University of South Carolina

"The Effects of Climate Change and Urbanization on the Virulence and Antibiotic Resistance of Vibrio Bacteria and Harmful Algal Blooms (HABs) Affecting Seafood Safety and Contact Recreation in the Coastal Zone"

Geoffrey I. Scott

Professor and Chair

Dept. of Env. Health Sciences and

Director of the NIEHS Center for Oceans and Human Health

and Climate Change Interactions

Arnold School of Public Health

University of South Carolina

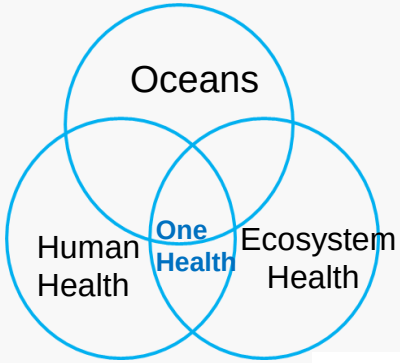
Columbia, SC 29208

(email: giscott0@mailbox.sc.edu; Phone: 803/777-8964)

Center for Oceans and Human Health and Climate Change Interactions at the University of South Carolina

NIH NIEHS

Oceans and Human Health



- **Traditionally Ocean Health Assessments** – Man's Impact on **Ecosystem Health**
- If human impacts make the ocean environment unhealthy then we need to be concerned about **Human Health**
- **Oceans and Human Health – A One Health Concept** that Attempts to Complete the Full circle by Connecting Ocean Health & Human Health = **One Health Approach**

OHHC²I

NIEHS Center for Oceans and Human Health on Climate Change Interactions at the University of SC

- **USC is one of 4 OHH Centers funded by NSF and NIEHS OHH Program**

- **Focus: OHHC²I** 's main purpose will be to assess the effects of ocean health-related illness and disease and then to use this information to develop prevention strategies against ocean-related illness and disease to better protect public health.

- **Focus**: Climate change-related factors that may enhance the presence, abundance and virulence of ***Vibrio Bacteria*** and ***Freshwater Harmful Algal Blooms and effects of microplastics.***

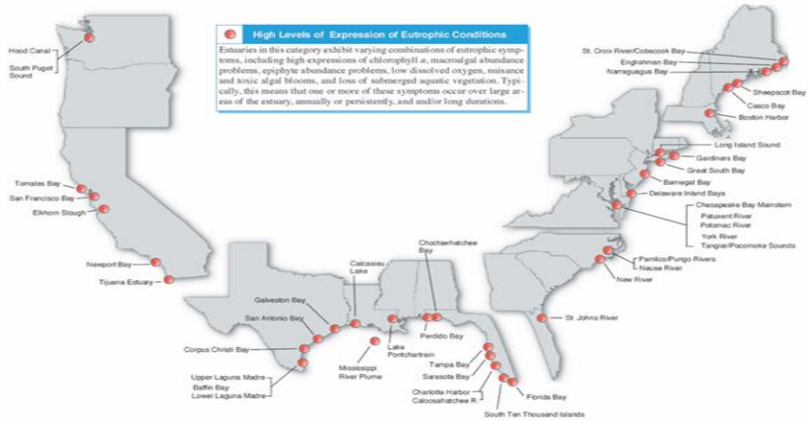
Sir John Snow: *V. cholerae* Outbreak In London 1854

Center for Oceans and Human Health and Climate Change Interactions
at the University of South Carolina

Urbanization and Climate Change

Urbanization Effects

- Hydrological Cycle
- Nitrogen Cycle
- Phosphorous Cycle

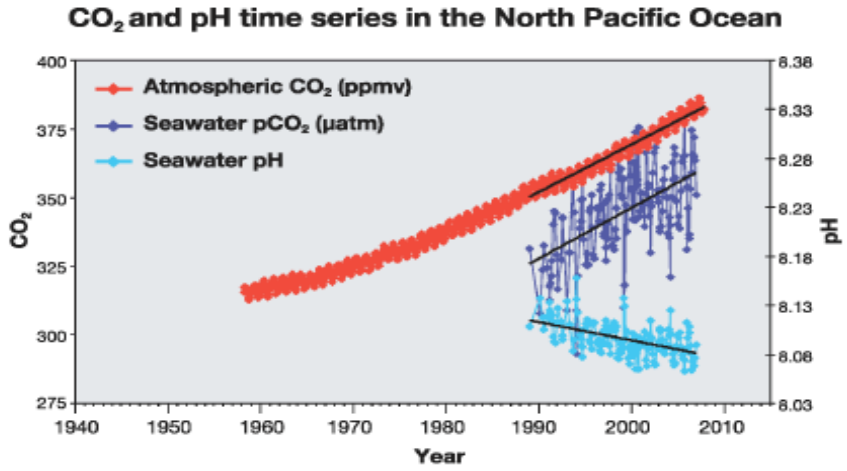


Hypoxia (lack of oxygen) and Eutrophication (increased nutrients) are Common Effects

- Legacy Pollutants & Contaminants of Emerging Concern

Climate Change

- Carbon Cycle
- Sea Level Rise
- Ocean Acidification



-Temperature, Salinity, & pH

- ***Interactions of Future Climate Change & Urbanization Effects?***

Impacts of Pathogens and HABs

Marine and Coastal Waters

- Pathogens may cause disease in humans from consumption of food, drinking water and contact recreation, such as swimming. Effects may include gastrointestinal effects, upper respiratory illness and would infections.

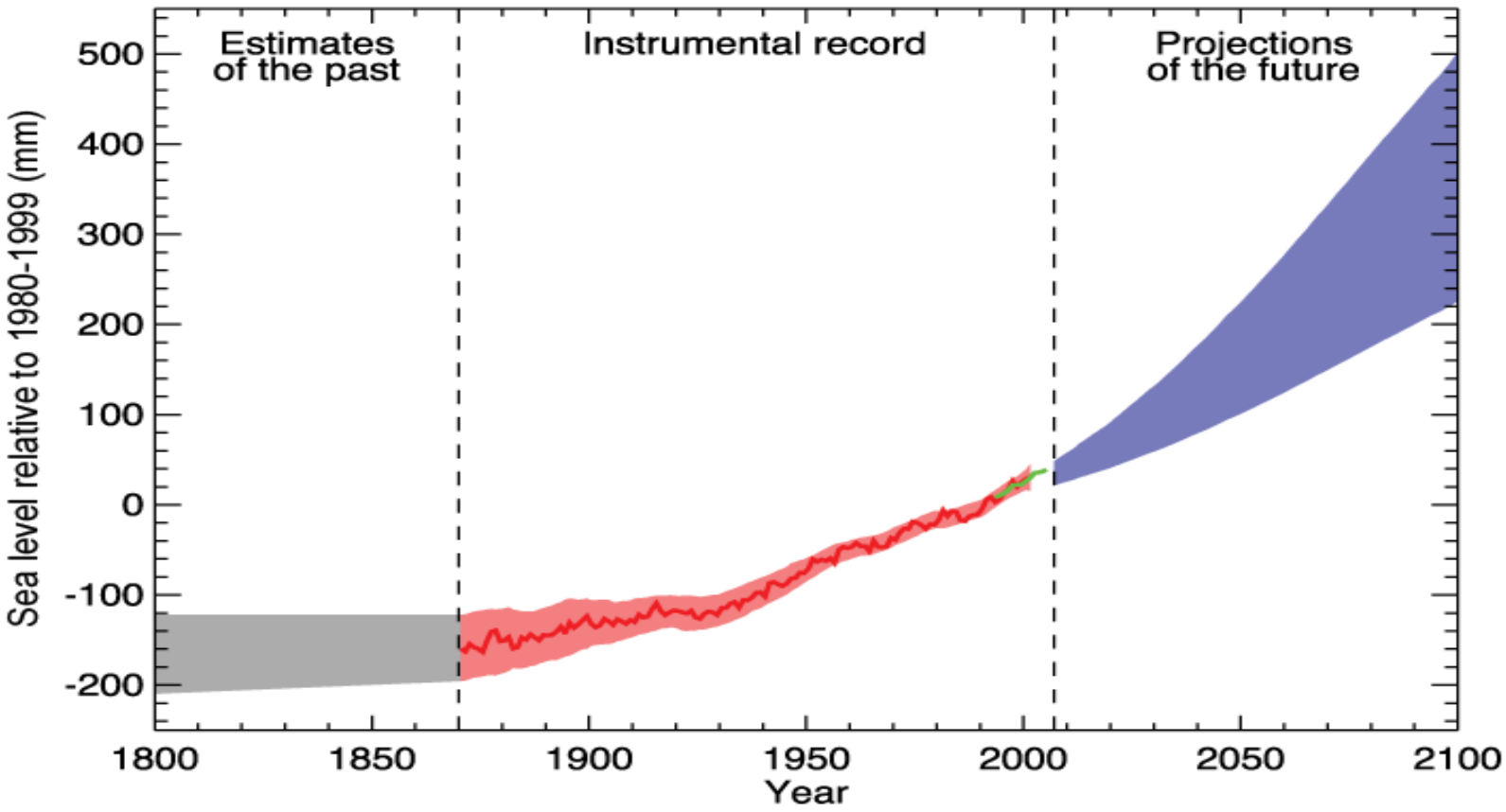
- The health consequences due to **marine-borne pathogens in the USA** have annual costs on the order of **$900 million** (Ralston et al., 2011). This includes:

- **$350 million** due to pathogens and marine toxins specifically identified as causing **food-borne disease**,
- **$300 million** due to seafood-borne disease with **unknown etiology**,
- **$300 million** due to gastrointestinal illness from **beach recreation** and
- **$30 million** from direct exposure to the **Vibrio species** (Ralston et al., 2011).

