Introduction

About the book

With 111 species of reptiles (96 terrestrial and 15 marine), Oman harbors approximately 50% of the total number of reptile species in the Arabian Peninsula, ranking as one of the countries with the highest reptile diversity. Due to an increased interest in the systematics of Oman's reptiles, the pace of species descriptions and taxonomic knowledge has increased exponentially within the last 10 years and shows no sign of reaching a plateau (Fig 1). Because of the recent interest in Oman's herpetology, the country's current level of taxonomic knowledge ranks among the highest in Asia. Most of the groups have been investigated using an integrative approach, including both morphological and molecular data, analyzed with multivariate, phylogenetic, population genetic, genomic, and geospatial methods. This approach has uncovered considerable levels of undescribed diversity, including several remarkable examples of cryptic diversity.

The main objective of this book is to provide an updated account on the systematics, diversity and distribution of Oman reptiles. This work is based on 16 years of intensive field and laboratory work by the authors, the work of many past and present collaborators (see acknowledgements), and all the previous knowledge compiled by several researchers in books, book chapters, scientific journals and other publications, some of which have been listed in the bibliographic section at the end of the book. Although the book includes accounts for all the 111 currently described species of Oman reptiles, the reptile diversity analyses by governorate and using a 10 arc-minute grid are presented for the 96 described species of Oman terrestrial reptiles. The 15 marine reptiles include 10 sea snakes and 5 marine turtles that visit the Oman territorial waters and the immediate sand beaches sporadically for breeding (marine turtles), or get stranded on the beach after storms or when they are weak, ill or disoriented (sea snakes).

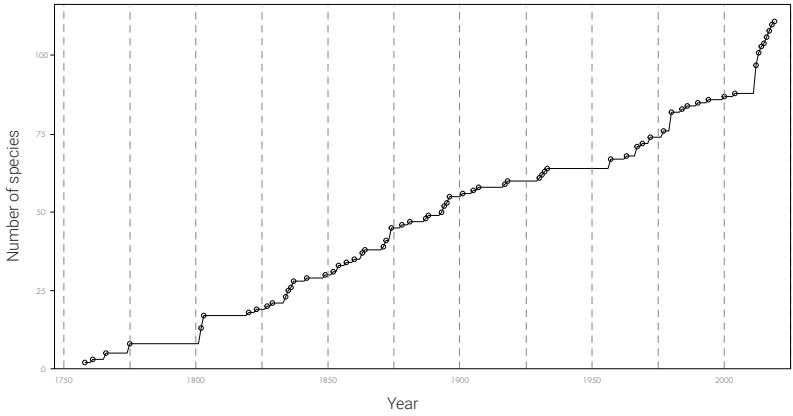

Fig 1: Number of species displayed in a cumulative way. Dots represent the years with species descriptions. Dashed lines divide the graph into intervals of 25 years.

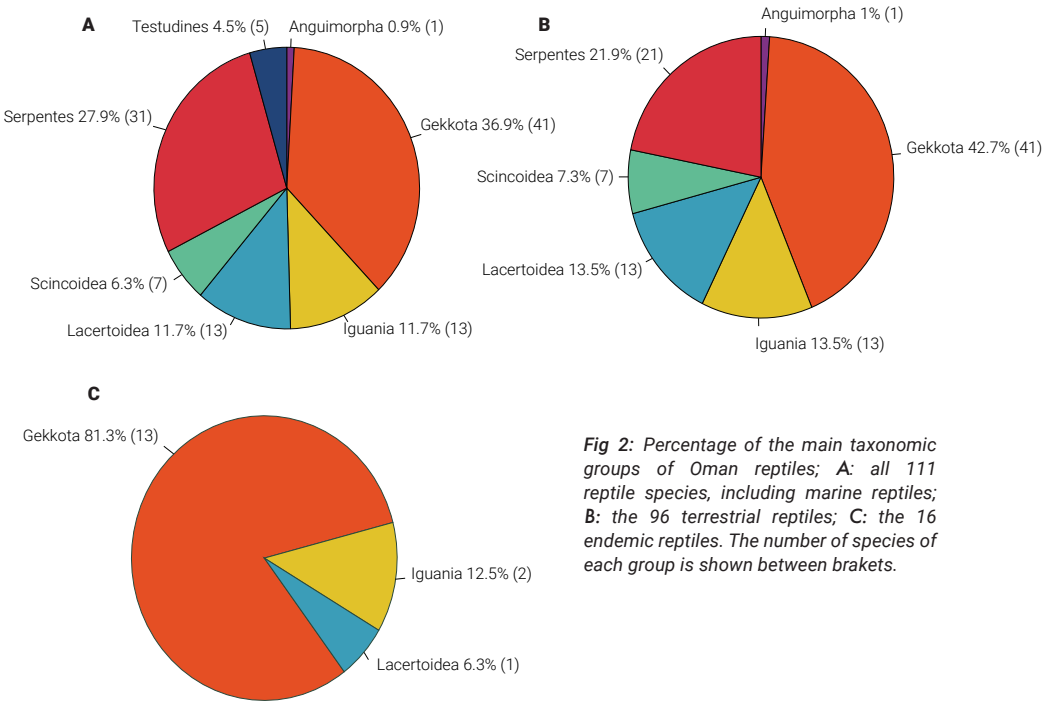

Fig 2: Percentage of the main taxonomic groups of Oman reptiles; A: all 111 reptile species, including marine reptiles; B: the 96 terrestrial reptiles; C: the 16 endemic reptiles. The number of species of each group is shown between brakets.

The 111 Oman reptiles are classified into seven main groups and the 96 terrestrial reptiles into six main groups. The number and proportion of species within each group for all the Oman reptiles, including endemic species, is shown in Fig 2.

The dataset used for the analyses of species richness, endemicity, conservation, ecology, and for the species accounts of all 96 terrestrial reptiles of Oman covered by the book includes 5,986 records. As can be seen in the spatial distribution of the samples using a grid of 10 arc-minutes of latitude and longitude covering the entire country, 429 (38.72%) out of 1,108 grids have information (Fig 3 on page 15). As a result of the origin of our data, it is impossible to differentiate between grids that have been visited without success (no observations) and grids that have not been visited (unsampled grids). In any case, reptiles are a major component of the vertebrate fauna of Oman and in the records obtained by S.Carranza's research team there was not a single grid that had been visited without success (no observations). This suggests that most of the grids without presence data are the result of the lack of exploration rather than lack of reptile presence. The sampled grids cover the entire Hajar Mountains and adjoining areas (the coastal Batinah plain and the inland areas) and the Dhofar Mountains (including both the lush south-facing side and, to a lesser extent, the dry north-facing side of the mountains) (see Fig 3 on page 15 & Fig 4 on page 16). The eastern coastal area of the Arabian Sea is also well sampled. The less sampled areas are the Rub' Al Khali Desert in the western part of the country, in the border area with Saudi Arabia, and the barren desert areas of Jiddat Al Harasis.

The distribution of all 5,986 observations in the two-dimensional climatic space of Oman (Fig 3B) indicates that the samples are widespread across the whole climatic space defined by annual precipitation and mean annual temperature, with no important gaps. The maximum number of observations cluster around the area of the graph defined by high annual mean temperatures and low values of annual precipitation, which is also the most dominant climate in Oman. The area of Oman with lower mean annual temperatures (10–15 ºC) and relatively higher values of precipitation (around 350 mm/year), include fewer observations but also have less area available and are, thus, proportionally well sampled.

As shown in Fig 5 on page 17, the observations are also well distributed across the climatic space defined by the Principal Component Analysis of 12 climatic variables. However, when the area is divided into clusters grouping 10% of the explained climatic variance by PC1 and PC2 (see Fig 5A & B), not all 20 resulting clusters include observations. Some of the clusters, such as clusters 18 and 19, cover very large areas across the whole country (Fig 5C), including the Rub' Al Khali Desert, Jiddat Al Harasis and the Al Sharqiyah Sands. Other clusters are only present in northern or southern Oman (clusters 6 and 13, respectively) and some, such as clusters 15 and 16, are present in both areas of Oman. The highest number of clusters is found in the Hajar Mountains, with 15 clusters, including clusters 1 and 4, both with just 2.52 km^2, the smallest of all 20 clusters. In the South, the highest number of clusters is found in the Dhofar Mountains and the Salalah Plain.

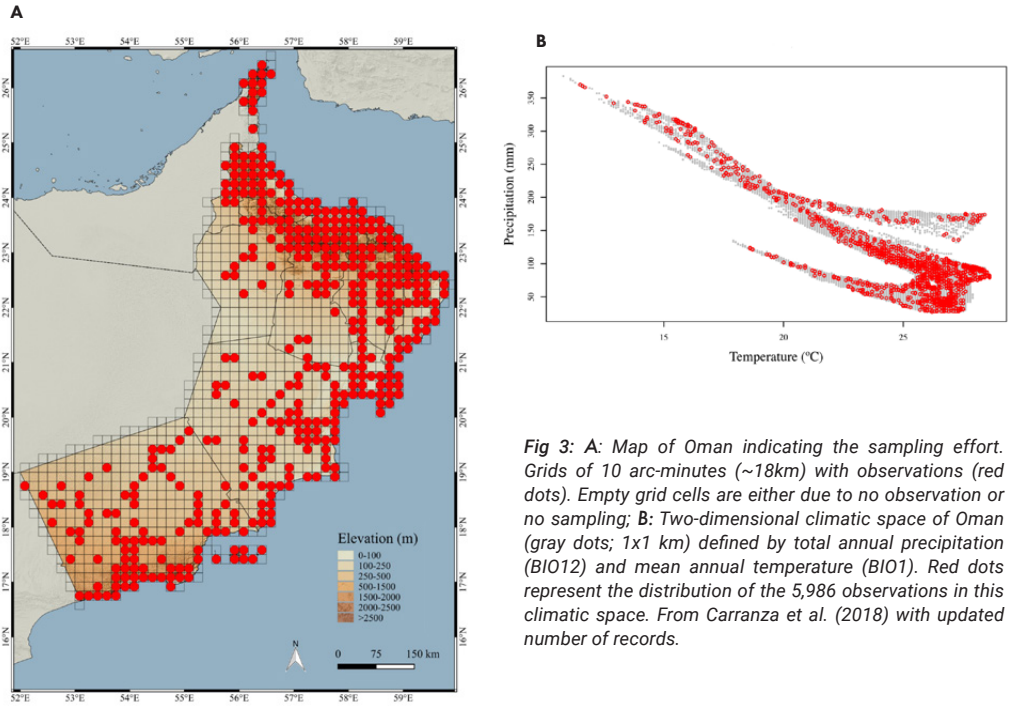

*Fig 3: **A**: Map of Oman indicating the sampling effort. Grids of 10 arc-minutes (~18km) with observations (red dots). Empty grid cells are either due to no observation or no sampling; **B**: Two-dimensional climatic space of Oman (gray dots; 1x1 km) defined by total annual precipitation (BIO12) and mean annual temperature (BIO1). Red dots represent the distribution of the 5,986 observations in this climatic space. From Carranza et al. (2018) with updated number of records.*

