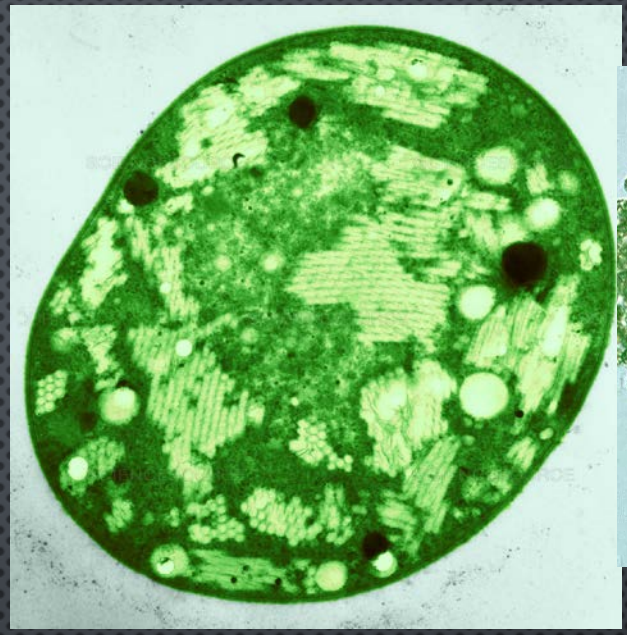
HARMFUL ALGAL BLOOMS; TOXIN TYPE AND POTENTIAL CONTRIBUTING FACTORS

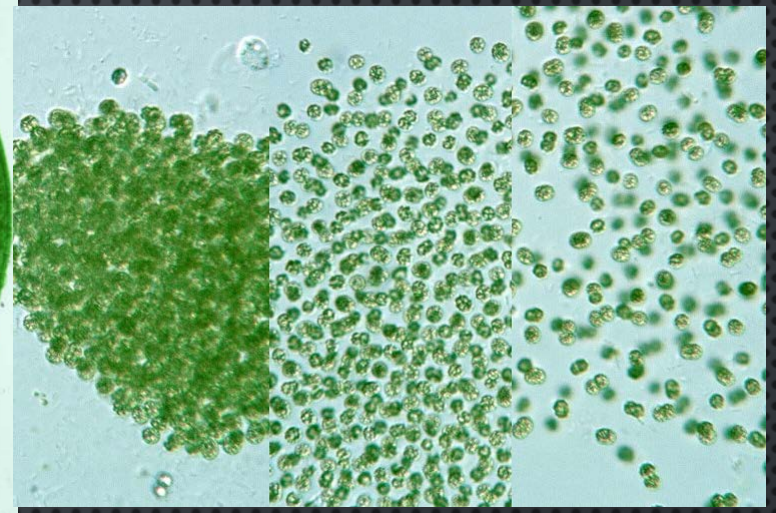
David Walker, PhD

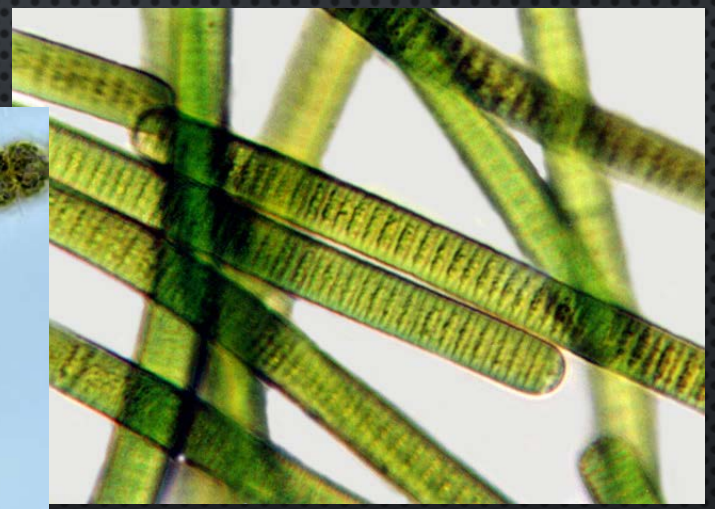
University of Arizona

CYANOBACTERIA

- ~ 3.5 billion years old
  - Rock is only 3.8 billion!
- If it weren't for cyanobacteria, we wouldn't be sitting here today.
- Given such a relatively simplistic organism, we still don't have good ideas about why they produce toxins.







