996). Maps were produced using the Geographical Information System ArcGIS 10.0 (ESRI, Redlands, California, USA).

Three types of synthetic maps (i.e. richness of amphibians, richness of reptiles and total species richness) were generated by adding individual 5 x 5 km presence observations of species using Spatial Analyst (ArcGIS).

The field observations georeferenced with a GPS were intersected with land-cover categories (BICHERON *et al.*, 2008; 250 m resolution; Table 1) to quantify preliminary patterns of habitat selection. Analyses were conducted using Spatial Analyst tool functions (ArcGIS).

RESULTS

Overall, we identified and mapped distributions of 11 species of amphibians (1515 observations) and 53 of reptiles (3573 observations) in the study area (Table 2, Appendix 1).

Regarding species distribution patterns, four groups of amphibians and reptiles were identified: (1) species with widespread distribution, such as *Amietophrynus mauritanicus*, *D. scovazzi*, *P. saharicus*, *A. erythrurus*, *A. impalearis*, *Mauremys leprosa*, *P. vaucheri*, *Psammodromus algirus*, *Tarentola mauritanica*, *Natrix maura*, *H. hippocrepis* and *Malpolon monspessulanus*; (2) species with limited and / or fragmented distribution, such as *Salamandra algira*, *Alytes maurus*, *B. spinosus*, *Bufotes boulengeri*, *Pelobates varaldii*, *Pleurodeles waltl*, *Acanthodactylus boskianus*, *Acanthodactylus maculatus*, *Blanus tingitanus*, *Chalcides colosii*, *Chalcides minutus*, *Chalcides ocellatus*, *Chalcides pseudostriatus*, *Emys orbicularis*, *Mesalina olivieri*, *P. blanci*, *S. fasciatus*, *Saurodactylus mauritanicus*, *S. perspicillata*, *Stenodactylus mauritanicus*, *Trogonophis wiegmanni*, *Spalerosophis dolichospilus*, *Natrix natrix* and *D. mauritanica*; (3) species that may be considered rare in northern Morocco, but apparently common throughout their distribution areas in Morocco, such as *Chalcides mionecton*, *Chalcides polylepis*, *H. koellikeri*, *Mesalina guttulata*, *T. boehmei*, *Lytorhynchus diadema*, *M. cucullatus* and *S. dolichospilus*; and (4) rare species with less than 13 observations, such as *P. microdactylus*, *P. blanci*, *T. pater*, *O. occidentalis*, *C. ebneri*, *C. mauritanicus*, *C. parallelus* and *E. jaculus*. Concerning the latter group, *C. mauritanicus* was recorded in two locations, the Moulouya River mouth and Ras El Mae (WD 5986 and WD 5587, respectively), *C. parallelus* was observed in six new locations in the Oriental Region (WD 5587, WD 2386, WD 1196, WD 1187, WD 2384 and WD 7256), and both *P. blanci* and *O. occidentalis* were recorded in two new locations (WC 9993 and WD 9502, and WC 3665 and WC 9993, respectively).

Several patterns of habitat selection were observed in the herpetofauna of northern Morocco (Table 2). All amphibians, Testudines and Scincidae were frequently linked to mosaics with combina-

Table 2: Taxonomic list of amphibians and reptiles observed in northern Morocco. Asterisks (*) indicate endemic species. N obs: number of observations, N UTM: number of 5 x 5 km squares in which species was observed (number of news records), %: percentage of area occupied, and percentage of observations in each land-cover category (see Table 1 for land-cover category abbreviations).

Order / suborder	Taxa	N obs	N UTM	%	Crop	Shru	Crvg	Vgcr	Brfo	Nefo	Fosh	Bnsh	Brsh	Vege	Gras	Urba	Bare	Cons	Wate
Urodela	*Pleurodeles waltl*	46	42 (4)	1.5	4.8		47.6	33.3			9.5						4.8		
	Salamandra algira	110	80 (11)	2.8	5.2		19	44.8	5.17	6.9	1.7	12.1	3.5			1.7			
Anura	*Alytes maurus**	79	43 (4)	1.5	3.3		21.7	50.0	1.67	5.0	1.7	16.7							
	Amietophrynus mauritanicus	344	242 (52)	8.5	7.6		22.2	35.6	2.22	1.3	3.6	12.0	2.7	4.9	0.9	4	1.3	0.4	1.3
	Bufo spinosus	75	45 (6)	1.6	4.9		17.1	36.6	12.2	2.4	2.4	24.4							
	Bufotes boulengeri	56	56 (13)	2.1	16.2		21.6	21.6		2.7		2.7	2.7	2.7	10.8	10.8	2.7	5.4	
	*Discoglossus scovazzi** + *D. pictus*	209	150 (13)	5.4	1.6		24.2	35.5	4.03	0.8	4	20.2	4	0.8	1.6	2.4	0.8		
	Hyla meridionalis	127	111 (18)	3.9	11.9		21.4	35.7	4.76	2.3		9.5	3.6	4.8	1.2	3.6			1.2
	*Pelobates varaldii**	75	55 (0)	2.0	36.7		30.0	25.0				5.0				3.3			
	Pelophylax saharicus	394	225 (59)	8.0	9.4		21.2	35.3	0.59	0.6	1.8	17.7	1.8	1.8	1.8	1.8	2.9	2.4	1.2
Chelonia	*Testudo graeca*	147	137 (32)	4.9	17.0		23.4	21.3	3.2		3.2	11.7	3.2	2.1	6.4	5.3	3.2		
	Emys orbicularis	31	25 (4)	0.9	4.6		22.7	54.6	4.6			9.1					4.6		
	Mauremys leprosa	230	152 (38)	5.5	5.4		31.3	32.0	2.0	0.7	4.8	8.2	2.0	5.4	1.4	2.0	4.1		0.7
Sauria	*Acanthodactylus boskianus*	54	34 (12)	1.2			10.0	13.3			3.3	3.3		10	13.3		33.3	10.0	3.3
	Acanthodactylus erythrurus	215	182 (38)	5.6	5.3		23.2	31.3			3.3	15.2	3.3	6.0	3.3	1.3	5.3	2.0	0.7
	Acanthodactylus maculatus	71	55 (11)	2.0	4.2		8.3	2.1			4.2			8.3	25.0		31.3	16.7	
	Agama impalearis	255	216 (70)	7.7	7.4		17.3	26.2	1.0	1.5	3.5	10.9	3.0	10.9	6.9	1.0	5.0	5.0	0.5
	*Chalcides colosii**	54	43 (15)	1.5	3.3		23.3	40.0		3.3	6.7	10.0	6.7	3.3		3.3			
	*Chalcides ebneri**	3	3 (0)	0.1			100												
	Chalcides mauritanicus	9	7 (1)	0.3	33.3		16.7	16.7								16.7			16.7
	*Chalcides minutus**	24	22 (3)	0.8	4.6		13.6	22.7			4.6	9.1		4.6	22.7		4.6	13.6	
	*Chalcides mionecton**	13	11 (1)	0.4	11.1		22.2	11.1			11.1	11.1		11.1		22.2			
	Chalcides ocellatus	94	90 (19)	3.1	4.6		18.2	18.2			4.6	3.0	1.5	13.6	4.6	3.0	16.7	12.1	
	Chalcides parallelus	13	13 (6)	0.5	16.7		16.7	33.3	16.7								16.7		
	*Chalcides polylepis**	7	6 (1)	0.2			25.0	50.0						25.0					
	*Chalcides pseudostriatus**	23	20 (6)	0.7	13.3			20.0	6.7		6.7	20.0		6.7		20.0			6.7
	Chamaeleo chamaeleon	66	60 (18)	2.2	11.6	2.33	20.9	25.6			7.0	9.3		7.0	4.7	4.7	2.3		4.7
	Eumeces algeriensis	41	40 (5)	1.4	16.1		22.6	16.1				3.2		16.1	9.7	3.2	3.2	6.5	3.2
	Hemidactylus turcicus	15	11 (2)	0.4	11.1		22.2	44.4				11.1					11.1		
	Hyalosaurus koellikeri	12	11 (0)	0.4	12.5		12.5	50.0				25.0							

Table 2 (cont.).

