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Endemic scorpion species and subspecies in Morocco: A comprehensive overview

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ABSTRACT

Scorpion fauna is abundant in regions with arid and semi-arid climates, exposing these areas to a risk of envenomation, especially for children. Scorpion envenomations cause thousands of deaths each year, with notable incidences in the MENA region, South America, Latin and Central America, and India. Morocco is one of the countries most affected by this phenomenon; according to statistics from the Moroccan Poison Control and Pharmacovigilance Center (CAPM), approximately 8565 scorpion stings and envenomations were recorded annually between 2016 and 2022, mainly among children. A literature review was conducted to identify and catalog the endemic scorpion species in Morocco and explore the impact of climate change on their distribution. Sources included scientific journal articles, university theses, and field reports. The collected data were compiled and analyzed to create a distribution map of the endemic species. Our results identified fifty-five endemic species and subspecies in Morocco. The family Buthidae is the most widespread, with seventeen endemic species of the genus Buthus, nine of the genus Androctonus, five of the genus Butheoloides, four of the genus Buthacus, two each of the genera Orthochirus, Compsobuthus, and Hottentota, and one species each of the genera Microbuthus, Cicileiurus, and Saharobuthus. The family Scorpionidae includes nine endemic species, and two subspecies belonging to the genus Scorpio. A high level of endemism is observed in southern Morocco, highlighting a significant concentration of these species in this region. Ongoing climate change is likely to expand the population and distribution of scorpions, as well as the number of envenomations. The results underscore the importance of implementing control and prevention strategies to reduce the risks of envenomation, particularly in the context of climate change. Therefore, to develop management and prevention strategies is based on a thorough understanding of species distribution and their habitats to improve the safety of vulnerable populations.

1. Introduction

Scorpion sting pose significant medical challenge, particularly in tropical and subtropical regions. Annually, approximately 1,5 million cases of scorpion stings are reported worldwide, with an estimated mortality rate of about 2600 deaths per year due to scorpion envenomation. The highest incidence of stings occurs in four highly endemic regions, including Mexico, the eastern Andes of South America, North Africa, and the Middle East (Chippaux, 2009, 2012; Isbister and Bawaskar, 2014). Currently, a total of 24 scorpion families, comprising approximately 2800 species, have been identified (Rein, J.O., 2023). The MENA(Middle East and North Africa) region is particularly notable for its high know scorpion diversity, ranking among the most diverse globally (Jenkins et al., 2021; Lourenço, 2015). This remarkable diversity is likely a result of evolutionary adaptations to the arid climate conditions prevalent in the region (Lourenço, 2018). According to Ward et al.; Kazemi and Sabatier; Rein; Jenkins et al.; Kazemi et al.; and Baradaran et al.; Morocco harbors the highest number of endemic

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scorpion species (specific to Morocco) in the MENA region indicating their exclusive distribution within the country after Iran(Bardaran et al., 2024; Jenkins et al., 2021; Kazemi et al., 2024; Kazemi and Sabatier, 2019; Rein, J.O., 2023; Ward et al., 2018). 73% of which are endemic, are represented by 68 species and subspecies in the Moroccan scorpiofauna collection (Touloun, 2019; Touloun et al., 2024). This remarkable diversity is primarily found within the Buthidae and Scorpionidae families, particularly frequent in the southern regions of the country, which are characterized by high levels of endemism (el Hidan et al., 2021). while the majority of Moroccan species have been recorded, the inventory remains provisional; further studies are necessary to refine the classification of certain species and clarify their distribution, especially concerning endemic Moroccan species (Touloun et al., 2016b). This effort is crucial for developing effective adaptive strategies to manage potential risks associated with scorpion envenomations.

This study plays a vital role in improving the management and awareness of scorpion stings in Morocco. By collating and analyzing existing data on the distribution and taxonomy of endemic scorpion species in Morocco; the study while identify gaps knowledge gaps that need addressing to enhance public health responses. Additionally, it will explore the potential impacts of climate change on the distribution of scorpion and the incidence of envenomations, as rising temperatures may increase human exposure to these venomous species.

This comprehensive approach aims to inform local health authorities and policymakers, leading to the implementation of targeted educational campaigns and preventive measures that can mitigate the risks associated with scorpion stings in vulnerable communities.

2. Material and methods

2.1. Ecology of the study area

Morocco, located at the northwestern edge of Africa, is bordered by the Atlantic Ocean to the west and the Mediterranean Sea to the north. It shares land borders with Algeria to the east and Mauritania to the south. This strategic location enables Morocco to encompass a diverse array of ecosystems, including forests, steppes, Saharan regions, marine and coastal areas, inland waters, and caves (Elmourid et al., 2023a; Touloun et al., 2001). These varied environments support a rich array of flora and fauna, including many endemic species, contributing to Morocco's exceptional biodiversity. The country hosts more than 24,000 animal species and 7000 plant species, 1700 of which are rare or threatened, with an overall endemism rate of 11% for animals and more than 20% for vascular plants (ONEM, n.d.).

