Planktonic:

In-water Intervention and Prevention Strategy
Limited/Emerging Supporting Field Data

Benthic:

In-water Intervention and Prevention Strategy
Limited Supporting Field Data

Many species of cyanobacteria can regulate their buoyancy in the water column using internal structures known as gas vesicles (Reynolds and Walsby 1975, Walsby et al. 1997). Cyanobacteria cells with gas vesicles accumulate at the surface during the day to use available light for photosynthesis, shading out competing phytoplankton. Late in the day, accumulated sugars or carbohydrates from daytime photosynthesis overcome the buoyancy from the gas vesicles, and cells sink to cooler, nutrient-rich water. The ability to regulate their vertical position in the water column allows cyanobacteria cells with gas vesicles to continue growing and maintaining dominance over other phytoplankton. Not all cyanobacteria species produce gas vesicles, and even among similar species, differences in relative abundance and activity of gas vesicles are evident (Brookes, Ganf, and Oliver 2000).

Ultrasound radiation treatments reduce cyanobacterial growth by causing structural and functional cellular damage. Ultrasound radiation in water induces acoustic cavitation bubbles (Wu, Joyce, and Mason 2012) that collapse and cause localized high temperature and pressure conditions. The extreme conditions cause gas vesicles in cyanobacteria to collapse, resulting in loss of buoyancy and cell sedimentation (Park et al. 2017). The sedimentation of cyanobacteria cells thus causes a decline in cellular photosynthesis due to limited light access (Rajasekhar et al. 2012).

Ultrasound refers to a wide range of applications, so care must be taken to distinguish among technologies. Typically, ultrasonic generators produce a frequency (measured in megahertz, MHz), at a set power intensity (measured in watts per square centimeter), at a set duration (measured in time, typically minutes). High-power ultrasound is used to destroy bacteria and plankton in wastewater treatment (Wu and Mason 2017) and ship ballast (Holm et al. 2008). Ultrasonic technologies intended for cyanobacterial control use high-frequency sound waves to collapse gas vesicles (Rajasekhar et al. 2012).

The technology appears to have been used in the field first in the early 2000s (Lee, Nakano, and Matsumura 2002), and was more recently evaluated in reservoirs (Purcell, Parsons, and Jefferson 2013, Schneider, Weinrich, and Brezinski 2015). This exposure results in gas vesicle collapse but typically not complete lysis or degradation of the cell. Anecdotal cyanobacterial control was reported as some of the ultrasound operational parameters were not well optimized, and in some cases, ultrasound was combined with other control methods (Lee, Nakano, and Matsumura 2002, Purcell et al. 2013, Schneider, Weinrich, and Brezinski 2015). Frequencies between 1.7 MHz and 20 kHz are typically used in some modulation (Hao et al. 2004), with reported durations ranging from few-second pulses to pulses of several hours. Effective removal of most HCB species appears to occur within 10 minutes of exposure under laboratory conditions, though there are limited field data to support this observation (Park et al. 2017, Wu, Joyce, and Mason 2012).

Since ultrasound may also disrupt colonies and even break cell walls (Lürling and Tolman 2014), this technology can cause the release of intracellular cyanotoxins. Some laboratory testing shows destruction of the cyanotoxin microcystin (Liu et al. 2018, Song et al. 2005), probably by generation of free radicals (Joyce, Wu, and Mason 2010). However, the mechanisms responsible for these effects in laboratory settings may not apply directly to field application. Controlled laboratory conditions are rarely true to field conditions, where rainfall, water quality, water flow, turbulence, and water volume under sonic generators appear to play a vital factor in device performance (Park et al. 2017). Even under ideal conditions, energy transmission falls off quickly with increasing distance (Rajasekhar et al. 2012). Hence, the technique has a limited range.

Under field conditions, effectiveness depends on the generation of frequencies that match resonant frequencies of the gas vesicles (Rajasekhar et al. 2012). The few results are anecdotal with highly variable results. In a recent review, Lürling and Mucci (2020) concluded that low-frequency ultrasound should be avoided, as it is ineffective; high-frequency treatment is more effective, but it is costly due to energy demand, and its effective range is limited. Review of commercial claims on efficacy is difficult, as manufacturers consider technical specifications as proprietary information, making controlled, independent testing difficult. Studies that include technical details are rare and usually confined to laboratory conditions (Kong et al. 2019). Ultrasonic technologies are also not a short-term improvement technology, with many observed decreases or changes to ecological condition occurring over several weeks (Schneider, Weinrich, and Brezinski 2015, Villanueva et al. 2015). Off-target effects on other aquatic organisms, including zooplankton (Lürling and Tolman 2014), insects, and vertebrates such as fish, are possible, though documentation is limited.