CYANOTOXIN TYPES BY PHYSIOLOGICAL EFFECT

- DERMATOTOXINS
- HEPATOTOXINS
- NEUROTOXINS

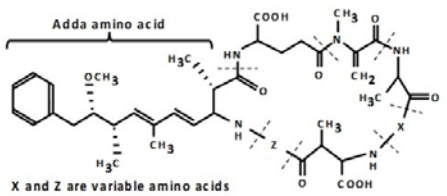
Hepatotoxins

Health Effects

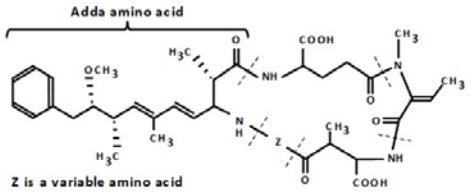
Short-Term
- Gastroenteritis
- Death

Long-Term
- Cancer

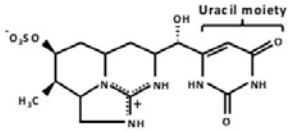
Microcystin



Nodularin

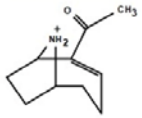


Cylindrospermopsin

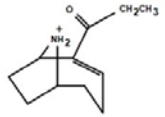


Neurotoxins

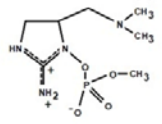
Anatoxin-a



Homoanatoxin-a



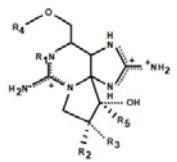
Anatoxin-a(s)



Health Effects

Short-Term
- Paralysis
- Death

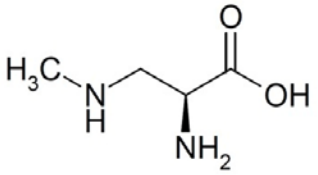
Saxitoxin



Toxin	R_1	R_2	R_3	R_4	R_5
STX	H	H	H	$CONH_2$	OH
GTX2	H	H	OSO_3^-	$CONH_2$	OH
GTX3	H	OSO_3^-	H	$CONH_2$	OH
GTX5	H	H	H	$CONHSO_3^-$	OH
C1	H	H	OSO_3^-	$CONHSO_3^-$	OH
C2	H	OSO_3^-	H	$CONHSO_3^-$	OH
C3	OH	H	OSO_3^-	$CONHSO_3^-$	OH
C4	OH	OSO_3^-	H	$CONHSO_3^-$	OH
neoSTX	OH	H	H	$CONH_2$	OH
GTX1	OH	H	OSO_3^-	$CONH_2$	OH
GTX4	OH	OSO_3^-	H	$CONH_2$	OH
GTX6	OH	H	H	$CONHSO_3^-$	OH
dcSTX	H	H	H	H	OH
dcneoSTX	OH	H	H	H	OH
dcGTX1	OH	H	OSO_3^-	H	OH
dcGTX2	H	H	OSO_3^-	H	OH
dcGTX3	H	OSO_3^-	H	H	OH
dcGTX4	OH	OSO_3^-	H	H	OH
LWTX1	H	OSO_3^-	H	$COCH_3$	H
LWTX2	H	OSO_3^-	H	$COCH_3$	OH
LWTX3	H	H	OSO_3^-	$COCH_3$	OH
LWTX4	H	H	H	H	H
LWTX5	H	H	H	$COCH_3$	OH
LWTX6	H	H	H	$COCH_3$	H

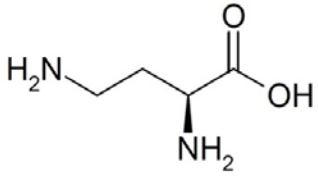
"Emerging" Neurotoxin
β-Mehylamino-L-Alanine (BMAA)

Biosynthesis
Potentially all species of cyanobacteria



Toxicity
Neurotoxin
(biomagnification)

