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Atlas of amphibians and reptiles in the Moroccan section of the Mediterranean Intercontinental Biosphere Reserve: distribution patterns and habitat use

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This study presents the first comprehensive atlas of the distribution of amphibians and reptiles within the Moroccan section of the Intercontinental Biosphere Reserve of the Mediterranean (IBRM). Data were gathered from literature reviews, museum collections, and extensive field surveys conducted between 2008 and 2019. A Geographical Information System (GIS) was utilized to generate updated distribution maps, assess species richness within a 10x10 km UTM grid, and analyse associations of species with habitat categories. A total of eight amphibian and 25 reptile species, representing five and 17 families, respectively, were recorded. Three distinct distribution patterns emerged for both taxonomic groups: widespread species, species restricted to specific environments, such as high-altitude areas or coastal environments, and species with limited and / or fragmented ranges. Seventeen areas of high species richness (N > 10 species) were identified across the study area. These areas consistently overlapped across both taxonomic groups and were primarily associated with Mediterranean-type habitats. While amphibians exhibited relatively homogeneous habitat preferences, reptiles demonstrated four distinct assemblages: species prefer mixed vegetation mosaics; species occupy forest-agriculture edges; species adaptable to diverse habitats and environments and species privilege open grasslands-rocky areas. The IBRM's complex topography likely contributes to high levels of environmental diversity, supporting a remarkable proportion of Morocco's herpetofauna: 60% of amphibian species and 25% of reptile species. These findings underscore the critical importance of the Moroccan IBRM for herpetofaunal conservation at the national and international levels.

Key words: conservation; diversity; herpetofauna; IBRM; land-cover; species richness.

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The Mediterranean Basin is widely recognized as one of the world's biodiversity hotspots, characterized by its exceptional species richness and high levels of endemism (Cox *et al.*, 2006). Within this region, North-western (NW) Morocco stands out as a particularly significant area due to its unique geographical and climatic conditions, which have fostered a remarkable diversity of flora and fauna. This area is considered a key zone for biological conservation, as it supports a wide range of ecosystems and species, many of which are endemic to the region. The Intercontinental Biosphere Reserve of the Mediterranean (IBRM), a UNESCO designated transcontinental reserve since 2006, uniquely spans southern Spain and northern Morocco, bridging the Mediterranean realm over continents (UNESCO, 2006; DINERSTEIN *et al.*, 2017).

North-western Morocco, situated at the crossroads of Europe and Africa, displays pronounced bioclimatic gradients, ranging from the humid and cool conditions of the Rif Mountains to the warmer and drier Mediterranean coastal areas. These gradients span over the Ecoregion of Mediterranean conifer and mixed forests and Mediterranean woodlands and forests (DINERSTEIN *et al.*, 2017). The Rif Mountains, with their complex topography spanning coastal plains to high-altitude forests, host a mosaic of microhabitats. This remarkable environmental diversity provides an ideal setting for studying the diversity, distribution and conservation of local biodiversity.

Concerning the amphibians and reptiles, NW Morocco harbours a rich assemblage, including several endemic and threatened species (MARTÍNEZ-FREIRÍA *et al.*, 2013; MEDIANI *et al.*, 2015; MARTÍNEZ DEL MÁRMOL *et al.*, 2019). For example, 30 out of the 120 recorded amphibian and reptile species in Morocco are endemic, highlighting the area's importance for biodiversity conservation (MARTÍNEZ DEL MÁRMOL *et al.*, 2019; ARGAZ *et al.*, 2020). The geographic diversity of the region has promoted allopatric speciation events in many species (e.g. MARTÍNEZ-FREIRÍA *et al.*, 2020, 2021; DONIOL-VALCROZE *et al.*, 2024). Indeed, genetic studies have frequently uncovered a remarkable amount of previously unrecognized diversity among Moroccan reptiles and amphibians, resulting in the description of new species or subspecies (e.g. MARTÍNEZ-FREIRÍA *et al.*, 2020, 2021; MIRALLES *et al.*, 2020).