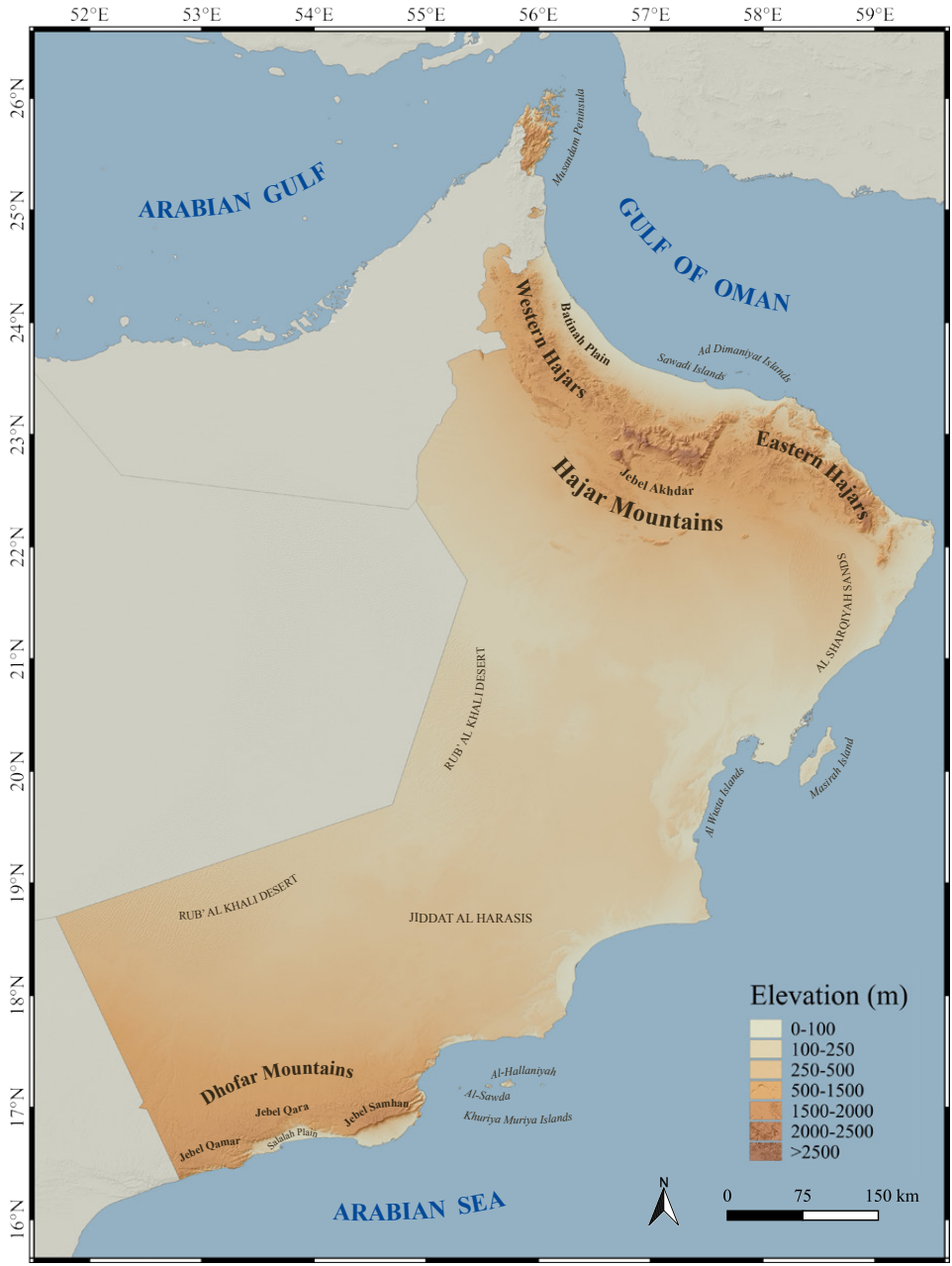

Fig 4: Physical map of Oman showing the topographical relief and names of the most relevant toponymies mentioned in the book.

Reptile diversity and systematics

With 11,570 species (August 2021), reptiles represent the world's most diverse group of terrestrial vertebrates and a major component of the global biodiversity, remarkable from an ecological and evolutionary point of view. Despite their relevance, their evolutionary relationships and their taxonomy have been very contentious and could not be clarified until genetic and, more recently, genomic data have been available. An updated taxonomic hypothesis based on the most recent phylogenetic results is necessary for a correct interpretation of the biogeography, ecology, behavior, and evolution of reptiles and has also played an important role in the organization of the present book. These relationships are summarized in the phylogenetic tree presented in Fig 6 on page 18.

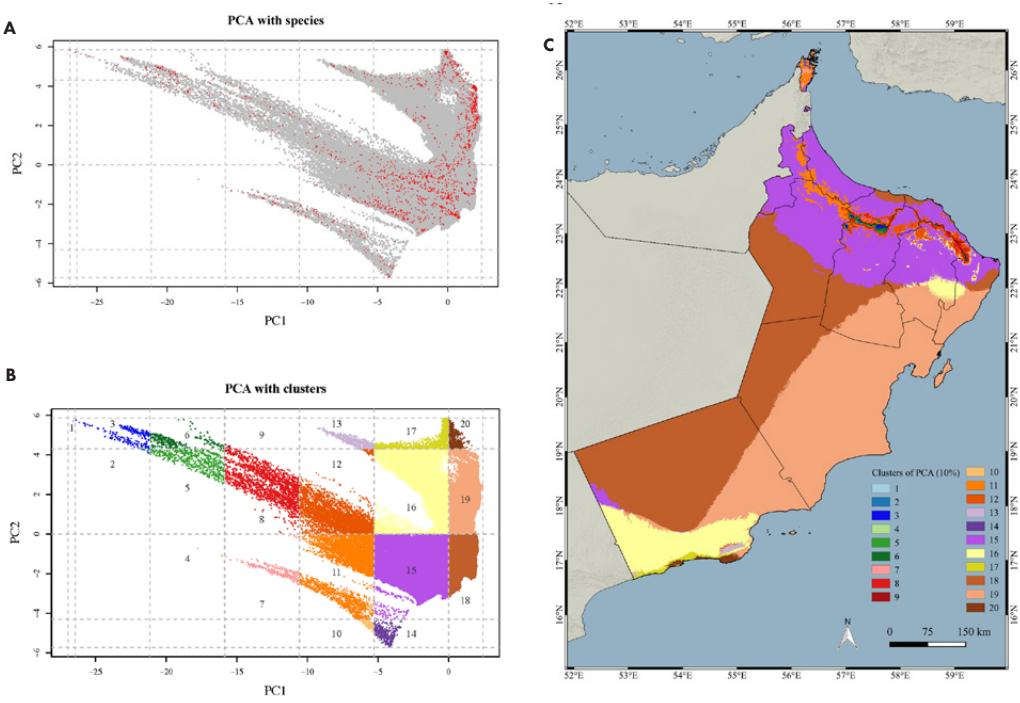

*Fig 5: **A**: Principal Component Analysis (PCA) of the climatic space of Oman (gray dots) using 12 BIOCLIM variables. Dashed lines delimit the climatic clusters that group 10% of the explained variance by PC1 and PC2. Red dots represent the distribution of the 5,986 observations in the PCA of the climatic space; **B**: Principal Component Analysis (PCA) of the climatic space of Oman using 12 BIOCLIM variables showing the 20 climatic clusters that group 10% of the explained variance by PC1 and PC2 painted in different colors and numbered from 1 to 20 with the following order: from left to right and from bottom to top; **C** Map showing the geographic distribution and extension of the 20 climatic clusters of Oman that group 10% of the explained variance by PC1 and PC2. From Carranza et al. (2018) with updated number of records.*

