Waterways
Centre for Freshwater Management

Patch dynamics of *Phormidium* in Canterbury Rivers

Summer Scholarship Report

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Executive Summary

In recent decades there has been an apparent increase in the prevalence of blooms of *Phormidium* in medium-sized rivers in Canterbury. Given the propensity for this alga to be toxic, this has implications for the management of these rivers, and considerable research has gone into attempts to understand what is driving the increase in blooms, and hence how it may be controlled. To date these investigations have been largely statistical, using broad surveys of bloom frequency, intensity and river attributes to attempt to identify correlates, which may then be investigated as potential causative agents. This statistical approach has implicated a number of possible variables, but as yet no "smoking gun" leading to a "silver bullet" has emerged.

In this study we attempt to develop a new approach to understanding *Phormidium* blooms in Canterbury Rivers by studying the dynamics of the patches of algae that make up river bed cover, rather than just measuring cover. To this end, individual patches were followed for four weeks in four rivers (Opihi, Ashley, Selwyn and Tengawai), by repetitive photography. We also attempted to map the dynamics of patches at river scale using an unmanned aerial vehicle. The study was coordinated with other ongoing work on this river, and at a later date it will be possible to assess results against water quality variables from each river (still under analysis).

Key findings of this project were that,

- When patches were undisturbed over the study period, their area increased at rates that could be described using an exponential growth formulation. The rates of exponential growth were very consistent within rivers (e.g. Opihi patch area increased at rates of 0.77 ± 0.13 $week^{-1}$ N=9), but varied between rivers (e.g Tengawai increased at 0.37 ± 0.14 $week^{-1}$).
- Patches could increase in size, decrease, or be lost completely, and the loss rate varied between rivers. A common pattern was to increase then be partially removed.
- Where rivers developed very high %cover this was due to a low loss rate for individual patches rather than a high growth rate.
- After patches were ablated, regrowth from residual populations could be rapid.
- UAV's demonstrated how patchy *Phormidium* cover is on a river basis, how % cover evolved over time, and allowed a rapid and extensive evaluation of river status that provided a higher resolution of "problem areas" than manual surveys, which are inherently biased towards the specific survey site.

The ability to relate bloom formation to the balance of patch increase and decrease allows the potential for the processes controlling these processes to be investigated in detail. By resolving how different variables affect accrual and ablation separately, a much more refined understanding of processes controlling *Phormidium* blooms may be possible.

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Introduction

Harmful cyanobacterial blooms are becoming increasingly prevalent worldwide. They, pose a serious threat to freshwater systems and human health (Paerl *et al*., 2011). While concern has traditionally mainly related to planktonic blooms (Chorus & Bartram, 1999; Azevedo *et al*., 2002), in recent years there is growing appreciation of the problems associated with benthic cyanobacterial blooms (Quiblier *et al*., 2013).

Benthic mat-forming cyanobacteria grow attached to stable substrates and, under favourable conditions, can attain high cover across long stretches of rivers, including in NZ. In recent decades, there has been an apparent increase in blooms of the benthic cyanobacterium *Phormidium* in New Zealand rivers, (Heath *et al.*, 2011; Wood & Young, 2011; McAllister 2014; 2015) and guidelines of percent cover of Phormidium mats for contact recreation have been established (Wood *et al*., 2009). Attempts to determine the factors underlying this shift in the status of NZ rivers have primarily been through statistical models, that attempt to relate observed cover over some time period to environmental variable over a similar or different time period. Such investigations have related extensive *Phormidium* proliferations to a wide range of environmental drivers, including periods of low, stable flow and high temperatures (Biggs, 1990; Heath *et al*., 2011; Wood & Young, 2011, 2012; Heath *et al*., 2013) low Dissolved Reactive Phosphorus <0.01 mg/L and elevated Dissolved Inorganic Nitrogen >0.2 mg/L (Wood *et al*., 2014). Statistical models that include such a wide range of variables, and with poorly differentiated threshold values, are difficult to use for identifying causative links and thus for desiging management interventions. Understanding of the factors deterining river periphyton blooms are lagging behind their planktonic counterparts, where more mechanistic modelling is made possible by the more homogenous planktonic growth environment and a greater understanding of underlying relationshiops between growth, loss and environment.