2.2. Research strategy

We conducted a bibliographic search using PubMed, Google Scholar, Web of Science, and ScienceDirect databases. Within this search, we employed various keyword combinations, including "scorpion fauna in Morocco", "specific composition and geographical distribution of scorpions in Morocco", "scorpion species endemic to Morocco" and "Effects of climate on scorpion distribution in Morocco". We selected only the articles that specifically focused on species endemic to Morocco.

2.3. Inclusion and exclusion criteria

The inclusion criteria required that articles identify scorpion species endemic to Morocco and provide data on the geographical distribution; exclusion criteria included articles that did not clearly present information on the presence of endemic scorpion species in Morocco, as well as publications focused on other arachnids and insects or other countries, reviews, and meta-analyses.

2.4. Analysis strategy

The analyses and representations required for this study is based on a combination of tools, including Python, and Mapchart. The percentage of scorpion genera and regions where they are most widespread were calculated from the data collected and entered into Excel. Using appropriate formulas, we determine the exact proportions by dividing each individual value by the corresponding total and multiplying by 100, to ensure optimal accuracy.

To create our cartography, we used Mapchart to visually represent the geographical distribution of scorpion families; based on the geographical locations identified in the Excel data from the literature search. This method produced clear and informative cartographic representations and figures, which facilitated the interpretation of the study results.

3. Results

3.1. Research characteristics

The current search follows the guidelines of the PRISMA statement (Fig. 1). A systematic search of PubMed, ScienceDirect, Google Scholar and Web of Science was carried out screening a total of 9437 articles to select those containing relevant data. 9403 articles were. excluded from the analysis due to lack of relevance, as they only mentioned search terms such as scorpion, Morocco, and climate in the title or abstract, without any relation to our inclusion criteria. After a thorough review, 7852 articles were excluded due because they were reviews, meta-analyses, editorials, encyclopedias, book chapters, or duplicates. An additional 1551 articles did not specify whether the scorpions studied were endemic to Morocco; or dealt with no-Moroccan species, other insects, or the climate with some other phenomenon. Ultimately, 34 articles met our criteria and were included in our systematic review.

3.2. Moroccan scorpion fauna

The epidemiology of scorpions in Morocco is marked by distinctive features due to the diversity of scorpion species present in different regions of the country. There are 68 species and subspecies in the Moroccan scorpion fauna collection (Touloun et al., 2024), classified into two families: Buthidae, which is the most dangerous due to its inclusion of the most venomous species (Aboumaâd et al., 2014a) (Table 1), and the Scorpionidae family. Fifty-five of the species that have been identified are endemic to Morocco with a percentage of 80.88%. The Buthidae family, which accounts for 80% of the scorpions endemic to Morocco, Buthus, Androctonus, Butheoloides, Buthacus Hottentota, Orthochirus, Compsobuthus, Cicileiurus, Microbuthus, and Saharobuthus are among the ten genera that are included in this family. However, there is only one genus (Scorpio) in the Scorpionidae family, which makes up 20% of the fauna (Fig. 2A). This genus is found throughout Morocco, with its various species and subspecies; and is especially widespread in the southern and central regions, where the climatic conditions are favorable for its development. The distribution of these arthropods by genus shows that Buthus represents the largest proportion, accounting for 30.90% of Morocco's endemic scorpions, followed by Scorpio at 20%, and Androctonus in third place with 16.36%. The remainder of the species is distributed among Butheoloides, Buthacus, Orthochirus, Compsobuthus, and Hottentota; 9.09%, 7.27%, and 3.63%, respectively. The genera Saharobuthus, Microbuthus and Cicileiurus have the lowest representation, each constituting 1.81% (Fig. 2B).

