Ultrasound Technology to Manage Harmful Algae Blooms (HABs)

A Presentation By

The Ugly Side of Algae…

OUTLINE OF PRESENTATION ON ULTRASOUND TO MANAGE HARMFUL ALGAE BLOOMS

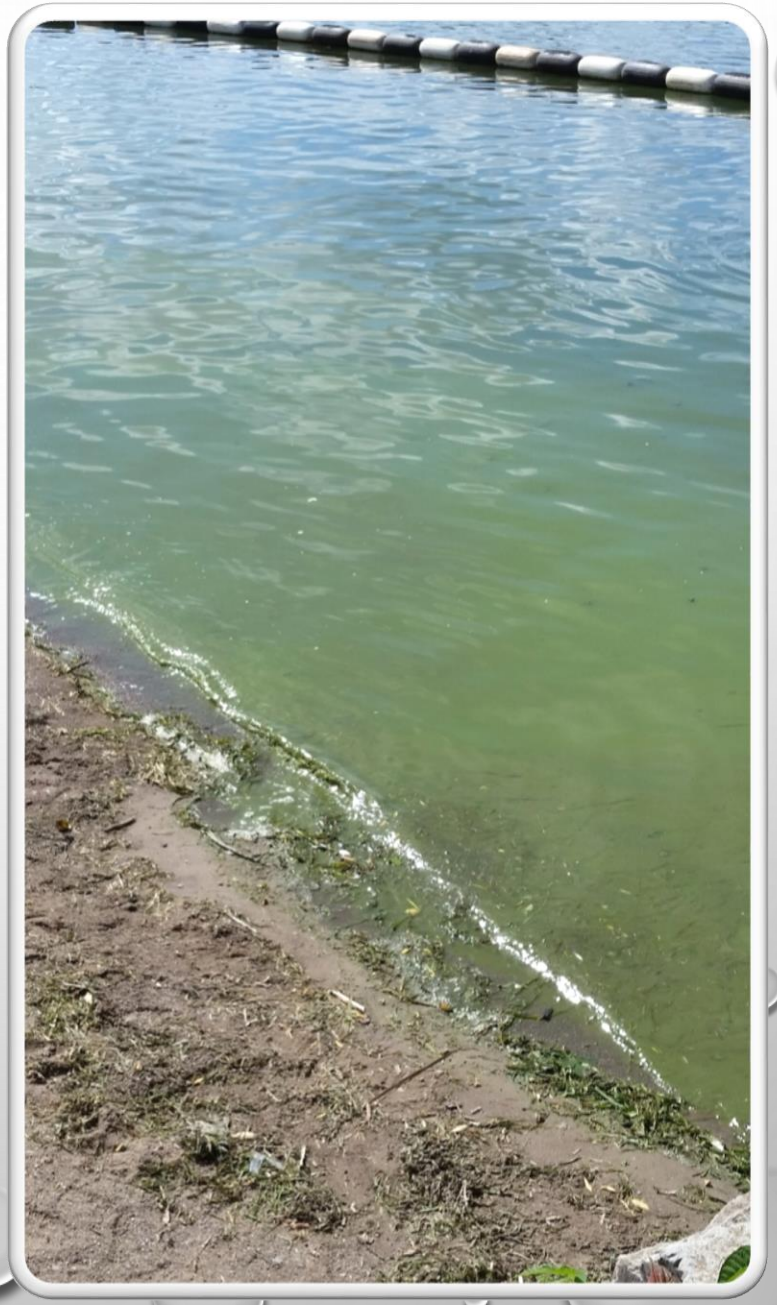
- BRIEF HISTORY OF BLUE-GREEN ALGAE
- OVERVIEW OF THE SITUATION IN ONTARIO
- WHY DO WE NEED TO CONTROL ALGAE BLOOMS NOW?
- HOW CAN THEY BE MOST EFFECTIVELY CONTROLLED?
- ULTRASOUND – INTRODUCTION AND PROPOSED APPLICATIONS

BRIEF HISTORY OF BLUE-GREEN ALGAE

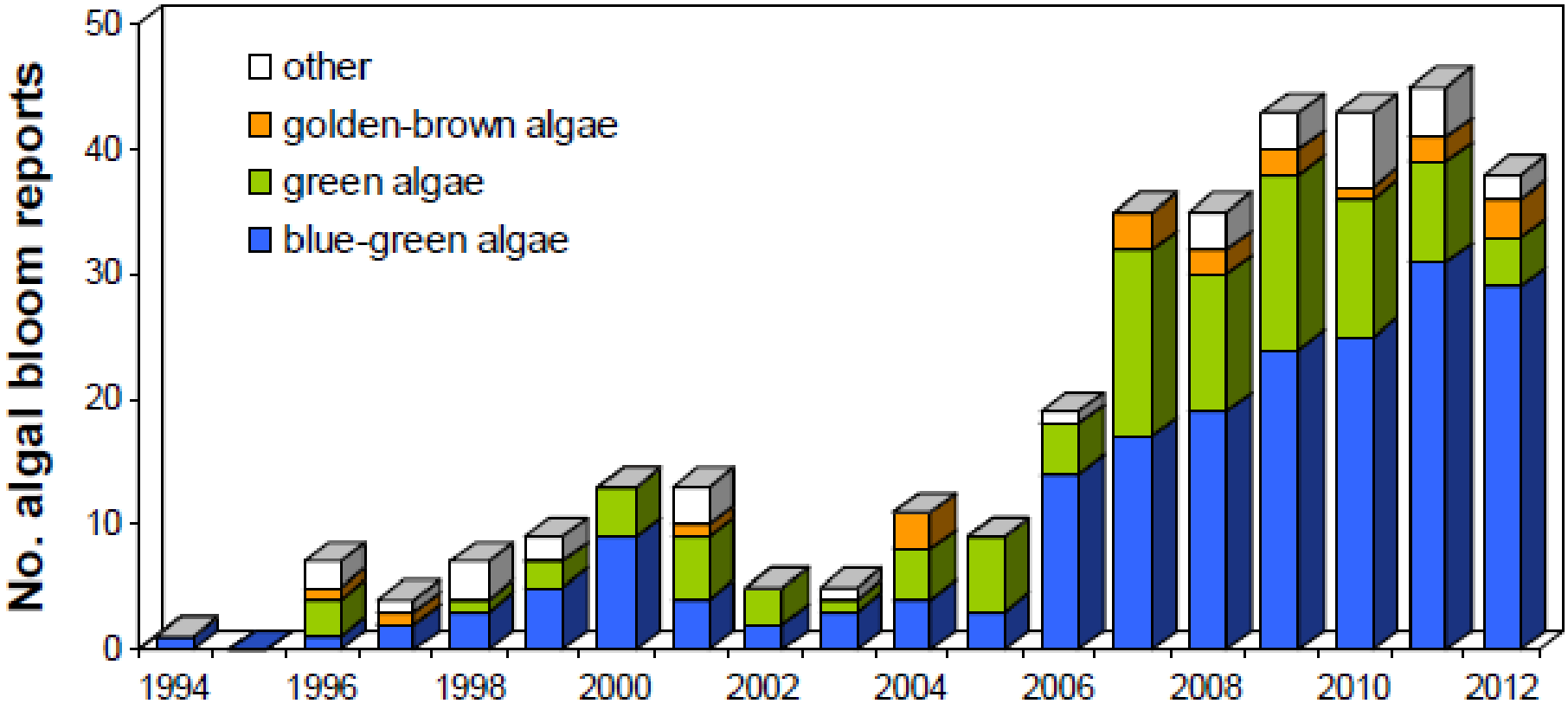
- PALAEOGEOLOGICAL EVIDENCE OF THEIR EXISTENCE DATING BACK MILLIONS OF YEARS
- THE FIRST REPORTED OBSERVATION OF CYANO BACTERIA POISONING OCCURRED ABOUT 1000 YEARS AGO - CHINESE GENERAL ZHU-GE LIANG REPORTED THE DEATH OF TROOPS WHO DRANK GREEN COLOURED WATER FROM A RIVER IN SOUTHERN CHINA.
- THE FIRST PUBLISHED REPORT OF AN INCIDENCE OF CYANOBACTERIA POISONING DATES FROM THE POISONING OF AN AUSTRALIAN WATER BODY IN 1878 (FRANCIS, G. POISONOUS AUSTRALIAN LAKE NATURE 18, 11-12 (1878).
- CYANOBACTERIA ARE FOUND ALMOST EVERYWHERE, BUT PARTICULARLY IN CALM WATERS OF LAKES AND PONDS AND COASTAL MARINE AREAS WHERE, UNDER CERTAIN CONDITIONS, THEY REPRODUCE EXPONENTIALLY TO FORM BLOOMS.

