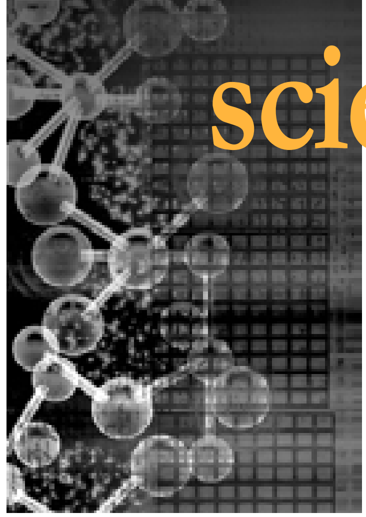


Walking on Water

Marine Insects

—and the strange case of the Halobates

Sea skater, *Halobates*. Photo courtesy of Scripps Institution of Oceanography, La Jolla

Text by Michael Symes
Photos courtesy of Dr Lanna Cheng, University of California-San Diego and Scripps Institution of Oceanography-La Jolla

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 acquatic 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.

A Marine Chironomid (midge)
Photo by Dr Lanna Cheng, University of California-San Diego

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, KJ. 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 percent 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.

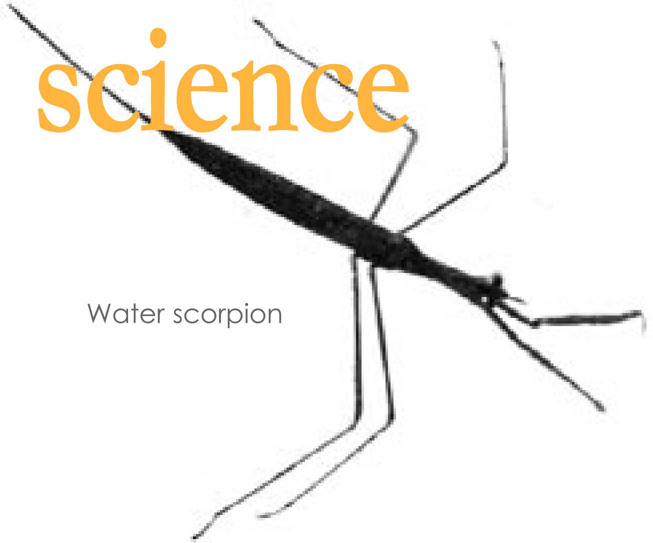
Freshwater habitats are the only aquatic habitats where insects dominate. In saltwater and brackish habitats, crustacea (the next most numerous arthropod) dominate. Although only 3% of all insects are aquatic for some part of their life cycle, insects make up more than 90% of small creatures found in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

Map of A Marine Chironomid (midge) habitat. *Pontomia* are found only in lagoons or tide pools in the Indo-Pacific. Illustration courtesy of the University of Nebraska-Lincoln Department of Entomology