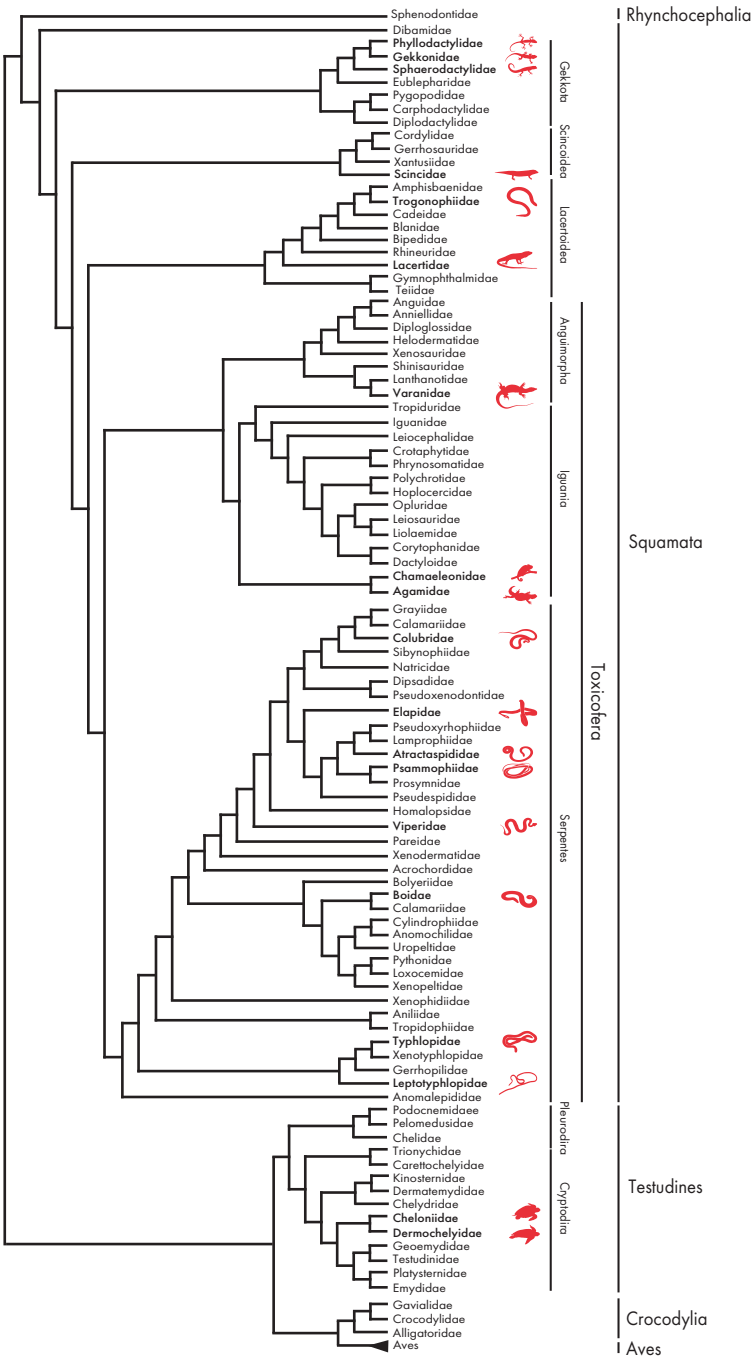

Fig 6: 4Phylogenetic tree of Sauropsioda showing the evolutionary relationships between the different families of Rhynchocephalia, Squamata, Testudines and Crocodilia. Notice that crocodiles (Crocodilia) are more closely related to birds (Aves) than to the rest of reptiles. All the different reptile families with representatives in Oman are indicated in bold and with red silhouettes.

Present-day reptiles consist of four major Orders:

1.- Turtles, belonging to the order Testudines, include approximately 361 species. They are one of the easiest groups of reptiles to recognize, because all of their representatives have a shell composed of two parts: the ventral plastron and the dorsal carapace, which protect the animal's trunk. There are turtles living on land (tortoises), in fresh water (freshwater turtles), and a few groups that have conquered the seas (marine turtles).

Crocodylus acutus, *American Crocodile.*

Geochelone elegans, *Indian Star Tortoise.*

2.- Crocodiles, alligators, and gharials, belonging to the order Crocodilia, include 26 species of aquatic predators, among which is the largest reptile on earth - *Crocodylus porosus*, the saltwater crocodile of southeast Asia and North Australia, which can reach over 6 meters and weigh over 1,200 kg. Crocodiles are oviparous, and their habits are generally crepuscular and nocturnal. Interestingly, they are more related to birds (Class Aves) than to other reptiles (see Fig 6), a relationship that makes reptiles a paraphyletic group. To solve this systematic problem, it has been suggested to abandon the term "reptiles" and use the more inclusive term Sauropsida (sauropsids) to refer to the monophyletic group formed by "reptiles" and birds. Like birds, Crocodilia have a heart divided into four chambers and their cerebral cortex is more developed than that of other reptiles.

3.- Tuataras, with only one extant species belonging to the genus *Sphenodon*, are the only survivors of the order Rhynchocephalia. The order includes diverse families and a great number of genera and species, now extinct, that diversified during the Mesozoic Era. Because the tuataras have changed very little morphologically, they are considered living fossils, which makes them very interesting from an evolutionary point of view. Noteworthy, among the unique characteristics of tuataras are the presence of two or three teeth fused to the bone of the premaxilla, a double row of teeth in the upper mandible (maxillary and palatine teeth) and the absence of a copulatory organ in males.

Sphenodon punctatus, *the Tuatara endemic to New Zeland.*

4.- The order Squamata (squamates) is the most numerous group of reptiles, with 11,182 described species (August 2021). Their taxonomy has changed in recent years and the following groups are now recognized: Dibamidae (25 species), Gekkota (2,095 species), Scincoidea (1,870 species), Lacertoidea (1,029 species), Anguimorpha (239 species), Iguania (2,003 species), and Serpentes (snakes) (3,921 species) (see Fig 6). They are characterized by a diapsid-type skull in which some structures have been lost and others have been modified, converting the skull into a moveable structure with equally moveable joints that help them to capture and better manipulate prey. The skull modifications and especially the appearance of venom more than 100 million years ago in the ancestor of the clade Toxicofera (Fig 6), venom glands, and specialized structures to inject venom and subdue prey without fighting in some snake groups, are considered one of the major factors of their great diversification.

Squamates have lost limbs partially or completely in more than 25 occasions during their evolution, and have developed viviparous reproduction about 100 times independently. In summary, they present a high level of morphological and physiological plasticity that has allowed them to colonize very different habitats. They have a skin with epidermal keratinized scales that is replaced with time. All

The pit viper Trimeresurus albolabris *showing the left pit underneath the preocular scales, in the anterior part of the eye. It connects interiorly to the sensory organ that allows pit vipers to perceive infrared radiations.*

squamate groups present internal fertilization, and are the only group of reptiles in which the males have hemipenes (paired copulatory organs).

There are oviparous, ovoviviparous, viviparous, and parthenogenetic species. Sex-determining mechanisms in reptiles are broadly divided into two main categories: genotypic sex determination (GSD) and temperature-dependent sex determination (TSD). In temperature-dependent sex determination, it is the environmental temperature during a particular point of the embryonic development that determines whether an egg becomes a female or a male. This thermosensitive period occurs after the egg has been laid, so sex determination in these reptiles depend on the thermal conditions affecting the eggs. Moreover, new

Naja arabica, *Arabian Cobra hatching.*

Naja arabica, *Arabian Cobra shedding the skin.*

evidence indicates that both sex chromosomes and temperature can be involved in the sex determination of some reptile species.

The most successful group of squamates, the snakes, is the group of reptiles with more modifications to their general body plan. This group with 3,921 species is an example of adaptive radiation, having conquered nearly all environments. There are marine, freshwater, and terrestrial snakes and they are distributed through all continents with the only exception of Antarctica. All snakes have elongated bodies, absence of limbs, ear canal, outer ear (no eardrum but inner ear) and left lung (due to elongation). Jaws join at the anterior side by an extensible ligament and have a very flexible skull. Their eyelids are fused into a transparent membrane with little eye mobility. They have a forked (bifid) and extensible tongue that carries the captured scent molecules to the vomeronasal organ (Jacobson's organ) located on the roof of the mouth that acts as an organ of smell to complete the olfactory areas of the nose. Some vipers (pit vipers) have sensory organs to perceive infrared radiations from warm bodies, allowing them to locate prey even in the most absolute darkness. Pythons and boids also have infrared receptors on their lips but are thought to be of independent origin than those of vipers. All snakes, like all members of the Toxicofera clade, are thought to have toxins and many groups of snakes have developed teeth specialized in venom inoculation that cause more than a million envenomations and 100,000 deaths worldwide every year.

The importance of reptiles for ecosystem functioning

Reptiles are major components of current biotas globally. They have successfully colonized all continents of the world (with the exception of Antarctica), including the continental and marine waters and thousands of islands. Reptiles have played a crucial role in the origin and subsequent radiations of amniote vertebrates, and in the function of past and modern day ecosystems. The role of reptiles as main ecological players in our planet started a long time ago, when reptiles acquired water-independent reproduction that resulted in their establishment as the first fully-terrestrial vertebrates, and triggered their diversification during the Mesozoic Era, between the Triassic (245 million years ago) and the end of the Cretaceous (65 million years ago), when reptiles ruled the earth for 150 million years. Within the reptile lineage appeared some of the most incredible animals that have ever lived on our planet, including many different dinosaur species, very large marine reptiles like the mosasaurs and plesiosaurs, and a radiation of flying reptiles, the pterosaurs, which included the largest animal that has ever flown, *Quetzalcoatlus northropi*, with a wing span of 10 m.

One of several specimens of the Jebel Akhdar endemic Asaccus montanus *Mountain Leaf-toed Gecko found preying on insects on a hotel wall at night.*

The 5th mass extinction (occurred approximately 65 million years ago) brought the reign of the dinosaurs to a sudden end and also triggered the extinction of all flying reptiles and the large marine reptiles. This catastrophic event, opened a window of opportunity for several groups of small vertebrates. Thanks to the extinction of most large reptiles, mammals (constituted by small, nocturnal species at that time), birds, and small reptiles, had the opportunity to radiate and diversify.

As a result of radiations occurring over hundreds of millions of years, reptiles have accumulated a vast diversity of morphological, behavioral, ecological, life history, and defensive strategies to cope with the selective pressures that they have encountered. Since the last mass extinction, reptiles have consolidated as the most successful lineage among terrestrial vertebrates in terms of species richness, morphological and ecological diversity. Indeed, with 11,570 species, reptiles represent the world's most diverse group of terrestrial vertebrates and include some of the most remarkable examples of vertebrate evolutionary radiations. Particularly notorious cases are the hyper diverse iguanian genus *Anolis*, with

Representative of a highly diverse genera, Hemidactylus alkiyumii, *Al-Kiyumi's Gecko, Dhofar, Oman.*

436 species known from tropical America, the geckos of the genus *Cyrtodactylus*, with 314 species distributed across Southeast Asia, or the geckos of the genus *Hemidactylus*, with 173 species widely distributed across the world, including 14 species in Oman.

Apart from the high number of species, some reptile species also have large populations and therefore play an even more vital role in ecosystems functioning. For instance, the most abundant terrestrial vertebrate in the Hajar Mountains is a very small gecko of the genus *Pristurus (P. rupestris*), which preys on

Representative of a highly diverse genus, Anolis porcatus*, Cuban Green Anole, Cuba.*

ants and other small insects that can harm crops, and therefore it is a natural source of pest control. Some snakes can also live close to human settlements, preying on rats and mice, keeping their populations in check. At the same time, reptiles fall prey to a large number of other vertebrates, including birds and small mammals, being a very important food source for them.

