MARINE REPTILES: ADAPTATIONS, TAXONOMY, DISTRIBUTION AND LIFE CYCLES

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Summary

The marine reptiles come from ancient terrestrial forms that eventually colonized the sea. The number of true marine species represents only 1% of all the reptile species that exist today. The true marine species are sea turtles, Marine Iguana and sea snakes. Some other species of turtles, lizards, snakes and crocodiles have estuarine habits, but always need freshwater to some extent.

The fossil record tells us that the marine environment became colonized several times by different groups of reptiles. Some of the families involved only contain marine species. During the Mesozoic they achieved a great diversity of forms.

The marine environment has a high content of salt. For that reason the marine reptiles have developed adaptive mechanisms to limit salt intake and to facilitate its excretion. Other physiological adaptations are related to diving and to thermoregulation. Also some anatomical adaptations have been needed to move efficiently in the water.

The present sea turtles are represented by eight species. They are found in all the oceans of the world, mainly in tropical and temperate waters. Only the females come out of the water to lay eggs. They build their nests in tropical and subtropical sandy beaches and can lay over 100 eggs in each clutch. They have many predators, mainly during the egg and hatchling period. Many populations have suffered a dramatic regression due to human causes.

The Marine Iguana is endemic to the Galápagos Islands. It is the only living lizard that has colonized the marine environment. It digs its nests in sand or volcanic ash and lays up to six eggs. It feeds on marine algae. It has no natural predators except for rats and feral animals like dogs and pigs. Its populations are not in danger, but strong El Niño effects do cause them significant impacts.

The sea snakes have the greatest diversity: 64 species in 3 families. The Hydrophiidae family contains 57 species and has viviparous reproduction. They never leave the water and if they get stranded accidentally, cannot return to the sea. The Laticaudidae are 4 species and have oviparous reproduction. They lay their eggs on sandy beaches out of the water. They feed mainly on fishes and are very venomous, with danger coloration. They have no predators. They live in the Indian Ocean and in Australia. Their populations are not in danger.

1. Introduction

The species of marine reptiles that we find today come from old terrestrial forms that invaded the aquatic environment a long time ago. This was made possible by some physiological adaptations that they already had when they lived on land. Two of the main problems they had to solve, when adapting to the marine environment, was how to retain water in their bodies and how to keep the salt concentration low. These difficulties in osmotic regulation may be the reason why the modern-day reptiles have been relatively unsuccessful in colonizing the sea.

There are approximately 7150 species of reptiles presently known, but only 74 species are really marine inhabitants. This represents only 1.0% (see Table 1).

Order	**Family**	**Number of species**
Testudines (turtles and tortoises)	Dermochelyidae (Sea turtle)	1
	Cheloniidae (Sea turtles)	8
Squamata (lizards, snakes and amphisbaenians)	Iguaniidae (Marine iguana)	1
	Hydrophiidae (True sea snakes)	57
	Laticaudidae (Sea kraits)	4
	Colubridae (Water snakes)	3

Table 1. Number of species of living marine reptiles grouped into families and orders.

These true marine species belong to three big groups: sea turtles, Marine Iguana and sea snakes. At least eleven more can be considered estuarine species or dwellers of mangroves, saltmarshes and coastal areas. But these are not completely marine species (Table 2).

Order	**Family**	**Specie**
Testudines (turtles and tortoises)	Emydidae (Freshwater turtles)	*Callagur borneoensis* (adults)
		Malaclemys terrapin
Squamata (lizards, snakes and amphisbaenians)	Varanidae (Monitor lizards)	*Varanus semirex*
	Colubridae (Water snakes)	*Fordonia leucobalia*
		Gerarda prevostiana
		Myron richardsoni
		Nerodia fasciata
		Cerberus rhyncops
	Acrochordidae (File snake)	*Acrochordus granulatus*
Crocodylia (crocodiles)	Crocodylidae (Crocodiles)	*Crocodylus porosus*
		C. acutus

Table 2. Species of living reptiles than occupy estuaries, mangroves, saltmarshes and coastal areas.

Finally there are few other species that can survive in marine habitats for short periods of time, like some freshwater turtles and lizards, that are occasionally found in those environments.

The species that live in estuarine habitats, mangroves, saltmarshes or coastal areas and are not strictly marine, being adapted to freshwater environments as well as to salt water environments. Most of these species can be found in both environments during their life cycles, developing different life strategies. Some of them migrate when the conditions change or when they grow older. Some others choose favorable microhabitats or even drink lots of freshwater when it is available. Some experiments have proved that if they can choose between salt water and freshwater, they prefer freshwater.