3.3. Distribution analysis of the endemic scorpion of Morocco

The majority of high species richness localities are situated in the arid and semi-arid regions of Morocco(el Hidan et al., 2021).Our

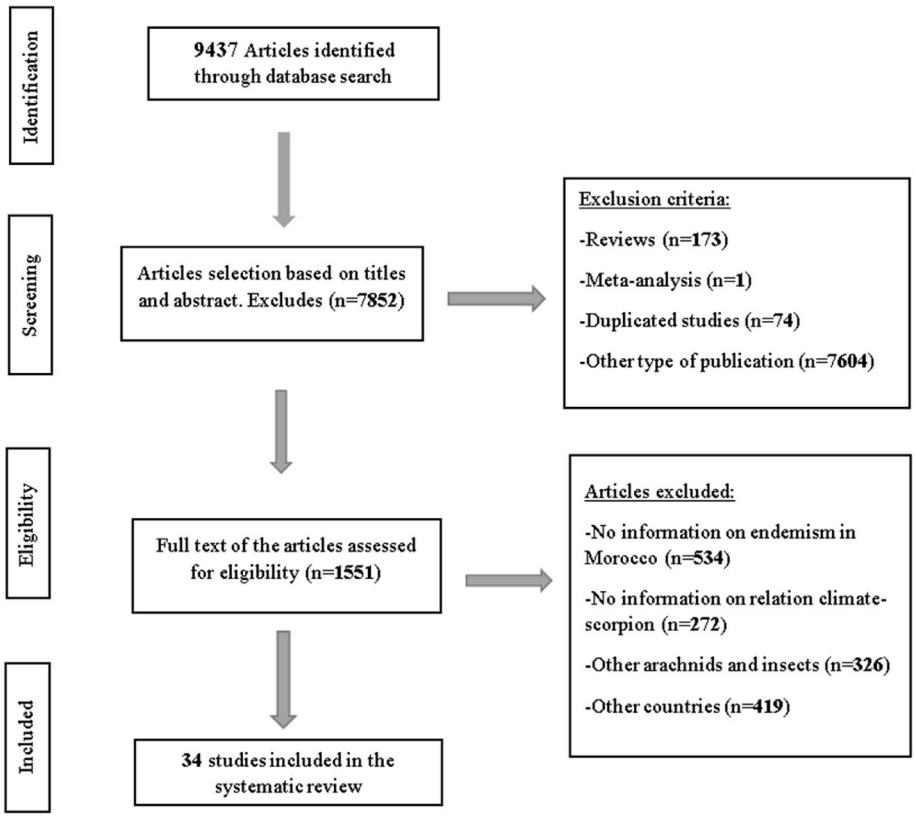

Fig. 1. Diagram of eligible studies.

Table 1
Distribution of the most venomous Moroccan scorpion.

Family	Species	Photograph location	Climate
Buthidae		Tinghir province	Arid
	Androctonus liouvillei		
		Temara, Rabat	Arid to semi-arid
	Androctonus mauritanicus		
		Haouz plain, El kalâa des Seraghna, Chichaoua	Arid to semi-arid
	Buthus malhommei (Touloun et al., 2012)		
		Tinghir province	Arid
	Hottentotta gentili		

findings indicate that 42.22% of all endemic scorpions are found in southern Morocco (Fig. 3A), highlighting their preference for warm, dry environments typical of the region's arid climate. Central Morocco also hosts a significant scorpion population (40%), suggestingting that its conditions are similarly favorable. In contrast, northern Morocco, characterised by a humid to sub-humid climate, has the lowest scorpion population (17.77%), This distribution aligns with paleogeographical and palaeoclimatological patterns, as Vachon noted (Max Vachon, 1952).

Specifically, the presence of the Buthidae family was dominant, it represents 59.37% of the scorpion fauna of southern Morocco. In the center, this family accounts for 40.62% of scorpions, and only 12.5% in the north. The family Scorpionidae is absent in the south, but present in the north, where it comprises 57.14% of the scorpion species, and 42% in the center of the country. This distribution of scorpion families highlights the areas most at risk from envenomation for human populations. The southern regions, in particular, are more exposed to scorpions of the Buthidae family, known for their powerful and potentially dangerous venom for humans.

More specifically (Fig. 3B), the Buthidae family comprises ten genera of scorpions endemic to Morocco. The genus Buthus is the most endemic with 17 species; it is followed by the genus Androctonus with ten species considered endemic to Morocco until proven otherwise. This is due to doubts about the taxonomic species validity of this genus (Table 2); The genus Butheoloides contains five species, with Buthacus by four endemic species, Orthochirus, Compsobuthus, and Hottentota, which each have two endemic species and the last on the list, the genera Microbuthus, Cicileiurus and Saharobuthus which each have one endemic species to Morocco, are particularly abundant in the Guelmim-Oued Noun region, with equally large populations in the Souss Massa and Drâa-Tafilalet regions. The Marrakech-Safi and Béni Mellal-Khénifra regions also have significant populations of these scorpions. Conversely, their presence in the Laâyoune-Sakia El Hamra, Dakhla-Oued Ed-Dahab, Casablanca-