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Water body types: Pond, lake/reservoir • Depth: Shallow to moderate • Surface area: Small • Any trophic state • Any mixing regime, though mixed systems could result in less contact time • Any water body use
NATURE OF HCB • Effective on gas-vesicle-containing cyanobacteria • Toxic or nontoxic HCBs • Other aquatic algae can be targeted • Intervention strategy
ADVANTAGES • Can move generators as needed and adjust frequency and length of exposure to target different species • Some devices are coupled with real-time sensors to measure the treatment effectiveness • Does not introduce ecologically relevant treatment residuals
LIMITATIONS • Highly variable results • Does not appear to remove cyanotoxins • May cause cell lysis, and increase extracellular cyanotoxin levels • Does not control nutrients • Benthic blooms may still occur • Expensive and proprietary constraints prevent inspection of conditions, frequencies, etc. • High-power treatments can affect other organisms • Limited by an effective treatment radius for impact

COST ANALYSIS

Financial costs depend on site-specific geographical and lake morphology factors and water conditions. For example, multiple generators may be required to effectively control a bloom in a large water body. The treatment range and limitation, as well as the service and maintenance of each generator, must be factored into the cost of deploying this technology. As this is a preventive technology that does not address nutrient input, a backup treatment option should be planned for blooms of cyanobacterial species that do not form gas vesicles or are otherwise outside the treatment range of the technology.

Relative cost per growing season: Ultrasound

ITEM	RELATIVE COST PER GROWING SEASON
Equipment	$$–$$$
O&M Costs	$$–$$$
OVERALL	**$$–$$$**

REGULATORY AND POLICY CONSIDERATIONS

Some generators can use solar panels for electricity, while others require shoreline tethering for power. Local permitting for installation and potential impacts to zooplankton and other aquatic life must be considered.

CASE STUDY EXAMPLES

Reservoir, New Jersey, U.S.: Schneider, Weinrich, and Brezinski (2015) deployed a system of ultrasonic buoys in a 200-acre reservoir that historically had blooms with taste and odor issues. The reservoir had previously used copper as its primary treatment.

Reservoir 1 is a 200-acre water body with a mean depth of 17 feet. It is fed by a small brook and adjacent reservoir (Reservoir 2).

Four ultrasonic buoys were deployed in May 2014 to reduce total algae abundance and concentrations of taste and odor compounds. While total numbers of algae cells appeared to decline, it should be noted that copper applications were used along with the buoys. Also, technical specifications of the ultrasonic buoys (frequency and intensity) were not reported.

General levels of cyanobacteria increased during the monitoring period; however, a bloom of *Aphanizomenon* occurred once water from Reservoir 2 was allowed to flow into Reservoir 1 (August 13, 2014). A reduction in the bloom was not noted until September 17, 2015, and may have been due to either the length of exposure or the change in the ultrasound frequency to target *Aphanizomenon* spp.

REFERENCES

Brookes, Justin D., George G. Ganf, and Roderick L. Oliver. 2000. "Heterogeneity of cyanobacterial gas-vesicle volume and metabolic activity." *Journal of Plankton Research* 22 (8):1579-1589. doi: https://doi.org/10.1093/plankt/22.8.1579.

Hao, Hongwei, Minsheng Wu, Yifang Chen, Jiaowen Tang, and Qingyu Wu. 2004. "Cavitation Mechanism in Cyanobacterial Growth Inhibition by Ultrasonic Irradiation." *Colloids and Surfaces B: Biointerfaces* 33:151-156. doi: https://doi.org/10.1016/j.colsurfb.2003.09.003.

Holm, E. R., D. M. Stamper, R. A. Brizzolara, L. Barnes, N. Deamer, and J. M. Burkholder. 2008. "Sonication of bacteria, phytoplankton and zooplankton: application to treatment of ballast water." *Maring Pollution Bulletin* 56 (6):1201-8. doi: https://doi.org/10.1016/j.marpolbul.2008.02.007.

Joyce, E. M., X. Wu, and T. J. Mason. 2010. "Effect of ultrasonic frequency and power on algae suspensions." *Journal of Environmental Science and Health, Part A, Toxic/Hazardous Substances and Environmental Engineering 45 (7):863-6*. doi: https://doi.org/10.1080/10934521003709065.

Kong, Y., Y. Peng, Z. Zhang, M. Zhang, Y. Zhou, and Z. Duan. 2019. "Removal of *Microcystis aeruginosa* by ultrasound: Inactivation mechanism and release of algal organic matter." *Ultrasonics Sonochemistry* 56:447-457. doi: https://doi.org/10.1016/j.ultsonch.2019.04.017.

