ULTRASONIC CONTROL OF ALGAE IN STORMWATER SYSTEMS

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ABSTRACT (200 WORDS MAXIMUM)

Large concentrations of algae pose immediate water quality issues. Water quality issues posed by the presence of large concentrations of algae include: decreased water clarity, increased suspended solids, reduced dissolved oxygen levels, altered pH levels and in some instances production of deadly toxins. Controlling algae in stormwater systems helps to prevent this degradation of water quality and reduces the rate of sediment build up while also providing aesthetic improvement.

Recently ultrasonic resonance has been successfully applied to control algae in many different applications including stormwater ponds. A specific "blend" of ultrasound frequencies and a relatively low amplitude, or output power (W/cm^3) is used to selectively target and destroy the cellular structure of different types of algae.

Benefits of the technology include low energy consumption and maintenance requirements. In addition, the device is very environmentally friendly with no adverse effects on humans, plants or animals with the exception of aquatic organisms that have hearing ranges within the frequencies used.

Previous research on both high and low power ultrasound to control algae are reviewed. A need for more peer reviewed research on the subject to be published is identified; specifically with respect to species tolerance levels and optimal frequencies.

KEYWORDS

Algae, Cyanobacteria, Resonance frequencies, Ultrasound, Cavitation

PRESENTER PROFILE

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1 INTRODUCTION

The occurrence of algae blooms is a direct result of high nutrient loading and eutrophic waters (Anderson et al., 2002; Hallegraeff, 1993; Lee et al., 2001). The severity and frequency of algae bloom occurrence has increased worldwide over the last thirty years (DeLorenzo & Fulton, 2009). This is most likely due to anthropogenic affects including high intensity farming, sub-standard waste water treatment systems, channelisation of natural waterways and the loss of riparian vegetation. Specifically, strong correlations have been demonstrated between total phosphors inputs and algae production in freshwaters; and between total nitrogen input and algae production in estuarine and marine waters (Anderson et al., 2002).

The term algae historically referred to mainly aquatic autotrophic organisms, which could be unicellular, colonial, filamentous or multi-cellular (seaweed). This definition included both the prokaryotic cyanobacteria and the rest of the eukaryotic organisms fitting the definition. More recently cyanobacteria have been removed from the term algae and are more commonly referred to as bacteria. Cyanobacteria do not have a nucleus and other organelles, but have protoplasts, containing mainly Chlorophyll *a* for photosynthesis. Thus, true algae are eukaryotes and have a nucleus enclosed within a membrane. Algae differ from plant because their tissues are not organised into complex structures and they lack true roots, stems and leaves. The term algae used throughout this paper will refer to both true algae and cyanobacteria, with the exception of macrophytic algae such as seaweed.

A certain amount of algae is a natural and important part of a healthy aquatic ecosystem and essential as part of the natural trophic structure. In fact, in natural concentrations algae can positively influence the water quality by consuming nutrients, producing oxygen and serving as a food source for fish and certain zooplankton such as *Daphnia spp.* however, when anthropogenic effects cause algae concentrations to increase rapidly to high levels an algae bloom occurs. Lewitus et al. (2003) described stormwater ponds as "incubators" for algal blooms. This is due to the fact that they often have stratified water columns, high concentrations of nutrients, and warm water temperatures.

These algae blooms upset the natural balance of the ecosystem within which they occur and cause a variety of negative impacts. Negative impacts of algae blooms include: aesthetic, taste and odour issues (Ahn et al., 2003; DeLorenzo & Fulton, 2009; Mahvi & Dehghani, 2005; Smith et al., 1999); potential health risks to humans, wildlife, stock and domestic animals, from species that are able to produce toxins (Ahn et al, 2003; Anderson et al., 2002; Dittmann & Wiegand, 2006; Landsberg, 2002; Mahvi & Dehghani, 2005); death of water plants due to a reduced penetration of light through the water column and competition for nutrients (Graneli & Turner, 2008); changes in water chemistry such as, turbidity, pH, suspended solids and oxygen levels (Mahvi & Dehghani, 2005; Smith et al., 1999; Zhang et al., 2006); jamming of filters, outlets and mechanical structures (Zhang et al., 2006). These issues require large amount of resources to manage and ultimately result in an economic drain on the community.