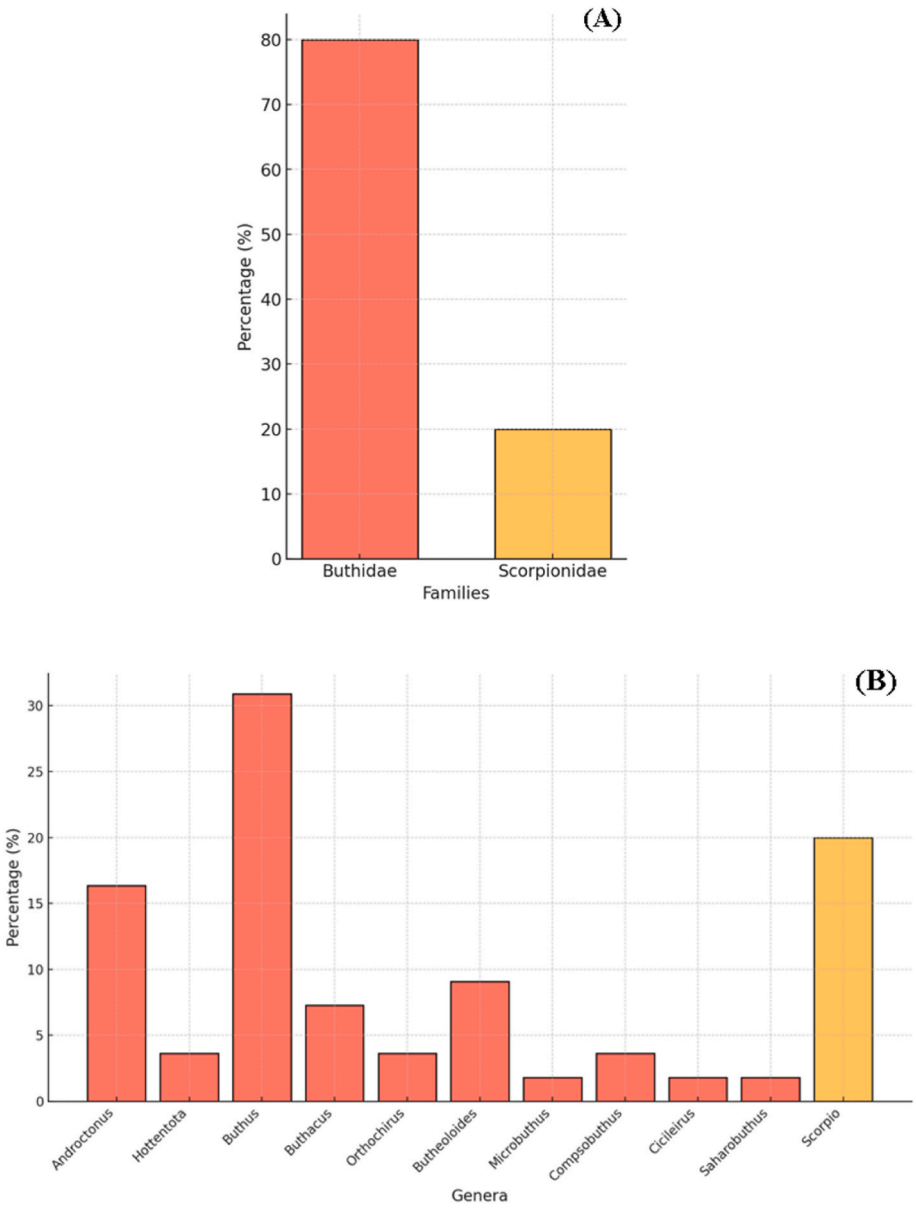

Fig. 2. (A). Proportions of the Moroccan-endemic scorpion family; (B). Proportions of Morocco-endemic scorpion genera.

Settat, Rabat-Salé-Kénitra, Tanger-Tétouan-Al Hoceima and l'Oriental regions is less notable than in the regions mentioned above. The Fès-Meknès region is particular in that it does not have a significant abundance of this family of scorpions (Fig. 4).

However, the Scorpionidae family, represented by the single genus Scorpio, has eleven endemic species that are particularly abundant in the Oriental region, followed by Béni Mellal-Khénifra, Tangier-Tétouan-Al Hoceima, Marrakech-Safi and Rabat-Salé-Kénitra. At the same time, this family is virtually absent in the other regions (Fig. 3C).

