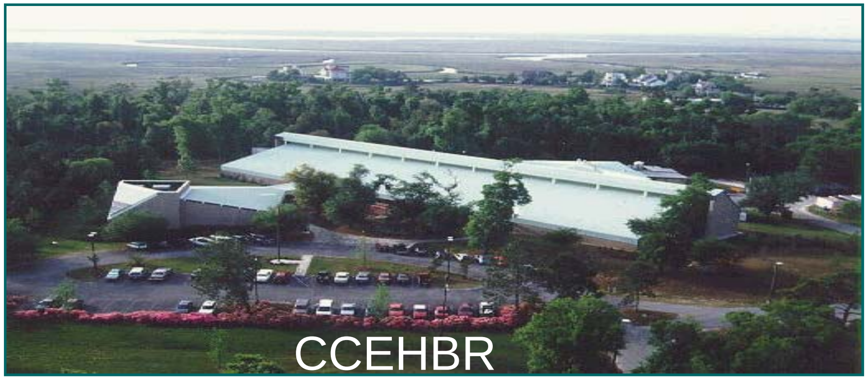
“Coastal Development and Climate Change: A Recipe for Disaster for Coastal Ecosystem Health”



Geoff Scott

NOAA/NOS National Centers for Coastal Ocean Science

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Collaborators

- **NOAA, NOS, NCCOS, Coastal Center for Environmental Health and Biomolecular Research and Hollings Marine Laboratory, Center of Excellence in Oceans and Human Health Research**

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  Tom Chandler, Dennis Alan and Dwayne Porter

- **Centre for Atmospheric Research Experiments, Environment Canada**

  Terry Biddleman

- **NOAA, National Climate Data Center**

  Thomas C. Peterson

Urbanization in Coastal Ecosystems

- Globally > 55% of the world's population lives within 50 miles of the coast, 33 of the 50 largest cities in the world are located in coastal areas & more than 80% of world commerce is transported by ships (Dean, 1997)
- Half of the US population (>141 million people) reside within 50 miles of the coast, which occupies less than 11% of the land area of the lower 48 states (NOAA, 1999; 2005)
- U.S. population has increased by 33 million (28%) since 1980 and is expected to increase by anther 12 million by 2015 (Crossett et al.; 2004)
- **PEW COMMSSION:** 25% of all conversion of rural land into suburban/urban land use in the last 300 years for the U.S. has occurred in the 15 year period from 1982-1997 (NRI, 2000)

Urbanization in Coastal Ecosystems

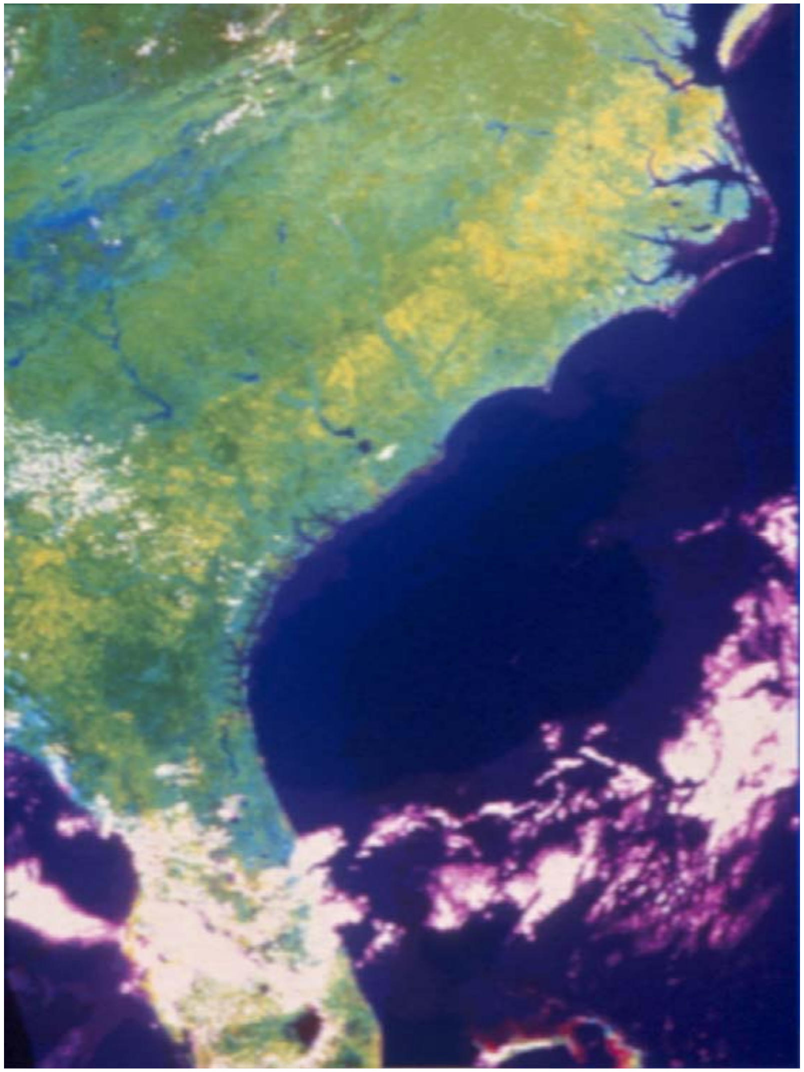
- This influx of people, and the associated residential and commercial development of the coastal zone has resulted in significant modification of landscapes such as increased imperviousness.
- Major alterations of the hydrological cycle, which change the transport and delivery of water to coastal watersheds.
- This in turn results in increased discharges of toxic chemicals (pesticides, trace metals, PAHs, personal care products, and pharmaceuticals), nutrients, and microbes.

Urbanization in Coastal Ecosystems

- **COASTAL CONDITION REPORT**: 44% of Estuarine Ecosystems were impaired primarily due to NPS pollution (EPA, 2002)
- **Bricker et al. (1999)** similarly has reported that 67% of our estuaries and bays in the U.S. are moderately or severely impacted by eutrophication
- **In 2001 > 13,000 beach advisories** or closures occurred in the U.S. (EPA, 2001)
- **> 40% of the shellfish beds in the U.S.** had harvest restrictions resulting from urban runoff, discharges from septic tanks, runoff from animal feedlots and wildlife pollution sources (EPA, 2001)

South Atlantic Bight

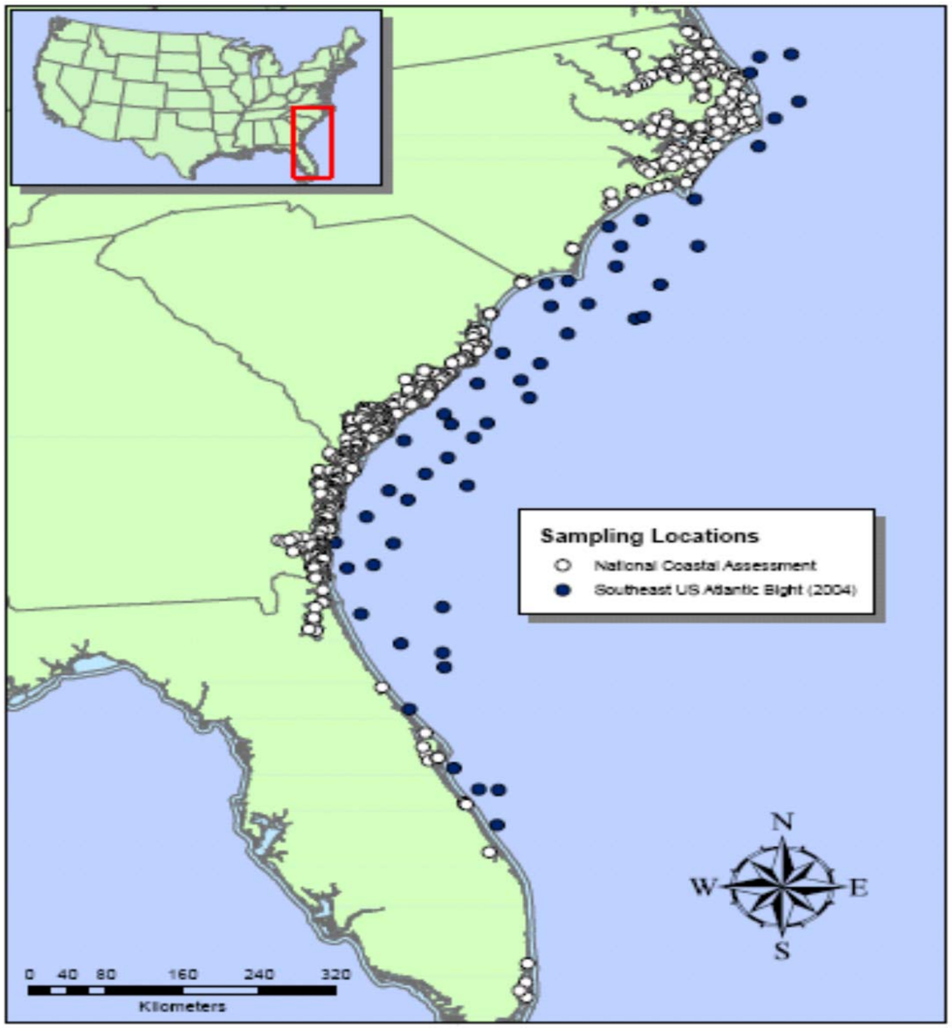
- The greatest rate of population change has been in the southeastern US (58% increase) followed by the Pacific (46%) & Gulf of Mexico (45%) coastal regions (Crossett et al., 2004)
- Southeastern U.S. includes FL, GA, SC & NC



Urbanization Studies in SE U.S.

- **Land Use in Coastal Ecosystems Study (LUCES)**
  - **Focus:** Compartmental Interfaces in Estuarine Systems Affected by Coastal Urbanization
  - **Location**: SC and GA
  - **Text Book:** Coastal Urbanization.2007 (G. Kleppel et al., Eds.): Van Norstam Press
- **Tidal Creek Project**
  - **Focus:** Tidal Creeks as Sentinel Habitats
  - **Location:** GA, SC & NC
  - Numerous Reports and Manuscripts (F. Holland and D. Sanger Lead Authors)
- **Urbanization in Southeast Estuarine Ecosystems (USES)**
  - **Focus:** Comparison of Suburban and Pristine Estuarine Ecosystems (Multi-Disciplinary)
  - **Location:** Murrells Inlet (Suburban) vs. North Inlet (NOAA NERRS Site) in SC
  - **Text Book:** Sustainable Development in the Southeastern Coastal Zone (F.J. Vernberg, W.B. Vernberg and T. Siewicki Eds.); Belle W. Baruch Library in Marine Science Vol. 20; Univ. of South Carolina Press

Example of Ongoing Effort with EPA in the SE U.S.: *Estuaries & Coastal Ocean Combined*



- **Using data from prior complementary probabilistic surveys**
- **Estuarine Sites: 2000-2004, n = 697 (from EPA's EMAP/NCA program) and Offshore Sites: 2004, n = 50 (from NOAA's SAB-04 survey)**

<u>Sampling Parameters</u>:

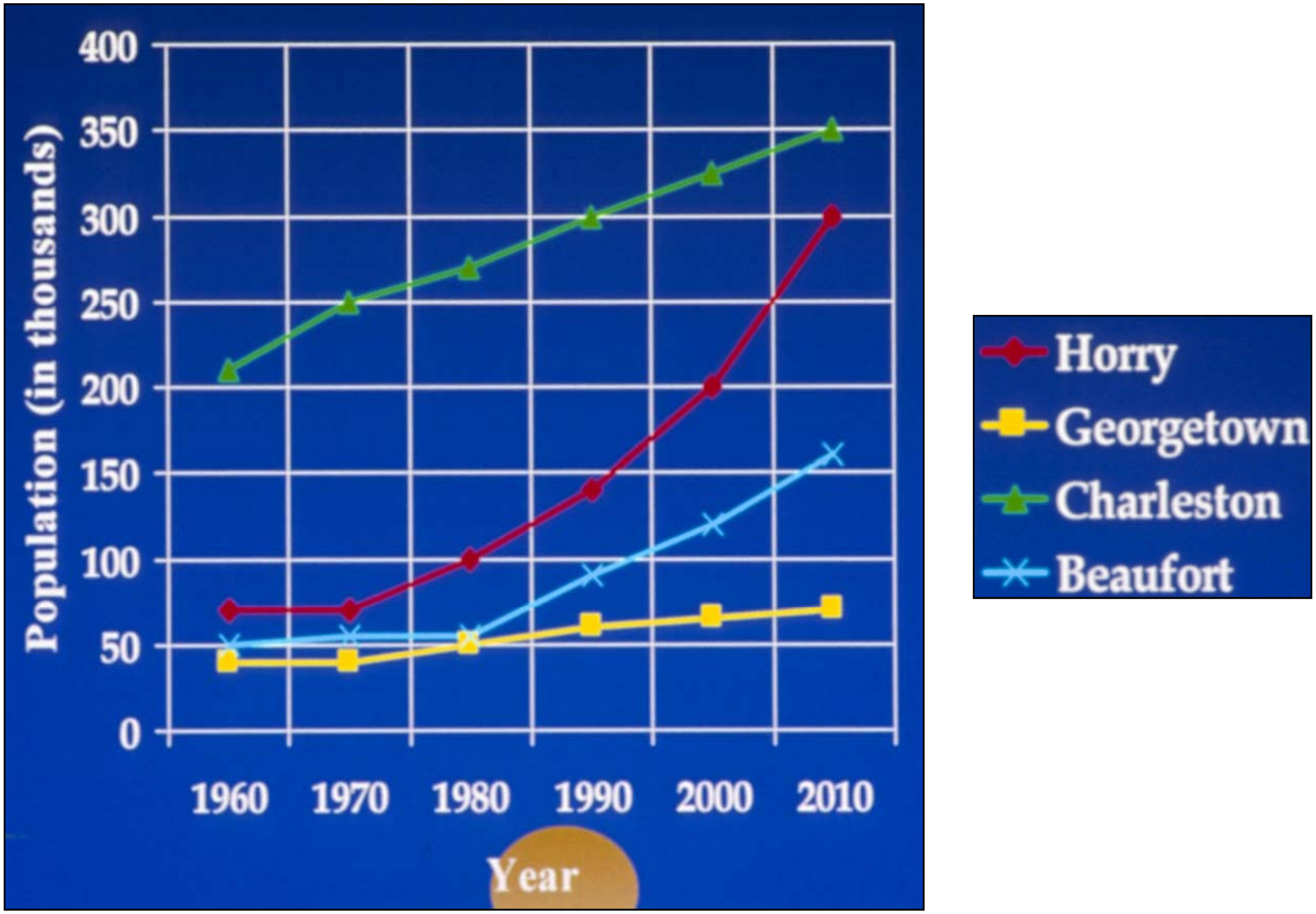
•Habitat Characteristics (T, S, DO, nutrients, chlorophyll a, grain-size, TOC)

•Stressors (Chemical contaminants in sediments & biota, hypoxia, organic enrichment)

•Biological Condition (Benthos, Fish)

•Human Health Risks & Aesthetics

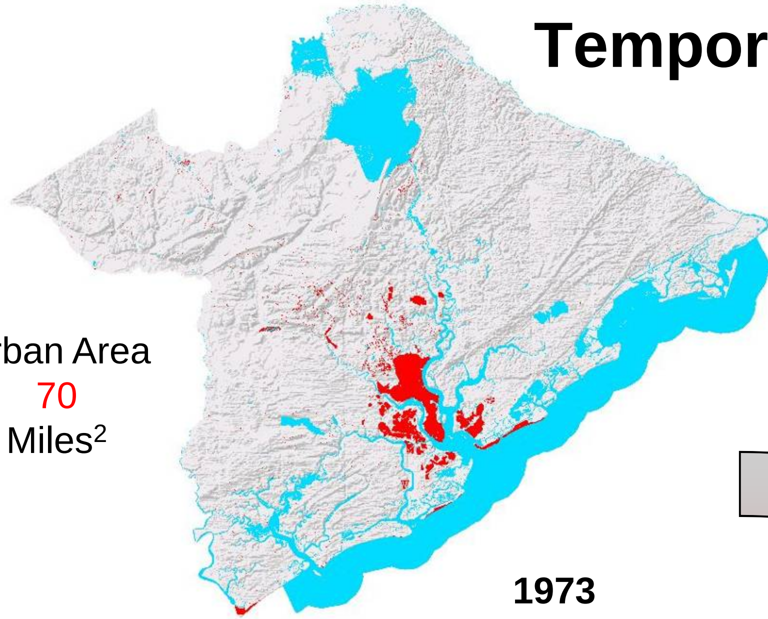
Population Trends Along the South Carolina Coast