The removal of algae from water is difficult due to the often small size of algae and corresponding low gravitational pull (Zhang et al., 2006). The ideal solution is to control or limit the nutrient loading of waterways to a level where algae blooms will not occur – thus, "treating the problem and not the symptom". However, this is often difficult as many of the problem nutrient sources are non-point in origin (Lee et al., 2001). In addition, removing nutrients from an environment already containing an algae bloom may increase the risk of toxicity as some algae species transfer nitrogen from chlorophyll molecules to toxin molecules under nutrient stress (Graneli & Turner, 2008).

In addition to limiting nutrient inflow, historical methods for controlling algae blooms have included: the addition of chemicals or algaecides, usually copper sulphate based (Joyce et al., 2010; Ma et al., 2005; Mahvi & Dehghani, 2005; Zhang et al., 2006); diversion of high nutrient waters or flushing with clean water (Ahn et al., 2003; Mahvi & Dehghani, 2005); aeration and artificial mixing (Ahn et al., 2003; Joyce, Wu, & Mason, 2010; Lee et al., 2001) and more rudimentary methods such as the addition of straw bales (Joyce et al., 2010). With the exception of the use of straw bales most of these approaches are either costly, complex or add secondary pollutants into the environment (Lee et al., 2001) (Zhang et al., 2006).

The idea that ultrasound can be used to control algae has been around since the 1920's (Harvey & Loomis, 1929). Until very recently the use of ultrasound to control algae has focused on high power ultrasound causing cavitation (Joyce et al., 2010; Mahvi & Dehghani, 2005; Lee et al., 2001; Tang et al., 2004; Zhang et al., 2006). Cavitation is a phenomenon where high power ultrasound causes the formation of bubbles that implode upon themselves causing intense heat (4,500 – 7,500 Degrees Celsius) and pressure (approximately 10,000 Bar) (Askokkumar et al., 2007; Flint & Suslick, 1991; Mason et al., 2003; Suslick et al., 1986). This intense heat and pressure occurs on a nanosecond time scale and drives significant gas phase chemical reactions. This heat and pressure can destroy cells and has been known to damage red blood cells and plant filaments since the 1920's (Wood & Loomis, 1927). In addition, unstable cavitation produces highly reactive hydroxyl radicals that can interfere with organic material (Petrier et al., 1998). Dolphins can create cavitation bubbles when swimming at high speeds. It is the pain caused by cavitation which limits the speed at which they are capable of swimming, rather than physical ability (Brahic, 2010). The potential damage to non-target cells and organisms has been one of the reasons why power ultrasound causing cavitation is not an ideal solution for algae control in the natural environment. However, it may have a suitable use within water treatment facilities outside of the natural environment. In addition to the potential damage to non-target organisms there has been concern within the water treatment industry over the economic cost of implementing high power ultrasound for treatment of algae (Mason et al., 2003). Much of this concern is based on calculations involving the direct scale up of power consumption in small-scale laboratory experiments. Although it may be economically viable to use power ultrasound to treat algae in small tanks or flow through systems, its use within lakes or stormwater ponds is unlikely to be viable.

Much more recently a second type of ultrasonic control of algae has been utilised. Low power ultrasound does not control algae through the high pressures and temperatures associated with cavitation; but instead by utilising resonance frequencies and the sound pressure caused by a sound wave propagating through a water column. Resonance frequencies are those frequencies that match a systems natural frequency. When resonance frequencies are applied to a system, oscillations with large amplitudes can occur with only a limited input force. This phenomenon can be likened pushing a swing at the "right" time. There has been numerous trials with low power ultrasound to control algae in different situations with different levels of success, however, only a few of these have been published to date (Klemencic et al., 2010; Nakano et al., 2001; Srisuksomwong et al., 2011; Zimba & Grimm, 2008). Studies of high power ultrasound to control algae have shown that different species of algae have differing susceptibility and resistance to ultrasound (Klemencic et al., 2010). As different algae species and structures will have different resonance frequencies, it is likely that they also have varied tolerance to low power ultrasound.