OVERVIEW OF THE SITUATION IN ONTARIO

- WHETHER BECAUSE OF AWARENESS OR IMPROVED REPORTING THE SITUATION IS GETTING WORSE!
- THERE IS CONFUSION IN THE REPORTING WITH BOTH LOCAL HEALTH UNITS REPORTING AND THE ONTARIO SPILLS HOTLINE RECEIVING REPORTS – AND SOMETIMES NO ONE REPORTS IT!
- ONTARIO'S 12-POINT PLAN ON BLUE GREEN ALGAL BLOOMS



Algal bloom trends over time



total, green & blue-green algae bloom reports from 1994-2012 ($p < 0.001$)

For more information see: Winter et al. (2011) Algal blooms in Ontario, Canada: Increases in reports since 1994. Lakes & Reservoir Management, 27:105-112.

Ontario

MORE RECENT DATA ON BLUE-GREEN ALGAE BLOOMS IN ONTARIO

#confirmed BG blooms reported by MOECC region	South-western	West Central	Central	Eastern	Northern
2006	2	0	2	0	10
2007	4	0	1	3	9
2008	3	0	0	3	14
2009	2	0	2	5	15
2010	1	1	3	8	12
2011	0	1	3	12	16
2012	1	0	1	13	14
2013	3	0	4	7	12
2014	0	0	2	5	9
2015	1	0	3	12	35
2016 (to Oct 18th)	2	3	2	16	18

Is the reporting effective and comprehensive?

LAKES IN MOECC'S NORTHERN REGION WITH CONFIRMED BLUE-GREEN ALGAE BLOOMS

HTTPS://WWW.GOOGLE.COM/MAPS/D/VIEWER?MID=1SRDCCYVASMXKI2WKBXXX3JCVKTQ&LL=46.371688%2C-81.1439900000003&Z=8

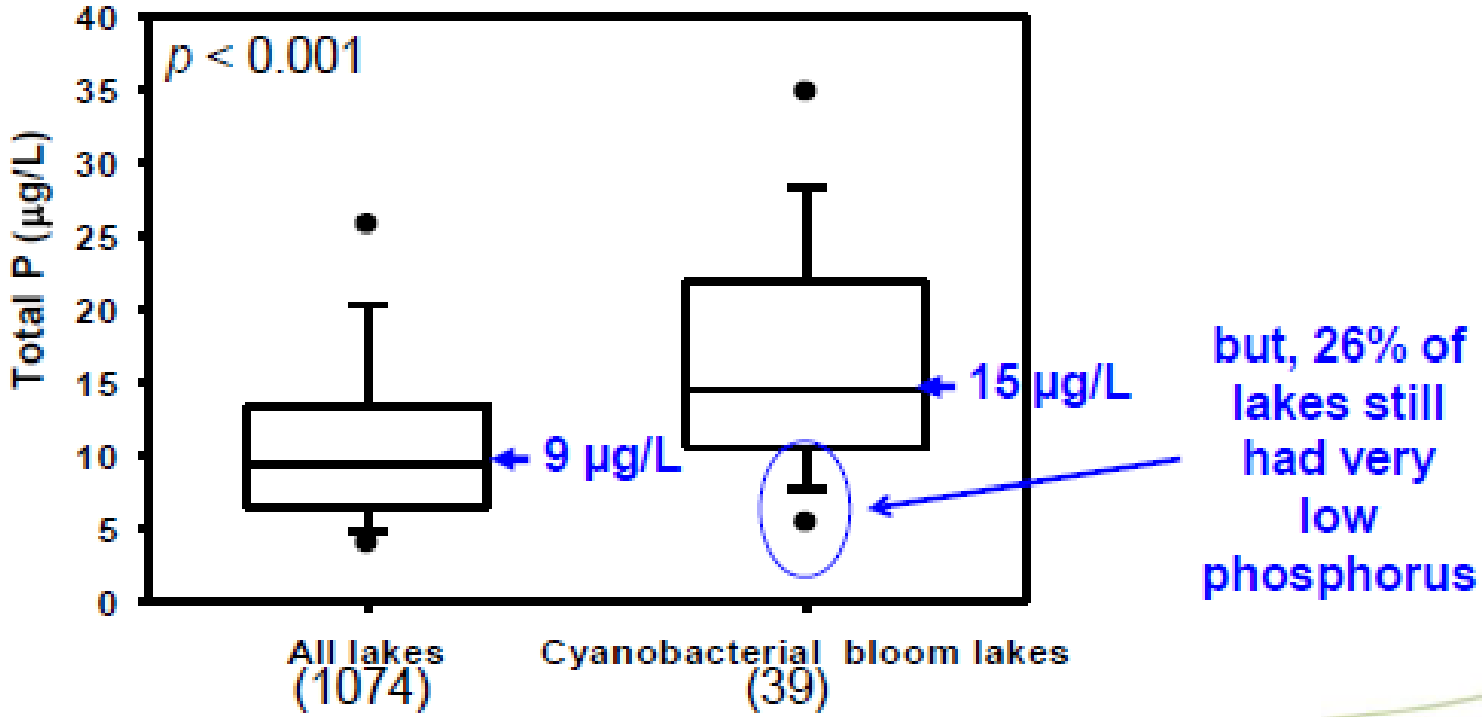
- INTERESTING TO NOTE THAT MANY OF THESE WOULD NOT BE CHARACTERIZED AS NUTRIENT RICH WATERS

Water Bodies		
Bethel Lake	Richard Lake	Wolsey Lake
Ella Lake	Vermillion River	Agnew Lake
Grant Lake	Whitson Lake	Aspey Lake
Hanmer Lake	Wanapitei Lake	Clear Lake
Hannah Lake	Windy Lake	La Cloche Lake
Little Panache Lake	Dry Pine Bay	Nagasin Lake
Long Lake	French River	
Makada Lake	Lake Nipissing	
McCharles Lake	Nepewassi Lake	
McFarlane Lake	Murdock River	
Middle Lake	Bass Lake	
Nepahwin	Big Lake	
Panache Lake - North East	Ice Lake	
Ramsey Lake	Mindemoya Lake	
Red Deer Lake	Tobacco Lake	

Why have bloom reports increased?

