Lower Vasse River Circulation Trial 2019-2020

Technical Report

April 2020

Report to the City of Busselton

Prepared by Robyn Paice, Ottelia Ecology

Ottelia Ecology Environmental Services | Aquatic Ecosystem Specialists

Contents

Document Control

Document Status	Prepared by	Reviewed by	Date
Final report	R. Paice		3/06/2020
Final draft report	R. Paice	M. Breton (CoB) G. McGrath (DBCA) L. Kalnejais (DWER	22/04/2020
Draft Report 2	R. Paice	K. Hastings	22/04/2020
Draft Report 1	R. Paice	K. Hastings	15/04/2020

Summary

The Lower Vasse River experiences severe blooms of cyanobacteria (blue-green algae) every summer due to very high concentrations of nutrients and optimal physical conditions for phytoplankton growth. Water circulation may have potential to improve water quality in the Lower Vasse River, through addressing the still and 'stagnant' conditions during summer and autumn. This is currently the only option for water movement, as no 'new' water is available for flushing. A trial of water circulation was undertaken from 19th December 2019 to 16th March 2020 to inform its potential use as a management tool. The Lower Vasse River circulation trial provided circulation of the volume of river water within the trial area every 1-2 days over a period of three months.

Unfortunately, the establishment of the seasonal algal bloom prior to circulation meant that the potential for this approach to prevent formation of a bloom could not be assessed. Although there was a decline in phytoplankton levels following an initial increase, levels remained well in excess of recreational and ecosystem protection guidelines, and the algal bloom persisted. Despite the water movement, still conditions with high nutrient levels remained in the test area. Some treatment of the recirculated water would be required to achieve a beneficial outcome and even then, ongoing nutrient release from internal sediments may be sufficient to fuel algal blooms. There was no effect on oxygen levels, which are consistently very high at this time of year. Other methods of aeration (e.g. fountains) would similarly not increase oxygen levels under already super-saturated conditions.

Management of algal blooms in the Lower Vasse River will require implementation of multiple management tools, as intended to be achieved through a Living Streams approach. The use of separation curtains has been shown that separated areas respond to localised conditions, suggesting that improvements may be achievable within seasonally isolated areas. Creation of deeper areas through removal of accumulated organic sediments may facilitate more effective circulation if deeper, cooler waters have lower algal biomass and can be mixed with surface waters. Providing for some treatment of the recirculated water is essential, and inclusion of channel zones associated to create more turbulence in the system may also be helpful.

The recommendation from this trial is to consider further evaluation of circulation in combination with additional treatment measures within the trial design, such as Phoslock and/or hydrogen peroxide. If pursued further, recommended improvements to the current circulation design are:

- ensure commencement well in advance of the onset of seasonal algal bloom;
- modify the return outflow to incorporate a longer riffle run to create additional time in turbulent flow;
- increase pumping capacity; and
- exclusion of a geotextile bag.

Introduction

The Lower Vasse River experiences severe blooms of cyanobacteria (blue-green algae) every summer due to very high concentrations of nutrients and optimal physical conditions for phytoplankton growth. Significant work has been undertaken over the past 20 years to reduce nutrients from catchment sources, however algal blooms have prevailed in the river leading managers to explore additional management options. Other factors that contribute to algal blooms are internal nutrient loading from sediments, still warm conditions, and lack of shading.

Water circulation has been thought to have potential to improve water quality in the Lower Vasse River, through addressing the still, 'stagnant conditions' during summer and autumn. Cyanobacteria thrive in warm, still conditions. They benefit from stable water columns, with gas vesicles and formation of large colonies that improve buoyancy (Romo et al. 2013). This allows cells to stay within optimal temperature, light and nutrient conditions for growth. Their buoyancy also results in accumulation of cells at the surface, providing a competitive advantage over other species of phytoplankton (Huisman et al. 2018).

Reducing water residence times through flushing (moving water through the system and replacing it with 'new' water) has been shown to reduce growth of blue-green algae (Stroom et al. 2016). Mixing within a water body can also reduce sedimentation losses of less buoyant species and so increase the growth rate of less harmful species such as diatoms and green algae (Ptacnik et al. 2008). Mixing of deeper lakes can limit cyanobacteria by reducing stratification and diluting with cooler water with lower cell density due to lack of light (Visser et al. 2016). However, in the Lower Vasse River, there is no external water availability for flushing or deep areas for mixing, so internal circulation is the only option to disrupt the stable water column to provide less optimal conditions for growth of cyanobacteria.

A water circulation trial was conducted from December 2019 to March 2020. The trial aimed to evaluate the potential for internal water circulation to limit phytoplankton growth, and assess its potential application in future redesign of the river as part of a Living Streams approach to management. The Living Streams approach proposes changes to river morphology to enhance ecosystem processes and increase resilience to nutrient enrichment by providing less favourable conditions for algal blooms (CoB 2019).

It was planned to commence the trial prior to the onset of an algal bloom, as suppression of phytoplankton growth was considered more achievable than algal bloom treatment. Unfortunately, a dense cyanobacteria bloom became established, earlier in the season than in previous years, before the trial commenced.

Methodology

The Lower Vasse River circulation trial was set up during 12th - 19th December 2019 and the pump was turned on in the afternoon of 19th December. Pumping of river water in the trial area was maintained at a rate of 60m^3/hour, providing a residence time of 1-2 days, and continued uninterrupted for three months until 16th March 2020.

Site layout

Three sections of river were isolated using four PVC separation curtains (Figure 1). These sections provided three trial areas for monitoring: a 'downstream' control area approximately 130m in length; a 'test' area approximately 50m in length; and an 'upstream' control area approximately 100m in length. Curtains had a floating top and chain attached to the base to form a barrier throughout the water column. Curtains reached across the width of the river and were tied in place and the edges weighted down. There was some leakage around the edges of the curtains, mainly from wind-driven water movement, however they were considered to provide sufficient separation to measure any water quality differences between trial areas.

The 50m test area had an approximate average width of 30m and depth of 1m, providing a water volume of about 1500 m^3. To create a residence time of 1-2 days, a 60m^3/hr capacity submersible pump was installed 1.5m from the bank at the south-east corner of the test area. Water was pumped through 100mm diameter pipe to the outflow area at the north west corner, into a 5m x 2.25m geotextile bag (mesh size 0.2mm) within a plastic-lined bunded 'pond' area and overflow water from the pond returned to the river via a rocky waterfall/riffle zone (Figure 2).

Water quality monitoring

Water quality monitoring was undertaken prior to the trial commencing (11th December 2019); three weeks after commencing (9th January 2020); and on a fortnightly basis until 5th March 2020. This included fortnightly in-situ measurements of dissolved oxygen, pH, temperature, salinity, and secchi depth; fortnightly laboratory analysis of chlorophyll a and turbidity; and four-weekly analysis of nutrients and phytoplankton (species composition and cells counts). Sites included the test area, downstream and upstream control areas, and the pond in the outflow area.

Within the river, sampling was undertaken from a boat in approximately the centre of each site area. Water samples for laboratory analysis were collected as integrated samples through the water column using a weighted bottle, with three subsamples combined for each sample. Water quality samples were chilled immediately and analysed by the Marine and Freshwater Research Laboratory (NATA accredited). For phytoplankton analysis, both fresh (chilled) and preserved (Lugol's) samples were sent for taxonomic analysis and enumeration by Dalcon Environmental (NATA accredited).

Maintenance

The circulation trial infrastructure installation was completed, and the pump activated on 19th December 2019. The pump operated constantly without any problems. The Geotextile bag mesh became covered with growth of biofilm, which caused the bag to bloat creating concerns about a potential reduction of flow. However, water continued to flow through the bag at the same flow rate, as indicated by an in-line pressure gauge. The bag was periodically washed down with water at high pressure to clean it.