Charleston, SC Urban Growth

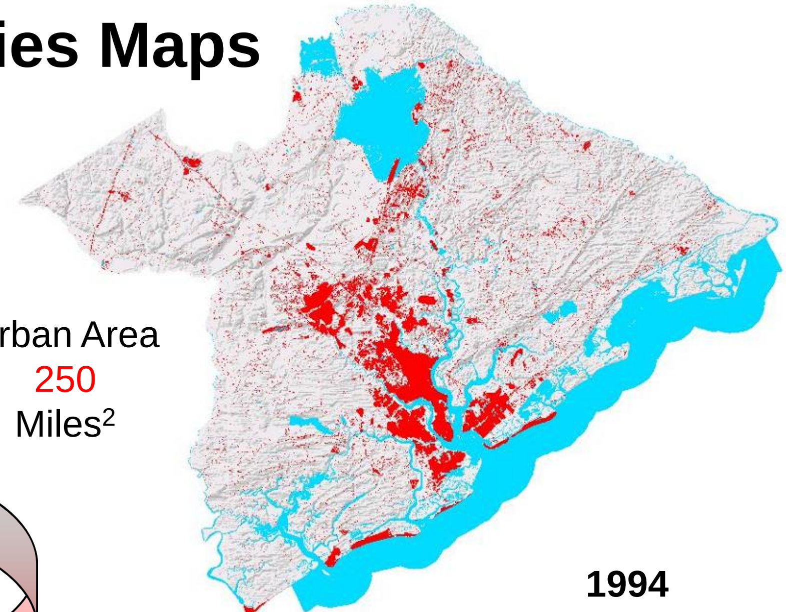
Temporal Series Maps

Urban Area
70
Miles^2



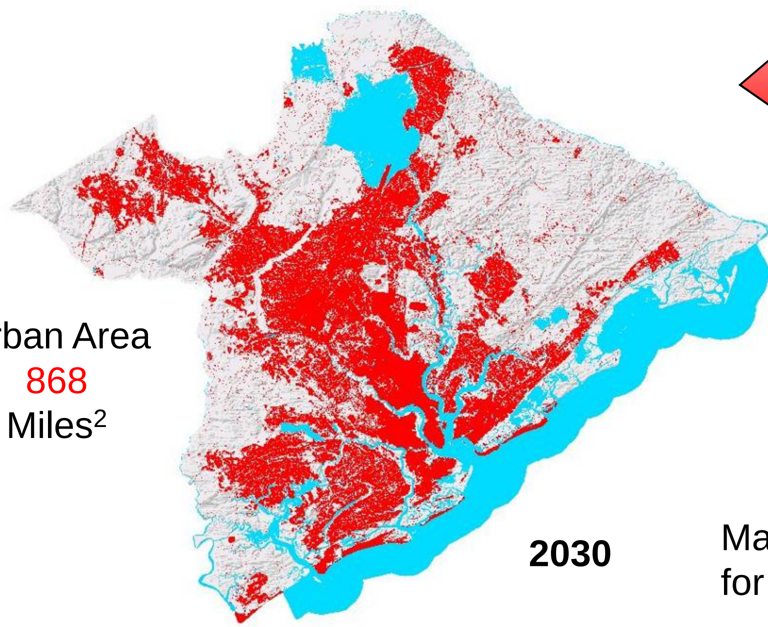
1973

Urban Area
250
Miles^2



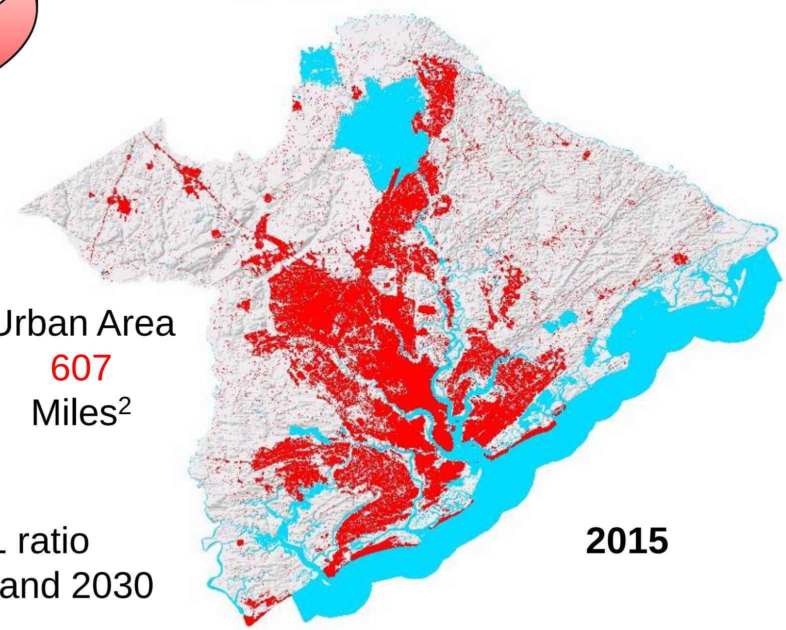
1994

Urban Area
868
Miles^2



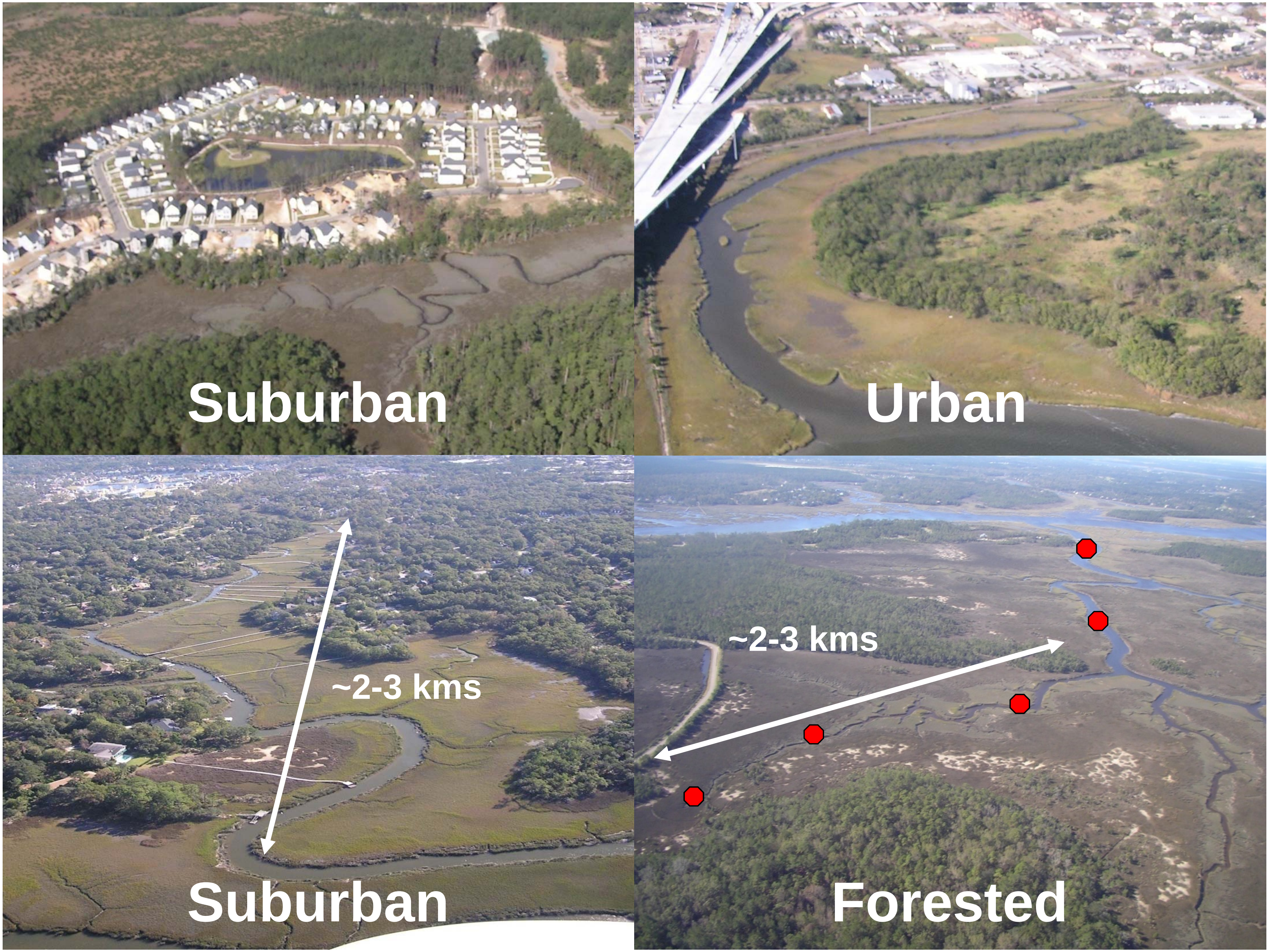
2030

Urban Area
607
Miles^2



2015

Mapped at 5:1 ratio
for year 2015 and 2030



Suburban
Urban
~2-3 kms
Suburban
~2-3 kms
Forested

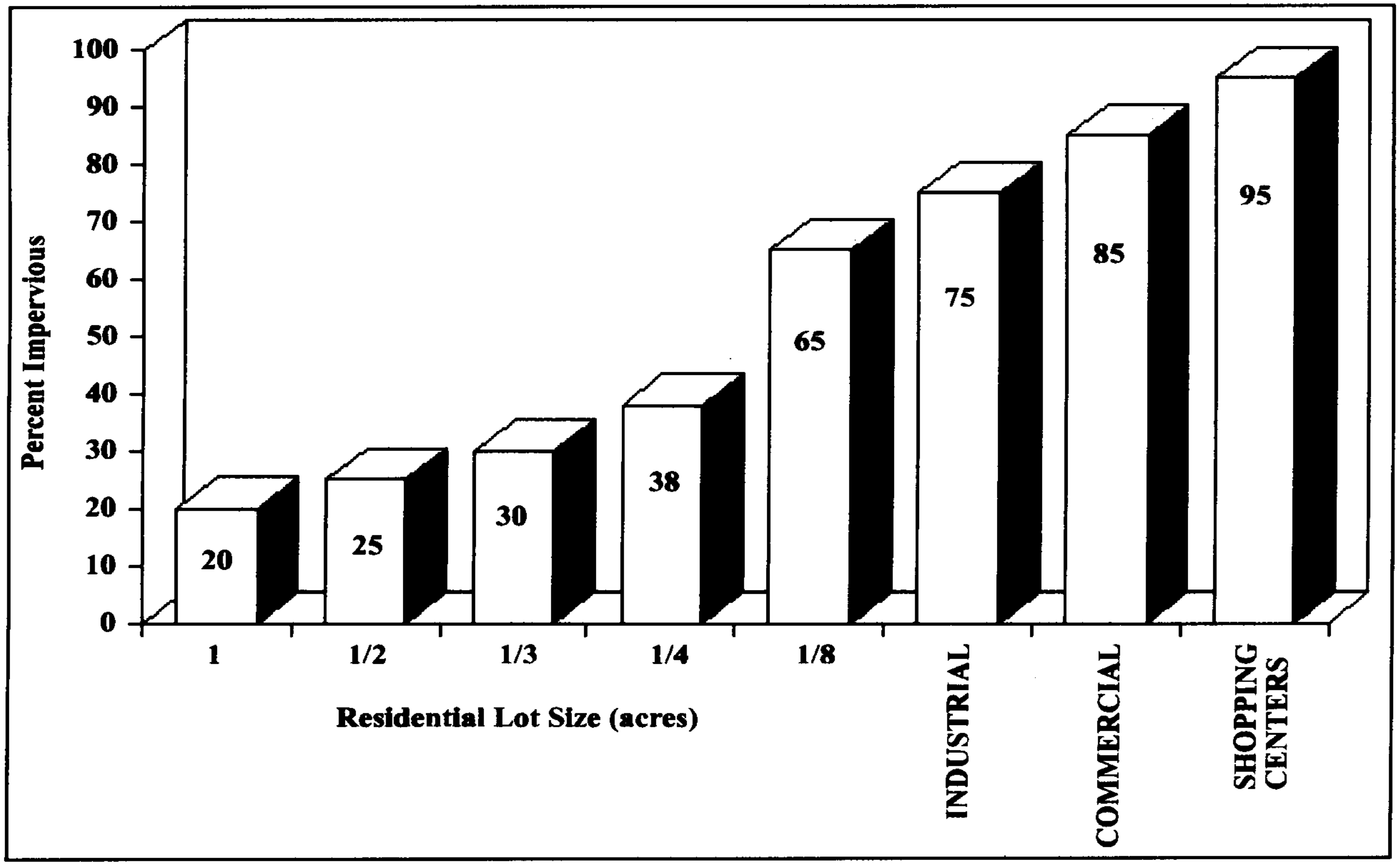
Impacts of Coastal Development on Marine Ecosystem and Human Health

Contamination of seafood & beaches

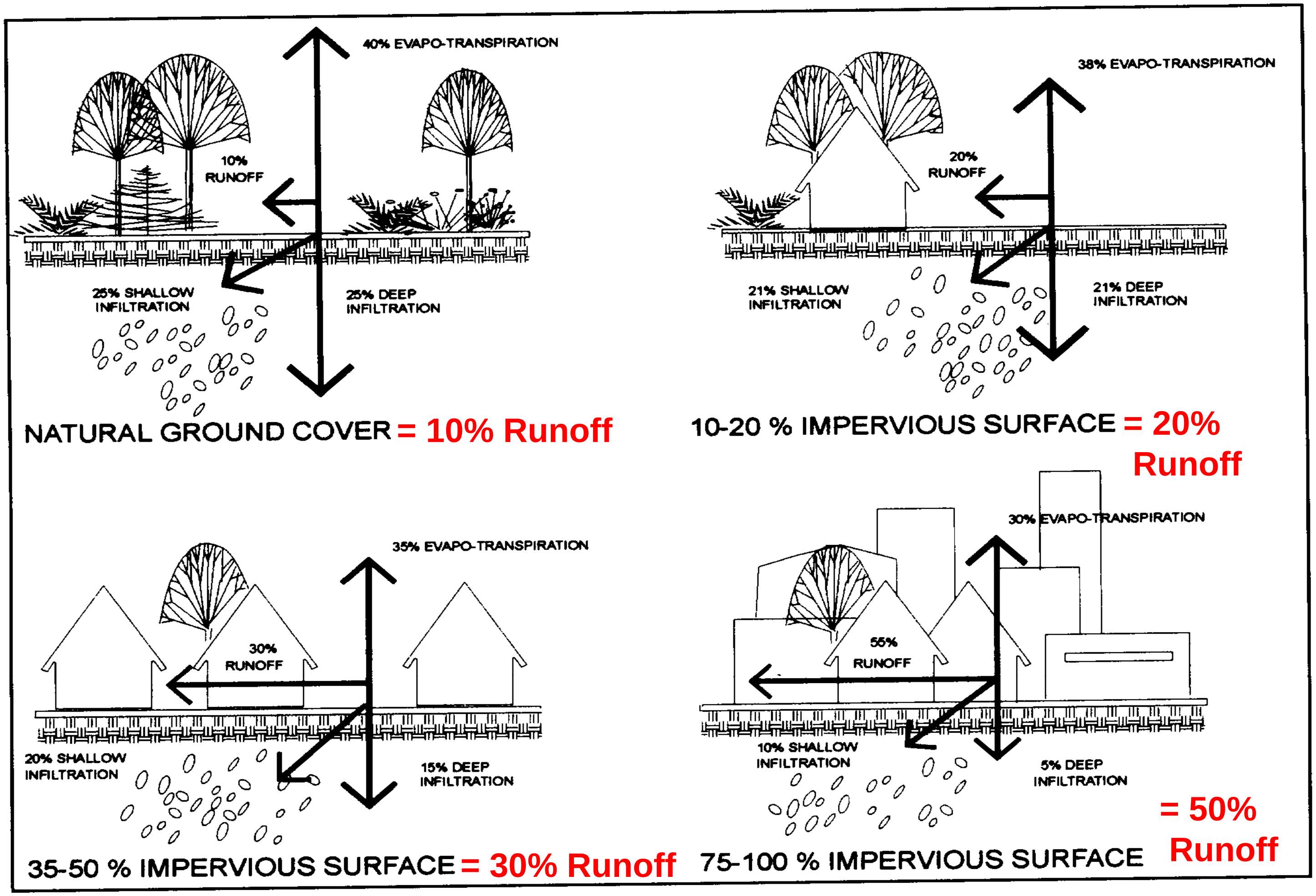
Altered hydrography & increased flooding

