When we think of the animals of the oceans our first thoughts are generally of whales, sharks, dolphins, tuna fish, and perhaps octopusses. All these have been in the news lately, also in this magazine, for reasons regarding their behaviour or exploitation. These are large animals, and like the lesser food fishes such as salmon and herring, we have many reasons for our interest in them. However, even the very small aquatic creatures such as krill and zooplankton are important because they are at the bottom of the food chains of the larger fish which themselves again are food for those at the top of the chains, we humans. Thus, all marine life in someway or other is important to us.

There is one important common factor in the examples of marine life given above. They all have their prime existence in the water, i.e. at least partially below the surface. We rarely, if ever, consider the other sort of animal life associated with the oceans, that which lives by or on the ocean but not in it at all. Here I am thinking about the marine insects.

According to an excellent, newly published book (Evolution of the Insects, D Grimaldi, M.S Engel, Cambridge University Press) there are approximately 926,400 described species of extant hexapods i.e. insects. Estimates of the total number of insect species vary from about 2 million species to 30 million species and more. However, an estimate of about 5 million species is probably the most accurate. (Gaston, K.J. 1991. The magnitude of global insects species richness. Conservation Biology 5: 283-96). Thus, only about 20% of the global insect fauna is probably known and named.

**Big numbers**

Insects comprise more than 75% of all described animal species. Some 30,000 to 40,000 insect species, i.e. just 3 to 4 percent of all insects, are aquatic, or have aquatic larval stages, and live in all sorts of watery habitats. About 9,000 species (mostly bugs and beetles) have all stages under or on water. In about 30,000 species only the larval stage is aquatic (flies, mosquitos).

Insects are found throughout the world except near the poles and, with but a single exception, pervade every habitat except the sea. Some are found at depths of 1,300 meters in Lake Baikal, some are to be found only in rain-filled tree holes, while others inhabit caves and underground aquifiers.

Freshwater habitats are the only aquatic habitats where insects dominate. In saltwater and brackish habitats, crustacea (the next most numerous arthropod) dominate. Although only 3% of all insects are aquatic for some part of their life cycle, insects make up more than 90% of small creatures found in mountain streams.

**Impact**

Despite their low numbers compared to the terrestrial insects, marine insects still have a tremendous impact on man. Flies...
Marine Insects

are the most numerous and economically important species of marine insects. The disease-bearing mosquitoes, biting horse flies, deer flies, and midges have impeded the human development of enormous areas of coastal land. And other marine flies can transmit diseases such as Leishmaniasis.

Unlike the dominating land-based insects, however, the marine insects have additional problems to overcome in their fight for survival. For example, how do aquatic insects avoid drowning? Most insects that land on water are trapped by the water surface tension and tiny ones can even drown inside a water droplet, unable to break out of the bubble surface. Aquatic insects cope by having a waterproofed skin so the water doesn’t get into the body. Many are covered with a water-repellent waxy layer. They also usually have hairy or waxy legs which repel water so they don’t get trapped by the water surface tension.

The oxygen problem
There is very little oxygen in water (as low as 0.4% and often zero). Water contains less oxygen the warmer it is. This is why there is often more life in a cool pond shaded by trees and in temperate climates. There is much more oxygen in air (20%), and water is much heavier than air.

So, to extract oxygen from water, an animal will have to process a lot of water to get the same amount of oxygen. That is probably one reason why adult aquatic insects continue to breathe air instead of developing gills. Usually only aquatic insect larvae develop gills to absorb oxygen underwater. A skin of air that is trapped by hairs on the body or under the wing covers (Water Beetle). The insect breathes the air in the bubble through the holes in its abdomen (spiracles) just like other insects.

Making the best of both worlds
Living on the margin of water and air, many aquatic insects have developed ingenious ways to sense the world and to move around. Most aquatic insects are sensitive to water ripples to detect predators or prey. Some even create their own ripples on the water surface and process the returning “echoes” to detect prey. Many also create ripples to find mates and communicate with each other (Whirligig Beetle, Pond Skater).

In a double-vision adaptation the Whirligig Beetle has eyes divided horizontally to see both under and above water. This is very useful when predators can attack you from both below and above. Many paddle underwater with oar-like legs. These legs are long, flattened and fringed. The hairy fringes spread out on the power stroke increasing the surface area and bend in on the
Marine Insects

Among the most interesting aspects of the Halobates is how they manage to walk or skate across the surface of the ocean. The secret is the tiny water-repellent hairs on their legs and feet that allow them to “tiptoe” across the surface of the water. These hairs also help to spread the insects’ weight over a larger surface area, preventing them from sinking.

The surface tension of the air-sea interface allows them to stand or move on the water at a speed as fast as one meter per second. As long as the surface tension is maintained, sea skaters are able to move normally. If the surface tension is lowered by pollutants or detergents, they flop on the surface and eventually sink. Tiny hook-shaped hairs, about 1.5 microns long, also cover the sea skaters’ bodies. These trap a layer of air surrounding the insect, making them buoyant. Thus, they are basically enclosed in an air bubble; if they are pushed under the water, they quickly pop up again. If sea skaters are caught in rough seas and trapped beneath the surface for short periods, this jacket of air provides them with enough oxygen to survive.

No other animal on Earth lives in such a vast two-dimensional habitat. They are the only marine invertebrates constrained to traveling, feeding and reproducing only at the surface of the ocean. Among the difficulties of living in such a vast world is how the Halobates find each other to breed and lay eggs.