A comprehensive distribution atlas of the Moroccan herpetofauna was published in the mid-1990s (BONS & GENIEZ, 1996), and later updated based on revisions on the systematics and taxonomy and distribution data available (MARTÍNEZ DEL MÁRMOL *et al.*, 2019). However, subsequent research has focused on specific regions, such as the Rif Mountains (Fahd & PLEGUEZUELOS, 1996, 2001; MEDIANI *et al.*, 2015; ARGAZ *et al.*, 2020), leaving significant gaps in our understanding of species distribution patterns, particularly within undersampled and difficult-to-access regions, such as the highest peaks of the Rif Mountains and the Moroccan sections of the IBRM. Furthermore, since the seminal work of BONS & GENIEZ (1996), and even since the most recent distribution atlas (MARTÍNEZ DEL MÁRMOL *et al.*, 2019), substantial advancements have occurred in herpetofaunal taxonomy. Numerous taxonomic revisions have redefined the status of many species (e.g. Martínez-Freiría *et al.*, 2020, 2021, 2024; Miralles *et al.*, 2020; Doniol-Valcroze et al. 2024; Harris *et al.*, 2024). Moreover, a wealth of new distribution data has been generated through recent field surveys and research efforts (e.g. Argaz *et al.*2020; Bouazza *et al*. 2021; Martínez-Freiría *et al.*, 2023). As such, a revised atlas of the distribution of amphibians and reptiles of NW Morocco is highly warranted.

The distribution and habitat selection of herpetofauna in NW Morocco are intricately linked to a complex interplay of factors, including climate, topography, vegetation cover, and human activities (e.g. Martínez -Freiría *et al.*, 2013; Mediani *et al.*, 2015). For instance, amphibians typically exhibit a strong preference for aquatic or semi-aquatic environments for breeding and larval development. In contrast, many reptiles, such as lizards and snakes, demonstrate broader ecological tolerance and can be found across a diverse range of habitats, including dense forests, open shrublands and rocky hillsides. Habitat selection is further influenced by factors such as food availability, predation risk, and the critical need for thermoregulation. Different species exhibit distinct patterns of habitat use based on their specific ecological adaptations and physiological requirements (Mediani *et al.*, 2015), and several species in the region exhibit strong microhabitat specialization, rendering them particularly vulnerable to environmental changes (Foden *et al.*, 2013). As human activities continue to alter the landscape, understanding these habitat selection patterns is crucial for effective conservation within the IBRM, particularly considering the effect of global changes (Martínez-Freiría *et al.*, 2013).

Therefore, this study aims to: 1) update the taxonomic list of amphibians and reptiles present within the Moroccan section of the IBRM, incorporating recent taxonomic revisions; 2) upgrade our understanding of the spatial distribution of amphibians and reptiles; 3) detect areas containing high species richness; and 4) investigate preliminary connections between land-cover variability and species distribution. The findings of this study are expected to contribute to the broader understanding of north Moroccan biodiversity and provide crucial support for efforts to maintain the ecological integrity of the IBRM in the face of increasing environmental pressures. Ultimately, this research aims to establish a robust framework for developing effective conservation strategies for amphibian and reptile populations within the Moroccan section of the IBRM.

Materials and Methods

Study area

The study area encompasses the Moroccan section of the Intercontinental Biosphere Reserve of the Mediterranean (IBRM), a UNESCO-designated transboundary reserve shared between Spain and Morocco. Established in 2006, the IBRM spans approximately one million hectares, extending from 4°41'24" W, 36° 57'29" N to 5°50'25" W, 34°47'38" N (Fig. 1). Bridging two continents, Europe and Africa, the reserve traverses the marine zone of the Strait of Gibraltar.

The Moroccan section of the IBRM exhibits a unique blend of European and Af-

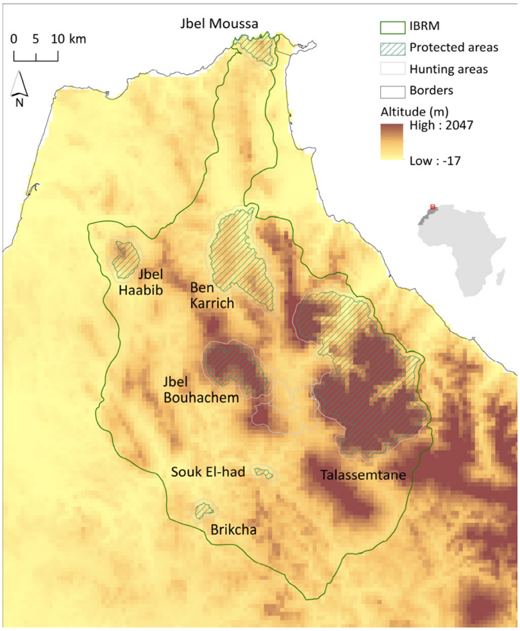

Figure 1: Limits of the Intercontinental Biosphere Reserve of the Mediterranean (IBRM) in north-western Morocco and protected areas and hunting areas in the region. (C).

rican biogeographic influences, resulting in diverse habitats. The region experiences a Mediterranean climate characterized by hot, dry summers and mild, wet winters. Temperatures vary significantly across the landscape, influenced by factors such as altitude and proximity to the coast. Winter temperatures typically range from 3°C to 14°C, while summer temperatures can reach 38°C. Annual precipitation varies considerably from 500 to 2000 mm, with higher amounts observed in mountainous regions (CLIMATE DATA, 2024).