Observations of the development of *Phormidium* blooms suggested that these mats have subtly different dynamics to other periphyton groups. Specifically, blooms appear to develop by the expansion of patches rather by colonisation and growth forming a new patch. If this is the case, the balance between factors promoting patch growth and patch attrition, as well as the residual number, size and distribution of patches after disturbance, will affect the regrowth of *Phormidium* blooms. If these processes can be modelled for any given river, and driving environmental variable identified, an understanding of patch dynamics of *Phormidium* mats has implications for improved prediction of bloom formation. Furthermore, the more we can understand the processes driving growth and loss, the better we can target management for minimising bloom formation.

To date the linkage between patch expansion and overall bloom dynamics has not been evaluated rigorously, and we designed an experiment to; (a) develop methods to explore patch dynamics, and (b) investigate whether this provides insights into overall bloom dynamics. The specific objectives of the experiment were:

- To determine the dynamics of patches of *Phormidium* at sites in four Canterbury rivers (outlined in the main body of this report) by repeatedly photographing specific rocks.

- To compare the expansion and contraction of patches with the overall cover dynamics recorded at the four study sites.
- To compare patch expansion rates between rivers to determine which environmental variables were related to growth rate.

In addition, the possibility of using aerial observations to track reach-scale patch dynamics was investigated using an Unmanned Aerial Vehicle (UAV).

Methods

Experiments were undertaken at sites described McAllister (2015) in the Opihi, Ashley, Tengawai and Selwyn rivers. Nine medium sized cobbles were selected and marked by placing a fluorescently-painted stone nearby. The position of each cobble was recorded using a Garmin hand-held GPS device to facilitate relocation. Each rock was photographed at weekly intervals from 4 to 23 December 2014, using a digital camera mounted in a bathyscope. A scale object was included in every image. Water velocity was measured using a propeller-type meter immediately above each cobble and at 0.6 x channel depth. Water depth was also recorded. Overall *Phormidium* coverage data from the main body of this report, collected on the same field trips, was used to provide broader context.

After uploading to a computer, images were analysed using Image J (http://rsb.info.nih.gov/ij/) software. In each case, the scale was set using the scale object, then the perimeter of the study patch was isolated, and the area subtended therein determined.

To determine if measurement of patch dynamics at larger scales is feasible, the University of Canterbury fixed-wing unmanned aerial vehicle (UAV) was flown at the Opihi River site on two occasions (2 and 16 March 2015), a fortnight apart (Fig. 1). The UAV can be both manually or autonomously along a set GPS route. It required propulsion via a slingshot for take-off as well as a safe and flat runway for landing. The aerial survey covered up to 2 km of river, including the regular monitoring site, with constraints imposed only by the need to maintain visual contact with the UAV at all times. The payload consisted of a high definition camera, and images (taken every two seconds) were rectified and combined to deliver a strip mosaic of the river bed. To date, resources have not been available to attempt any automated analysis of the imagery.

Figure 1. The fixed-wing UAV at the Opihi River shown with the catapault, which launches it.

Results

Summary of reach-scale cover dynamics at each site

Of the four rivers included in this patch dynamics experiment, the percentage cover showed an overall increasing tendency in the Opihi, while at the Ashley cover decreased after the first week but increased again in week 4 (Fig. 2). At the Selwyn and Tengawai no clear increasing or decreasing tendency was evident (Fig. 2). In each case the spread of cover at each site was wide, with the 25 percentile value being zero in many cases.

