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What can be done about toxic algal blooms?

The long-term answer lies in better catchment and river management; bio-control may also have a role

Blue-green algae (also known as cyanobacteria) are perhaps the most primitive living things on Earth. Indeed, their ability to fix nitrogen appears to have been responsible, some three billion years ago, for changing the planet's atmosphere to one rich in oxygen as well as nitrogen.

Cyanobacteria not only provide the primary food resource for more complex organisms: they also have the power to end life as well as to give it. In response to appropriate environmental conditions, they undergo spectacular population explosions, resulting in so-called algal blooms that are toxic to a wide range of aquatic and terrestrial animals. The cyanobacteria of main concern in terms of toxic blooms are *Nodularia*, *Anabaena*, *Oscillatoria* and *Microcystis* species, which are found in fresh or brackish water throughout the world.

In 1830, explorer Charles Sturt noted that the waters of the Darling had 'a taste of vegetable decay as well as a slight tinge of green'. In 1878, *Nature* published the world's first scientific report of an algal bloom, 'Poisonous Australian Lake', about a massive bloom of the cyanobacterium *Nodularia spumigena* in Lake Alexandrina, South Australia. The bloom was so intense that a number of sheep and cattle died after drinking affected water.

Fresh-water cyanobacteria use internal gas vesicles to float at various depths in lakes, billabongs and rivers, employing chlorophyll to convert sunlight into energy through photosynthesis.

Variations in temperature, the size of the body of water and rates of flow affect algal growth. Turbidity and water mixing are also important. Turbidity influences the amount of sunlight penetrating into the water, and this in turn influences the amount of light available to each cell: turbid water means less light, so slower growth. Mixing carries cells from the well-lit surface layers to deeper, darker zones, and the proportion of the time each cell spends in the surface zone largely determines the amount of light it has available for growth; when mixing is reduced by low water flows, weirs or calm weather, algae can spend more time in the light... and thus grow more quickly.

However, levels of nutrients — especially phosphorus and nitrogen — are the most important influences on algal populations.

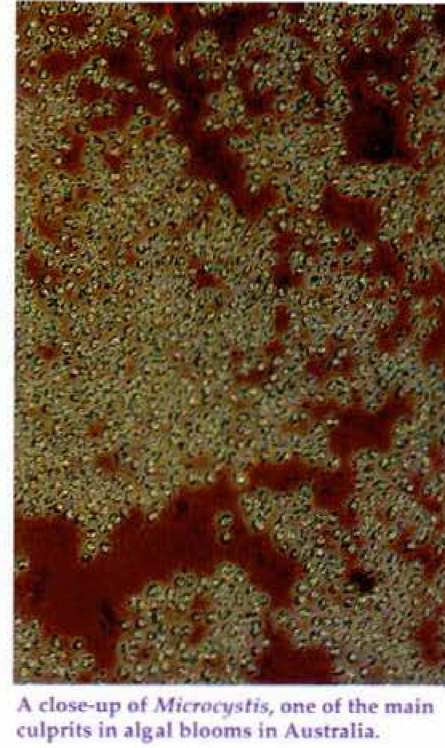
Eutrophication is the process by which bodies of water become enriched with nutrients. Natural eutrophication is a very slow process and is subject to large-scale changes due to, for example, floods or droughts: but so-called cultural eutrophication, caused directly by human activities, is far more rapid and dramatic in its effects.

Those activities include land-clearing, agriculture and human settlement, and in particular the disposal of sewage and industrial effluents into waterways.

Sewage and agricultural run-off contain large amounts of nitrogen and phosphorus compounds, providing

Photos: Division of Water Resources

Aerial views of algal blooms show how rapidly algae spread throughout slow-moving rivers. Toxins produced by the algae make water unfit to drink, and can poison livestock.



A close-up of *Microcystis*, one of the main culprits in algal blooms in Australia.

ideal nutritional conditions for sudden eruptions of cyanobacteria. When nutrient inputs combine with reduced water flows as a result of irrigation, industry and domestic use, reduced numbers of grazers on phytoplankton and the degradation of river and lake ecosystems through disturbance of natural food webs, the result can be an environmental disaster of the first magnitude. Food web disturbance may arise from, say, the introduction of exotic fish such as carp, the draining of wetlands or the destruction of macrophytes (water plants) by carp and cattle.