Some species of geckos of the genus *Hemidactylus* and other genera live in or around human habitations and are usually seen at night by lights preying on insects, therefore acting as a natural source of pest control and even as a control of vector-borne diseases transmitted by some mosquito species. Other terrestrial groups also consume other insects like grasshopers that, depending on their abundance, can pose a serious threat to cultivated areas.

Apart from the important role of reptiles in the food web of ecosystems as both predators and prey, there are other less studied and less known roles of reptiles that have a pivotal role for ecosystem functioning, at least in some particular environments where reptiles are one of the major components (or the only component) of the terrestrial vertebrate faunas, as for instance in remote archipelagos. Under these circumstances, reptiles can play a crucial role as both pollinators and seed dispersers for endemic plants. For instance, it has been recently discovered that an endemic gecko, *Hemidactylus dracaenacolus* from Socotra Island, acts as a pollinator of the Dragon's Blood Tree (*Dracaena cinnabari*), a unique tree endemic to the Socotra Archipelago, highly valuable from a natural and economic point of view. Another well-studied example includes the lacertid lizard radiation of the genus *Gallotia* endemic to the Canary Islands, Spain.

The Socotran endemic species Hemidactylus dracaenacolus*, Dragon Blood Tree's Gecko, on the tree trunck of the endemic Socotran tree* Dracaena cinnabari, *Dragon's Blood Tree.*

These large lizards eat plant material on a regular basis, consuming seeds. It has been shown that seeds of some Canary Islands' endemic plants that passed through the guts of lizards had a better chance of germinating, and did so faster, than plants that were not consumed by lizards. One of the main characteristics of islands is that they show low species richness, sometimes being devoid of any terrestrial mammals and with very few bats and birds. That means there are few species that could potentially take the place of lizards. If plants lose a pollinator or a disperser, they probably do not have another species to fall back on.

Pristurus rupestris, *Rock Semaphore Gecko, one of the most abundant terrestrial vertebrates of the Hajar Mountains. They can be very useful as pest control and, at the same time, they are an important source of food for other animals.*

The snake Echis carinatus sochureki, *Sindh Saw-scaled Viper, eating a mouse in a garden. It can help to keep rodent populations in check.*

Stenodactylus doriae, *Dune Sand Gecko, preying on a grasshopper. These insects sometimes cause important damages to cultivated areas.*

The snake Spalerosophis diadema cliffordii, *Clifford's Diadem Snake, eating a Brown Rat* (Rattus norvegicus) *in a farm. This snake species is usually found close to cultivated areas and helps to control rodent populations.*

Uromastyx aegyptia microlepis, *Small-scaled Spiny-tailed Lizard. An Arabian reptile species adapted to live in extremely arid conditions, central Oman.*

Like islands, extremely arid areas or sand dune deserts show low levels of species richness, not only of terrestrial mammals but also of birds and bats. Under these extreme conditions that constitute a large part of the Arabian Peninsula, reptiles thrive. They have been able to adapt and diversify, pushing to the limits their physiology and modifying their behavior to cope with these extreme conditions. Therefore, reptiles have become the main vertebrate component of the world's arid ecosystems in terms of both species numbers and individuals. Some of these reptiles (the Spiny-tailed Lizards of the genus *Uromastyx*; pictured above) are also plant eaters and therefore their role as seed dispersers remains to be studied.

Phrynocephalus sakoi, *Sako's Toad-headed Agama, is an endemic species of the Sharqiyah Sands, Oman, adapted to live in extremely arid conditions.*

Importance of conserving reptile diversity

Reptiles play an important role in natural ecosystems, as predators, prey, grazers, seed dispersers, commensal species, and as natural pest control. This role is even more accentuated in arid environments and islands, with overall low levels of species richness but high levels of reptile diversity.

Apart from the obvious affectation to the ecosystem, conserving reptile diversity can also have important benefits for our medical health. Modern science gives us the ability to investigate the chemistry of compounds in search of more powerful pharmaceutical drugs, and even build them from scratch, but nature continues to be a huge source of drug discovery. In fact, the World Wildlife Fund says that of all small molecule drugs introduced in the last 25 years, at least 70% were derived from natural sources. For instance,

a hormone in the saliva of the Gila Monster (*Heloderma suspectum*), a venomous lizard from southwestern USA and northwestern Mexico, produces insulin to keep the animal's blood glucose levels in check. A synthetic version of this hormone called exenatide is now used to treat type 2 diabetes in humans. The Gila Monster, meanwhile, is classified as Near Threatened as a result of climate change and habitat loss resulting from development in southwestern USA.

Other pharmaceutical drugs have been developed from snake venoms. Venoms are not composed of single toxins but cocktails of complex chemical mixtures of pharmacologically active components including proteins, peptides, and enzymes with specific biological activities, as well as some non-protein compounds such as carbohydrates, lipids, metal ions and other unidentified substances. Despite their medical interest, less than 0.01% of these toxins have been identified and characterized. For instance, Captopril® (Enalapril), Integrilin® (Eptifibatide), and Aggrastat® (Tirofiban) are drugs used to treat cardiovascular diseases based on snake venoms. Many more compounds beneficial for humans are awaiting to be discovered, reinforcing the necessity of preserving reptile diversity, and especially venomous snakes.

A key factor in conservation are endemic species. Endemic species are species that do not live anywhere else in the world and therefore their protection and global survival falls completely in the hands of the country where they are found. If the country fails to protect them, they can go extinct, meaning that we would lose a branch in the tree of life (see Fig 6 on page 18). Depending on the depth of the branch, we could loose from a few thousand to millions of years of evolutionary change and, with it, many unique adaptations to the particular ecological and environmental conditions. This would consequently affect the ecosystem and the food web, with the added danger of losing compounds of medical relevance.

Reptiles have the highest level of endemicity of all Oman vertebrates. As a result of its geographical position in southeastern Arabia, surrounded by sea to the North, East and South, and especially its varied climatic conditions and the presence of very high mountain ranges, Oman presents high levels of reptile diversity and especially endemicity. Out of the total of 111 species of reptiles, 16 are endemic. This represents a proportion of 14.4% of species that do not live anywhere else in the world and therefore their conservation falls completely in the hands of Oman.

Heloderma suspectum*, Gila Monster.*

Crotalus atrox*, Western Diamondback Rattle Snake.*

The high level of endemicity found in reptiles contrasts with other terrestrial vertebrate groups. In birds, there are about 494 species, but none of them are endemic to Oman, and there are about 60 species of terrestrial mammals of which there is only one endemic species. This highlights the relevant role of reptiles as surrogates for conservation studies in Oman and other arid countries. They can play a very important role in defining priority conservation areas and to evaluate the coverage of the current network of protected areas. As a result of that, more resources should be devoted to study the Oman reptile fauna, especially the 16 endemic species in order to know more about their population structure, biology, ecology and threats.

Reptiles are of paramount importance for the health of the environment. However, their small home ranges, high levels of endemicity, thermoregulatory constraints, and morphological specialization, mean that they are especially sensitive to some of the alterations that humans make to their habitats. However, some reptile species are very resilient and can adapt well and even thrive in man-modified environments and man-made structures, such as tunnels and buildings. A study of the threats and conservation status of all the Data Deficient and Not Evaluated species of Oman reptiles (see page 45) would be very important in order to plan the appropriate conservation actions and to tackle any threats, especially threats that might affect the endemic species.

Oman geography and climate

Oman borders with the UAE to the North and northwest, with Saudi Arabia to the West and with Yemen to the southwest (Fig 7 on page 29). The country is divided into 11 governorates, Musandam being the smallest, with just 1,805 km^2, and Dhofar the largest, with 104,498 km^2 and covering nearly 33% of the country.

The population in the country is mainly concentrated in the capital, Muscat, and surrounding areas, making Muscat the most populated governorate, with approximately 1,421,409 inhabitants in 2019. The country does not have a large network of tarmac roads and motorways but there is an extensive and excellent network of off-road trails that communicates villages, sometimes across desert areas, and connects oil refineries from the interior of the country with the main harbor in the Al Wusta Governorate. Some of these roads have been used to survey the biodiversity of remote and previously inaccessible areas, sometimes resulting in unexpected discoveries.

About 60% of the approximately 330,000 km^2 of Oman consist of flat arid areas below 250 m (Fig 4). These vast areas are mostly barren, vegetated by small areas of widely spaced low perennial shrubs, interspersed between much broader areas of bare sand, gravel and rocks. The mean annual temperatures are high (28 ºC) and annual precipitation is very low (<150 mm).