This varied landscape supports a wide range of plant communities, including forests, woodlands, and shrublands. The IBRM is renowned for its exceptional biodiversity and cultural heritage. Key protected areas within this section include Talassemtane National Park, Bouhachem Natural Park; and several Sites of Biological and Ecological Interest (SIBE Ben Karrich, SIBE Brikcha, SIBE Souk el had, SIBE Jbel Haabib, SIBE Jbel Moussa, SIBE Souk el had).

Diversity of species

This study utilized the most up-to-date taxonomic information available for Moroccan amphibians and reptiles, incorporating recent revisions until 2023 (GENIEZ *et al.*, 2004; MARTÍNEZ DEL MÁRMOL *et al.*, 2019). The nomenclature follows the most recent taxonomic authorities (e.g. BEUKEMA *et al.*, 2013, 2015; MARTÍNEZ DEL MÁRMOL *et al.*, 2019; BOUAZZA *et al.*, 2021; MARTÍNEZ-FREIRÍA *et al.*, 2021).

This study relied on a comprehensive database that compiled available taxonomic and distributional data for amphibians and reptiles Morocco. This database, resulting from a concerted effort to collect and integrate data from multiple sources, serves as a valuable tool for studying Morocco's herpetological biodiversity. It was constructed using data from: 1) intensive field surveys conducted by the research teams at LESCOBIO (Faculty of Sciences, Tetouan, Morocco) and CIBIO (University of Porto, Portugal); 2) an exhaustive bibliographic review spanning from 1989 to 2024 (e.g. BONS & GENIEZ, 1996; FAHD, 2001; FAHD & MEDIANI, 2007; HARRIS *et al.*, 2008, 2024; BEUKEMA *et al.*, 2013; VELO-ANTÓN *et al.*, 2014; FAHD *et al.*, 2015; BEN HASSINE *et al.*, 2016; MARTÍNEZ DEL MÁRMOL *et al.*, 2019); 3) public databases (e.g. GBIF.ORG, 2025; UETZ *et al.*, 2025); and 4) information extracted from academic theses conducted in Moroc-

Table 1: Land cover categories and their availability in the study area, including the number of pixels (N) and percentage (%) occurrence (adapted from BUCHHORN *et al.*, 2020).

Land Cover Category	Code	N	%
Water bodies	WATE	2874	0.56
Trees	TREE	175820	34.47
Crops	CROP	94239	18.47
Built areas	BUIL	35973	7.05
Bare areas	BARE	855	0.167
Rangeland	RANG	200301	39.26

co and other unpublished sources (e.g. unpublished reports, personal communications, citizen science data). This comprehensive dataset allows for the identification of areas with high biodiversity and the assessment of potential population trends.

Diversity of species

Individual species distribution maps were generated for each recorded species. All data were georeferenced and mapped using ArcGIS 10.3 software (ESRI, Redlands, California, USA), using a 10 x 10 km UTM grid system. Then, species richness maps were created for amphibians, reptiles, and both taxonomic groups together. Richness maps were generated by overlaying individual species distribution maps within each 10 x 10 km grid cell.

Land-cover variation and species distribution

A high-resolution land cover map of NW Morocco was generated using Sentinel-2 imagery from the European Space Agency (ESA) (BUCHHORN *et al.*, 2020). Multispectral images with a 10 m resolution were utilized to classify different land cover types (Table 1). The images were georeferenced using ground control points to ensure accurate alignment with the geographic projection of the study area (UTM coordinates). A supervised classification method was then applied to categorize the land cover. Training samples were defined for each class, including forests, agriculture, urban areas, natural environments (e.g. scrubland, grasslands), and other relevant classes based on the local ecosystem. The accuracy of the classification was evaluated by comparing it to ground truth data collected in the field, alongside existing land cover data (BUCHHORN *et al.*, 2020; 100 m resolution; Table 1). The resulting land cover map was projected onto the study area using the local coordinate system (UTM) for optimal spatial accuracy; and to assess initial trends in habitat selection (Fig. S1). The analyses were performed using the Spatial Analyst tool functions within ArcGIS.

The species observations were cross-referenced with land cover maps using GIS tools. The geographic coordinates of the observations were overlaid onto land cover categories to determine the type of cover associated with each observation. Then, the percentage of observations in each category was calculated by dividing the number of observations per category by the total number of observations, and then multiplying by 100 to obtain a percentage distribution (following MEDIANI *et al.*, 2015).