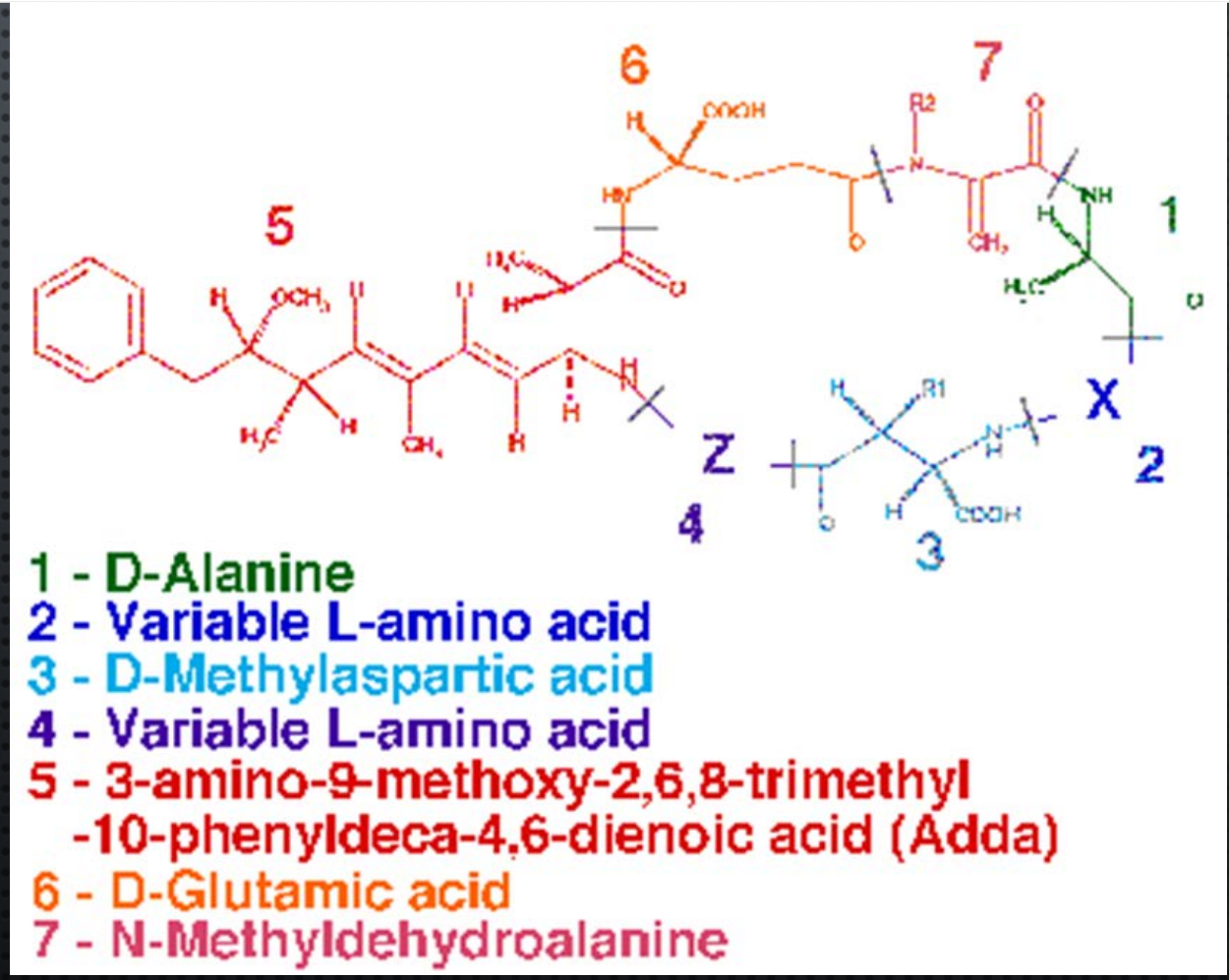
Health Effect
Long-term
Potentially involved in neurodegenerative diseases (ALS, Parkinson)



MICROCYSTIN

- CYCLIC HEPTAPEPTIDE
- BETWEEN 60 AND 140 VARIANTS (DEPENDING ON WHO YOU ASK!)
- MICROCYSTIN-LR IS THE MOST COMMON.
- VARIANT IS DEPENDENT UPON THE L-AMINO ACID STRUCTURE.