For low power ultrasound to be an effective means of algae control the output frequency needs to be matched to the natural resonance frequency of a vital structure of the algae species being targeted, for example, the cell wall, or gas vacuole. In 1895 three German microbiologists (Ahlborn, Klebahn and Strodtmann) showed that by applying pressure to cyanobacteria their gas vesicles could be made to disappear and the algae sink (Walsby, 1972). This was confirmed by Walsby (1969) by applying an ultrasonic pulse below a cyanobacteria culture.

There are some clear advantages to using low power ultrasound to control algae. Firstly, it does not cause damage to plants or animals, as different types of interconnecting cells cannot be brought into resonance, and the power is not great enough to cause cavitation (Oyib, 2009a; Oyib, 2009b). Secondly, the power consumption allows for more economically viable use outside of laboratory experiments (Lee et al., 2001; Nakano et al., 2001). Lastly, there is an advantage over more traditional chemical methods in that there is no secondary pollution to the environment.

2 DISCUSSION

2.1 SUMMARY OF STUDIES CONTROLLING ALGAE WITH ULTRASOUND

The phenomenon of cavitation has been intensely studied and the process by which sound waves can cause bubbles within liquid to expand and collapse causing intense heat and pressure is well documented (Askokkumar et al., 2007; Flint & Suslick, 1991; Mason & Lorimer, 2002; Shad et al., 1999; Suslicketal., 1986). The power per volume threshold (W/cm^3) that is required to cause cavitation in liquids is not constant and changes in relation to different variables. These variables include dissolved oxygen, surface tension, temperature, total suspended solids (TSS), total dissolved solids (TDS) and frequency (Fowlkes & Crum, 1988; Mason & Lorimer, 2002; Naito et al., 1998; Shadet al., 1999)

Joyce et al. (2010) comments on the study by Hao et al. (2004) stating that the quotation of power is unusual in that it is exactly the same for each frequency and that this is very difficult to achieve in terms of power entering the system (W/cm^3). It is suspected that in this case (as with many others) the power rating stated is the input power rather than the output power. Not all ultrasonic devices convert input power to output power equally. The power loss strongly depends on the type of transducer used and the conversion method.

In reviewing studies concerning the control of algae with ultrasound it is apparent that many authors neglect to include all specifications of the study parameters. Often the volume of treatment is not stated or the power rating is not stated to be input or output power. In order to compare different studies a standardised measurement of output power per volume is required. Many studies have investigated the effectiveness of different frequencies and power to control algae; however, relatively few studies have investigated this in terms of output power per volume and assessed this against the cavitation threshold in the given situation.

Paper	**Species involved**	**Treatment Volume (cm3)**	**Power (W)**	**Frequency (Hz)**	**Power per Volume (W/cm3)**
Studies where cavitation is assumed					
(Zhang, Zhang, (Wang, & Liu, 2006)	*Microcystis aeruginosa*	1000	32-80	20-1320KHz	0.032-0.080
(Tang, et al., 2004)	*Microcystis aeruginosa* and *Synechococcus PCC 7942*			1.7MHz	0.6
(Lee et al., 2001)	*Microcystis aeruginosa* and *Microcystis viridis*	1100	120-1200 [(1)]	28-100kHz	0.11-1.1
(Joyce et al., 2010)	*Microcystis aeruginosa*	200		20-146 kHz	0.0015-0.17
(Mahvi & Dehghani, 2005)		400-1000	155W [(1)] 40W [(2)]	42kHz	0.04-0.1
(Mason et al., 2003)	*B. subtilis*	20,000	300 [(3)]	27kHz [(4)]	0.015
(Zhang et al.,2006)	*Microcystis aeruginosa*			25khz,	0.32
(Hao et al., 2004)	*Spirulina platensis* [(5)]	800	20-80	20kHz-1.7MHz	0.025-0.1