Freshwater

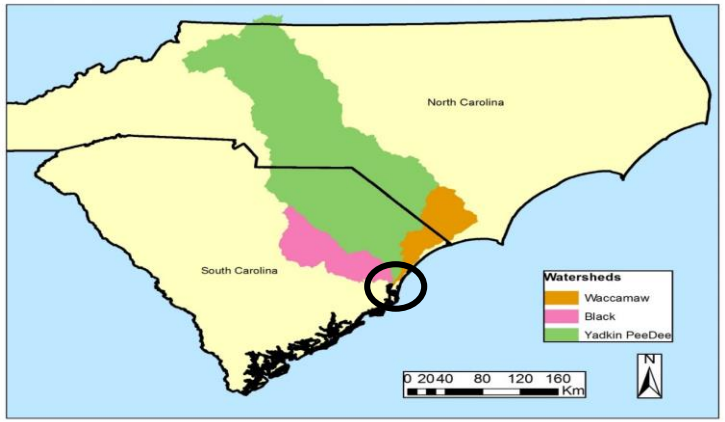
- **> 4 Billion Public Health Events with > 90 million Cases of gastrointestinal, upper respiratory, eye, ear and skin illnesses/year in the US** associated with swimming, paddling, motor-boating, and fishing costing **> $2.2-$3.7 Billion** (DeFlorio-Baker et al., 2018. *Environmental Health* 17:3 DOI 10.1186/s12940-017-0347-9)

Climate Change Sea Level Rise

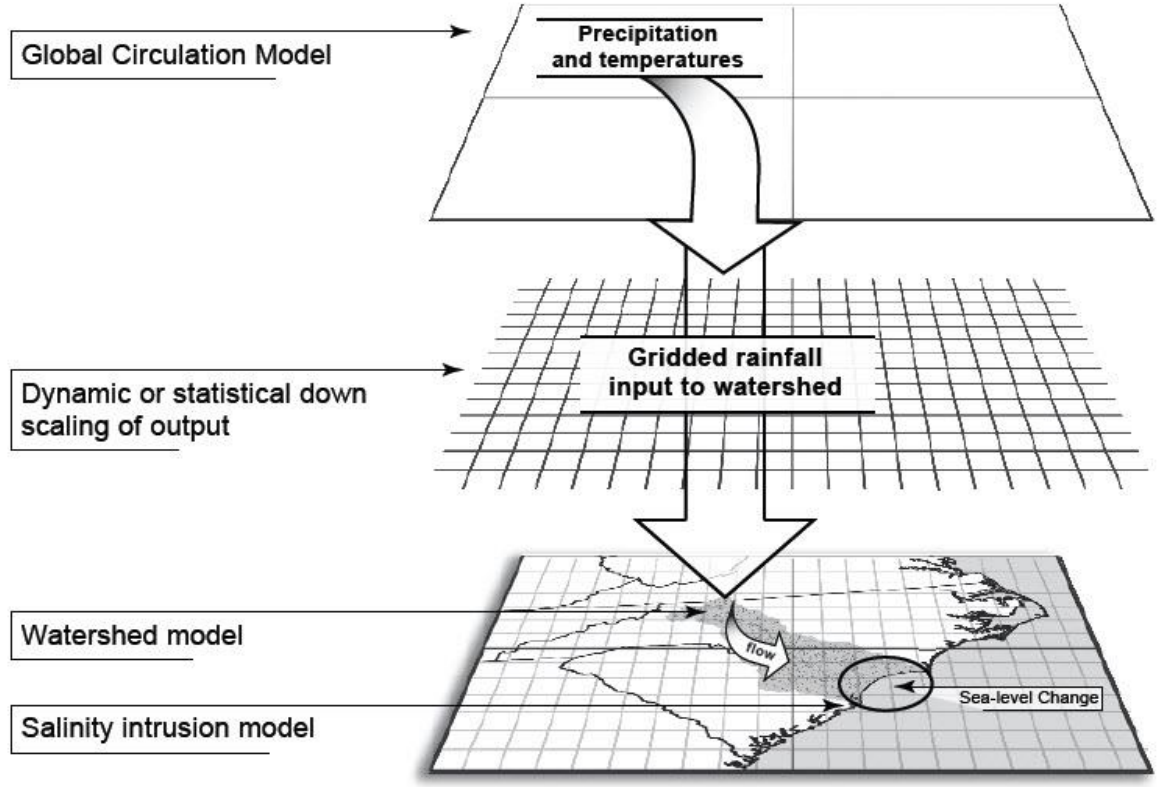


Climate Downscaling for the Nueral Network Watershed Model

- **Multi-Linear Regression Model** for the environmental variables to predict *Vibrio vulnificus* densities:
  - Conductivity ($p < 0.0001$)
  - Turbidity ($p < 0.0001$)
  - Temperature ($p < 0.0654$)



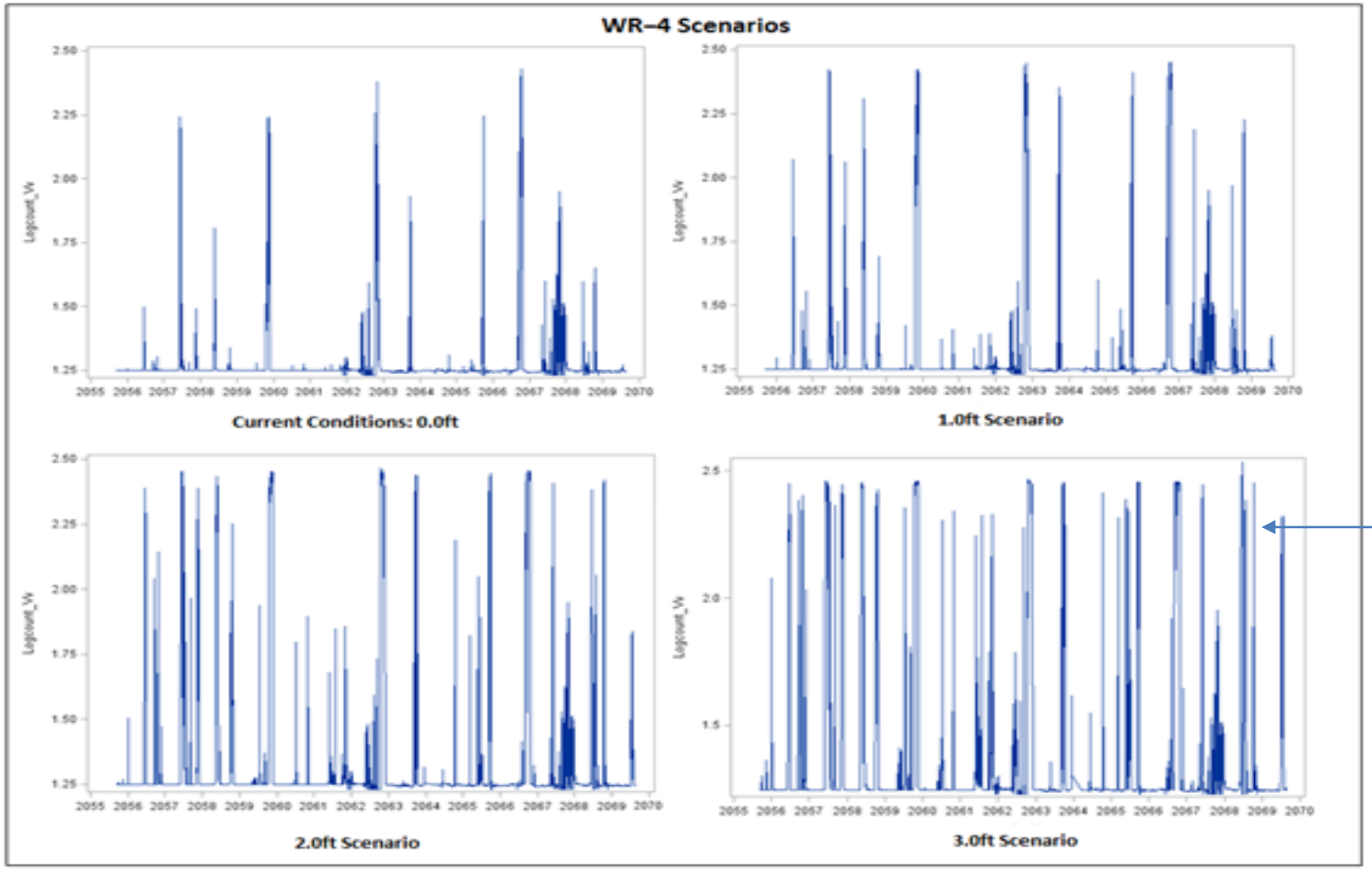
USGS and CISA Neural Network Model



Source: Conrads et al (2013)