Impaired ecosystems

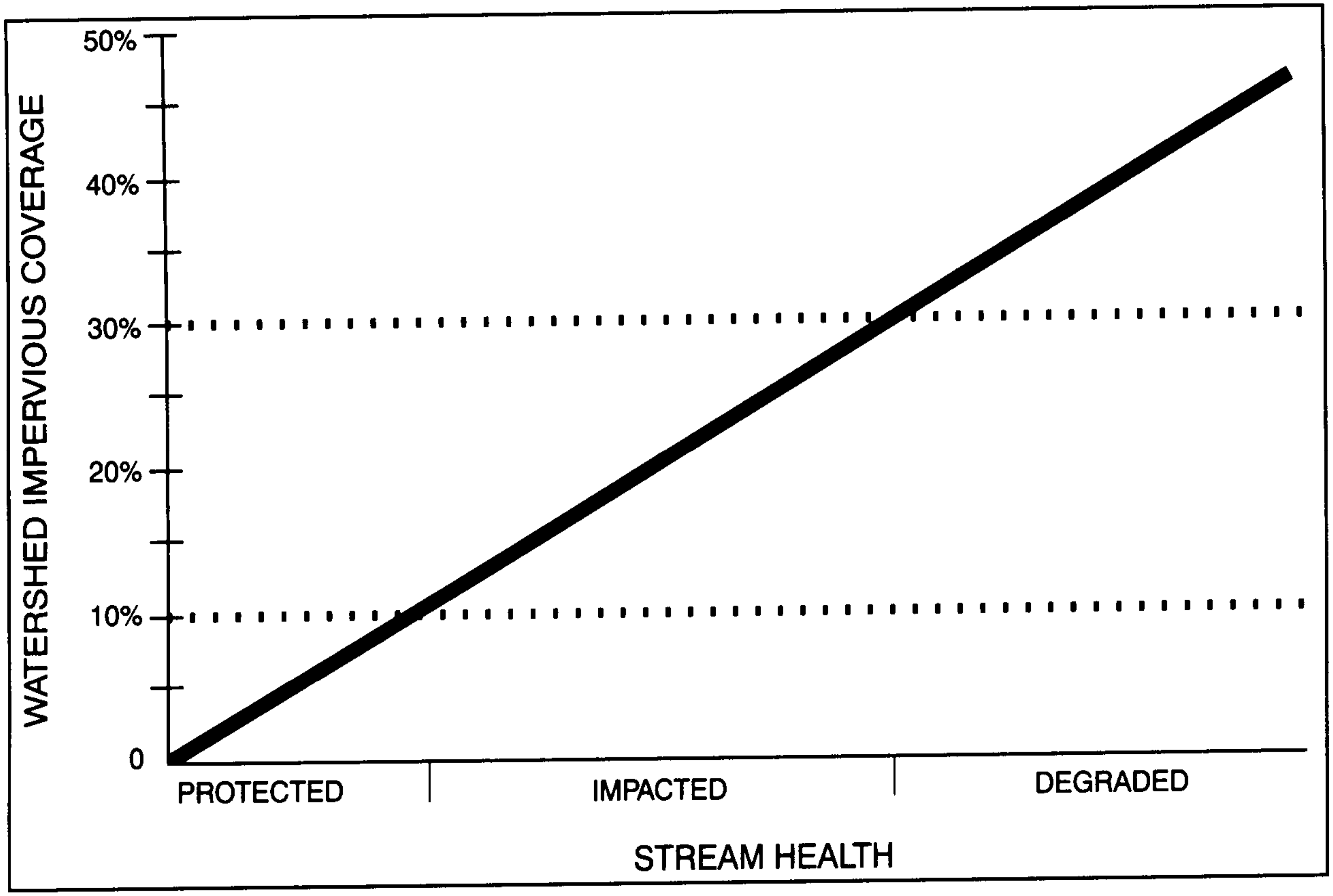
Effects of Lot Size on Imperviousness



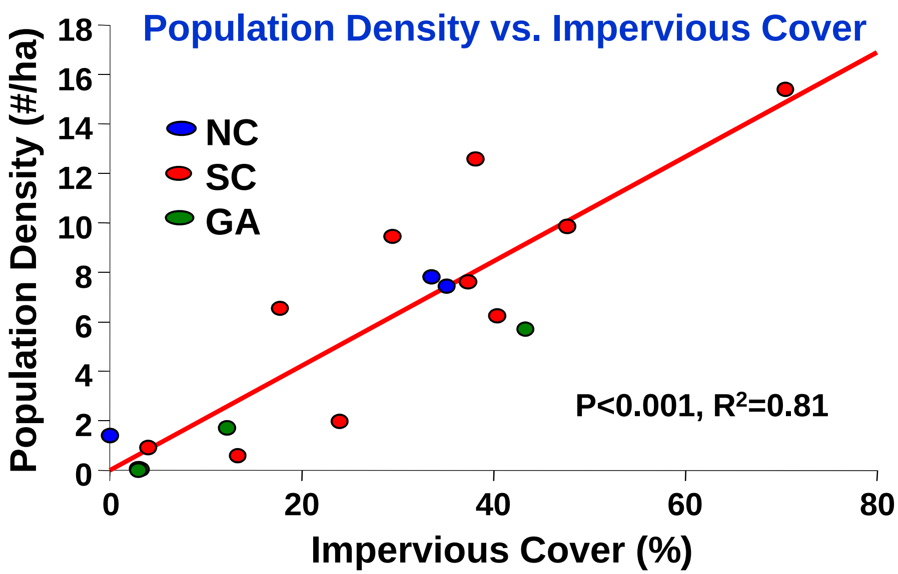
Effects of Imperviousness on the Water Cycle

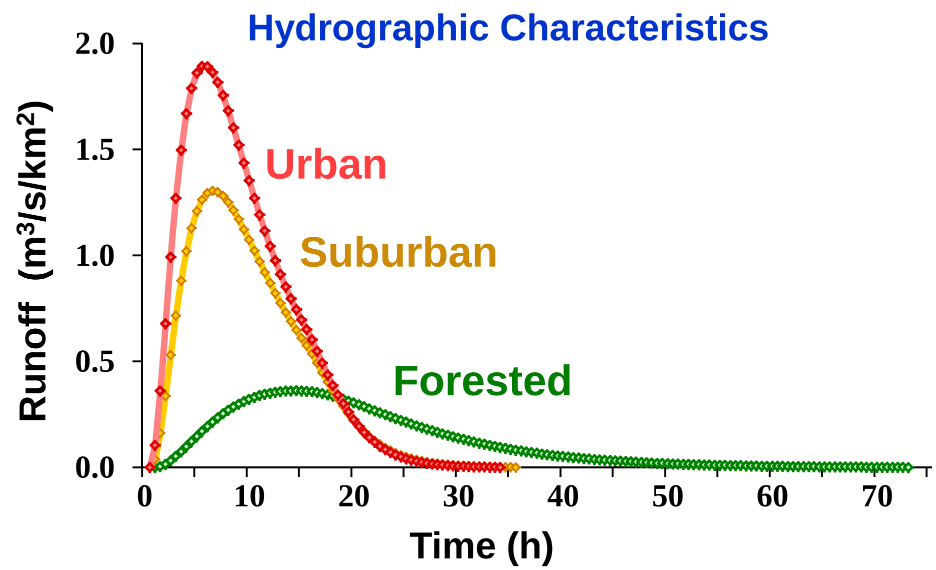


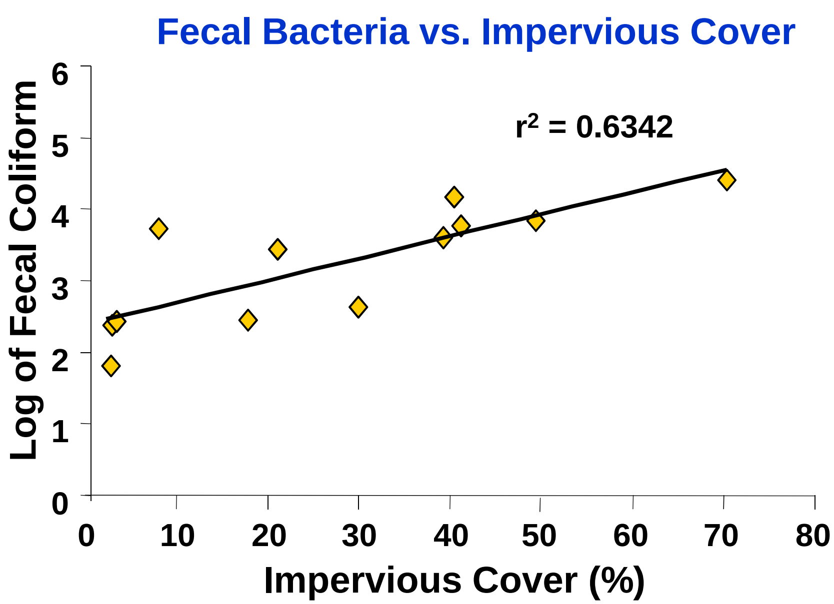
Effects of Imperviousness on Water Quality (Schuler et. al. 1992)

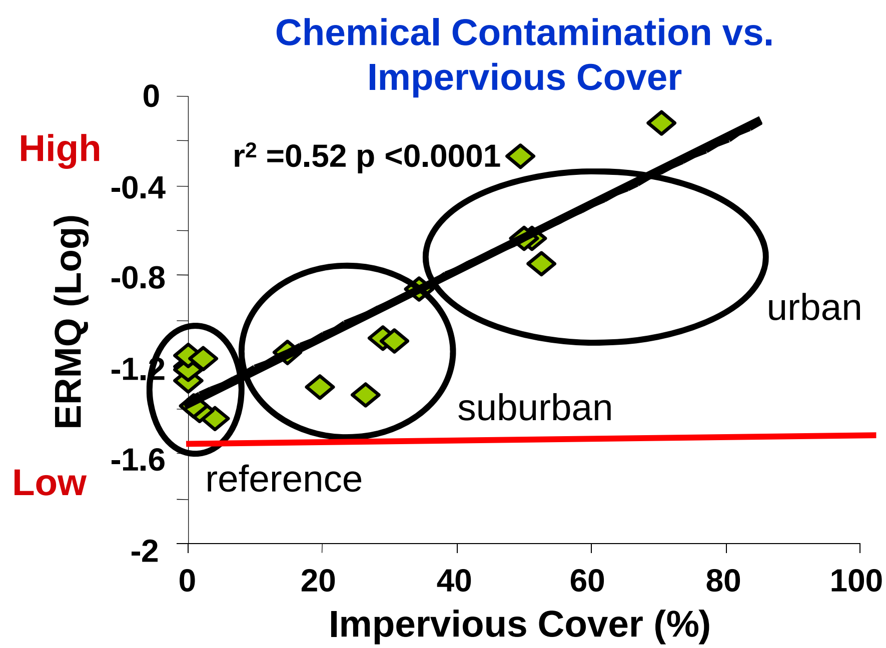


Summary: Urbanization Effects









Urbanization Effects on Coastal Ecosystems

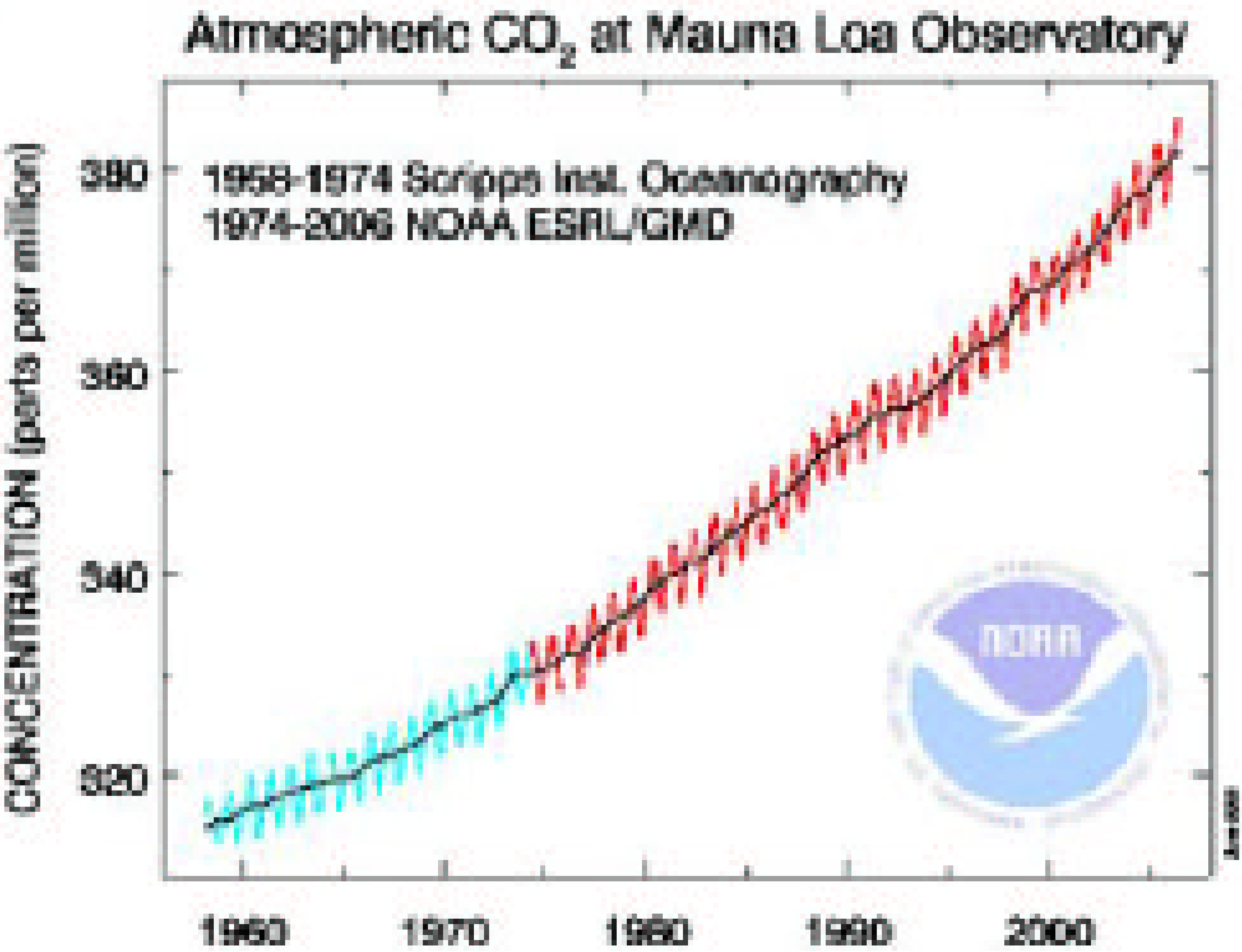
Stressor	Exposure	Ecological Response	Human Response
Coastal Development Activities	**Physical-Chemical Changes**	**Living Resources**	**Health and Welfare**
Increased Population Density	Impaired Water Quality & Hydrography	Reduced Biological Productivity	Beach and Shellfish Bed Closures
Altered Land Cover	Microbial and Pathogen Contamination	Altered Food Webs	Vulnerability to Flooding
Increased Impervious Cover	Chemical Contamination	Impaired Animal Health	Quality of Place
			Quality of Place

10-20% Impervious Cover (Stressor → Exposure)

20-30% Impervious Cover (Exposure → Ecological Response)

10-30% Impervious Cover (Ecological Response → Human Response)

Global warming interactions with urbanization??