Order / suborder	Taxa	N obs	N UTM	%	Crop	Shru	Crvg	Vgcr	Brfo	Nefo	Fosh	Bnsh	Brsh	Vege	Gras	Urba	Bare	Cons	Wate
Sauria	*Mesalina guttulata*	4	3 (0)	0.1			25.0							50.0			25.0		
	Mesalina olivieri	34	35 (6)	1.3	12.0		4.0	20.0				4.0	4.0		8.0		24.0	24.0	
	Ophisops occidentalis	11	12 (2)	0.4				11.1									22.2	66.7	
	Podarcis vaucheri	270	174 (52)	6.1	2.4		19.4	33.3	5.6	2.4	4.0	19.1	4.0	5.6	1.6	0.8	0.8		0.8
	Psammodromus algirus	351	247 (72)	8.8	4.2		22.3	30.1	1.8	3.6	3.6	15.1	2.4	5.4	4.2	0.6	3.0	1.8	1.8
	Psammodromus blanci	8	8 (2)	0.3			14.3				14.3			14.3	28.6		14.3	14.3	
	*Psammodromus microdactylus**	6	6 (0)	0.2			60.0	20.0								20.0			
	*Saurodactylus fasciatus**	18	18 (2)	0.6				38.5			7.7	30.8	15.4			7.7			
	Saurodactylus mauritanicus	65	44 (15)	1.6	15.2		21.2	15.2			6.1	12.1		12.1	15.2				3.0
	Scelarcis perspicillata	29	25 (4)	0.9			30.8	38.5				7.7			15.4			7.7	
	Stenodactylus mauritanicus	31	33 (4)	1.1	6.3						6.3			12.5	18.8		50.0	6.3	
	Tarentola mauritanica	291	227 (72)	7.9	8.7		22.7	30.7	2.7	0.7	4.0	11.3	2.0	4.0	2.7	2	5.3	2.0	1.3
	Timon tangitanus	120	100 (25)	3.7	6.3		26.6	40.6		3.1	4.7	12.5	1.6	1.6		1.6	1.6		
	Timon pater	3	3 (0)	0.1	0.3		0.3					0.3							
	Trapelus boehmei	12	11 (2)	0.4		10.0								30.0	10.0		30.0	20.0	
	Uromastyx nigriventris	37	36 (9)	1.3	6.3			3.1						21.9	12.5		43.8	12.5	
Amphisbaenia	*Blanus tingitanus**	53	51 (15)	1.7	17.7		23.5	32.4	2.9			14.7	2.9	2.9		2.9			
	Trogonophis wiegmanni	64	59 (13)	2.1	16.7		19.4	22.2				2.8		11.1	5.6	5.6	13.9		2.8
Serpentes	*Coronella girondica*	74	62 (18)	2.2	2.6		20.5	33.3		5.1	5.1	20.5		5.1			2.6	2.6	2.6
	Eryx jaculus	3	3 (0)	0.1	50			50											
	Daboia mauritanica	47	44 (14)	1.6	9.4		15.6	34.4			3.1	18.8	9.4		3.1			3.1	3.1
	Hemorrhois hippocrepis	193	157 (30)	5.7	8.9		17	36.3			5.9	11.1	2.2	3.7	3	2.2	5.9	2.2	1.5
	Natrix maura	143	129 (27)	4.5	7.2	1.2	16.9	31.3	1.2	2.4	3.6	16.9	4.8	3.6	4.8	4.8	1.2		
	Natrix natrix	21	16 (3)	0.7	9.1		18.2	45.5		18.2		9.1							
	Lytorhynchus diadema	1	1 (0)	0.04														100	
	Macroprotodon abubakeri	10	10 (3)	0.4	42.9		14.3	14.3			14.3					14.3			
	Macroprotodon brevis	59	59 (10)	2.1	13.5		16.2	35.1	2.7	2.7	8.1	5.4		2.7		10.8	2.7		
	Macroprotodon cucullatus	12	11 (1)	0.4	9.1						9.1			18.2	9.1		18.2	36.4	
	Malpolon insignitus	14	11 (3)	0.4			9.1				9.1	9.1			27.3		18.2	27.3	
	Malpolon monspessulanus	150	130 (17)	4.6	5.6		21.5	29	1.9		8.4	10.3	4.7	8.4	0.9	0.9	7.5		0.9
	Psammophis schokari	33	33 (6)	1.2	14.3		9.5				4.8	9.5		14.3	19.1		23.8	4.8	
	Spalerosophis dolichospilus	6	6 (0)	0.2				50			50								
	Vipera latastei	24	19 (4)	0.7	6.7		13.3	46.7	6.7			20				6.7			

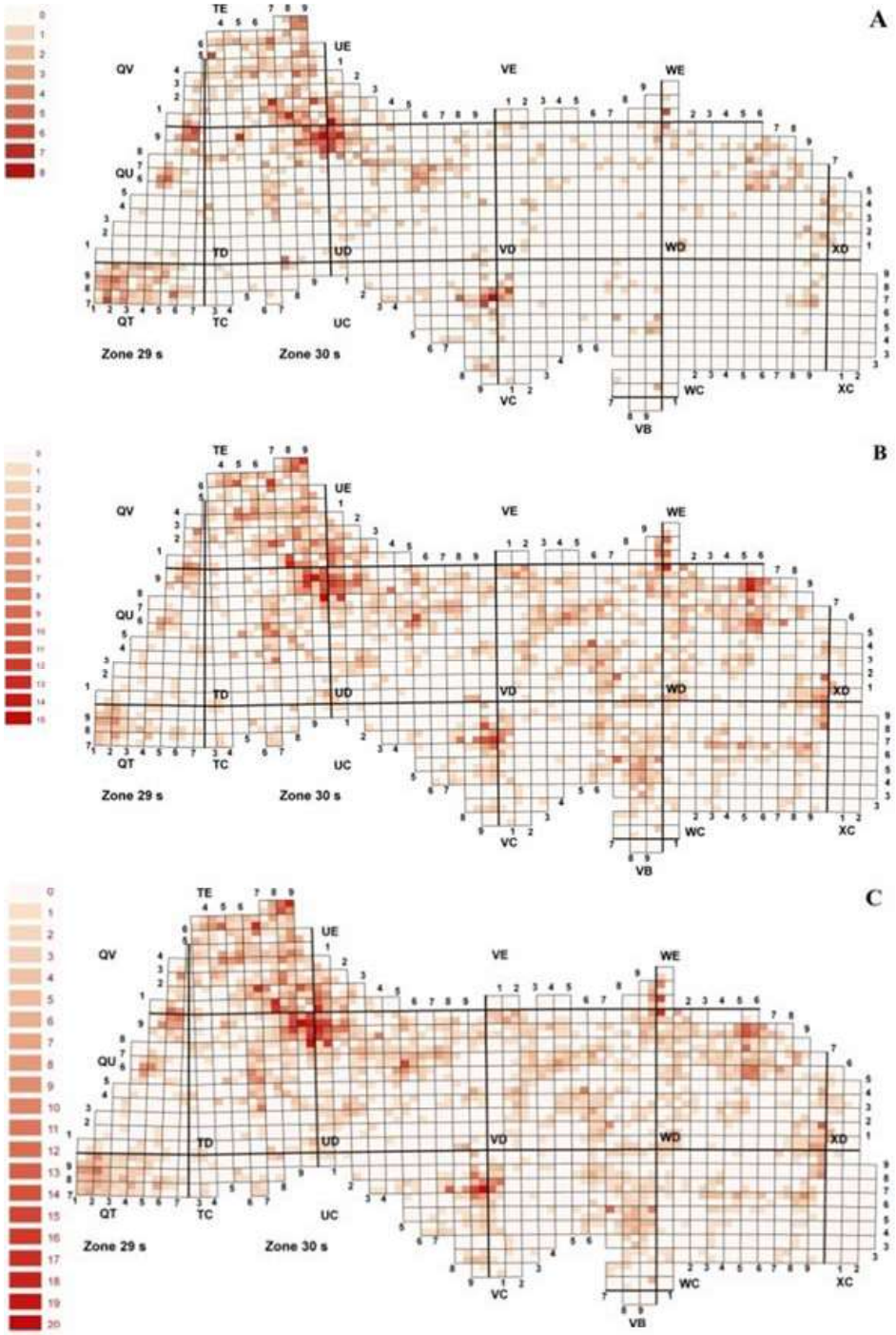

Figure 2: Representation in UTM 5 x 5 km grid of (A) amphibian species richness, (B) reptile species richness, and (C) total species richness in northern Morocco.

tions of vegetation and croplands, where some species from the other taxonomic groups were also frequently found, including *Chamaeleo chamaeleon*, *H. koellikeri*, *Eumeces algeriensis*, *P. microdactylus*, *S. fasciatus*, *S. perspicillata*, *T. tangitanus*, *T. wiegmanni*, *E. jaculus*, *Coronella girondica*, *D. mauritanica*, *N. natrix*, *S. dolichospilus*, *M. brevis* and *M. abubakeri*. Other species such as *B. boulengeri*, *P. saharicus*, *A. erythrurus*, *A. impalearis*, *P. vaucheri*, *P. algirus*, *T. mauritanica*, *N. maura* and *M. monspessulanus* exhibited relatively general patterns of habitat selection. Finally, there are few species associated with desert habitats, including *A. boskianus*, *A. maculatus*, *Saurodactylus*

mauritanicus, *O. occidentalis*, *P. blanci*, *U. nigriventris*, *L. diadema*, *M. cucullatus*, *M. insignitus* and *Psammophis schokari*.

Areas of relatively high amphibian species richness were highly fragmented and located in the western Rif, Tingitana Peninsula, Mamoura Forest (Gharb Basin), Jbel Tazekka, along the Atlantic coast, and in a narrow stripe in the north-east (Fig. 2a). A large number of reptile species were located in the Tingitana Peninsula, western Rif, Jbel Tazekka, Trois Fourches Cape, the mouth of Moulouya River and Jbel Chekhar. Other relatively rich areas for reptiles are located along the high plains of the oriental and central Rif, pre-Rif and Mamoura Forest (Fig. 2b). The distribution of total species richness follows the same patterns exhibited by the distribution of reptile's richness (Fig. 2c).

Discussion

Northern Morocco hosts 11 species of amphibians and 53 species of reptiles. These 64 species represent 56% of the herpetofauna of Morocco, which is a relatively high proportion in comparison to the relative surface of the study area (about 7.5% of Morocco). About 31.6% and 34.7% of the observations of amphibians and reptiles, respectively, are new localities, while the remaining fractions predominantly come from published references for amphibians (Bons & Geniez, 1996; Beukema *et al*., 2013) and reptiles (Bons & Geniez, 1996; Fahd & Pleguezuelos, 1996, 2001). All amphibians and reptiles of northern Morocco were included in this study with the exception of sea turtles and two terrestrial reptiles (*Psammodromus hispanicus* and *Cerastes cerastes*). The former was considered by several authors as introduced in Morocco (Melilla and Sidi Ifni; de Zulueta, 1909; Joleaud, 1934), while the presence of *C. cerastes* in the plain of Tafrata near Debdou (Laurent, 1935) has been considered as doubtful (Bons & Geniez, 1996).