The two species of marine crocodiles live mainly in the river outlets and their surroundings. The Estuarine Crocodile *Crocodylus porosus*, chooses its environment according to its age and to the social structure. They are born in the rivers and live there during their first years. But when they become sub-adults they are expelled to more salty areas or to the sea by the dominant individuals. They can also occupy other tidal river systems that have lower crocodiles density. This species can make long trips across the sea, up to 1000 km in adult individuals.

The Diamondback terrapin *Malaclemys terrapin* is an estuarine species, which has a salt gland, but needs freshwater to survive. When it has to live in a salt water environment for extended periods of time, it reduces its food ingestion, to lower the salt intake. And when there is freshwater available it drinks lots of it, to store it in the body.

This article has the following structure: First it describes the extinct groups of marine reptiles. Then it explains the adaptations that helped the reptiles colonize the marine environment. And finally it describes the three present groups of marine reptiles and their relevant biological features.

2. The fossil marine reptiles

Colonization of the sea by the reptiles required several steps during their evolution. Some groups were formed exclusively by marine species, but others that had (or still have) species that live in terrestrial, freshwater and/or marine environments.

The first group of marine reptiles was the Mesosaurs during the Permian (between 280 and 248 million years ago). Their bodies were adapted to swim and they had a long flattened tail. There is no evidence that other groups of marine reptiles would have evolved from the Mesosaurs. Later on, during the Mesozoic (between 248 and 65 million years ago), other groups of marine reptiles did appear. Some of them dominated the marine environment and lived through the whole long era. Sauropterygia, Placodontia and Ichthyosauria where some of the exclusively marine orders. All of them are now extinct. Sauropterygia were species that looked like lizards, but had a long neck and were between 1 and 15 meters long. In some cases their legs were partially transformed into fins. Placodontia had a robust body and their legs were transformed into fins. Some species had turtle-like armors, but were not related to them. Ichthyosauria were fish-looking reptiles, superficially similar to our present dolphins. Some species of Ichthyosaurs lived through the whole era and their sizes were between 1.5 m and 10 m in length.

Some families, genera and species belonging to the present orders have become extinct. For example, in the order Squamata (lizards, snakes and amphisbaenians), the Mosasaurs than lived during the Upper Cretaceous became extinct. Their body and tail were very slim and were used for swimming, while the fins where used for steering.

Some species could reach 10 meters long. At least three genera of the snake family Paleophidae were marine animals and lived between the Cretaceus and the early Tertiary.

Some marine families from the order Crocodylia (crocodilians) became extinct: the Teleosauridae, which lived during the Jurassic (between 190 and 140 million years ago); the Metriorrinquidae, which were very specialized to the marine environment with limbs like fins, and lived between the middle of the Jurassic and the beginning of the Cretaceous; and the Dirosauridae, which had some coastal species between the beginning and the middle of the Cenozoic (between 65 and 37 million years ago).

Finally in the order Testudines (turtles and tortoises) the families that became extinct were Plesiochelyidae (Jurassic), Toxochelyidae and Protostegidae (both Upper Cretaceous), and also some genera of the family Cheloniidae, that lived between the Upper Cretaceous and the end of the Tertiary. The largest sea turtle was *Archelon ischyros*, from the family Protostegidae, and could reach 3 m long.

3. Physiological adaptations to sea life

The marine reptiles had to adapt to an aquatic environment which is full of salt and had to develop a breathing capacity adapted to diving. They also had to solve the locomotory problem in an environment which has a higher density and viscosity than air. Nevertheless, some of their physiological adaptations that already had developed for their prior life on land helped them during their new colonizing process. These helpful reptile adaptations were the ectothermy, the capacity for anaerobic metabolism, tolerance of acid-base disturbance, ventilation with apneic periods, and a circulation system with intra-ventricular shunting.

3.1. Salt and water balance

Seawater has a complex chemical composition, with many dissolved salts, of which chlorine and sodium ions are the most abundant. But there are also important quantities of magnesium, potassium, strontium, bromine, fluorine, sulfate and carbonate ions. And there are more ions in few quantities. Animals cannot accumulate these ions in their bodies, because they will become toxic if they reach certain levels. For that reason, marine reptiles need to maintain water balance to survive. They attain this by reducing losses of body water and by facilitating salt excretion. Body water is normally lost while breathing, through the skin and through excretion (salt glands, urine and feces), and salt comes into the body during feeding and through diffusion.