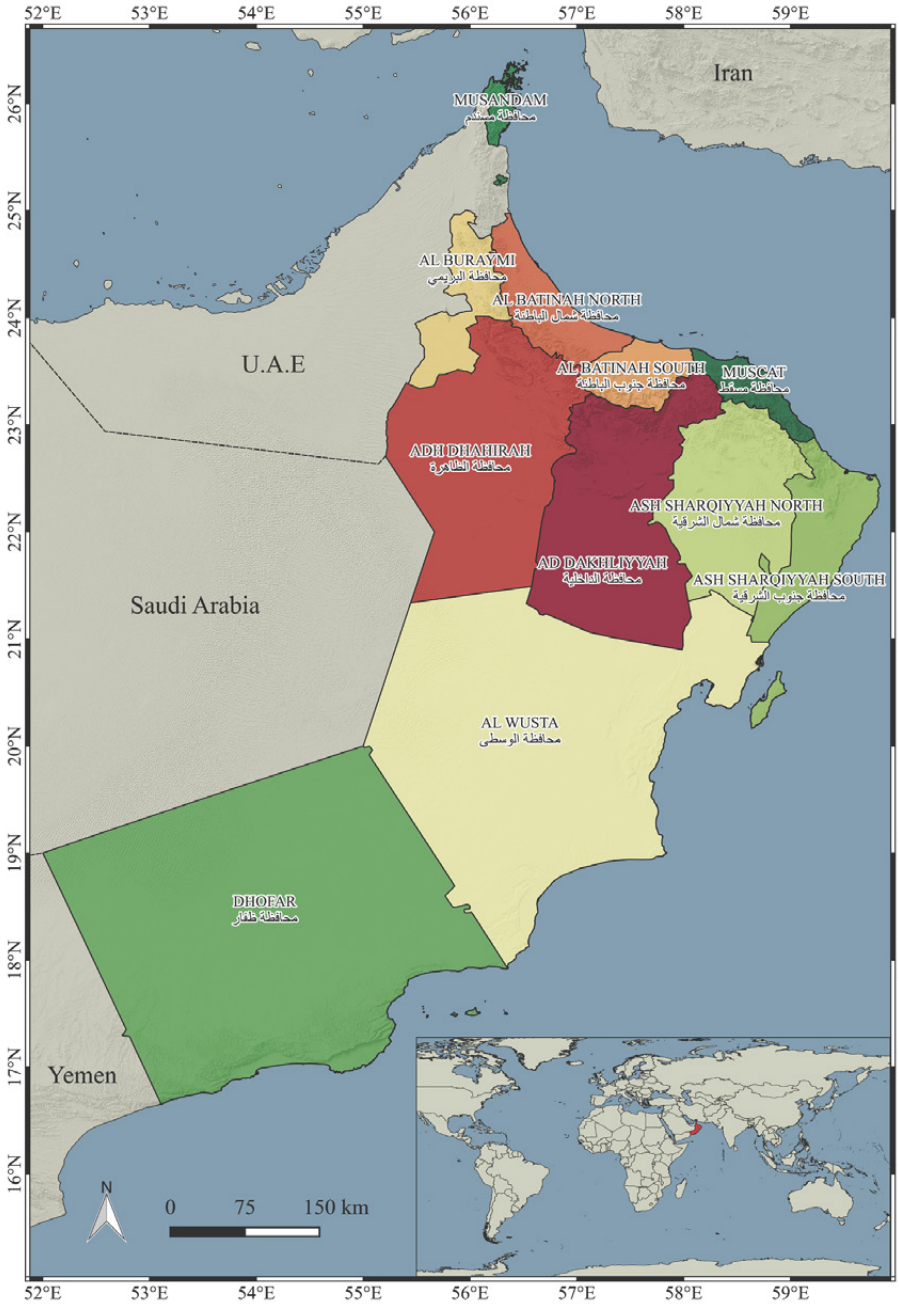

Fig 7: Political map of Oman showing the limits of the 11 governorates.

Rub' Al Khali Desert, western Oman, autumn 2013 expedition.

Sand Dune Deserts

The hot arid environment of Arabia, with evaporation exceeding rainfall by more than one hundred times, has triggered the origin of several types of deserts. The great sand dune deserts of Arabia are amongst the largest in the world. In Oman there are two sand dune deserts that are very important from a biodiversity point of view:

The Rub' Al Khali (Empty Quarter) is the world's largest continuous sand desert, with sand dunes extending for hundreds of Km and up to 250 m in elevation, covering an area of over 640,000 Km^2. It is mainly distributed across southern Saudi Arabia and southern UAE. In Oman, the Rub' Al Khali desert occupies a relatively small area in the western side of the country, right next to the western border with Saudi Arabia and the UAE (Fig 4). Despite its extreme aridity, there are several species of sand desert adapted reptiles such as *Scincus mitranus*, *Eryx jayakari*, *Phrynocephalus arabicus*, several species of *Acanthodactylus*, *Trigonodactylus arabicus*, and *Stenodactylus doriae*, among other taxa that thrive in this extreme and hostile environment.

Rub' Al Khali Desert, western Oman, autumn 2013 expedition.

Northern edge of the Sharqiyah Sands, Oman, autumn 2010 expedition.

The Sharqiyah Sands is a relatively small aeolian sand dune desert situated in the extreme northeast of the country, between the Hajar Mountains and the Arabian Sea (Fig 4). It extends across an area of approximately 12,500 km^2. The eastern side of the desert lies very close to the coast and therefore this side of the desert receives important amounts of fog that have a positive impact into its biodiversity. The sands are arranged in a mega-ridge sand system on a North-South line believed to have been formed by the monsoons. The largest dunes in the northern part of the desert can reach up to 100 m in elevation. This desert was the subject of a thorough exploration organized by the Royal Geographic Society between 1985 and 1987 and the published reports indicated the existence of a rich reptile fauna. More recent surveys and analyses have resulted in the description of two endemic reptiles to the Sharqiyah Sands (*Phrynocephalus sakoi* and *Trigonodactylus sharqiyahensis*).

Although sand dunes occupy 27% of the Arabian Peninsula and a large part of Oman, vast areas are occupied by gravel plains. One of the largest is the Jiddat Al Harasis.

Northern edge of the Sharqiyah Sands, Oman, autumn 2013 expedition.

Gravel plain in the Jiddat Al Harasis, Oman, autumn 2016 expedition.

Gravel Plains and Sabkha

The Jiddat Al Harasis is a limestone plateau ranging between 100 and 150 m in elevation, covering a very large area of approximately 27,000 km^2. It is situated between the Arabian Sea in the East and the Rub' Al Khali in the West (Fig 4). It is an extremely arid, flat area with very low levels of rainfall. Like the Sharqiyah Sands, the fog plays a very important role in the areas close to the Arabian Sea coast, supporting some vegetated areas with trees. Despite its extreme aridity, it is inhabited by several reptile species, including some endemic species such as *Hemidactylus inexpectatus* endemic to Al Wusta Governorate and *Uromastyx thomasi*.

Sabkhas (salt flats) are another important habitat type in Oman and are one of the harshest environments on the planet. They are hypersaline areas of sand or slit often containing layers of gypsum or anhydrite. Crusts of halite and gypsum may be present in some parts. Sabkhas can occur by the sea or far inland. Despite being an inhospitable habitat, some reptiles have been able to adapt to these conditions and one of them, *Pseudoceramodactylus khobarensis*, has become a specialist and is mainly found in this harsh environment.

Sandy plain near the coast, Jiddat Al Harasis, Oman, autumn 2013 expedition.

Sabkha in the Rub' Al Khali Desert, western Oman, autumn 2013 expedition.

Sabkha in the Rub' Al Khali Desert, western Oman, autumn 2013 expedition.

Area of white sands in southeastern Masirah Island, Oman, autumn 2010 expedition.

Islands

Islands represent outstanding examples of biodiversity, endemicity and species extinctions. Island species are often unique, yet are highly vulnerable to novel disturbances, such as invasive species. As the risk of extinction is highest on islands, it is very important to know their diversity in order to monitor and conserve it. One of the most important islands of Oman is Masirah Island.

Masirah Island is the largest island in Oman (approx. 700 km^2). It is situated in the Arabian Sea, approximately 15 km off the east coast of Barr Al Hikman and has relatively large hills of ophiolitic origin, especially on its eastern side. It is the Oman island with the highest number of reptile species, 21, which represent 21.8% of Oman's terrestrial reptiles. Only two reptile species, *Hemidactylus masirahensis* and *Pristurus masirahensis,* are island endemics and both of them are endemic to Masirah Island. Other islands like **Al-Hallaniyah** or **Al-Sawda**, the first and second largest islands of the **Khuriya Muriya Islands,** off the coast of southeastern Oman, are much smaller (less than 60 km^2 each), and have a remarkable diversity of reptiles, although there are no endemics. The **Ad Dimaniyat Islands**, off the Batinah Plain coast of North Oman, are a group of 9 small islands (1 km² of total area) with rather low levels of reptile diversity, although they include a population of the rare skink *Heremites septemtaeniatus*.

Rocky area in southern Masirah Island, Oman, autumn 2010 expedition.

Al-Hallaniyah Island, Oman, autumn 2013 expedition.

Ad Dimaniyat Islands, Oman, spring 2013 expedition.

Wadi As Sarin Nature Reserve, Eastern Hajars, Oman, autumn 2014 expedition.

Mountains

If aeolian deserts, gravel flat plains, sabkhas and islands harbor moderate levels of reptile diversity in arid areas, mountains represent hotspots of biodiversity. Mountains offer essential vertical environmental gradients for life over short areas otherwise only seen over several thousands of kilometers of horizontal distance. A steep diverse topography provides opportunities for species diversification, leading to high levels of biodiversity and endemicity. Mountains are at the same time centers of speciation and refugia of diversity and, given the wide spectrum of environmental conditions that they cover, they are key to conservation, containing half of the currently defined biodiversity hotspots in the world. In Oman, there are two mountain ranges with high levels of reptile diversity and endemicity. The Hajar Mountains in the North of the country and the Dhofar Mountains in the South.

The Hajar Mountains are the highest in eastern Arabia, forming a spectacular isolated wall of mountains that rises dramatically from the ocean below. The Hajars run northwest to southeast in a 650 km continuous arc paralleling the Oman and UAE coast of the Gulf of Oman and are surrounded by the sea to the East and by a very large desert to the West. Cut by deep canyons, these arid mountains have a complex topography and can be divided into three distinct areas or blocks, the Western Hajars, the Jebel Akhdar massif, and the Eastern Hajars; separated by some topographical discontinuities (Fig 4). With a maximum elevation of 3,009 m, Jebel Shams in the Jebel Akhdar massif is the highest peak in the Hajar Mountains, although high mountains also occur in the Western (2,087 m at Jebel Harim) and Eastern (2,200 m at Jebel Khadar) Hajars. The Hajar Mountains are the only area in eastern Arabia with habitats above 2,000 m in elevation and with an annual mean temperature of 13 ºC at the highest peaks. Despite the altitude, annual rainfall is low (between 250–300 mm), evapotranspiration is high, and the almost treeless, barren nature of the ter-

Jebel Shams and Wadi Gul canyon, Jebel Akhdar massif, Oman, summer 2017 expedition.

rain has made some scientists to consider the Hajars a mountain desert. However, recently published analyses using a Principal Component Analysis (PCA) of the climatic space of Oman using 12 environmental variables, indicate that the Hajar Mountains are one of the most climatically variable areas in Oman .