Over the past year a deadly combination of drought, high summer temperatures, river flows lowered by withdrawals of water for irrigation, and inputs of nutrients from agriculture and townships created ideal conditions for a massive bloom of *Anabaena*. The inevitable happened towards the end of 1991, when an estimated 1000 km of the Barwon and Darling Rivers erupted in foul-smelling green.

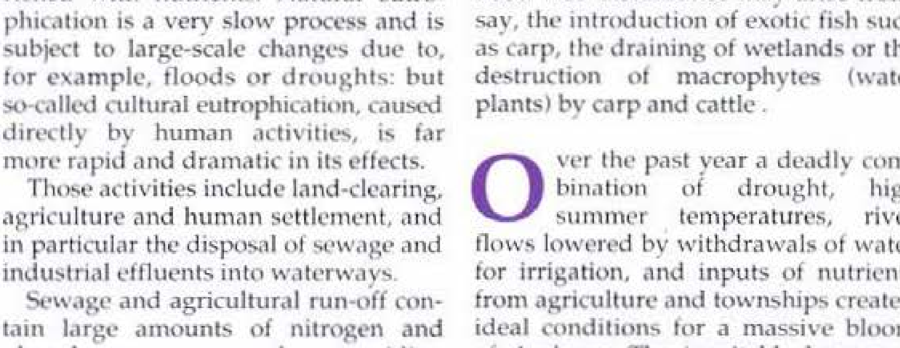
Commentators with a taste for the dramatic pointed out the similarities between that event and an algal bloom (which might have been of *Oscillatoria* cyanobacteria, or perhaps of estuarine or marine phytoplankton) reported in the Old Testament book of Exodus:

And [Aaron] lifted up the rod, and smote the waters that were in the river... and all the waters that were in the river were turned into blood. And the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river; and there was blood throughout all the land of Egypt. And all the Egyptians digged around about the river for water to drink, for they could not drink of the water of the river.

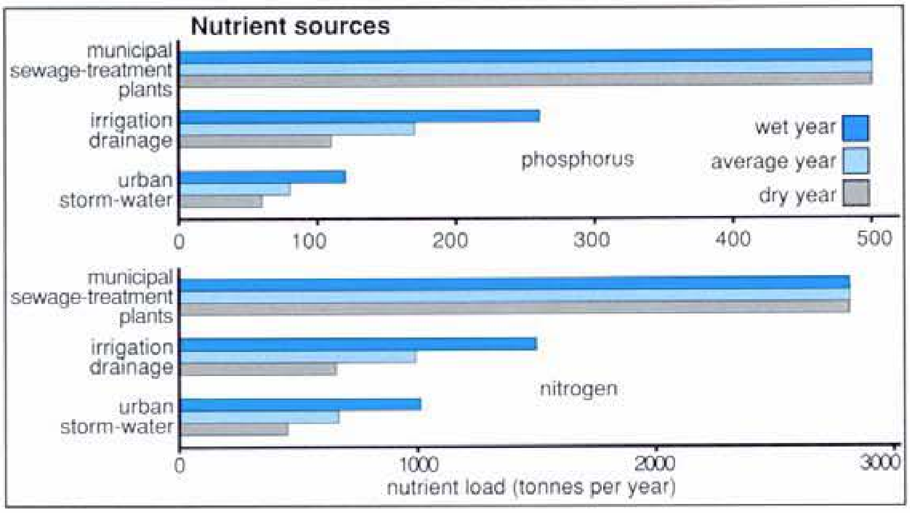
Moses made astute political use of that environmental disaster, claiming it lent divine weight to his case for releasing the Israelites from bondage. No such claims were made on the Barwon or the Darling, but the New South Wales government declared a state of emergency. Residents who normally took their drinking water from the river had to shut off water pumps and rely instead on almost empty rain-water tanks; in some cases Army engineers were called in to provide emergency water-filtration equipment for badly affected areas.

