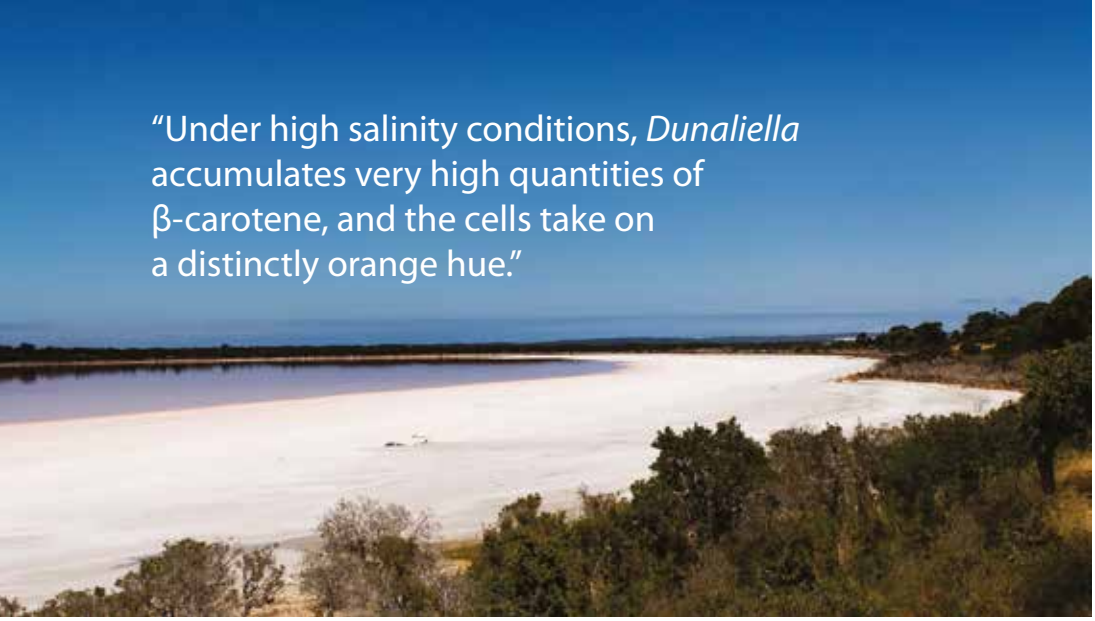
And the *rivers ran red*

The story behind the shoreline of Lake Warden's sudden and spectacular transformation to a blood-like pool could be the plot of a Shakespeare play, but the reason behind this mysterious phenomenon is more fact than fiction.

by John Huisman and Don Cater



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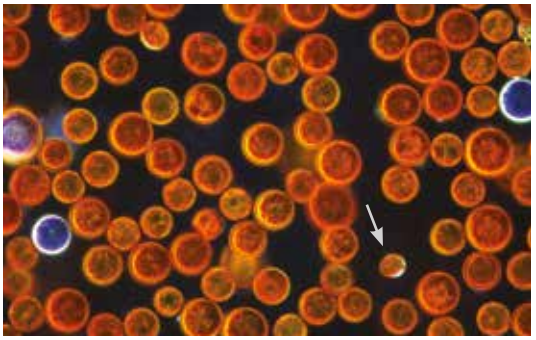

Recent visitors to Western Australia's Lake Warden, near Esperance, might have thought they'd witnessed a phenomenon of biblical proportions. Coating the lake's shoreline was a vivid red liquid that could aptly be described as blood-like, the scene's forebodingness heightened by a sputum-like froth contrasting with the deep crimson. What might have caused this morbid sight?

Thankfully a simple explanation was in reach. A short stroll from Lake Warden is Esperance's famous Pink Lake, known worldwide for the tinted waters that give the lake its name. Surely whatever makes Pink Lake pink must also be behind the ominous scene at Lake Warden. Well, yes and no.

WHAT MAKES ESPERANCE'S PINK LAKE PINK?