Given that sampling effort was not uniform along space and time, interpretations of distribution maps of individual species and species richness should be made with care. In particular, the frontier areas with Algeria, some mountains of Beni Snassen, between Taourirt and Touissite and some oriental Rif mountains were not visited. Future fieldwork sampling efforts should concentrate on those areas in order to update distribution maps.

Species distribution maps were updated according to our field observations and literature. Some old observations were re-evaluated and in some cases they were considered as erroneous and excluded from our study. These observations included *A. maurus* in the Tingitana Peninsula (see Bons & Geniez, 1996) and three records of *Vipera latastei* at Trois Fourches Peninsula and Oued Kert (Yus Ramos & Cabo Hernández, 1986). On the contrary, the single observation of *E. orbicularis* in the eastern Rif (Fahd & Pleguezuelos, 1996) was considered in this work because there are recent photographic evidences of the species presence in this region. We also gave veracity to the observation of *P. waltl* at Talamagaït (Mateo, 1991), despite our intense sampling in eastern Rif and in this locality failed to find the species. However, there are some local guides confirming its presence. Further research should be conducted throughout the eastern region to determine the specific status of *P. waltl*

in this area.

In comparison with the previous atlases of distribution of amphibians and reptiles in Morocco (BONS & GENIEZ, 1996; FAHD & PLEGUEZUELOS, 1996, 2001; BEUKEMA *et al.*, 2013), new observations were recorded outside the known distribution area for one amphibian and three reptile species. The amphibian, *B. boulengeri*, was recorded in several localities of the western Rif (UE 0404, TD 9891, UD 1188 and UD 0185), as well as in the watershed of Oued Laou (western Rif) by FAHD & MEDIANI (2007). This species had been considered absent from this region by previous works (DONAIRE *et al.*, 2011b; BEUKEMA *et al.*, 2013), probably because of lack of prospection in the localities mentioned above. Regarding reptiles, *C. pseudostriatus* was observed (May 2002) in a wetland of the Moulouya River (WD 5453), an area probably inhabited also by *C. minutus*, as the two species are known to occur in sympatry in the Middle Atlas Mountains (GENIEZ & SOTO, 1994). This species was recorded in southern Debdou (VC9758, DAMAS-MOREIRA *et al.*, 2014), also outside its previously known distribution range. These two observations merit more attention in future genetic analyses, because the identification of these two specimens was based on morphological analyses only. Finally, *S. perspicillata* was recorded at the Beni Snassen Mountain in 2010 and 2014 (WD 7256). Taken in combination, these new observations extended significantly the known distribution areas of these three species in northern Morocco. Additionally, the records that we have compiled in the present work also contributed to extend the known ranges of *P. varaldii* and *N. natrix*, which can be attributed to increased sampling efforts in recent years by both professional and amateur herpetologists (e.g. PIEH, 2006; GUZMÁN *et al.*, 2007; HARRIS *et al.*, 2008, 2010; BARNESTEIN *et al.*, 2010, 2012; BARATA *et al.*, 2011; DONAIRE *et al.*, 2011a).

During our field expeditions in northern Morocco, contact zones between parapatric *Discoglossus* species were sampled. According to phylogenetic and morphological reviews of the genus, *D. scovazzi* clearly differs from its congener *D. pictus* by the absence of tympanum (FROMHAGE *et al.*, 2004; MARTÍNEZ-SOLANO *et al.*, 2004; ZANGARI *et al.*, 2006; PABIJAN *et al.*, 2012). The former species has a wide distribution, from the Atlantic Coast to the west of Moulouya Basin, while the latter species occurs on the eastern side of Moulouya River (BEUKEMA *et al.*, 2013; VENCES *et al.*, 2014). In eastern Morocco, all sampled populations examined east of the Moulouya River were clearly assignable to *D. pictus*. This species was also found along the Mediterranean Coast west of Moulouya River, in the cities of Nador and Melilla, suggesting that the potential barrier to the distribution of these frogs corresponds to the wide and arid river valley and not to the river itself (VENCES *et al.*, 2014). During our field expeditions, sampling of localities north of the Moulouya Valley was unable to detect sympatry between *D. scovazzi* and *D. pictus*, which further supports the genetic revisions of VENCES *et al.* (2014).

Three species of *Macroprotodon* snakes are known to occur in Morocco (*M. abubakeri*, *M. cucullatus* and *M. brevis*) according to the latest revision on the genus (WADE, 2001; CARRANZA *et al.*, 2004). During our field expeditions in the Trois Fourches

Peninsula, no specimens of *M. abubakeri* were found west of Moulouya Valley. Nevertheless, Wade (2001) attributed to *M. abubakeri* the specimens found in two localities west of the Moulouya Valley (Ras El Mae), which shows that the Moulouya River does not act as a geographic barrier for the species. Therefore, the exact distribution limits between *M. brevis* and *M. abubakeri* remain unknown and the occurrence of contact zones is highly probable (WADE, 2001; CARRANZA *et al*., 2004). The same problem was found with *M. cucullatus* and *M. brevis* because their distribution limits were apparently not related with geographical barriers. Because of these difficulties in determining the limits of their distribution areas, the three species were combined into a single map (Appendix 1). Both ecological and genetic studies are needed in order to better understand the habitat selection patterns of these species and how genetic diversity is spatially structured.

According to our study, the northwestern limit between the snakes of the genus *Malpolon* (*M. insignitus* and *M. monspessulanus*) is not very clear, but apparently the Moulouya Valley might be acting as a barrier between these two species to the southeast. *Malpolon insignitus*, once considered a subspecies of *M. monspessulanus*, was elevated to the rank of species by the phylogenetic study of CARRANZA *et al*. (2006), and most citations of this species are found in the valley of Moulouya, at the eastern high plateau (BONS & GENIEZ, 1996). An intermediate form between *M. monspessulanus* and *M. insignitus*, based on morphological characteristics, was discovered at Saïdia (GENIEZ *et al*., 2006) suggesting the possibility of hybridization between these two species. Further detailed studies on genetic and phenotypic diversity in contact zones are needed to understand population dynamics.

The distribution maps of many species show a trend for more or less contiguous observations, suggesting that their areas of distribution are fairly well documented. These species include *A. mauritanicus*, *P. saharicus*, *D. scovazzi*, *A. erythrurus*, *A. impalearis*, *C. ocellatus*, *H. hippocrepis*, *M. monspessulanus*, *M. leprosa*, *N. maura*, *P. algirus* and *T. mauritanica*, and particularly those species that have been subject of previous detailed studies, such as *A. maurus*, *S. algira, Discoglossus* spp., *P. varaldii* and *Macroprotodon* spp.. On the contrary, some species reported previously in northern Morocco, such as *C. cerastes* and *P. hispanicus*, require more detailed studies to confirm their presence in the region. The lizards *Acanthodactylus savignyi, Acanthodactylus dumerili* and *P. vaucheri* have been documented in the western regions of Algeria (SALVADOR, 1982; ARNOLD, 1983, BONS & GENIEZ, 1996), suggesting their likely presence in eastern Morocco as well. Recently, *A. maurus* was recorded in the neighbouring Tlemcen province in Algeria (LOUKKAS, 2006), and its presence suggested in north-eastern Morocco, particularly in the wettest environments of the highlands of Debdou and Meseta-Oran, as shown by ecological modelling (DE POUS *et al*., 2013). To clarify the status of these species in north-eastern Morocco, further sampling is required. For other species, such as *C. ebneri*, *E. jaculus*, *T. pater*, *S. dolichospilus*, *P. microdactylus*, *P. varaldii*, *M. guttulata* and *H. koellikeri*, no new records were made, suggesting also that further sampling is need-

ed in particular areas of northern Morocco.

The majority of new data collected in our study comes from the Tingitana Peninsula and western Rif, while the central and eastern Rif, the Gharb, the Middle Atlas, and eastern Morocco (highlands of Debdou, Beni Snassen Mountain, and regions in the border with Algeria) remain poorly studied. The interpretations of distribution maps should take into account such geographical sampling bias. Still, important observations were made in those regions. For instance, *C. pseudostriatus* and *S. perspicillata* were recorded for the first time in the eastern region of northern Morocco, and *P. waltl* was observed in the eastern Rif, far from the previously known range of the species.

Concerning patterns of habitat selection, the main results are supported by previous works on the subject (e.g. BONS & GENIEZ, 1996; REAL *et al.*, 1997; FAHD & PLEGUEZUELOS, 2001). All amphibians apparently occur outside the semi-desert areas, in habitats with important primary production (mosaics of cropland and natural vegetation). These habitats are found mainly in north-western Morocco, in areas with high levels of precipitation. Eastern Morocco is much drier and the majority of habitats found in the south-east correspond to bare areas, which results in reduced species richness. One of the most obvious and direct effects of reduced rainfall on the herpetofauna is the scarcity of breeding sites for amphibians. According to our data, croplands would constitute a breeding habitat for most amphibians in northern Morocco, which is consistent with other observations (DE POUS *et al.*, 2011b; BEUKEMA *et al.*, 2013). For reptiles, there are apparently three groups of species according to their habitat selection patterns: 1) species occupying the arid regions of the eastern plains dominated by bare soil or with some vegetation cover, 2) generalist species usually exhibiting wide distributions across northern Morocco, and 3) species occupying Mediterranean environments that are usually abundant in north-western regions.