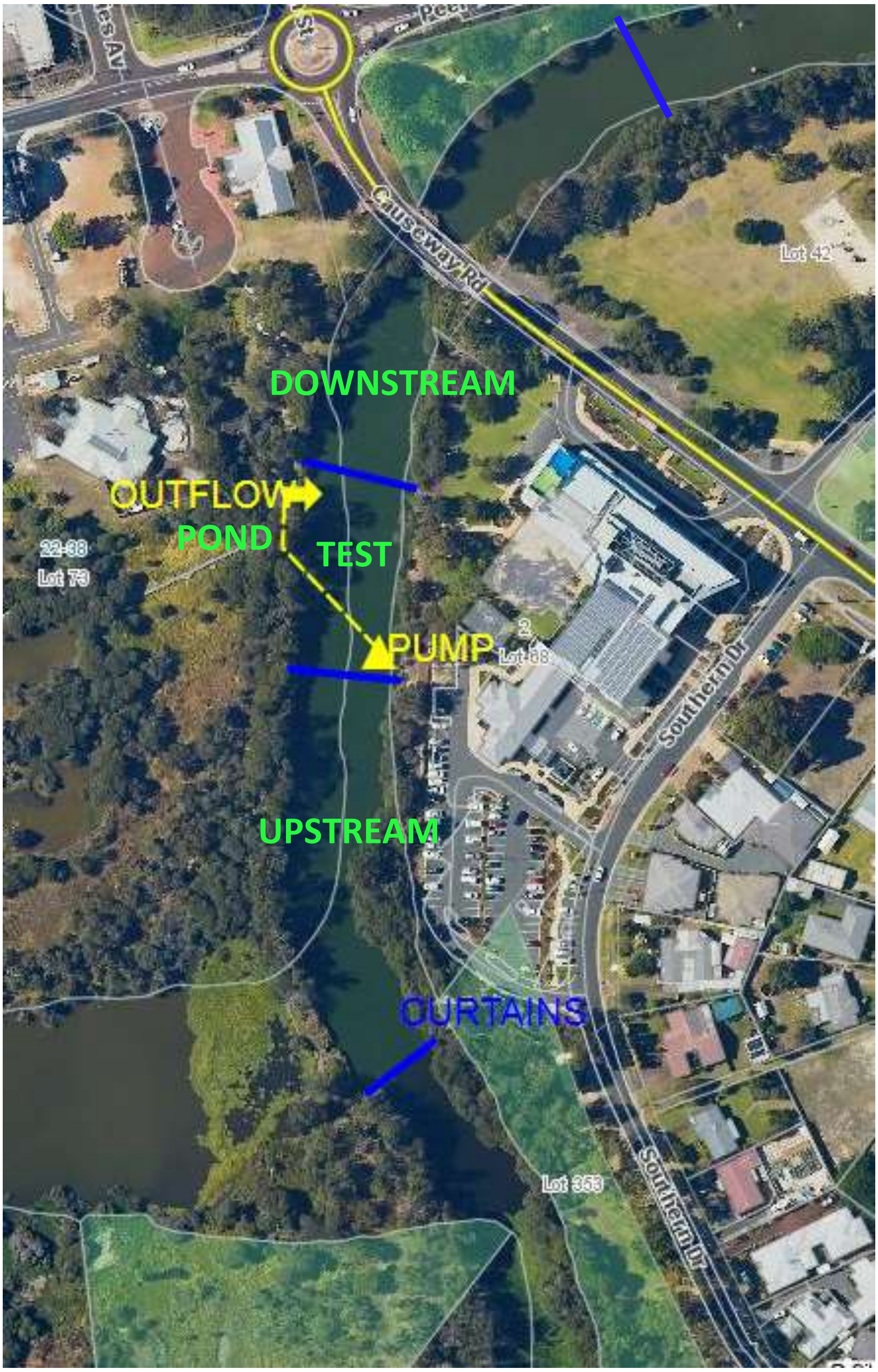

Figure 1.Lower Vasse River circulation trial layout 2019-2020 showing: location of pump, pipe (yellow dashed line) and outflow; separation curtains (blue, approximate location) and water quality monitoring sites (labelled in green).

Figure 2. Circulation trial set-up photos showing: (a) PVC separation curtain, (b) submersible pump, (c) the geotextile bag and pond in the outflow area and (b) the rock riffle return to the river.

Figure 3. Photos from 19th December showing the cyanobacterial bloom prior to circulation commencing, with surface scum accumulating on different sides of the curtain in the morning (left) and afternoon (right) due to prevailing winds.

Results

The presence of a dense cyanobacterial bloom (blue-green algae) was evident prior to the trial commencing, with turbid green water throughout the project area. Scums were present at the surface, accumulating against the separation curtains according to the direction of prevailing winds (Figure 3). Freight delays owing to the upcoming Christmas period made it difficult to get the trial underway sooner.

Phytoplankton and water clarity

Prior to the trial commencing, the dense bloom of cyanobacteria was reflected by very high chlorophyll *a* (mean 270µg/L) and turbidity (mean 47NTU) (Figure 4) across all sites. Cyanobacteria cell density was also extremely high, and was much higher in the downstream area (1,098,000 cells/mL) than in the test area (595,000 cells/mL) and upstream (479,000 cells/mL). The establishment of the algal bloom was earlier than usually observed, likely owing to very high temperatures in early December, when maximum temperatures of 32.7^{o}C-37.5^{o}C from 1st to 6th December compared to average temperatures over this time of 25.4 ^{o}C (BoM data). All sites remained above ecosystem protection guidelines for chlorophyll a and turbidity throughout the trial (Figure 4).

Three weeks after commencement of circulation there was a minor (15%) decrease in chlorophyll a in the test area, but substantial decreases in both control areas (downstream 82%; upstream 70%). Chlorophyll a in the test area then increased to 410µg/L on 23rd January, followed by a consistent decline over the remainder of the trial period by 68% to 130µg/L on 5th March (Figure 4a). Chlorophyll a in the pond area differed to the test area early in the trial and then results were very similar for the final six weeks. In the downstream control area, chlorophyll a remained at comparatively low concentrations (though well above the guideline) with a higher peak on 20th February. Concentrations were consistently higher in the upstream than the downstream control (Figure 4a). In the upstream control, chlorophyll a rose to 460µg/L on 20th February and declined during the final two weeks. Chlorophyll a in the pond and test area were similar to the downstream control area from 20th February.

Turbidity closely followed the pattern of chlorophyll a results, other than no initial decrease observed for the test area (Figure 4b). This confirms phytoplankton as the main source of turbidity in the river. Secchi depths also reflected turbidity results, showing lower water clarity in the test area in January (0.19m) than both controls (downstream 0.39m; upstream 0.29m), but increasing clarity thereafter, and consistently higher clarity in the downstream control (mean 0.41m).

Phytoplankton species composition and cell density counts were completed on three occasions: prior to commencing, three weeks after commencing, and nine weeks after commencing. Cyanobacteria dominated the phytoplankton community at all sites, comprising 98-99% of total cell density. After three weeks of circulation (9th January), there was a visual difference in the algal bloom in the test area, which had a brighter green colour (Figure 5). Cyanobacteria density increased by 40% in the test area (829,500) and was 3 to 4 time higher than in control areas and, notably, the pond area (Figure 6a). Despite this difference in cell counts, the pond and test areas had similar chlorophyll a levels, which may be explained by relatively high levels of unicellular green algae (Chlorophyceae) in the pond (Figure 6b). The final phytoplankton sampling on 20th February (6 weeks later) found a 42% reduction cyanobacteria density in the test area, with values similar to the downstream control, while density had increased in both control areas.