2) Increased nutrient inputs to lakes

- enhanced human activity & development near lakes may be promoting algal growth
- spring total phosphorus was higher in bloom lakes than in a large set of Ontario lakes without reported blooms



For more information see: Winter et al. (2011) Algal blooms in Ontario, Canada: Increases in reports since 1994. Lakes & Reservoir Management, 27:105-112.

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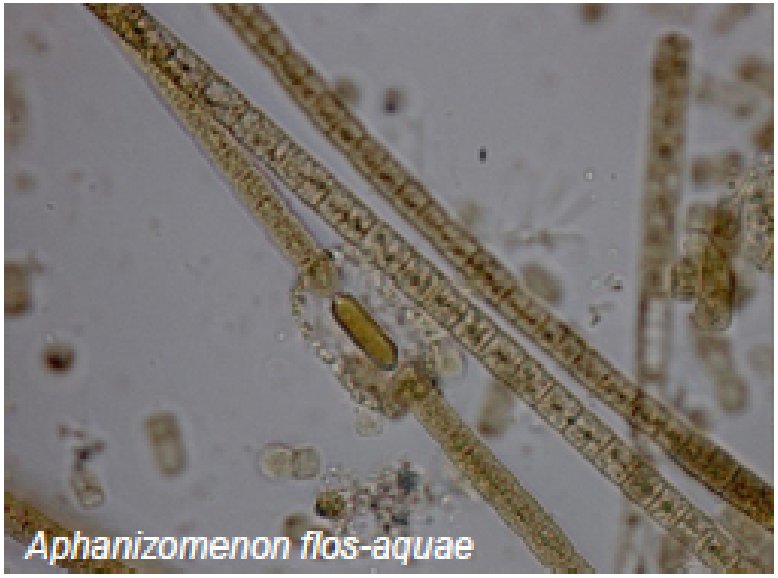
Linking climate change & algal blooms

Blooms like it hot

- warmer water temperature
- less ice-cover & longer growing period
- longer stratification & less mixing
- higher nutrient loading
- precipitation changes
- longer residence time


Aphanizomenon flos-aquae

Warming benefits blue-green algae

- grow better than many other algae at high water temperatures
- can control their buoyancy by forming gas vesicles
- can accumulate at the surface & shade underlying algae
- nitrogen fixers

For more information see: Paerl & Huisman (2008) Blooms like it hot. Science, 320:57-58.

Ontario

IT IS GOING TO GET WORSE! DO WE HAVE EFFECTIVE REPORTING IN ONTARIO? (a custom designed phone app will allow fast initial reporting for subsequent confirmation – Lake name, lat and long, date, photograph, name and contact information optional)

- 

Install bloomWatch app on your smartphone or tablet

- The State of Vermont reported almost 1800 b-g algae blooms in 2015, all confirmed by trained personnel
- We are aware of several blooms in Ontario that appear to have gone unreported

WHY DO WE NEED TO CONTROL HARMFUL ALGAE BLOOMS (HABs) NOW?

- WATERSHED MANAGEMENT IS THE RECOMMENDED APPROACH BUT:
  - ✓ Generally does not address HABs*
  - ✓ Does not generally consider legacy nutrient loads and recycling
  - ✓ Nonpoint source BMPs have proven difficult to implement and may come with unintended consequences
  - ✓ Does not address cyanobacteria's need for quiescent water
  - ✓ Blooms feed blooms
  - ✓ Long term solutions with high costs and generally no observable short term benefits
  - ✓ <u>In the meantime, potential human health impacts and closures remain</u>
  - ✓ Real costs including property value losses (cottages)**
  - ✓ Climate change and urban expansion

- WHY ACT NOW: HUMAN HEALTH IMPACTS AND ECONOMICS

Recent studies (Caller et al., 2009; Holtcamp, 2012; Bradley et al., 2013; Hlavsa et. Al, 2014) suggest that significant exposure to high levels of cyanobacteria producing toxins such as BMAA* which can cause amyotrophic lateral sclerosis (ALS). People living within a half-mile of cyanobacterially contaminated lakes have had a 2.3-times greater risk of developing ALS than the rest of the population; people around New Hampshire's Lake Mascoma had up to 25 times greater risk of ALS than the expected incidence.

- One cottage association in Ontario estimates property value losses of the order of a million dollars on one lake

SOME METHODS TO CONTROL HARMFUL ALGAE BLOOMS

- ALTERNATIVE DIRECT HAB CONTROLS#
  - ✓ AERATION AND MECHANICAL MIXING (LIMITED EFFECTIVENESS)
  - ✓ COPPER SULFATE AND OTHER COPPER BASED ALGAECIDES (CAN AFFECT NON-TARGET ORGANISMS, RESIDUALS, RISK OF CELL LYSES AND RELEASE OF TOXINS)
  - ✓ POTASSIUM PERMANGANATE (CAN AFFECT NON-TARGET ORGANISMS, RESIDUALS, USER RISKS)
  - ✓ CHLORINE (CAN AFFECT NON-TARGET ORGANISMS, RESIDUALS, USER RISKS)
  - ✓ BARLEY STRAW (INHIBITS GROWTH OF NEW ALGAE ONLY AFTER 2-8 WEEKS, FISH KILLS, AESTHETICS)
- SECONDARY CONTROLS
  - ✓ COAGULANTS AND FLOCCULANTS TO SETTLE CYANOBACTERIA (CELLS LYSE AND TOXINS RELEASED)
  - ✓ P REDUCTION WITH ALUM, ALUMINUM SULFATE OR POLYMERS (RESIDUALS, DEPTH AND SPATIAL LIMITATIONS)