The distribution patterns of observed richness of amphibians, reptiles and herpetofauna in general were almost similar. The highest species richness was observed along a large area of the central and western Rif. These regions correspond to the most humid bioclimatic zone of Morocco (EMBERGER, 1962; BENABID, 1982, 2000) and support also rich and diversified forest communities, including *Abies marocana*, *Cedrus atlantica*, *Quercus suber*, *Quercus ilex*, *Quercus canariensis* and *Quercus fructicosa* (VALDÉS *et al.*, 2002). For the herpetofauna, these regions tend to harbour species of different biogeographical origins, which originates a high species richness. These species include those of Palaearctic affinity, resulting from faunal exchange between Africa and Europe during geological times (STEININGER *et al.*, 1985), and those of sub-Saharan origin which tend to follow the arid corridor of the Moulouya River Valley (FAHD & PLEGUEZUELOS, 1996; Real *et al.*, 1997).

The distribution maps presented here constitute framework tools for future establishment of new potential protected areas or enlargement of the current ones.

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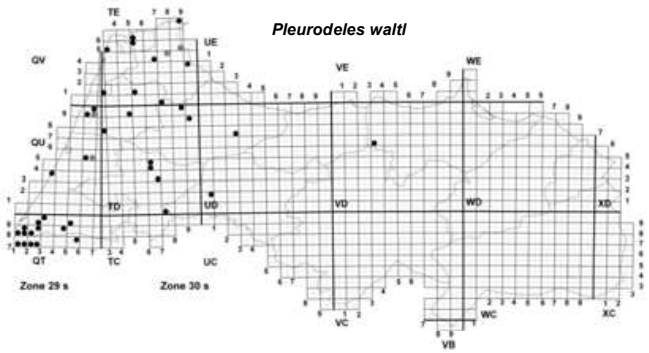
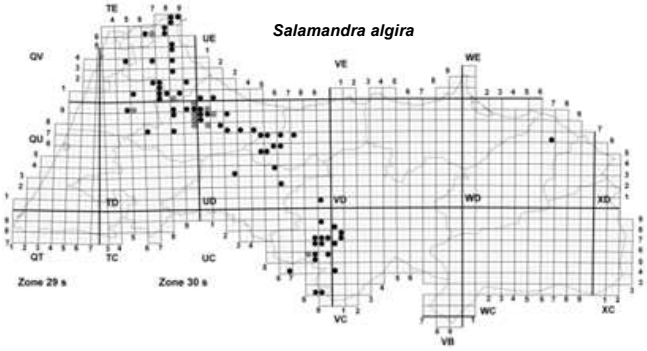
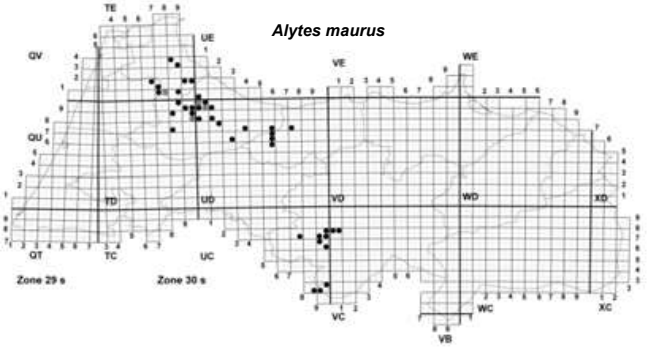
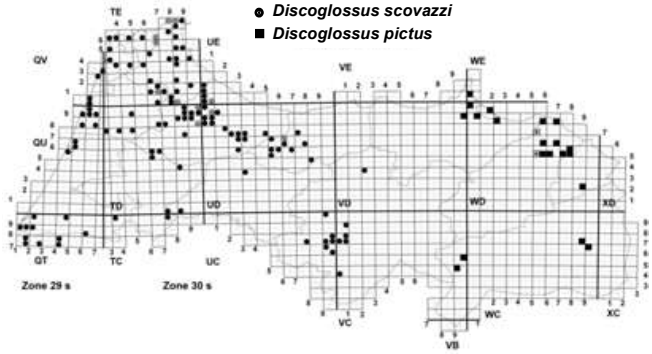
Appendix 1

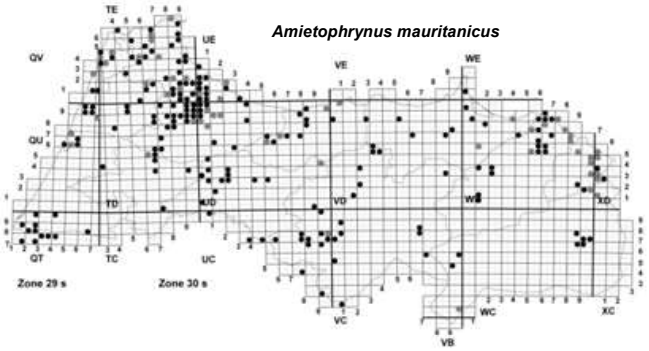
Distribution maps of the amphibian and reptiles species in northern Morocco. Solid black marks represent records from bibliographical sources. Grey marks with a central dot represent records from our own field observations.