Pink lakes worldwide host several microscopic organisms that give them their colour. One of these, surprisingly, is a green alga, the single-celled, salt-loving *Dunaliella salina*. Like all green plants and algae, *Dunaliella* has several accessory pigments such as β (= beta)-carotene, the same pigment that gives carrots their orange colour. In green algae and plants, these are usually in low quantities and the colour is masked by the green chlorophyll pigments. Under high salinity conditions, *Dunaliella* accumulates very high quantities of β-carotene, and the cells take on a distinctly orange hue. *Dunaliella* also has one other competitive advantage, one that is shared by very few organisms: it is able to live in water with extremely high salt concentrations, up to saturation when salt crystals form. Why is this ability an advantage? By living where little else can survive, *Dunaliella* has very few competitors and predators, and can form a virtual monoculture. Populations can reach very high densities, and even though individual cells are microscopic and invisible to the naked eye, when in high concentrations their great numbers colour the water noticeably.

How does *Dunaliella* cope with these high salinities? If you subject most plants to very salty water the results will be quick and grim; the difference between the high salt concentration in the water and that of the plant cells sucks all of the water from the plants, causing dehydration and a rapid demise. *Dunaliella*, however, has a neat trick. To combat the external salt, it accumulates glycerol in its cells and this serves to balance the salt concentration. This enables *Dunaliella salina* to be one of the most environmentally tolerant organisms known and it can handle a salinity range from seawater (three per cent salt) to saturation (31 per cent salt). It can also survive temperatures ranging from below 0°C to about 38°C, although its preferred temperature is above 20°C.

Esperance's Pink Lake unfortunately does not always live up to its name. The pink colour waxes and wanes, which Parks and Wildlife monitoring suggests is a result of fluctuations in the lake's salinity. During

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Main With the appearance of something more sinister, the shoreline of Lake Warden was coated with a crimson liquid.
Photo – Don Cater/Parks and Wildlife

Above left Lake Warden with its pink-tinged edges.
Photo – Mick Sonneman

Top The green, oval-shaped motile (swimming) cells of *Dunaliella viridis* amongst *Dunaliella salina* cysts.

Above *Dunaliella salina* cysts under a microscope. The slightly smaller, oval-shaped cell swimming in the clear space on the bottom right is a motile cells.
Photos – John Huisman/Parks and Wildlife

"In WA, commercial production of *Dunaliella is* undertaken at Hutt Lagoon, near Port Gregory north of Geraldton. The algae are cultivated in water made up of salt-saturated brines obtained from the lagoon..."

periods of low salinity density of *Dunaliella salina* declines, its place taken by diatoms, ciliates, and the smaller green species *Dunaliella viridis*.

Despite its often high concentration, *Dunaliella* is not the sole cause of the pink colour in salt lakes. The unusual, salt-loving, bacteria-like organism *Halobacterium* also contributes. Although a prokaryote, like the bacteria, *Halobacterium* is classified in the separate domain Archaea, which also includes other organisms found in extreme environments such as hot springs. The colour of salt lakes has also been attributed to yet another tinted organism, the red bacterium *Salinibacter*, which is found worldwide. Undoubtedly these or similar organisms occur in WA's pink lakes, but how much they contribute to their colour is yet to be established.

AND LAKE WARDEN?

As previously stated, the cause of Lake Warden's spectacular transformation is related to the cause of Pink Lake's colour, but there are differences. *Dunaliella salina* was responsible for the recent red colour of the Lake Warden shoreline, but in a slightly different form. In its normal, vegetative state, *Dunaliella* is a free-swimming, single cell, about 15µm long (=0.015mm), somewhat oval-shaped with two flagella emerging from one end. The cells usually divide by simply splitting in two along the long axis, but occasionally they can undergo sexual reproduction where the cells fuse by joining at their flagellated ends, the resulting cells then forming a smooth-walled spherical cyst known as a 'zygospore' which, after a time, will germinate to produce up to 32 cells.

Top left *Dunaliella* on the lake surface.

