Ultrasonic Algae Control

Basic Technology and Application

Presentation to Iowa Rural Water Association

by

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AlgaeControl.us

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Ultrasonic Algae Control: A Hope Fulfilled

"Finally, it is suggested that the information we have gathered on the stability of gas vesicles under various conditions might also be employed in their destruction. If gas vacuoles are so important to the success of planktonic blue-green algae which form water blooms, we might be able to control these nuisance organisms by collapsing their vacuoles. Pressures generated by explosions have been found effective in this respect and field trials are in progress; **but it is hoped that fundamental studies on these curious structures might lead to less catastrophic solutions**."

A. E. Walsby, Concluding remarks in his study "Structure and Function of Gas Vacuoles", 1972.

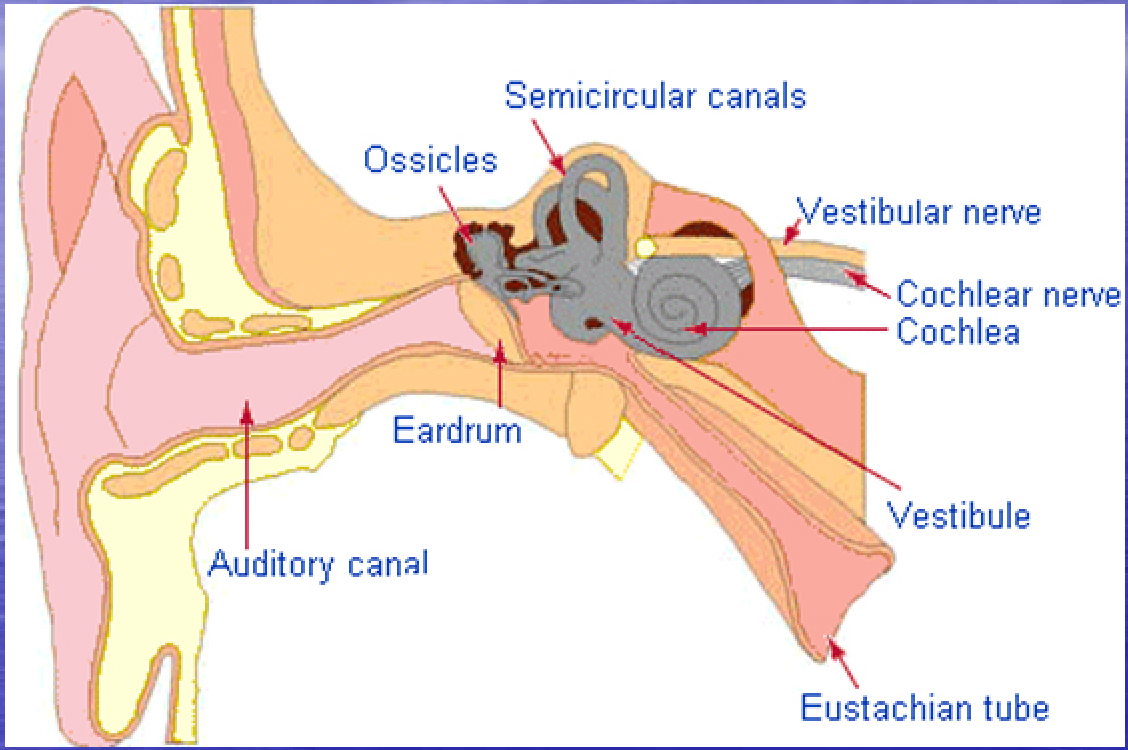
Understanding Ultrasound

"Ultra" basically denotes a sound that is beyond the frequency that can normally be heard in air by the human ear.

The human ear can hear sounds between 20 Hz and 20,500 Hz. The upper limit is set by the middle ear that acts as a high pass filter.

If the sound emitter vibrates the skull without passing through the middle ear, the cochlear nerve will allow you to hear up to 200,000 Hz, an effect discovered by divers who were able to hear sonar pings at about 50,000 Hz.

Understanding Ultrasound



The cochlear nerve will allow you to hear ultrasounds frequencies to 200,000 Hz if the sound vibrates your skull, skeletal structure, or blood stream.

Uses of Ultrasound

Medical:

- Lithotripsy of kidney stones
- HIFU: High Intensity Focused Ultrasound: non-invasive ablation surgery
- Fetal Imaging
- Dental hygiene

Industrial:

- Metal and weld integrity testing
- Catalytic reaction enhancement
- Sludge lysing and disintegration
- Level detection, flow meters

Other:

- Sonar and other echo-location
- Bacterial disinfection via cavitation
- Parts cleaning (jewelry, medical equipment)
- Algae control (last but not least!)

Ultrasound: Doing the Math

Sound travels at 4710 feet/sec or roughly 0.9 miles/sec in fresh water, over 4 times faster than in air.

Speed/frequency = wavelength

4710/28000 Hz= 0.168 feet or 2 inches

4710/56000 Hz= 0.084 feet or 1 inch

Ultrasound: Measuring Sound Intensity
Just What Is A Decibel?

The decibel scale:

The quietest sound the average person can hear has an intensity of about 1 pW (Picowatt) per square meter (1×10^{-12} W/m^2). This is defined as the reference intensity level which is equivalent to 0 decibels (0 dB) or I_0.

Intensity levels (IL) are measured in bels (B)

IL = $\log_{10}$ sound intensity / intensity at hearing threshold (1pW/m^2)

= $\log_{10} I / I_0$

1 decibel (dB) = 10 bels (B)

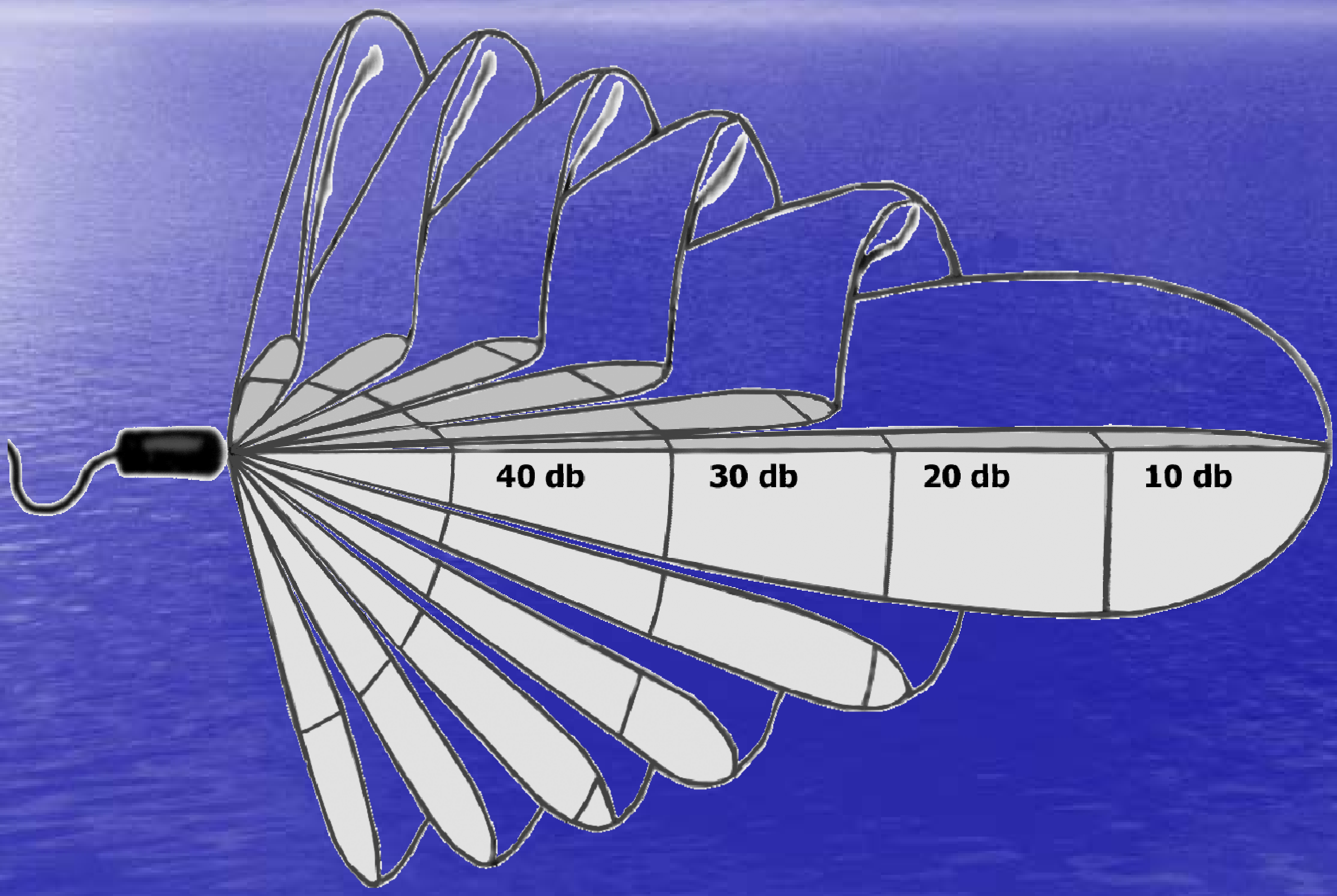
IL (dB) = $10 \log_{10} I / I_0$

Example:

A sound has intensity 1 W/m^2. What is the intensity level in dB?

IL (dB) = $10\log_{10}$ (1 W/m^2 / 10^{-12} W/m^2) = **120 dB**

Ultrasound: 3D Cutaway of Typical Transducer Output Pattern



Ultrasound: Impact of Intensity

- **Ultrasound can be produced with different intensities that have very different effects on biological cells.**
- Very high intensities cause a phenomena called cavitation.
- Cavitation has been described as “cold boiling” because countless micro bubbles form around the ultrasonic output device.
- These bubbles look similar to normal boiling except that the surrounding liquid temperature is not hot enough to sustain boiling.
- When these bubbles collapse, they create a shock wave due to their rapid collapse. At the collapse point, they have an estimated temperature of about 5000˚F!
- Biological cells subjected to cavitation can be lysed or broken into smaller fragments.

Ultrasound: Cavitation Effects

Cavitation definition:

formation of gas-filled cavities in liquids in motion when the pressure is reduced to a critical value. Low pressure regions are often created by rotating ship propellers. As the propellers rotate, bubbles form in the water. A loud acoustic sound is created when these bubbles collapse.

Ref: http://www.dosits.org/glossary/pop/cavitati.htm

Ultrasound: Cavitation Effects

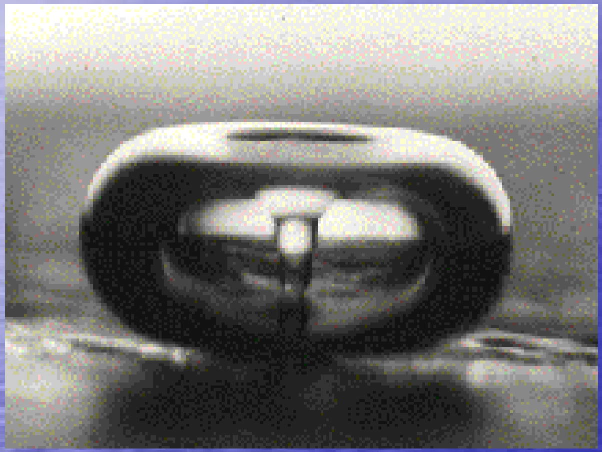


Image from University of Washington, Applied Physics Laboratory (Lawrence Crum, Ph.D.) bubble diameter approximately 1 mm.

A cavitation bubble exists only for a microsecond. The rapid expansion and shockwave resulting from it's collapse can cause devastating results on biological organisms and other materials.

Ultrasound: Cavitation In Nature

Click picture to hear sound.

<u>Snapping Shrimp:</u>

Even Mother Nature Uses Cavitation!

Snapping shrimp produce a loud crackling noise so intense that it disturbs underwater communication. It originates from the violent collapse of a large cavitation bubble generated under the tensile forces of a high-velocity water jet formed each time a shrimp's snapper claw snaps shut.

It's shock wave is used to stun or even kill prey animals. A sonoluminescence or light emission effect has been measured in the wake of this wave attesting to the extreme conditions in the hot bubble interior when it collapses.

Ref: http://stilton.tnw.utwente.nl/shrimp/shrimpoluminescence.htm

To Cavitate or Not to Cavitate?
That is the Question.

Will ultrasonic cavitation effects kill algae? **Absolutely.**

The knowledge that ultrasonic sound waves cause destruction of algae stems from work done over 80 years ago during the development of submarine sonar during WWI. The famous French scientist Paul Langevin (1872-1946) executed extensive studies and experiments in this field and was the first to achieve practical means to detect submarines under water by sound echo.

During these experiments some biological effects were also discovered, as micro-organisms like algae cells were hit by the ultrasonic waves and died. The powerful transducers used at the time created a cavitation effect that caused the algae to die.

To Cavitate or Not to Cavitate? That is the Question.

So do you have to produce ultrasonic cavitation to kill algae? **Absolutely not!**

The current ultrasonic algae control devices do not produce a cavitation effect. It was discovered that certain ultrasonic sound vibrations in water, produce critical resonance frequencies of algae gas vesicles, vacuoles and plasmalemma cell lining. Exposure to these sounds cause the cell membranes of these critical life functions to break or tear. Once torn, the life cycle of the algae cell is broken and it dies.

Effect of Resonance Frequency

<u>Is it live or is it Memorex?</u>

Many of us remember the audio tape commercial where a crystal wine glass was broken by Aretha Franklin with her voice and then with a recording of her voice.

<u>How does this work?</u>

A vibrating system resonates at its own natural frequency. That is, the amplitude of the steady-state response is greatest in proportion to the amount of driving force when the driving force matches the natural frequency of vibration.

To break a wineglass by singing, an opera singer must first tap the glass to find its natural frequency of vibration, and then sing the same note back.

The next slide shows a crystal glass resonating from rubbing the top with a wet finger.

Algae Biological Parts Make Them Susceptible To Breaking From Vibration At Their Critical Resonance Frequency

Gas Vacuole:

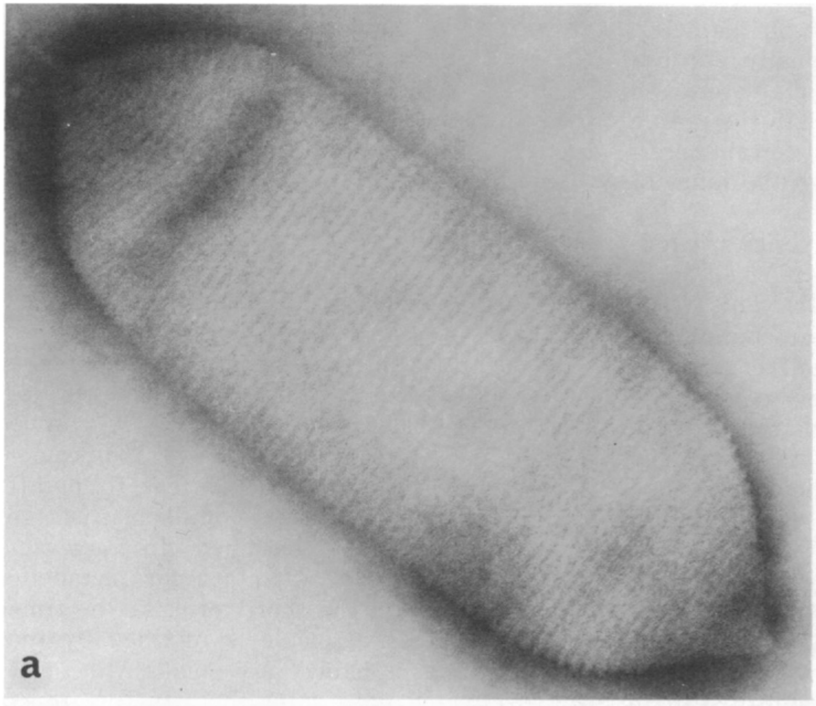
A prokaryotic cellular organelle consisting of cylindrical vesicles around 75 x 300nm, often in clusters. The wall of the gas vacuole, which is permeable to gases but not to water, is formed from a monolayer of a single protein of about 2 nm thickness. Gas vacuoles are found mainly in planktonic cyanobacteria and their primary function is to make the bacterium buoyant.