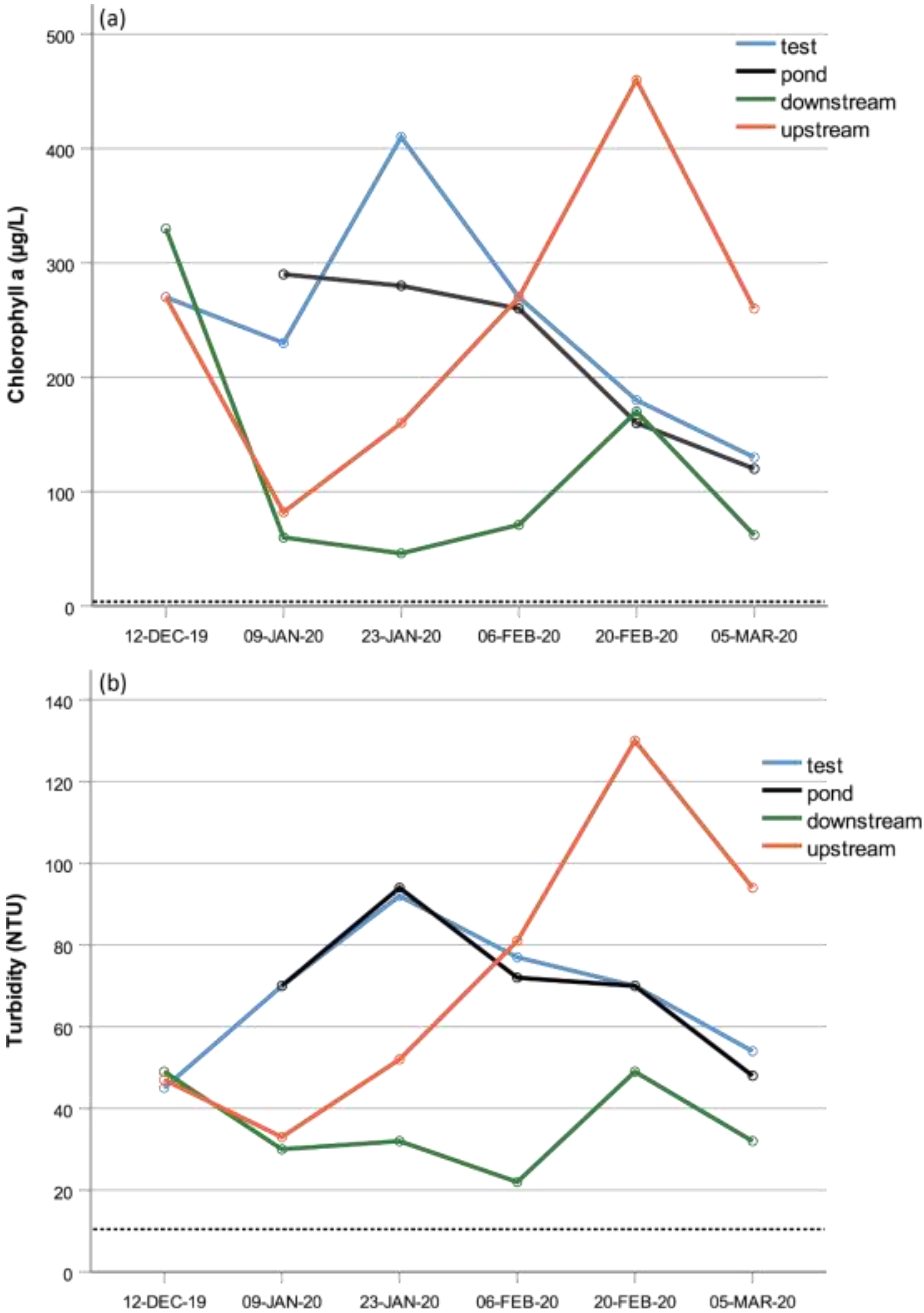

Figure 4. (a) Chlorophyll a *concentrations and (b) turbidity levels at each site during the trial, measured at fortnightly intervals. Dashed lines are guidelines for ecosystem protection (ANZECC and ARMCANZ 2000).*

Cyanobacteria dominated the phytoplankton community throughout the trial, accounting for more than 98% of cells present in all samples other than two: the pond and upstream control areas on 9th January, when 13-15% of cells were unicellular green algae (Chlorophyceae) (Figure 6b). The only phytoplankton groups other than cyanobacteria comprising more than 1% of the community were Chlorophyceae and Bacillariophyceae (diatoms). Phytoplankton analysis results were generally consistent with chlorophyll a concentrations.

Within the group of cyanobacteria (Class Cyanophyceae), sixteen taxa were encountered with most of the biomass comprised of seven taxa. Composition of taxa were similar across sites for each sample date, although densities varied (Figure 6a). When much higher cyanobacteria density was found in the test area in January compared to other sites, composition differed mainly in higher densities of *Dolichospermum circinale* and *Planktolyngbya limnetica* (both toxin-producing). This difference was visible, with the test area appearing a brighter green than control areas. *Microcystis flos-aquae* was also high in both the test and upstream areas in January. The final phytoplankton monitoring on 20th February found all open water areas dominated by the common and the toxin-producing species *Microcystis aeruginosa. Microcystis* species were also found to dominate the river downstream of the study area in sampling undertaken by Department of Water and Environmental Regulation in late February to early March.

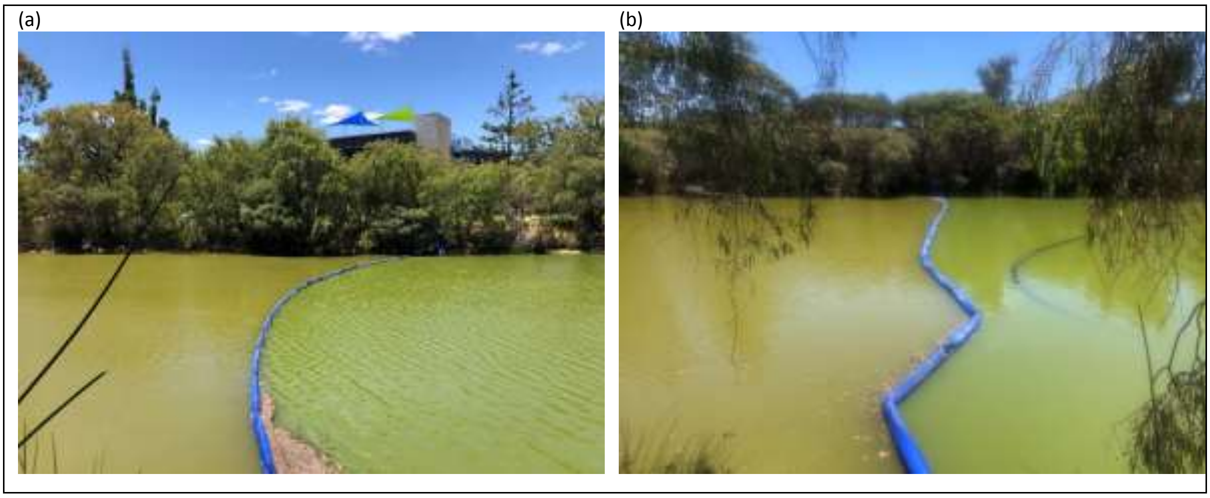

Figure 5. Visual differences between trial and control areas on 9th January, three weeks after the trial commencing. The test area is on the right in phot photos, compared with (a) downstream control and (b) upstream control.