Paper	Species involved	Treatment Volume (cm3)	Power (W)	Frequency (Hz)	Power per Volume (W/cm3)
Studies where non-cavitation is assumed					
(Nakano et al., 2001)		$365*^{E9}$	10 units of 2x 100W	200khz	$0.55*^{E-8}$
(Klemencic et al., 2010)	50+ spp. [(6)]	$36*^{E6}$	12	20-200 kHz	$0.33*^{E-6}$
(Shimizu et al., 2003)		180,000			
Kotopoulis et al. (2009)	*Anabaena spaerica*			200 kHz-2.2 Mhz	[(8)]
Studies where output power could not be obtained					
(Ma, et al., 2005)	*Microcystis spp*		30-90	20kHz-1.7MHz	
(Ahn et al., 2003)	*Microcystis aeruginosa*		600	20 kHz	
(Srisuksomwong et al., 2011)	*Microcystis aeruginosa* [(7)]		3	29-1000 kHz	

Table 1: Summary of power and frequency (where specified) for studies demonstrating the successful use of ultrasound to control algae. Cells are left blank where parameters were not specified within the paper or the parameter could not be calculated from the information supplied. [(1)] Power was specifically specified as the input power; [(2)] Power was specifically specified as the output power; [(3)] A range of powers was used; however, the lower level of this range was not specified; [(4)] A range of frequencies was used; however, the upper level of this range was not specified; [(5)] Filamentous species; [(6)] This study was conducted in a natural environment with over 50 different species of algae identified; [(7)] *Microcystis aeruginosa* was the most dominant species (*M. aeruginosa* (80%), *Peridinium sp.* (9%), *Botryococcus braunii* (9%), *Pseudanabaena mucicola* (1%) and *Cylidrospermopsis raciborskii* (1%)); [(8)] Shown not to cause cavitation through Mechanical Index (MI) calculations.

2.2 HIGH POWER ULTRASOUND

High power ultrasound is unlikely to offer a viable solution for controlling algal blooms in stormwater systems due to the economic cost of operation and the potential to harm non-target organisms. However, as most of the studies to date investigating the effect of ultrasound on algae have focused on high power ultrasound and cavatational forces, a short discussion will be made here.

There is a wide range of power per volume values throughout the literature investigating ultrasonic control of algae. The sample of experiments shown in table 1 have power per volume ranges of 0.55^{*E-8} – 0.6 W/cm^3. Joyce et al. (2010) cited cavitation as a primary cause of algae control within the experiment (power per volume range of 0.0015–

0.17W/cm^3). It is therefore assumed that any study with a power per volume range greater than this is utilising cavitation as the main algae control mechanism. However, as mentioned above, the cavitation threshold within water is dependent on several variables which are not stated within many of these studies. Nakano et al. (2001) and Klemencic et al. (2010) used very low power per volumes values of 0.55^{*E-8} and 0.33^{*E-6} respectively. It is assumed that a value this low is incapable of causing cavitation within water.

Zhang et al. (2006) investigated how different frequencies and power of ultrasound affect the control of algae in an attempt to find the most efficient frequency and power. They looked at the time required to control 90% of the algae, however, they also looked at the concentration of microcystins released. The study found that higher power and frequencies equated to more efficient control of algae, however, higher powers increased the concentration of microcystins released, while frequency had no effect on microcystin release. They recommend that the power be not greater than 48W. In terms of meaningful power per volume this equates to 0.048 W/cm^3. Joyce et al. (2010) also investigated a range of frequencies and discovered a non-linear result in efficiency (defined as [% inactivation of the algae] / [ultrasonic intensity applied]) (580 > 864 > 1146 > 20kHz). Hao et al. (2004) obtained a similar non-linear result (200 kHz > 1.7MHz > 20 kHz) as did Srisuksomwong et al. (2011) (200 > 108 > 43 > 29kHz >1MHz).