RESULTS

Diversity of species

A total of 1244 observations were made of amphibians (N = 434) and reptiles (N = 810) within the IBRM (Table 2), totally documenting eight amphibian and 25 reptile species. Amphibians (eight species) belong to two orders, five families, and eight genera. *Salamandra algira* was the most frequently observed amphibian species (N = 98), while *Pleurodeles waltl* was the rarest one (N = 6). Reptiles (25 species) belong to two orders, 14 families, and 20 genera. *Hemorrhois hippocrepis* was the most frequently observed reptile species (N = 117), while *Psammodromus microdactylus* and *Chalcides polylepis* were the rarest ones.

Notably, the herpetofauna of the IBRM exhibits a high level of endemism, with approximately 30% of the recorded species being endemic to north-western Morocco (Table 2). Endemic species include *Alytes maurus*, *Blanus tingitanus*, *Discoglossus scovazzi*, *Chalcides colosii*, *Chalcides polylepis*, *Chalcides pseudostriatus*, *Psammodromus microdactylus*, *Saurodactylus faciatus*, and *Timon tangitanus*.

Distribution of species

Distribution maps for each of the eight amphibian and 25 reptile species present in the region are available in Figure S2. Three distinct distribution patterns can be observed among the amphibians and reptiles within the IBRM: 1) widespread species that exhibit relatively widespread distributions across the study area, including for example *Discoglossus scovazzi*, *Pelophylax saharicus*, *Acanthodactylus erythrurus*, or *Agama bibronii*; 2) species with restricted distribution, such as *Chalcides polylepis*, *Psammodromus microdactylus*, and *Psammophis schokari*; 3) species with limited or fragmented distributions, including *Alytes maurus*, *Bufo spinosus*, *Hyla meridionalis*, *Blanus tingitanus*, *Chamaeleo chamaeleon*, or *Saurodactylus fasciatus*.

Local hotspots of herpetofaunal richness were identified in the Talassemtane National Park and Jbel Bouhachem for amphibians, and in the southeast of the SIBE of Ben Karrich, the southeast of Jbel Bouhachem, and the southwest of the Talassemtane National Park for reptiles (Fig. 2).

Land-cover associations

Analysis revealed at least four main patterns of habitat association among the herpetofauna within the IBRM (Table 1, Fig. S1): 1) species associated with mosaics of vegetation, including forests, shrublands, and grazing lands, which included the amphibians in general and the reptile families Sphaerodactylidae and Chamaeleonidae, together with other reptiles (e.g. *Acanthodactylus erythrurus*, *Blanus tingitanus*, *Podarcis vaucheri*, *Psammodromus algirus*, *Timon tangitanus*, and *Emys orbicularis*); 2) species associated with a mix of forest edges and agricultural landscapes, such as *Natrix astreptophora*, *Macroprotodon brevis*, *Hemorrhois hippocrepis*, *Chalcides pseudostriatus*, and *Chalcides colosii*; 3) species exhibiting a broad range of habitat preferences, adapted to a variety of environments, such as *Natrix maura*, *Pelophylax saharicus*, *Salamandra algira*, *Mauremys leprosa*, and *Agama bibronii*; and 4) species demonstrating a strong preference for open habitats, including grasslands and

Table 2: Taxonomic list of the amphibians and reptiles observed in the Moroccan section of the Intercontinental Biosphere Reserve of the Mediterranean (IBRM). N: number of observations, UTM: number of 5 x 5 km grid cells where each species was observed, %: percentage of occupied area, and the percentage of observations in each land cover category (see Table 1 for land cover category abbreviations). IUCN Red List category (IUCN, 2024) (EN: Endangered, VU: Vulnerable, LC: Least Concern, NT: Near Threatened). Asterisks (*) indicate endemic species.

