# Life on Land vs Life in Water

The greatest natural divide in life on the planet is whether an organism lives in water, is **aquatic**, or lives on land, is **terrestrial**. The difference in these environments is great and only a few organisms can transition easily between them both. Even the vertebrate class

"both sides" "life"

**amphibians** which includes frogs and salamanders, usually undergo a

"after" "form" "state of"

**metamorphosis**, changing from an aquatic larval form, like tadpoles, to the terrestrial adult form to manage the difficulty of living in each environment. For the first 3.5 billion years, life was aquatic. Until 600 million years ago, life would have needed to evolve specific compounds to protect it from the lethal ultraviolet radiation it would be exposed to on land. By 600 mya, enough oxygen had accumulated in the atmosphere to produce the ozone ($O_3$) layer that protects terrestrial life from ultraviolet radiation. Animals evolved in the sea about 630 mya and didn't venture on to land until about 460 mya, but these were probably aquatic arthropods taking strolls on land before returning to the water. The first truly terrestrial animals were probably scorpions which evolved about 430 mya. The first terrestrial vertebrates evolved about 375 mya. To understand why this was so difficult for life to do, we will compare the sister clades crustacea and insecta (meaning each clade evolved from the same common ancestor).

Japanese Spider Crab, the largest arthropod



Little Barrier Giant wētā, the heaviest insect



First, how is water different than air. Both are fluids but are in different states. Water is liquid and air is gaseous, which means water molecules are in contact with each other and air molecules occasionally bump into each other. This makes a huge difference. It makes water much **denser**, so it is harder to move through, but it is slower to gain or lose heat. It also makes it more **buoyant**, able to displace more weight of anything immersed in it. That means things like huge ships can float on it. The density of air is so much less than water that animals sink in air and must deal with living on the land, although many animals have evolved flight as an efficient means of locomotion. But animals do not float through the skies like jellyfish do through the oceans.

As animals go deeper in water, the weight of the water above them, the **water pressure**, increases immensely. Every 10 m change in depth increases the pressure equivalent to the pressure exerted by the whole 1000 km height of the atmosphere, when standing at sea level. Hence, the pressure of every 10 m depth of water is called an atmosphere.

Air, being much less dense gains and loses heat quickly. Animals adapt to this by narrowing their range to specific latitudes (north-south) or altitudes, by evolving body structures like fur, feathers and fat or by changing behavior, like only venturing into the environment at particular times of day or seasons. Some do all three. Black bears live in temperate climates, have fur and fat to survive in winter when they hibernate. Marine (saltwater) organisms will evolve for specific water temperatures, but the water at any location changes slowly because of its large heat capacity, and the temperature range is much smaller. The waters of the Northumberland Straight between Prince Edward Island and the mainland has a low of $-2^0$ C in the winter to a high in some places of $25^0$ C in the summer, a difference of $27^0$ C, one of the largest sea surface temperature range in the world. The air temperature on P.E.I., meanwhile, has an average low of $-30^0$ C and an average high of $30^0$ C, a change of $60^0$ C, nowhere near a record range.

Oxygen gas easily mixes in air, so it now makes up 20.95% of air, or 209.5 mL of $O_2$ per litre of air. Water vapour, on the other hand, makes up only 0 - 3% of air. Typically, in water there may only be 4 – 8 mL of $O_2$ per litre of water. So, on land, $O_2$ is plentiful and water is scarce. In water, water is plentiful and $O_2$ is scarce.

Light in the sea varies in intensity by depth, deeper is darker, and a smaller range of wavelengths for eyes to see. As you go deeper, the light gets dimmer. Deeper than 200 – 1000 m no light penetrates, and you are in permanent darkness except for light produced by organisms, bioluminescence. In the shallow surface waters near visible and visible light penetrates, but the short wavelengths, UV, red, orange, yellow, start being absorbed in that order as you go deeper than even a few tens of centimetres, explaining why underwater pictures taken without underwater strobes look bluish. As a result, marine organisms do not rely on sight as much as chemoreception, like smell and taste. On land, vision is often a primary sense, with many animals evolving the ability to see at night using the light of the moon and stars.