The distribution of scorpion species generally depends on a range of climatic and environmental factors, including temperature, precipitation, altitude, slope, aspect, soil properties, vegetation type and land cover. They tend to be more abundant in deserts and arid regions, where cold climates are unfavorable for their proliferation (Sadine et al., 2012). As a result, there is a monthly variation in scorpion envenomations, with the dry season presenting the highest risk(Touloun et al., 2012). In addition, climate change is making conditions more favorable for scorpions, with a transition from hot months to whole years of warmth. In this way, as climate change affects the composition of scorpion assemblages it also increases the incidence of scorpion siting (Ghorbani et al., 2021; Lira et al., 2020). As indicated, the Buthidae family, which is the most abundant, thrives in regions with warm, dry climates, which prevail in most of the country. Whereas, the Scorpionidae family is mainly found in the Oriental region, where the climate is Mediterranean. This climatic variation explains the greater abundance of Buthidae compared to Scorpionidae in Morocco; and their monitoring of toxic incidents. On this basis, climate is the ecological factor that impacts the distribution of scorpions, while temperature is the main factor controlling their distribution (Hidan et al., 2017).

4. Discussion

Morocco is home to fifty-six endemic scorpion species and subspecies. Our results demonstrate a correlation between the distribution of scorpion species and climatic zones, with greater diversity observed in arid climates. These observations are consistent with previous studies, such as Vachon and El Hidan et al., who reported that environmental factors influence the distribution of scorpions in Morocco (Hidan et al., 2017; Max Vachon, 1952). The southern and central regions of Morocco are particularly rich in scorpions, including some of the most dangerous

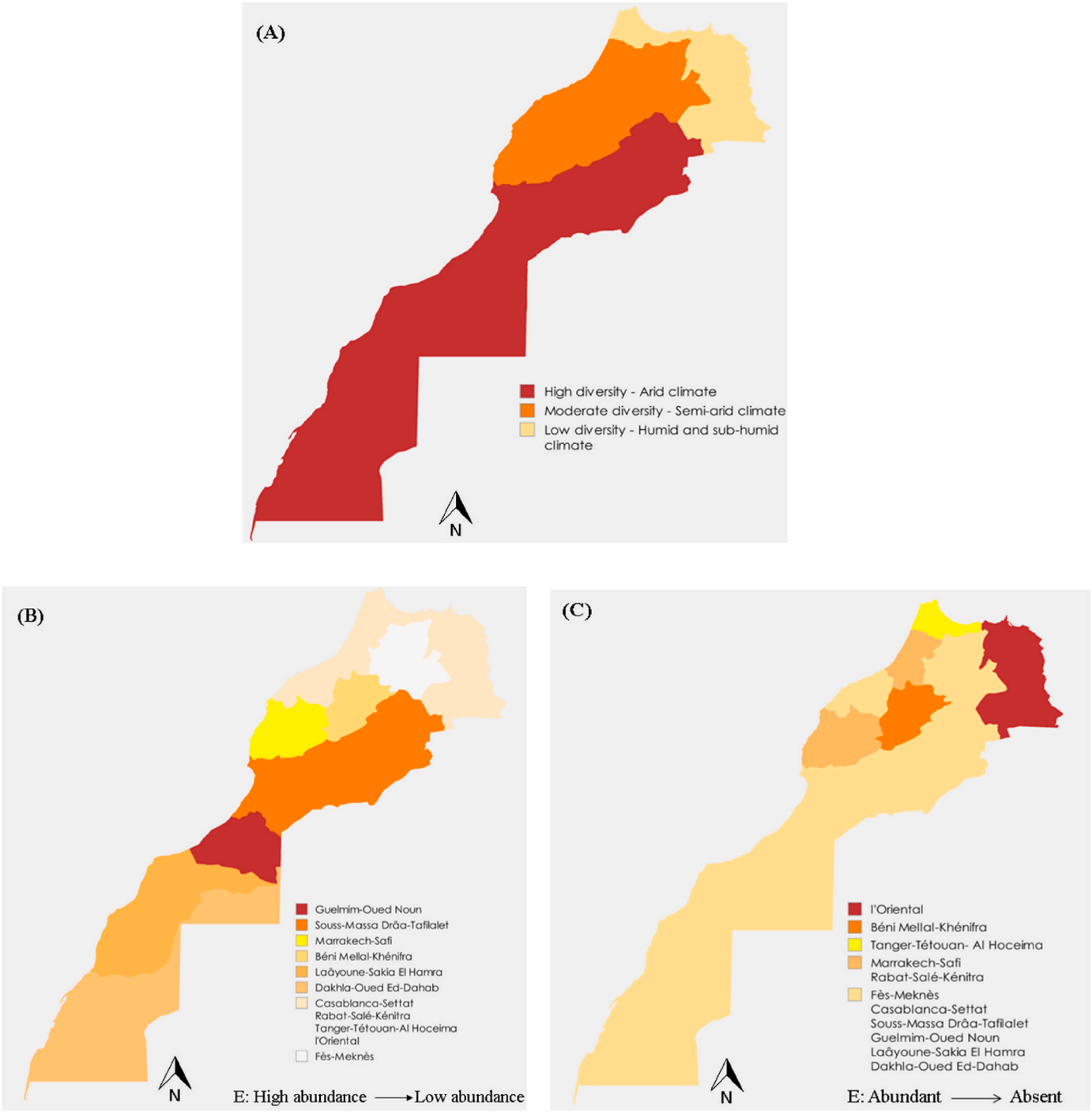

Fig. 3. (A) Map of scorpion distribution in Morocco by climate zones. (B) Distribution of Moroccan buthidae family. (C) Distribution of Moroccan scorpionidae family.