Family and species	N	UTM	%	WATE	TREE	CROP	BUIL	BARE	RANG	IUCN
Alytidae										
*Alytes maurus**	65	30	12.3		18	13	7		27	EN
*Discoglossus scovazzi**	66	37	15.2		30	11	5		20	LC
Bufonidae										
Bufo spinosus	38	30	12.3		18	8	3		9	LC
Sclerophrys mauritanica	62	56	23.0		16	10	4		32	LC
Hylidae										
Hyla meridionalis	45	28	11.5		24	4	3		14	LC
Ranidae										
Pelophylax saharicus	54	44	18.0	1	19	9	6	1	18	LC
Salamandridae										
Pleurodeles waltl	6	5	2.0		2	2			2	LC
Salamandra algira	98	50	20.5		43	7	11	1	36	VU
Agamidae										
Agama bibronii	27	23	9.4		8	7	5		7	LC
Blanidae										
*Blanus tingitanus**	16	12	4.9		8	3			5	LC
Chamaeleonidae										
Chamaeleo chamaeleon	14	7	2.9		57.1				42.9	LC
Colubridae										
Coronella girondica	26	16	6.6		53.9	11.5	15.4		19.2	LC
Hemorrhois hippocrepis	117	50	20.5		34.1	30.8	7.7		27.4	LC
Macroprotodon brevis	48	21	8.6							LC
Emydidae										
Emys orbicularis	18	13	5.3		7	3	2		6	NT
Geoemydidae										
Mauremys leprosa	29	22	9.0		12	2	5	1	9	VU
Lacertidae										
Acanthodactylus erythrurus	27	24	9.8		10	6	2		9	LC
Podarcis vaucheri	56	37	15.2		35.7	17.9	10.7		35.7	LC
Psammodromus algirus	64	55	22.5		43.8	15.7	6.2		34.3	LC
*Psammodromus microdactylus**	1	1	0.4		100					EN
*Timon tangitanus**	74	37	15.2		41.8	14.8	10.8	2.8	29.8	LC
Lamprophiidae										
Malpolon monspessulanus	60	29	11.9		16	13	9		22	LC
Psammophis schokari	4	1	0.4						100	LC
Natricidae										
Natrix astreptophora	21	8	3.3		8	7			6	NT
Natrix maura	75	40	16.4	4	27	13	10	2	19	LC
Phyllodactylidae										
Tarentola mauritanica	36	31	12.7		13	9	4		10	LC
Scincidae										
*Chalcides colosii**	26	16	6.6		7	9	3		7	LC
*Chalcides polylepis**	1	1	0.4						100	LC
*Chalcides pseudostriatus**	5	5	2.0		20	40	20		20	NT
Sphaerodactylidae										
*Saurodactylus fasciatus**	6	3	1.2		33.3				66.7	VU
Testudinidae										
Testudo graeca	33	22	9.0		14	9	4		6	VU
Viperidae										
Daboia mauritanica	6	6	2.5		16.7		16.7		66.6	NT
Vipera monticola	20	18	7.4		10	2	3		5	VU

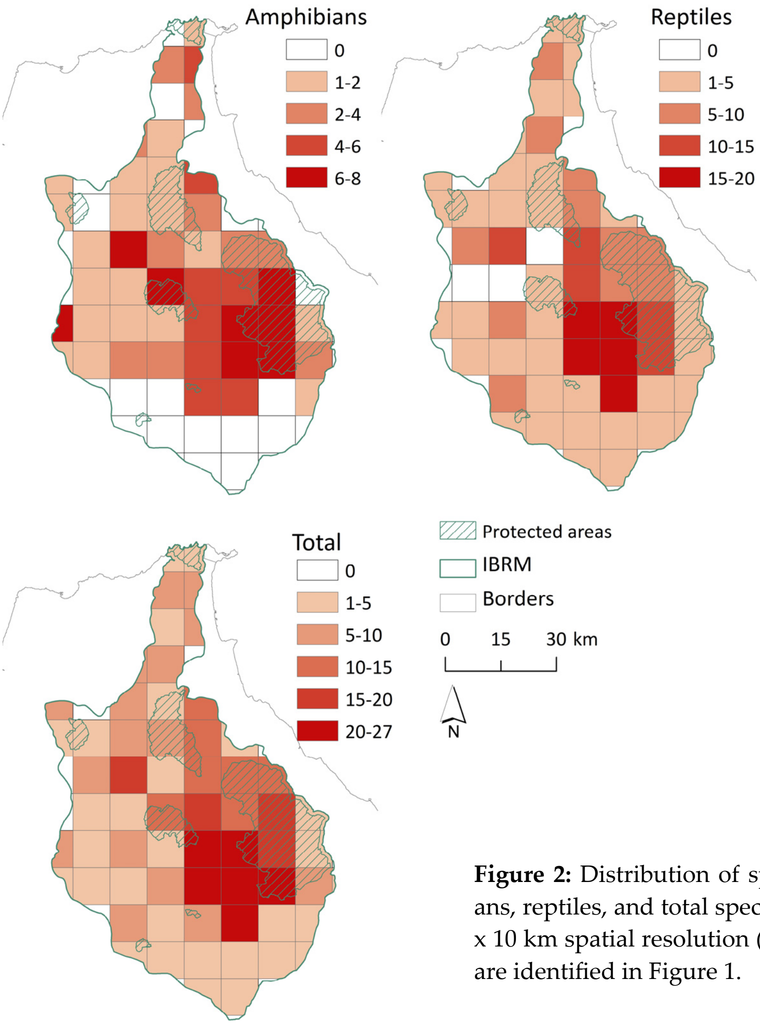

Figure 2: Distribution of species richness of amphibians, reptiles, and total species within the IBRM, at a 10 x 10 km spatial resolution (UTM grid). Protected areas are identified in Figure 1.