Above left Shorebirds feeding at Lake Warden.
Photos – Don Cater/Parks and Wildlife

Above Farming *Dunaliella* at Hutt Lagoon.
Photo – Steve Back

On occasions, cells can also form asexual cysts, which are known as 'aplanospores'. These are also spherical cysts, but in contrast to the zygospores they have rough walls. The formation of zygospores is thought to be a response to a drop in salinity. Unlike the motile cells of *Dunaliella,* the aplanospores contain canthaxanthin, a different carotenoid pigment that is usually a deeper red than β-carotene. When the Lake Warden shoreline water was analysed under a microscope, it was seen to contain millions of aplanospores, and virtually no motile cells. The blood-red water was the result of these high levels of aplanospores, probably pushed onto the shore by prevailing winds. Unfortunately

this spectacle was witnessed by only a few people, as the aplanospores were soon dispersed and Lake Warden returned to its more usual dirty-pink colour.

OTHER PINK LAKES

Esperance's Pink Lake and Lake Warden are not the only tinted lakes in the region. Perhaps the most impressive of all, but unfortunately the least accessible, is Lake Hillier on Middle Island, the largest of the islands that make up the Recherche Archipelago off the coast of Esperance (see 'A visit to Middle Island', *LANDSCOPE*, Spring 2006). Lake Hillier is about 600m long and was first seen by the explorer Matthew Flinders in 1802, when he climbed the island's highest peak (now known as Flinders Peak) to survey the surrounding waters. Parks and Wildlife scientists have been monitoring the various lakes, and have shown that Lake Hillier also supports a population of *Dunaliella salina* and an as-yet unidentified bacterium, which in combination are probably the reason for the lake's spectacular hue.

DUNALIELLA AS A CROP

The idea of using *Dunaliella salina* as a commercial source of β-carotene was first mooted in the 1960s. The species is characterised by its ability to accumulate very high levels of β-carotene, and concentrations of up to 14 per cent of dry weight have been reported. β-carotene is a valuable product, its uses include as a naturally derived food colouring, but it is also promoted as a dietary supplement, where the claimed health benefits are many including boosting energy and vitality, supporting the immune system, and promoting healthy skin and eyes. Levels found in commercial products are much less (about two per cent dry weight), and promotional literature often compares this favourably to the levels in raw carrots (about 0.008 per cent; or 0.12 per cent dry weight). Australia is the largest producer of *Dunaliella salina* in the world, but commercial scale production also occurs in the USA and Israel.

In WA, commercial production of *Dunaliella* is undertaken at Hutt Lagoon, near Port Gregory north of Geraldton. The algae are cultivated in water made up of salt-saturated brines obtained from the lagoon, with the salinity controlled by the addition of seawater and nutrients added as required. When the ponds have reached the appropriate β-carotene content, the water is pumped to a specially designed facility and the *Dunaliella* harvested, after which the remaining water is returned to the ponds and the salinity and nutrient content adjusted.

Whether colouring a lake or as a source of valuable pigments, *Dunaliella* is an impressive beast, especially when you consider its microscopic size (about 12,000 individuals would fit on the head of a pin). WA abounds with unique plants and animals, but this miniscule alga must surely qualify among the more unusual, and as one of the many miracles that nature has bestowed us.

Visiting the Pink Lakes

Each of WA's pink lakes has its own particular character. Easily the best known and most accessible is Pink Lake, near the town of Esperance on the south coast. This lake is only a short 7km drive west of the town and a great way to see it is as part of the 40km Great Ocean Drive, a loop that includes Esperance's spectacular coastal scenery. The remarkable Lake Hillier is located in a pristine wilderness on Middle Island in the Recherche Archipelago and can only be seen from the air, either by helicopter or light plane from Esperance. You can also explore the islands and abundant wildlife of the Recherche Archipelago on a cruise. A third lake, also called Pink Lake, is near the town of Port Gregory, north of Geraldton on the central west coast. At this site one can also see the only commercial operation harvesting *Dunaliella* for β-carotene, and vast ponds have been established that are carefully managed for optimum pigment production.

Above left The spectacular Lake Hillier on Middle Island.
Photo – Jiri Lochman

Below Sputum-like froth atop blood-red coloured water.
Photo – Don Cater/Parks and Wildlife

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