WATER RESEARCH COMMISSION

April 2008

The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

WATER POLLUTION

Predicting the development of harmful algal blooms

Eutrophication

The threat of eutrophication

Water resources in South Africa are under constant pressure of pollution from agricultural, mining, industrial and domestic uses. High concentrations of organic and inorganic compounds enhance eutrophication and concomitant algal blooms impact detrimentally on water quality.

The fact that most rivers in southern Africa are regulated further increases the susceptibility of watercourses and impoundments to eutrophication.

Eutrophication leads to changes in the phyto-plankton composition of surface water, often shifting the dominance toward cyanobacteria and other species that form algal blooms. These algal blooms result in the development of unpleasant odours and tastes as part of the general decline in water quality.

Some of the bloom-forming species are potentially toxic and, as a result, pose a serious health risk to humans and animals alike. The increase in the frequency and severity of bloom events, especially of ***Microcystis aeruginosa***, also poses a problem for potable water supply in that classical methods of water treatment result in the release of high concentrations of toxins into the water. How environmental and metabolic variables relate to occurrences of blooms and toxin production in algal cells is, however, still largely unknown.

In order to explain and predict the development of harmful algal blooms and related toxins, a more complete understanding of the physiological basis for their occurrence is essential. Key questions to be answered are:

- What makes certain species more competitive than others, allowing them to displace other species from phytoplankton assemblages?
- How do such species maintain prolonged competitive dominance?
- Under what conditions do blooms associated with such species become toxic?

Algal blooms

The most important nutrients for algal growth are compounds of nitrogen and phosphorus. These occur in different forms in the aquatic environment, but only a few are readily available for use by phytoplanktons. The enzymes, phosphatase and nitrate reductase, respectively transform nitrate and phosphate compounds into bio-available forms, thereby playing essential roles in the nutrient recycling process. The activity of these enzymes conveys information about the utilisation of nutrients in the aquatic environment.

Despite suggestions that enzyme activity is related to nutrient availability or concentration in the water, there is some uncertainty about such a relationship. This uncertainty may be due to the connection being dependent on the ratio of nutrients rather than their absolute concentration, as well as on the species composition of the phytoplankton in the water.

The clearing up of uncertainty is key to developing systems for early warning of potential algal blooms and for managing environmental conditions in the interests of ensuring ecosystem health and sustainability.

Algal toxins

An understanding of key relationships would also be of practical benefit in managing potable water supplies that are potentially impacted by cyanotoxins. A model developed to simulate the mechanism whereby toxin production is modulated would facilitate water management and treatment.

Toxin production in cyanobacteria has been shown to correlate with external stimuli such as light, as well as with nutrient concentrations and ratios, although conflicting results have been reported in this regard. The only variable that has previously been shown to be quantitatively related to toxin production has been algal growth rate.

Investigating the environmental factors involved in the modulation of toxin production in ***M. aeruginosa***, with specific emphasis on the role of environmental nitrogen and the co-modulatory effects of environmental phosphorus, therefore remains the key to successful prediction of cyanotoxin production.

Seeking understanding through research

A programme of research comprising various studies has been addressing the various knowledge gaps responsible for the inadequate understanding of factors that give rise to occurrences of harmful algal blooms and toxin production.

Studies have sought to:

- Determine the effect of different N:P ratios as well as the combined effect of other environmental variables, namely light and temperature on
  - the growth dynamics;
  - activities of various enzymes; and
  - performance index and physiological status;

  of problematic bloom-forming cyanobacteria namely, ***Oscillatoria simplicissima*** and ***M. aeruginosa***, isolated from the Vaal River;
- Use molecular approaches to follow ***in situ*** physiological changes, particularly in the expression of key metabolic enzymes of specific, harmful species of problem taxa;
- Determine the modulatory role of environmental orthophosphate and nitrate levels on cyanotoxin (microcystin) production by ***M. aeruginosa*** in South African freshwater impoundments and develop a model to describe the cellular mechanisms by which these environmental parameters modulate toxin content; and,
- Assess the patterns of appearance and persistence of the ***M. aeruginosa*** in the Hartbeespoort Dam, giving special attention to: over-wintering mechanisms that provide inoculums for each ensuing season's growth; the distribution with depth in the dam throughout the year as a function of buoyancy changes; and, the correlation of algal bloom formation and growth patterns to nutrients and other abiotic factors such as temperature, pH and light penetration.

Conclusions from research

Relative dominance of cyanobacteria species

Distinct differences exist between physiological behavioural responses of the two problematic cyanobacteria isolated from the Vaal River. ***O. simplicissima*** grows better than ***M. aeruginosa*** in optimum temperature and light conditions whenever nutrient availability is limiting. Under these conditions, ***O. simplicissima*** is the better adapted of the species to low, or fluctuating, N and P concentrations.

Possible reasons for the greater abundance of ***O. simplicissima*** in the Vaal River, compared to ***M. aeruginosa***, include better P storing capacity, more effective P consumption during conditions of both P excess and limitation, and more effective N transport, uptake and utilisation.

Other environmental variables, such as increased turbidity, may also benefit ***O. simplicissima*** which is able to make more efficient use of low light intensities than ***M. aeruginosa***. Moreover, higher temperatures favour an increase in growth and enhance both alkaline and acid phosphatase activities in ***O. implicissima***, whilst causing alkaline phosphatase activity in ***M. aeruginosa*** to decrease.

Toxin production and modulation

Cellular microcystin content is positively correlated with both nitrate uptake and cellular nitrogen content, and negatively correlated with carbon fixation rates, phosphate uptake, and cellular phosphorus. Contrary to what has been reported previously, cellular microcystin content is controlled not only by growth rate, but also by other variables, with nitrogen being the most significant modulator.

Microcystin production occurs where nitrogen assimilation exceeds the use of assimilation products for growth, the growth rate being determined primarily by carbon fixation rate (in turn dependant on phosphorus availability and photosynthetically active radiation) and nitrogen assimilation rate.

Besides growth rate, primary environmental modulators of toxin production by ***Microcystis*** that are easily measured and suitable for use in predictive models are, therefore, nitrogen and phosphorus. However, given the complexity of the regulation of microcystin production and the variation among strains, it does not seem likely at this stage that a single general model will emerge that allows accurate long-term prediction of toxin levels.

Despite this, reasonably accurate short term prediction does seem possible, as does general prediction of toxin level fluctuations over periods of up to one month.

Annual variation and persistence

The massive bloom formation in Hartbeespoort Dam in 1993 is attributable to higher levels of phosphorus, nitrogen and temperature compared to years with more moderate blooms. Inoculums of cyanobacterial species are found to occur in the sediment or on sheltered rock surfaces of the dam throughout winter.

These provide for an over-wintering mechanism, establishing the potential for algal blooms in successive years. The buoyancy control mechanism possessed by ***M. aeruginosa*** provides an ecological advantage, allowing it to exploit spatial separations between nutrients and light and accumulate at the surface, effectively excluding other phytoplankton species in the water profile.

Further reading:

- *A Model for Environmental Regulation of Microcystin Production by Microcystis* (**Report No: 1401/1/07**)
- *The Role of Nutrient Utilisation and Photosynthetic Capacity in Micro-algal Bloom Formation and the Production of Cyanotoxins* (**Report No: 1401/2/07**)
- *Environmental Factors Affecting the Persistence of Toxic Phytoplankton in the Hartbeespoort Dam* (**Report No: 1401/3/07**)

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