Hot hypotheses

Dr Lanna Cheng, a well-known long-time expert on marine insects at the University of California, San Diego, with others, gives several hypotheses as to why this is so.

The first hypothesis suggests that insects are limited by salinity. While this may be true for the majority of insects, many flies have efficient osmoregulatory mechanisms that allow them to tolerate salinity in excess of 3 times that of the ocean.

The second hypothesis suggests that ocean depth limits an insect’s ability to complete its development. This is true of many insects and yet chironomid fly larvae survive at depths below those that even the deepest diving mammals can
Marine Insects

Finally, a fourth hypothesis considers the fact that insects were successful because they colonized land. By moving away from the ocean, they adapted to a terrestrial existence while their major competitors the crustaceans stayed in the sea and continued to adapt. As millions of years passed, insects lost their ability to successfully compete in the ocean while crustaceans have had only limited success in invading land. Dr Lanna Cheng believes that this is the most likely explanation for the absence of insects in the oceans. As potential evidence, it is noted that the only insects that live on the open ocean, live on its surface. As such, they never come in contact with the crustaceans living beneath its surface.

Final thoughts

There are many questions still unanswered about this strange case of the Halobates. How come that they alone of the so many insects managed to adapt to life on the oceans? Whatever hypothesis is true, though, if any of them are, the Halobates are a really remarkable example of marine life rarely, if ever, to be observed by divers.

For more information on marine insects, visit the Marine Insects Home Page of the Department of Biology at the University of Nebraska at Kearney: www.unl.edu
Or visit the Marine Insects page of the Department of Entomology at the University of Nebraska at Lincoln: entomology.unl.edu

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Marine Skater, Halobates. Photo by Dr Lanna Cheng, University of California-San Diego

A DIVING BELL

The Water Spider (Argyroneta aquatica) is not an insect, but it is an aquatic expert. It lives underwater by creating an underwater air chamber. It gathers a small bubble of air from the surface on its hairy hind legs, then releases it into a web woven among water weeds. It waits inside this underwater lair to catch passing prey. The spider mates and lays eggs inside this air chamber which works like a gill and allows the insect to absorb oxygen directly from the water. As the insect uses up the oxygen in the bubble, dissolved oxygen in the water diffuses into the bubble so the insect actually get more oxygen than originally in the bubble. However, nitrogen must be present for this to happen. The nitrogen provides stability to the bubble (it diffuses more slowly out into water than other gases). So, the insect goes back to the surface to replenish nitrogen rather than to get fresh oxygen. In an experiment, an aquatic insect provided with pure oxygen survives only 30 mins underwater, while with air it can survive 4 hours. ■
Surface tension is a quantity which we often meet in daily life without thinking too much about it. It plays a large role in washing and cleaning procedures, for example, as well as in lubrication, cosmetics and rainwear. Among the numerous anomalous properties of water is its very high surface tension. This has great consequences for all life forms, both human and otherwise. In the article on Marine Insects in this issue of X-ray-mag the ability of insects to ‘walk on water’ is ascribed to its surface tension. The effect of this phenomenon is thus of vital importance to these insects.

Surface tension has properties resembling a stretched elastic membrane. This is due to the fact that water molecules at the liquid–gas interface have lost potential hydrogen bonds directed at the gas phase and are pulled towards the underlying bulk liquid water by the remaining stronger hydrogen bonds, of which there are many. (An explanation of hydrogen bonding was given in the previous number of X-ray-mag.)

In the bulk of the liquid each molecule is pulled equally in all directions by neighbouring liquid molecules, resulting in a net force of zero. At the surface of the liquid, the molecules are pulled inwards by other molecules deeper inside the liquid, but there are no liquid molecules to balance these forces, so the surface molecules are subject to an inward force of molecular attraction which is balanced by the resistance of the liquid to compression. There may be a small outward attraction caused by the air molecules, but as air is much less dense than the liquid, this force is negligible.

As the forces between the water molecules are several and relatively large on a per-mass basis, compared to those between most other molecules, the surface tension of water is large.

Surface tension is measured in newtons per meter (N m⁻¹) and is defined as the force along a line of unit length perpendicular to the surface. At 20°C it has the value 7.29 x 10⁻² N m⁻¹. For comparison, mercury, in which the intermolecular bonds are electrostatic rather than hydrogen bonding, has the value of 46 x 10⁻² N m⁻¹ i.e. about 6 times greater. This is why mercury forms bigger spherical drops than water on, for example, a glass surface.

Dimensional analysis shows that the units of surface tension, N m⁻¹, are equivalent to joules per square meter (J m⁻²). This means that surface tension can also be regarded as a surface energy. Energy is required to increase the surface area so it is minimised and held under tension. As a sphere has the smallest surface to volume ratio i.e. the least surface energy, this will make the sphere the most stable shape for a bubble.

The hydrophobic legs of a water strider
A water strider can walk on water because its feet do not break through the surface. This is because its feet and legs are hydrophobic i.e. water repelling. It has been shown that the water resistance of the legs is due to their special structure, being covered by large numbers of oriented tiny hairs with fine nanogrooves. It is this physical structure that is more important than the chemical properties of the waxy coatings of the legs. It has been calculated that the maximal supporting force of a single leg is 0.00152 newton, which is about 15 times the total body weight of the insect. This shows that the surface of the leg is strikingly water repellent. It is no wonder, then, that these insects are so good at dashing around on the surface of water. ■