The South Australian government monitored the progress of the blooms with special concern, since more than 90% of that State's population depends on reticulated water from the Murray River.

Yet the obvious aspects of the bloom — especially the bright green discolor-



Blue-green algae come in a bewildering array of shapes and sizes: more than 200 have been found in the Murray–Darling Basin. *Anabaena* and *Nodularia* are common sources of toxic algal blooms.



Sewage-treatment plants are the major point sources of both nitrogen and phosphorus inputs into the rivers of the Murray–Darling Basin, providing almost three times as much as irrigation drainage in an average year.

ation caused by a 'soup' of *Anabaena* — are often just late symptoms, since the numbers of cyanobacteria can reach a climax weeks prior to becoming visible. The musty, earthy odour associated with *Anabaena*, for example, had been detectable for some time, growing worse as the algal population increased. Humans can detect geosmin, the chemical responsible for the odour (and a natural by-product of photosynthesis in this group of cyanobacteria) at a concentration of 10 parts per trillion — equivalent to one tablespoonful of geosmin in 200 Olympic swimming pools.

All the accounts recognised that the Barwon–Darling disaster was man-made. While the previous year's floods might have exacerbated the situation, a report prepared on behalf of the Murray–Darling Basin Commission declared that 'there is little doubt that the frequency and intensity of these blooms is getting worse... The reasons include pollution of waterways with nutrients (phosphorus and nitrogen); reduced flows... as more and more water is used for irrigation, industry and domestic supplies; [and] degradation of river and lake ecosystems.'

The report found that, in dry conditions, most nutrients come from so-called point sources, particularly sewage-treatment works: in wet conditions, especially during floods, most nutrients come from agricultural lands or forests.

Although cyanobacteria are environmentally and economically so important, we know surprisingly little about the mechanisms that trigger blooms.

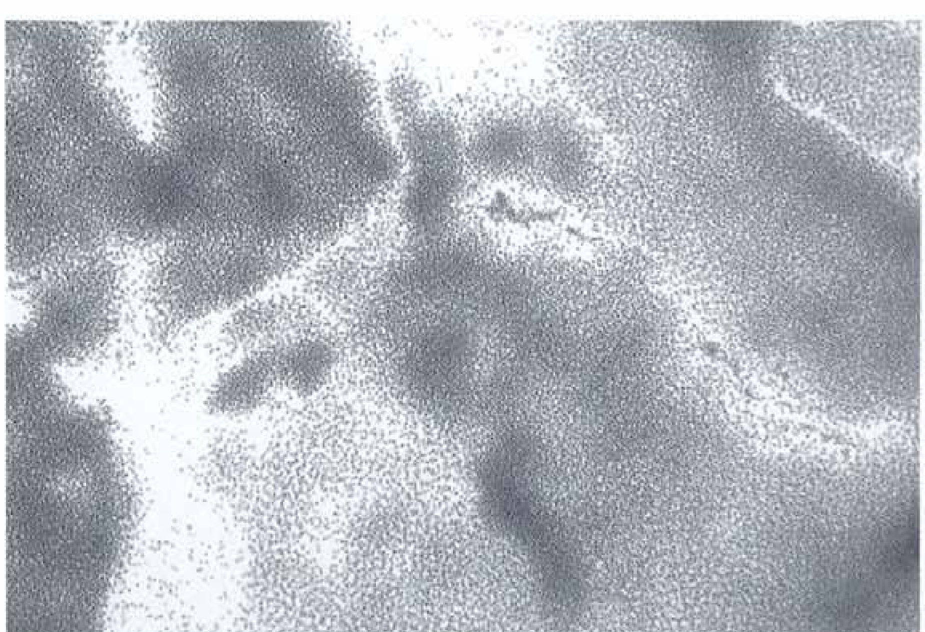
We know how blooms occur, but not why: high nutrient levels, high temperature and so on may be present without a massive population explosion occurring. Turbidity is obviously an inhibiting factor: the Darling's normally high turbidity tends to preclude the calm, sun-filled water needed for cyanobacteria populations to explode. Drought and reduced flow, however, reduce turbidity, allowing more sunlight to penetrate, warming the water and producing ideal conditions for growth.