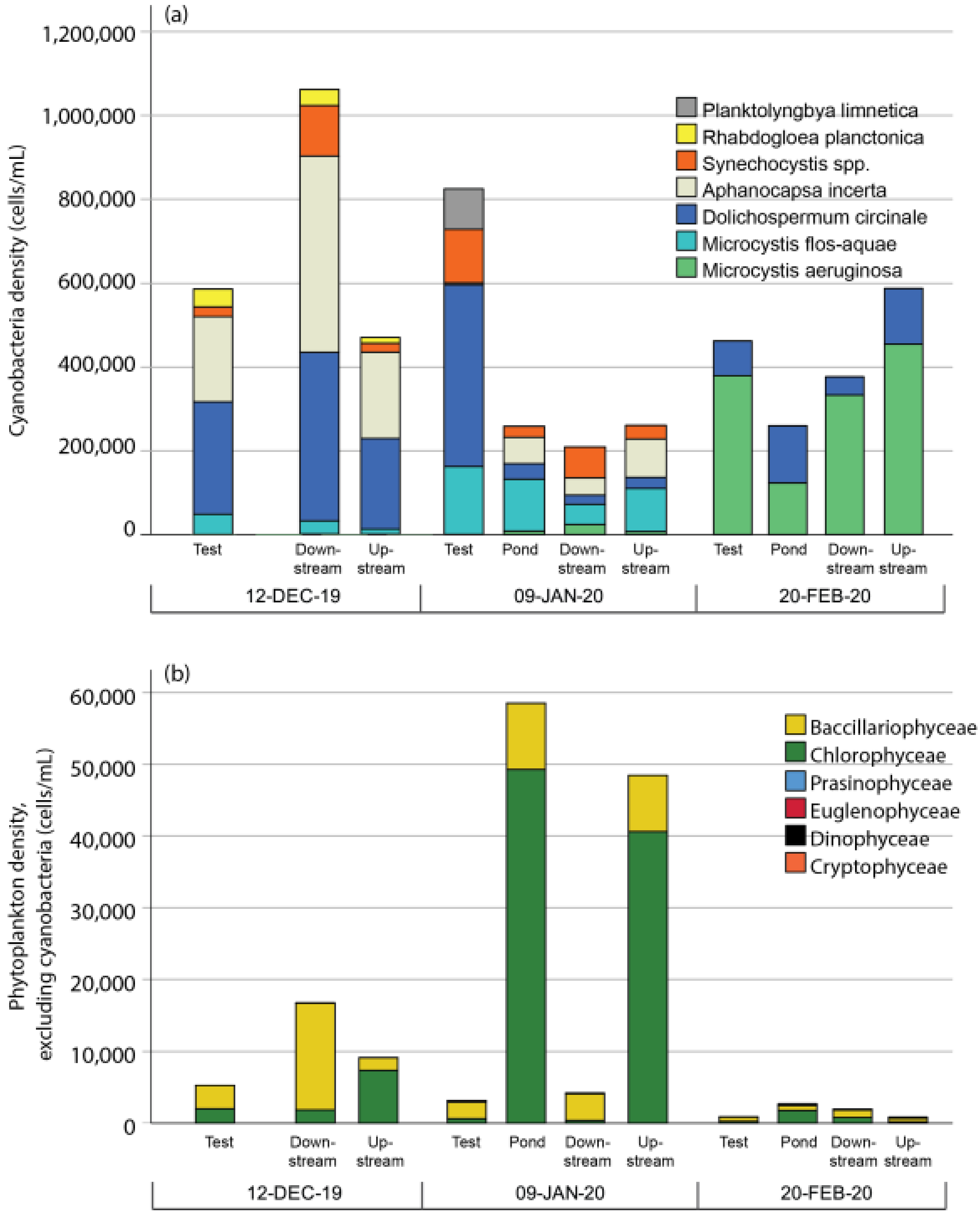

Figure 6. Phytoplankton density and community composition in the study area during the trial: (a) Cyanobacteria and (b) other phytoplankton groups.

Nutrients

Phosphorus results did not indicate any effect of water circulation. Concentrations of both total and dissolved phosphorus in the pond and treatment area were closely aligned, a likely effect of mixing.

Prior to the trial in December, all areas had similar concentrations of total phosphorus (TP) and dissolved phosphorus, with values greatly above guidelines for ecosystem protection (Figure 7). Following three weeks of circulation, TP had increased slightly in the test and pond areas and was higher than in control areas, but after a further six weeks had declined and was much lower than in the upstream control (Figure 7a). Downstream, TP declined during the trial, while upstream concentrations increased over time. Higher TP in the test and upstream control reflects greater phytoplankton levels in those areas compared with downstream, as phosphorus bound within algal cells is included in TP concentrations.

Dissolved phosphorus (orthophosphate, available phosphate) initially increased in all areas, and then dropped substantially in February, when concentrations were below guideline levels in the test, pond, and downstream control areas (Figure 7b). Dissolved phosphorus was much higher in the upstream control in January than other areas, which may explain increasing phytoplankton growth over time until February sampling, when less phosphorus was available.

Similar to the test area, dissolved phosphorus downstream dropped below guideline levels in February and was also relatively low in the upstream area. This indicates lower phosphorus availability and was followed by a decline in phytoplankton levels (chlorophyll a) in March.

Total nitrogen concentrations in the test area remained similar over the duration of the trial, while greater variability was found in the control areas (Figure 8). Dissolved inorganic nitrogen (ammonium and oxides of nitrogen) remained well-below ecosystem protection guidelines and were also more variable in control areas. Greater consistency of values may be due to increased mixing in the test area, however there was no evidence for any overall effect of circulation on nitrogen levels.