Although the skin is a water-permeable tissue, it plays an important role in osmotic regulation and in ionic balance. In marine and estuarine species this permeability is smaller than in freshwater species, to avoid dehydration process due to the salt rich environment. In addition the skin permeability is more resistant to the passage of water outward from the body. Another important feature of reptiles' skin is the ionic impermeability, which avoids salt entry, especially sodium.

On the other hand, the salt concentration in the marine reptile's body is less than that in the surrounding seawater. In contrast to other marine species, reptiles cannot tolerate high salt levels in their bodies. This would kill them. However, the plasma's osmotic concentration of electrolytes and nitrogenous compounds is higher in marine reptiles than in freshwater ones. This is because of the high levels of sodium, chloride and urea. They accumulate these ions and the urea in the extracellular fluid. When marine or estuarine reptiles are dehydrated, it is commonly due to sodium accumulation (hypernatremia) and not to potassium accumulation (hyperkalemia), because high concentrations of potassium are toxic to them. Unusual high concentrations of intracellular potassium will damage the activity of the enzyme systems and synthesis of DNA, RNA and protein.

A good system of eliminating salt excess while avoiding water loss is excreting very concentrated urine. Mammals accomplish this by producing a urine which is more concentrated in salts than their body fluids, using a counter-current mechanism in the kidney. But the kidney of reptiles is not able to produce urine more concentrated than the blood. Marine reptiles regulate salt content by the means of specific salt glands. Sea snakes, sea turtles, crocodiles, Marine Iguana and some lizards have salt glands, but they are all a result of convergent evolution. They are not a homologous salt gland. The Marine Iguana *Amblyrhynchus cristatus* and some lizards use a nasal gland; the sea turtles and Diamondback Terrapin use a lachrymal gland; the true sea snakes (Hydrophiidae), the sea kraits (Laticaudidae) and the *Acrochordus* use a sublingual gland; the Cerberus use the premaxillary gland; and the crocodiles use a lingual gland. These glands excrete mainly sodium and chloride ions, but also potassium and bicarbonate ions. The Marine Iguana excrete great quantities of potassium, which is an abundant ion in their diet but which is toxic in big concentrations.

As a general rule, marine reptiles do not drink sea water. They obtain the necessary water out of their food. Estuarine species and some sea snakes, however, do drink when they have freshwater available.

Finally, there are some species that use estuarine environments, but are not marine species, like some turtles, lizards, crocodiles and snakes. They select a favorable microhabitat where salt content is smaller than in the sea. When salinity is low, they stay in the estuarine habitat. But when the salinity increases they migrate to the rivers and freshwater areas. An example of migrating behavior to control salinity is the case of the Painted Terrapin *Callagur borneoensis*. This species does not have a salt gland, but the adults can tolerate seawater, so they nest in sea beaches. However, the hatchlings migrate immediately to the rivers after being born.

3.2. Respiration and diving adaptations

Respiration in reptiles has characteristic apnea periods, whose duration vary from one species to the other and depends on the circumstances. In aquatic reptiles the apneic periods are longer than in terrestrial species. These apnea periods allow them to stay a long time underwater with no effort. Because reptiles are ectothermic organisms and produce little metabolic heat, they need less oxygen than a mammal or a bird of the same size—another point that allows them to prolong their sojourns underwater.

Their breathing cycles present a characteristic series of rapid breaths, followed up by an apneic period. This will last until a new series of rapid breaths come. Sea turtles and sea snakes take only one breath each time they surface. Sea kraits show different breathing rythms when they are in the sea than when they are on land. In the water they have long apneic periods followed by several rapid breaths, but on land they have frequent and regular breaths.

Sea snakes can breathe through the skin, in addition to their pulmonary respiration. Through the skin they obtain around a fifth of the oxygen they need and almost all the produced carbon dioxide is eliminated through the skin. This latter feature is very important during the immersions, because it avoids its over-concentration in blood. Also nitrogen elimination through the skin can reduce the risk of bubble formation in long dives, that would produce decompression sickness.

Marine reptiles can control their buoyancy and maintain a position in the water column without spending extra energy in active swimming. They can stay on the bottom (negative buoyancy), at certain depth (neutral buoyancy) or on surface (positive buoyancy) just by getting air in or out of their lungs, just like the buoyancy control device of a scuba diver.

For example, the Yellow-bellied Sea Snake *Pelamis platurus* can control its buoyancy with its elongated lung. It can keep a positive buoyancy and remain at the surface, or stay neutral at four meters depth. The Marine Iguana reaches the neutral buoyancy when it is at four to five meters depth.