USEPA – Control and Treatment of HABs

ULTRASOUND (US) CAN BE AN EFFECTIVE METHOD TO CONTROL HABs

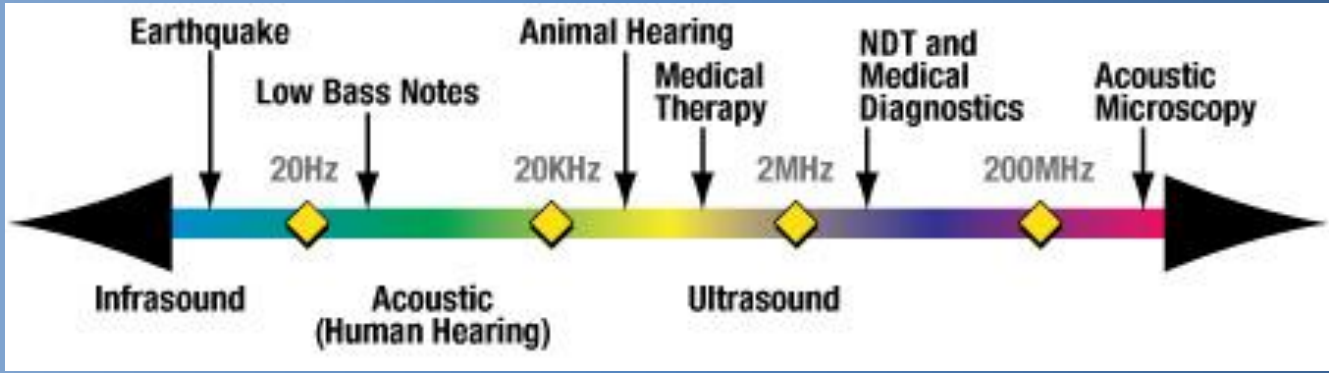
- HAB SUPPRESSION CAN BE ACHIEVED IN MANY INSTANCES USING ULTRASOUND (US)
  - B-G ALGAE – US RUPTURES GAS VESICLES BUT DOES NOT RELEASE TOXINS
  - GREEN ALGAE – US VIBRATION BREAKS BOND BETWEEN CELL WALL AND INSIDE OF CELL
  - CONTINUOUS USE OF US AVOIDS TREATMENT THAT MAY RUPTURE CELLS AFTER BLOOM IS DENSE
  - SAFE, LOW POWER CONSUMPTION
  - AVOIDS LARGE O_2 DEMAND AND DOES NOT ADD TO NUTRIENT RESERVOIR
  - MAJOR LIMITATION IS RANGE OF COVERAGE

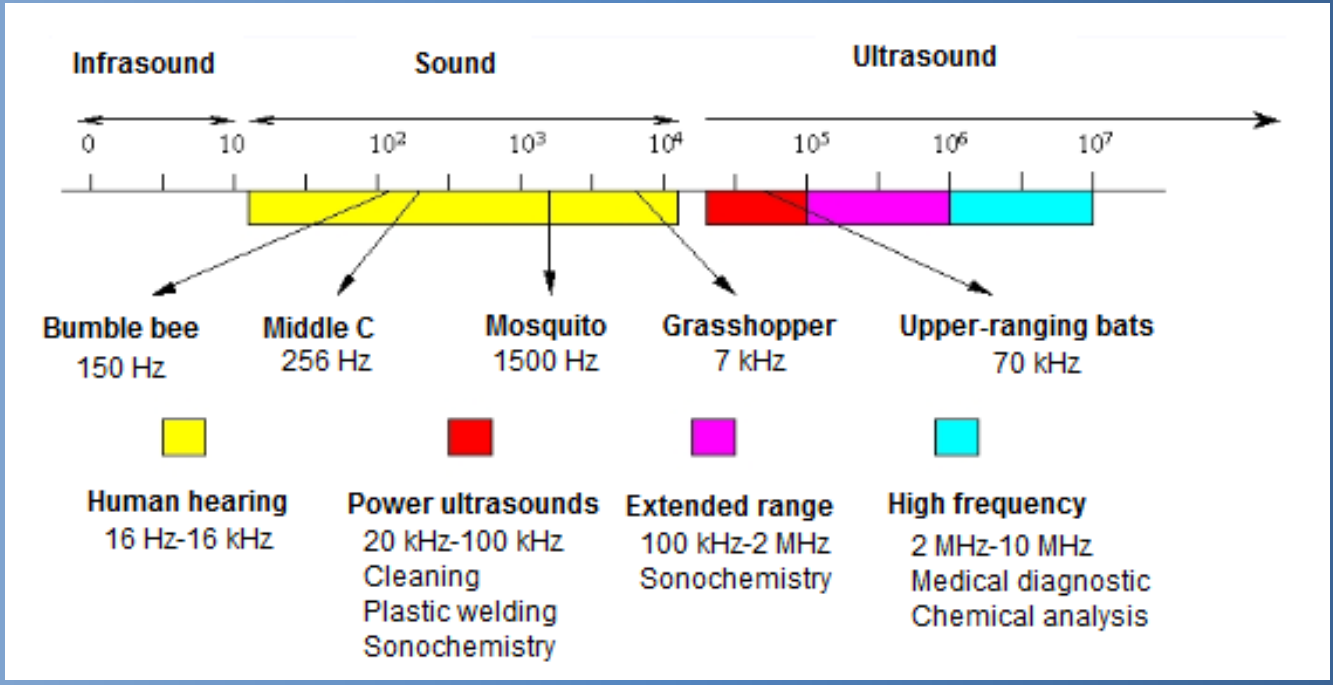
Ultrasonic Algae Control: A Hope Fulfilled

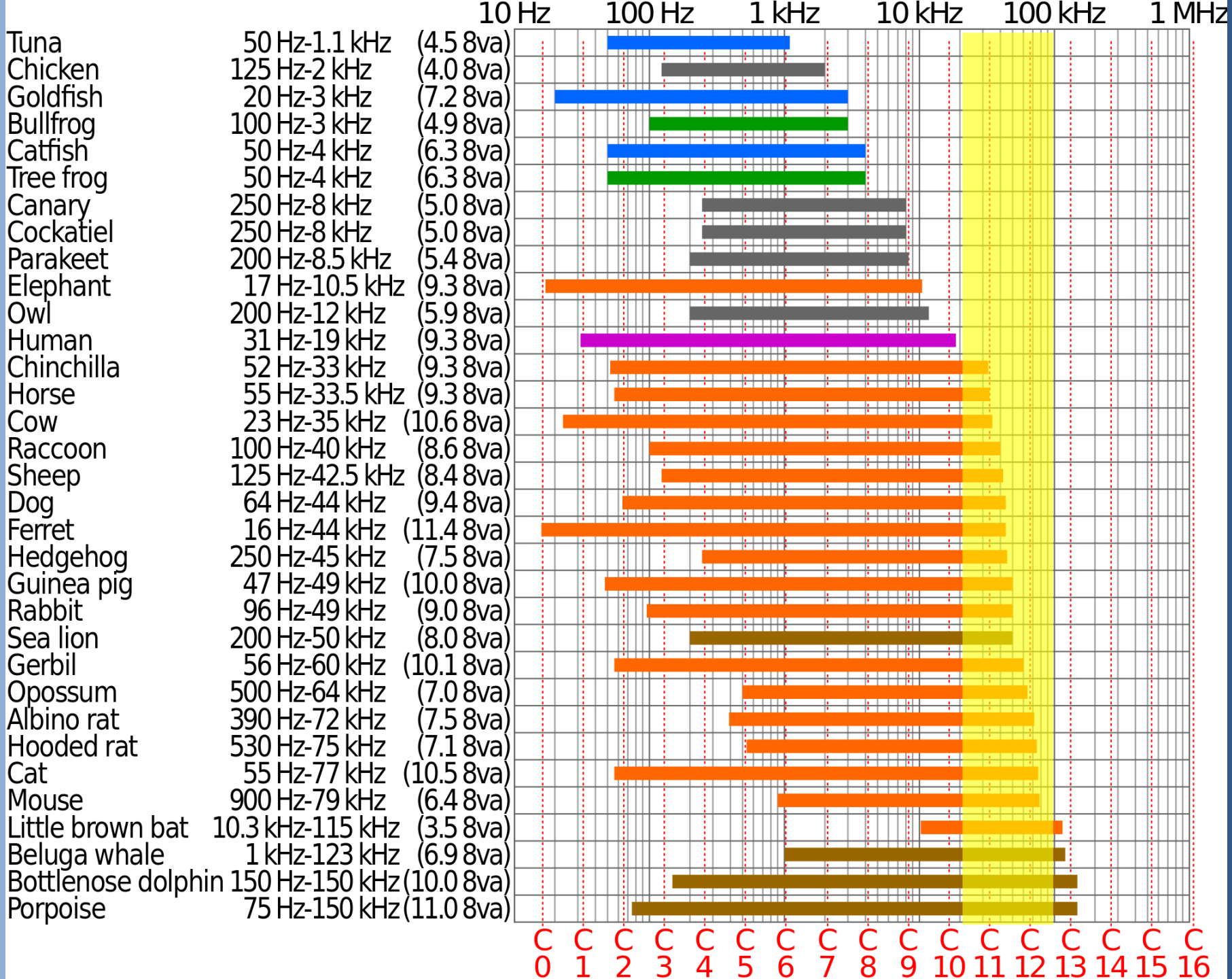
"Finally, it is suggested that the information we have gathered on the stability of gas vesicles under various conditions might also be employed in their destruction. If gas vacuoles are so important to the success of planktonic blue-green algae which form water blooms, we might be able to control these 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.