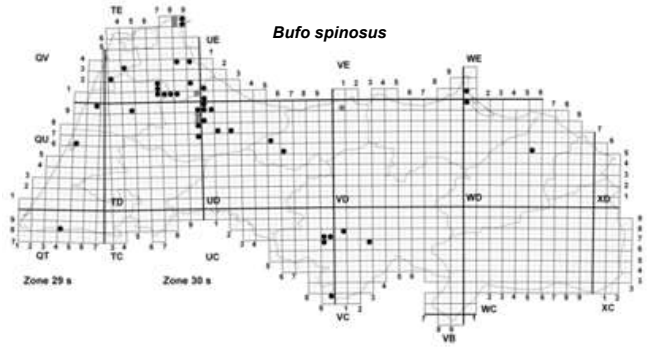


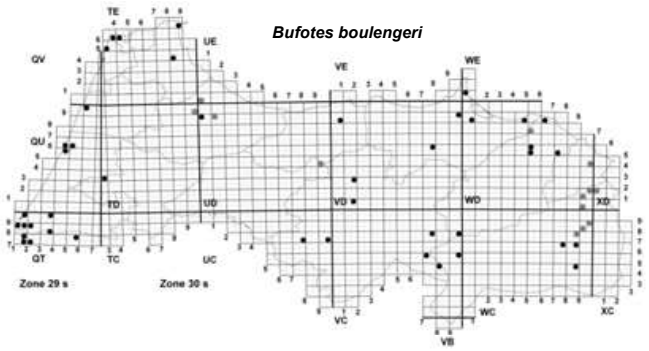


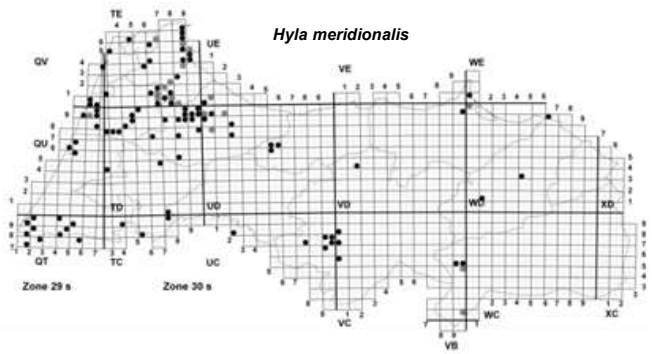


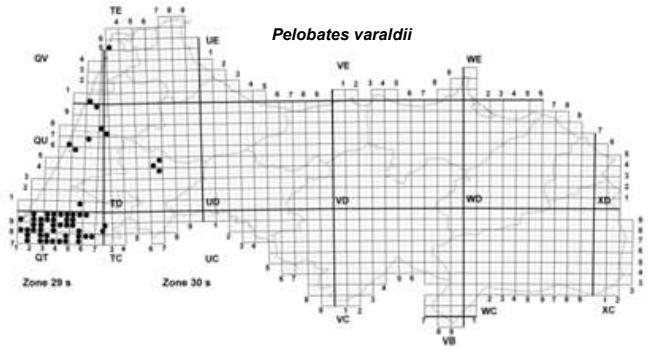











Pelobates varaldii
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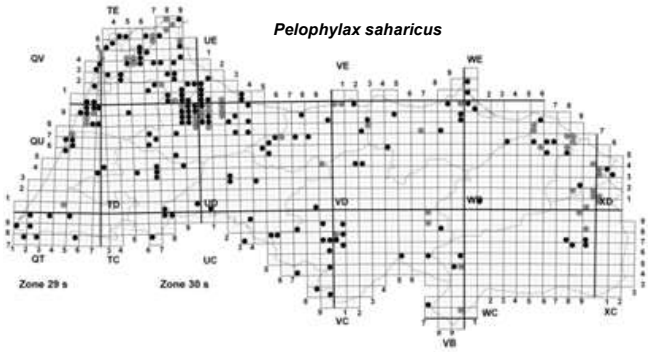
Pelophylax saharicus
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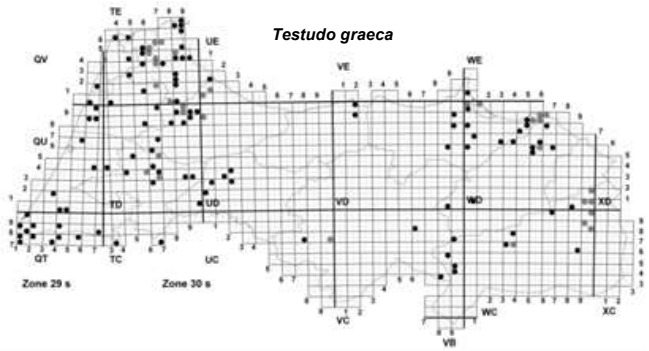
Testudo graeca
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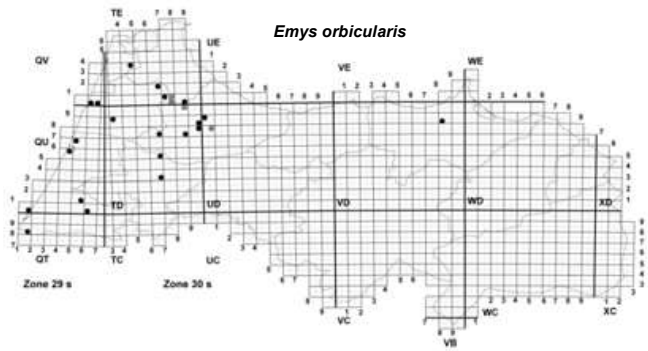
Emys orbicularis
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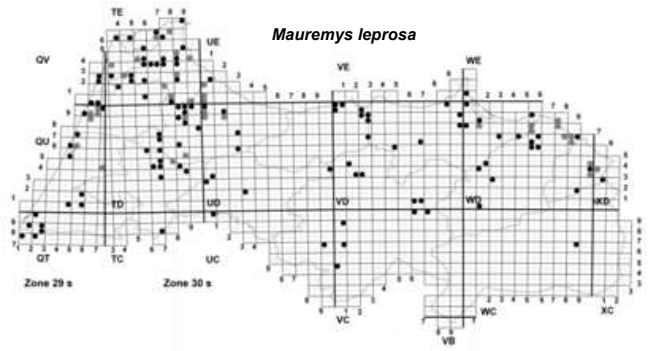
Mauremys leprosa
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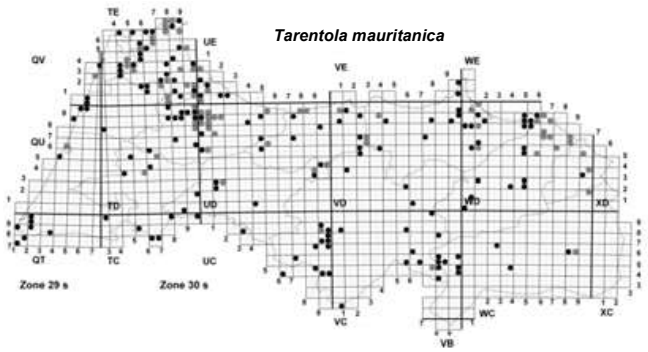
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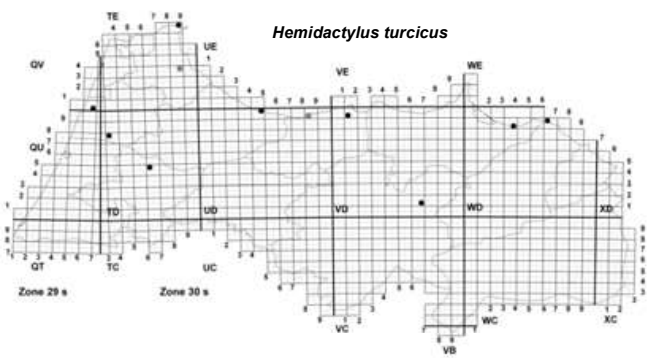
Hemidactylus turcicus
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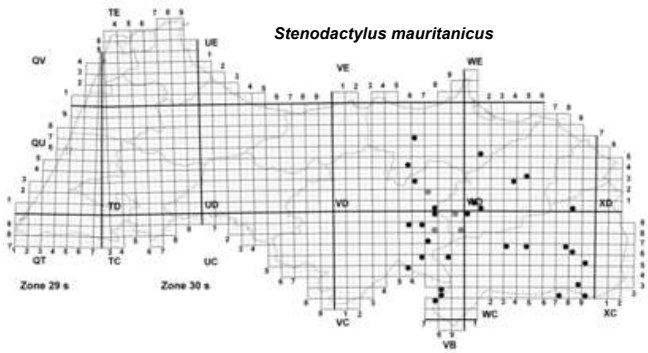
Stenodactylus mauritanicus
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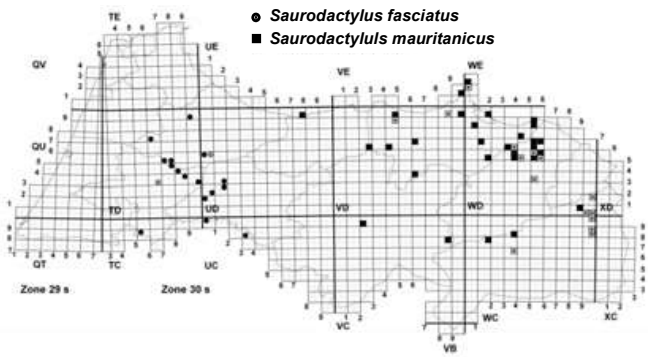
Saurodactylus fasciatus
Saurodactyluls mauritanicus
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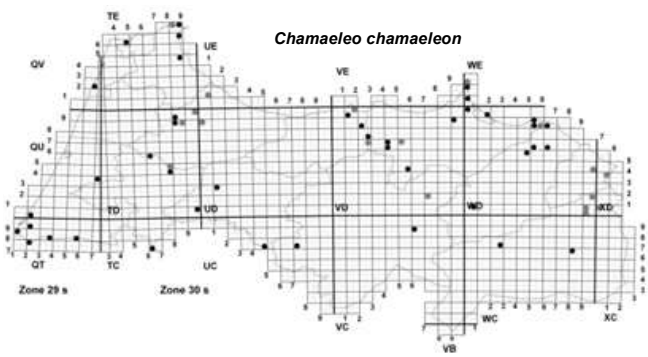
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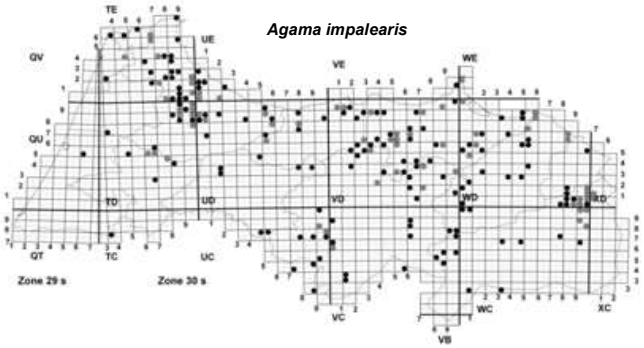
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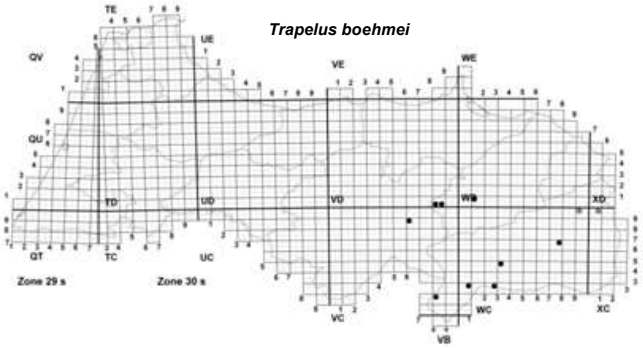
Trapelus boehmei
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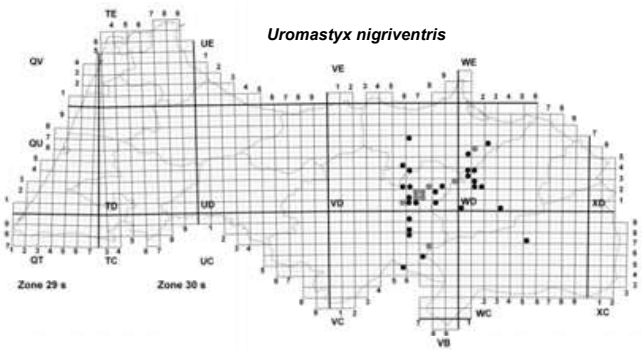