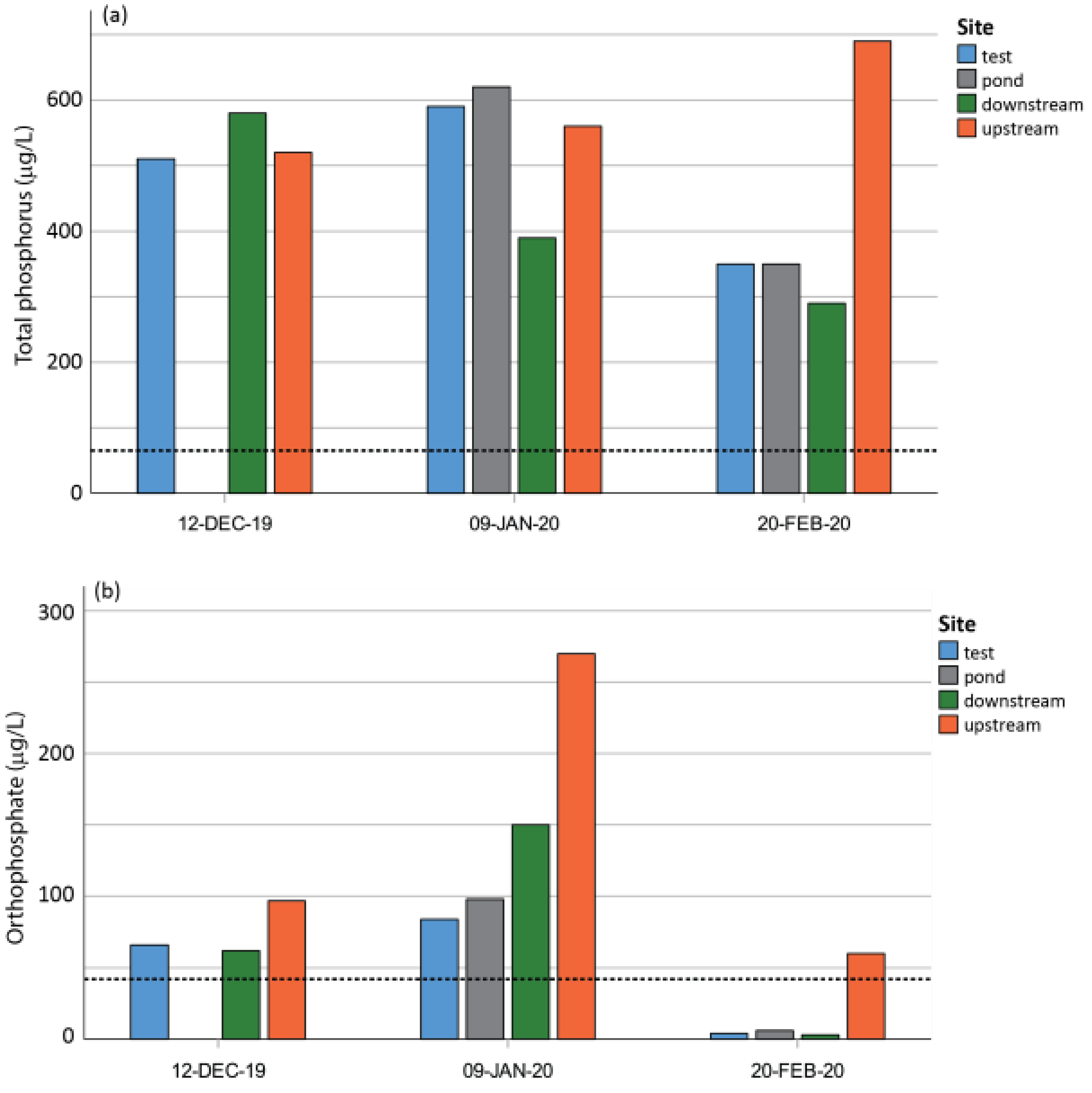

Figure 7. Phosphorus concentrations in the study area during the trial: (a) total phosphorus and (b) orthophosphate (dissolved phopshorus).

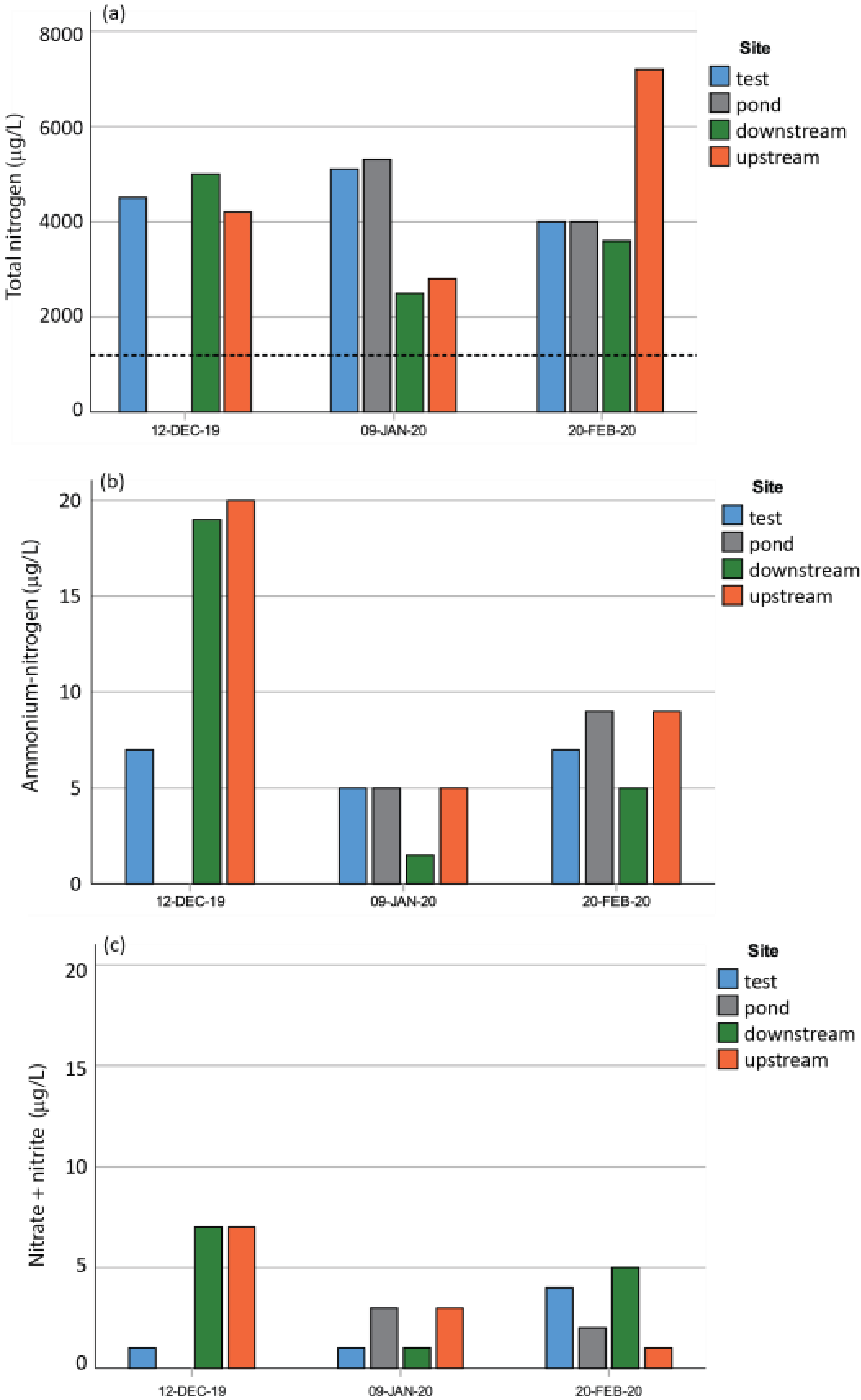

Figure 8. Nitrogen concentrations in the study are during the trial: (a) total nitrogen and dissolved nitrogen forms (b) ammonium and (c) nitrate plus nitrite (oxidised nitrogen).

Physicochemical variables

Dissolved oxygen was extremely high throughout the study area prior to circulation commencing, with a mean surface concentration of 23mg/L and 297% saturation (Figure 9a). These were the highest levels observed during the trial. The river was also more stratified at this time than later, with mean dissolved oxygen near the bottom of the water column of 10.95mg/L. This is a result of extremely high levels of photosynthesis associated with the algal bloom during hot, sunny conditions. Oxygen had dropped throughout the study area three weeks after the trial commenced, but was still at very high levels at all sites and remained high for the duration of the trial. Surface concentrations in the test area were similar to control sites, however there was an indication of greater stratification in January to early February, suggesting greater phytoplankton activity near the surface. Dissolved oxygen levels in the pond area were consistently lower than other sites suggesting that although phytoplankton levels were high, photosynthetic activity was lower than in open waters.

Throughout the trial, pH was very high at all sites, generally around 9-10 (Figure 9b). In conditions of algal blooms, high pH is common due to high levels of photosynthesis. Carbon dioxide in water forms a weak acid, lowering pH, but as it is depleted during photosynthesis the pH increases.

Prior to circulation, river temperatures were very high throughout the study area (Figure 10a), particularly at the surface, and the highest temperature was found in the test area. Following commencement of the trial, temperature was consistently slightly lower in the treatment and pond sites than in upstream and downstream control areas.

The river remained relatively fresh throughout the trial, but conductivity did increase over time (Figure 10b). Conductivity remained similar across sites until 20th February, when it was slightly higher with distance upstream. This continued into March, when the downstream area declined slightly, the test area remained the same and the upstream area increased slightly. This may be related to greater groundwater input to the deeper waters just downstream of the Causeway bridge.