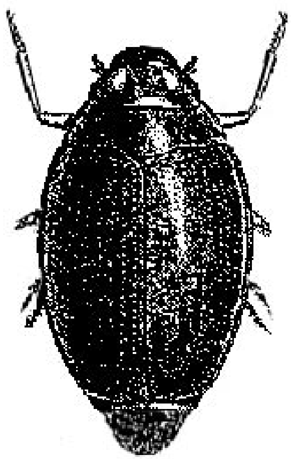
Impact

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

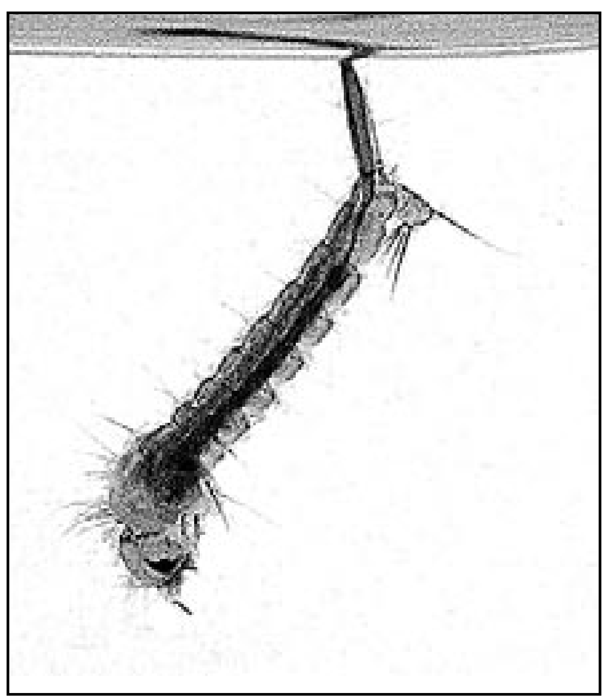
Marine Insects



Water scorpion



Whirligig Beetle live on the surface of the water at the edges of lakes and streams. They are 5-25 mm long and are named so, because they swim in circles



A mosquite larva uses a snorkel-like breathing tube at the posterior end of its abdomen

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.

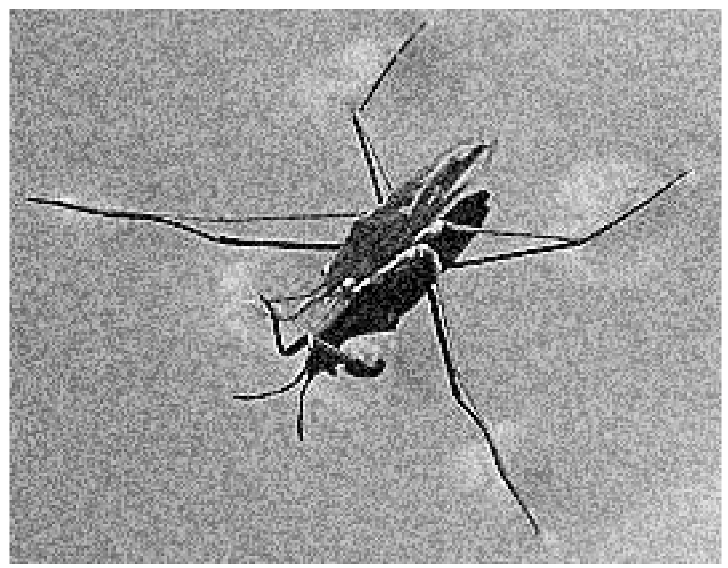
Unlike the dominating land-based insects, however, the marine insects have additional problems to overcome in their fight for survival. For example, how do aquatic insects avoid drowning? Most insects that land on water are trapped by the water surface tension and tiny ones can even drown inside a water 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 from the water. So, how do aquatic insects obtain their oxygen?



Pond Skater

Like mosquito larva and water scorpion, they can snorkel with a breathing tube. The end of the tube usually has bristles to break the water surface tension and keep the tube open. This method, however, doesn't allow the insect to travel far from the water surface.

Others have a scuba tank. These "divers" create an "air tank" for greater freedom of movement 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.

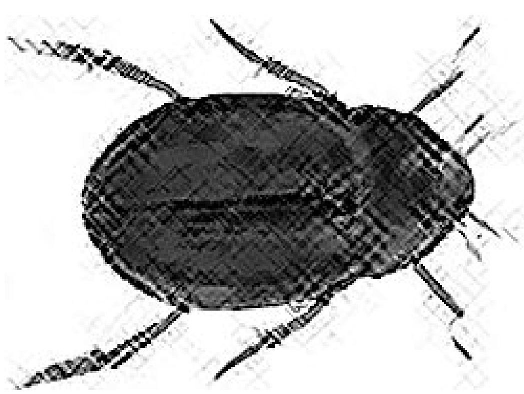
Many paddle underwater with oar-like legs. These legs are long, flattened and fringed. The hairy fringes spread out on the power stroke increasing the surface area, and bend in on the

Marine Insects

Marine Skater Eggs on a floating Spirulla shell. Even though *Halobates* live their entire lives on the ocean, they require floating objects upon which to place their eggs. These objects can include floating seashells, sea bird feathers, pieces of wood, plastic or lumps of tar. The eggs, which are often crowded on small objects due to the lack of available egg deposit sites, are rather large in size compared to the body size of the female who produces 10 to 20 matured eggs at a time. Photo by Dr Lanna Cheng, courtesy of the University of Nebraska-Lincoln Department of Entomology

return stroke to reduce water resistance. (Water Beetle, Water Boatman). These insects usually have flattened streamlined bodies or are torpedo-shaped.