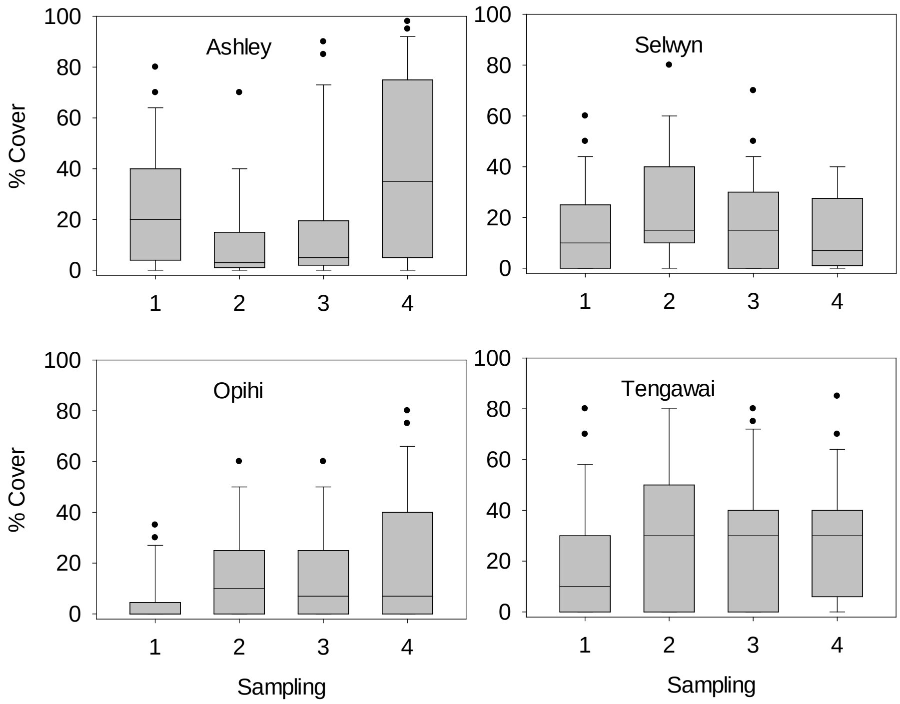

Figure 2. The overall cover of *Phormidium* in each of the four rivers, based on five quadrats on five transects (N=25). Central bars indicate the median, wide bar the 25 and 75 percentiles and the whiskers 90 percentiles. Outliers are marked as dots.

Individual Patch Dynamics

Overall cover dynamics is the effect of the net change in patch size and patch number. Our study of nine patches at each site showed a variety of responses, from steady growth to partial or complete ablation. The probability of a patch remaining in place after four weeks varied from river to river, from a maximum of 100% in the Opihi, to 0% in the Ashley. By fitting an exponential decay curve to survival data in the form;

Decay coefficient = $\ln(N_1/N_2)/(T_2-T_1)$

where N_1 is the number of surviving patches at time T_1 etc,

we estimated the half-life of a patch from “infinite” in the Opihi, through 25-30 days in the Selwyn and Tengawai, to 4.4 days in the Ashley (Table 1). There was no simple increase in patch loss rate with either point or mid-stream velocity; the best correspondence was a tendency for patch loss rate to decrease with increasing water depth (Table 2).

Patches that remained on cobbles showed a range of tendencies. Often there was a steady growth in area, and an exponential growth rate (EGR) for each patch could be calculated using;

$$EGR = \ln(A_2/A_1)/(T_2-T_1)$$

where A_1 is patch area at time T_1 etc.

When EGR for patches which continued to increase in size for 3 or 4 weeks are considered, EGR varied from river to river, with remarkable consistency within any one river (Table 1). The two sites with the most surviving patches for estimation of accrual show exponential growth rates of 0.37±0.14 week^{-1} (Tengawai, N=5) and 0.77±0.13 week^{-1} (Opihi N=9). In these cases an exponential fit described the increase, with r^2 for the exponential curve fit always exceeding 0.96 (data not shown). Examination of images from these two rivers illustrate contrasting patterns of net accrual. In the Opihi, exponential accrual continued on all nine cobbles through the gradual expansion of patches; little detachment was detected except for one cobble on week 4 (Fig. 3). In the Tengawai, slow increase occurred on some cobbles, though this was frequently offset by abrupt ablation of all or part of the patch (Fig. 4). In the Selwyn, rapid growth, comparable to the Opihi occurred, but this was offset by ablation losses (Fig. 5). Of interest in Figure 4 (top line of photographs) is the rapid regrowth of a patch on the upper right side of the cobble, which in the first image clearly shows traces of residual *Phormidium* from where a patch had abraded prior to the start of the experiment. At least two growth modes are thus demonstrated, patch recovery and patch expansion.

Table 1. Summary attributes of patch dynamics in the four study rivers. Exponential growth rate was calculated whenever patch size had increased over a continuous three or four week period.

Attribute	Ashley	Selwyn	Tengawai	Opihi
Patches (N=9) that survived to 4 weeks	0	5	6	9
Patches (N=9) that survived, but decreased in size	0	3	2	0
Exponential patch loss rate (wk^{-1})	1.09	0.19	0.16	0
Patch half-life (days)	4.4	25	30	-
Exponential growth rate (wk^{-1})	0.30	0.67±0.07[a]	0.37±0.14	0.77±0.13
N for growth mean and sd estimate	1	2	5	9

a = mean and range

Differences in performance of patches are not readily reconciled with physical differences between rivers (Table 2). In all cases, cobbles of similar size were selected, removing this as an explanatory variable, and while the poorest patch survival coincided with the shallowest water and slowest flow rates, and the higher survival and growth with deeper, faster flowing rivers, there are currently insufficient data to test this relationship. Existing water quality data suggest that of the Opihi (fast growth) and Tengawai (slow growth). The former tends to have higher median nitrate concentrations and lower phosphate (ECan periphyton model data), though again a comprehensive understanding will require a broader spread of patch expansion data.