Sound Spectrum






10 Hz
100 Hz
1 kHz
10 kHz
100 kHz
1 MHz
Tuna 50 Hz-1.1 kHz (4.5 8va)
Chicken 125 Hz-2 kHz (4.0 8va)
Goldfish 20 Hz-3 kHz (7.2 8va)
Bullfrog 100 Hz-3 kHz (4.9 8va)
Catfish 50 Hz-4 kHz (6.3 8va)
Tree frog 50 Hz-4 kHz (6.3 8va)
Canary 250 Hz-8 kHz (5.0 8va)
Cockatiel 250 Hz-8 kHz (5.0 8va)
Parakeet 200 Hz-8.5 kHz (5.4 8va)
Elephant 17 Hz-10.5 kHz (9.3 8va)
Owl 200 Hz-12 kHz (5.9 8va)
Human 31 Hz-19 kHz (9.3 8va)
Chinchilla 52 Hz-33 kHz (9.3 8va)
Horse 55 Hz-33.5 kHz (9.3 8va)
Cow 23 Hz-35 kHz (10.6 8va)
Raccoon 100 Hz-40 kHz (8.6 8va)
Sheep 125 Hz-42.5 kHz (8.4 8va)
Dog 64 Hz-44 kHz (9.4 8va)
Ferret 16 Hz-44 kHz (11.4 8va)
Hedgehog 250 Hz-45 kHz (7.5 8va)
Guinea pig 47 Hz-49 kHz (10.0 8va)
Rabbit 96 Hz-49 kHz (9.0 8va)
Sea lion 200 Hz-50 kHz (8.0 8va)
Gerbil 56 Hz-60 kHz (10.1 8va)
Opossum 500 Hz-64 kHz (7.0 8va)
Albino rat 390 Hz-72 kHz (7.5 8va)
Hooded rat 530 Hz-75 kHz (7.1 8va)
Cat 55 Hz-77 kHz (10.5 8va)
Mouse 900 Hz-79 kHz (6.4 8va)
Little brown bat 10.3 kHz-115 kHz (3.5 8va)
Beluga whale 1 kHz-123 kHz (6.9 8va)
Bottlenose dolphin 150 Hz-150 kHz (10.0 8va)
Porpoise 75 Hz-150 kHz (11.0 8va)
C 0
C 1
C 2
C 3
C 4
C 5
C 6
C 7
C 8
C 9
C 10
C 11
C 12
C 13
C 14
C 15
C 16

ARE YOU COMFORTABLE WITH ULTRASOUND (US)? SOME COMMON USES

- MEDICAL
  - ✓ LITHOTRIPSY OF KIDNEY STONES
  - ✓ HIFU: HIGH INTENSITY FOCUSED ULTRASOUND FOR NON-INVASIVE SURGERY
  - ✓ FETAL AND INTERNAL ORGAN IMAGERY
  - ✓ JOINT AND MUSCLE PAIN
  - ✓ DENTAL HYGIENE
- INDUSTRIAL
  - ✓ METAL AND WELD INTEGRITY TESTING
  - ✓ CATALYTIC REACTION ENHANCEMENT
  - ✓ SLUDGE DISINTEGRATION
  - ✓ LEVEL DETECTION, FLOW METERS
- OTHER
  - ✓ SONAR AND OTHER ECHO-LOCATION
  - ✓ BACTERIAL DISINFECTION THROUGH CAVITATION
  - ✓ LABORATORY, INDUSTRIAL AND RETAIL CLEANING (JEWELRY)

Type	Use	Frequency	Power	Notes
Sonicator Q700	Homogenizing and lysing cells	20 kHz	700 watts	
Sonicator Q55	Homogenizing and lysing cells	20 kHz	55 watts	
Qsonica US Cleaner	Cleaning	40 kHz		50 watts per litre of solution
ELMA US Cleaner	Cleaning	25 kHz - 80 kHz		300 watts per 6 L bath
Deep Water Echo Sounder		30 kHz	3000 W	
Shallow Water Echo Sounder		200 kHZ	250 - 1000 W	
Seal Scarers		15 kHz	5 watts	300 m range max
Fish Deterrent		<10 Hz	50 -100 W	Infrasound
Sonic Solutions	Cyanobacteria	~ 40 kHz	<10 watts	5 mW per cm^2 at source
US Welding – Metals		20 kHz	2500 W	
US Welding – Plastic		15 - 70 kHz	900 - 6200 W	
US Welding - Carbon Fiber		15 - 70 kHz	8000 W	
Medical	Therapeutic	700 kHz - 3.3 MHz	3 Watts per cm^2	Penetrates 2 - 5 cm, Max Power defined by HC rules.
Medical	Diagnostic	1 - 18 MHz Used	20-720 mW per cm^2	50 - 100 MHz (Experimental)

ULTRASOUND (US): HOW DOES IT AFFECT BLUE-GREEN ALGAE

- The bacteria contains many tiny cylindrical vesicles about 75 x 300 nm in size, often in clusters
- The wall of the gas vesicle is permeable to gases but not to water and is about 2 nm thick
- Gas vesicles are found mainly in planktonic cyanobacteria and their primary purpose is to make them buoyant
- US disrupts the wall of the gas vesicle resulting in a loss of buoyancy and eventual "starvation"
- Some fungi and archaea bacteria and some green algae may also be affected