Marine reptiles generally do their immersions under conditions of aerobic metabolism. But when the dives last very long or are very repetitive in a short period of time, the metabolism becomes anaerobic. For example, the Marine Iguana does its short feeding immersions using aerobic metabolism, but during the longer escape dives, the metabolism can become anaerobic. When sea turtles hibernate, they stay completely submerged or buried in the mud for weeks. In this case the anaerobic metabolism plays an important role.

3.3. Thermoregulation

Reptiles are ectothermic animals, but their life cycles take place in a range of optimal body temperatures. When under or over this range the reptiles will cease their activities. And if the lower or upper critical threshold is surpassed, they will die. As with all other reptiles, they have some control of their body temperature—it is not always the same as the temperature of the surrounding environment. They can increase or decrease their body temperature through certain behaviour, like basking on the surface or like selecting microhabitats at lower or higher temperatures.

But even when reptiles have low rates of metabolic heat production, they can also produce some internal body heat and keep it, thanks to a layer of insulating fat. For example, the Leatherback Turtle *Dermochelys coriacea* can have a body temperature 18 ºC above the sea temperature. This can be done thanks to the large size that they attain. They are the largest present marine reptiles, reaching 2.4 meters and weighting 900 kg.

Their favorable surface-volume relation helps them to reduce body heat losses, as does their thick layer of fat under the carapace and their counter-current circulatory system at the fins. This capacity allows them to remain active in waters at just 6 to 8 ºC. The Green Turtle *Chelonia mydas*, can maintain a temperature 8 ºC over that of the surrounding sea water. This thermic regulation capacity is less developed in smaller sea turtle species.

Sea snakes like the Yellow-bellied Sea Snake can have a body temperature 2.4 ºC above the sea temperature. Anyway, since all the species from this group live in tropical or subtropical waters, their body temperature is very similar to the sea temperature. The sea kraits can get out of the water to bask in the sun and regulate their temperature. The Yellow-lipped Sea Krait *Laticauda colubrina* maintains its body temperature between 29 to 31 ºC when it is on land, even when the surrounding temperature does change. This thermic regulation is due to its behaviour. It selects the cooler places during the hottest hours, and exposes itself to the sun to increase body temperature, when the temperature drops down.

The Marine Iguana controls its body temperature by basking in the sun on the shore, and reaches up to 35 to 37 ºC. The sea in the Galápagos islands is cold. So, when the iguana does a foraging trip to the sea, its body temperature drops, to as low as 25 ºC. It has two strategies to control its body temperature. The smaller animals do short trips, returning quickly back to the shore. By doing so, they keep their body temperature more or less stable. The bigger animals do longer trips and can stay in the sea until their body heat drops down to 25 ºC.

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Biographical Sketches

Albert Bertolero was born in May 1966 in Lima, Peru. He is a biologist from the University of Barcelona, Spain. He works on wildlife monitoring, especially on chelonians and birds. He has been working since 1991 in different research and management projects in the Ebro Delta Natural Park for the catalan government and for the University of Barcelona. In these projects he has been working in the field on species such as tortoises, freshwater and sea turtles, shore and sea birds, passerines and raptors of wetlands. He has also participated in several projects on sea lions and Humboldt penguin on the Peruvian coast, during and before the El Niño event. After ten years of field study, he prepared a Zoology PhD on Hermann's Tortoise *Testudo hermanni hermanni* at the Ebro Delta and he is one of the authors of the recovery plan of this species. He has written many scientific papers and popularization articles on turtles, tortoises and birds. He is a member of the Spanish Herpetological Society and the Catalan Ringing Group.

Jacqueline Donoyan was born in January 1966 in Lima, Peru. She graduated in Mass Commucation from the University of Lima, Peru, and obtained a Master in Co-operation and Development from the University of Barcelona, Spain. For many years she worked as a professor of semiotics at the Mass Communication School, University of Lima, Peru. She was also a TV and advertising producer. She later moved to Tarragona, Spain, where she lived since 1996. There she became interested in wildlife and conservation, especially of wetlands. Since then she works as a free-lance writer and translator on these subjects, and has published guides and popularization articles. Currently she works at the documentary centre of the Ebro Delta Natural Park, in Spain.

Boris Weitzmann was born in November 1966 in Barcelona, Spain. A biologist at the University of Barcelona, he is dedicated to the marine environment. For many years he has been living beside the Mediterranean Sea as a researcher, and teaching environmental education. He is also a scuba instructor. He has been working in several research and nature management projects: for the Spanish Government in a *Caulerpa taxifolia* survey, for the University of Barcelona in the Medes Islands Marine Reserve and the Aigüestortes National Parc; for DEPANA-NGO and for the catalan government in the creation of the new Natural Site Punta de la Mora in Tarragona.