Furthermore, once a bloom does happen its toxicity can vary despite apparently stable environmental conditions. While we're familiar with the geosmin odour associated with algal blooms and with the effects of the toxins produced by *Anabaena*, *Microcystis* and *Nodularia*, we know very little about why these cyanobacteria produce toxins and others don't; nor do we know why some blooms do not produce toxins. Toxin persistence also varies: in some cases the scum of algae that drifts to riverbanks and that can remain, dried out, as water levels fall may remain toxic for weeks or months. Boiling suspect water destroys the cyanobacteria, but not the toxins they produce.

To confuse matters even further, different cyanobacteria produce different kinds of toxins, with different effects. *Microcystis*, *Nodularia*, *Anabaena* and some species of *Cylindrospermopsis* and *Oscillatoria* produce peptide-based hepatotoxins, which break down liver cells and produce the symptoms of gastro-enteritis in humans, and can kill domestic and farm animals through necrosis of the lungs, kidneys, adrenal glands and intestine. *Microcystis* produces a hepatotoxin called microcystin, which has been shown to accumulate in the tissues of filter-feeders such as fresh-water mussels.

A laboratory mouse injected with a solution of peptide hepatotoxins will die 30 minutes to 24 hours later. A mouse injected with a concentrated solution of *Anabaena* toxins may survive unharmed, may develop symptoms of hepatotoxin poisoning... or may die in 2–3 minutes.

This is because *Anabaena* may not produce any toxins at all, or produce



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The microscope reveals that *Microcystis* occurs in dense 'colonies': to the naked eye, it resembles a green slime that is most noticeable on the surface of rivers or lakes.

hepatotoxins, or produce an alkaloid-based neurotoxin called anatoxin-A (structurally related to cocaine) that has no sub-acute effects: an organism ingesting anatoxin-A either recovers or, much more often, dies.

Algal blooms alter the physical, biological and chemical characteristics of the water, and the alterations — if the water is destined for agriculture or human consumption — lower its quality (see the box). Treatment costs more because colour, odour and suspended solids all increase; filters, meters, valves and irrigation drippers may become blocked.

The biology of the system will change, if only in the short term, since more organic material will be available to zooplankton and to animals higher in the food chain. Dying blooms also lower the oxygen content of the water, with adverse effects on zooplankton and fish.

Predicting, controlling and minimising algal blooms pose complex problems: we must find a balance between the availability of water for irrigation and human consumption, water quality and conservation. Economically, the problems are magnified by the cost involved not only in new systems of management, but also in the research needed to arrive at management strategies.

With financial assistance from the Natural Resources Management Strategy, the Land and Water Resources Research and Development Corporation and the Urban Water Resources Association of Australia, CSIRO scientists are active in studying toxic algal blooms and the organisms responsible for them, with a view to developing strategies that will help manage, minimise and, it is hoped, eventually prevent them.

At the CSIRO Division of Water Resources at Griffith, N.S.W., project leader Dr Gary Jones, who leads a research team looking at algal blooms from a variety of perspectives, suggests the problem must be addressed by a combination of strategies.

Long-term strategies, he says, must include catchment management to reduce nutrient input. However, deciding how we use water is the central issue. Water used for irrigation may cost users up to $70 a megalitre, but it is not possible to place a similar dollar value on the ecological health of our over-worked rivers; better management of irrigation water could help address the issues of salinity and wetlands degradation, too.

Action on diverse fronts

At CSIRO's Centre for Environmental Mechanics in Canberra, Dr Ian Webster leads a project to investigate the effect of turbulent mixing on the growth and distribution of phytoplankton... affectionately known as Project Billabong.