The Camphor Beetle (Stenus) also skates on the water surface but has a neat trick to enhance its speed. When alarmed, it releases a chemical from its back legs that reduces the water surface tension. In this way, the water surface tension on the front pulls it forwards. It shoots forwards on its front feet which are held out like skis, and steers itself by flexing its abdomen. This tiny beetle is the size of a rice grain but can travel nearly 1m a second this way. It doesn't hunt on water, but at the water's edge, and saves this trick to escape predators.



Lesser Water Beetle

The *Halobates*

As we have seen above, marine insects have developed succesful strategies for survival in an aqueous environment. However, if we read further in 'Evolution of the Insects' (referred to above) one finds the very surprising statement (page 317) "*Halobates* is the only pelagic insect" —i.e it is the only insect that lives on the open oceans!

Halobates, or sea skaters as they are called, are a group of wingless insects that can "skate" on ocean water. Sea skaters feed primarily on zooplankton trapped at the sea surface, grasping their prey with their short front legs and sucking them dry. They have never been observed breaking the water surface to feed—i.e they do not dive.

While members of the coastal species deposit their eggs on fixed materials such as mangrove tree trunks or rocks, open-ocean species lay eggs on just about anything that floats, including empty seashells, wood, feathers, seeds and even lumps of tar.

Walking on the ocean

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.

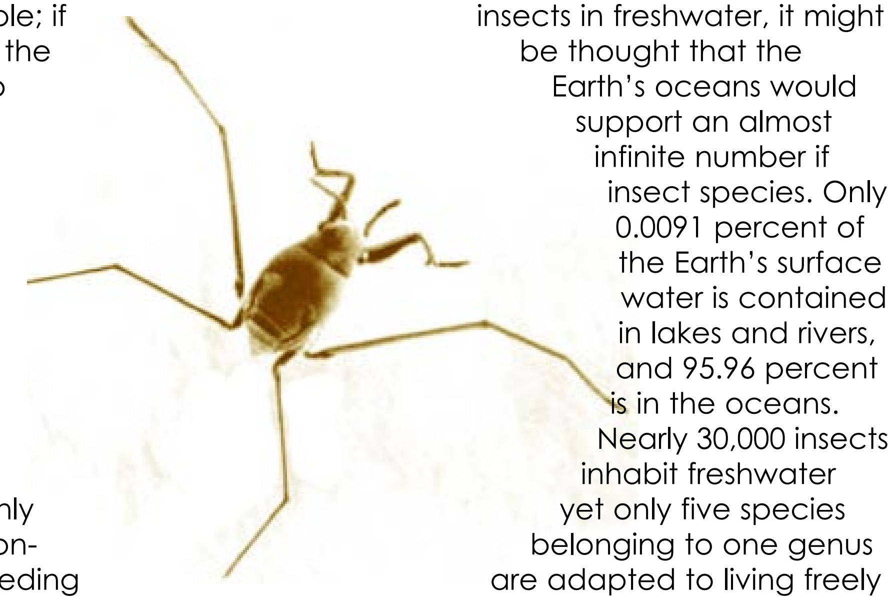
The surface tension of the air-sea interface allows them to stand or move on the water at a speed as fast as one meter per second. As long as the surface tension is maintained, sea skaters are able to move normally. If the surface tension is lowered by pollutants or detergents, they flop on the surface 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 dificulties of living in such a vast world is how the *Halobates* find each other to breed and lay eggs.