rocky outcrops, such as *Alytes maurus*, *Chalcides polylepis*, *Daboia mauritanica*, and *Saurodactylus fasciatus*.

DISCUSSION

Diversity of species

This study documented eight amphibians and 25 reptiles in the IBRM, representing 60% and 24% of the total species recorded in Morocco, respectively (*sensu* MARTÍNEZ DEL MÁRMOL *et al.*, 2019). The Lacertidae family is identified as the most diverse reptile group, accounting for 28% of all reptiles observed within the IBRM.

Approximately 30% of the recorded species in the IBRM are endemic to Morocco, highlighting the unique character of this biodiversity hotspot. Endemism is particularly pronounced within the families Scincidae, Sphaerodactylidae, Lacertidae (three species each), and Alytidae (two species). This high level of endemism can be attributed to the variety and specificity of environmental habitats within the IBRM. The region encompasses a diverse range of ecosystems, including mountains, plains, coastal areas, forests, rivers, and a mosaic of natural and cultural landscapes, creating unique ecological niches for specialized species (Fig. S1). This unique biodiversity of northern Morocco, particularly in the IBRM, stems from a combination of historical and ecological factors. The Atlas uplift and paleo-land bridges with Europe (notably during the Messinian Salinity Crisis, 5.96-5.33 Ma) facilitated transcontinental reptile colonisations, as evidenced by biogeographic affinities between Moroccan and Iberian herpetofauna, posteriorly leading to vicariant processes (e.g. VEITH *et al.*, 2006; MARTÍNEZ-FREIRÍA *et al.*, 2020; ENRIQUEZ-URZELAI *et al.*, 2022). Subsequent Plio-Pleistocene climatic oscillations isolated populations within the IBRM's mountain ranges (Rif), which reinforced the region's high endemism (STUCKAS *et al.*, 2014; DINIS *et al.*, 2019; ARGAZ *et al.*, 2020; MARTÍNEZ-FREIRÍA *et al.*, 2020).

The IBRM's Mediterranean ecosystem mosaic (oak forests, wetlands, mountains) plays a pivotal role in maintaining this historically generated diversity. The reserve's microhabitats harbour relict lineages like the endemic lizard *Podarcis vaucheri* (BARATA & HARRIS, 2015) and North African fire salamander *Salamandra algira* (DONAIRE-BARROSO & BOGAERTS, 2003; VEITH *et al.*, 2004; DINIS *et al.*, 2019), while altitudinal gradients enable coexistence of ecologically divergent species (for example between the dry-adapted and humid-adapted Mediterranean vipers of the genera *Daboia* and *Vipera*, respectively; BRITO *et al.*, 2011). This transcontinental zone thus serves as both a natural laboratory for evolutionary processes and a priority conservation hotspot (BRITO *et al.*, 2014).

Distribution of species

Amphibian species richness hotspots were primarily located within or adjacent to protected areas, notably Talassemtane National Park and Bouhachem Natural Park. However, some species-rich sites are found outside these protected areas, such as the north-western part of Jbel Bouhachem or the extreme western section of the IBRM (Fig. S2). Reptile species richness hotspots were more widely distributed, occurring both within and outside protected areas (Fig. S2).

This study revealed three fascinating patterns in how amphibians and reptiles are spread across Morocco's IBRM region. First, some generalist species like *Discoglossus scovazzi* and *Acanthodactylus erythrurus* have made themselves at home across wide areas, thriving in various environments, from river valleys to arid scrublands. On the other hand, specialists like *Chalcides polylepis* and *Psammodromus microdactylus* stick to particular habitats, such as the humid cedar forests of Talassemtane, where decaying logs offer near-optimal niche conditions for the thermoregulation of *Chalcides polylepis*. More concerning are species like *Alytes maurus* and *Blanus tingitanus*, whose populations appear scattered and vulnerable, possibly due to habitat loss or their strict environmental needs, particularly the degradation of mountain streams and moist leaf litter microhabitats that these species depend on (MEDIANI *et al.*, 2015). It should be noted that amphibians are mainly found in protected areas such as the Talassemtane National Park and Jebel Bouhachem, while reptiles are more abundant in the rugged south-east of Ben Karrich. This distribution highlights the essential role of these conservation areas in preserving Morocco's unique fauna, especially as habitat degradation threatens biodiversity outside these areas.