The project seeks to model the influence of weather and sunlight on mixing, circulation and stratification in turbid water bodies; to determine the influence of turbulence on the suspension and distribution of phytoplankton; and to examine the effect of mixing on light penetration (and thus its influence on algal growth). To broaden our understanding of how cyanobacteria behave under normal conditions, and of the mechanisms involved in blooms, Dr Webster and colleague Dr Brad Sherman have installed sophisticated instruments at various points in a billabong to measure: temperature at various depths; wind speed and direction; and sunlight. The information collected by these devices has been incorporated into a mathematical model that will contribute to early warnings of algal blooms.

As part of the project, Australian National University doctorate student Mr Paul Hutchinson is developing mathematical descriptions of how algae circulate under the influence of wind. Fortunately for his research, an algal bloom in Lake Burley Griffin in January 1992 provided living cyanobacteria for use in the Centre's wind tunnel; a 10-m-long simulation of a water body enables him to investigate how wind affects the way buoyant cyanobacteria are spread. He has found that conventional algal-sampling techniques present an unrealistic picture of cyanobacteria distribution and that a more accurate distribution model, which he and Dr Webster are developing, must be applied.

Effluent irrigation

A Division of Forestry research team led by Dr Brian Myers is examining the use of treated sewage effluent for irrigating trees. At Forest Hill outside Wagga Wagga, N.S.W., they are supplying a 7·5-ha pine and eucalypt plantation with water and organic waste from sewage-treatment works.

The 4500 billion litres of sewage effluent pumped into Australia's rivers and oceans every day are a major source of nitrogen and phosphorus — the most important nutrients for cyanobacterial growth and, coincidentally, the same nutrients that (together with water) most limit the growth of trees. Dr Myers estimates that the effluent 'resource' in the Murray–Darling Basin is sufficient to support 18 000 ha of tree plantations, capable of supplying 360 000 tonnes of wood per year from land that would otherwise produce little usable timber.

Such plantations would use water at a higher rate than agricultural crops, require less intensive management and, if the effluent contains toxic components, effectively lock these up so they cannot enter food chains. The use of treated sewage in this way would cost more than disposal into rivers, but would offer significant environmental benefits, recover some costs by providing municipal authorities with a financial return and, just as importantly, reduce the likelihood of toxic algal blooms by cutting off one of the most important sources of the nutrients on which they depend.

Algae counts

Even relatively low numbers of cyanobacteria can cause water-quality problems, and authorities must monitor water supplies so they can detect and deal with cyanobacteria before a full-blown bloom occurs. At present we have only two laborious and time-consuming methods of monitoring the amount of algae in water samples: counting, using a microscope or extracting and measuring the photosynthetic pigments that provide the organisms' colour.

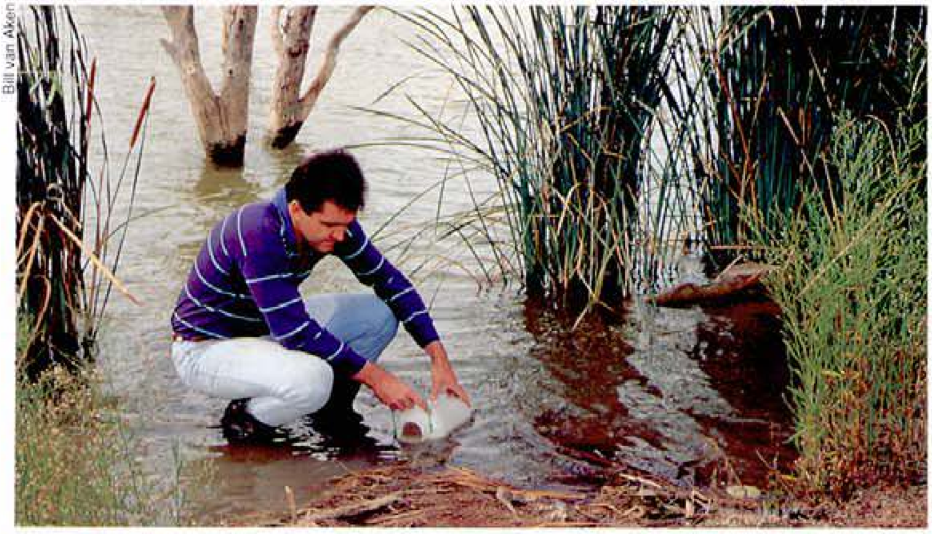
Dr Rod Oliver, a researcher with the CSIRO Division of Water Resources, at present on secondment to the Murray–Darling Freshwater Research Centre, is seeking to overcome this problem by developing new techniques for rapid, direct estimates of algal populations — using fluorescence to measure the amount of light emitted by pigments during photosynthesis.