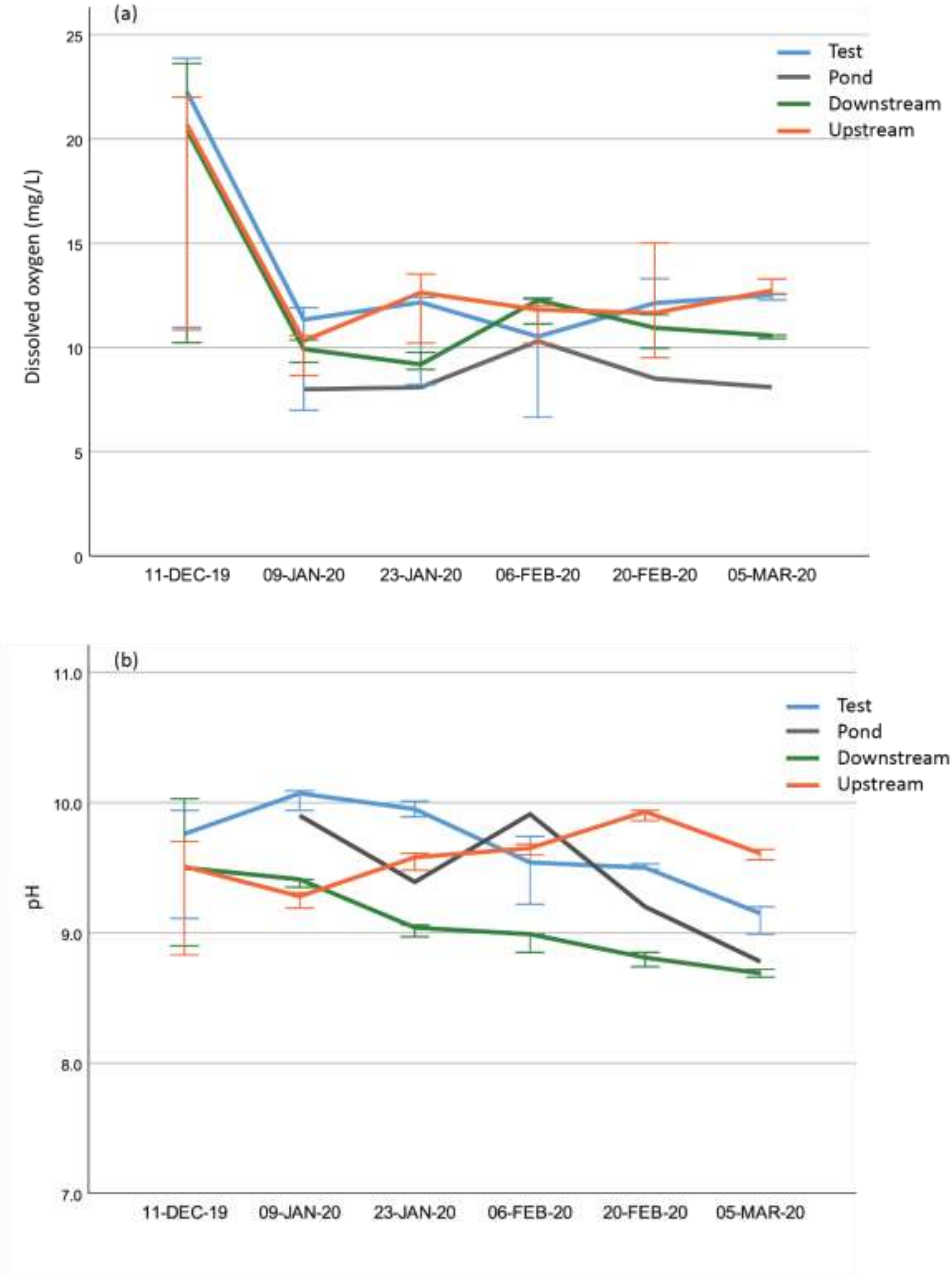

Figure 9. (a) Dissolved oxygen and (b) pH in the study area during the trial. Lines show values at 0.5m depth and error bars show values at surface and close to bottom of water column.

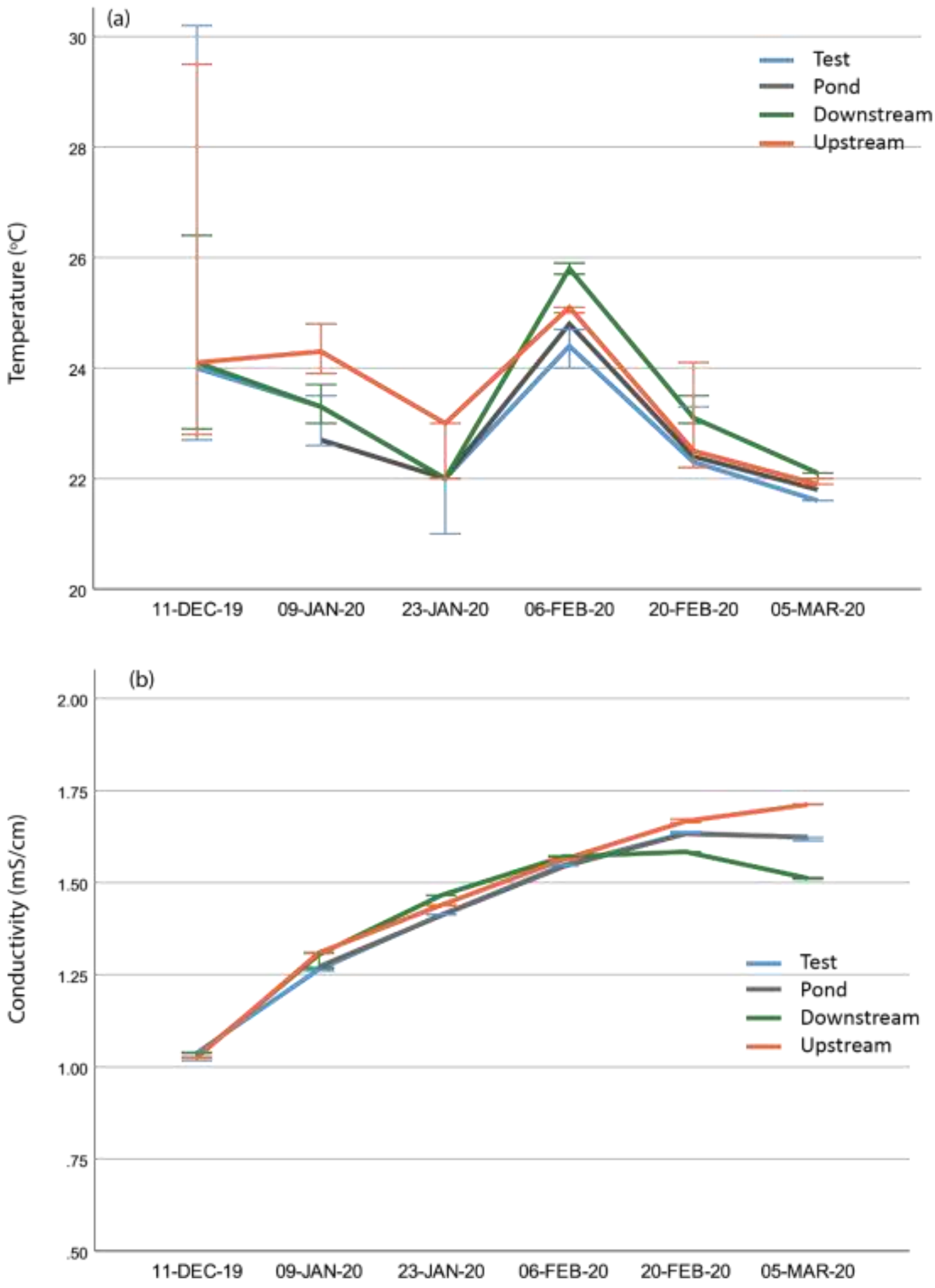

Figure 10. (a) Temperature and (b) conductivity (indicator of salinity) in the study area during the trial. Lines show values at 0.5m depth and error bars show values at surface and close to bottom of water column.