The Hajar Mountains have a complex geological history and have long been known to have more structural and petrological features in common with the Zagros Mountains of southwestern Iran than with neighboring parts of Arabia. They originated around 200 million years ago, with orogeny taking place during the Oligocene and Miocene, triggered due to the tectonic motions that resulted in the opening of the Red Sea and the Gulf of Aden. The final uplift probably occurred approximately 4–6 Mya. Owing to its old geological origin, high elevations, very deep canyons, geographic isolation from other mountains, and relative diversity of ecological niches, high levels of species richness and endemicity are recorded in varied animal and plant groups, including an endemic genus and species of mountain goat (*Arabitragus jayakari*). The Hajar Mountains contrasts sharply with the Dhofar Mountains of southern Oman.

Wadi Shab, Eastern Hajars, Oman, autumn 2008 expedition.

Tawi Attair sink hole, south-facing side of the Dhofar Mountains, Oman, summer 2017 expedition.

The Dhofar Mountains are bound to the North by the Rub' Al Khali (also known as the Empty Quarter), the largest desert in Arabia, to the South by the Arabian Sea, and are separated from the rest of Oman in the northeast by the gravel desert plain of Jiddat Al Harasis (Fig 4). The summit of the mountain range is a relatively wide (10–25 km) flat plateau that runs for about 150 km, mostly between 700 and 900 m in elevation, from Jebel Qamar in the West, through Jebel Qara in the central part, to Jebel Samhan, an independent massif that can be considered an eastern extension of the Dhofar Mountains. The highest point is over 2,000 m in elevation in Jebel Samhan, where temperatures reach the lowest values in southern Oman. The Dhofar Mountains lie within the monsoon belt, and most rain falls in July and August, during the summer monsoon season. This results in the unique green vegetation on the south-facing (sea) side of the mountain range, where the clouds form a variable belt along the coast from Jebel Qamar to Jebel Samhan that press against the mountain ridges causing frequent fog and light rain that does not surpass 200 mm per year. Clouds only occasionally spill over the top of Jebel Qamar but on the much lower Jebel Qara they ride up to the summit. However, the northern slopes across the whole mountain range are in a rain shadow. As a result, the north-facing (inland) side of the Dhofar Mountains is much drier and less vegetated than the lush south-facing side. These climatic differences have played an important role in shaping the flora and fauna of this interesting biodiversity rich region.

Wadi Ayun, northern side of the Dhofar Mountains, Oman, autumn 2005 expedition.

Patterns of terrestrial reptile species richness in Oman

The 96 species of terrestrial reptiles, including endemic species, are not equally distributed across the whole territory of Oman. If we analyze species richness by governorate, Dhofar has the highest diversity, with 60 species, and is followed by Ash Sharqiyyah South with 48. The remaining governorates have 42 or less species, being Musandam (21), Al Buraymi (29) and Al Batinah North (27) the governorates with the lowest number of species (Fig 8A). When the species richness is analyzed using the 10 arc-minutes grid, the highest number of species appear in the high elevation parts of the Hajar Mountains (Jebel Akhdar), the coastal area and wadis around the capital (Muscat), and in the Dhofar Mountains and the Salalah Plain in the South (Fig 8B).

In total, 16 species are endemic to Oman. The governorate with the highest endemicity is Ash Sharqiyyah South, in the extreme northeast part of the country, which has 8 out of the 16 endemic Oman reptiles (50%). It is followed very closely by Ad Dakhliyyah and Al Wusta, with 5 endemic species (31.2%) (Fig 9A on page 40; Table 1 on page 41). However, when the endemicity richness is analyzed at a finer scale (10 arc-minutes grid), the areas with the highest values are found in the Hajar Mountains in northern Oman and, more specifically, in the Jebel Akhdar massif, that contains as many as 5 endemic species in some grids. Other grids with relatively high levels of endemicity richness are found in the northeast of the country, including Masirah Island. Endemicity is not very high in Dhofar, with the highest values of grid endemicity being two grids situated in the south-facing sea side of the Dhofar Mountains, and one grid in the north-facing land side of the mountains (Fig 9B on page 40).

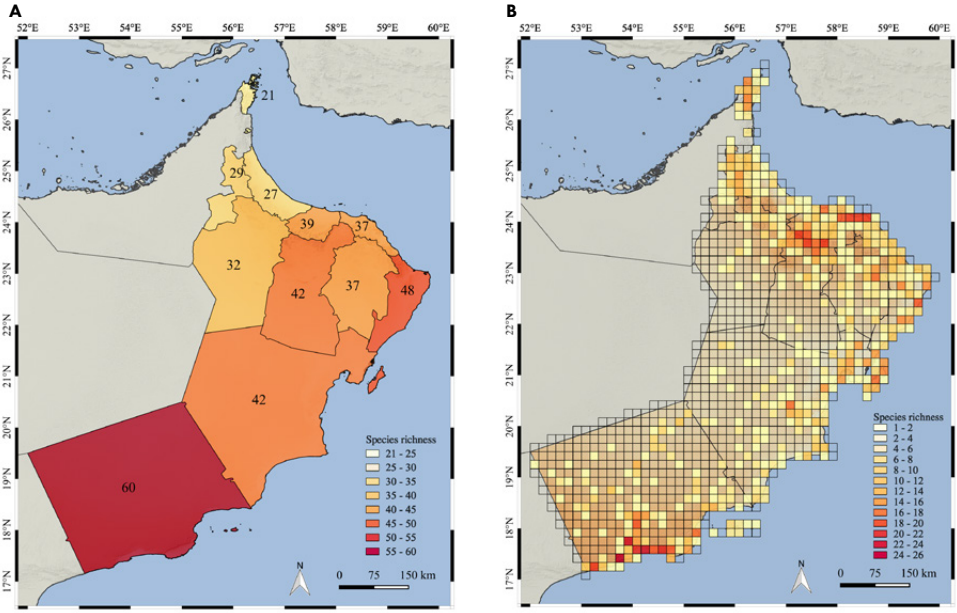

Fig 8: Maps of species richness of the 96 Oman terrestrial reptiles. A: Species richness by governorate; B: Species richness by grids of 10 arc-minutes of latitude and longitude.

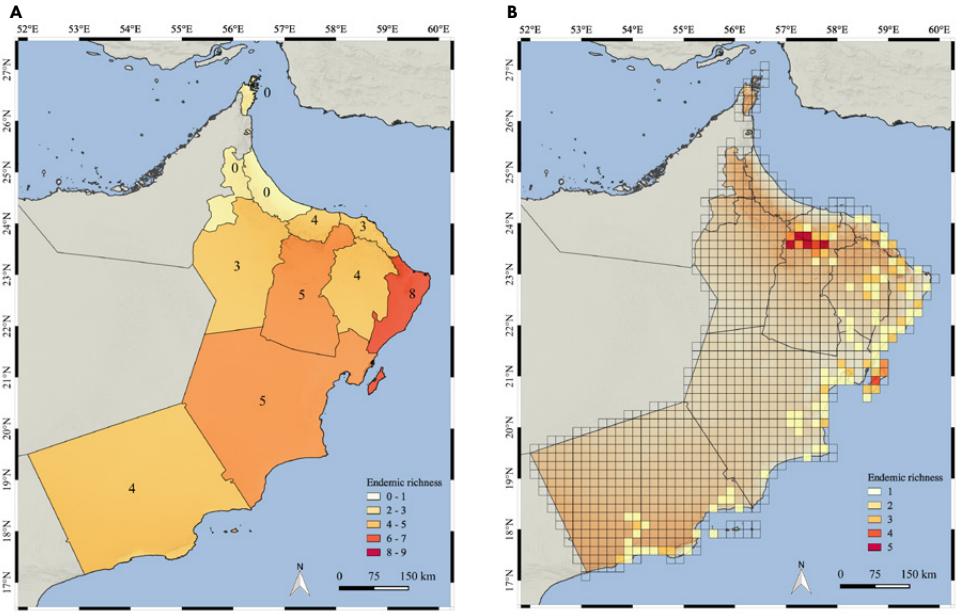

*Fig 9: Maps of endemic species richness. **A:** Endemic species richness by governorate; **B:** Endemic species richness by grids of 10 arc-minutes of latitutde and longitude.*

Most of the grids with the highest values of species richness are situated in the Hajar and the Dhofar Mountains. Two very contrasting areas within the same country that highlight the incredible diversity of landscapes in Oman, with very arid mountains in the North and lush tropical mountains in the South.

The Hajar Mountains of Oman and the UAE are one of the most biodiversity rich regions in Arabia and have 19 described endemic species of reptiles and several other species in the process of being described. Of all the species endemic to the Hajar Mountains, six are endemic to Oman (are not found in the UAE).

The highest levels of species richness within the Omani part of the Hajar Mountains concentrate in the Jebel Akhdar massif. Interestingly, some areas of high species richness are around the capital, Muscat, and most probably result from the combination of two factors: 1) it is a diverse and ecologically rich area, including well preserved beaches, plains, wadis, mountains and wetlands, and 2) as a result of its proximity to the capital, it has been surveyed very thoroughly or many records were assigned generically to Muscat. In the South, the highest diversity is concentrated in the Dhofar Mountains, where the climatic differences between the lush south-facing sea side and the dry north-facing land side of the mountains have played an important role in shaping the flora and fauna of this interesting biodiversity rich region.