The proteins form aggregates of rigid hollow cylindrical structures with conical ends. When algae cells need to change their position in the water column, they will deflate the vesicles to regulate their depth in the water so they are at the proper light intensity.

http://www.biology-online.org/

Algae Biological Parts Make Them Susceptible To Critical Resonance Vibration

Gas Vacuole:

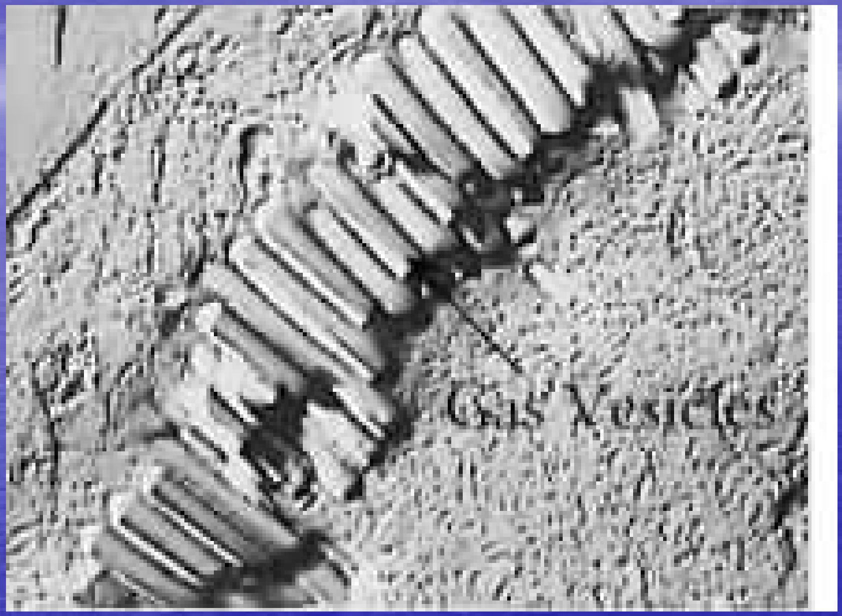


Intact gas vesicle of Anabaena flos-aquae negatively stained with phospho-tung-state showing corrugated profile of the ribbed structure x300000.

Ref. Fig. 12 Structure and function of gas vacuoles. A E Walsby, 1972.

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=378419

Algae Biological Parts Make Them Susceptible To Critical Resonance Vibration



Gas vesicles are the exception to the rule that all bacterial cells have one contiguous membrane. Gas vesicles are found in *Cyanobacteria*, which are photosynthetic and live in aquatic systems. In these lakes and oceans, the *blue-green algae* want to control their position in the water column to obtain the optimum amount of light and nutrients.

Ref: http://lecturer.ukdw.ac.id/dhira/BacterialStructure/Inclusions.html

Algae Gas Vesicle Rigidity Makes Them More Susceptible To Critical Resonance Vibration

Gas Vesicles

Gas vesicles are spindle or cylinder shaped structures consisting of a ribbed protein wall. The major structural protein is a hydrophobic protein that forms the 4 nm ribs of the gas vesicle wall.

Ref: http://biosun.bio.tu-darmstadt.de/pfeifer/research.html

Algae Gas Vesicle Rigidity Makes Them More Susceptible To Critical Resonance Vibration

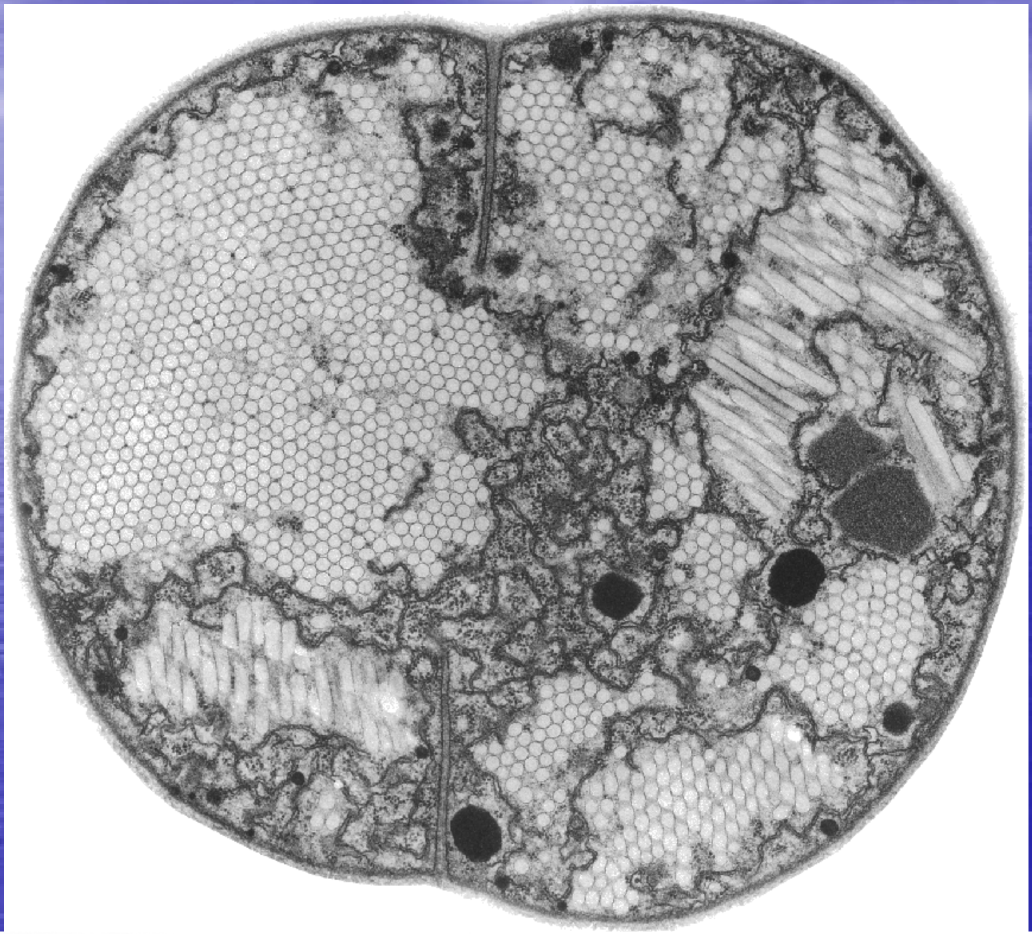


FIG. 1. Transverse section of a dividing cell of the cyanobacterium *Microcystis sp.* showing hexagonal stacking of the cylindrical gas vesicles. (Micrograph by H. S. Pankratz.) Magnification, x31,500.

Ref: "Gas Vesicles", Anthony E. Walsby, Microbiological Reviews, March, 1994

Other Targets of Ultrasound Resonance Vibration

Contractile vacuoles are osmoregulatory organelles which periodically expel fluid from cells in many freshwater algae.

When the function of these vacuoles are damaged by the ultrasound resonance frequency, over pressuring of the cells can result causing the outer algae sheathing or outer membrane to tear or rupture.

Alternately, the malfunction can cause the fluid flow to become static and proper cell function is disrupted. In this case, this can be a slow process that can take more than a week before the cell is completely dead.