Lee, T. J., K. Nakano, and M. Matsumura. 2002. "A novel strategy for cyanobacterial bloom control by ultrasonic irradiation." *Water Science and Technology* 46 (6-7):207-15.

Liu, Cheng, Zhen Cao, Siyuan He, Zhehao Sun, and Wei Chen. 2018. "The effects and mechanism of phycocyanin removal from water by high-frequency ultrasound treatment." *Ultrasonics Sonochemistry* 41:303-309. doi: https://doi.org/10.1016/j.ultsonch.2017.09.051.

Lürling, M., and Y. Tolman. 2014. "Beating the blues: is there any music in fighting cyanobacteria with ultrasound?" *Water Research* 66:361-373. doi: https://doi.org/10.1016/j.watres.2014.08.043.

Lürling, Miquel, and Maíra Mucci. 2020. "Mitigating eutrophication nuisance: in-lake measures are becoming inevitable in eutrophic waters in the Netherlands." *Hydrobiologia*. doi: https://doi.org/10.1007/s10750-020-04297-9.

Park, J., J. Church, Y. Son, K. T. Kim, and W. H. Lee. 2017. "Recent advances in ultrasonic treatment: Challenges and field applications for controlling harmful algal blooms (HABs)." *Ultrasonics Sonochemistry* 38:326-334. doi: https://doi.org/10.1016/j.ultsonch.2017.03.003.

Purcell, D., S.A. Parsons, B. Jefferson, S. Holden, A. Campbell, A. Wallen, M. Chipps, B. Holden, and A. Ellingham. 2013. "Algal bloom control using barley straw and ultrasound." *Water and Environmental Journal* 27:148-156. doi: https://doi.org/10.1111/j.1747-6593.2012.00338.x.

Purcell, Diane, Simon A. Parsons, and Bruce Jefferson. 2013. "The influence of ultrasound frequency and power, on the algal species *Microcystis aeruginosa, Aphanizomenon flos-aquae, Scenedesmus subspicatus* and *Melosira* sp." *Environmental Technology* 34 (17):2477-2490. doi: https://doi.org/10.1080/09593330.2013.773355.

Rajasekhar, Pradeep, Linhua Fan, Thang Nguyen, and Felicity Roddick. 2012. "A Review of the Use of Sonication to Control Cyanobacterial Blooms." *Water Research* 46:4319-29. doi: https://doi.org/10.1016/j.watres.2012.05.054.

Reynolds, C. S., and A. E. Walsby. 1975. "Water-Blooms." *Biological Reviews* 50 (4):437-481. doi: https://doi.org/10.1111/j.1469-185X.1975.tb01060.x.

Schneider, Orren D., Lauren A. Weinrich, and Scott Brezinski. 2015. "Ultrasonic Treatment of Algae in a New Jersey Reservoir." *Journal of the American Water Works Association* 107 (10):E533-E542. doi:

https://doi.org/10.5942/jawwa.2015.107.0149.

Song, W., T. Teshiba, K. Rein, and K. E. O'Shea. 2005. "Ultrasonically induced degradation and detoxification of microcystin-LR (cyanobacterial toxin)." *Environmental Science and Technology* 39 (16):6300-5. doi: https://doi.org/10.1021/es048350z.

Villanueva, Maria V., Maria C. Luna, Maria I. Gil, and Ana Allende. 2015. "Ultrasound treatments improve the microbiological quality of water reservoirs used for the irrigation of fresh produce." *Food Research International* 75:140-147. doi: https://doi.org/10.1016/j.foodres.2015.05.040.

Walsby, Anthony E., Paul K. Hayes, Rolf Boje, and Lucas J. Stal. 1997. "The selective advantage of buoyancy provided by gas vesicles for planktonic cyanobacteria in the Baltic Sea." *New Phytologist* 136 (3):407-417. doi: https://doi.org/10.1046/j.1469-8137.1997.00754.x.

Wu, X., E. M. Joyce, and T. J. Mason. 2012. "Evaluation of the mechanisms of the effect of ultrasound on *Microcystis aeruginosa* at different ultrasonic frequencies." *Water Research* 46 (9):2851-8. doi: https://doi.org/10.1016/j.watres.2012.02.019.

Wu, Xiaoge, and Timothy Mason. 2017. "Evaluation of power ultrasonic effects on algae cells at a small pilot scale." *Water* 9:470. doi: https://doi.org/10.3390/w9070470.