Geotextile bag

The geotextile bag was incorporated into the design to provide additional disturbance to phytoplankton cells and potentially break up or trap larger cell colonies. An algal biofilm built up on the bag surface, which caused the bag to bloat, creating concern about blockage (Figure 11a). Washing the bag down with a high-pressure hose was effective in removing the algae. There was also considerable build-up of algal material in the bottom of the pond (Figure 11b). During phytoplankton analyses, material scraped from the geotextile bag and pond liner were sent for identification of dominant algal types. The biofilm growing on the bag was predominantly diatoms, while the algae growing on the pond liner was dominated by cyanobacteria.

Water quality in the pond, which comes directly from the bag, was similar to the treatment area in chlorophyll a, turbidity and nutrient levels, suggesting the bag did not have a significant effect overall. Of interest is after the first three weeks of circulation, substantially lower cyanobacteria density and higher green algae density were found in the pond compared with the treatment area. It is possible that there was some initial benefit provided by the bag. However, the small size of the bag and the need for periodic washing down to prevent blockage would have limited this effect.

(a) (b)

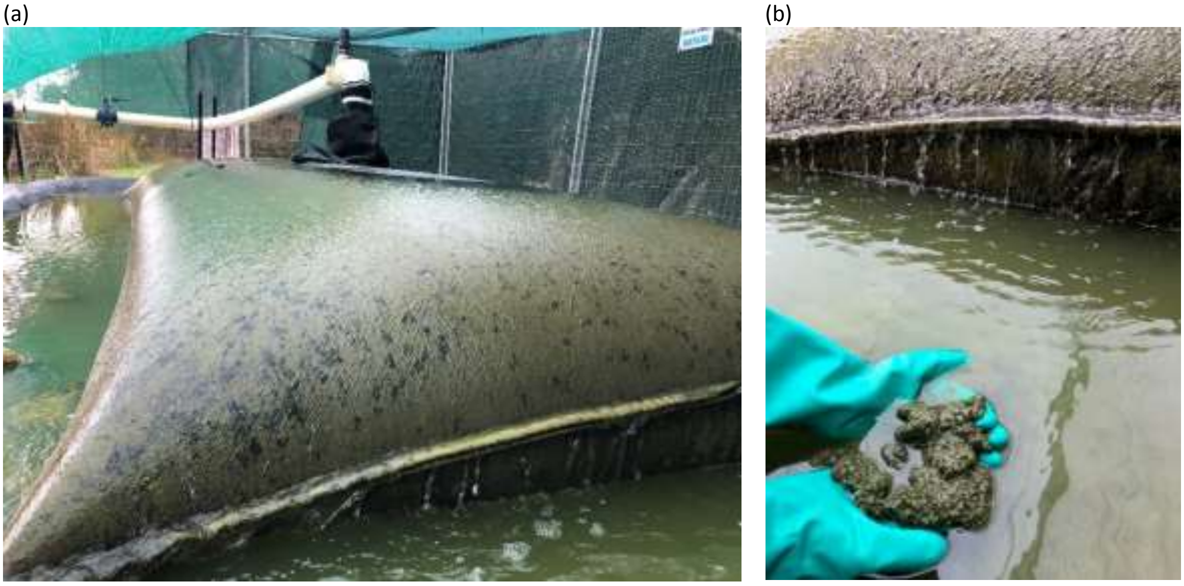

Figure 11. Algal growth on the geotextile bag (a) and scooped from the pond liner (b).

Discussion

The Lower Vasse River circulation trial provided circulation of the volume of river water within the trial area every 1-2 days over a period of three months from 19th December 2019 to 16th March 2020. The mixing effect of circulation was evident in the similarity of water quality results for the pond and test area. A severe algal bloom was established in the river prior to commencement of the trial and remained in both test and control areas throughout the trial. Cyanobacteria (blue-green algae) dominated the phytoplankton community throughout the trial, with similar species present in the test and control areas. There was variation in phytoplankton levels between the test area and control areas, and also within control areas, however phytoplankton levels greatly exceeded recreational and ecosystem protection guidelines throughout the study area during the trial period.

Each area of the trial showed a different pattern in phytoplankton levels. In the test area, there was an increase in phytoplankton levels (indicated by chlorophyll a) over the first five weeks of circulation five weeks, followed by a consistent gradual decline over the remainder of the trial. In the downstream area, phytoplankton levels declined substantially early in the study and then remained relatively consistent. In the upstream area, an initial decline in phytoplankton levels was followed by a substantial increase over six weeks, when this area exhibited the highest phytoplankton levels found in the study. These differences show effective separation by the PVC curtains, and the contrast in results from the two control areas suggest that localised conditions within the river do influence algal growth. So, differences in the test area over time may also have been due to natural variation rather than an effect of the trial. The potential for localised conditions within the river to influence algal growth does suggest that improvements may be possible within isolated areas (e.g. summer river pools) if this was included in changes to river form through a Living Streams approach.

With the bloom established, it is possible that water movement may have initially enhanced phytoplankton growth. In other studies, this has been caused by increased phosphorus loading from sediments due to disturbance (Lurling et al. 2016). However, results did not suggest an obvious effect of circulation on nutrient levels. Total phosphorus was higher in the test area than control areas at this time, but this was not maintained, and available phosphorus was low in the treatment area. In contrast, the decline in chlorophyll *a* over the final six weeks of the trial was somewhat encouraging, however the role of circulation in this is not clear and it was not sufficient for an observable effect on the algal bloom.

It is interesting to note the presence of green algae and diatoms in the study area, which have been found to become more competitive in mixed conditions (Visser et al. 2016). However, there was no evidence that circulation promoted their growth. Green algae were found at relatively high density in the pond area, but similar levels occurred in the upstream control at the same time.

Very high oxygen levels during the trial occurred throughout the study area due to the algal bloom prevented any assessment of the influence of circulation on oxygen levels. Increased oxygen levels is a common outcome of artificial mixing and has been related to lower internal phosphorus loading (Lehman 2014). The lower Vasse River is typically well-oxygenated from late spring to autumn (CoB 2019), so aeration would be expected to have little benefit at this time. This would also apply to other methods of aeration, such as the use of fountains. It should be noted however, that high oxygen at this time is likely due to phytoplankton productivity (photosynthesis) and may well be much lower in the event of phytoplankton control. If aeration was considered necessary, anoxic conditions would remain within the thick organic sediment layer and this may not be improved by increased oxygen at the water-sediment interface only (Gachter and Wehrli 1998). It is also important that circulation methods do not disturb the sediment surface, as this may cause phosphorus release and exacerbate cyanobacterial blooms (Lurling et al. 2016).

It is unfortunate that the trial was not able to be established prior to the onset of the seasonal agal bloom. It is extremely difficult to treat cyanobacteria blooms once established, as these organisms have several competitive advantages over other, less harmful species of phytoplankton. Successful control through mixing is more likely for deeper lakes, where deeper water with lower biomass (due to light limitation) and cooler temperatures dilutes surface waters (Visser et al. 2016). Internal circulation is currently the only option for reducing residence times in the Lower Vasse River in an effort to manage algal blooms. However, it does not achieve true reduction in residence time because there is no replacement with better quality water.