- We used five different GCMs – spanning a range of predictions
- Two simulation periods
  - Historic 1981 – 2010
  - Future 2041 – 2070

Winyah Bay Station WR 4: Future *Vibrio vulnificus* Abundances with different Sea Level Rise Predictions and Vibrio Algorithm



Spikes = Periods of Optimum Vibrio Growth Conditions

A 230% Increase In Optimum Vibrio Growth Conditions With a 3' Sea Level Rise

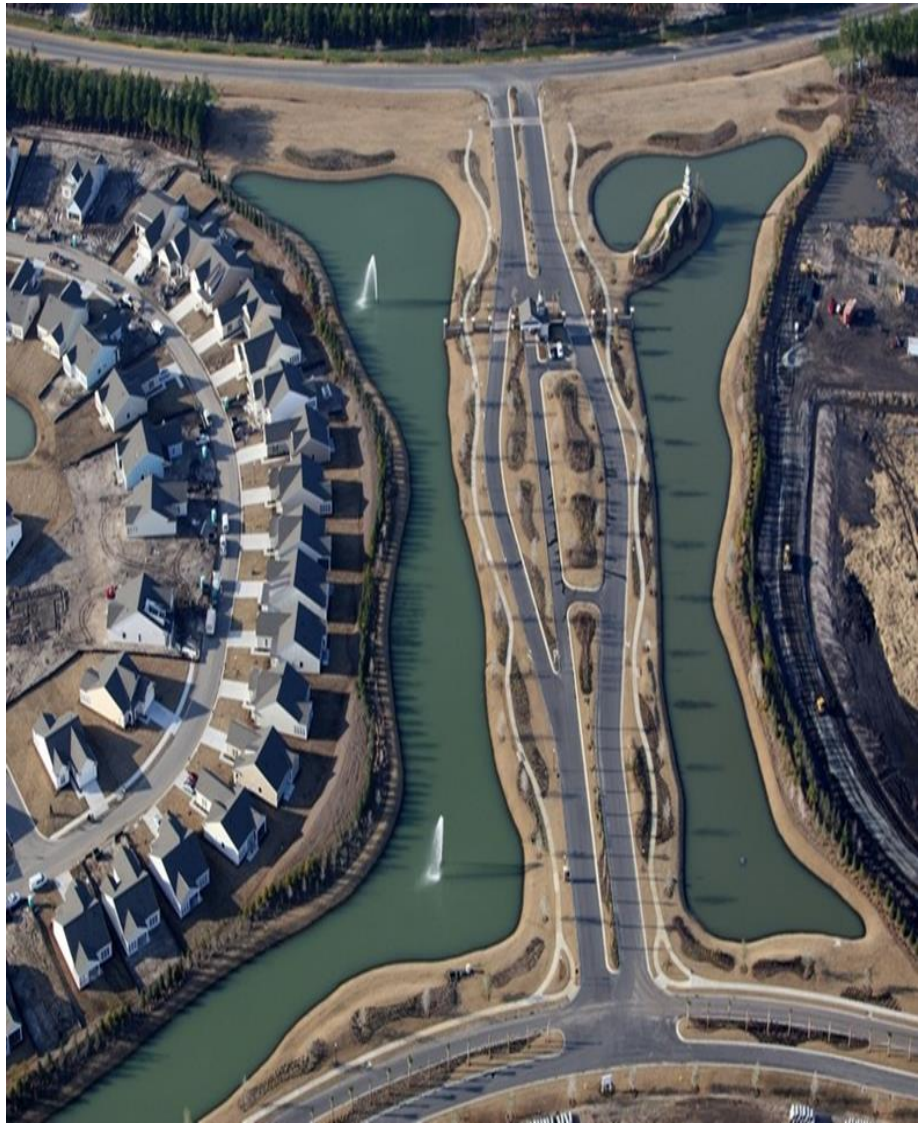
(Deeb et al., 2018. *Estuaries and Coast* 41(8): 2289–2303)

SC Sea Grant: Urbanization and Stormwater Ponds in SC

- To control the NPS pollution associated with this coastal urbanization, stormwater ponds have been constructed to collect runoff and reduce pollution loadings in estuarine tidal creeks.

- Many are constructed in urban areas associated with residential development.

- **SC** - 21,594 Ponds Total with a cumulative area of 29,395 acres of ponds (45.9 sq. miles) and 50% of these ponds have people living on these (Dr. Eric Smith, 2020)



Trace Metal Pollution and Antibiotic Resistance

Resistance mechanism	Metal ions	Antibiotics	Refs
Reduction in permeability[b]	As, Cu, Zn, Mn, Co, Ag	Cip, Tet, Chlor, ß-lactams	[68,69]
Drug and metal alteration[c]	As, Hg	ß-lactams, Chlor	[70,71]
Drug and metal efflux[d]	Cu, Co, Zn, Cd, Ni, As	Tet, Chlor, ß-lactams	[72,73]
Alteration of cellular target(s)[e]	Hg, Zn, Cu	Cip, ß-lactams, Trim, Rif	[74,75]
Drug and metal sequestration[f]	Zn, Cd, Cu	CouA	[76,77]

[a]Abbreviations: Chlor, chloramphenicol; Cip, ciprofloxacin; CouA, coumermycin A; Rif, rifampicin; Tet, tetracycline; Trim, trimethoprim.

[b]Includes reduction of membrane permeability to metals and antibiotics.

[c]Includes drug and metal inactivation and modification.

[d]Includes rapid efflux of the metal and antibiotic.

[e]Includes alteration of a cellular component to lower its sensitivity to the toxic metal and antibiotic.

[f]Includes drug and metal sequestration.

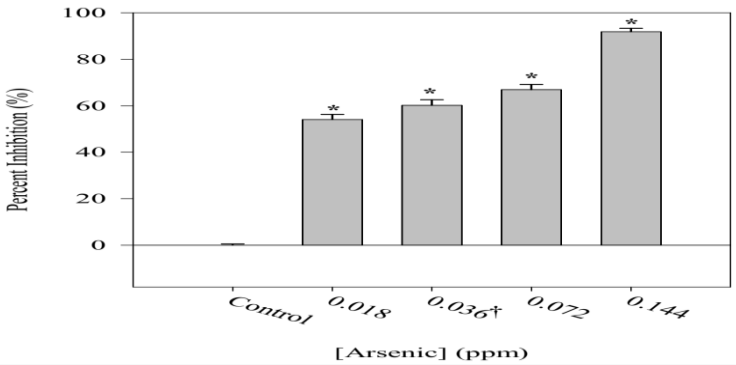
Retention Ponds had the Highest Concentrations of Cd, Cu, Cr, & Zn

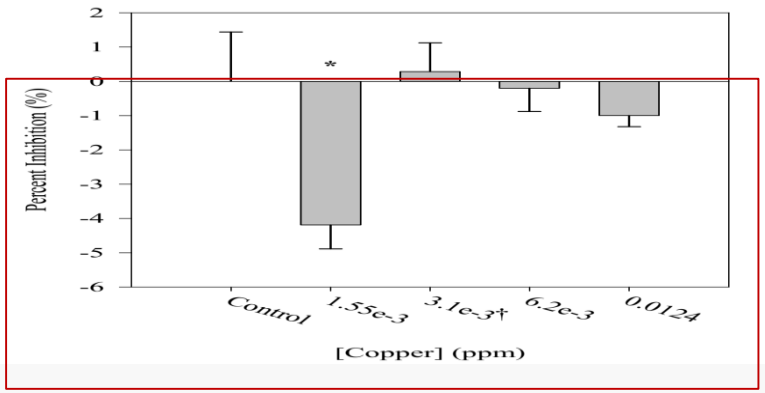
(Source: Baker-Austin et al. 2006. Trends in Microbiology 14(4): 176-182)

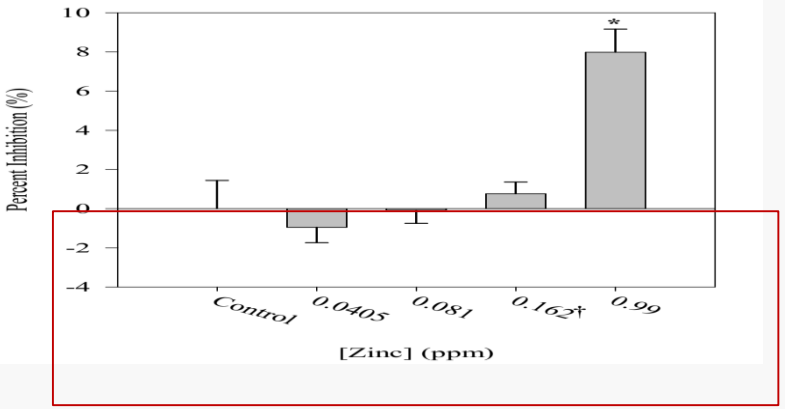
Vibrio vulnificus: Growth Response to Trace Metals