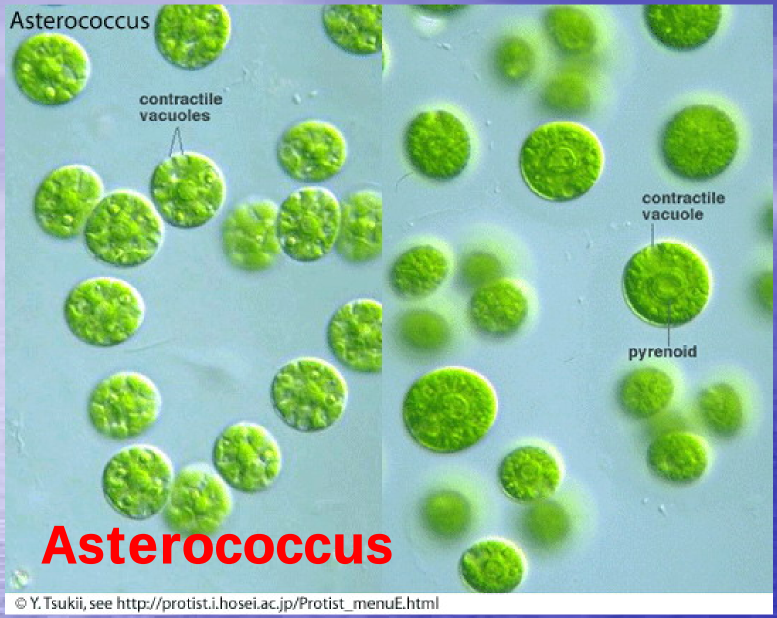
Targets of Ultrasound Resonance Vibration

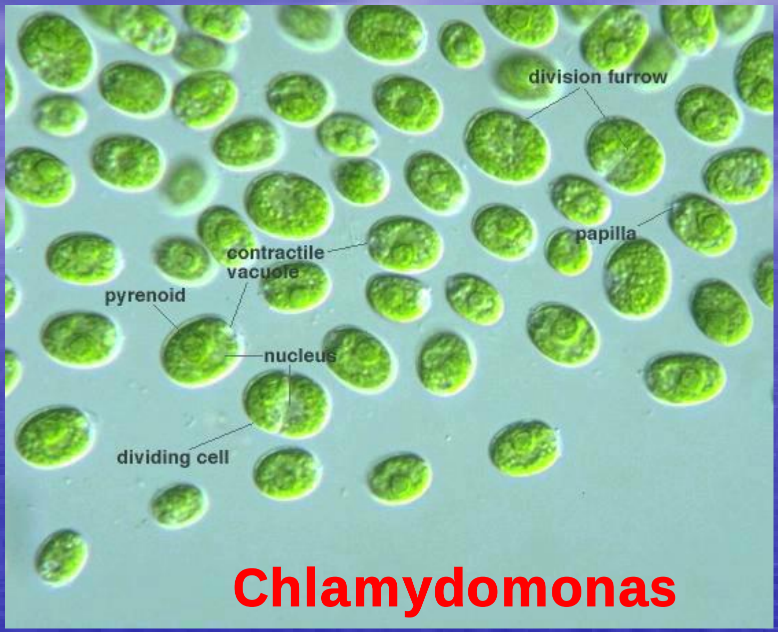
How this works:

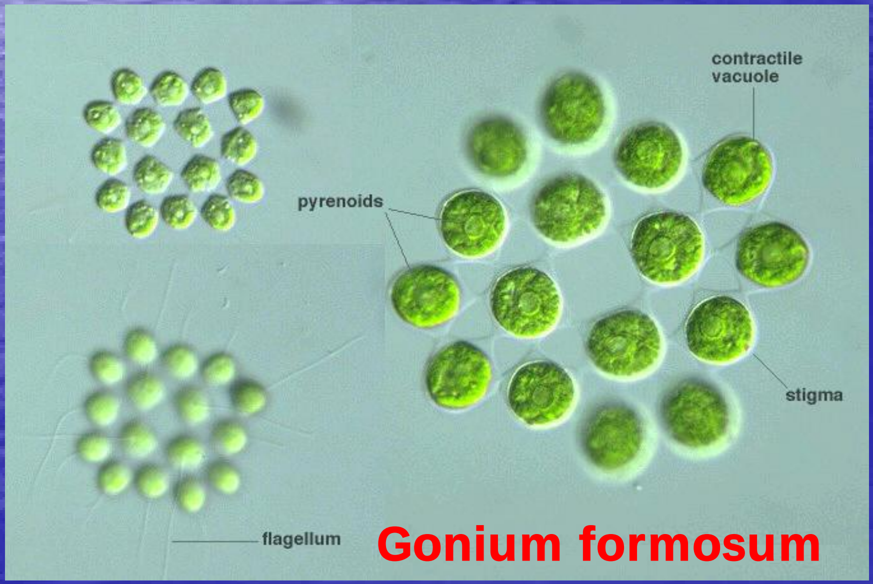
Vacuoles take up water through specialized membrane transporters called aquaporins. The hydrostatic pressure that develops within each cell, known as turgor pressure, is required for cell expansion and growth and is carefully regulated in plants, fungi, and many algae by controlling rates of water and ion movement through the tonoplast.

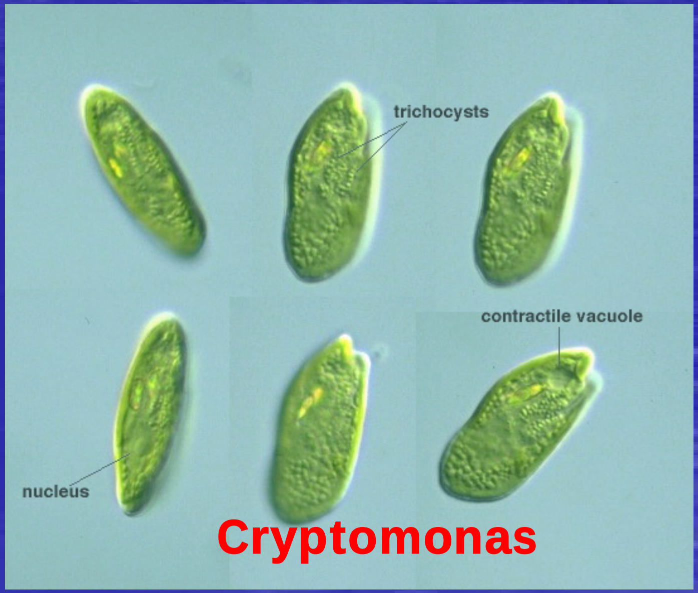
In fresh water algae and fungi lacking cell walls, contractile vacuoles fill with excess water from the cytosol and their contents are expelled from the cell through specialized pores. Disruption of this process by ultrasonic resonance vibrational damage to these specialized membranes results in loss of critical life functions.

Common Algae With Contractile Vacuoles









Comparison of Algae Destruction By Ultrasonic Resonance Frequency To Other Methods