Blue-Green Algae Can Have Thousands of Gas Vesicles

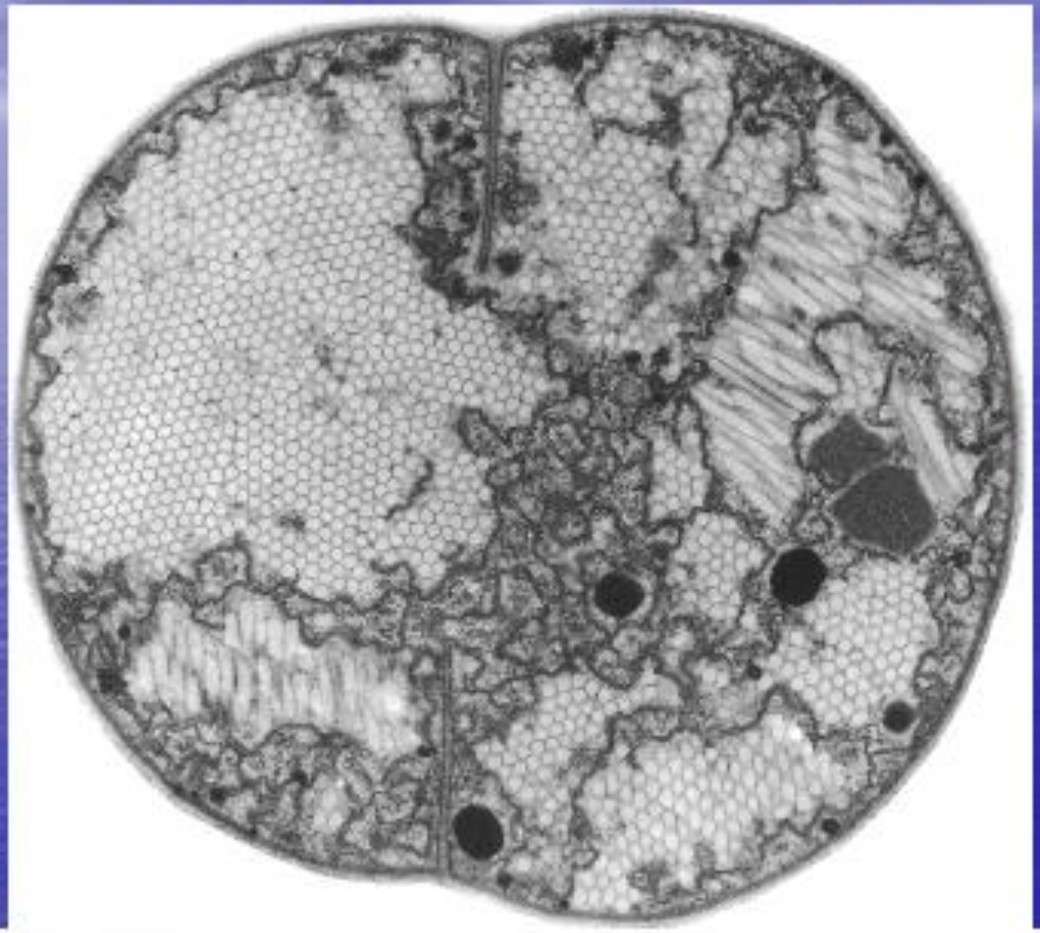
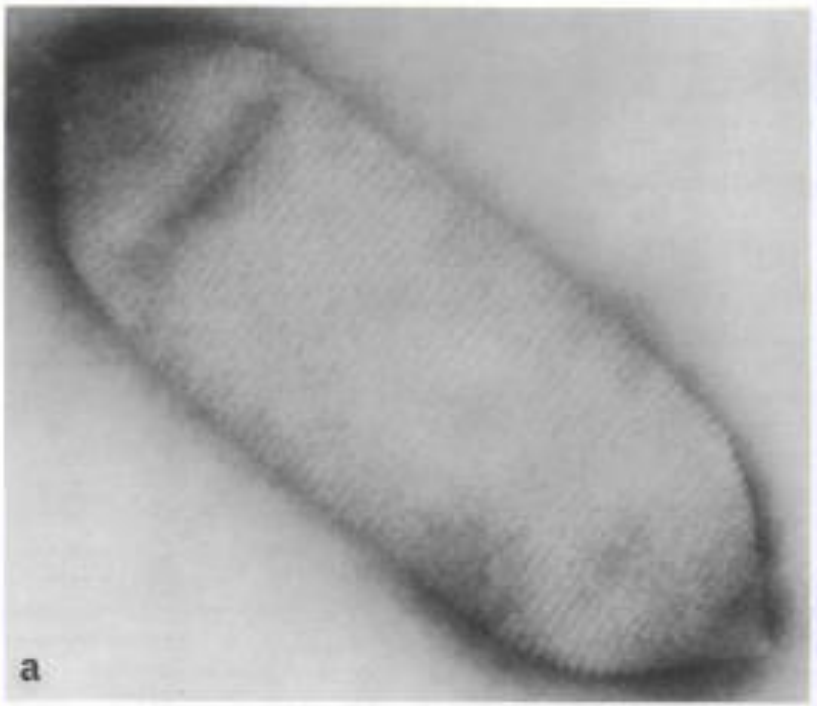


FIG. 1. Transverse section of a dividing cell of the cyanobacterium *Microcystis sp.* showing hexagonal stacking of the cylindrical gas vesicles. (Micrograph by H. S. Pankratz.) Magnification, x31,500.

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

Algae Biological Parts Make Them Susceptible To Critical Resonance Vibration



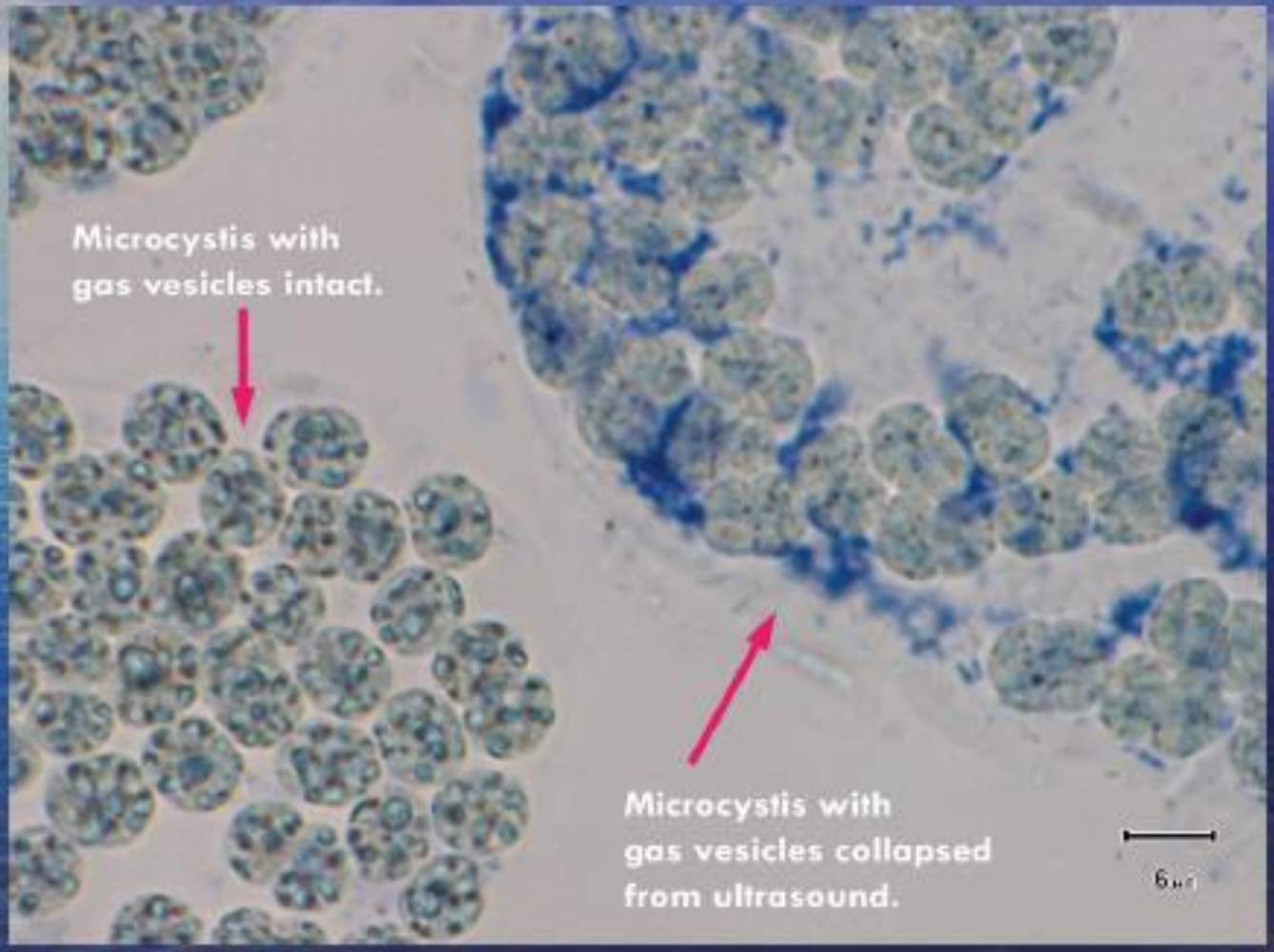
Intact gas vesicle of Anabaena flos-aquae negatively stained with phospho-tung-state showing corrugated profile of the ribbed structure x300000.

