Available online at www.sciencedirect.com
SCIENCE DIRECT
Harmful Algae 4 (2005) 697–715
HARMFUL ALGAE
www.elsevier.com/locate/hal

Ecophysiology of the marine cyanobacterium, *Lyngbya majuscula* (Oscillatoriaceae) in Moreton Bay, Australia

A.J. Watkinson[a,*], J.M. O'Neil[b,1], W.C. Dennison[a,1]

[a] *School of Life Sciences, University of Queensland, St. Lucia, Qld 4072, Australia*
[b] *Centre for Marine Science, University of Queensland, St. Lucia, Qld 4072, Australia*

Received 21 May 2004; received in revised form 6 August 2004; accepted 20 September 2004

Abstract

Large blooms of the marine cyanobacterium *Lyngbya majuscula* in Moreton Bay, Australia (27°05′S, 153°08′E) have been re-occurring for several years. A bloom was studied in Deception Bay (Northern Moreton Bay) in detail over the period January–March 2000. In situ data loggers and field sampling characterised various environmental parameters before and during the *L. majuscula* bloom. Various ecophysiological experiments were conducted on *L. majuscula* collected in the field and transported to the laboratory, including short-term (2 h) ^{14}C incorporation rates and long-term (7 days) pulse amplitude modulated (PAM) fluorometry assessments of photosynthetic capacity. The effects of *L. majuscula* on various seagrasses in the bloom region were also assessed with repeated biomass sampling. The bloom commenced in January 2000 following usual December rainfall events, water temperatures in excess of 24 °C and high light conditions. This bloom expanded rapidly from 0 to a maximum extent of 8 km^2 over 55 days with an average biomass of 210 $g_{dw}{}^{-1}$ m^{-2} in late February, followed by a rapid decline in early April. Seagrass biomass, especially *Syringodium isoetifolium*, was found to decline in areas of dense *L. majuscula* accumulation. Dissolved and total nutrient concentrations did not differ significantly ($P > 0.05$) preceding or during the bloom. However, water samples from creeks discharging into the study region indicated elevated concentrations of total iron (2.7–80.6 μM) and dissolved organic carbon (2.5–24.7 mg L^{-1}), associated with low pH values (3.8–6.7). ^{14}C incorporation rates by *L. majuscula* were significantly ($P < 0.05$) elevated by additions of iron (5 μM Fe), an organic chelator, ethylenediaminetetra-acetic acid (5 μM EDTA) and phosphorus (5 μM $PO_4{}^{-3}$). Photosynthetic capacity measured with PAM fluorometry was also stimulated by various nutrient additions, but not significantly ($P > 0.05$). These results suggest that the *L. majuscula* bloom may have been stimulated by bioavailable iron, perhaps complexed by dissolved organic carbon. The rapid bloom expansion observed may then have been sustained by additional inputs of nutrients (N and P) and iron through sediment efflux, stimulated by redox changes due to decomposing *L. majuscula* mats.

Keywords: *Lyngbya majuscula*; Moreton Bay; Cyanobacteria; ^{14}C incorporation; PAM fluorometry; Nutrient

* Corresponding author. Present address: National Research Centre for Environmental Toxicology, 39 Kessels Road, Coopers Plains, Brisbane, Qld 4108, Australia. Tel.: +61 7 32749004; fax: +61 7 32749003.
E-mail addresses: a.watkinson@uq.edu.au (A.J. Watkinson), joneil@hpl.umces.edu (J.M. O'Neil), dennison@ca.umces.edu (W.C. Dennison).
[1] Present address: University of Maryland Center for Environmental Science, PO Box 775, Cambridge, MD 21613, USA.

1568-9883/$ – see front matter
doi:10.1016/j.hal.2004.09.001

1. Introduction

Toxic cyanobacterial blooms in Australia's freshwater supplies have been well documented for over 100 years (Francis, 1878). While much of the early research and observations of cyanobacterial abundance was restricted to freshwater environments, the ecology and proliferation of marine cyanobacteria, especially toxic forms, has become important as well. Of particular concern is the increasing frequency of nuisance cyanobacterial blooms in urbanised coastal areas, such as *Lyngbya majuscula* occurrences in Southeast Queensland (Dennison et al., 1999; Dennison and Abal, 1999).