species. These data align with the high rates of scorpion envenomation, which are the main cause of poisoning in Morocco according to the Moroccan Anti-Poison Centre, mainly in the regions of Marrakech-Safi, Souss-Massa, Béni Mellal-Khénifra and Drâa-Tafilalet(El Oufir Rhizlane, 2022). However, it is also essential to consider the southern regions of Morocco, which are high risk areas home to venomous endemic scorpion species. It is crucial to recognize while some scorpion stings result in mild reactions, others provoke cause severe symptoms, including death. The severity envenomation and the associated mortality rates are closely tied to, the age of the victims, as the immaturity of physiological systems compromises the body's defenses against severe insults. Critical factors include the venom dose in relation to body weight, with the venom's composition being a key determinant, which varies by scorpion species and their geographic distribution (Darkaoui et al., 2024; Rebahi et al., 2022; Touloun et al., 2012). Therefore, it is imperative to catalog and map the distribution of scorpion species, particularly those that are endemic, to safeguard vulnerable populations, especially children those under 15 years of age.

However, the recurring problem is the disparity between studies on the endemic status of certain species. For instance, scpecies such as *Buthus mardochei*, *Androctonus amoreuxi*, *Scorpio hesperus* and *Scorpio birulai* are considered endemic in some studies (Ajdi et al., 2024;

Table 2
Taxonomic statuts of the endemic scorpion species and subspecies.