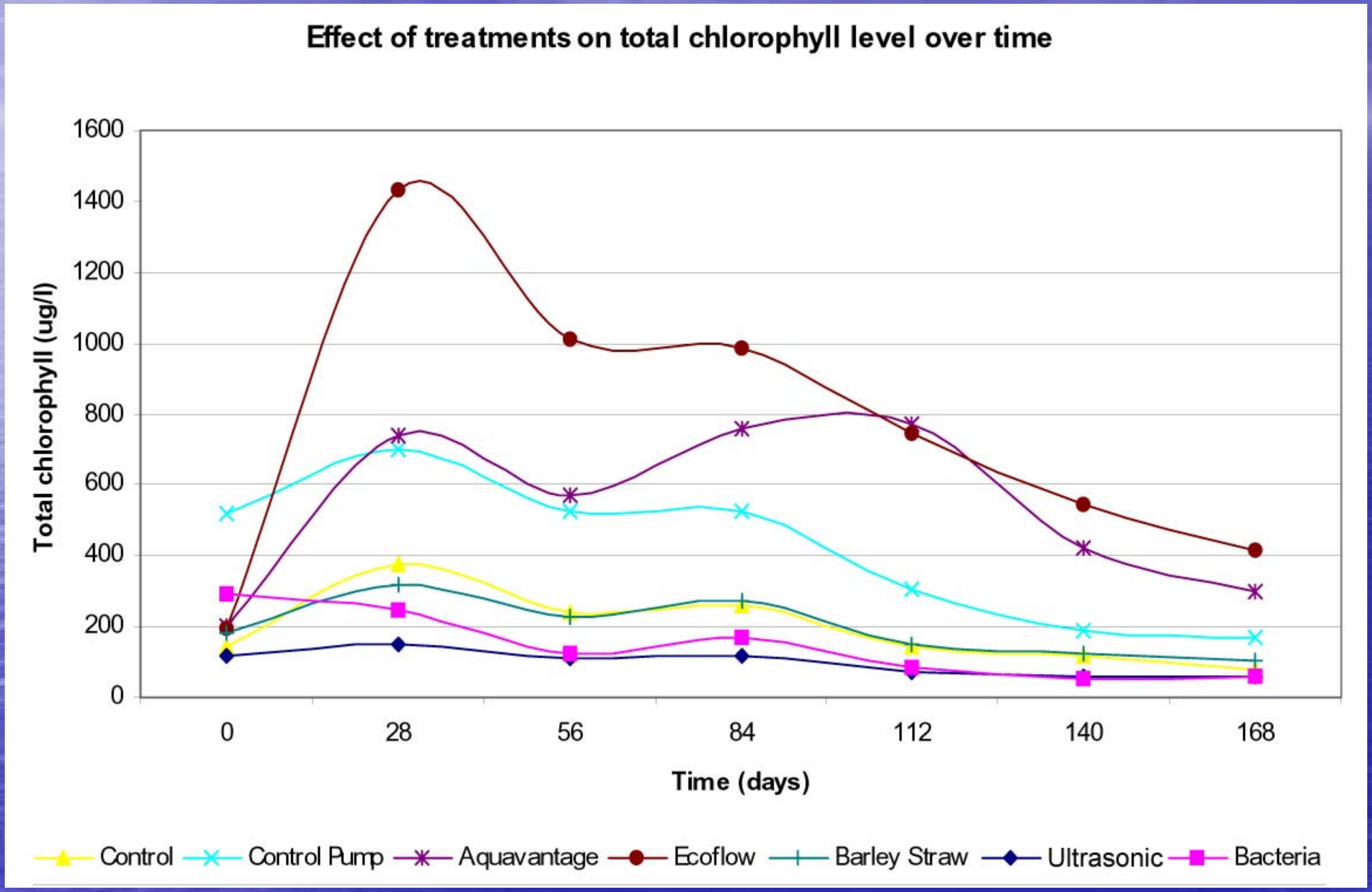


Figure 1. *Graph showing change in chlorophyll over time under different treatment conditions. Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.*

CAPM Study Conclusions About Algae Destruction By Ultrasonic Resonance Frequency

Given the success of the ultrasound treatment in the ponds, the CAPM were asked to investigate the mode of action of ultrasound on algae. The following light micrograph pictures of *Selenastrum* were taken form algal samples exposed to ultrasound for 8 weeks.

The pictures of *Spirogyra* were taken over a three week period form a tank experiment undertaken in controlled conditions in the glasshouse. The mode of action appears to be by disruption of the connections between the plasmalemma and the algal cell walls. This causes loss of membrane integrity, probable leakage of cytoplasm and a collapse of the cell into a dense brown mass. The cells remain buoyant for at least 4-5 weeks after exposure, although they are no longer viable.

Plasmalemma is the algae plasma membrane that isolates the inner algae cell from the environment.

Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

Effects Of Ultrasound On Algae
by Dr. Jonathan Newman

Centre for Aquatic Plant Management, UK

The picture on the left shows *Selenastrum capricornutum* with the cytoplasm bunched towards the centre of the cell. This is a result of separation of the plasmalemma from the cell wall, clear gaps can be seen where the dark stripes appear. The cytoplasm has split into three sections in this species, an indication of complex binding patterns between cell walls and plasmalemma in different species of algae.

Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

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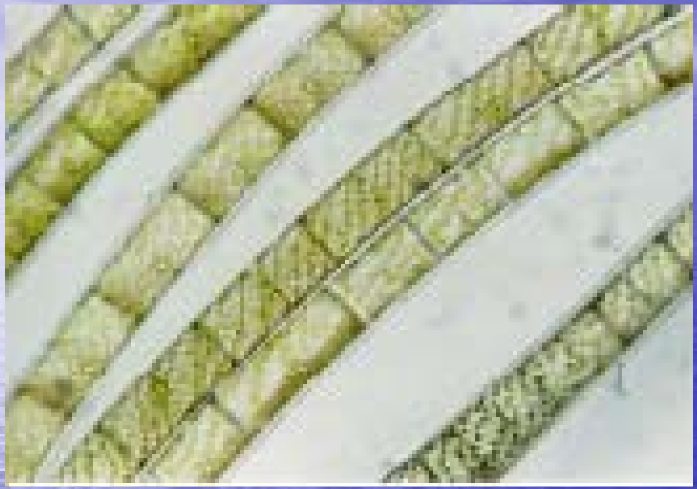
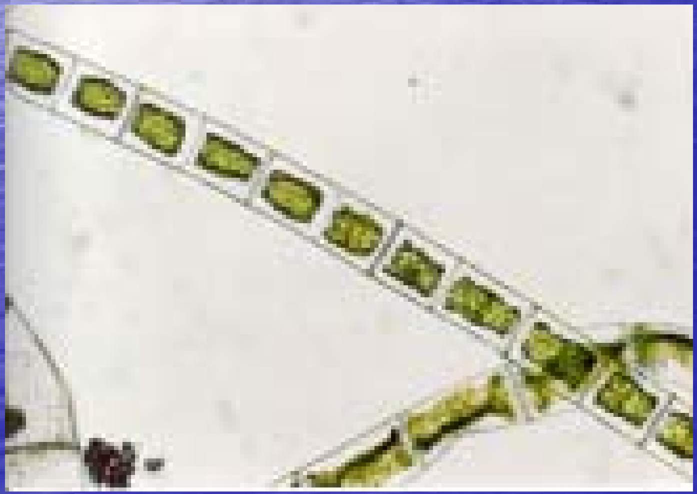


The picture on the left shows healthy *Spirogyra*, with cells full of cytoplasm, and the characteristic spiraling chloroplasts. The algae was sourced from a tank at the CAPM in Sonning and had been healthy for at least 5 years.



This picture was taken after only 7 days exposure to ultrasound. Already the plasmalemma is coming away form the cell wall, and the cells have shrunk. There is increased granulation of the cytoplasm, indicating loss of chloroplast structure, and loss of connectivity with other cells and the external environment.

Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

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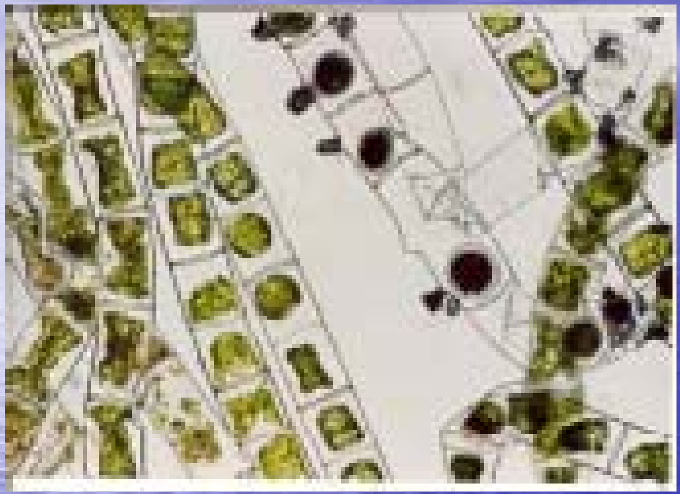
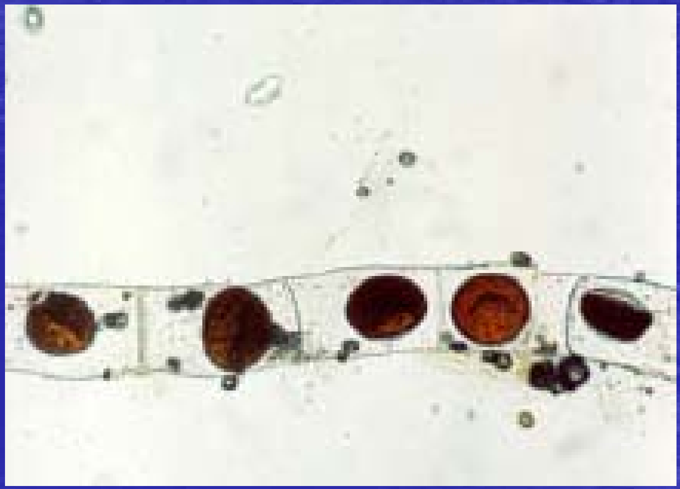


This picture was taken after 14 days exposure. The cells have continued to shrink, with some forming denser circular brown agglomerations in the centre of the cell. There is some evidence of cytoplasm leakage from the cells, indicating further damage to the cell walls.