A map of the world-wide distribution of the marine insect, Sea Skater, *Halobates*. The known distribution is displayed in white. There are five known species of *Halobates* distributed around the earth approximately between latitutdes 40-degrees south and north of the equator. Questions remain about whether the insects require the warm ocean waters in this region or whether they are distributed more widely but scientists have not yet been able to find them through sampling. It is also not clear why there are only a few species and how they live in a habitat where no other insects are found. Some hypotheses state that the insects may be currently adapting to life on the ocean and *Halobates* is just the first to make the transition. Illustration courtesy of the University of Nebraska-Lincoln Department of Entomology

Just one genus living on the oceans

But why is there only just this one single genus of insect living on the open oceans? The five known species of Halobates are distributed around the world roughly between latitudes 40-degrees north or south of the equator. Do Halobates require these warm waters, or are they more widely distributed but have not yet been detected? Why are there so few species, and how do they live in a habitat where no other insect occurs? Given the diversity of insects in freshwater, it might be thought that the Earth's oceans would support an almost infinite number if insect species. Only 0.0091 percent of the Earth's surface water is contained in lakes and rivers, and 95.96 percent is in the oceans. Nearly 30,000 insects inhabit freshwater yet only five species belonging to one genus are adapted to living freely in the world's most vast ecosystem. This is very strange indeed.



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 effecient osmoregulatory mechanisms that allow then 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

INSET IMAGES: A sea skater, *Halobates*. Photo courtesy of Scripps Institution of Oceanography, La Jolla

Marine Insects

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

reach.

The third hypothesis suggests that the combination of salinity and depth imposes a further limitation of oxygen content in ocean water. Again, certain fly larvae are able to survive months without oxygen, and numerous aquatic insects survive in polluted waters with similar or lower oxygen concentrations.

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

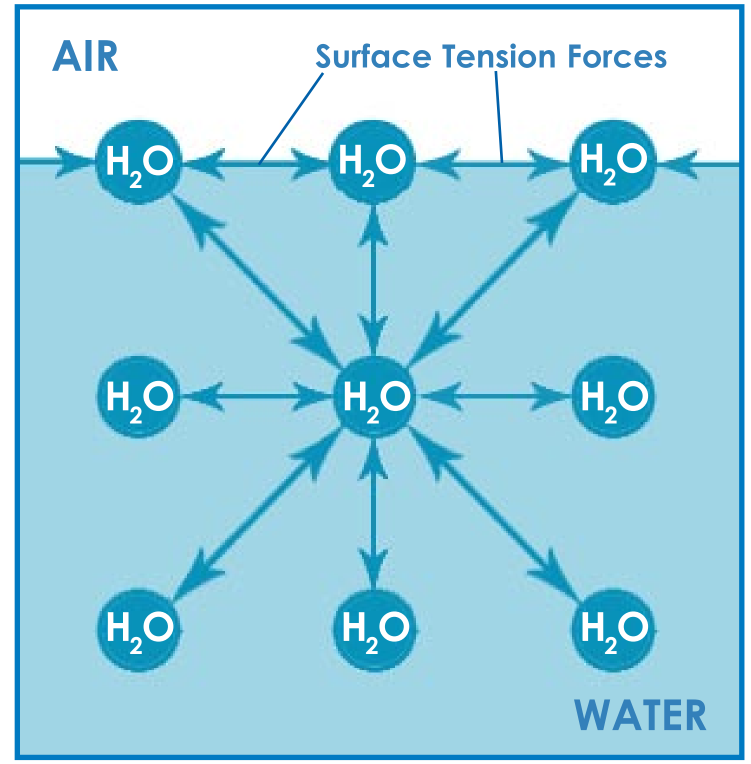
There are many questions still unanswered about this strange case of the *Halobates*. How come that they alone of the so many insects managed to adapt to life on the oceans? Whatever hypothesis is true, though, if any of them are, the *Halobates* are a really remarkable example of marine life rarely, 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 Kearny: **www.unk.edu**
Or visit the Marine Insects page of the Department of Entomology at the University of Nebraska at Lincoln: **entomology.unl.edu** ■

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. ■

Water Strider



Model illustrating bond forces of water

Text by Micheal Symes

Water Facts

Surface tension

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 Xray-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 Xray-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 $7.29 \times 10^{-2}\ N\ m^{-1}$. For comparison, mercury, in which the intermolecular bonds are electrostatic rather than hydrogen bonding, has the value of $46 \times 10^{-2}\ N\ m^{-1}$ 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. ■