Hao et al. (2004) also investigated the efficiency of different power ratings and reported on the reduction in biomass within a defined time period for different powers (40% at 40W, 42% for at 60W and 44% at 80W). It was concluded that the most efficient power in terms of electrical cost was that of 40W (at 20kHz). Again, it should be noted that this is most likely input power (Joyce et al., 2010). It is generally accepted that an increase in power is correlated to increases in control, however, depending on how the efficiency and effectiveness is defined lower powers may be optimal.

Tang et al. (2004) investigated the effect of ultrasound at a frequency of 1.7MHz on both an algae with the presence of a gas vacuole and one without. The study found that the ultrasound was significantly more effective at controlling the gas-vacuolate species over the species lacking a gas vacuole. This indicates that a frequency of 1.7MHz and a power per volume of 0.6W/cm^3 targets the gas vacuole and that the collapse of the gas vacuole is the primary method of control. Mahvi & Dehghani (2005) also showed that the collapse of gas vacuole was the main cause of control and suggested that control may not be as effective on species without gas vacuoles. Several studies into the control of algae using high power ultrasound suggest cavitation as a means of control (Ahn et al., 2003; Hao, et al., 2004; Joyce et al., 2010; Mahvi & Dehghani, 2005; Tang et al., 2004). The study by Hao et al. (2004) confirmed this to be the case under the conditions of their experiment through the use of light microscopy and interference microscopy.

The study by Francko et al. (1994) may offer a caution to the use of ultrasound to control algae. Under specific parameters Francko et al. (1994) found that ultrasound promoted higher growth rates in algae cultures when compared to cultures that were grown with reciprocal shaking. It was suggested that this may be cause by the ultrasound increasing the gas and nutrient exchange efficiency of the algae thus stimulating growth, without damaging cells or internal structures.

2.3 LOW POWER ULTRASOUND

Low power ultrasound offers more viable solution to controlling algae within stormwater systems. To date there have been few published peer reviewed journal articles concerning the application of this technology, however, there are products established within the market place that claim the successful use of low power (non-cavitational) ultrasound to control a wide range of algae species through the use of a specific "blend" of ultrasound frequencies. One of these providers is LG Sound, the producer of the LG Sonic device used by Klemencic et al. (2010). It is possible to locate a fair amount of anecdotal evidence and "in house" published material suggesting the success of these devices

The study conducted by Nakano et al. (2001) utilised low power ultrasound to control cyanobacteria within a lake situation, however, this was in conjunction with water jet circulation and existing flushing processes. The study found that the inclusion of water jet circulation and low power ultrasound significantly reduced the levels of chlorophyll-a, suspended solids and improved transparency (Graphical representation is included within the study, however, improvement values and statistical analysis is not).

Similarly, the study by Klemencic et al. (2010) did not exclusively utilise low power ultrasound to control algae. Instead they used low power ultrasound in conjunction with ultraviolet technology and fibre filters. Klemencic et al. (2010) showed that the combination of treatment caused significant sedimentation of planktonic algae and that the water in the treatment pond was clear with almost no algae present in the water column. In addition the mean Chlorophyll-a levels within the treatment pond was 97.5 mg/m^3, while the control pond had a mean Chlorophyll-a level of 988.5 mg/m^3; indicating significant control of algae. Klemencic et al. (2010) did find that some algae species were tolerant of the treatment (*Oedogonium spp., Mougeotia spp. and Spirogyra spp.*). Correspondingly, they also found that the algae species composition within the treatment pond differed to that of the control pond following treatment. Klemencic et al. (2010) suggested that issues could arise when algae is sedimented in shallow ponds where light can significantly penetrate and thus still be capable of photosynthesis. Therefore, it is recommended that ponds are deep enough to prevent light reaching algae that have dropped out of the water column. Lee et al. (2001) created conditions within the laboratory to replicate the benthic layer of different lake conditions and found that affected algae cells did not proliferate when placed in these conditions.