The picture on the right was taken after 21 days, and shows complete breakdown of cell structure.



Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

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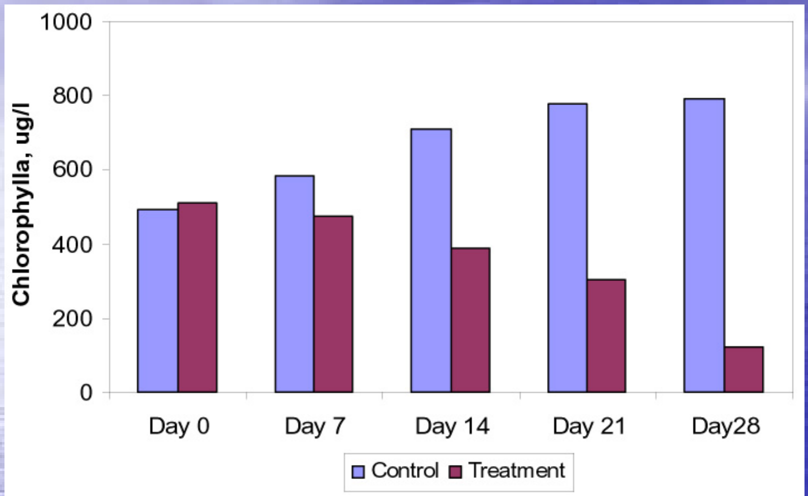
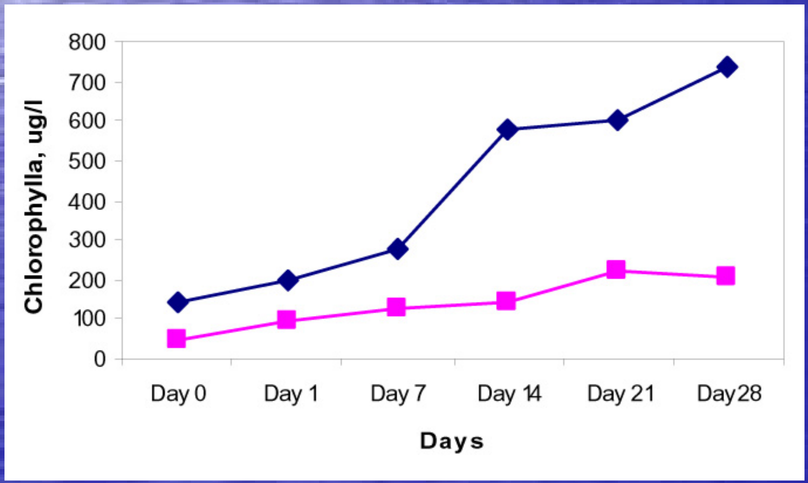


The damage to the cell structure is correlated with a decrease in the chlorophyll *a* concentration in the treated tanks. In contrast, in the control tank, chlorophyll *a* continues to increase. This can be seen clearly in the graph on the left.



In the 28 day regrowth experiment, the chlorophyll concentration continued to increase from Day 1. However, the increase in the ultrasonic treated *Spirogyra* was significantly less than in the control treatment. This indicates significant structural damage is associated with cell death in *Spirogyra*.

Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

Effects Of Ultrasound On Algae

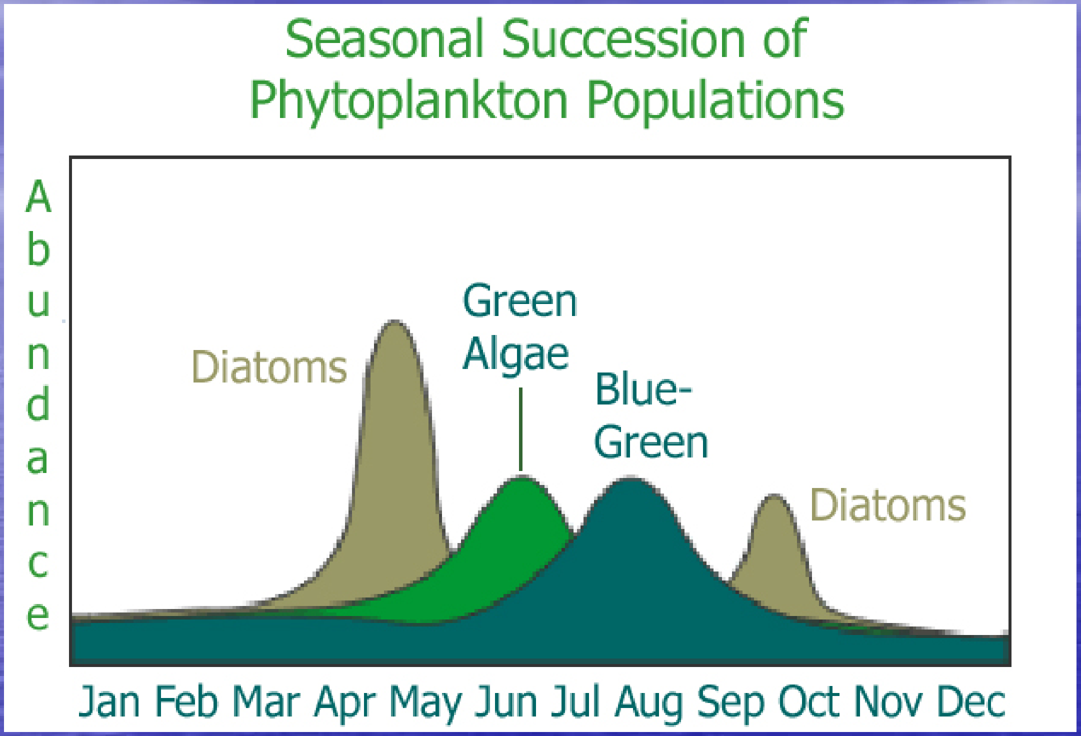
"In summary, exposure of *Spirogyra* and *Scenedesmus* to ultrasound waves causes irreversible structural damage to the cells, loss of chlorophyll and loss of viability. "

Ref. CAPM 2003 Annual Report, Dr. Jonathan Newman.

AlgaeControl.us reached similar conclusions based on ponds and waterways treated with ultrasonic technology.

Microscopic results recorded by AlgaeControl.us during ultrasonic treatment test work and performance reviews.

Seasonal Shift in Algal Population



http://www.waterontheweb.org

Current ultrasonic effective kill range:

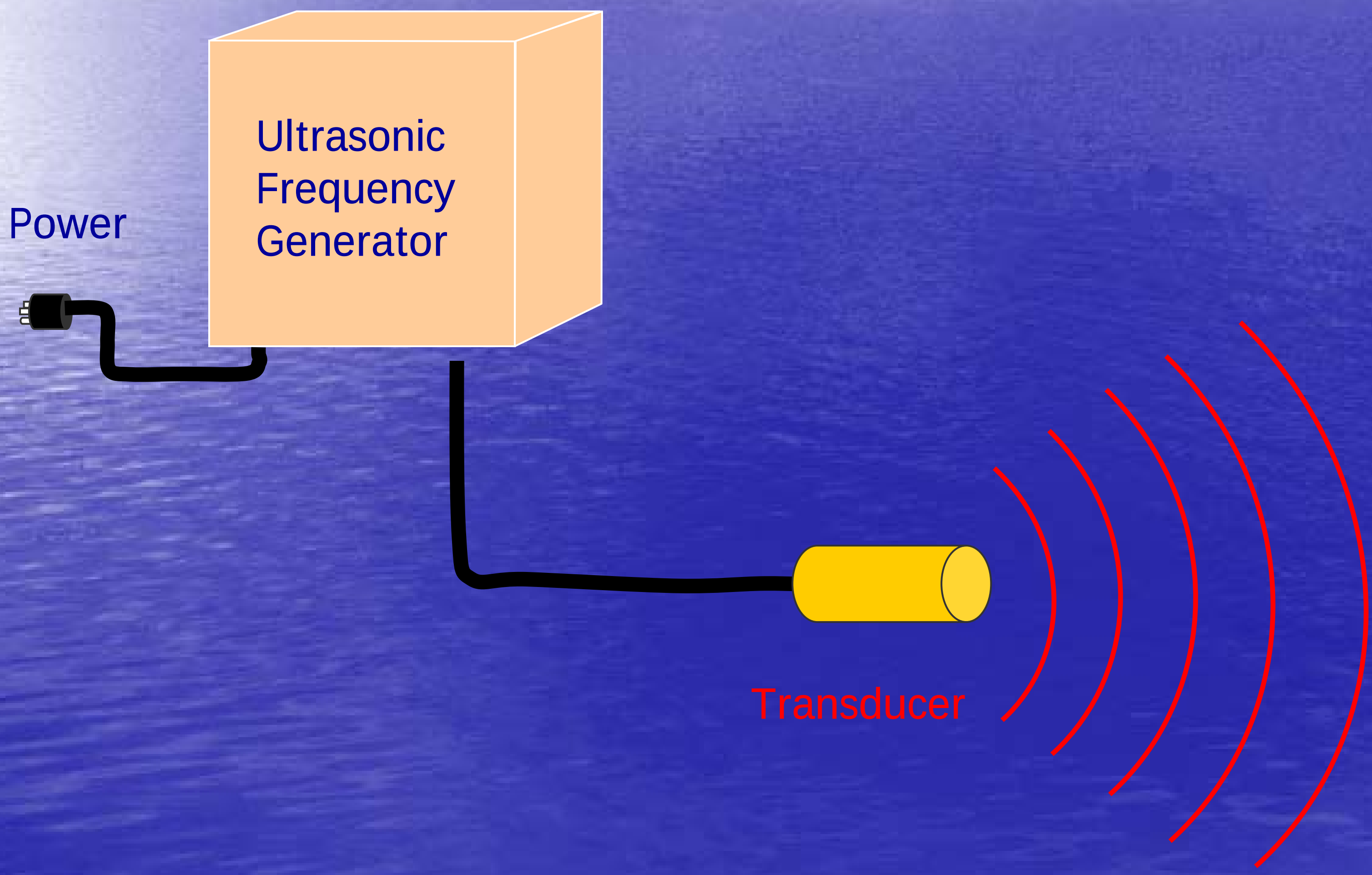
Diatoms and Green algae:	150 meters
Blue-green or cyanobacteria:	400 meters

Macrophytic Algae Not Controlled With Ultrasound

If it looks like a plant,
it is unlikely that
ultrasound will harm it.

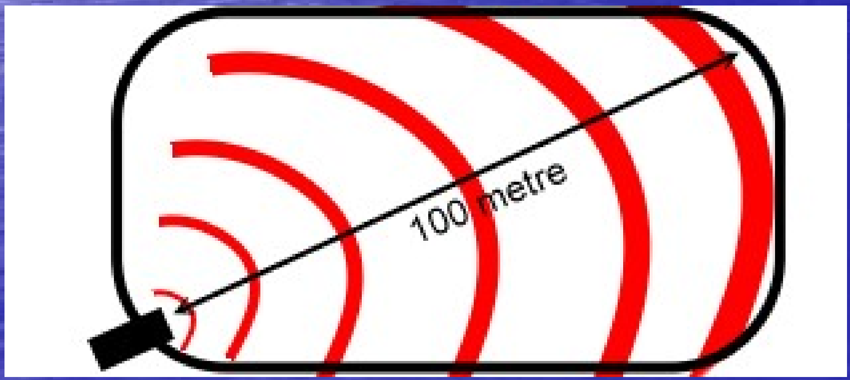
Results on 3.5 Acre Spring Fed Pond
Mt. Pleasant, SC

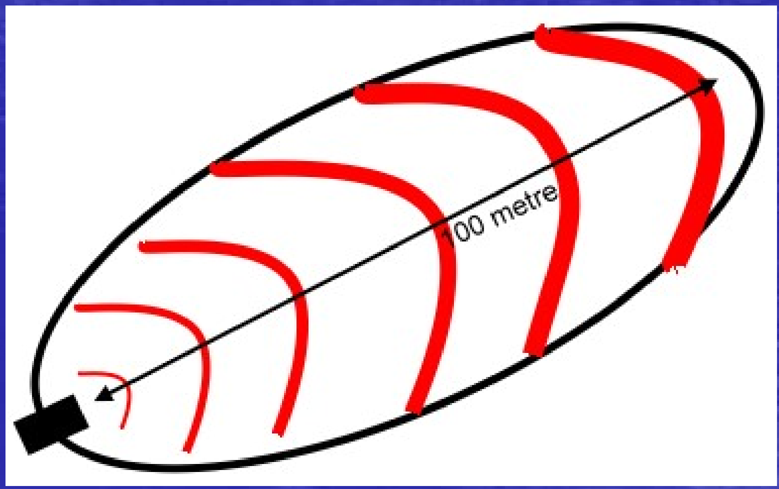
Ultrasound: Underwater Generation
The Basic Operation



Installation notes:

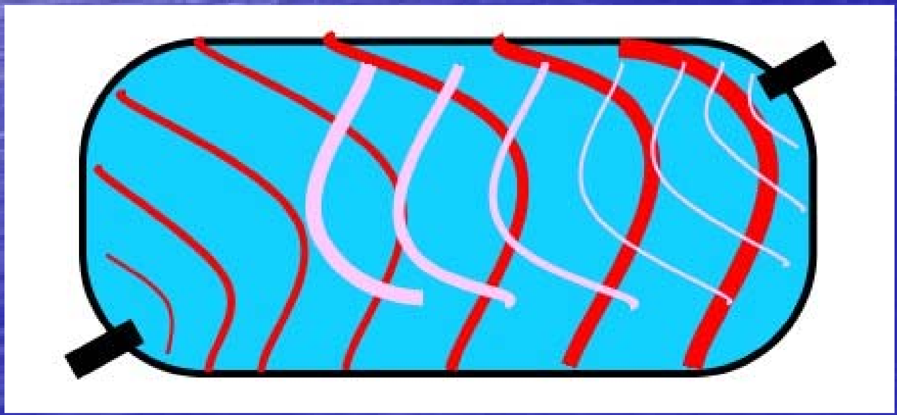
- Always make sure the ‘transducer front’ points towards the longest to be treated distance in the water.

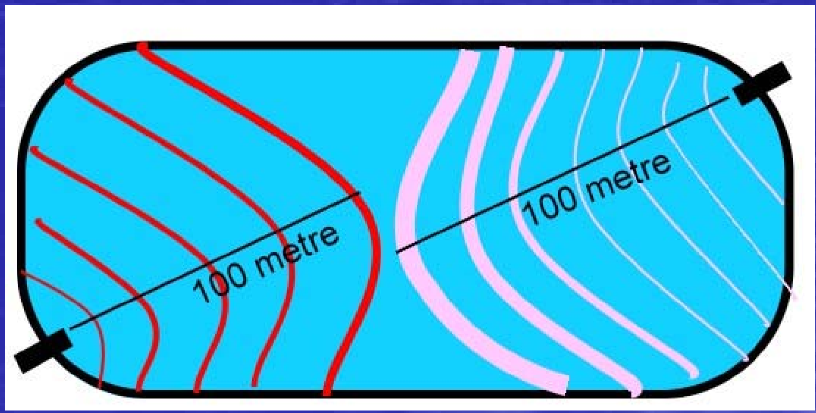




Installation notes:

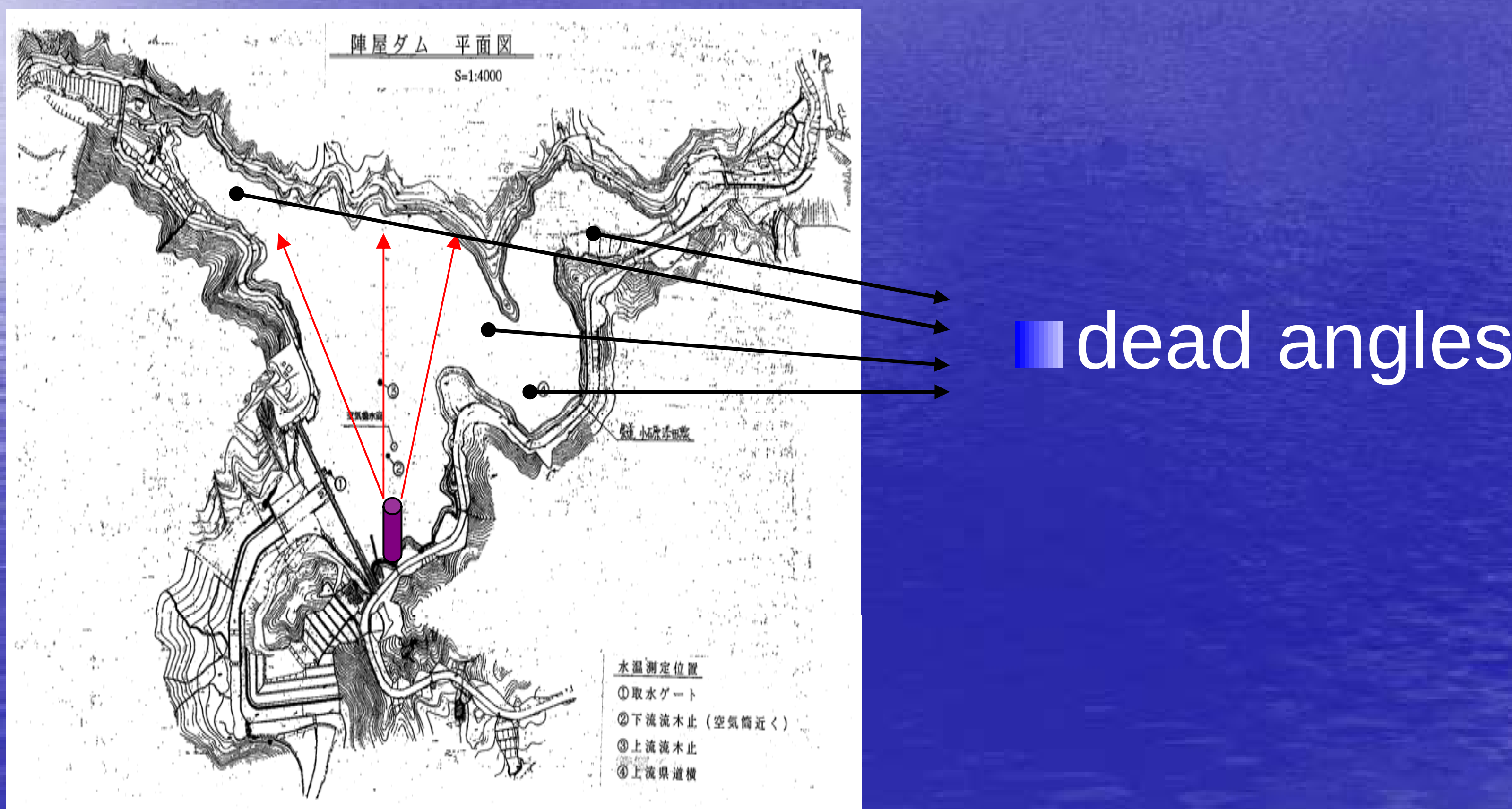
- Always check that the transducer is completely submerged.
- Don't let the sound waves of multiple transducers bounce with each other. (see next slide)





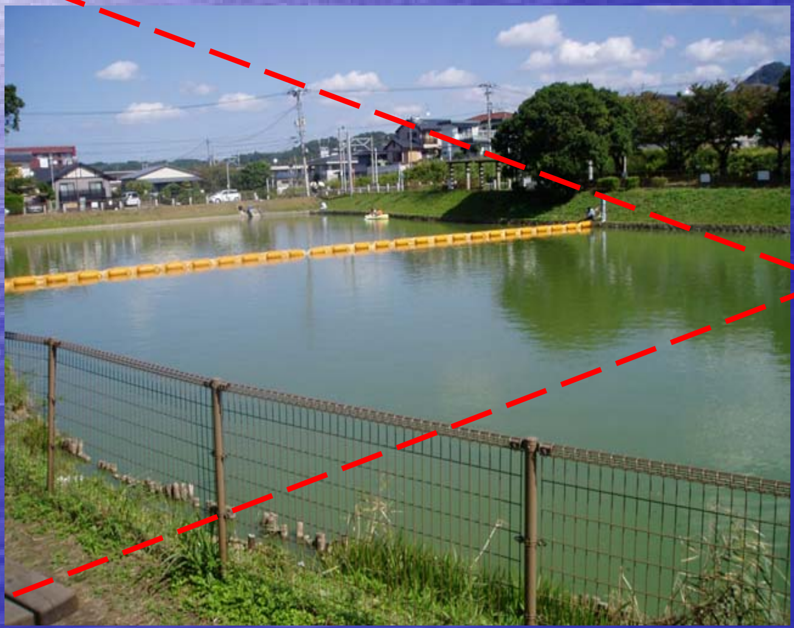
Installation notes:

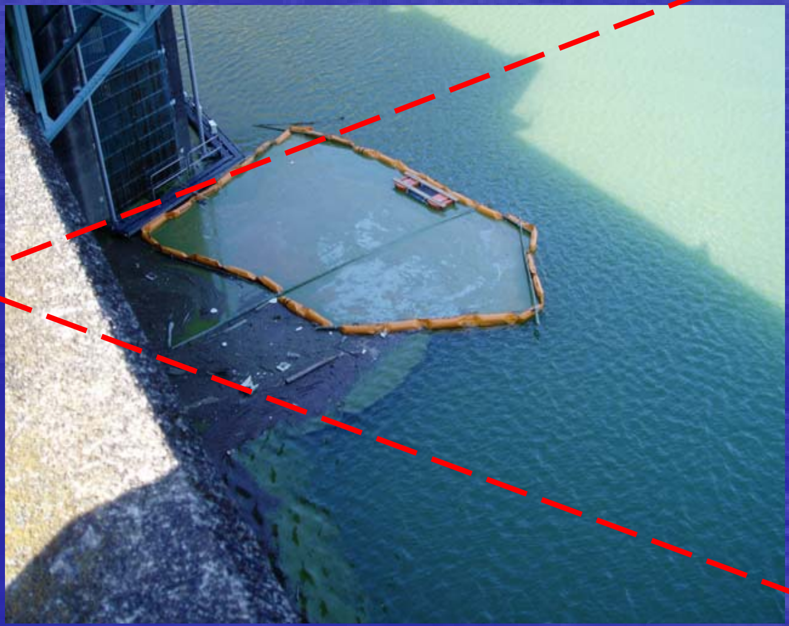
- Avoid dead angles



Installation notes:

- Do not use any materials that may absorb the sound waves





Advantages of Ultrasonic Algae Control

- ✓100% environmentally friendly.
- ✓No generation of by-products.
- ✓No additives are introduced with the ultrasonic system
- ✓No genetic mutation of survivors.
- ✓Simple to install.
- ✓Very little maintenance is required.
- ✓No chemicals needed.
- ✓Very low energy consumption.
- ✓Relatively inexpensive to purchase.
- ✓Sizeable water bodies are no problem.
- ✓Wall biofilm is significantly reduced or eliminated.

Disadvantages of Ultrasonic Algae Control

- ✓ Macrophytic or plantlike algae consisting of millions of cells form a bigger biological structure and are more difficult to eliminate or are unaffected.
- ✓ Thick plants or these plantlike macrophytic algae structures can prevent ultrasound vibration to reach other parts of the water to be treated.
- ✓ A "line of sight" to the algae must be available for the transducer output to be effective.
- ✓ A few algae types will not be affected by ultrasound (euglenoids, macrophytic, and some colonical types are resistant).

Summary:

- Ultrasonic algae control is now a viable and cost effective way to control most nuisance algae types.
- This technology offers an environmentally friendly approach, eliminating many chemicals and chemical handling issues.
- Other than a few fungi and bacteria that have gas vesicles, the ultrasound technology using resonance frequency has not been shown to affect life forms other than algae.