Name	X-position Amino Acid	Z-position Amino Acid	Molecular Weight
Microcystin LA	Leucine (L)	Alanine (A)	910.06
Microcystin YR	Tyrosine (Y)	Arginine (R)	1045.19
Microcystin RR	Arginine (R)	Arginine (R)	1038.2
Microcystin LR	Leucine (L)	Arginine (R)	995.17

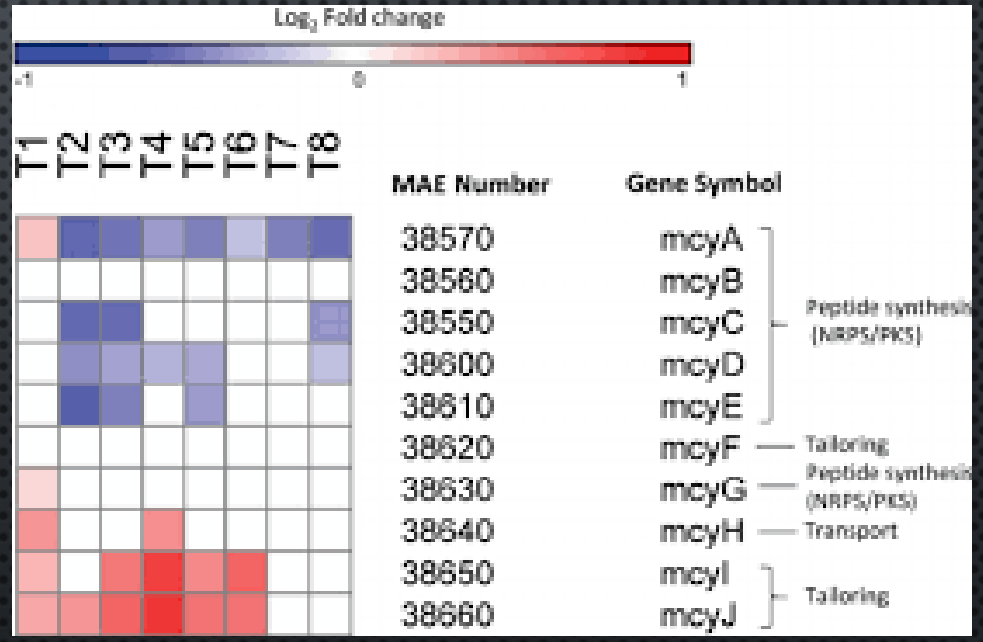


Stress agents and microcystin production

- Iron limitation/siderophores (Orr & Jones, 1998)
- Defense mechanism (Rohrlach et al, 1999)
- Photosynthesis/Light (Young et al, 2005)
- Intracellular, interspecies communication (Schatz et al, 2005)
- Trace metals (Lucak & Aegerter, 1993)