Atmospheric CO2 at Mauna Loa Observatory
1958-1974 Scripps Inst. Oceanography
1974-2006 NOAA ESRL/GMD
CONCENTRATION (parts per million)
380
360
340
320
1960
1970
1980
1990
2000

GLOBAL WARMING

- Present level of CO_2 – 380 ppm, which has increased by 25% since the start of the industrial revolution & has increased by 12% since 1960.

- This CO_2 increase has caused a 1 degree F increase in global temperatures during the 20th century.

- Projections are for CO_2 levels to double by 2050 which will increase global temperatures by 1.5 - 4.5 degrees F.

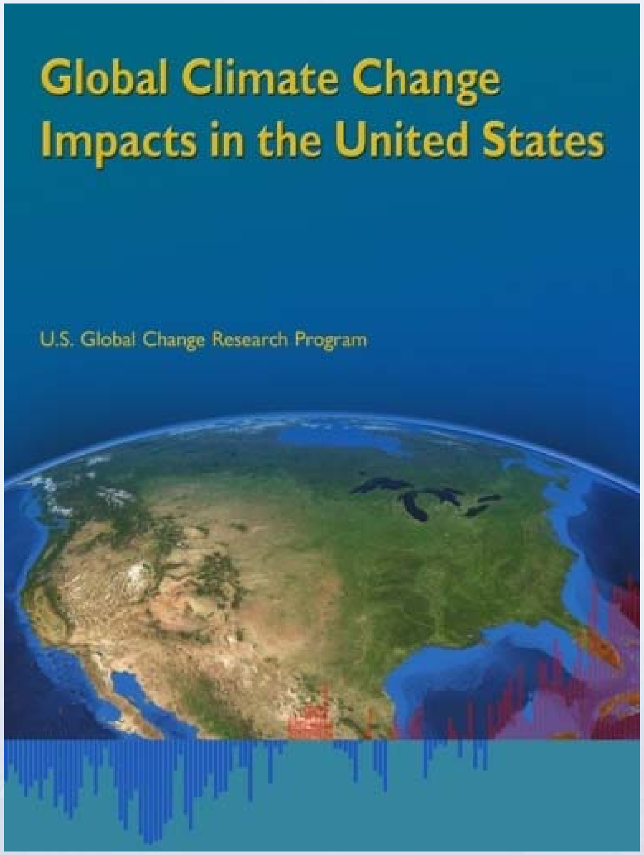
GLOBAL Climate Change: Green House

Gas	% Contribution	Atmospheric Conc. (ppm)
CO2	55%	355
CFCs	24%	(12,000X more potent than CO_2 & increasing @ 5%/year)
CH4	15%	2ppm (20X more potent than CO_2 & increasing @ 1%/year)
NO	6%	ppb conc.(>0.25%/yr)

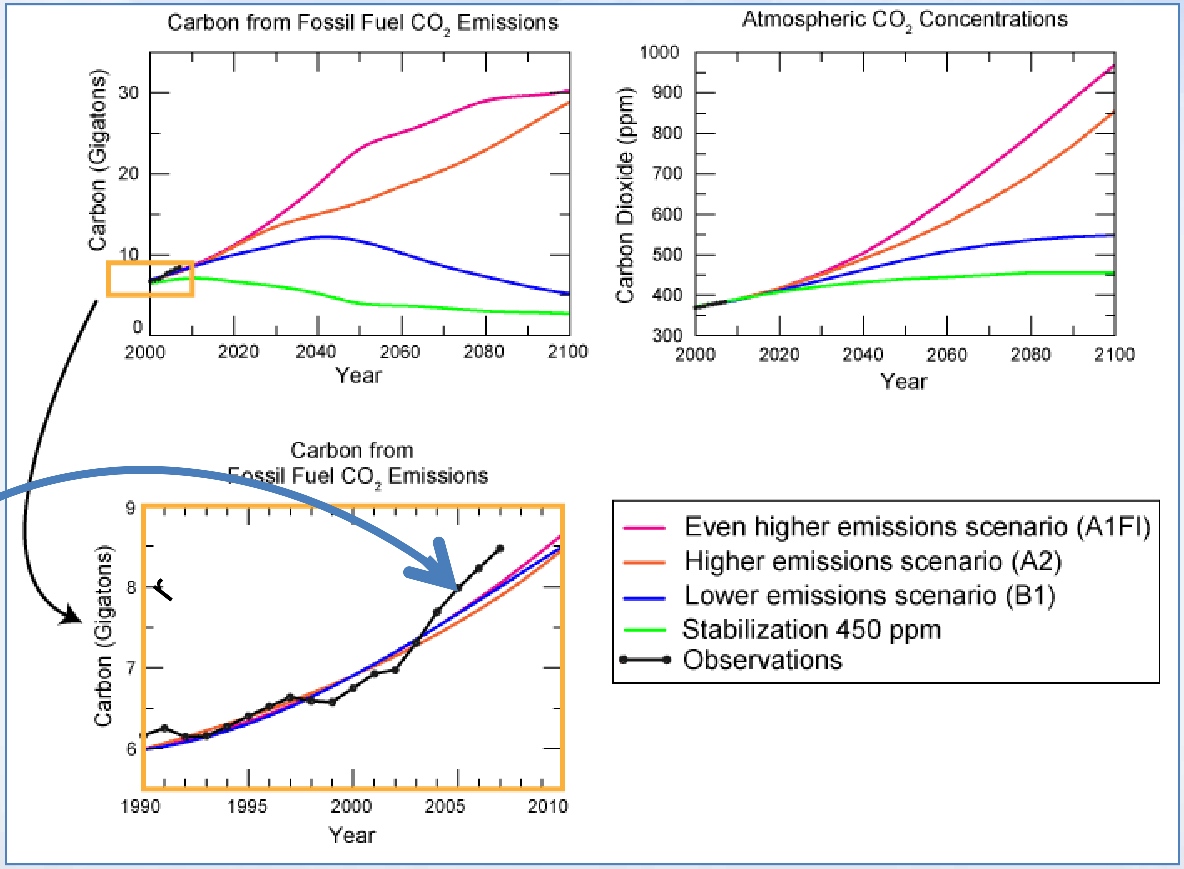
Sources of Information

(Dr. Thomas C. Peterson
NOAA's National Climatic Data Center)

- *Global climate change impacts on the United States*
  - Released June 2009
  - Intense peer-review
  - Intense public-review
  - Available from
    - www.globalchange.gov/usimpacts



A bit about emission scenarios



- Recent carbon dioxide emissions are, in fact, above the highest emissions scenario developed by the IPCC

- About 1/3 of the CO_2 from fossil fuel burning remains in the atmosphere after 100 years
- About 1/5 of it remains after 1000 years

How May Climate Change Affect These Ocean Health Threats?

- Climate may directly affect growth, survival, persistence, distribution, transmission, and virulence of disease-causing organisms and harmful algal blooms and distribution and concentrations of chemical contaminants in coastal and ocean waters.
- Climate may also affect the distribution of disease vectors, including marine organisms.
- Major climate factors are temperature, precipitation (and associated drought, flooding, and runoff), sea level rise, salinity, extreme weather events, and ecological shifts.

Increased Temperature

Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Increased Temperature	Increased melting of polar ice	Increased release of Hg, Pb, DDT, and other contaminants into air and surface waters of boreal ecosystems
	Increased thermal stress	Enhanced toxicity of many emerging contaminants of concern (EECs) in combination with elevated temperatures
	Ecological shifts of marine organisms	Increased occurrences of marine animal diseases and human illness/diseases associated with microbes and harmful algal blooms

Global Climate Change: *Temperature Effects*

- **Number of days with temperatures > 100 degrees F**

  - Washington, DC – from 1 day/year to 14 days/year

  -Dallas, TX – from 19 days/years to 78 days/year

- **Diminishing Crop Production**

  - Mid West will have 30-60% less rain, which will reduce crop production

  -Decreasing protein content of P3 plants (soybeans)

  - Weeds (P4 plants) will have higher growth rates in CO2 enriched air = ***more herbicide use***

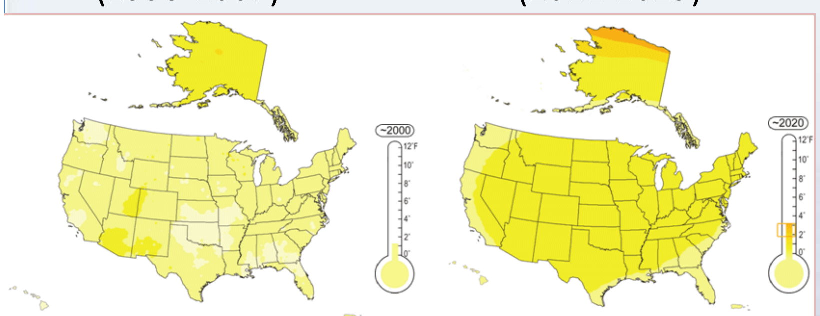
  -Insect pests will consume more P3 plants to meet protein needs = ***more insecticide use***

A tendency to have more warming in the middle of continents

Partly due to:

- More drying due to increased evaporation

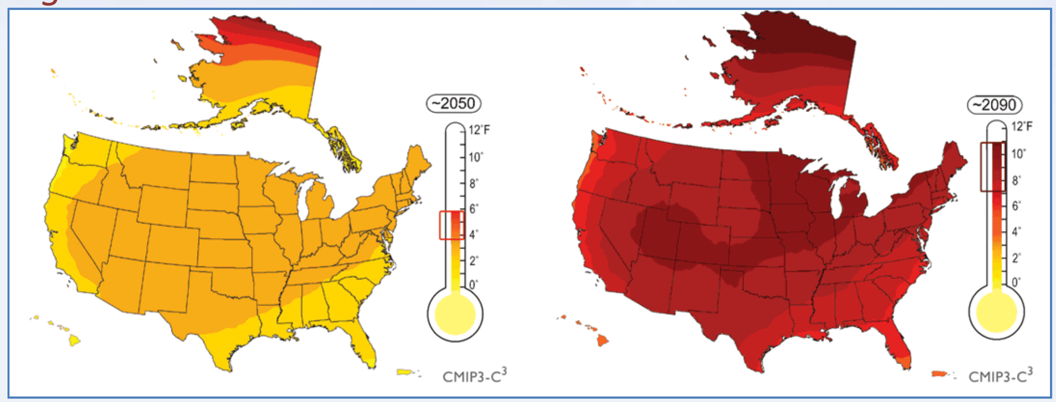
Present-Day Change (1993-2007) Near-Term Projected Change (2011-2029)



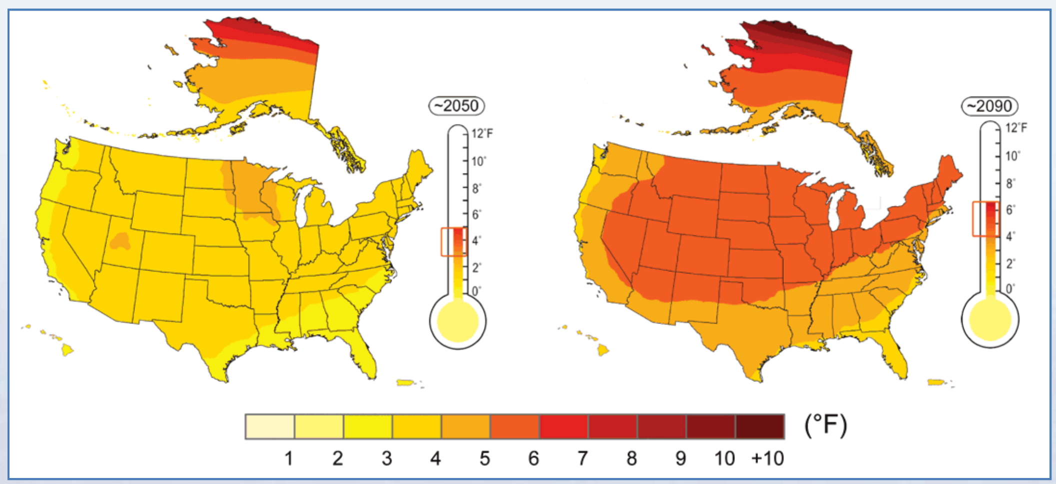
Projected Temperature Change (° F)
from 1961-1979 Baseline

Mid-Century (2041-2059 average) End of Century (2081-2099 av.)