Significant sampling gaps persist across the IBRM, particularly in three key areas: the SIBE Jbel Haabib region, the corridor between SIBE Ben Karrich and Jbel Moussa, and the southern and western sectors of the IBRM. Our study reveals a strong sampling bias towards Protected Areas, with the majority of collected data originating from Talassemtane National Park, Bouhachem Natural Park, SIBE Ben Karrich and the area between Talassemtane and Bouhachem Parks. This uneven coverage has created substantial knowledge gaps about species distributions in intervening areas and ecological corridors. To develop a comprehensive understanding of biodiversity distribution patterns across the entire IBRM landscape, targeted surveys must be conducted in these underrepresented zones, particularly focusing on connectivity areas between existing protected sites.

Land-cover associations

Regarding habitat selection patterns, the main findings are corroborated by previous work on the subject (e.g. BONS & GENIEZ, 1996; FAHD & PLEGUEZUELOS, 2001; MEDIANI *et al*. 2015). Amphibians predominantly inhabit humid, high-productivity habitats within protected areas, while some species are found in adjacent habitats characterized by mosaics of cultivated and natural vegetation. Conversely, the southern and south-western parts of the IBRM, characterized by drier conditions and open grasslands, generally exhibited lower amphibian diversity (Table 2). This likely reflects the scarcity of suitable breeding sites in these regions. While our data suggests that cultivated lands may serve as breeding habitats for some amphibian species, as observed in other Mediterranean regions (e.g. DE POUS *et al*., 2011; BEUKEMA *et al*., 2013; MEDIANI *et al*., 2015), further investigation is needed to confirm this observation in the IBRM.

For reptiles, there appear to be three species groups based on their habitat selection patterns: 1) species occupying the temperate plains regions in the south and southwest of the IBRM, dominated by grazing lands or agricultural lands; 2) generalist species, which typically have a wide distribution throughout the majority of the IBRM; and 3) species occupying forested environments, which are generally abundant in protected areas, particularly Talassemtane National Park in the east, Bouhachem Natural Park in the centre, and SIBE of Ben Karrich in the north.

Overall, the distribution patterns observed for amphibian and reptile richness were generally quite similar. The highest species richness was found in an area located between Talassemtane National Park, Bouhachem Natural Park , the Souk El Had SIBE, and the Ben Karrich SIBE. These territories, situated in the southeastern part of IBRM, correspond to the most humid bioclimatic zone of the study area and also host rich and diverse forest communities, including *Abies marocana*, *Cedrus atlantica*, *Quercus suber*, *Quercus ilex*, *Quercus canariensis*, and *Quercus fruticosa* (VALDÉS *et al*., 2002). These territories tend to harbour species of diverse biogeographic origins, resulting in high species richness. These species include those with Mediterranean and Palearctic affinities, stemming from faunal exchanges between Africa and Europe over geological time (STEININGER *et al*., 1985; MEDIANI *et al*., 2015).

Conservation

The IBRM's herpetofauna highlights the critical need for conservation initiatives. Establishing additional protected areas and reserves that prioritize representation objectives (MARGULES & PRESSEY, 2000; MARGULES & SARKAR, 2007) is essential. These efforts should align with Morocco's national strategy for the protection of its fauna and flora, ensuring the preservation of the IBRM's unique herpetofauna as part of the global biological heritage.

Indeed, it is worth noting that among the 33 species identified in the IBRM, two are considered as "Endangered" (*Alyles maurus*) and (*Psammodromus microdactylus*), five are currently classified as "Vulnerable" (*Salamandra algira*, *Mauremys leprosa*, *Saurodactylus fasciatus*, *Testudo graeca*, *Vipera monticola*) and eight are both rare and "Nearly Threatened" (*Bufo spinosus*, *Pleurodeles waltl*, *Chalcides pseudostriatus*, *Daboia mauritanica*, *Emys orbicularis*) according to the IUCN Red List of Threatened Species (IUCN, 2024). In addition, *Psamodromus microdactylus* is considered one of the rarest Lacertidae species in Morocco (SCHLEICH *et al*., 1996; CROCHET *et al*., 2004; MARTINEZ DEL MÁRMOL *et al*., 2019).

