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Survival of cyanobacteria in rivers following their release in water from large headwater reservoirs

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ABSTRACT

Cyanobacterial survival following their release in water from major headwaters reservoirs was compared in five New South Wales rivers. Under low flow conditions, cyanobacterial presence disappeared rapidly with distance downstream in the Cudgegong and Hunter Rivers, whereas the other three rivers were contaminated for at least 300 km. Cyanobacterial survival is likely to be impacted by the geomorphology of each river, especially the extent of gravel riffle reaches (cells striking rocks can destroy them) and by the different turbulent flow conditions it produces within each. Flow conditions at gauging stations were used to estimate the turbulent strain rate experienced by suspended cyanobacteria. These indicate average turbulent strain rates in the Cudgegong and Hunter Rivers can be above 33 and 83 s^{-1} while for the Murray, Edward and Macquarie Rivers average strain rate was estimated to be less than 30 s^{-1}. These turbulent strain rate estimates are substantially above published thresholds of approximately 2 s^{-1} for impacts indicated from laboratory tests. Estimates of strain rate were correlated with changes in cyanobacterial biovolume at stations along the rivers. These measurements indicate a weak but significant negative linear relationship between average strain rate and change in cyanobacterial biomass. River management often involves releasing cold deep water with low cyanobacterial presence from these reservoirs, leading to ecological impacts from cold water pollution downstream. The pollution may be avoided if cyanobacteria die off rapidly downstream of the reservoir, allowing surface water to be released instead. However high concentrations of soluble cyanotoxins may remain even after the cyanobacterial cells have been destroyed. The geomorphology of the river (length of riffle reaches) is an important consideration for river management during cyanobacterial blooms in headwater reservoirs.

1. Introduction

A significant portion of New South Wales (NSW), Australia experiences a warm temperate climate, with low rainfall. As a result most of the state's larger rivers have been impounded for water conservation purposes. The water is then used downstream for town water supply, livestock watering and irrigated agriculture, while the rivers and reservoirs themselves become focuses for water-based recreational activities (Jeffcoat, 1988). The creation of large water storage reservoirs can however produce a number of serious environmental problems. Those subject to eutrophication can develop major cyanobacterial blooms when they warm and undergo thermal stratification during the summer months of each year. Many of the large NSW reservoirs are subject to these blooms. In addition, summer thermal stratification leads to warm water in the epilimnion while the water in the hypolimnion remains cold and often can undergo anoxia. Hypolimnetic water from reservoirs, if released to rivers, can lead to unseasonal temperature depression for long distances downstream, a phenomenon known as cold water pollution. Cold water pollution in rivers can have severe negative ecological impacts, especially on native fish breeding (Preece and Jones, 2002).

In summer when reservoirs are thermally stratified and have major cyanobacterial blooms, the release of water for downstream environmental and consumptive uses presents a major

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issue for managers. Do they release cold deep water where cyanobacterial presence is low and risk ecological problems downstream from cold water pollution? Alternatively, to avoid cold water pollution, do they release warm surface waters and risk contaminating the river downstream with high concentrations of cyanobacteria, with potential adverse impacts to water users? Toxic cyanobacterial blooms are of major management concern in many parts of the world because of their potential detrimental impacts to the health of humans, livestock, wildlife (Hilborn and Beasley, 2015) and the aquatic environment (Ibelings et al., 2008). Although some in-reservoir management options such as algicide application or artificial destratification may be available, these are often prohibitively expensive for very large headwater reservoirs and may cause other environmental issues. One objective of this paper is to consider an alternative option that may be possible for some reservoirs and downstream river systems at little or no cost.

To aid reservoir and river managers, there is a need to assess the survival of cyanobacteria in rivers following their release from large headwaters reservoirs. Ingleton et al. (2008) have shown that while some cyanobacterial cells are destroyed during passage through the outlet works of a reservoir, many still survive and are viable for further growth in the river downstream if in-stream conditions are suitable for this. Although Steinberg and Hartmann (1988) considered that rivers were not good habitats for planktonic cyanobacteria, as they would be killed off by in-stream turbulence, cyanobacteria have been shown to survive for many hundreds of kilometres following their release from the main headwater reservoirs in a number of rivers. Examples include the lowland Murray River in Australia (Al-Tebrineh et al., 2012; Baldwin et al., 2010; Bowling et al., 2013; Crawford et al., 2017) and the Klamath River in California (Otten et al., 2015). In contrast however, elsewhere cyanobacteria have been shown to disappear rapidly with distance downstream, such as in the Narew River downstream of the Siemianówka Reservoir in Poland (Grabowska and Mazur-Marzec, 2016) and in the Tanglang River downstream of Dianchi Lake in China (Yu et al., 2015).