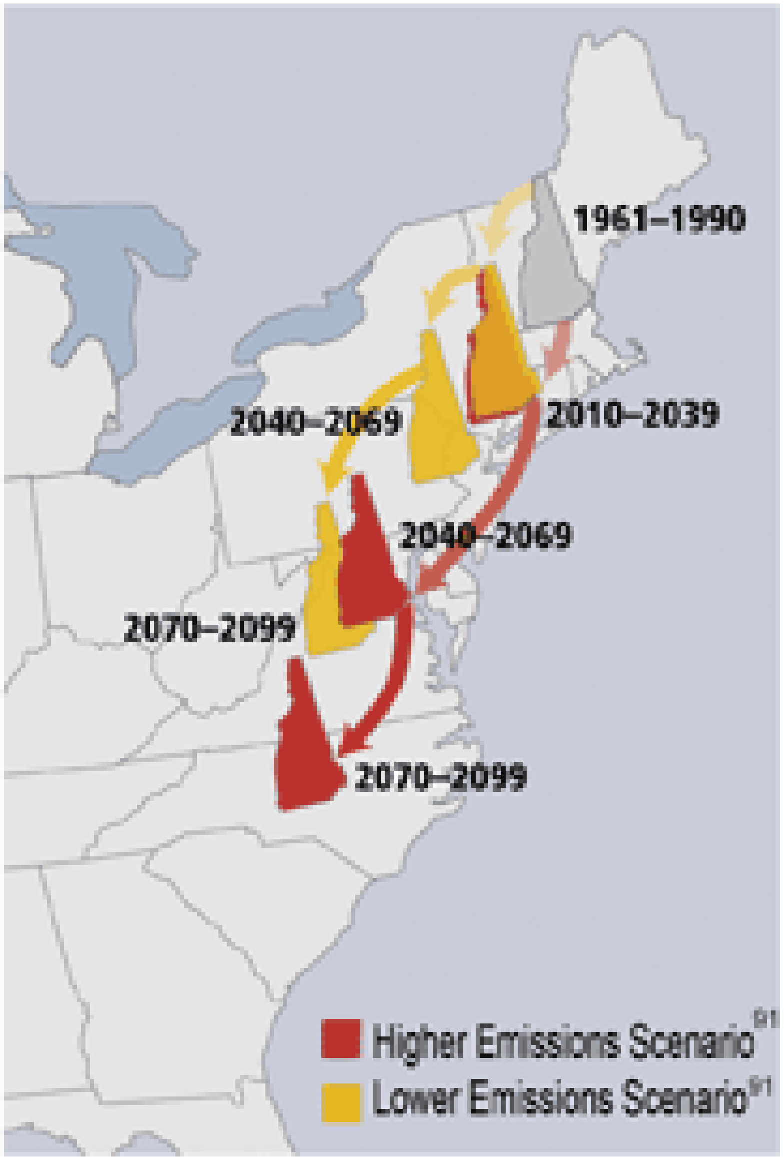
Higher Emissions Scenario

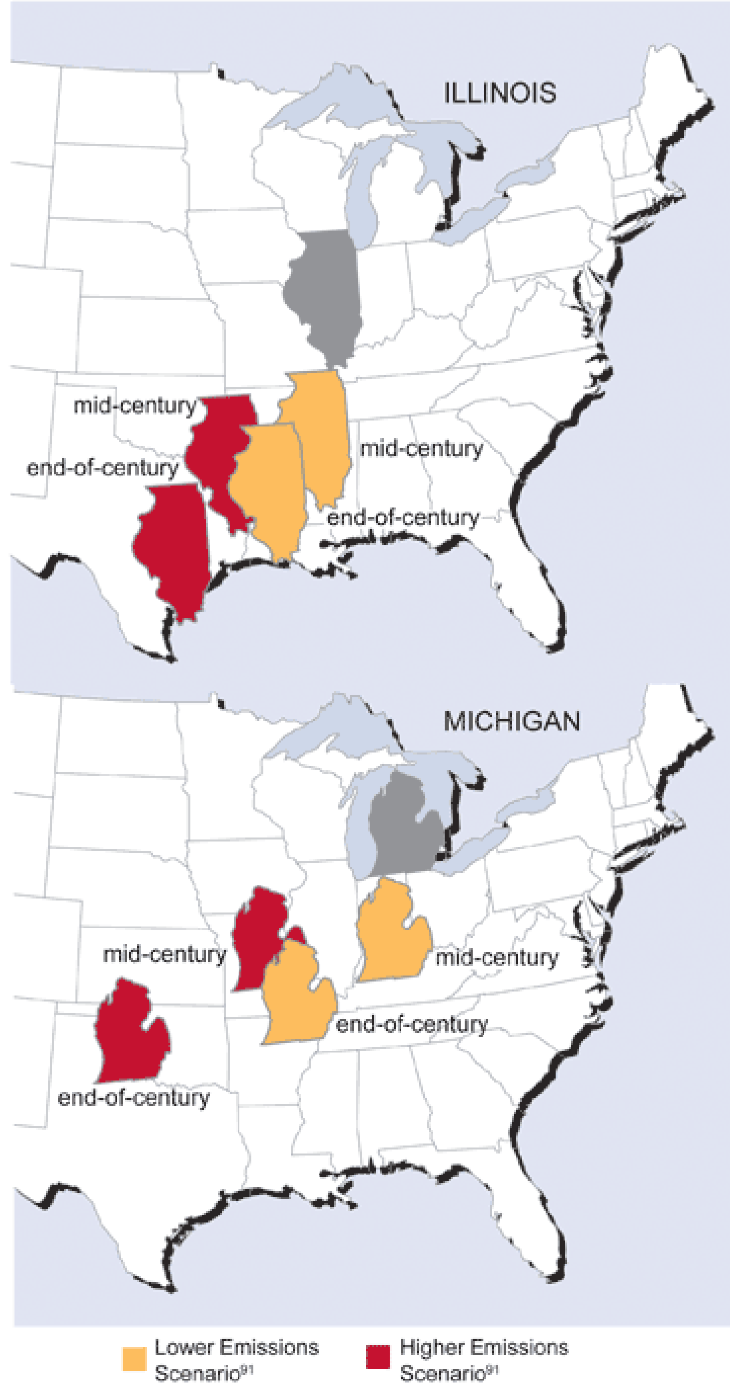


Lower Emissions Scenario



Moving states





enario F

5. Crop and livestock production will be increasingly challenged

Impacts for commercial agriculture, landscaping, and back yard gardeners

- Higher levels of CO_2 generally cause plants to grow larger
    - But often less nutritious
        - Particularly pastures
- Many weeds respond well to increasing CO_2
- Increasing CO_2 also makes some plants more water efficient.
- Extreme events (heavy downpours and droughts) likely to reduce crop yields
- Increased heat, disease, and weather extremes are likely to reduce livestock productivity.

Increasing CO_2 Reduces Herbicide Effectiveness

Current CO_2 Future CO_2 (+300 ppm)

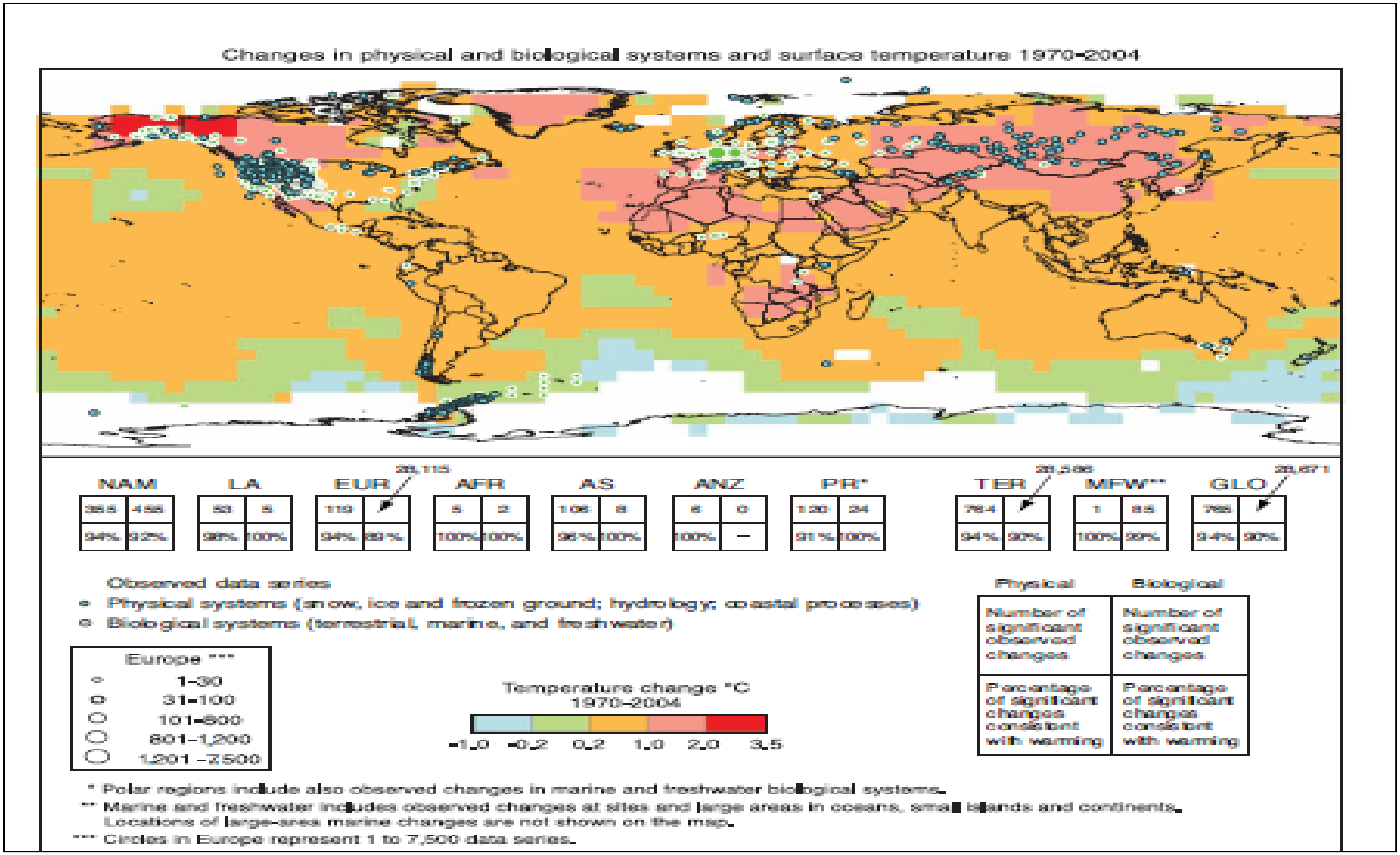
IPCC PREDICTED ECOSYSTEM IMPACTS OF GLOBAL CLIMATE CHANGE

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector: Agriculture, forestry and ecosystems [4.4, 5.4]	Water resources [3.4]	Human health [8.2, 8.4]	Industry, settlement and society [7.4]
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	[illegible]	[illegible]	[illegible]
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	[illegible]	[illegible]	[illegible]
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	[illegible]	[illegible]	[illegible]
Area affected by drought increases	Likely	La[illegible] lo[illegible] damage and failure; increased livestock deaths; increased risk of wildfire	[illegible]	[illegible]	[illegible]
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	[illegible]	[illegible]	[illegible]
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

[a] See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [Working Group I Fourth Assessment 10.6]. The effect of changes in regional weather systems on sea level extremes has not been assessed.