Uromastyx nigriventris
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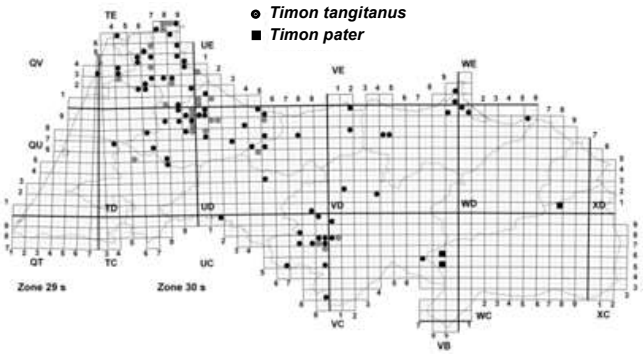
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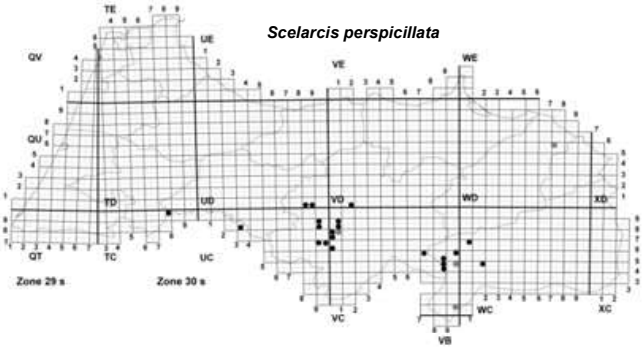
Scelarcis perspicillata
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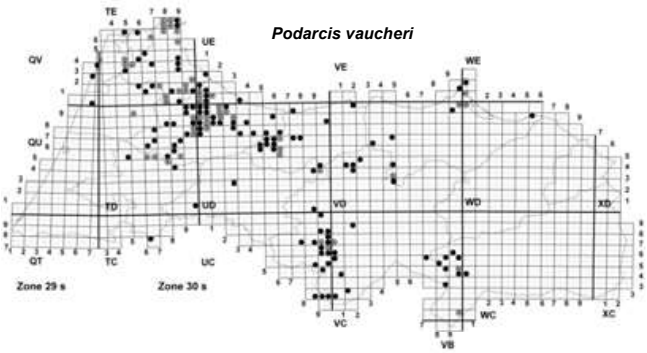
Podarcis vaucheri
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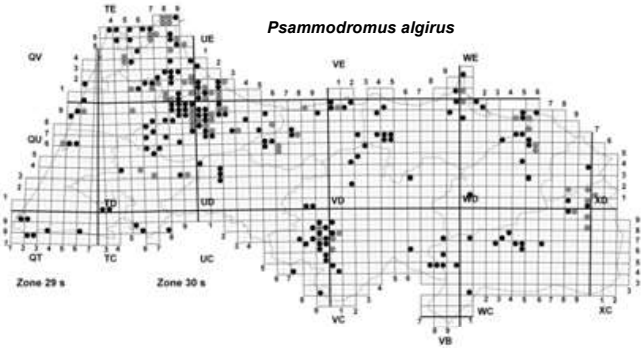
Psammodromus algirus
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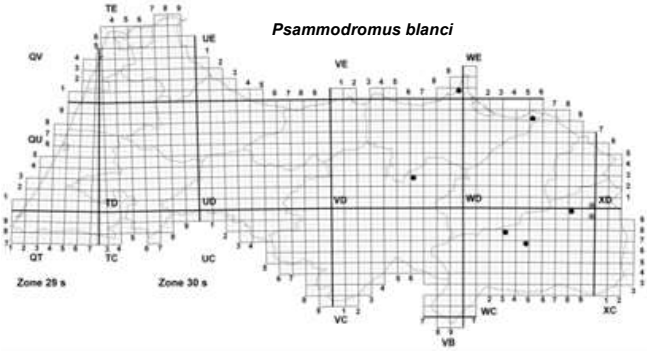
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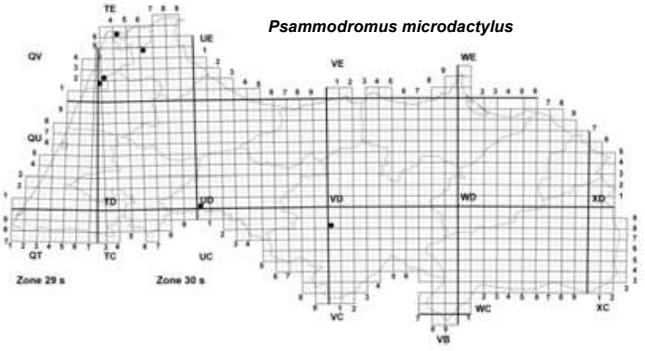
Psammodromus microdactylus
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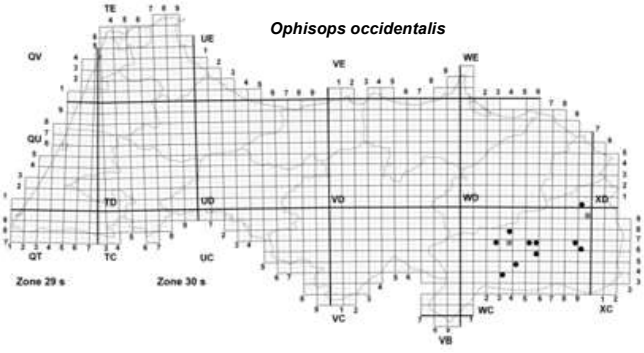
Ophisops occidentalis
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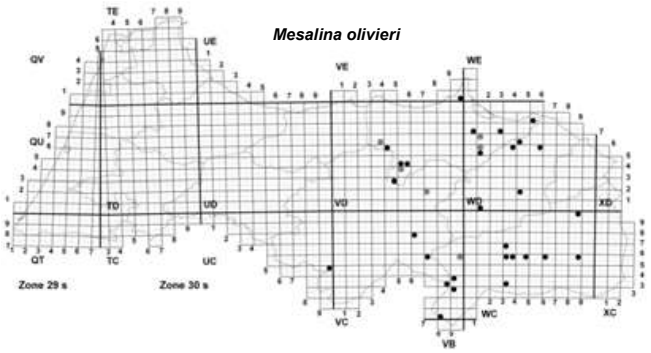
Mesalina olivieri
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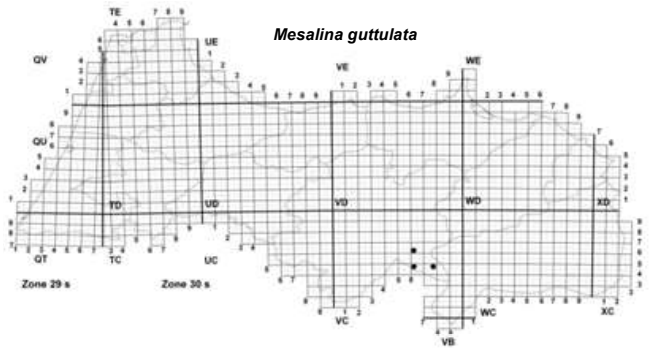
Mesalina guttulata
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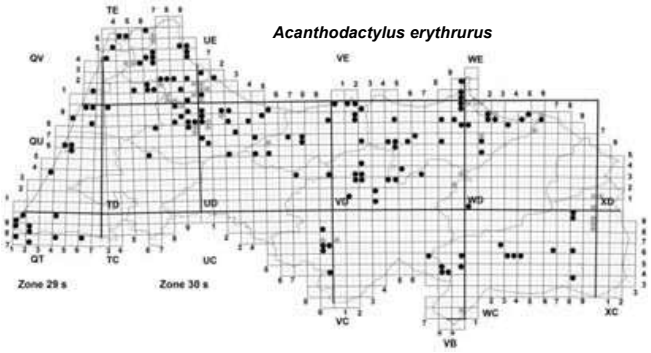
Acanthodactylus erythrurus
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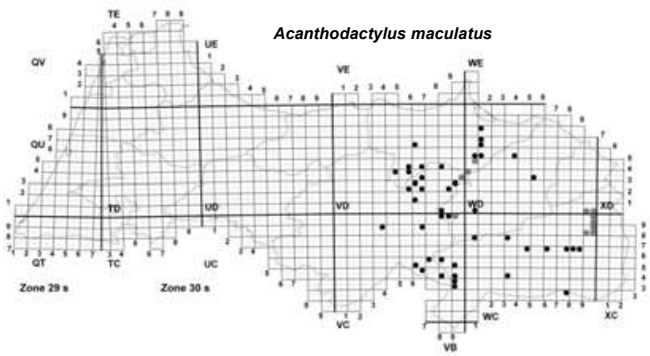
Acanthodactylus maculatus
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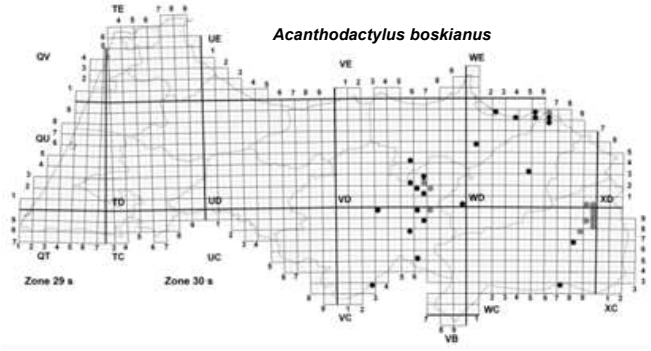
Acanthodactylus boskianus