Table 2. Summary environmental attributes of patch dynamic cobbles in the four study rivers. Bed velocity was measured immediately above the study cobble. Values are mean ± standard deviation of nine cobbles.

Attribute	Ashley	Selwyn	Tengawai	Opihi
Depth (cm)	29±13	35±9	33±10	50±22
Bed velocity (m s^{-1})	0.09±0.03	0.20±0.12	0.32±0.12	0.29±0.12
Velocity at 0.6 x depth(m s^{-1})	0.20±0.16	0.33±0.14	0.55±0.22	0.56±0.15

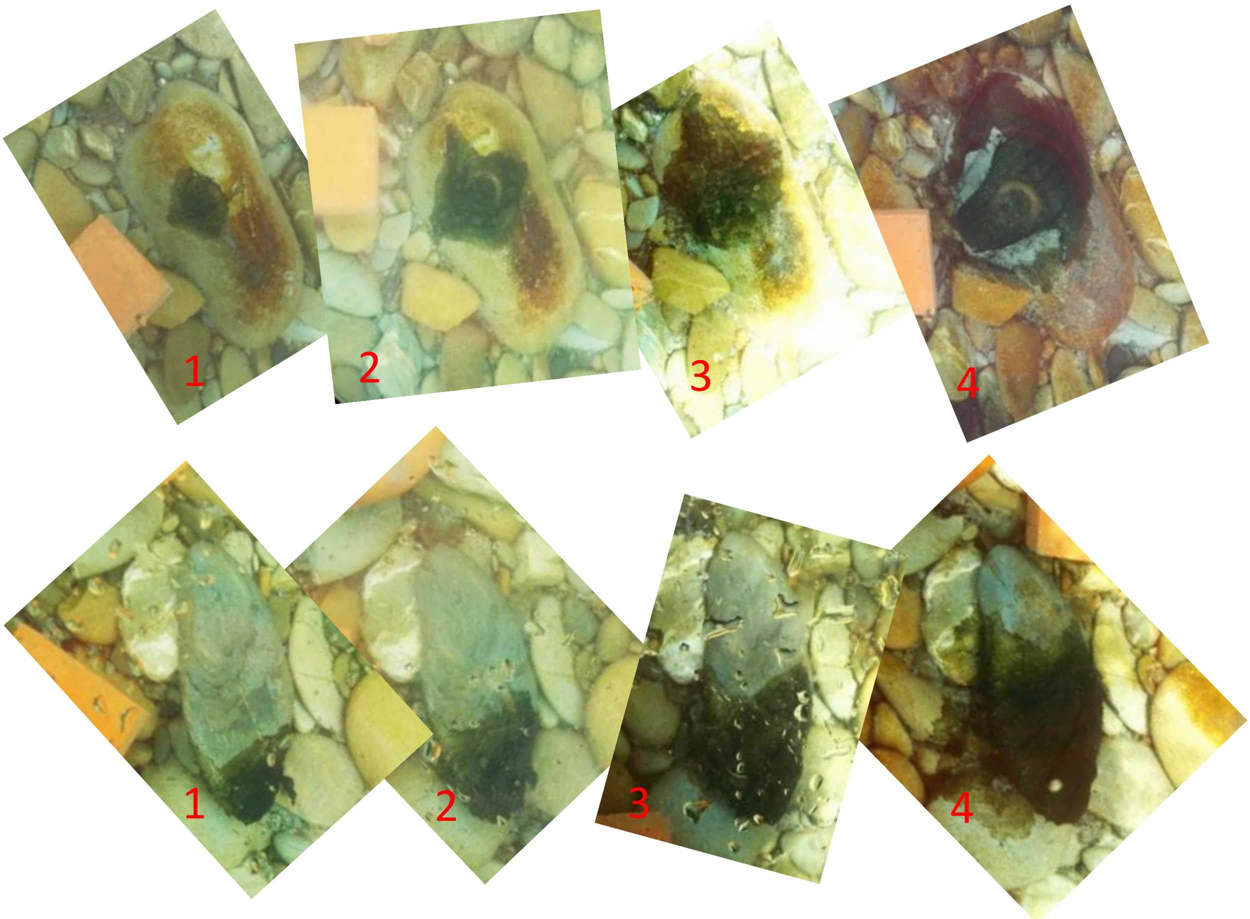