NIEHS Center for Oceans and Human Health and Climate Change Interactions at the University of SC

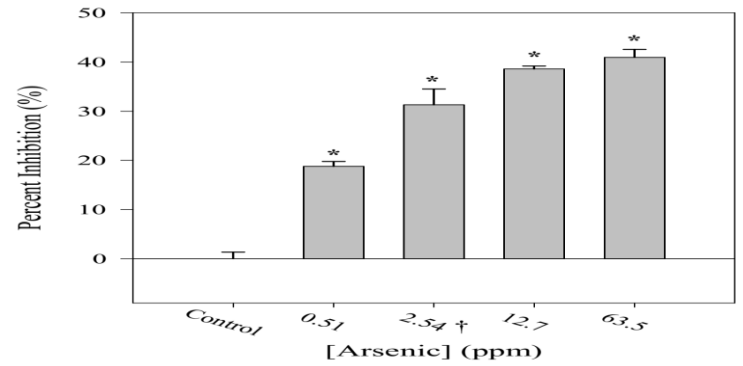
Criterion Continuous Criteria (Chronic Water Quality Criteria)

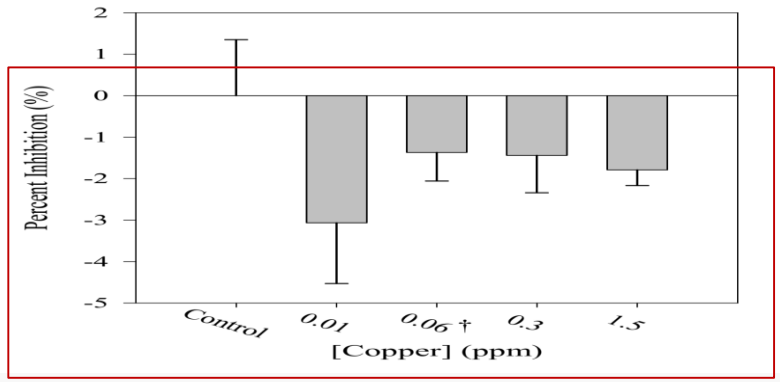


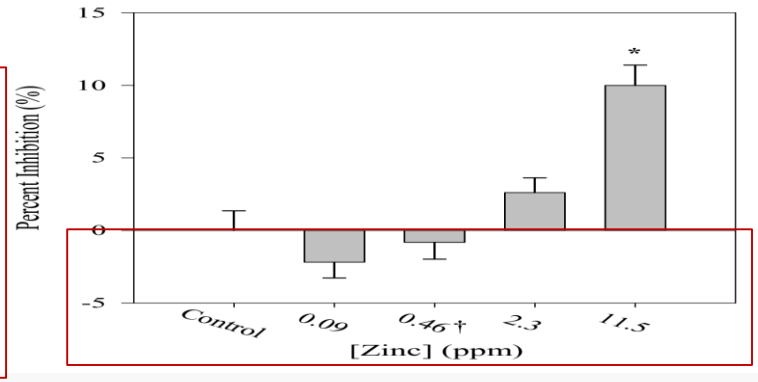




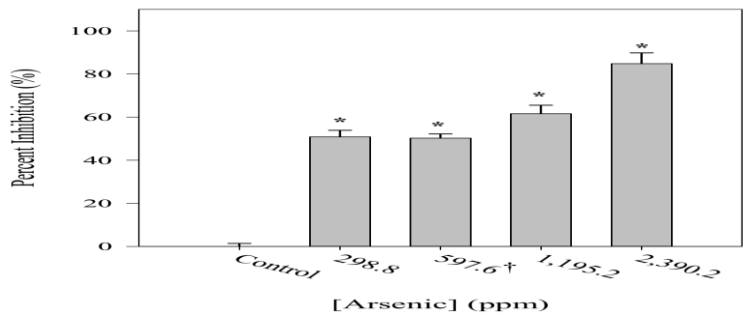
Acute LC_{20}

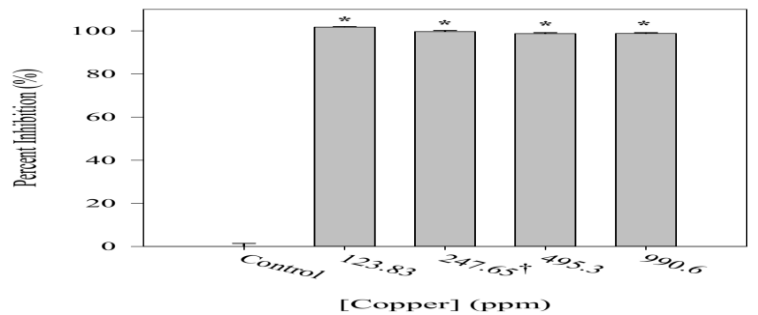


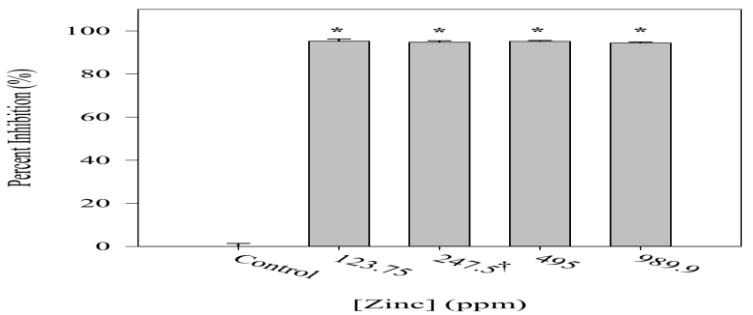




Minimum Inhibitory Concentration



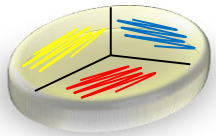




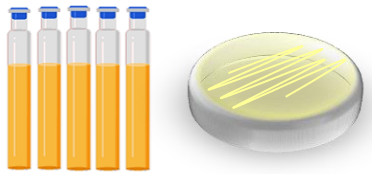
Frozen Stocks

Vibrio spp.
CHROMAgar Vibrio

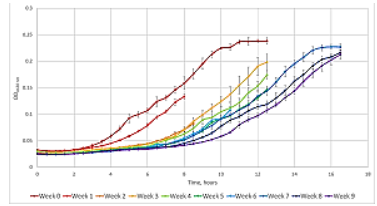
Fluorescent tagged
Vibrio spp.