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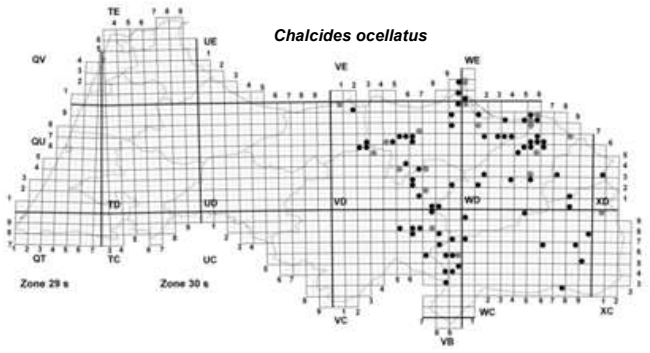
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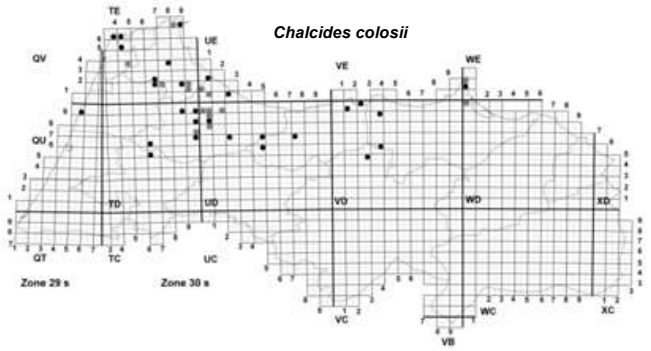
Chalcides colosii
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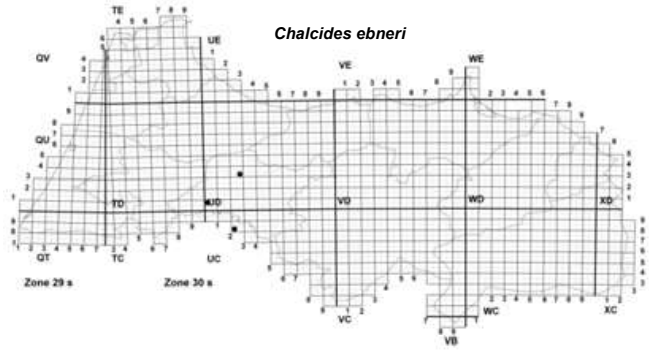
Chalcides ebneri
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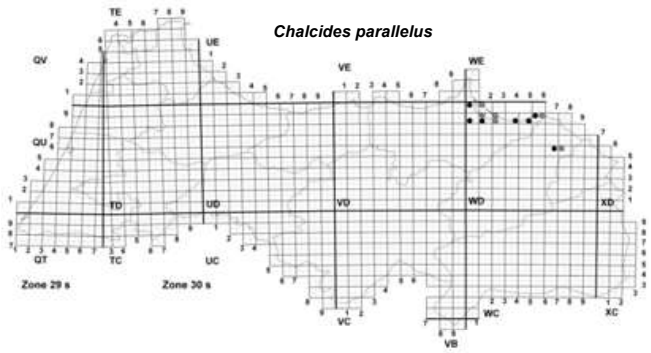
Chalcides parallelus
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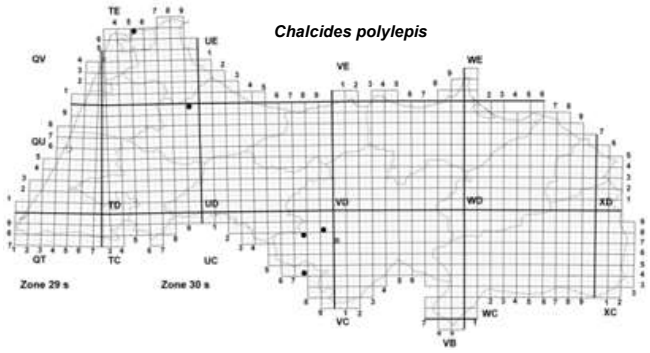
Chalcides polylepis
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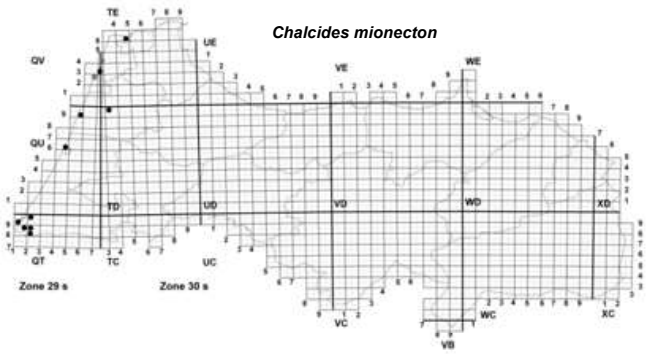
Chalcides mionecton
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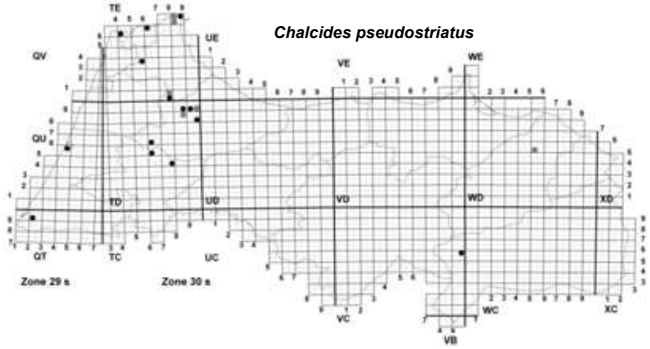
Chalcides pseudostriatus
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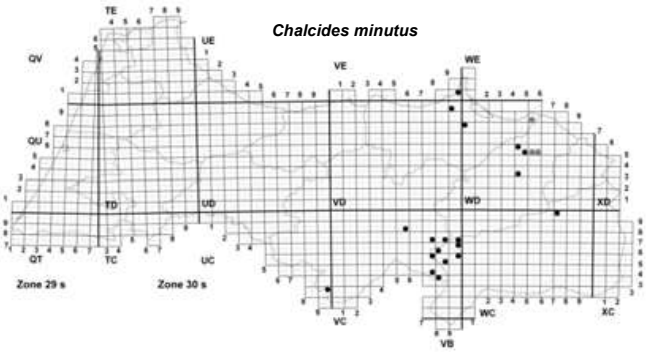
Chalcides minutus
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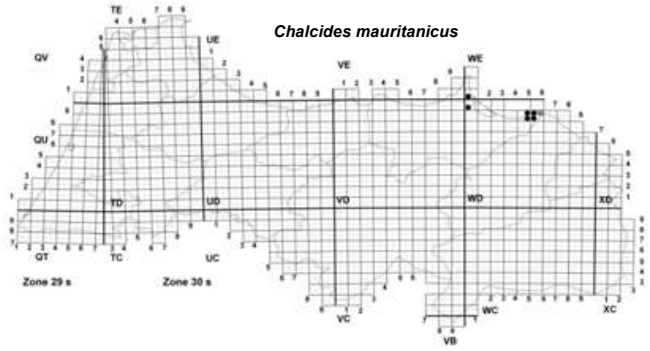
Chalcides mauritanicus
Zone 29 s
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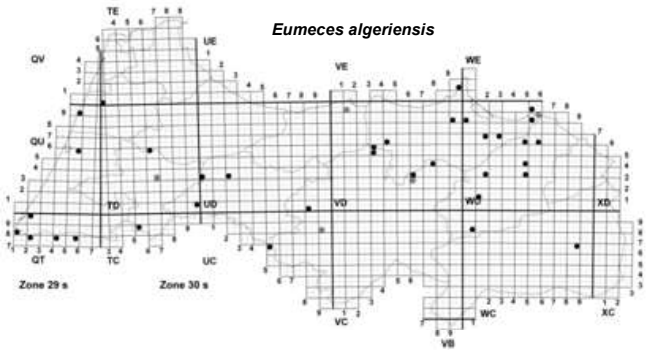
Eumeces algeriensis
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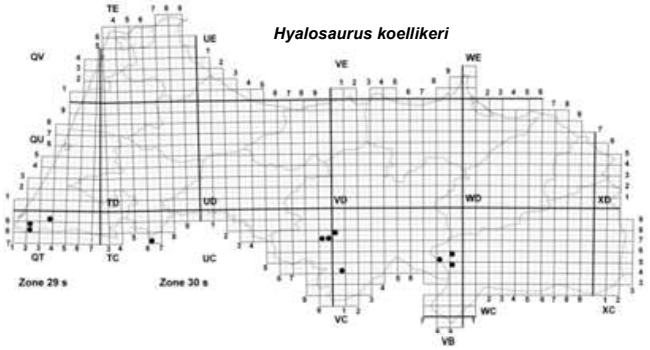
Hyalosaurus koellikeri
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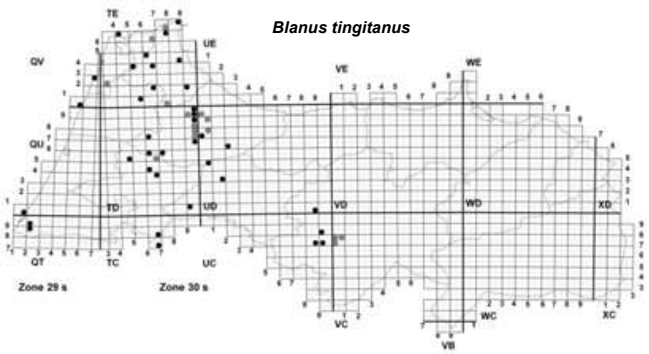
Blanus tingitanus
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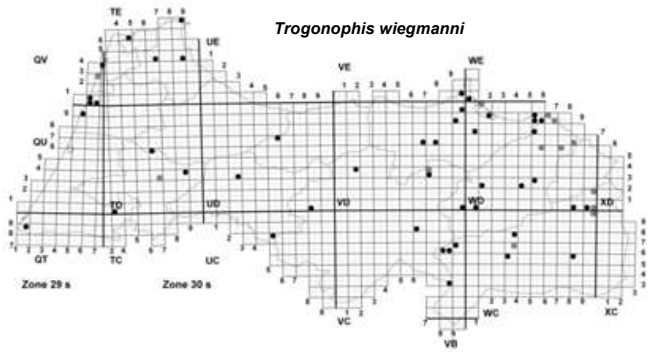
Trogonophis wiegmanni
Zone 29 s