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

Gas Vesicle:

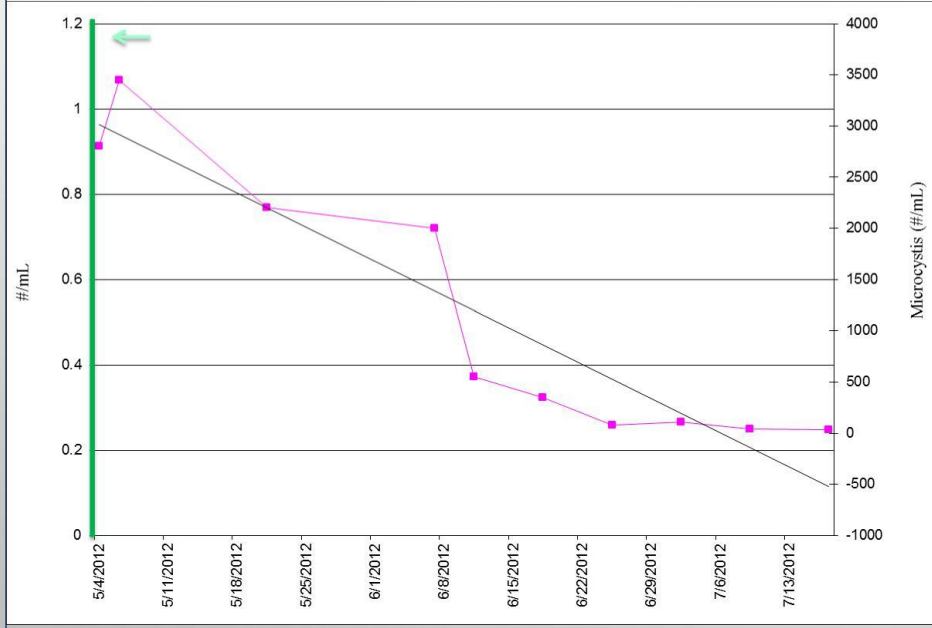
Rigid hollow cylindrical structures with conical ends made of proteins. As blue-green algae create carbohydrate mass or better termed ballast during sunlight hours, they will gain enough weight to be heavier than water and sink. This allows them to find necessary nutrients near the bottom or at lower depths. As the carbohydrate ballast is consumed, they slowly rise to the surface.

Blue-Green Algae With Ultrasonically Damaged Gas Vesicles – Before/After



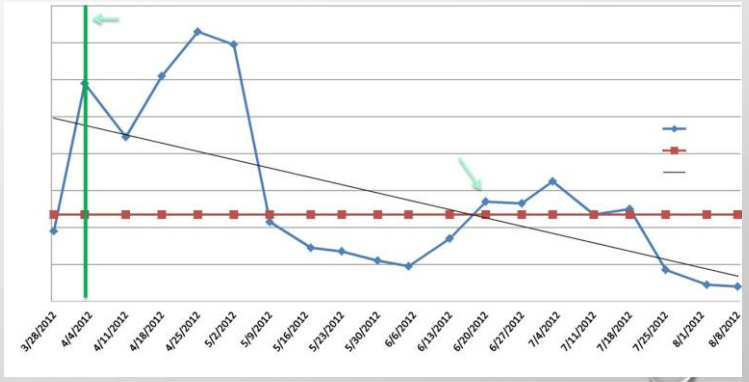
SOME EXAMPLES USING ULTRASOUND

- Microcystis cell counts for Lakeview Park pond in TX during ultrasound treatment (2012)



Time scale: May 4, 2012 to July 19, 2012
Achieved "0" by mid June

- Vaughan, MT waste water lagoon during ultrasound treatment starting April, 2012
- TSS



Time scale: March 28, 2012 to Aug. 8, 2012

MULTIPLE FLOATING UNITS WERE USED IN THE USA TO TREAT A 161,000 SQ. M. (1.6 HA) DRINKING WATER RESERVOIR

Ultrasound Side Benefit: Biofilm Impact

How does this work?

The base layer of biofilm is comprised of anaerobic bacteria. These bacteria spread in water systems by becoming oxygen tolerant for a short period. In turbulent water, studies have shown that these types of bacteria withdraw their pili (small filament used for attachment) and do not excrete polysaccharide glues that they use to attach to surfaces, so they do not form colonies in turbulent water. The ultrasonic waves give them a sense that the water is turbulent, though it is not.