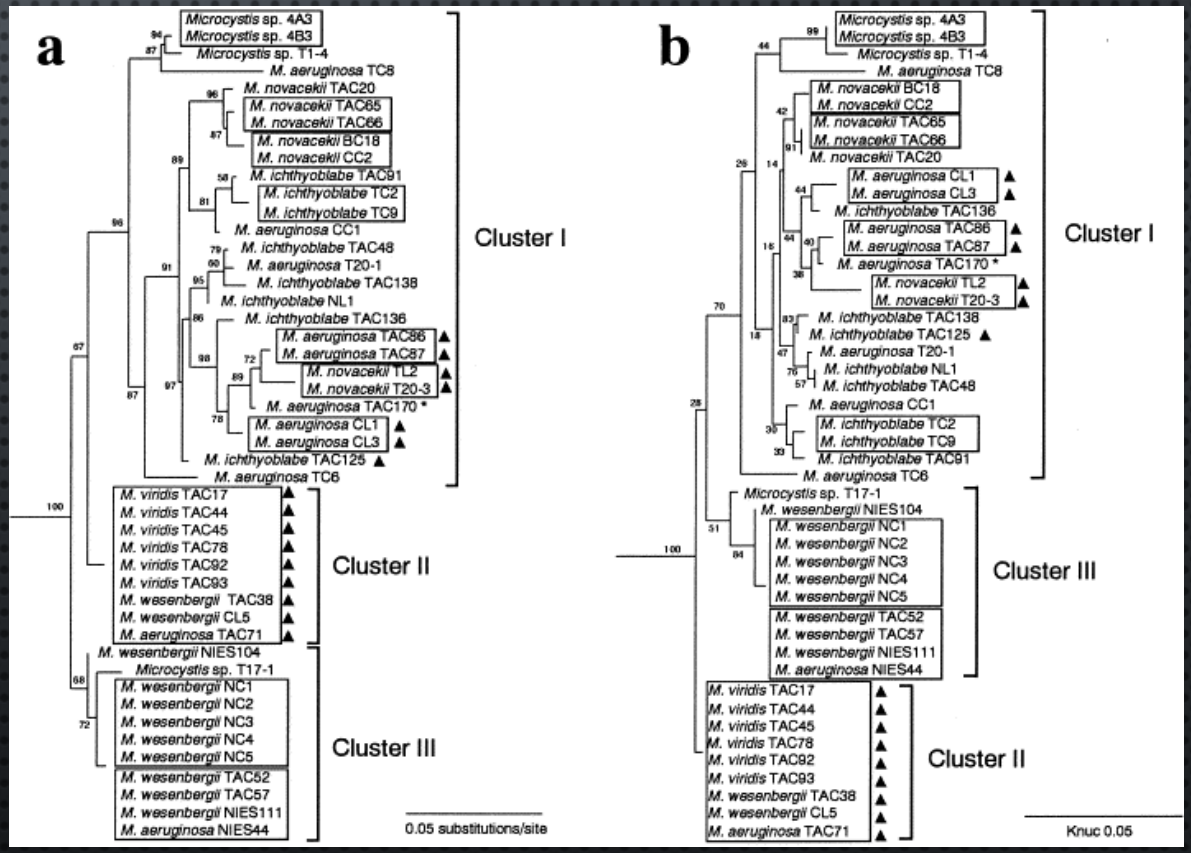
GENE REGULATION OF MICROCYSTIN

- INTRACELLULAR ROLE IS STILL UNDER INVESTIGATION
- GENE EXPRESSION AND REGULATION CAN CONTRIBUTE TO THE UNDERSTANDING OF TOXIN PUTATIVE CELLULAR FUNCTION.
- GENE CLUSTERS MCYA, MCYD, AND MCYE
- NTCA (GLOBAL NITROGEN REGULATOR) HAS BEEN DESCRIBED AS A POTENTIAL COMPONENT IN THE CONTROL OF MICROCYSTIN BIOSYNTHESIS.
  - DIRECT CORRELATION BETWEEN TRANSCRIPTS OF *MCYD* AND *NTCA* GENES HAS BEEN IDENTIFIED (PIMENTEL & GIANI, 2014)