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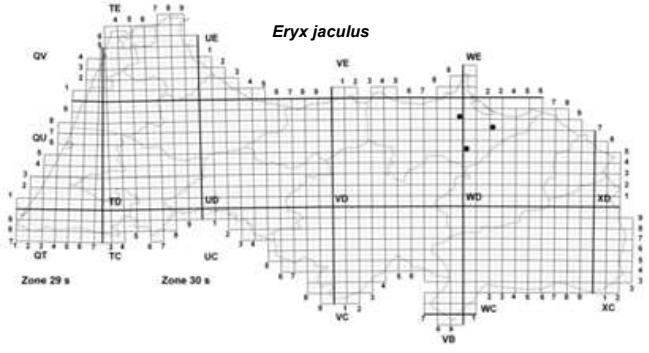
Eryx jaculus
Zone 29 s
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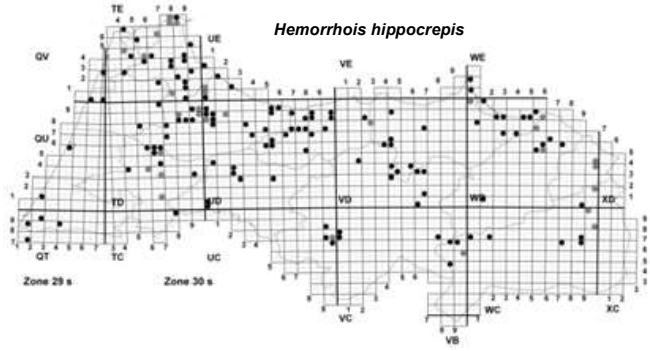
Hemorrhois hippocrepis
Zone 29 s
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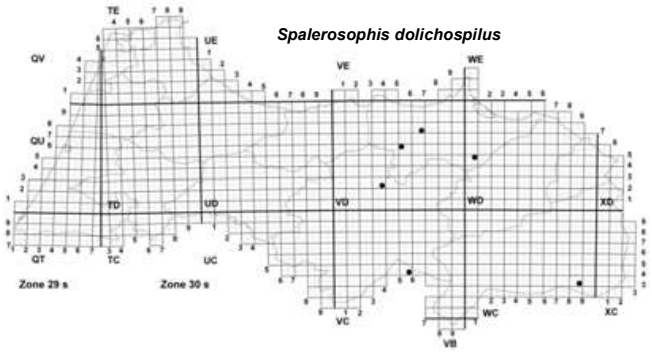
Spalerosophis dolichospilus
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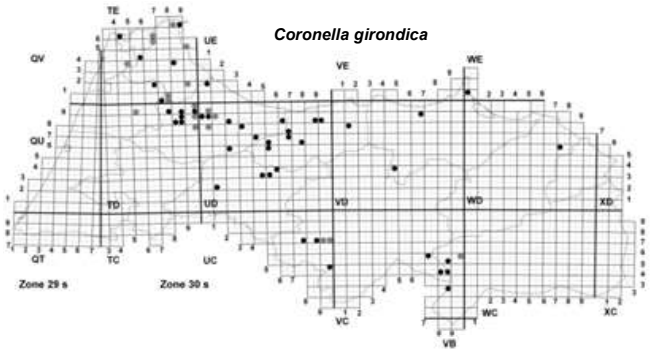
Coronella girondica
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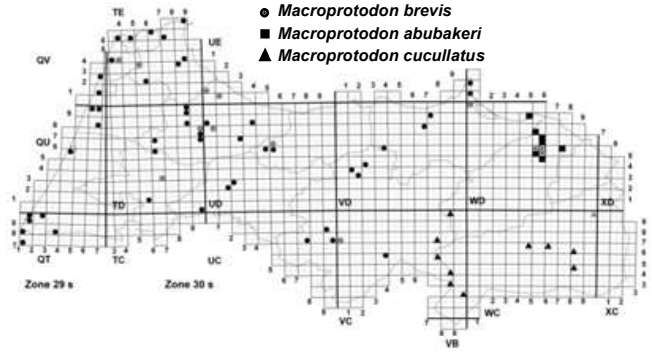
Macroprotodon brevis
Macroprotodon abubakeri
Macroprotodon cucullatus
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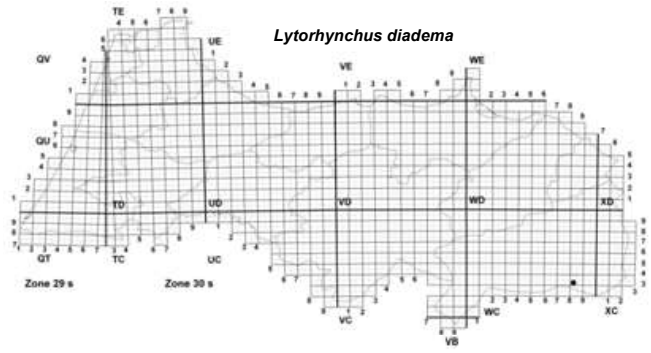
Lytorhynchus diadema
Zone 29 s
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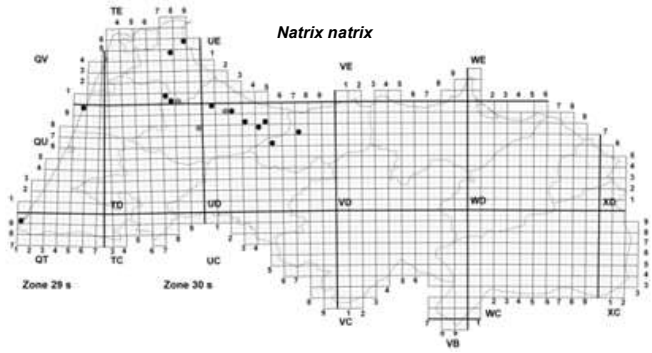
Natrix natrix
Zone 29 s
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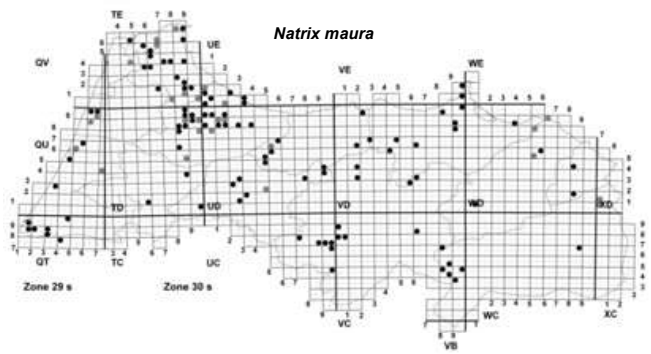
Natrix maura
Zone 29 s
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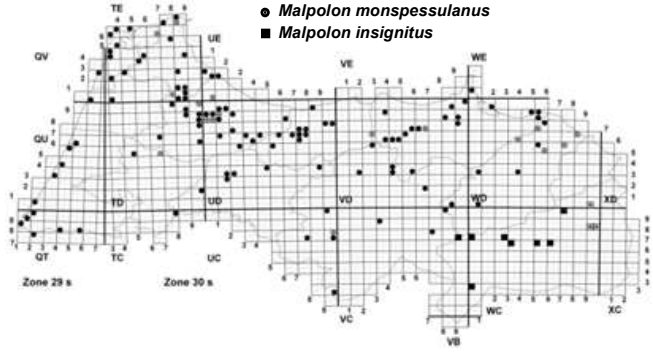
Malpolon monspessulanus
Malpolon insignitus
Zone 29 s
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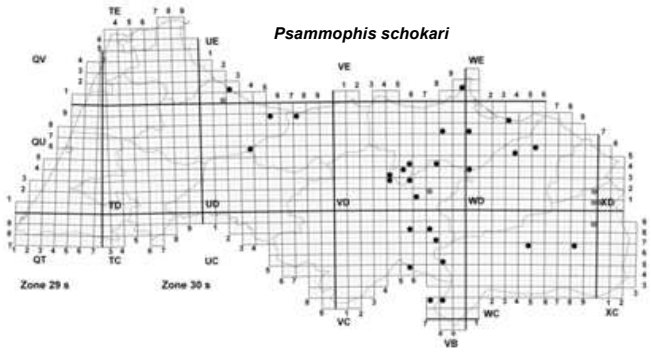
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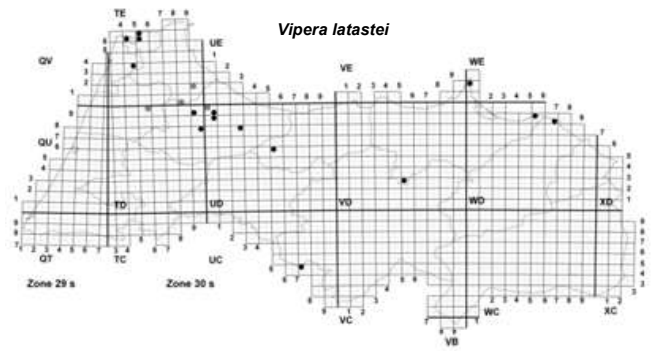
Vipera latastei
Zone 29 s
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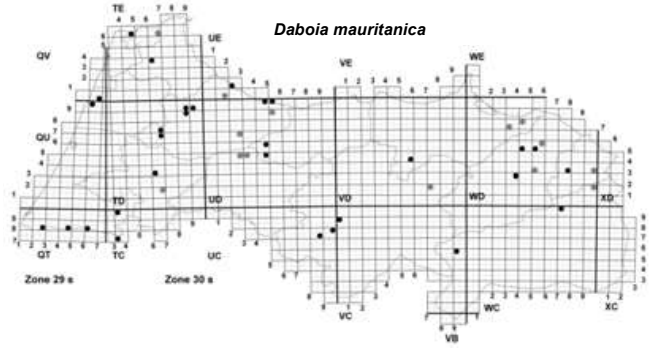
Daboia mauritanica
Zone 29 s
Zone 30 s