L. majuscula (Oscillatoriaceae) is a filamentous, non-heterocystous marine cyanobacterium inhabiting tropical and sub-tropical estuarine and coastal waters (Jones, 1990; Shannon et al., 1992). While *L. majuscula* may have always been part of the natural environment in discrete quantities, there is anecdotal evidence that the blooms have increased in severity and extent since the first reports were made in the early 1990s, in the Deception Bay/Pumicestone passage areas of Moreton Bay, Queensland, Australia.

As many cyanobacteria are capable of fixing nitrogen, phosphorus can often become a limiting nutrient controlling cyanobacterial growth, since nitrogen deficiencies can be overcome through use of atmospheric nitrogen. Micronutrients, such as iron (Paerl et al., 1994) and molybdenum (Howarth and Cole, 1985; Paerl et al., 1987), can also be potentially limiting factors for N_2 fixation and consequently, cyanobacterial growth. Iron has been identified as an important limiting nutrient in plankton productivity (Tranter and Newell, 1963; Martin et al., 1990), and in particular, cyanobacterial productivity (Paerl et al., 1994).

Preliminary studies suggested that elevated iron concentrations might be a key nutrient stimulating *L. majuscula* blooms in Deception Bay (Dennison et al., 1999). It is hypothesised that these high concentrations may be due to leachate from hydric soils and other soil disturbances in the area. Previous studies have shown *L. majuscula* to be stimulated by iron additions in culture (Gross and Martin, 1996) and recent work has indicated that naturally occurring organic material in the system prolongs the availability of Fe and can act as a transport mechanism (Rose and Waite, 2003a,b).

L. majuscula contains a suite of toxic secondary metabolites (Fujiki et al., 1985; Gerwick et al., 1994). These secondary metabolites have been shown to have adverse affects on humans, with reports of severe contact dermatitis, eye irritation and asthma-like symptoms amongst others (Moore, 1996; Osborne et al., 2001). Blooms of *L. majuscula* have been implicated as the causative agent in off-flavour in fish (Brown and Boyd, 1982) and intoxication due to ingestion of sea-turtle meat and macroalgae epiphytised by *L. majuscula* (Osborne et al., 2001).

Blooms of *L. majuscula* have resulted in detrimental impacts to affected areas including: (i) localised seagrass loss, (ii) poor crab and fish harvests (reported by fishermen), (iii) increase in bacterial biomass with bloom decomposition and (iv) significant localised input of bioavailable nitrogen through nitrogen fixation and release of organic and inorganic nitrogen through decay (Dennison et al., 1999). In addition, the local economy can suffer due to affected commercial and recreational fisheries, declining recreational use of the region due to health concerns, and the removal of large beach wracks of decaying *L. majuscula* by local government for health and aesthetic reasons (Dennison and Abal, 1999; O'Neil and Dennison, in press).

The role of abiotic factors (i.e. light, water temperature, salinity and rainfall) and ambient water quality parameters (i.e. dissolved inorganic nutrients and trace metal concentrations) have been shown to be critical for the formation of cyanobacterial blooms in both marine (Sellner, 1992, 1997) and freshwater environments (Codd et al., 1994). The aim of this study was to investigate the role of various environmental parameters in the stimulation of *L. majuscula* blooms in Deception Bay. This information may ultimately aid in devising a management strategy in order to potentially mitigate future *L. majuscula* blooms in the region.

2. Materials and methods

2.1. Study site

This study was conducted in northern Deception Bay, an embayment in Northern Moreton Bay on the mid-east coast of Queensland Australia (27°05′S, 153°08′E) (Fig. 1). Deception Bay is influenced by terrigenous input via the Caboolture River and Pumicestone Passage and oceanic flushing via North