Vibrio growth on different climate-link conditions



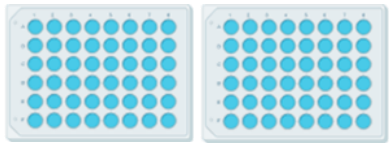
Vibrio altered growth conditions



Overnight Cultures under stress-inducing conditions

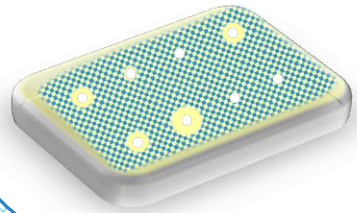
C. *elegans* Growth

Pathogenicity Assay:
C. *elegans* survival assay



Re-Isolation *Vibrio spp.*
CHROMAgar Vibrio

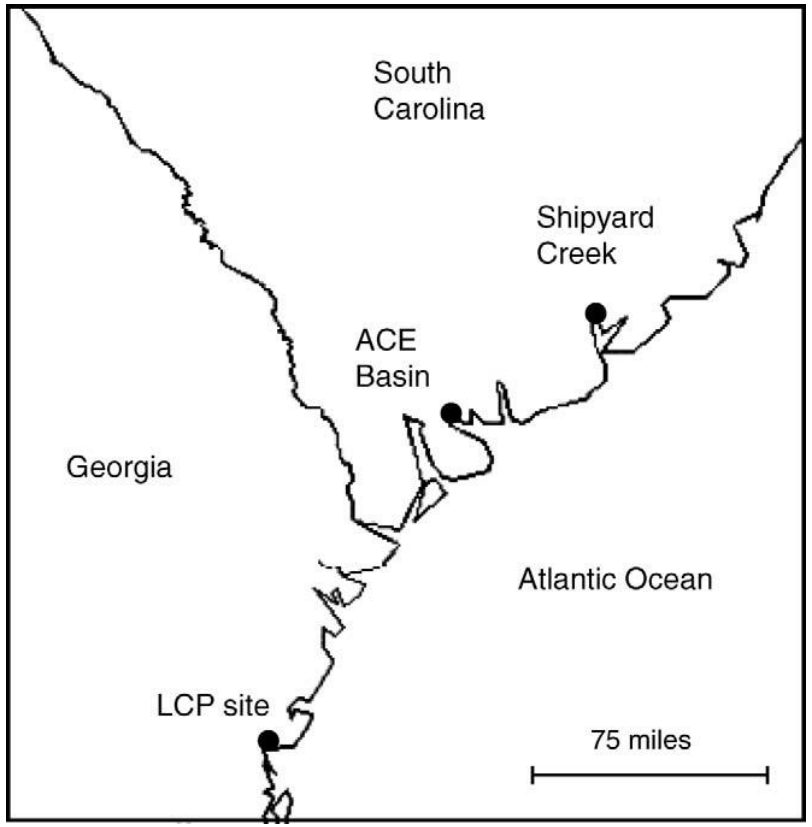
Antibiotic Resistance Assay

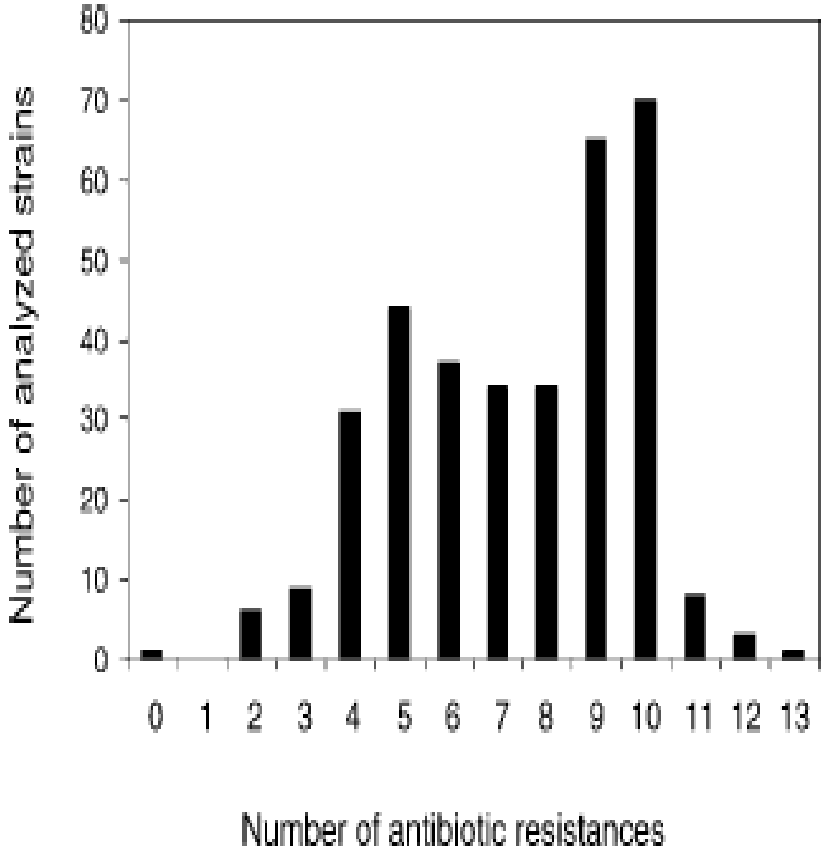


Determine how environmental parameters affect *V. vulnificus* and *V. parahaemolyticus* virulence and antibiotic resistance and virulence using a Caenorhabditis elegans model of pathogenicity.

Multifactorial Studies: Climate and Environmental Factors

Antibiotic Resistance in *Vibrio parahaemolyticus*

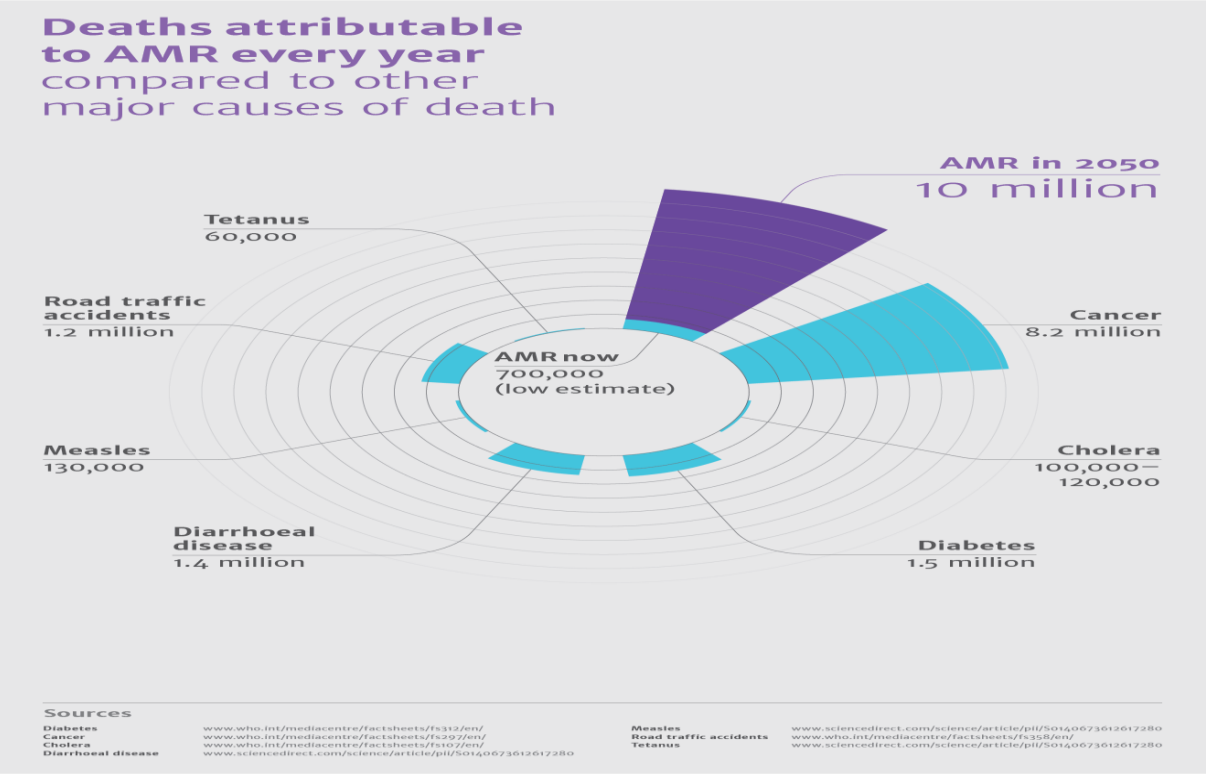




(Baker–Austin et al., 2008. Journal of Food Protection 71:2552)

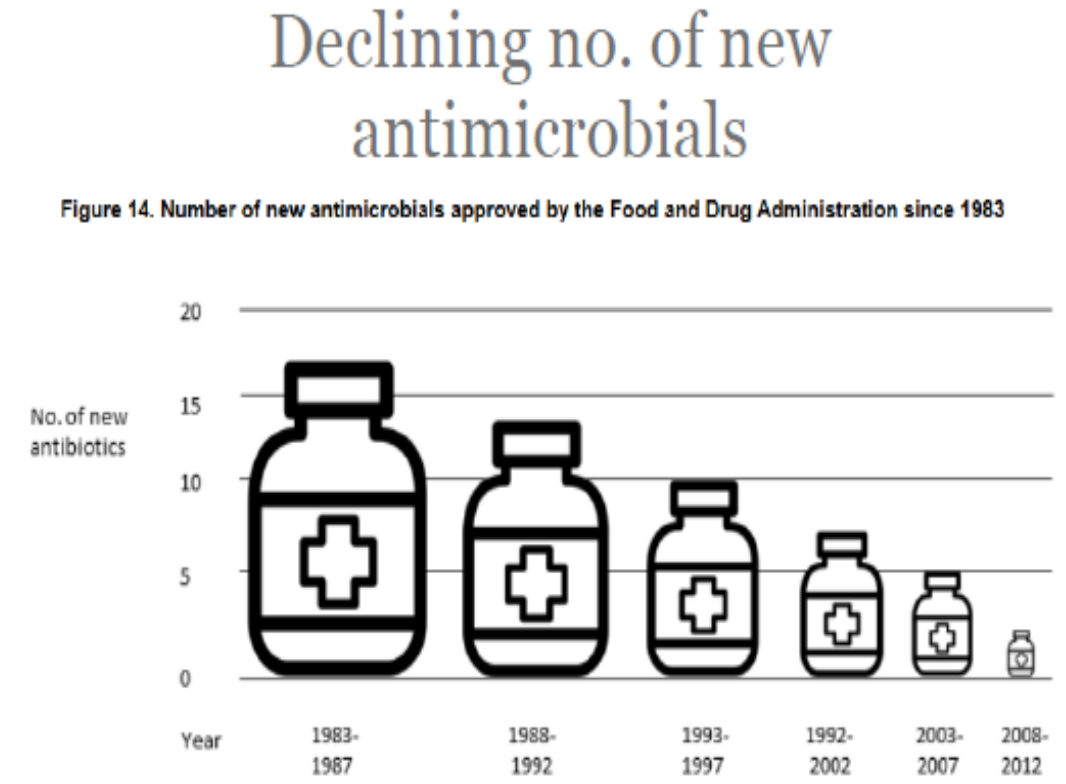
Cause for Concern ?