Figure 3. Images of two cobbles at four, weekly intervals (left to right) in the Opihi River. In each case the area covered by *Phormidium* is expanding steadily. Images are scaled similarly. Exponential growth models were fitted to these, and other similar data, and are summarised in Table 1.

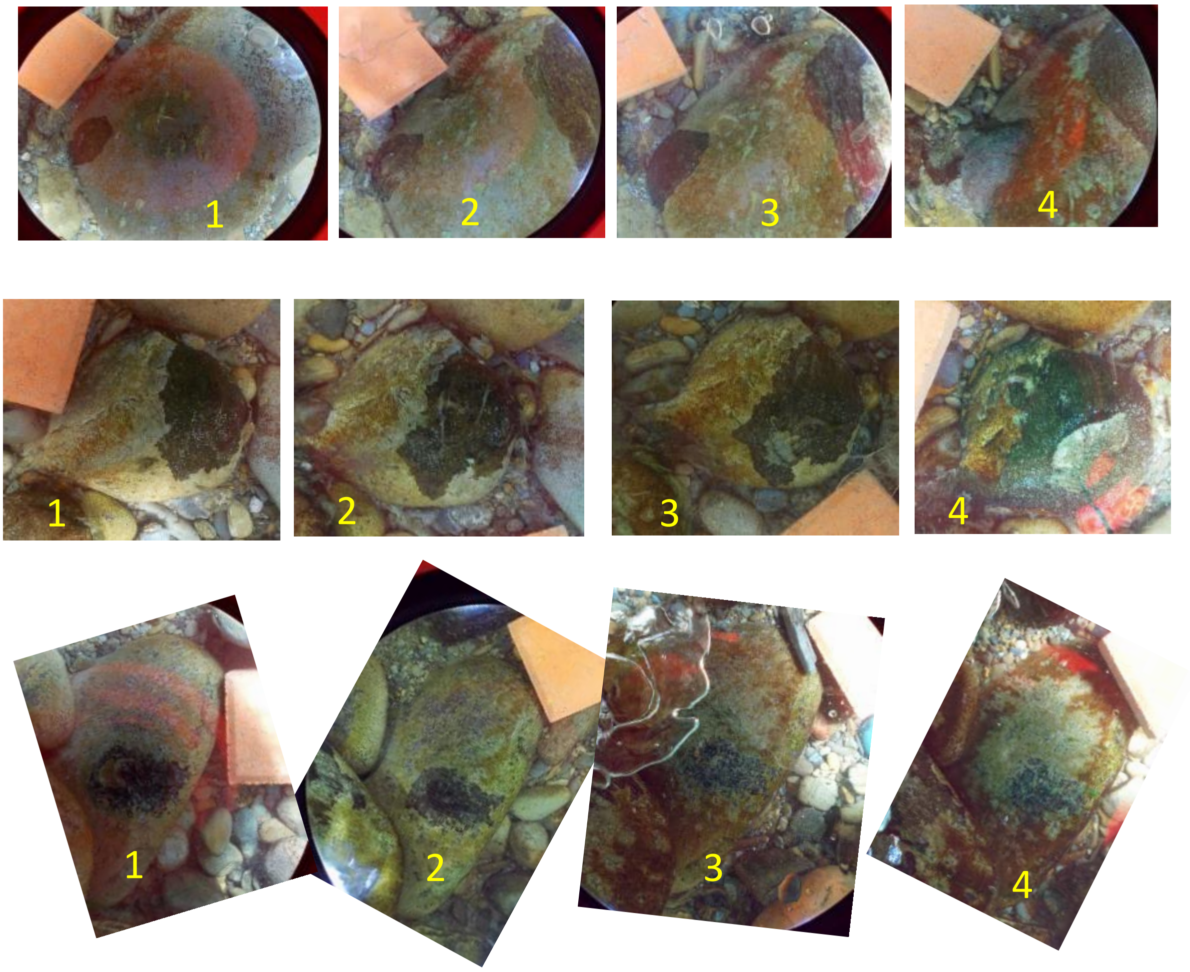

Figure 4. Images of three cobbles at four, weekly intervals (left to right) in the Tengawai River. Images are scaled similarly.