Let us look at the body systems of Crustaceans and insects to see how insects evolved to live in a drier, more oxygenated environment that allowed easy movement.

| Body System | Crustacean | Insect |
|---|---|---|
| Integumentary | A heavy, rigid exoskeleton made of a calcium carbonate shell in a chitin framework. | A light, inelastic two-layer exoskeleton composed of a waterproof waxy outer layer and a strong chitin underlayer. No $CaCO_3$ significantly decreases weight and the waxy cuticle prevents dehydration. |

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|---|---|---|
| Respiratory | $O_2$ is absorbed by exposed surfaces where the shell is thin, such as the smaller appendages, and, in bigger crustaceans, across feathery gills located under the shell of the carapace where water freely flows over them. | Air is brought into the body via openings on the sides of the abdomen and thorax called **spiracles** through tubes where $O_2$ and $CO_2$ are exchanged. This prevents water loss but is not very efficient, limiting insect size. In the late Paleozoic when $O_2$ levels reached 30%, dragonflies grew to have wingspans of 50 cm. |
| Excretory | The **antennal glands**, located in the head, maintain the salt content of the body fluid. Nitrogenous wastes are eliminated across body surfaces and the gills. | **Malpighian tubules**, extensions of the digestive system, remove nitrogenous wastes from the body fluid while conserving water and salts, then returns the end product, an almost solid paste, back to the digestive system for excretion. |
| Locomotion | Many legs adapted for walking and swimming. Some legs evolved as claws, as in crabs and lobsters. | Legs reduced to six that move like two sets of tripods, maximizing stability while minimizing the number of legs, and, therefore, weight. Insects are the only invertebrates to evolve flight, using either 1 or 2 pairs of wings. |
| Nervous | Brain is a pair of ganglia with nerves to the eyes and the two pairs of antennae. The antennae are chemoreceptors, as well as the many **tactile hairs** found over the body and around the mouth. A **statocyst** is found at the base of the first antennae and gives information on the orientation of the body. The compound eyes have different pigment cells to allow for sight in different light intensities. | The sensory systems of insects are vastly improved over Crustaceans. However, not all insects have the same capabilities. Insects with good vision usually have poor smell and smaller antennae. While those, like moths, with good smell have smaller eyes. Insects that can produce sound, can hear sound. Sight can extend into the ultraviolet as in many pollinators, or into the infrared, like the blood feeders. |
| Endocrine | Molting of the exoskeleton, required for growth, is controlled by the X-organ found at the base of the eye stalks. Crustaceans periodically molt to grow. | Some insects avoid cold or dry seasons by undergoing complete metamorphosis. They remain in a chrysalid throughout the bad weather season and emerge as an adult. |

Other changes also occurred. Neil Shubin in his book *Our Inner Fish*, about the discovery of the terrestrial vertebrate's fish ancestor, *Tiktaalik roseae*, found as a fossil in 375 million-year-old deposits in Ellesmere Island, discusses its similarities to terrestrial vertebrates and differences from other fishes. (In biology, fish is the plural within a group, and fishes is the plural for groups of fishes. There are three traditional classes of living fish: the Agnatha, lampreys and hagfish that have no jaws; the Chondrichthyes, sharks and rays that have skeletons made of cartilage, like our ears; and the Osteichthyes that have bony skeletons. Then each class is divided further in orders, families and genera.) One of his observations is the beginning of a **neck**. When looking at fish, heads are not delineated from their body by a neck. However, *Tiktaalik* showed a delineation. Most terrestrial vertebrates do as well. Frogs don't but their close relatives the salamanders do. Most reptiles have necks although it is hard to tell with snakes. Birds and mammals have necks, some being very prominent as in ostriches and giraffes.

Insects have an obvious separation between their middle section, the **thorax**, and their **head**. They can move their head freely. Crustaceans, on the other hand, have their thoraxes and heads fused into a single body part the **cephalothorax**. It is also interesting that **cetaceans**, the whales, do not have a trunk-neck delineation despite evolving from antelope-like hoofed mammals with necks.

***Pakicetus*, the earliest cetacean**

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**Humpback Whale**

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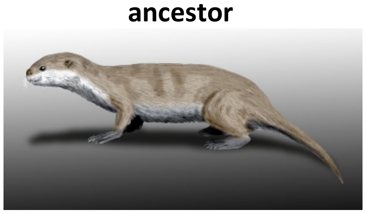
Even among the **pinnipeds**, the order that includes sea lions, walruses and seals, the most aquatic of the group, the "true" seals, have less of a neck than their cousins the sea lions. Why this is so, I am not sure. That this occurs repeatedly indicates it is more beneficial to not have a neck in water, and more beneficial to have one on land. I suspect it has something to do with hydrodynamics, moving through water versus moving through air.

***Puijila*, proposed seal ancestor**



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**South American Sea Lions**

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**Harbor Seal on Rocks**

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