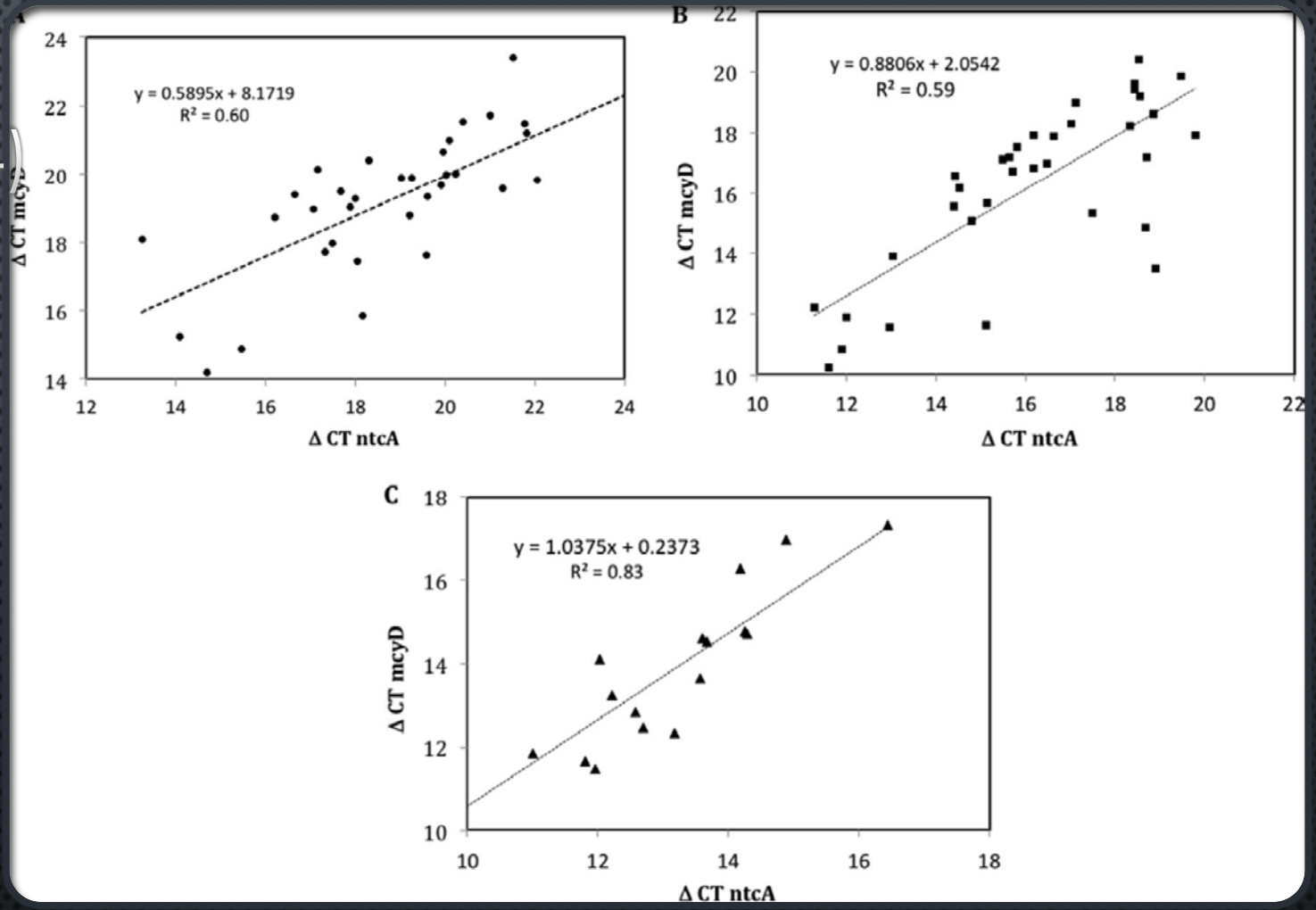
STRAIN-SPECIFICITY AND BIOMASS

- NOT ALWAYS A CORRELATION BETWEEN OVERALL BIOMASS AND TOXIN PRODUCTION.
  - RELATIVELY LOW BIOMASS AND A "HOT" STRAIN TRIGGERED BY ENVIRONMENTAL CONDITIONS
  - HIGH BIOMASS AND LOW-NO TOXICITY
- OFTEN, TOXIN PRODUCTION ISN'T EVEN SPECIES-SPECIFIC, BUT STRAIN-SPECIFIC.



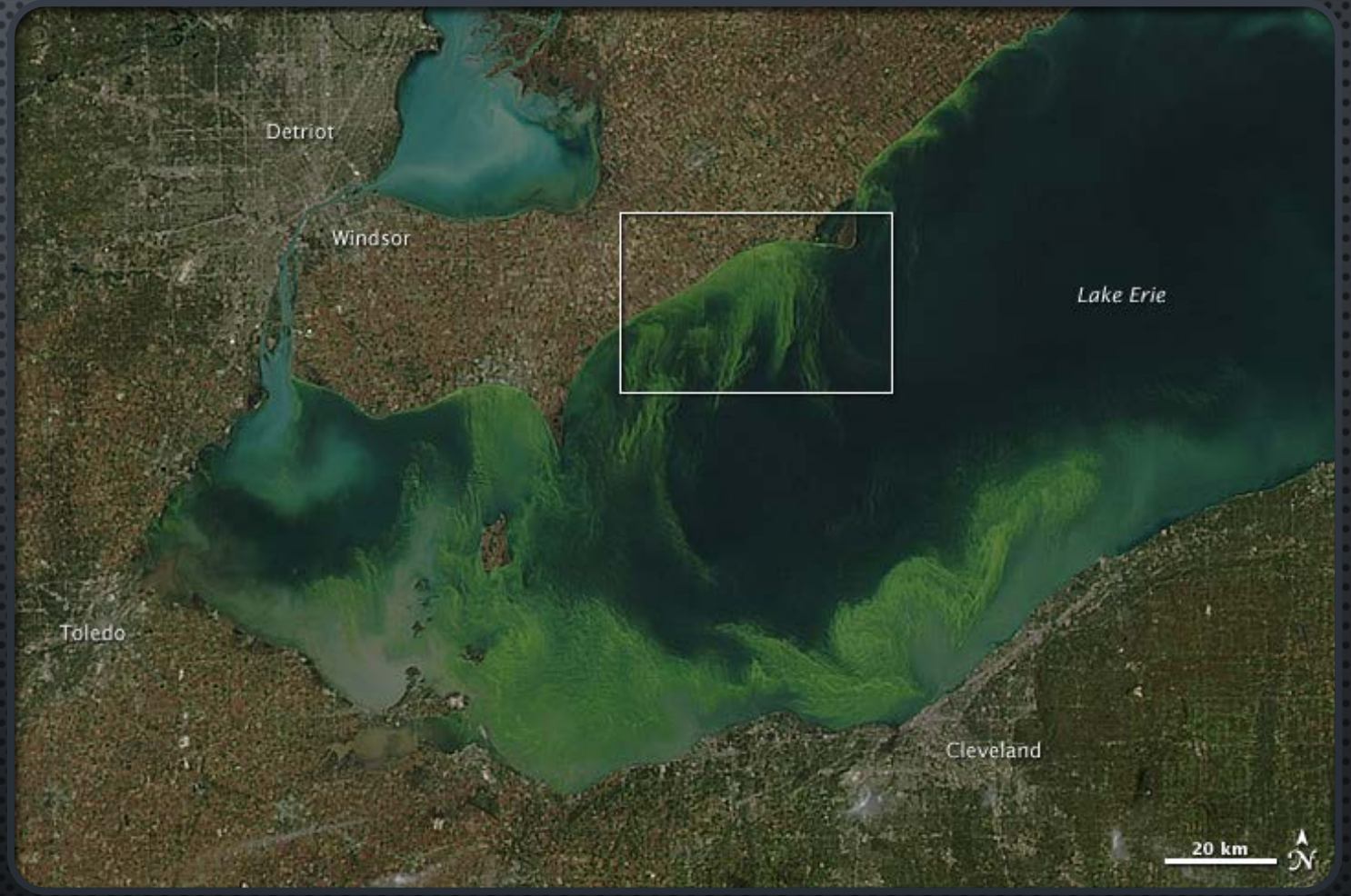
NUTRIENT LIMITATION (PIMENTEL & GIANI, 2014)