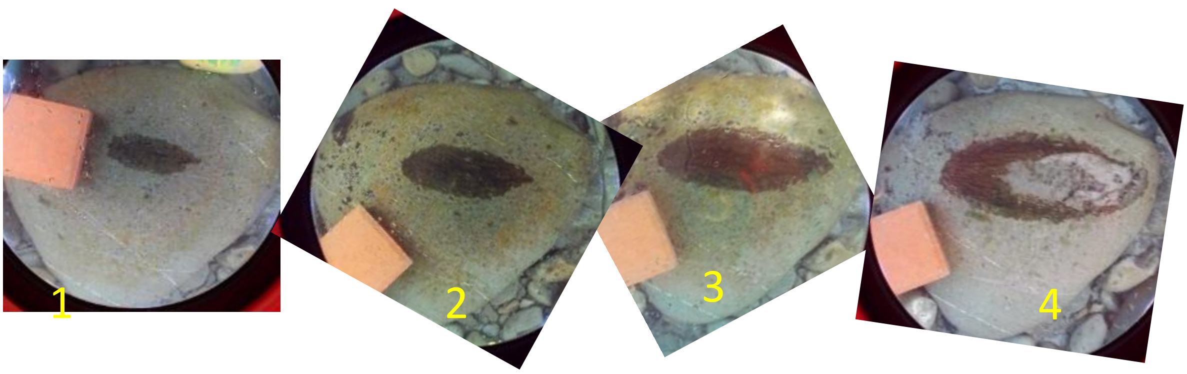

Figure 5. Images of a cobble at four, weekly intervals (left to right) in the Selwyn River. Images are scaled similarly.

When comparing the performance of individual patches with the whole-of-reach cover estimates (Fig. 2), the high early attrition and patch loss rate in the Ashley corresponds to a period of cover decline. Conversely the near-absence of ablation, and universal rapid growth, in the Opihi corresponds to steady accumulation of cover across the river and an increase in the number of quadrats with high percentage cover. The mixed performance in the other two rivers, with a combination of patch attrition, complete loss and net increase, is consistent with little change in overall cover on the reach scale over the study period.

Unmanned aerial vehicle imaging of river beds

The primary purpose of UAV monitoring of the Opihi site was to determine if this visualisation method could provide a cost-effective and accurate evaluation of *Phormidium* cover, and changes therein. This may enable insights into the progression of blooms and be an effective method of monitoring larger areas of rivers. Due to logistic constraints, we were only able to evaluate this one site, and on two occasions. The UAV dates are outside of the reporting period of this report, but *Phormidium* cover at the regular survey site (Fig. 6) was approaching an asymptotic high value of 80%, and flow was low and stable.