Klemencic et al. (2010), Zimba & Grimm (2008) and Shimizu et al. (2003) all used a commercially available ultrasonic algae control device (LG Sonic) within their investigations. Shimizu et al. (2003) achieved significant reductions in Chlorophyll-a (Graphical representation is included within the study, however, improvement values and statistical analysis is not) indicating effective control of the test species (*Microcystis ichthyoblabe*). The study also included very convincing before and after photographs, however, the results were not published in a peer reviewed journal and important frequency and power parameters were omitted from the report. Zimba & Grimm (2008) reported results of a 60% reduction in turbidity over three days and a 48% reduction in total algae biomass over a four week period using the same ultrasonic algae control device (LG Sonic).

2.4 ADVANTAGES OF ULTRASONIC CONTROL OF ALGAE WITHIN STORMWATER SYSTEMS

There are several advantages to using ultrasound to control algae within stormwater systems over more traditional methods. The use of ultrasound has an advantage over chemical control in that it does not introduce secondary pollutants into the environment. In addition to this low power ultrasound does not cause damage to non-target organisms, as cavitation from high power ultrasound would. Some studies have found low power to not adversely affect fish (Kemencic et al., 2010; Oyib, 2009a), while another aquaculture study found that catfish would not feed during continuous operation of low power ultrasound (Zimba & Grimm, 2008). Turning off the ultrasound signal during feeding resulted in the fish feeding and no further adverse effects. Some aquaculture trials have produced heavier fish yield when using low power ultrasound to control algae, it is suggested that this is a result of better immunity and health (Oyib, 2009b). It should be noted that the frequency ranges used by some of the commercially available low power ultrasound products are within the audible range of some aquatic organisms, notably dolphin species (Ketten, 2000). Therefore, caution should be taking if installing devices in locations that may interfere with communication between aquatic organisms.

The use of low power ultrasound also has the advantage that once installed there is very little input required for maintenance. It should also be noted that low power ultrasound products already in the market place claim to not be "sterilising" products, thus, a natural amount of algae is retained within the system, therefore not adversely affecting normal ecosystem function and trophic structure.

Controlling algae and preventing it from accumulating within a stormwater system will also help to reduce the rate of sediment build up, thus, extending the life of the system (providing concentrated algae is not flowing into the system). Reducing algae concentrations within the system will also reduce competition with plant growth, while also, providing aesthetic improvement.

3 CONCLUSIONS

A very large range of ultrasonic frequencies and powers have been shown to be effective at controlling algae. Due to the cavitational forces present, high power ultrasound is more effective at controlling algae than low power ultrasound. However, due to the economic cost and potential damage to non-target organisms when using high power ultrasound, low power ultrasound may be a more viable solution to control algae in stormwater systems. Benefits over more traditional algae control methods include reduced cost and maintenance while also not releasing secondary pollutants into the environment.

Ultrasonic control of algae appears to be most effective on cyanobacteria and gas-vacuolate species and less effective on benthic species depending on their morphological structure and on the frequencies and amplitude of ultrasound used. More research on the tolerance of different algae species to ultrasonic control is required. There is also a need for more studies investigating the most effective and efficient frequencies at low power for controlling different algae species.

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4 PEER REVIEW COMMENTS

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The first half of introduction is good, it introduces the issue well. However, the second part goes into too much details about the techniques that you are about to review in the main section (Discussion section), which result in too much repetition between these two sections. I suggest in introduction, you raise the issue, mention current control methods and mention briefly the potential of ultrasound techniques as a promising method for controlling algae bloom. Give the aims of this paper (review the studies on these techniques, compare the advantage and disadvantage of different ultrasound techniques and discuss the potential of using these methods in New Zealand).