Global Deaths Attrubutal to AMR, 2015



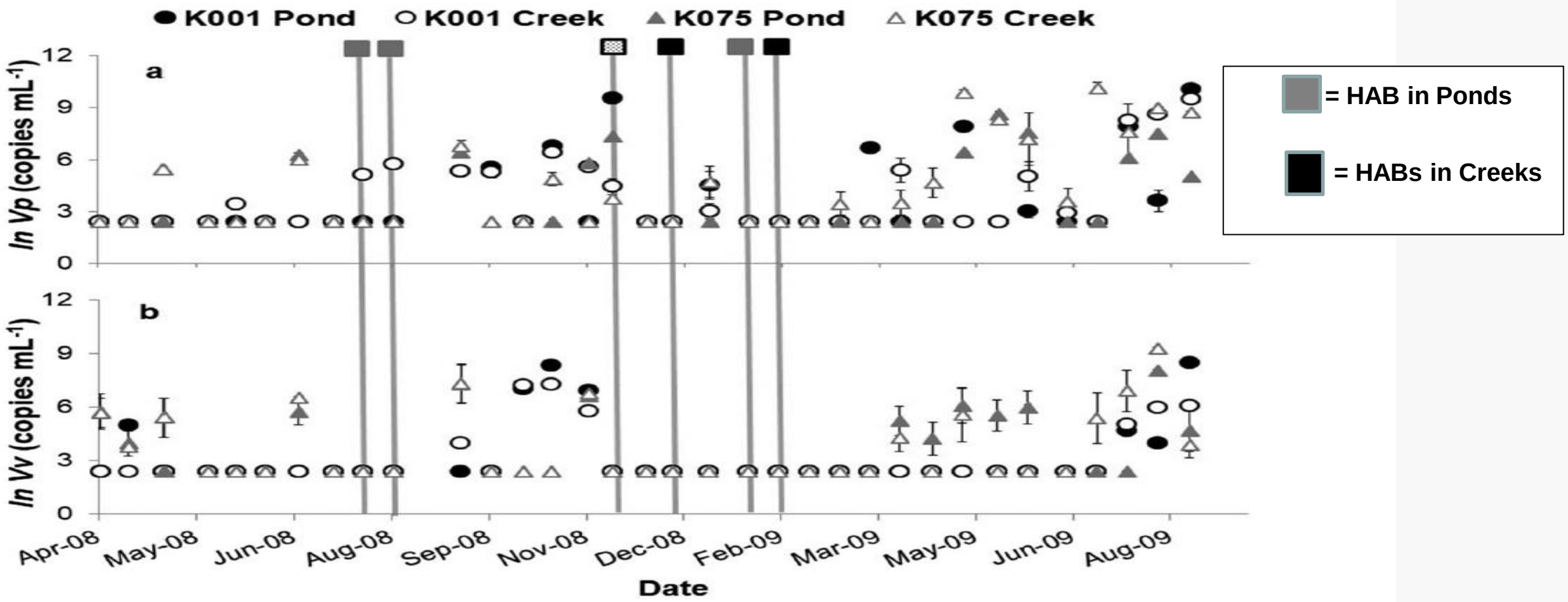
(**Reference:** O'neill, J. 2014. The Review of Antimicrobial Resistance. Study directed by UK Prime Minister)

Antibiotics in Shrinking Supplies



Source: Adapted from Infectious Diseases Society of America, 2011

Co-Occurence of Vibrios and HABs in Retention Ponds and Tidal Creeks



HABs Events (Cyanobacteria & Dinoflagellates)during warmer months (Aug- Nov) were followed by increased Vibrio abundances in both species while HAB events (dinoflagellates and euglenophytes) during cooler months(Dec-Feb) were not.

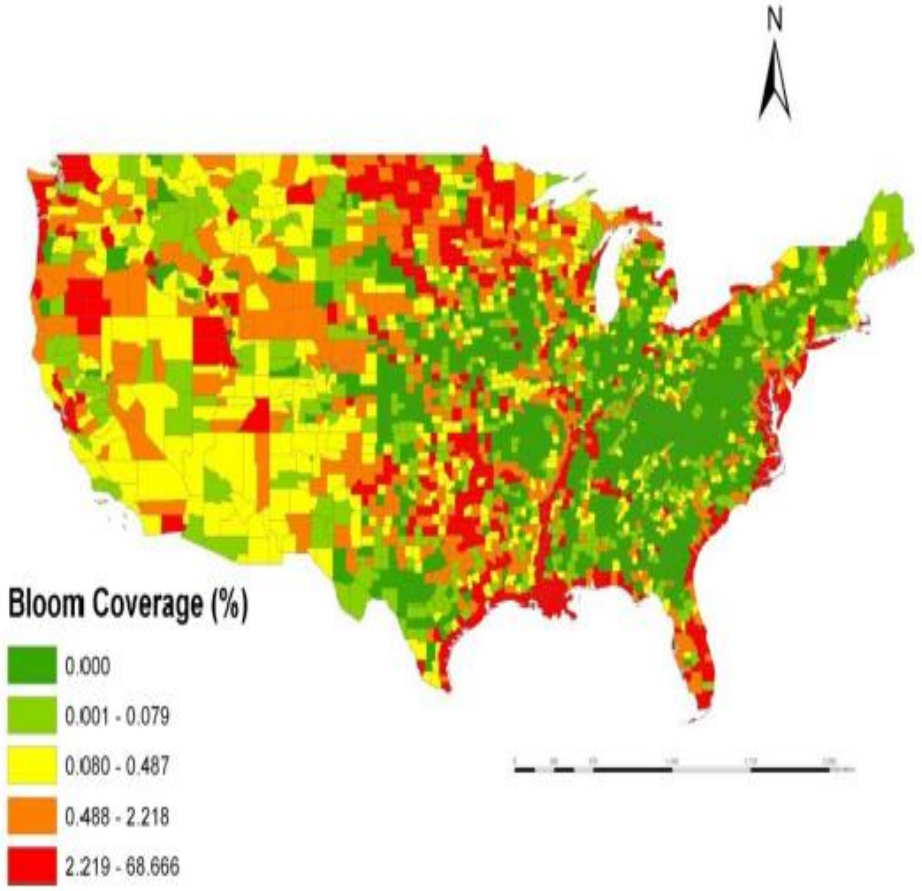
Vibrios Abundances were highly correlated with Temperature, DOM, and HAB Blooms!

(Source: Greenfield et al., 2017. GeoHeath10.1002/2017GH000094)

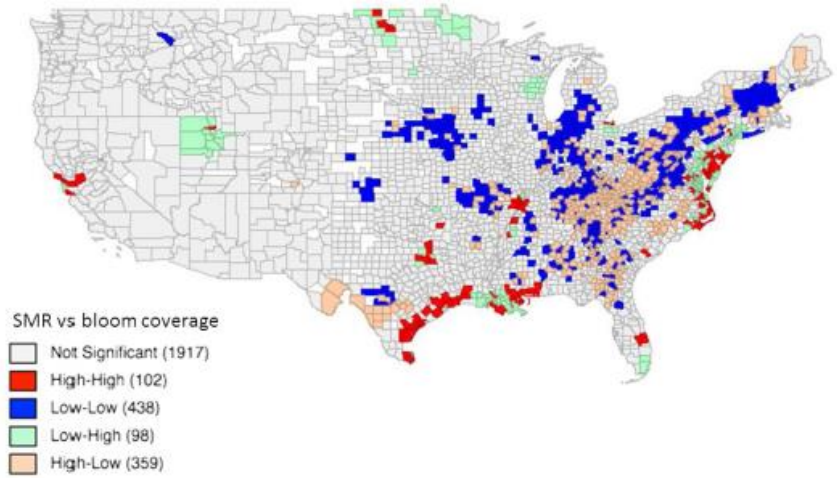
Correlation Between CHAB Blooms and Non-Alcoholic Fatty Liver Disease

(61% of US Counties Have CHABs and for Every 1% increase in CHABs Results in a 0.3% Increase in Non-Alcoholic Fatty Liver Disease)

CHAB Bloom Coverage



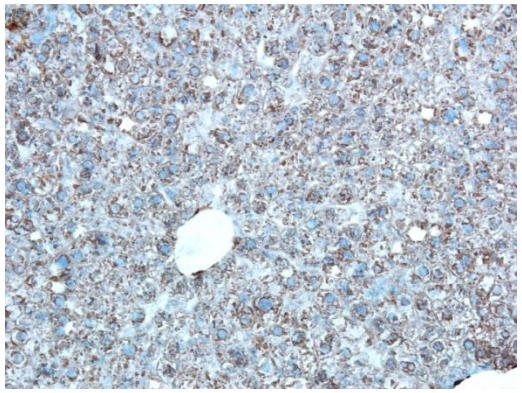
Fatty Liver Disease & CHABs



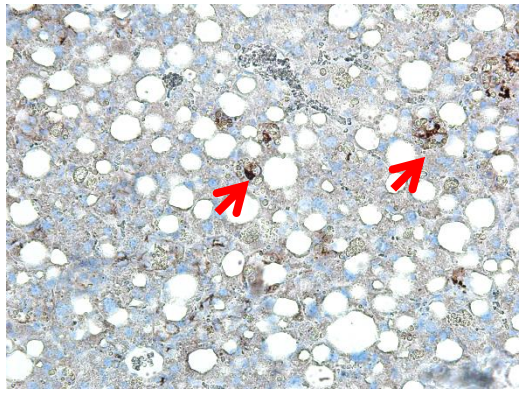
(**Source:** Zhang et al. 2015. Env. Health 14: 41-52)