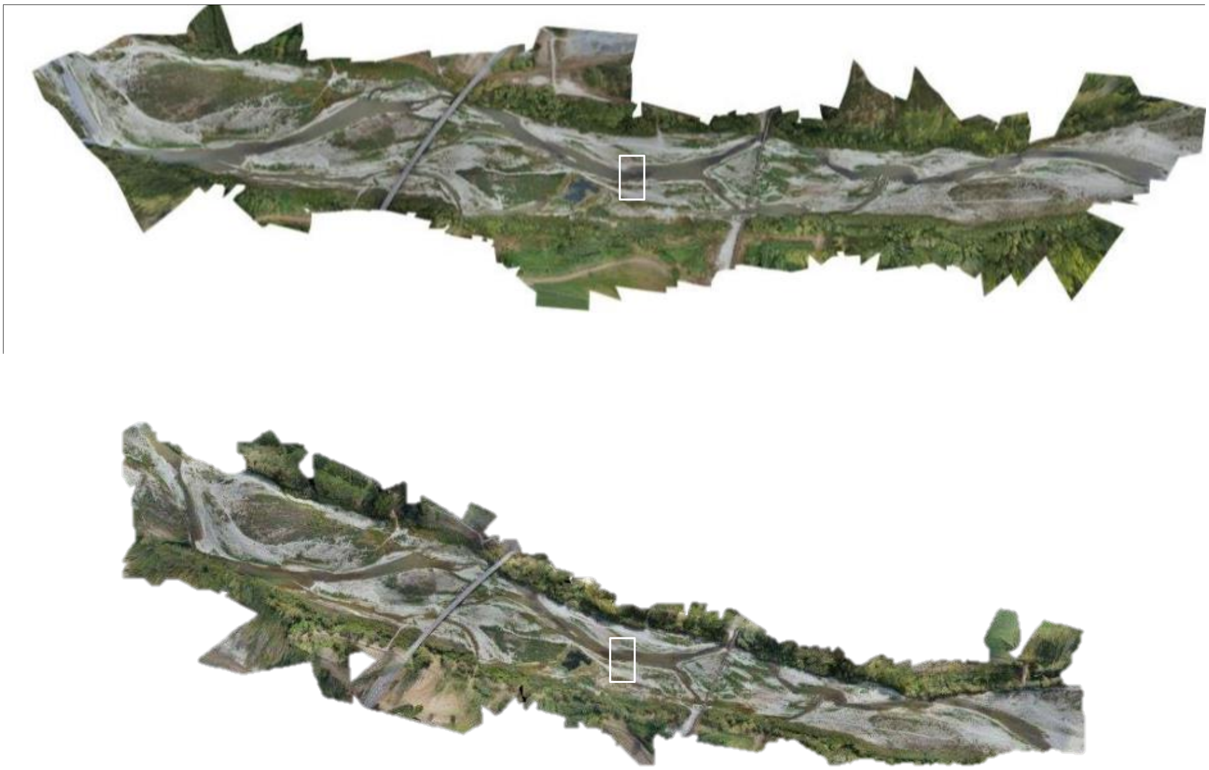

Figure 6. Aerial image mosaics of the Opihi River site on 2 March 2015 (top) and 16 March 2015 (below). The white box indicates the position of the regular sampling site. The resolution of these images has been reduced. High resolution images can be provided on request (up to 450 Mb).

UAV images were clear and of sufficient resolution to identify changes in the area covered by *Phormidium.* The best images were obtained on the cloudier of the two days (the first set of images), when surface reflection was least. The images clearly show the spatial variability of *Phormidium* in the Opihi River. *Phormidium* is largely confined to fast, turbulent reaches (riffles), while in the runs cover is low. Riffles occur at intervals down the section of river displayed, and there is some variability between the apparent cover at each of these; exact choice of a site clearly determines the result of monitoring efforts.

By zooming in on the images it becomes evident that they are of sufficient resolution to show changes in the area and shape of areas of high *Phormidium* cover. In Figures 7 and 8, expansion of the area of high cover, both upstream and downstream, is evident. At this stage it is thought that careful calibration analysis of images would allow construction of maps of percentage cover in the river, though this has not yet been attempted. This would also determine whether the UAV imagery is able to reliably distinguish areas that exceed current monitoring thresholds i.e., 20 and 50% coverage.