The pattern of endemic species richness in Oman changes dramatically and is mainly concentrated in the Jebel Akhdar massif (Fig 9B), with some areas with relatively high endemic species richness in the Eastern

Hajars and especially in Masirah Island. Interestingly, Dhofar has very low levels of endemicity. This pattern does not match with the map of species richness, where it's much higher in Dhofar than in the north (compare Figs 8B and 9B). This can be explained by the fact that some species in the Omani side of the Dhofar Mountains extend their range to the Yemeni side of the mountain range, and other species have disjoint distributions in Dhofar and the Western Mountains of Yemen and Saudi Arabia (similar to the situation in the Hajar Mountains, where many species also occur in the UAE side and are therefore not considered endemic to Oman; Fig 9 on page 40). All these species found in the Dhofar Mountains of Oman that also occur elsewhere in Yemen and Saudi Arabia (and are therefore not endemic) include:

Acanthocercus adramitanus, Chamaeleo arabicus, Pseudotrapelus dhofarensis, Uromastyx benti, Hemidactylus alkiyumii, H. festivus, H. lemurinus, H. minutus, Ptyodactylus dhofarensis, Trachydactylus spatalurus, Tropiocolotes scorteccii, Acanthodactylus felicis, Mesalina austroarabica, M. ayunensis, Atractaspis andersonii, Bitis arietans, Echis coloratus, E. khosatzkii, Naja arabica, Platyceps thomasi, and *Rhynchocalamus arabicus.*

Table 1: *Endemic species by governorate. From left to right ordered from higher to lower diversity. The three governorates without endemic species (Musandam, Al Buraymi, and Al Batinah North) are not represented in the table.*

SPECIES	Ash Sharqiyyah South	Al Wusta	Adh Dhahirah	Dhofar	Al Batinah South	Ash Sharqiyyah North	Ad Dakhliyyah	Muscat
Acanthodactylus masirae	✔	✔		✔				
Asaccus arnoldi	✔					✔		✔
Asaccus montanus			✔				✔	
Asaccus platyrhynchus			✔		✔			
Hemidactylus endophis								✔
Hemidactylus hajarensis	✔		✔		✔	✔		✔
Hemidactylus inexpectatus		✔						
Hemidactylus luqueorum			✔		✔		✔	
Hemidactylus masirahensis	✔							
Hemidactylus paucituberculatus				✔				
Phrynocephalus sakoi	✔	✔				✔		
Pristurus gallagheri			✔		✔		✔	
Pristurus masirahensis	✔							
Tropiocolotes confusus				✔				
Trigonodactylus sharqiyahensis	✔	✔				✔		
Uromastyx thomasi	✔	✔		✔				

The Dhofar and the Western Mountains of Yemen and Saudi Arabia are partially or totally affected by the moisture-laden southwestern monsoon winds that blow against the sea-facing cliffs between July and August. These are responsible for the unique green vegetation on the coastal side of the mountain ranges, creating an ecosystem similar to a tropical forest with a patchy distribution across more than 2,000 km that has facilitated the dispersal of tropical taxa.

Ecology of Oman reptiles

The Oman reptiles include some generalist and specialist species. For instance, the skink *Trachylepis tessellata* is distributed across the Hajar and Dhofar Mountains in the North and South of the country, respectively, and in Masirah Island. The species is found from sea level up to 1,900 m in elevation, and covers most of the bioclimatic area defined by the mean annual temperature and annual precipitation. It is the only lizard species with such generalist ecological preferences. Of the 21 species of terrestrial snakes, three show a similar generalist pattern: *Psammophis schokari*, *Telescopus dhara,* and *Platyceps rhodorachis,* the latter having the greatest elevational range (from sea level up to 2,600 m) and a distribution across the entire climatic space of Oman. The remaining species of reptiles are more restricted in elevation, climatic space, and land cover preferences and are linked to specific areas, such as coastal deserts, inland deserts, arid mountains (high and low elevation), tropical mountains, islands, and coastal plains, among others.

Within Iguania, there are the families Agamidae and Chamaeleonidae. Within Agamidae, the genus *Phrynocephalus* is restricted to the arid areas of Oman with high temperatures and low precipitation and has never been found above 400 m in elevation. The genus *Pseudotrapelus* has two morphologically very similar species with very different bioclimatic and elevation preferences. *Pseudotrapelus dhofarensis* is found in the Dhofar Mountains and some arid areas to the North, mainly at low elevation, while *P. jensvindumi* is mainly restricted to the Hajar Mountains of North Oman, with many

Trapelus flavimaculatus, *Yellow-spotted Agama*.

Cerastes gasperettii gasperettii, *Arabian Horned Viper burying itself in the desert sand to ambush passing by prey.*

records at high elevation. Nevertheless, both species seem to have similar preferences for the land cover type (bare areas with gravel and rocks). The two subspecies *Uromastyx aegyptia leptieni* and *U. a. microlepis* also have completely different ecological preferences in Oman, the latter inhabiting the Hajar Mountains between sea level up to 1,000 m in elevation with preference for bare areas with gravel and rocks, and the former inhabiting mainly lowland (up to 500 m in elevation) hot and dry desert areas of the interior, with preference for bare areas with gravel and rocks or sand. The only Chamaeleonidae in Oman, *Chamaeleo arabicus,* is mainly distributed across the monsoon affected areas of Dhofar up to 1,400 m, but it has an introduced population in Masirah Island. This population is within a private fenced area dedicated to water purification with high trees and bushes. The population seems stable.

With 41 species, Gekkota are the most diverse terrestrial reptile group in Oman and include the genera *Hemidactylus* (14 species); *Pristurus* (seven species); *Asaccus* (six species); *Ptyodactylus* (three species); *Stenodactylus* (two species); *Trigonodactylus* (two species); *Trachydactylus* (two species) and *Tropiocolotes* (two species). At the generic level, *Hemidactylus, Pristurus,* and *Trachydactylus* independently cover most of the climatic space of Oman, but at the specific level many ecological specializations are found, such as *Pristurus gallagheri* or *P. minimus*, restricted to high elevation areas of the Hajar Mountains and to the lowland hot and dry desert areas, respectively. The genus *Asaccus* is only found in the rocky and arid Hajar Mountains of North Oman and the genus *Tropiocolotes* is restricted to the tropical Dhofar Mountains and some arid areas of southern Oman. As a result, both genera show very different ecological preferences. The genus *Stenodactylus* is restricted to low elevation (usually below 800 m in elevation) in hot and dry desert areas, with preference for bare areas with gravel and rocks or sand. The three species of the genus *Ptyodactylus* inhabit mountainous areas in both the North (Hajar Mountains) and the South (Dhofar Mountains). The two species from the North

The introduced gecko Cyrtopodion scabrum, *Rough Bent-toed Gecko.*

(*P. orlovi* and *P. ruusaljibalicus*) and the southern species (*P. dhofarensis*) occupy a very similar habitat, but a rather different climatic space.

The 13 species of Lacertoidea include two families and four different genera: Family Trogonophidae, genus *Diplometopon* (one species), and the Family Lacertidae with *Acanthodactylus* (seven species), *Mesalina* (three species), and *Omanosaura* (two species). *Acanthodactylus* and *Mesalina* are mainly restricted to elevations usually below 1,000 m in hot and dry desert areas, while the two species of *Omanosaura* are restricted to the Hajar Mountains, with some populations reaching up to 2,800 m in elevation in environments with relatively high precipitation and low temperature. *Diplometopon* is a sand-dweller, restricted to low elevation areas in sand dune deserts.

The Scincoidea inhabit the entire ecological space of Oman and, with the exception of the generalist *Trachylepis tessellata* (see above), the other species are restricted to particular areas with different ecological preferences. *Varanus griseus* is the largest Oman terrestrial lizard (more than 1.2 m including the tail) and exploits a very particular habitat characterized by low elevation (up to 600 m), hot and dry bare and rocky areas with sparse vegetation.

The 21 species of terrestrial snakes compose the most ecologically heterogeneous group. Three of them are generalists (see above); others such as *Cerastes gasperettii gasperettii* only dwell at elevations below 500 m, in hot and dry sandy areas, and others such as *Pseudocerastes persicus* are only found in the highest parts of the Hajar Mountains (between 500 and 2,500 m in elevation), under relatively cold and humid conditions, and associated with rocky environments.

Finally, of the 96 species of terrestrial reptiles, five have been introduced into Oman. Three originally from India: the Agamidae *Calotes versicolor*, and the Gekkonidae *Hemidactylus flaviviridis* and *H. leschenaultii*. The Gekkonidae *Cyrtopodion scabrum* and the Typhlopidae (snake) *Indotyphlops braminus* are of unknown origin. The introduced snake

is the most widespread snake species in the world and is parthenogenetic. It is now present in at least 118 countries, in all continents except Antarctica and South America, and in more than 543 islands. It gets transported in the soil of commercial plants all over the world.

Conservation status of Oman reptiles

The IUCN Red List categories of all 111 Oman reptiles (terrestrial and marine) include species under the following categories (Fig 10): NE (Not Evaluated), DD (Data Deficient), LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), and CR (Critically Endangered). There are no EW (Extinct in the Wild) or EX (Extinct) species. Therefore, in Oman, the only threatened taxa are eight VU species (the terrestrial reptiles *Uromastyx aegyptia leptieni, Uromastyx aegyptia microlepis, Uromastyx thomasi, Asaccus montanus,* and *Acanthodactylus felicis*, and the marine turtles *Caretta caretta, Lepidochelys olivacea*, and *Dermochelys coriacea*), one EN species (the marine turtle *Chelonia mydas*), and one CR (the marine turtle *Eretmochelys imbricata*). The remaining taxa include six DD, 70 LC, one NT (*Pristurus gallagheri*) and 24 NE species. Importantly, 11 endemic species are classified as NE and one endemic species as DD, one LC, one NT, and two VU. Therefore, 12 species out of the 16 (75%) Oman endemics do not have an IUCN category. As a result of the small distribution of most of the endemic NE and DD species, some of them will be assessed in the future as threatened species through the B criteria (geographic range) in the red listing process.