It is important to highlight growing concerns for Moroccan amphibians and reptiles threatened by habitat loss and illegal wildlife trade. Unfortunately, mountain rivers are often disturbed by water exploitation for irrigation, extraction from springs and wells, leading to the desiccation of basins, as well as organic water contamination from livestock in rural areas or urban wastewater. These factors could have considerable consequences for Moroccan herpetofauna (habitat degradation and loss, water contamination and direct mortality, disruption of biological cycles, biodiversity decline and population collapse and cascading effects on ecosystems (EL KOURCHI *et al*., 2025). Certain characteristics of these species, such as ectothermic physiology, sensitivity to temperature fluctuations (POUGH, 1980), and limited dispersal ability (POUGH, 1980; SINERVO *et al*., 2010), make them particularly vulnerable to these disturbances. For example, the endangered species *Alytes maurus* benefits from protection in Talassemtane National Park and Bouhachem Natural Park, but its survival could be jeopardized by these ongoing environmental pressures.

Habitat loss indeed acts synergistically with illegal collection for the international exotic pet trade, which has further exacerbated species decline, with high mortality rates during smuggling attempts (CHALLENDER *et al*., 2023). This is noticeable for three emblematic species inhabiting the IBRM: *Salamandra algira* (North African fire salamander), *Hyla meridionalis* (Mediterranean tree frog), and *Vipera monticola* (Atlas Mountain viper). *Salamandra algira*, listed on CITES Appendix III since

2023, has suffered a 30% population decline over the past decade due to forest habitat degradation in its Rif Mountain stronghold (UNEP-WCMC, 2024). While not currently CITES-listed, *Hyla meridionalis* faces increasing collection pressure for the European pet trade, with numerous seizures reported at Moroccan ports (UNEP-WCMC, 2024). *Vipera monticola*, endemic to the Maghreb, and with more than 80 % of the records and most of the known genetic diversity occurring in Morocco, is endangered due to habitat fragmentation from overgrazing and climate change (MARTÍNEZ-FREIRÍA *et al.*, 2023, 2024).

Furthermore, the illicit cultivation of cannabis poses a severe threat to both the water resources and the surrounding habitats in the region (CHERGUI *et al.*, 2024). The illegal cultivation of cannabis often involves the use of harmful agrochemicals and the diversion of water from natural sources to irrigate crops. This not only leads to the degradation of water quality but also reduces the availability of water for other species, including those of amphibians and reptiles that are highly sensitive to changes in water availability (CHERGUI *et al.*, 2024). Moreover, large-scale illegal farming often takes place in sensitive ecosystems, such as forests and riparian zones, leading to soil erosion, habitat destruction, and fragmentation. These activities disturb the natural habitat, making it harder for wildlife to thrive. The destruction of natural vegetation and the alteration of water flows associated with illegal cultivation contribute to long-term ecological damage, threatening the survival of the region's biodiversity.

Consequently, it is crucial to create new protected areas for the many amphibian and reptile species (NORI *et al.*, 2015, 2018) living outside the already protected zones (COX & UNDERWOOD, 2011) (e.g. *Pleurodeles waltl*, *Psamodromus microdactylus*, *Chalcides polylepis*, *Chalcides pseudostriatus* and *Vipera monticola*). These new areas should be subject to scientific studies aimed at cataloguing the species residing there, particularly those that are threatened like *Psamodromus microdactylus*, *Chalcides pseudostriatus* and *Vipera monticola*. The establishment of new species distribution maps for herpetofauna in these new protected areas would be highly beneficial for monitoring and protecting species threatened by climate and water stress related to climate change (BINGHAM *et al.*, 2021). Additionally, the creation of ecological corridors plays a fundamental role in reducing the fragmentation of habitats (HIDALGO *et al.*, 2021). These corridors enable species to move between isolated habitats, ensuring genetic exchange, better adaptation to changing environments, and access to resources such as food and breeding grounds (HILTY *et al.*, 2020; GREGORY *et al.*, 2021). Without such corridors, isolated populations are at risk of inbreeding, reduced genetic diversity, and even extinction (MARGULES & SARKAR, 2007; MARTÍNEZ-FREIRÍA *et al.*, 2023). All these measures would allow for the conservation of biodiversity across larger landscapes, enhancing the resilience of ecosystems.

Conclusions

The findings of this study emphasize the importance of targeted conservation strategies, such as micro-reserves, in safeguarding endemic and endangered species while addressing habitat loss. By integrating spatial data with on-the-ground protection efforts, this approach can enhance biodiversity preservation in vulnerable ecosystems like the IBRM. Such measures not only support species recovery but also contribute to broader ecological resilience in the face of increasing environmental pressures.

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