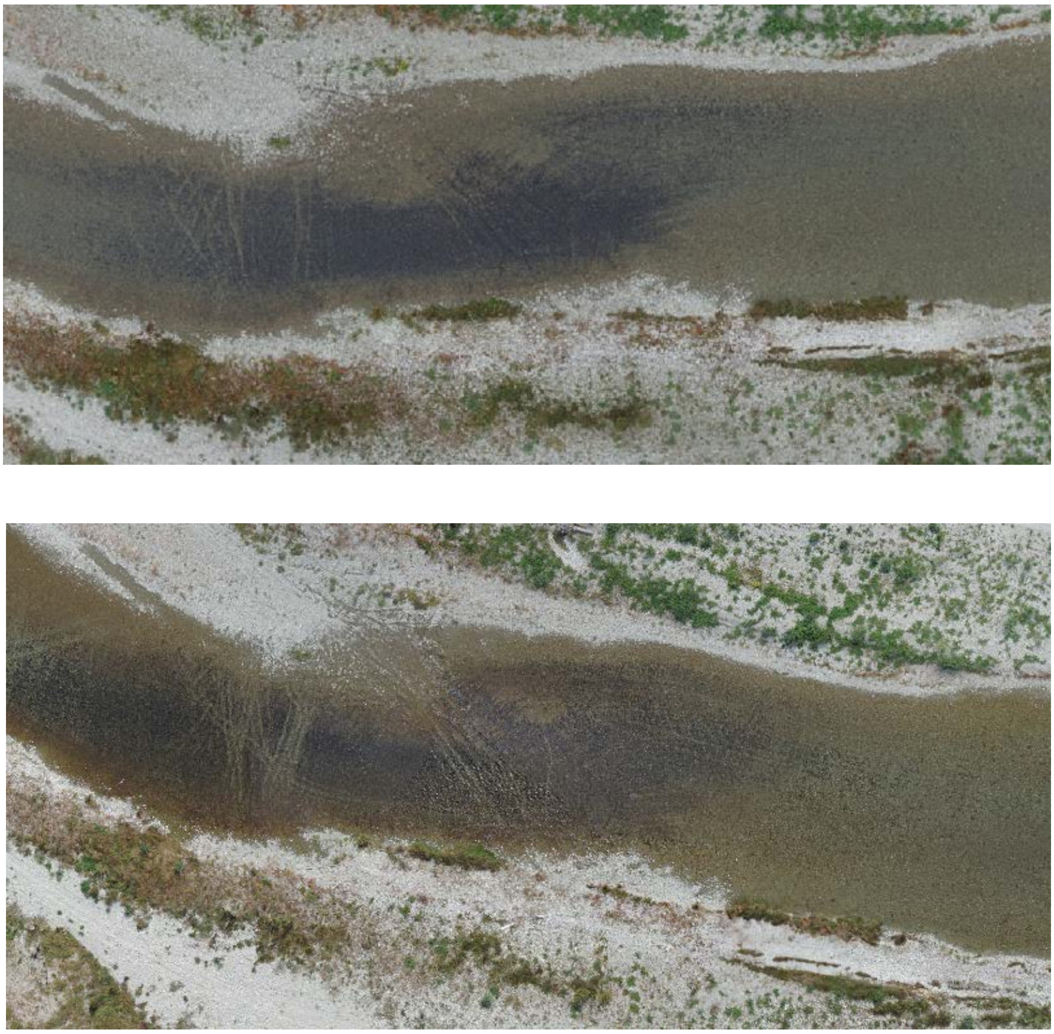

Figure 7. Imaging of the regular study riffle from the UAV (a zoom of Figure 6). The lower image was taken two weeks after the upper. The river is flowing left to right.

Figure 8. Imaging of a second riffle from the UAV (a zoom of Figure 6). The right hand image was taken two weeks after the upper. The river is flowing top left to bottom right.

Conclusions

Analysis of patch dynamics has provided new insights into how *Phormidium* blooms develop. Growth of patches is both by expansion from small footholds on stable substrata, and by regrowth from partially abraded patches. Patches readily expand across cobbles, and can move from one cobble to adjacent ones. The rate of expansion differs between rivers, which may provide insights in to why the intensity and regularity of *Phormidium* blooms varies within and among rivers. Further research is required to understand the relationships between patch dynamics and physiochemical variables. Over the study period, the river which developed the most expansive *Phormidium* bloom was the Opihi, and in this river patches expanded rapidly, and abraded very little. In other rivers blooms did not develop as extensively, and in these cases ablation rate was high and/or growth rate was slow. Net patch expansion or contraction is the driver of bloom development and growth, and understanding the controls on ablation and growth may help to develop better predictive models.

The preliminary trial of the UAV showed that this method allowed spatial variability of bloom development to be studied on a reach-scale. Limited application to Opihi River showed that blooms are initially confined to riffles and once formed, they increase in coverage over time by spreading from these areas. The use of UAVs could improve knowledge of reach-scale variability and bloom development, and have applied applications such as identifying areas of vulnerable to bloom formation. In concert with image analysis it has the potential to be used to rapidly assess bloom severity at a much larger scales than is currently possible using single site surveys.

Future work

Results to date allow a series of testable hypothesis that relate to the factors that determine the rate of patch expansion, the rate of ablation and probability and completeness of patch loss. These include:

- The rate of growth of *Phormidium* patches varies between rives and is determined by the water quality/chemistry.
- The rate of ablation of *Phormidium* colonies is determined not by water velocity, but by a combination of shear stress at the river bed and drag of colonies,
- Susceptibility to ablation is river-specific and relates to mat properties that affect drag, including incorporation of sediment.
- The probability of *Phormidium* patches to form a bloom and the rate at which this happens occurs depends on the availability of relict colonies for expansion to occur from.
- The probability and size of blooms is dependent on the relationship between susceptibility of the river bed to disturbance (substrate stability, depth, velocity), and prior disturbance regime (flood flows).

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