Toxicity assay

At the Division of Coal and Energy Technology's Centre for Advanced Analytical Chemistry (located at the Division's Lucas Heights laboratories), Ms Jennifer Stauber and Dr Gary Vaughan are developing bacterial assay techniques for measuring algal toxicity, as an alternative to current methods that rely on lethality in mice.

They are also looking at interactions between algae to determine whether those present in water bodies prior to cyanobacterial blooms promote or inhibit those blooms: the results of their work may suggest a bio-control method of preventing toxic algal blooms.

Bill van Aken



Dr Gary Jones collects samples of blue-green algae for identification and analysis.

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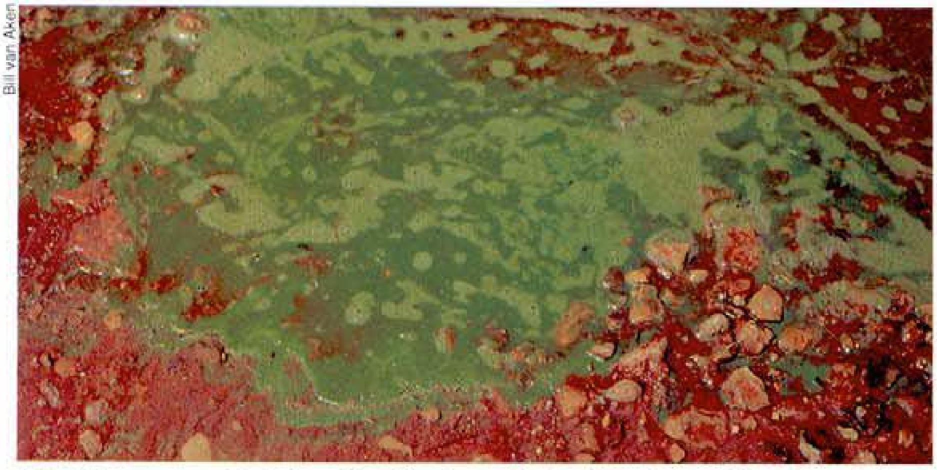

Algal blooms are particularly noticeable when water levels are low, or at the downwind margins of water bodies.

Daphnia carinata, one of the largest 'water fleas' in th Griffith laboratories of the Division of Water Resourc for dealing with algal blooms.

Short-term strategies must concentrate on flow regimes, reducing stratification and temperature fluctuations through management of weirs. Information gained from the CSIRO Centre for Environmental Mechanics' Project Billabong (see the box on page 17) will be important here.

Water management must concentrate on improving and maintaining water quality to reduce the frequency and severity of algal blooms, and on reducing the production of toxins.

Dr Jones and colleagues are looking at moving warm water over weirs to reduce stratification (and thus to alter the conditions that promote cyanobacterial growth). Dr Kath Bowmer, Assistant Chief at the Division's Griffith laboratories, has been looking (together with Mr Wolfgang Korth) at the chemistry of cyanobacterial odours since 1986, and warns that too-vigorous mechanical mixing of water bodies to reduce stratification may in fact be counter-productive, since mixing pushes cyanobacteria into deeper, darker water, where they respond to a lack of sunlight by producing more chlorophyll... and hence more geosmin.

Dr Rod Oliver, a researcher with the CSIRO Division of Water Resources, at present on secondment to the Murray–Darling Freshwater Research Centre (MDFRC), and microbiologist Dr Paul Boon are investigating the biological availability of phosphorus in streams.

Much of the phosphorus entering streams comes from agricultural superphosphate, which contains, on average, 10% sulfate and 9% phosphate, as well as other chemicals. Sulfate (which is an essential component for algal growth) moves through the soil more readily than phosphate, so more of it is washed into streams where sulfate-reducing bacteria break it down.