A range of environmental factors such as water temperature and nutrient availability are important in determining the accumulation of phytoplankton biomass and the structure of phytoplankton communities in large rivers (Ha et al., 2002; Bowling et al., 2016). In addition, flow-driven processes have also been shown to be important. Cyanobacterial blooms were shown to develop in a weirpool on a large Australian river during summer low-flow conditions, but were replaced by diatoms at higher flow (Sherman et al., 1998; Webster et al., 2000). In this paper, two additional factors, the influence of geomorphology and in-stream turbulence are examined to determine how these effect the survival of cyanobacteria in five NSW rivers where cyanobacterial contaminated water has been released from the headwater reservoirs.

Laboratory experiments of cyanobacteria and microalgae subjected to steady mean shear in laminar flow (Moisander et al., 2002; Thomas and Gibson, 1990) and shear in turbulent flow (Regel et al., 2004) have demonstrated the sensitivity of their growth and survival to the shear stresses applied by the fluid. In a turbulent flow the phytoplankton cells experience shear stress as a result of the time varying velocity fluctuations. The stress is proportional to the average turbulent strain rate developed in the flow (γ) which can be estimated from the turbulent dissipation rate (ε) and the fluid viscosity (ν),

$$\gamma = \sqrt{\frac{\varepsilon}{\nu}} \tag{1}$$

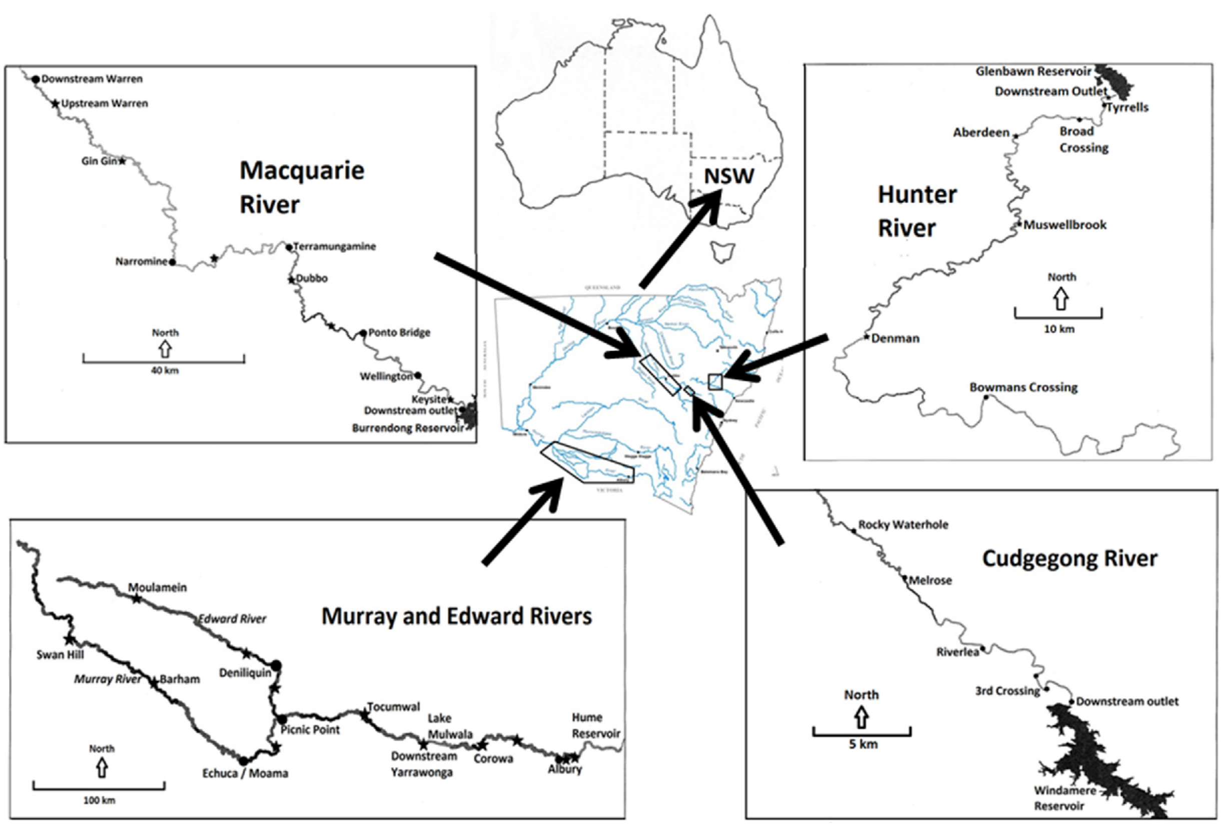

Fig. 1. Location of the rivers and the sampling sites on each river. Cyanobacterial sampling sites are shown as dots while streamflow gauging stations are shown as stars. Cyanobacterial samples were also collected at stream gauging sites.