This trial shows internal recirculation is not effective in treating a bloom, and it may also have limited potential in preventing a bloom as relatively still conditions with high nutrients would prevail. Some treatment of the water to remove nutrients and/or phytoplankton cells would be required prior to its return to the river. Even if this was achieved, ongoing release from nutrient-rich organic sediments is likely to provide an ongoing internal nutrient source sufficient to fuel agal blooms.

In regard to treatment of cyanobacteria blooms, it is important to note the potential risks involved. Once high cell densities are present, a successful treatment that did result in rapid death would pose a risk deoxygenation of the water column, with impacts on aquatic fauna. If such death is from cell lysis, toxins from within cyanobacteria cells become bioavailable and can harm aquatic life. This limits treatment options to flocculation and removal of phytoplankton from the water column, such as clays that sink algal cells, for example the hydrotalcite clay trialled in the river recently (Tulipani 2019). Other treatment options would almost certainly need to be implemented in a preventive approach to reduce risk. These may benefit from circulation or mixing to increase oxygen levels, because low levels of phytoplankton growth would likely result in reduced available oxygen (due to less photosynthesis).

The pumping rates used in this trial, although designed to reduce residence time to 1-2 days, did not create conditions of flow within the river. Still water conditions remained despite this circulation. Further, the lack of any water treatment meant that nutrient availability remained similar. A higher flow rate may be needed to create sufficient water movement to restrict cyanobacterial growth. The induction of turbulence in the system may be more important than increasing the turnover rate or reducing residence time (Huisman 2004). In the current trial, turbulence was limited to the waterfall outflow area. The length of time water is under turbulent conditions could be extended using a longer return channel that includes riffles.

The design of the circulation trial lends itself to addition of other management approaches, such as phosphorus-stripping clay (Phoslock) and the use of hydrogen peroxide as preventative measures. Interception of return waters with Phoslock has potential to reduce available phosphorus for growth of phytoplankton, which is particularly important for limiting growth of cyanobacteria. Hydrogen peroxide has been shown to selectively control cyanobacteria at very low dose rates without impacting other aquatic organisms (e.g. Matthis et al. 2012). It must be used when cell density is low, because killing of high concentrations of cyanobacteria in the treatment of an established bloom causes cell lysis, potentially releasing harmful toxins. A dosing system combined with mixing would be required to maintain a suitable concentration of hydrogen peroxide to provide ongoing control.

Conclusion

The establishment of the algal bloom prior to circulation meant that the potential for this approach to prevent formation of a bloom could not be assessed. Rather, the trial looked at potential to treat an existing cyanobacterial bloom, and it was not successful in terms of a visual or measurable improvement in the severity of the algal bloom. A key learning outcome from this trial is to plan intervention management actions well in advance of the algal bloom, taking a preventative rather than a treatment approach.

Although there was a decline in phytoplankton levels following an initial increase, levels remained well in excess of recreational and ecosystem protection guidelines, and the algal bloom remained obvious. Despite the residence time being reduced in the test area, little water movement was created and still conditions remained on the test area. Suppression of cyanobacteria by internal circulation would require inclusion of additional measures to treat nutrient availability and/or phytoplankton.

It is also important to note that disturbance of organic sediments through any mixing or circulation approach should be avoided due to the potential for phosphorus release. These sediments also limit potential for increased oxygen levels (e.g. through aeration) to reduce internal phosphorus loading from the sediments because anoxic conditions within the sediments are conducive to phosphorus release.

The design of the circulation trial may be suitable for additional management techniques to be implemented concurrently, which should be given thorough consideration in the development of a subsequent trial. While trials of individual techniques may be informative, it is very unlikely that algal blooms in the Lower Vasse River can be successfully managed through any single technique. The recommendation from this trial is to consider further evaluation of circulation in combination with additional treatment measures within the trial design, such as Phoslock and/or hydrogen peroxide. If pursued further, recommended improvements to the current circulation design are:

- ensure commencement well in advance of the onset of seasonal algal bloom;
- modify the return outflow to incorporate a longer riffle run to create additional time in turbulent flow;
- increase pumping capacity; and
- exclusion of the geotextile bag.

The Living Streams approach involves alteration of morphology to enhance ecosystem process and create less ideal conditions for algal growth. If this management approach creates deeper areas through removal of accumulated organic sediments, this may facilitate more effective circulation if deeper, cooler waters have lower algal biomass and can be mixed with surface waters. Providing for some treatment of the recirculated water is essential, whether this be by chemical (e.g. specialised clays) or ecological engineering (e.g. in-line treatment wetlands) or physical (e.g. filtration) means. Inclusion of channel zones associated with circulation to create more turbulence in the system may also be helpful. Through this and previous trials in the river, it has been shown that separated areas respond to localised conditions, suggesting that improvements may be achievable within seasonally isolated areas.

References

ANZECC and ARMCANZ (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1: The Guidelines.* National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

City of Busselton (2019) *Lower Vasse River Waterway Management Plan*. Revitalising Geographe Waterways Report, City of Busselton.

Tulipani, S. (2019) *Water Science Technical Series WST84, Lower Vasse River water treatment trials 2016-2018: synthesis report*. Department of Water and Environmental Regulation, Western Australia

Gachter, R. and Wehrli, B. (1998) Ten years of artificial mixing and oxygenation: no effect on the internal phosphorus loading of two eutrophic lakes. *Environmental Science and Technology* 32:3659–3665.

Huisman, J., Codd, G.A., Paerl, H.W., Ibelings, B.W, Verspagen, J.M.H. and Visser, P.M. (2018) Cyanobacterial blooms. *Nature Reviews – Microbiology* 16: 471-483.

Huisman, J., Sharples, J., Stroom, J.M., Visser, P.M., Kardinaal, W.E.A., Verspagen, J.M.H. and Sommeijer, B. (2004) Changes in turbulent mixing shift competition for light between phytoplankton species. *Ecology* 85:2960–2970.

Lehman. J.T. (2014) Understanding the role of induced mixing for management of nuisance algal blooms in an urbanized reservoir. *Lake and Reservoir Management* 30:63-71.

Lurling, M., Waajen, G. and de Senerpont Domis, L. (2016). Evaluation of several end-of-pipe measures proposed to control cyanobacteria. *Aquatic Ecology* 50:499-519.

Matthijs, H.C.P. Visser, P.M., Reeze, B., Meeuse, J., Slot, P.C., Wijn, G., Talens, R., and Huisman, J. (2012). Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide. *Water Research* 46:1460-1472.

Ptacnik, R., Diehl, S. and Berger, S. (2003) Performance of sinking and nonsinking phytoplankton taxa in a gradient of mixing depths. *Limnology and Oceanography* 48:1903–1912.

Romo et al. (2013) Water residence time and the dynamics of toxic cyanobacteria. *Freshwater Biology* 58: 513-522.

Stroom et al. (2016) How to combat cyanobacterial blooms: strategy toward preventative lake restoration and reactive control measures. *Aquatic Ecology* 50:541-576.

Visser et al. (2016) Artificial mixing to control cyanobacterial blooms: a review. *Aquatic Ecology* 50: 423-441.

Appendix 1. Trial photos

9th January 2020: Test area (right) and downstream control (left).

9th January 2020: Test area (right) and upstream control (left).

23rd January 2020: Test area (right) and downstream control (left).

23th January 2020: Test area (right) and upstream control (left).

6th February 2020: Test area (right) and downstream control (left).

6th February 2020: Test area (right) and upstream control (left).

20th February 2020: Test area (right) and downstream control (left).

20th February 2020: Test area (right) and upstream control (left).

5th March 2020: Test area (right) and downstream control (left).

5th March 2020: Test area (right) and upstream control (left).