- MCYD GENE EXPRESSION SHOWS CHANGES UNDER ALL EXTREME LIMITING CONDITIONS.
- THE *NTCA* GENE SHOWED A SIGNIFICANT INCREASE IN ITS EXPRESSION IN ALL EXPERIMENTS UNDER LIMITATION.
- ALTHOUGH OVERALL BIOMASS DECREASES, MICROCYSTIN CONCENTRATION/CELL GREATLY INCREASES.



GREAT LAKES EXAMPLE

- *Quagga mussel have been shown to strongly affect the foodweb structure and biogeochemical cycles of nutrients after their introduction to the Great Lakes.*
- Vanderploeg et al (2010) noticed the absence of the spring phytoplankton bloom in Lake Michigan.
- Cuhel & Aguilar, 2013. Found that quagga mussel affect nutrient cycling more so than zebra mussel.
- Bunnel et al (2014) Reported tht, Since 1998, Lakes Superior, Michigan, and Huron have shown evidence of oligotrophication.
    - Binding et al (2015) found the same using long-term satellite data



Oligotrophication….sort of

- Microcystis in Havasu likely shouldn't be blamed on increasing eutrophication.
- There's likely a shift of nutrients (and food web dynamics) towards the benthos
  - Only some fraction of those nutrients may make it back to overlying water and available for phytoplankton growth.
- Cyanobacteria have mechanisms for obtaining nutrients other phytplankters do not.
  - Nitrogen fixation, heterocysts
  - "Luxury" uptake of P
- Toxin production may occur toward the end of a bloom rather than during a growth phase.

TOXIN PRODUCTION IS FLASHY

- INCREASES DANGER AND RISK.
- CURRENTLY, IMPOSSIBLE TO PREDICT.
  - EVEN WITH SATELLITE IMAGERY.
- WE CAN'T CONTINUOUSLY MONITOR.
  - LONG-TERM DEPLOYMENT OF SONDES FOR CYANOBACTERIA EXIST (PHYCOCYANIN)
  - RESOLUTION OF *IN SITU* MEASUREMENTS OF TOXINS IS NOT GREAT.
- LC-MS-MS AND/OR ELISA HAVE MUCH HIGHER PRECISION AND ACCURACY, BUT TAKE TIME TO GET RESULTS BACK.

Needs

- We should at least determine which strain(s) of microcystis exist, on a seasonal basis, in Havasu.
- We should likely include BMAA in the cyanotoxin suite.
  - We can likely drop anatoxin
- Determine compartmentalism of nutrients.
  - Especially in the benthos
  - Perhaps using stable radioisotopes
- Once strains have been identified, determine potential causative agents of toxin production.
  - Including but not limited to, nutrient-limitation

- https://cchab.sfei.org/

QUESTIONS?