Microcystin-Exposure in NAFLD Mice Leads to Stellate Cell Activation in the Liver (Pre Fibrotic Stage)

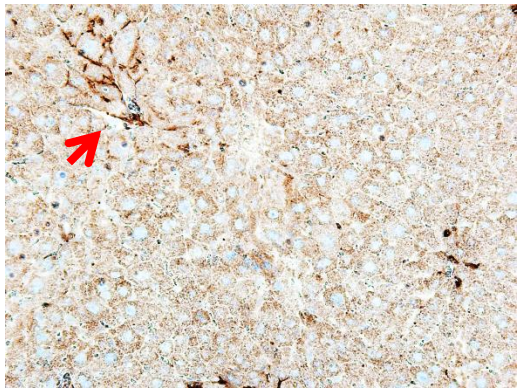
Alpha-Smooth Muscle Actin (marker for activated stellate cells)



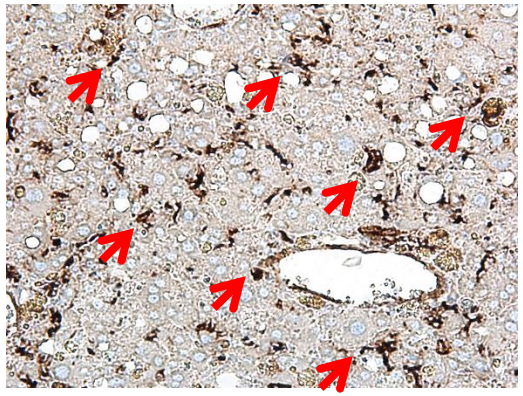
Healthy Controls



NAFLD

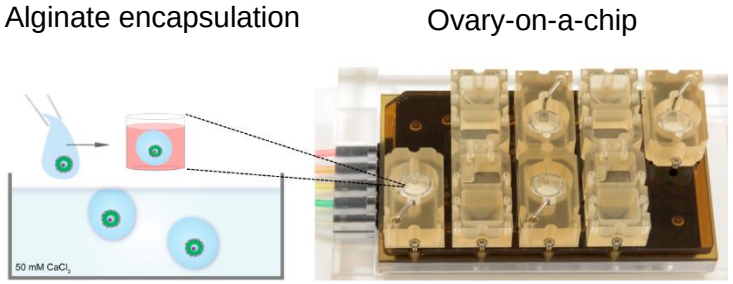


Healthy+ Microcystin



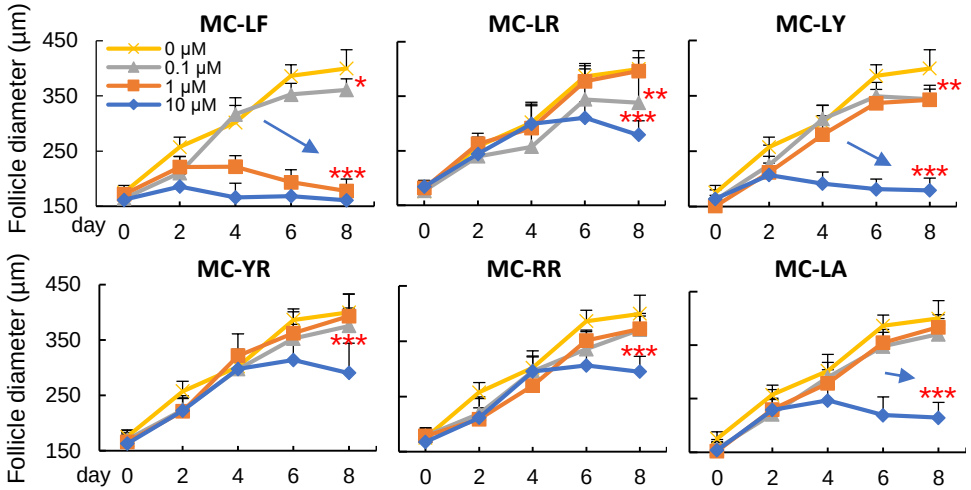
NAFLD + Microcystin

Use of a novel ovary-on-a-chip model to screen for the female reproductive toxicity of microcystins

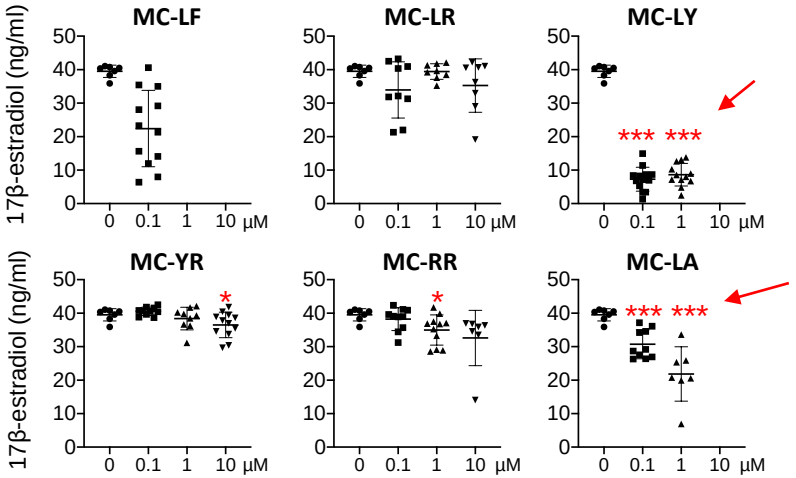


LF, LY & LA Isomers have Greatest EDC Effect not LR

Follicle growth and development

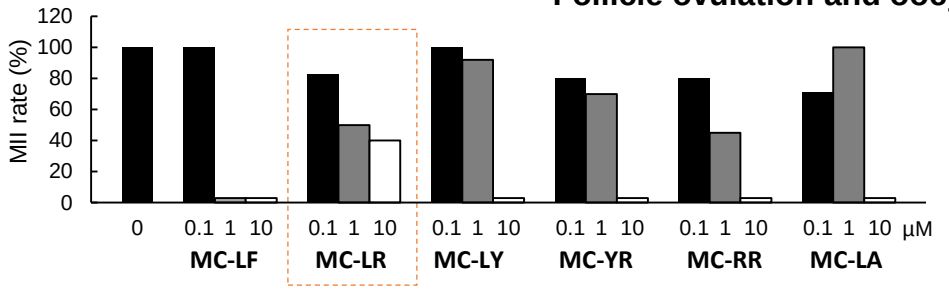


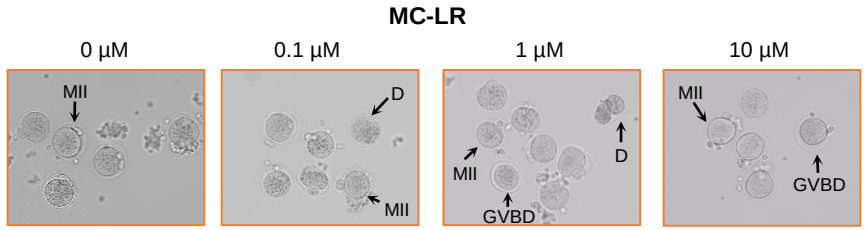
Ovarian hormone secretion



*p<0.05, **p<0.01, ***p<0.001

Follicle ovulation and oocyte meiotic maturation





Dr. Shou Xiao et al 2020.

Serum Microcystin Levels Positively Linked with Risk of Hepatocellular Carcinoma: A Case-Control Study in Southwest China

- Microcystins have been reported to be carcinogenic by animal and cell experimentation, but there are no data on the linkage between serum microcystins and hepatocellular carcinoma (HCC) risk in humans.
- In China a clinical case-control study was conducted to investigate the association between serum microcystins (MC-LR) and HCC risk after controlling several known risk factors, such as hepatitis B virus, alcohol consumption, and aflatoxin.
- The adjusted odds ratio for HCC risk by serum MC-LR was 2.9 (95% confidence interval [CI], 1.5-5.5) in all patients – establishing a clear relationship between MC-LR and HCC.
- Potential Additive Toxicological Interactions were investigated between MC-LR and hepatitis B virus infection (synergism index = 3.0; 95% CI, 2.0-4.5) and between MC-LR and alcohol (synergism index = 4.0; 95% CI, 1.7-9.5) = ***Suggesting Potential Synergism***