To me the Discussion section is a bit fragmented and lack of a line of logic due to paragraphs talking about a single study with too much details. Instead of talking about each study in a paragraph, it is better to synthesise the information, give a clear summarise of each ultrasound technique (high power and then low power, move the details introducing these techniques from the Introduction to relevant sections in Discussion), it's advantages and disadvantages, then discuss their potential as a methods for future control of algae bloom (and that in NZ).

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The paper is great. It is well laid out, with appropriate levels of research and discussion as an introductory paper on ultrasonic control of algae. I am actually surprised at the lack of rigorous research in the area of low power ultrasound given the benefits I've seen based on "before and after" photos. I think the paper is very topical because it is a prompt for more research and plug for the use of the technology.

Last paragraph in the introduction you summarize some of the advantages of low power sonic treatment. I would add another point… in the case of cynobacteria I understand that low power vacual bursting sonic treatment causes cynobacteria to die without releasing its toxins which is significantly different than other forms of treatment for cynobacteria where the treatment actually stresses the bacteria and cause it to produce the toxins. If this is true it's a huge plus for this method of red tide treatment and worth commenting on. As a litigious American I would also think that municipalities would be very interested in cynobacterial treatments that don't force it to release toxins as part of the treatment. There are huge liability issues if someone has to get up on the stand and testify that they actively initiated a process that resulted in fish/coral/animal kill.

I wonder a bit if you've talked too much about the high power treatment. Giving a morconcise explanation of it and its disadvantages (broad kill, high power requirements, not scalable etc.) and then dismissing it might be better. Maybe not though as people need to understand the difference and the full story behind it. I also thought initially to suggest putting the table of studies in the appendix rather than in the body of the paper but I think its most useful reason for being where it is, is to show how few studies there are with accurately defined variables. It's a pointed statement that this area is ripe for quality research.

Questions raised-

After reading you paper and doing a bit of research I have a bunch of questions/concerns/thoughts as listed below... Most of these are probably outside the context of the paper you are trying to present but they are worth having a think through as they may come up as questions after your presentation-

Isn't some level of algae growth important for ponds (natural or treatment)? By ultrasonicly treating a pond are we killing off one or more links in the life/nutrient/feeding cycle of that ecosystem? In a pond that is actively treated do you see changes in the fish/larval/crustacean populations over time?

Is there any data on how much nutrient load is consumed by a healthy active amount of algae (ie… not a bloom)? Should we be adding bubblers and beneficial algae/bacteria to promote treatment and saving the sonic treatment for blooms? If we are going to actively manage a pond maybe we should manage it for maximum treatment rather than sterilization. How about a system that fires up temporarily based on turbidity to try and keep the algae from going to bloom state?

By "treating the symptom and not the disease" as you state at one point are we shooting ourselves in the foot in treatment ponds. In anything less than destructive algae blooms should we be adding bubblers and encouraging beneficial, balanced algae growth as a treatment system instead of killing off broad swaths of algae. Are we just stabilizing the water with all its bad nutrient loads and sending them downstream where we will still have the nutrient and eutrophic issues in a less controlled environment? I would rather have scary, green, smelly treatment ponds providing a level of nutrient removal in Puhoi rather than actively preserve all those bad nutrients until they are dumped into the Wenderholm estuary and the coastal waters. It strikes me that anything that actively stops treatment is the wrong approach.

Will killing off the algae susceptible to the sonic treatment create opportunities for non-susceptible algae/organisms/weeds to thrive/bloom? Are we upsetting some sort of competitive natural balance?

So you turn on the sonic device and the current algae dies and sinks to the bottom… does it get eaten an absorbed by bottom feeders or does it become an issue blanketing the bottom over time? Does new algae begin to form and get to a certain size before being affected by the sonic device, then die or does no new algae form for the period the sonic device is running?