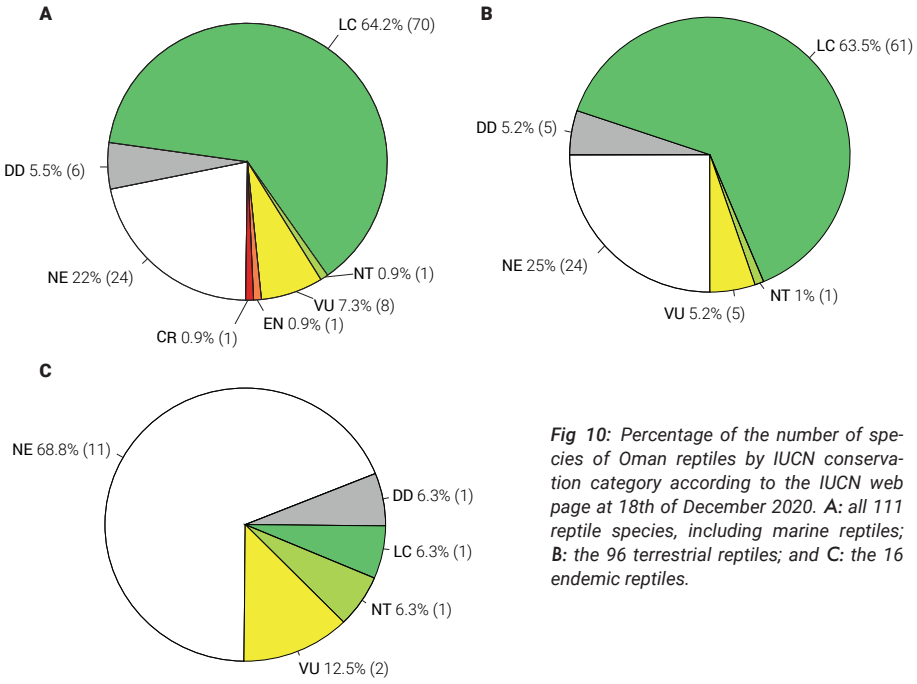

Fig 10: Percentage of the number of species of Oman reptiles by IUCN conservation category according to the IUCN web page at 18th of December 2020. ***A:*** *all 111 reptile species, including marine reptiles;* ***B:*** *the 96 terrestrial reptiles; and* ***C:*** *the 16 endemic reptiles.*

Medically important venomous snakes of Oman

As shown in the species accounts of both terrestrial and marine snakes, there are 19 medically important venomous snakes in Oman. In other words, snakes that have enough venom that can cause serious medical complications and require immediate medical attention in the unlikely event of being bitten by one of them. Of these 19 species, 10 are sea snakes of the family **Elapidae** and nine are terrestrial snakes of the Families **Elapidae, Atractaspididae,** and **Viperidae**.

Sea snakes

The 10 Sea Snakes that can be found in Omani waters are fully aquatic, which means that they do not need to leave the sea to breed (they are viviparous), drink (they drink from the falling rain), mate (they mate in the water), or eat (they eat fish). In principle, if they are found on the beach it is because they are stranded and will die if not returned to the sea quickly. They usually get stranded on the beach (sometimes in high numbers) after storms or when they are weak, ill, disoriented, or as a result of changes in water temperature, especially between seasons: April to June and September to November.

This can cause concerns, as sometimes there are several specimens stranded on the beach. Despite all 10 sea snakes that can be found in Omani waters are highly venomous and there is no antivenom available for them, they have never caused a single reported case of envenomation. Globally, sea snake bites are extremely rare with no recorded bites in decades, with the exception of intentional handling by snake catchers. That is because they are very shy and docile, preferring to swim away from humans and other creatures. If they are in the water, they will almost never bite unless you grab them and handle them with bare hands. When they are stranded on the beach they are vulnerable and more likely to bite, so it is very important not to handle them with bare hands.

Table 2: *List of medically important venomous snakes of Oman separated by families. TS = Terrestrial snakes; SS = Sea snakes.*

Family Elapidae	Family Atractaspididae	Family Viperidae
Naja arabica (TS)	*Atractaspis andersonii (TS)*	*Bitis arietans (TS)*
Hydrophis cantoris (SS)		*Cerastes g. gasperettii (TS)*
Hydrophis curtus (SS)		*Echis carinatus sochureki (TS)*
Hydrophis cyanocinctus (SS)		*Echis coloratus (TS)*
Hydrophis gracilis (SS)		*Echis khosatzkii (TS)*
Hydrophis lapemoides (SS)		*Echis omanensis (TS)*
Hydrophis ornatus (SS)		*Pseudocerastes persicus (TS)*
Hydrophis platurus (SS)		
Hydrophis schistosus (SS)		
Hydrophis spiralis (SS)		
Hydrophis viperinus (SS)		

What to do if Sea Snakes are found stranded on the beach

Like in the picture, sea snakes can be removed from the beach using a large bucket and a stick. They hardly move and are very easy to handle. Trash pickers also work very well. Once you have placed the snake in the bucket, it can be safely returned to the sea or transported to a marine rescue center for treatment.

Example on how to manipulate a sea snake, Hydrophis platurus, *Yellow-bellied Sea Snake, stranded on the beach.*

Terrestrial Snakes

As a result of their relevance from a human health and conservation point of view, the species richness of the nine species of terrestrial venomous snakes of Oman is shown for each governorate and each sampled grid of 10 arc-minutes (Fig 11). At the governorate level, Dhofar has the highest number of venomous species (six species), followed by Al Wusta (four species). With just one species, *Echis omanensis*, Al Buraymi is the governorate with the lowest number of venomous snakes (Fig 11A). The analyses at a finer scale (10 arc-minutes grid) reveal that species richness is also highest in Dhofar; more specifically in some areas of the eastern Dhofar Mountains (Fig 11B).

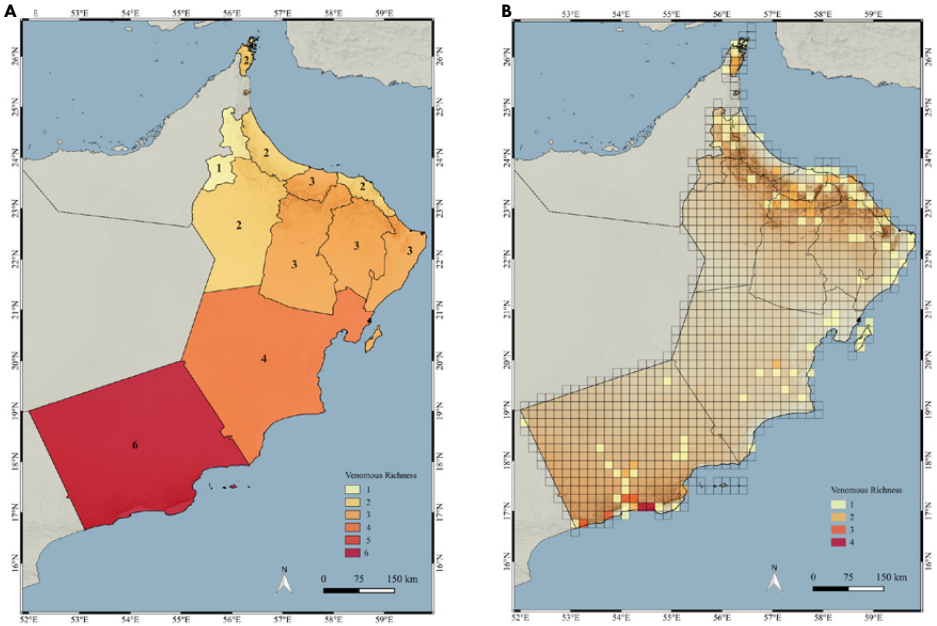

Fig 11: Maps of medically important venomous snake species richness. ***A:*** *Venomous snake species richness by governorate;* ***B:*** *Venomous snake species richness by grids of 10 arc-minutes of latitude and longitude.*

Defensive behavior of Bitis arietans, *Puff adder, Dhalkut, Oman.*

Of the nine terrestrial venomous snakes, *Naja arabica*, *Atractaspis andersonii,* and *Bitis arietans* are only found in Dhofar. *Echis coloratus* and *E. khosatzkii* are found in Dhofar and Al Wusta. *Cerastes gasperettii gasperettii* and *E. carinatus sochureki* have wider distributions. Finally, *E. omanensis* and *Pseudocerastes persicus* are restricted to the Hajar Mountains and immediate surrounding areas.

The venoms of these nine species have different effects. Although terrestrial venomous snakes are more aggressive than sea snakes, they will always try to escape and will warn before striking. It is recommended not to approach them or handle them, especially when they are in defensive (warning) mode. Among venomous snakes, different groups express various defensive behaviors to deter potential threats:

Defensive behavior of Cerastes gasperettii gasperettii, *Arabian Horned Viper, Sharqiyah Sands Oman.*

Defensive behavior of Naja arabica, *Arabian Cobra, Asir Mountains, Saudi Arabia.*

- *Bitis arietans* and *Pseudocerastes persicus* will hiss loudly by exhalating air through the nostrils, as warning before striking.
- *Cerastes g. gasperettii*, *Echis carinatus sochureki*, *Echis coloratus*, *Echis khosatzkii*, and *Echis omanensis* will make a warning rasping hiss with the serrated scales on the flanks of the body.
- *Naja arabica* will expand the sides of the neck if threatened, showing the characteristic cobra hood.
- *Atractaspis andersonii* may try to confuse the attacker with spasmodic movements to direct the attack to the tail.

Defensive behavior of Atractaspis andersonii, *Arabian Small-scaled Burrowing Asp, Wadi Dharbat, Dhofar, Oman.*

Snake bite first aid

It is very important that the bitten person is transported to a medical facility as quickly as possible. The following guidelines are only essential first-aid procedures.

1. Move the victim to safety from the area where people might be bitten again. It is important to bear in mind that all venomous snakes are capable of biting and envenomating repeatedly. If possible, take a picture of the snake for identification or try to remember some characteristics such as size, head shape and coloration.

2. It is VERY IMPORTANT to calm down and reassure the victim, who may be terrified as a result of the snakebite. This step is crucial and is justified as in many occasions venomous snakes give "dry bites", in which venom is not injected and therefore they do not produce any medical complications. Even if the victim is envenomed, there should be enough time to arrive to the nearest medical facility in Oman.

3. Immediately remove constricting clothing, rings, bracelets, bands, socks, shoes, etc. from the bitten limb, as in most occasions swelling occurs after the bite.

4. Immobilize the patient, especially the bitten limb, using a sling and try to keep the bitten limb below the level of the patient's heart. Muscular contractions anywhere in the body, but especially in the bitten limb help to spread the venom from the site of the bite, thus it is very important that the patient does not move excessively.

Transport the patient to a medical facility without any further delay.

IT IS VERY IMPORTANT THAT AFTER A BITE

- **DO NOT** give the victim any food, water or medication until reaching a medical facility. If there is a considerable delay before reaching medical aid (several hours to days) then give clear fluids by mouth to prevent dehydration.

- **DO NOT** use tourniquets, cut, suck, scarify, press or touch the wound, or apply ice, hot water, chemicals or electric shocks. These measures are useless and potentially dangerous.