Family	Genera	Species Subspecies *	Taxonomic status	Authors	References
Buthidae	**Androctonus**	*Androctonus bourdoni*	Incert	Vachon, 1948	(Ythier and Lourenço, 2022)
		Androctonus barbouri	Incert	Werner, 1932	
		Androctonus gonneti	Incert	Vachon, 1948	
		Androctonus liouvillei	Incert	Pallary, 1924	
		Androctonus sergenti	Valid	Vachon, 1948	
		Androctonus maroccanus	Valid	Lourenço, Ythier & Leguin, 2009	
		Androctonus agrab	Incert	Ythier & Lourenço, 2021	
		Androctonus donairei	Valid	Rossi, 2015	
		Androctonus mauritanicus	Valid	Pocock, 1902	
	Hottentotta	*Hottentota sousai*	Valid	Turiel, 2014	Turiel (2016)
		Hottentota gentili	Valid	Pallary, 1924	Aboumaâd et al. (2014b)
	Buthus (Ythier, 2023)	*Buthus albengai*	Valid	Lourenço, 2003	Elmourid et al. (2022)
		Buthus lienhardi	Valid	Lourenço, 2003	Elmourid et al. (2023b)
		Buthus malhommei	Valid	Vachon, 1949	Elmourid et al. (2022)
		Buthus bonito	Valid	Lourenço & Geniez, 2005	(Pedroso et al., 2013; Touloun et al., 2016b)
		Buthus parroti	Valid	Vachon, 1949	Pedroso et al. (2013)
		Buthus boumalenii	Valid	Touloun & Boumezough, 2011	Pedroso et al. (2013)
		Buthus mariefranceae	Valid	Lourenço, 2003	Pedroso et al. (2013)
		Buthus draa	Valid	Lourenço & Slimani, 2004	Pedroso et al. (2013)
		Buthus elmoutaouakili	Valid	Lourenço & Qi, 2006	Husemann et al. (2012)
		Buthus maroccanus	Valid	Birula, 1903	Sousa et al. (2017)
		Buthus oudjanii	Valid	Lourenço, 2017	Houria et al. (2020)
		Buthus atlantis	Valid	Pocock, 1889	Touloun et al. (2012)
		Buthus confluens	Valid	Lourenço, Touloun & Boumezzough, 2012	Touloun et al. (2014)
		Buthus maamora	Valid	Ythier E., 2023	Ythier (2023)
		Buthus nigrovesiculosus	Valid	Hirst, 1925	Sousa et al. (2017)
		Buthus rochati	Valid	Lourenço, 2003	Lourenço (2003)
		Buthus mardochei	Valid	Simon, 1878	Sousa et al. (2017)
	Buthacus	*Buthacus mahraouii*	Valid	Lourenço,2004	Lourenço and Leguin (2011)
		Buthacus ziegleri	Valid	Lourenço,2000	Kovařík et al. (2016)
		Buthacus stockmanni	Valid	Kovarik, Lowe & St'ahlavsky, 2016	Kovařík et al. (2020)
		Buthacus arenicola maroccanus	Valid	Lourenço,2006	Lourenço and Leguin (2011)
	Orthochirus	*Orthochirus cloudsleythompsoni*	Valid	Lourenço et Leguin, 2011	Lourenço and Leguin (2011)
		Orthochirus maroccanus	Valid	Lourenço and Leguin, 2011	Lourenço and Leguin (2016)
	Butheoloides	*Butheoloides slimanii*	Valid	Lourenço, 2010	Elmourid et al. (2023b)
		Butheoloides maroccanus	Valid	Hirst, 1925	Lourenço (2013)
		Butheloides littoralis	Valid	Lourenço, Touloun & Boumezzough, 2011	Touloun et al. (2016a)
		Butheoloides occidentalis	Valid	Lourenço,Slimani & Berahou, 2003	Lourenço et al. (2003)
		Butheoloides aymerichi	Valid	Lourenço,2002	Lourenço et al. (2003)
	Microbuthus	*Microbuthus maroccanus*	Valid	Lourenço, 2002	Lourenço and Duhem (2007)
	Compsobuthus	*Compsobuthus turieli*	Valid	Kovařík, Lowe, Stockmann & Šťáhlavský, 2020	Kovařík et al. (2020)
		Compsobuthus williamsi	Valid	Lourenço, 1999	Kovařík et al. (2020)
	Cicileiurus	*Cicileiurus monticola*	Valid	Teruel, 2007	Teruel, 2007
	Saharobuthus	*Saharobuthus elegans*	Valid	Lourenço & Duhem, 2009	Wilson and Duhem (2009)
	Scorpio	*Scorpio fuliginosus*	Valid	Pallary, 1928	Elmourid et al. (2023b)
		Scorpio mogadorensis	Valid	Birula, 1910	Touloun et al. (2012)
		Scorpio moulouya	Valid	YTHIER & FRANÇOIS, 2023	Ythier and François (2023)
		Scorpio iznassen	Valid	YTHIER & FRANÇOIS, 2023	Ythier and François (2023)
		Scorpio maurus legionis	Valid	Werner, 1932	Touloun et al. (2024)
		Scorpio hesperus	Valid	Birula, 1910	Touloun et al. (2014)
		Scorpio birulai	Valid	Fet, 1997	Ythier and François (2023)
		Scorpio touili	Valid	YTHIER & FRANÇOIS, 2023	Ythier and François (2023)
		*Scorpio maurus stemmleri**	Valid	Schenkel, 1949	Touloun et al. (2024)
		Scorpio weidholzi	Valid	Werner, 1929	Elmourid et al. (2023b)
		*Scorpio maurus behringsi**	Valid	Schenkel, 1949	Touloun et al. (2024)

Touloun et al., 2012; Ythier and François, 2023). However, they were excluded in 2024 (Touloun et al., 2024), and other species that are an uncertain taxa. Probably due to closer genetic ties with other species; than we have eventual understood, that the movement of goods can also alter the distribution of species beyond their original habitats, especially in those areas close to borders with neighbouring countries; as *Buthus oudjanii*, an endemic species of Morocco, has been found in the Sidi Bel Abbes region of Algeria, which is very close to Oujda, a northeast city of Morocco (Houria et al., 2020).This wider distribution indicates also that it may not be endemic species.

With all these details we are faced with a delicate issue that to highlights the need for field studies and genetic characterization to fill the gaps and obtain accurate results on the distribution, taxonomy, and determination of the possible existence of hybrid forms between these species. It may also help to determine the existence of a cline, as cited by Toulon et al. (Touloun et al., 2016b).

5. Conclusion

This study identified 56 endemic species and subspecies across Morocco, five of which pose a significant risk to humans. The findings, indicate that scorpion diversity and richness are concentrated in the