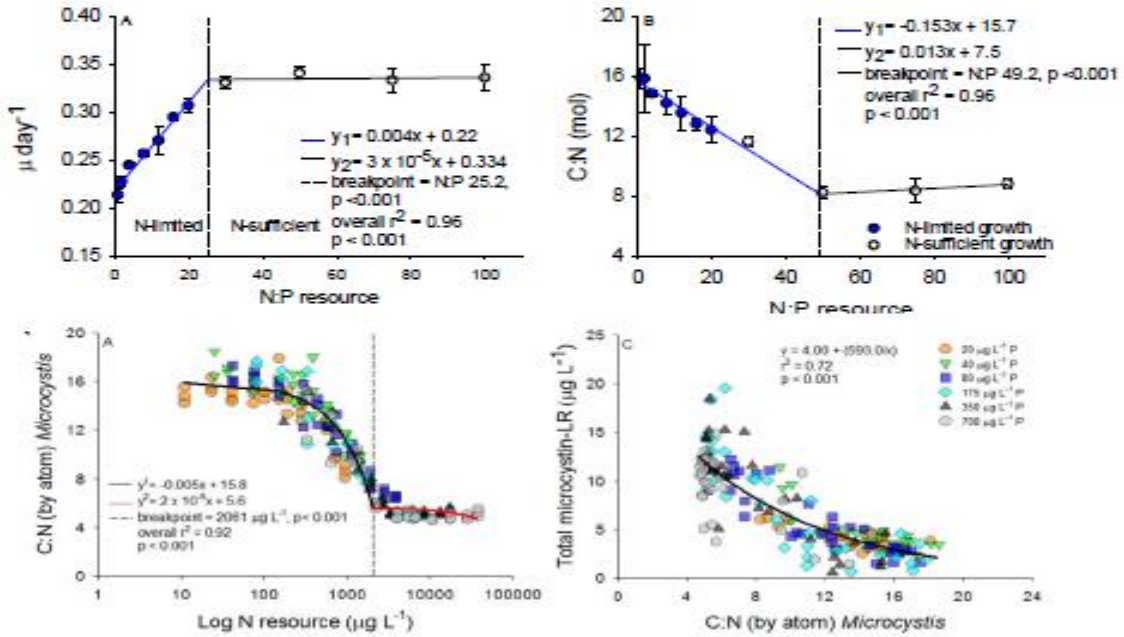
(Reference: Zheng et al, 2017. Hepatology 66(5):1519-1528. doi: 10.1002/hep.29310)

Research Projects: HABs – Drs. Bryan Brooks, Scott James and Thad Scott

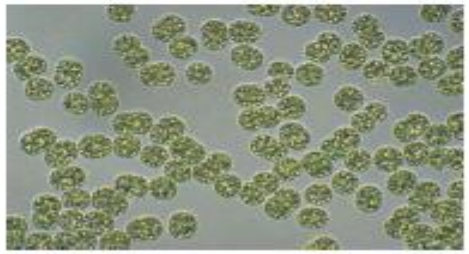
BAYLOR UNIVERSITY ENVIRONMENTAL SCIENCE

Forecasting Toxins Exposure?

Biological Stoichiometry Regulates Microcystin-LR Production in *Microcystis aeruginosa* (UTEX 2385)



High resource N:P ratios allowed *M. aeruginosa* to decouple microcystin-LR production from growth and generate more toxin than would have been predicted by growth alone



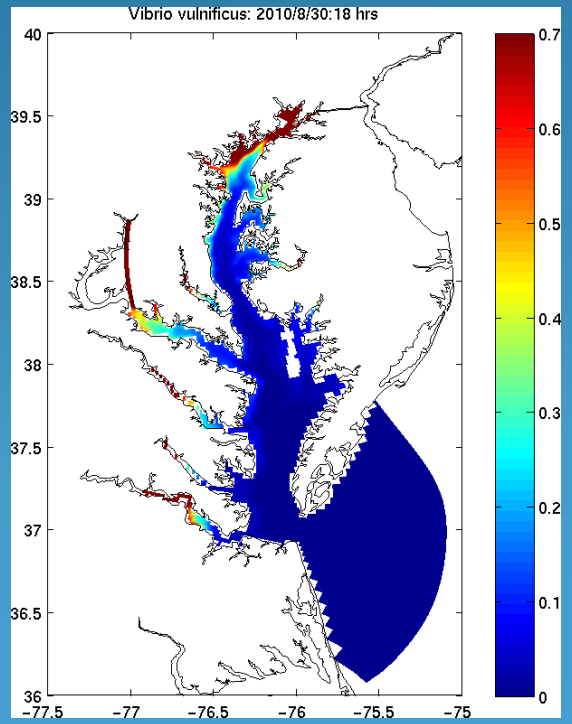
Wagner et al. 2019. *Toxins*

OHC²I

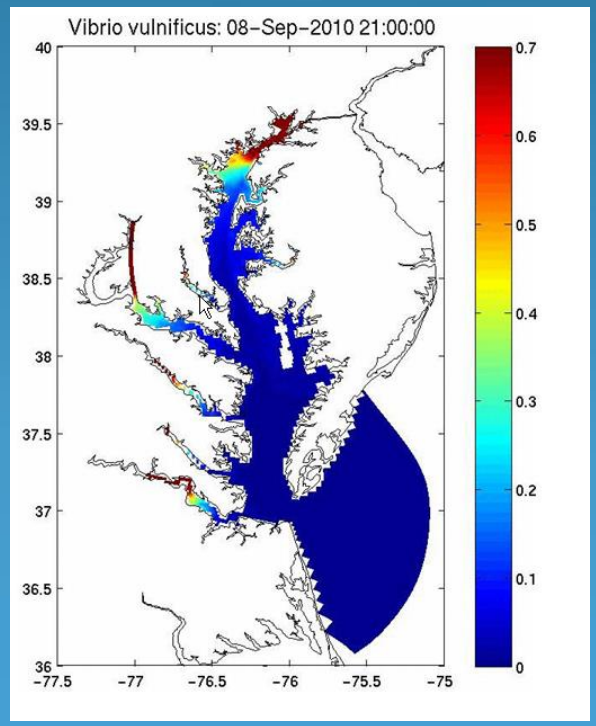
Current Experimental Vibrio Forecast Products

Forecasts and other Products

- Nowcasts and 3 day forecast – UMCES and NOAA
- 14 and monthly forecasts - UMD ESSIC



14 day



Monthly

OHH Center Research Will Evaluate the Effects of Climate Change Factors of Temperature, pH, and Salinity

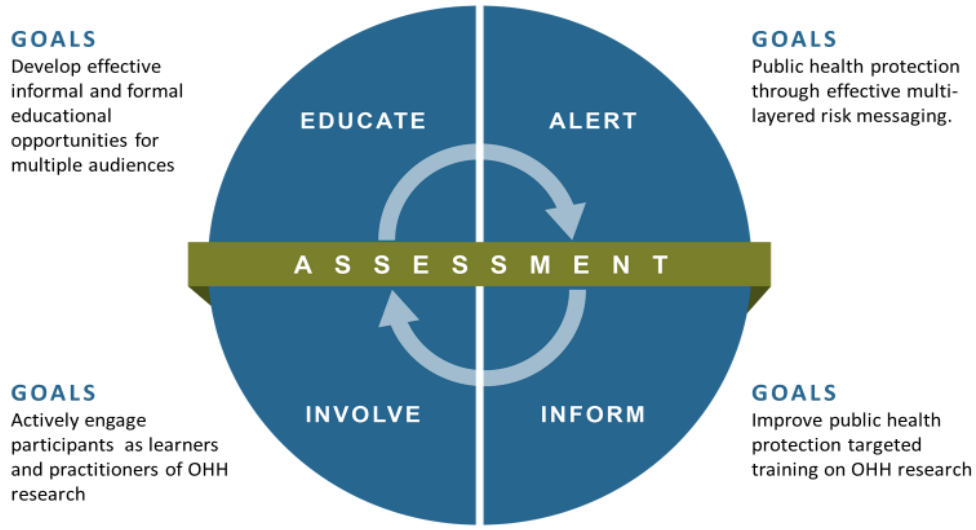
and

Urbanization Effects of Trace Metals and CECs (Pharmaceuticals and Personal Care Products) On Antibiotic Gene Expression & Virulence In Vibrio Bacteria

Developing an integrated community engagement strategy

Goal: How to achieve combined effort and impact.

- Leveraging existing resources and networks
- Identifying areas of distinction, areas of commonality
- Support each other in areas of distinction – collaborate more aggressively in areas of commonality
- Which of the communication and community engagement tools should be adopted by two or more or all four Centers, and how could they be connected and integrated across and among Centers?
- Strategy will broaden scope of initiatives and opportunities



Annual OHH Meeting of COHH Directors, NIEHS/NSF Program Managers, CEC PIs, Kimbel Living and Learning Center, Oct 2019

Woods Hole Center for OCEANS & HUMAN HEALTH

OHHC²I NIEHS Center for Oceans and Human Health and Climate Change Interactions at the University of SC

GREAT LAKES CENTER FOR FRESH WATERS AND HUMAN HEALTH AT BOWLING GREEN STATE UNIVERSITY

GREATER CARIBBEAN CENTER FOR CIGUATERA RESEARCH GCCCR

Collaborators

University of South Carolina

- **College of Charleston, Center for Coastal Environmental and Human Health, School of Sciences and Mathematics and the NIEHS Center for Oceans and Human Health and Climate Change Interactions (OHHC²I)**

  Paul Sandifer

- **University of South Carolina, Arnold School of Public Health and the NIEHS Center for Oceans and Human Health and Climate Change Interactions (OHHC²I)**

  Saurabh Chatterjee, Cassie Horton, Sean Norman, Shuo Xiao and Dwayne Porter

- **University of Maryland, Center for Environmental Science**

  Heath Kelsey

- **NOAA, NOS/National Centers for Coastal Ocean Science, Charleston and Hollings Marine Laboratories**

  Marie DeLorenzo