Ultrasound Side Benefit: Biofilm Impact

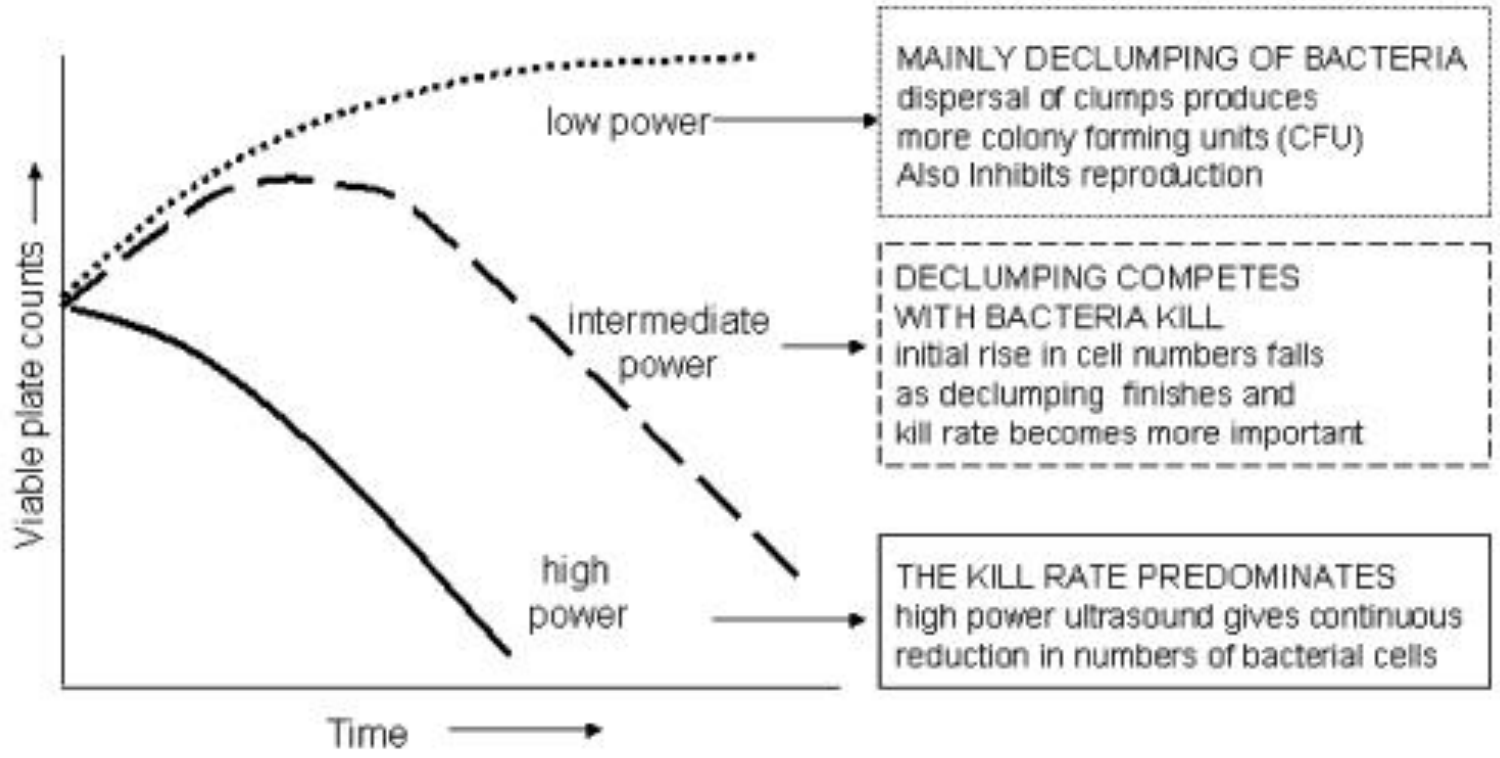


Figure 2: The effects of sonication alone on the survival of bacteria in water.

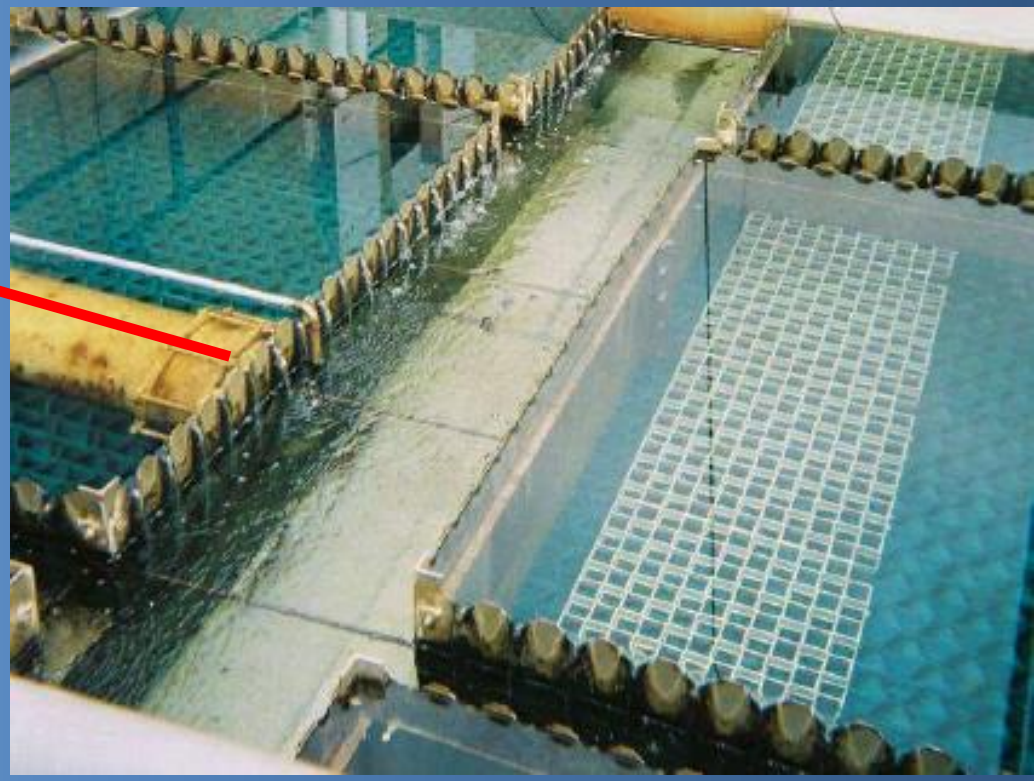
Ultrasound Side Benefit: biofilm impact

Before

Union, SC Potable Water Plant

Cleaning cycles increased from two to six
Weeks after introduction of Ultrasound

After



ULTRASOUND (US) TO CONTROL HABs - SUMMARY

- ADVANTAGES OF ULTRASOUND
  - B-G algae – ruptures gas vesicles but does not release toxins*
  - Green algae – vibration breaks bond between cell wall and inside of cell
  - Pro-active minimization of algae population eliminates blooms
  - Continuous use of US avoids treatment that may rupture cells after bloom is dense
  - Safe, low power consumption, little maintenance, no residual by-products
  - Relatively inexpensive to purchase and operate
  - Avoids large O_2 demand and does not add to nutrient reservoir

- LIMITATIONS
  - Macrophytic or plantlike algae are more difficult or are unaffected (e.g. Cladophora, euglenoids, oscillatoria, scenedsmus, pediastrum)
  - Thick plants, macrophytic algae and structures impede ultrasound vibrations
  - A "line of sight" to the algae must be available for the transducer output to be effective
  - Limited effective range (~250 m)

ULTRASOUND (US) TO CONTROL HABs - SUMMARY

- US CAN PROVIDE AN IMMEDIATE RELIEF TO A VISIBLE SYMPTOM OF EUTROPHICATION
- US CAN PROVIDE SOME REDUCTION OF IN-LAKE NUTRIENT CYCLING BY ELIMINATING THE OXYGEN DEMAND OF A DECAYING BLOOM
- US CAN REDUCE HUMAN HEALTH RISKS BOTH DUE TO DIRECT CONTACT AND AIRBORNE AEROSOLS
- US CAN REDUCE RISKS TO ANIMALS, WATERFOWL AND OTHER AQUATIC SPECIES INCLUDING FISH
- US CAN HAVE A DIRECT BENEFIT ON PRIVATE PROPERTY VALUES BY CONTROLLING HABs
- US CAN ENHANCE THE USE AND THE USER EXPERIENCE OF IMPORTANT TAXPAYER FUNDED PUBLIC FACILITIES
- US CAN DIRECTLY SUPPORT ONE CRITERION OF THE HAMILTON HARBOUR RAP

Contact Us with Questions