Most of the phosphorus settles into bottom sediments, but a proportion becomes bound to particles suspended in the water (in other words, to the substances that produce turbidity) and can continue to be available for algal growth for some time, even if no further nutrients enter the water. Sulfate-reducing bacteria produce chemical changes in bottom sediments that release the phosphorus in summer, when the water stratifies according to temperature and the bottom water becomes oxygen-poor.

To improve our understanding of how nutrient inflows stimulate algal blooms, Dr Jones's team is using organic bio-markers to track phosphorus inputs into waterways: at the Division's Canberra headquarters, Dr Bob Wasson and Dr Terry Donnelly are using natural isotopes of phosphorus in similar research, in order to determine how this important nutrient makes its way into streams and thus how it can be controlled.

For more immediate remediation, Dr Jones and Dr Ian Holmes of Melbourne University have been looking at the use of viral cyanophages to kill cyanobacteria.

To complement that research, Dr Jones and Mr David Bourne (a student from the University of Queensland) have also isolated four bacteria that attack and eat the very toxins associated with algal blooms. This work has

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world, is a useful predator of cyanobacteria. At the
. Dr Vladimir Matveev is investigating its potential

the potential to render obsolete the chemical algicides now used to control blooms; eventually it may be possible to grow colonies of the most efficient bacteria, which could then be packaged — along with viral cyanophages — and spread over algal blooms to dispose of both the cyanobacteria and the toxins.

Dr Vladimir Matveev, a visiting Russian research fellow at Griffith, may also have found a useful predator of cyanobacteria. He has been investigating herbivorous microcrustaceans that graze on cyanobacteria: more than 80 kinds of microcrustaceans, including *Daphnia, Bosmina, Ceriodaphnia, Moina* and *Diaphanosoma* species, have so far been identified in the Murray–Darling system.

Most are less than 2 mm long, but Dr Matveev has been studying a veritable giant among *Daphnia*, using specimens found, ironically, in an ornamental fish pond outside the Division's main building at Griffith. This monster, called *Daphnia carinata*, grows to 5 mm long, although a bizarre cephalic crest accounts for a significant part of its size.

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While temperature and lack of water movement are important to the growth of algal blooms, high nutrient levels are essential. As the bloom matures, it uses up available nutrients; later it produces toxins that can persist for days or weeks after the algae themselves have died.

D. carinata, which is found in a range of water bodies from temporary pools to large reservoirs, is a polymorphic species, able to change its shape in response to the presence of predators such as water-boatmen. When predator numbers are high, *D. carinata* produces a crest; this enables it to move more quickly through the water, giving it an edge of speed over predators, creates difficulties for insect predators trying to handle it and acts as a kind of disposable shield. Any planktivore lunging for a meal would be likely to grasp the crest, which breaks off and gives *D. carinata* a chance to escape.

Almost nothing is known about this curious organism's biology — nobody knows, for example, how algal toxins affect Australian *Daphnia*, or indeed whether toxins are produced to protect cyanobacteria from grazers — so Dr Matveev's research is aimed at learning more about what factors limit its numbers in the wild, what factors are involved in increasing those numbers and its potential for use as an algal biocontrol method.

Making effective use of plankton grazers such as *Daphnia carinata* also depends on reducing the numbers of planktonivorous fish, so Dr Matveev is also looking at *D. carinata*'s predators. Bio-manipulation — the control of predators on such useful species — has been successful in North America and Europe, and there is no *a priori* reason to suppose that similar techniques will not work in Australia. Removing or reducing the populations of predators by selective poisoning, netting or the introduction of piscivorous (fish-eating) fish over entire lakes has resulted in a considerable increase in water clarity and reductions in the numbers of some algae.

Dr Matveev warns that much more research is needed to assess the potential for control of cyanobacteria by grazers such as *D. carinata*. However, this odd and previously unregarded inhabitant of our waterways may one day play a vital role in controlling toxic algal blooms.

Carson Creagh

More about the topic

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