- Increased temperatures (warmer nights and fewer colder days)
- Increased heat waves
- Increased Heavy Precipitation Events
- Increased Periods of Drought
- Increased Tropical Cyclone Activity
- Increased Sea Level Rise
- ***Overall increased extreme weather***

GLOBAL CHANGE IN SURFACE TEMPERATURES, 1970-2004



Global Warming: Melting of Polar Ice

- Temperatures in the Arctic are rising at almost twice the rate of that of the rest of the world.
- According to the multinational Arctic Climate Impact Assessment, at least half of the Arctic's summer sea ice will melt by the century's end. The Arctic region is likely to warm 7 to 13 degrees Fahrenheit (4 to 7 degrees Celsius) during the same time.
- By all accounts, the glaciers of Greenland are melting twice as fast as they were five years ago. Recorded spring temperatures on the ice cap have reached almost 20 degrees above normal, hovering just below freezing.
- Glaciers in British Columbia have shrunk by 16 percent in total area between 1985 and 2000.
- Average temperatures worldwide have increased by 0.6 degrees Celsius, which is enough to raise sea levels and change rainfall patterns.
- According to *An Inconvenient Truth* by Al Gore, at least 279 species of plants and animals are already responding to global warming by moving closer to the poles.
- Average temperature in Antarctica has increased 6^{0}C over the past 30 years.

Trace Metal Levels in Polar Ice

Contaminant	Conc. In Polar Ice (ppt)	Reference
Pb	Arctic Snow/Ice 105 - 205 185 - 214	 Cheam at al.1998 Garbarino et al. 2002
Hg	Arctic Snow/Ice: 1.3 - 8.1	 Aspmoetal et al. 2006
Cd	Arctic Snow/Ice: 3.4 - 7.4 13 - 36	 Cheam et al. 1998 Barbarino et al. 2002

ppt = parts per trillion

Persistent Organic Pollutants (POPs) Levels in Polar Ice

Contaminant	Conc. In Polar Ice (ppt)	Reference
Endosulfan	Arctic Snow/Ice: 30.4 – 360	Hermanson et al., 2005
Chlorpyrifos	Arctic Snow/Ice: 16.2	Hermanson et al, 2005
Atrazine	Arctic Snow/Ice: 2.1	Hermanson et al., 2005
DDT	Antarctica Snow/Ice: 813 ng/m2 Antarctica Melt Water 18.7	Geisz et al., 2008

(*Note there is 3.6 tons of DDT estimated to be in Antarctica Peninsula Ice Sheet; West Antarctica Ice Sheet is losing ice at rate of 210 Gtons/yr = resulting in 1-4 Kg of DDT/Yr being released into the Antarctic Environment each year*)

Increased Temperature

Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Increased Temperature	Increased melting of polar ice	Increased release of Hg, Pb, DDT, and other contaminants into air and surface waters of boreal ecosystems
	Increased thermal stress	Enhanced toxicity of many emerging contaminants of concern (EECs) in combination with elevated temperatures
	Ecological shifts of marine organisms	Increased occurrences of marine animal diseases and human illness/diseases associated with microbes and harmful algal blooms

Sublethal Pesticide Exposure Effects on Thermal Tolerances of Fish

- Sublethal (e.g. LC_{25}) effects of 4 pesticides on thermal tolerances of 4 species of FW fish – Eastern Rainbow, Western Carp, Silver Perch & Rainbow Trout (Patra et al. 2007. ETC 26: 1454-59)
- Results:

	Reduction Upper Thermal Tolerance (°C)		
Species	**Endosulfan**	**Chlorpyrifos**	**Thermal Max W/O**
Silver Perch	- 3.8	- 3.8	32.2-34.7
Eastern Rainbow	-4.1	- 2.5	33.9 – 38.0
Western Carp	-3.1	- 4.3	31.8 – 36.1
Rainbow Trout	- 4.8	- 5.9	24.8 – 30.0

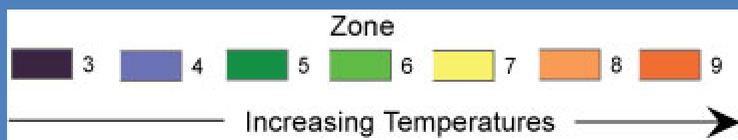
- Rainbow Trout the most coldwater species was affected the most and may not survive temperatures below 20°C

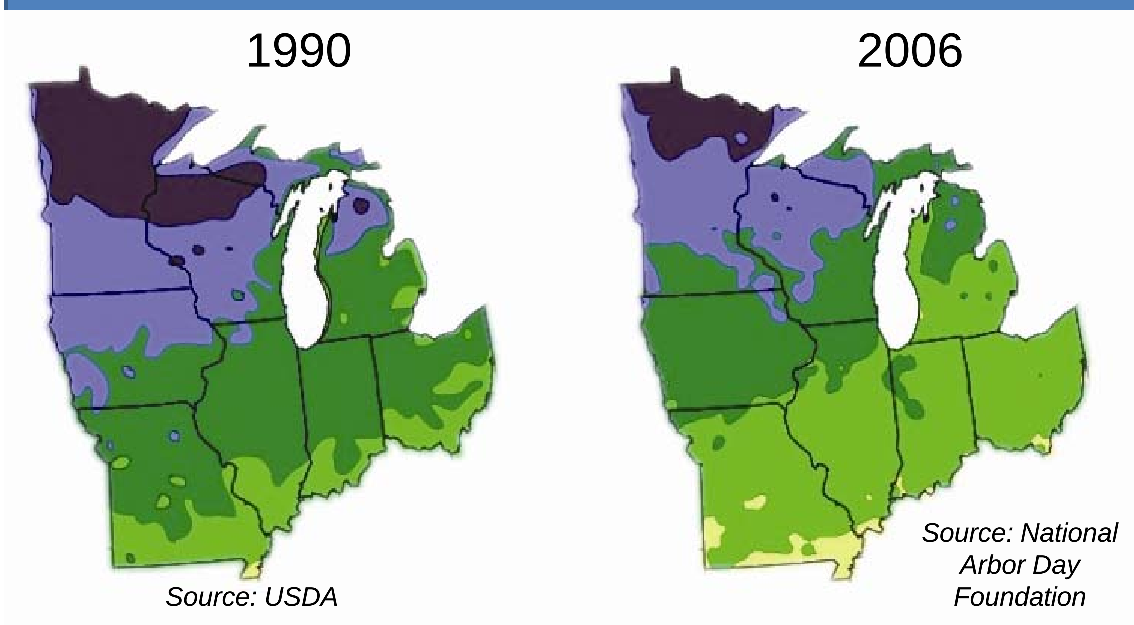
Increased Temperature

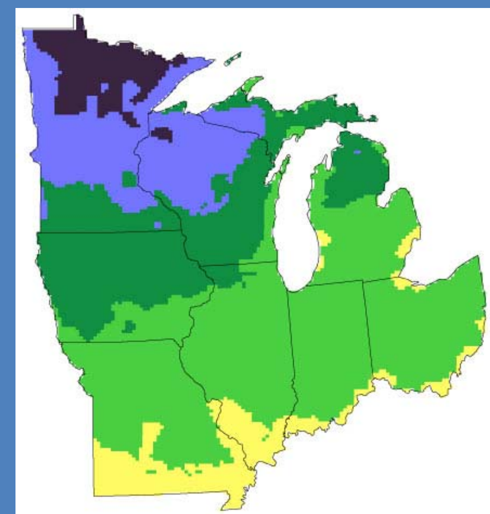
Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Increased Temperature	Increased melting of polar ice	Increased release of Hg, Pb, DDT, and other contaminants into air and surface waters of boreal ecosystems
	Increased thermal stress	Enhanced toxicity of many emerging contaminants of concern (EECs) in combination with elevated temperatures
	Ecological shifts of marine organisms	Increased occurrences of marine animal diseases and human illness/diseases associated with microbes and harmful algal blooms

Climate change is already impacting plant hardiness zones

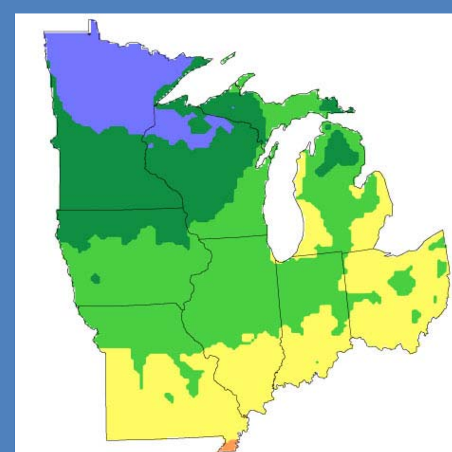
Observed and Projected Changes in Plant Hardiness Zones