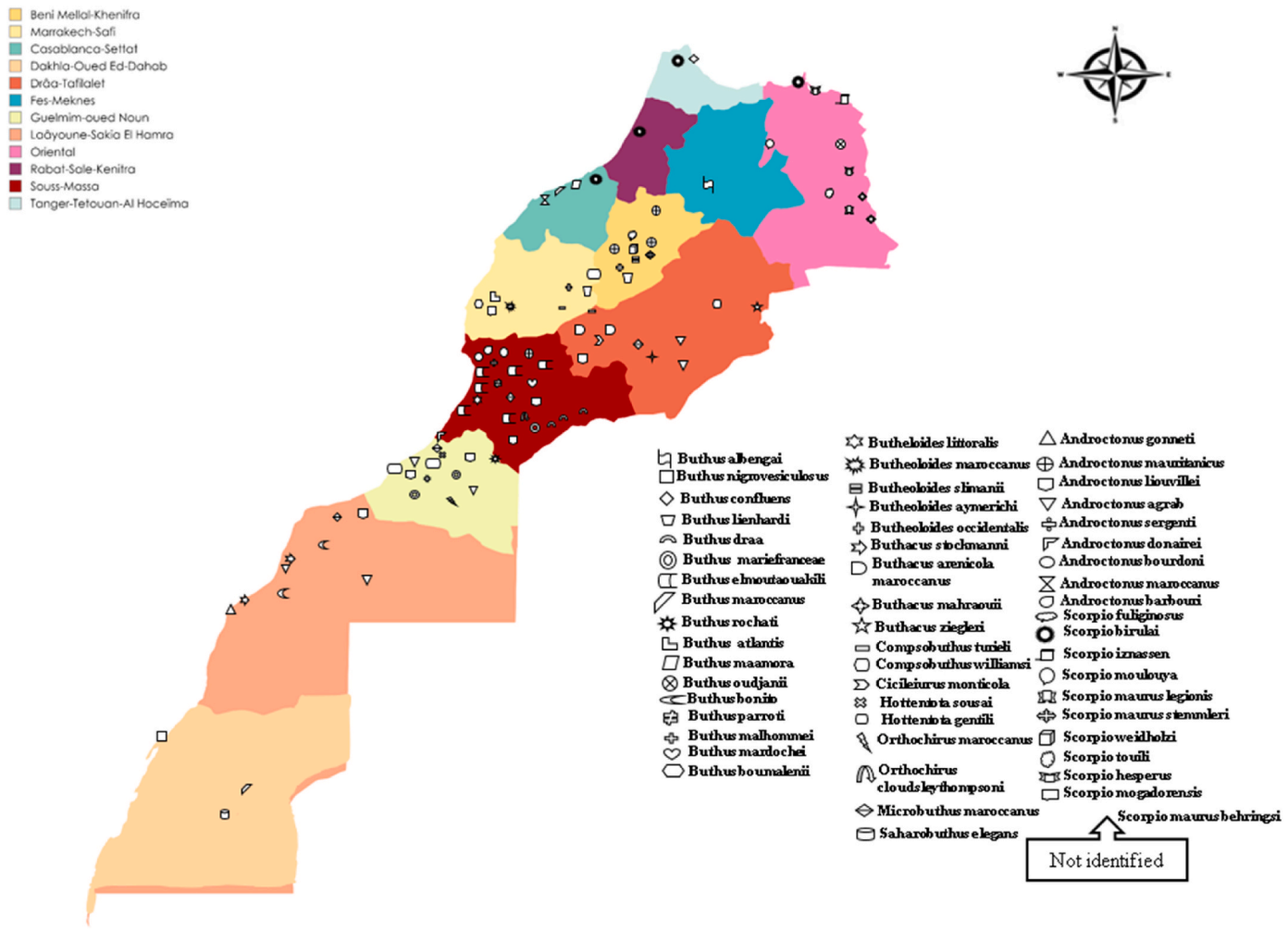

Fig. 4. Distribution of endemic scorpion species in Morocco.

central and southern regions of the country. These areas should be considered high-risk regions due to the presence of highly venomous endemic scorpion species, particularly in southern Morocco. Scorpion species are a very complex field, and despite extensive research significant confusion remains, posing major challenges for researchers in biology, pharmacology and ecology. In fact, studying scorpion genomes therefore will certainly facilitates and opens up new perspectives for evolutionary biology. Insights into how scorpion genes encode venom and other adaptive traits can drive the development of innovative biomimetic technologies and anti-venom products.

CRediT authorship contribution statement

Meriem Es-Saadi: Writing – original draft, Methodology, Investigation, Data curation. **Salsabil Hamdi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Data curation, Conceptualization. **Soukaina Khourcha:** Writing – review & editing, Validation. **Khalid Sadki:** Writing – review & editing. **Khaoula Errafii:** Writing – review & editing. **Naoual Oukkache:** Writing – review & editing, Validation, Supervision, Methodology, Data curation.

Ethical statement

All authors read and approved the final manuscript and agree with its submission to Toxicon – Journal. All generated data during this study are included in this manuscript, which has not been published before and is not currently being considered for publication elsewhere. And we have no conflicts of interest associated with this publication.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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