Lower Emissions Scenario by 2090

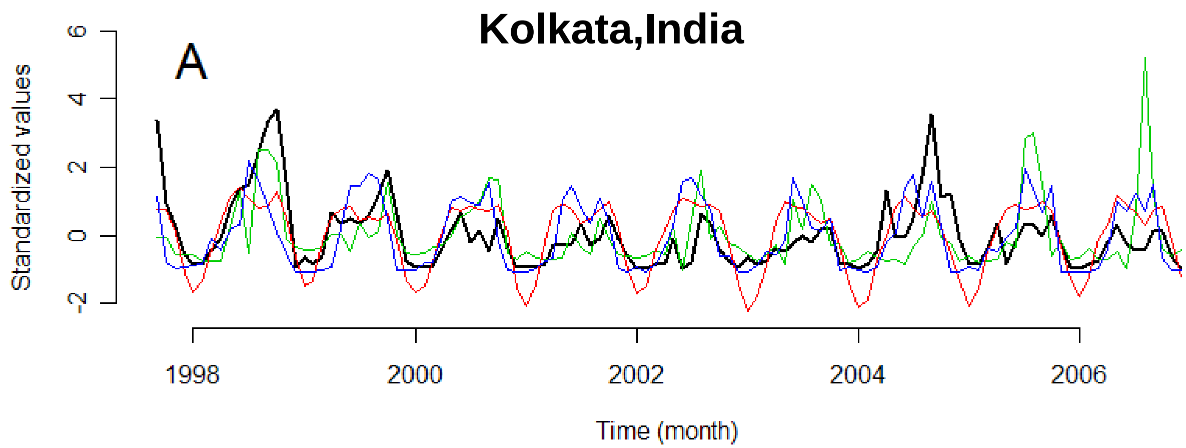


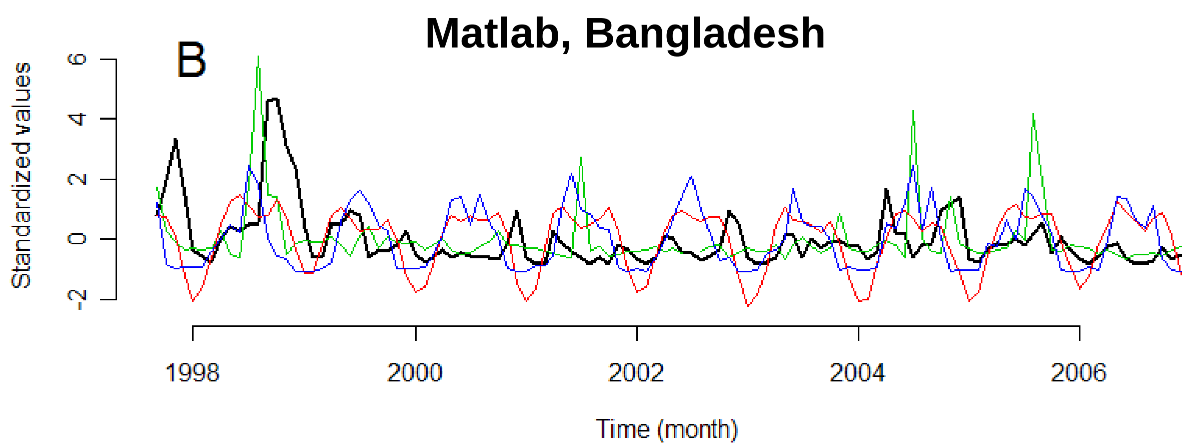
Higher Emissions Scenario by 2090

Vibrios and Climate Change

- Several *Vibrio* species (including *V. cholerae, V. parahaemolyticus,* and *V. vulnificus*) occur naturally and ubiquitously in US coastal waters
- Increasing prevalence of *Vibrios* associated with warmer waters have been noted in Northern Atlantic waters, including occurrences of *V. vulnificus*, and in the Pacific NW.
- Most alarming example: 2004 shellfish-associated outbreak of *V. parahaemolyticus* in Prince William Sound, Alaska, where it had never been found before and waters were thought to be too cold to sustain it. Clearly associated with warmer waters and impacted 62 people. Also appeared to be more virulent.

Incidence of Cholera in India and Bangladesh and Environmental Factors



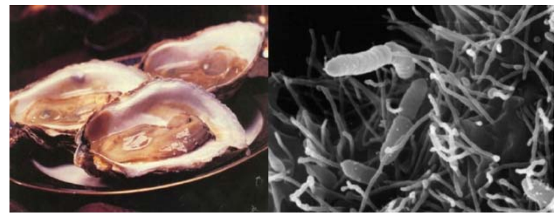


Cholera
CHL
SST
Rain

Guillaume Constantin de Magny et al. (in prep)

Vibrios: Naturally Occurring Harmful Bacteria

Vibrio cholerae



Vibrio parahaemolyticus (Vp)
Vibrio vulnificus (Vv)

- ***V. cholerae* occurs in US waters too!**
- **Vp and Vv most common cause of seafood poisonings** - underreported, misdiagnosed and increasing
- **Vv can result in death** ~ 200 ‘89 - ‘04 & 5 confirmed deaths related to Katrina; associated with 95% of fatalities associated with seafood consumption. 50-60% fatality rate for susceptible individuals; wound infections kill 20-30% of healthy individuals affected.
- **Vp estimated at 8,000 cases per year**, but this is thought to be very low due to under reporting; Not Officially Reported to CDC until 2007; Outbreaks all over the US including 1st time in Alaska in 2004.
- ***Vibrio* infection rates have increased 41% over the last decade.**
- **Rate of Antibiotic Resistance in Vibrios has increased 31% over the past decade (Colwell et al, 2009)**

Vibrio Infections in the US

Ho et al., 2004. CDC

- Between 1996 and 2001, the incidence of *Vibrio* infections increased by more than 80%.
- More importantly, despite a significant decline (30-45%) in the incidence of most bacterial foodborne infections in the United States in 2004, the incidence of *Vibrio* infections increased by 47% over the baseline period of 2001-2002.
- The CDC estimates that 8000 *Vibrio* infections and approximately 60 deaths related to *Vibrio* infections may occur annually in the United States.
- *Vibrio* infections are acquired through consumption of contaminated raw or undercooked shellfish such as oysters, clams, mussels, or crabs.
- Exposure of wounds to contaminated sea water, injury caused by contaminated seashells, and shark and alligator bites are potential alternative sources of infection.

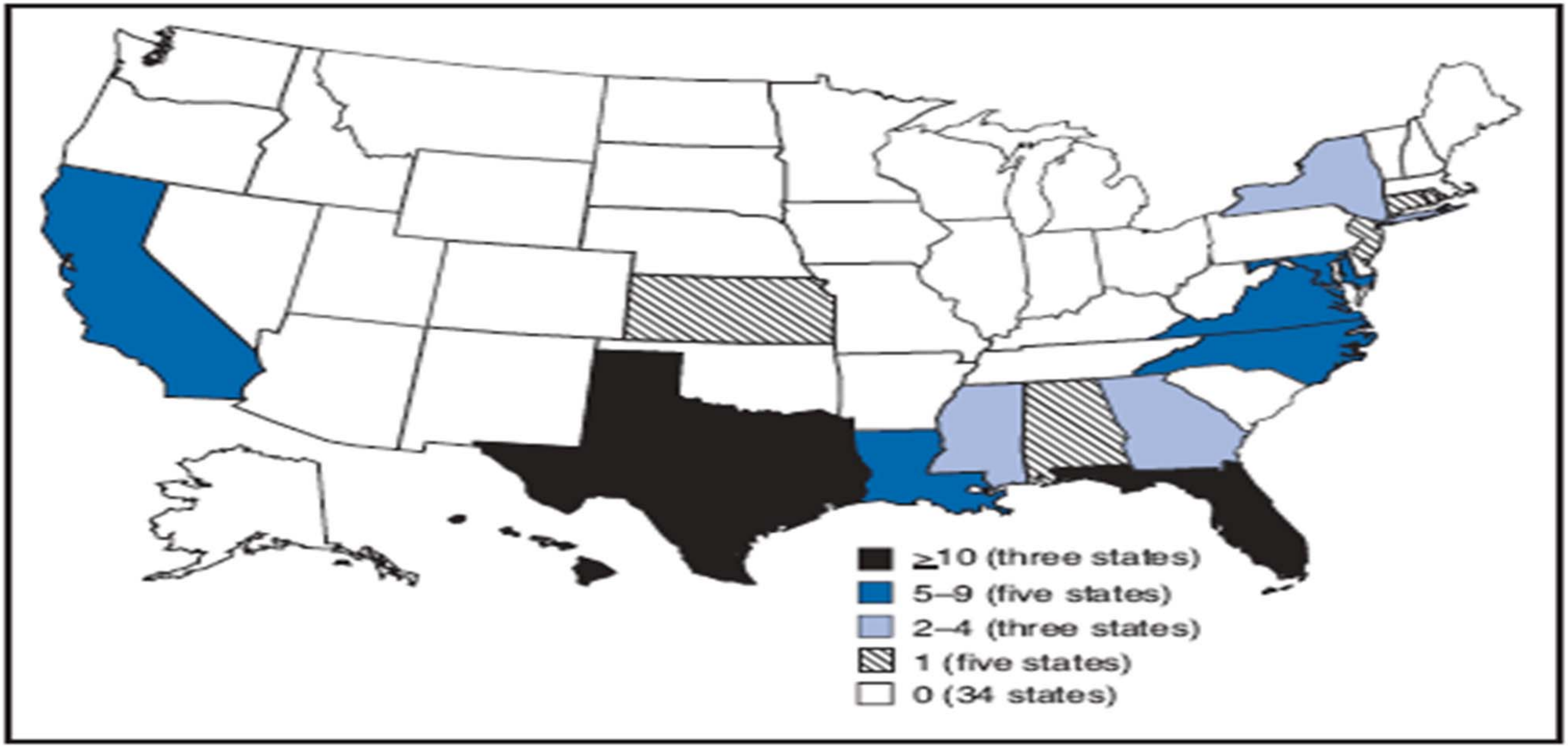
Vibrio Infections and Morbidty

Vibrio Species	Gastroenteritis (%)	Wound Infection (%)	Septicemia (%)	Miscellaneous (%)
V parahaemolyticus	59	**34**	5	2
V vulnificus	5	**45**	43	7
Non-01 V cholerae	67	9	15	...
V alginolyticus	5-12	71	1	10-15
V mimicus	85	3	3	...
V fluvialis	73	10	6	...
V damsela	Rare	**>95**	Rare	...
V furnissii	>90	Rare	Rare	...
Vibrio metschnikovii	Common	Rare	Rare	...
V hollisae	85	7	5	...
V cincinnatiensis	Rare	Rare	Rare	Meningitis

Ho et al., 2004. CDC

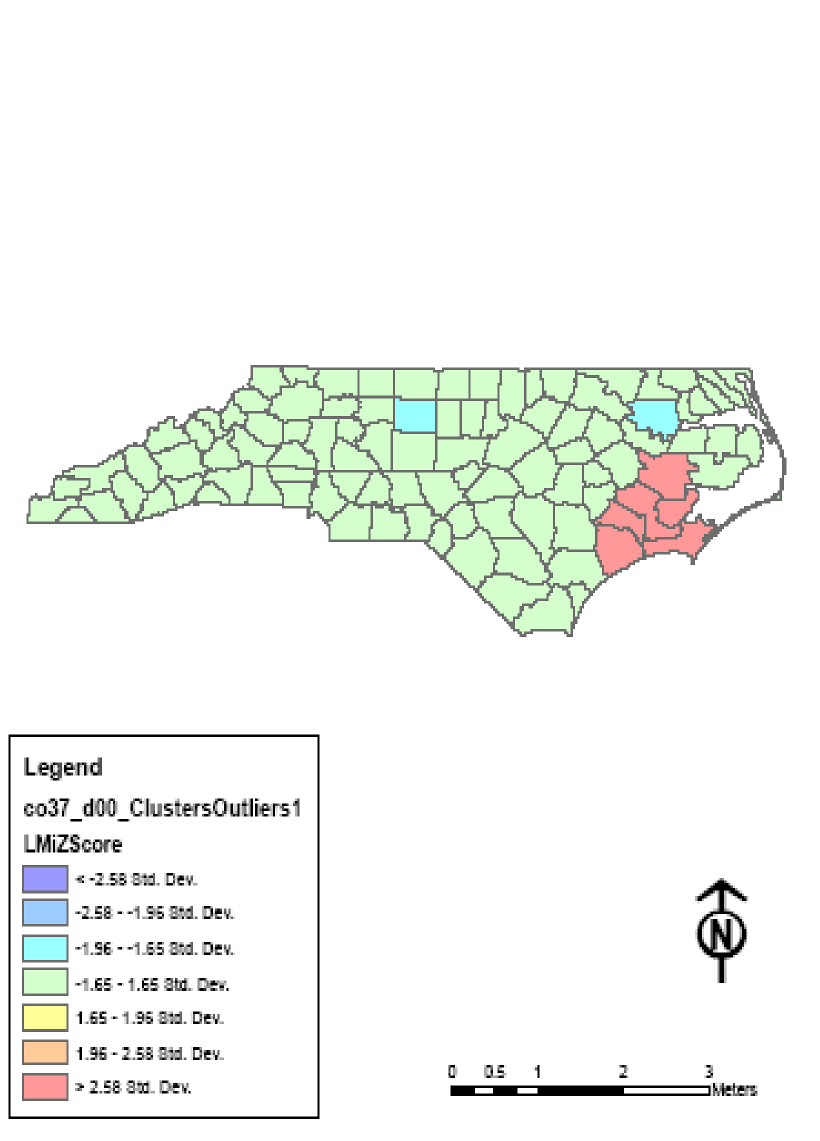
Vibrio Illnesses (# cases/state) Associated with Recreational Water: 2003-04

FIGURE 6. Number of illnesses associated with *Vibrio* isolation and recreational water exposure (n = 142) — United States, 2003–2004*

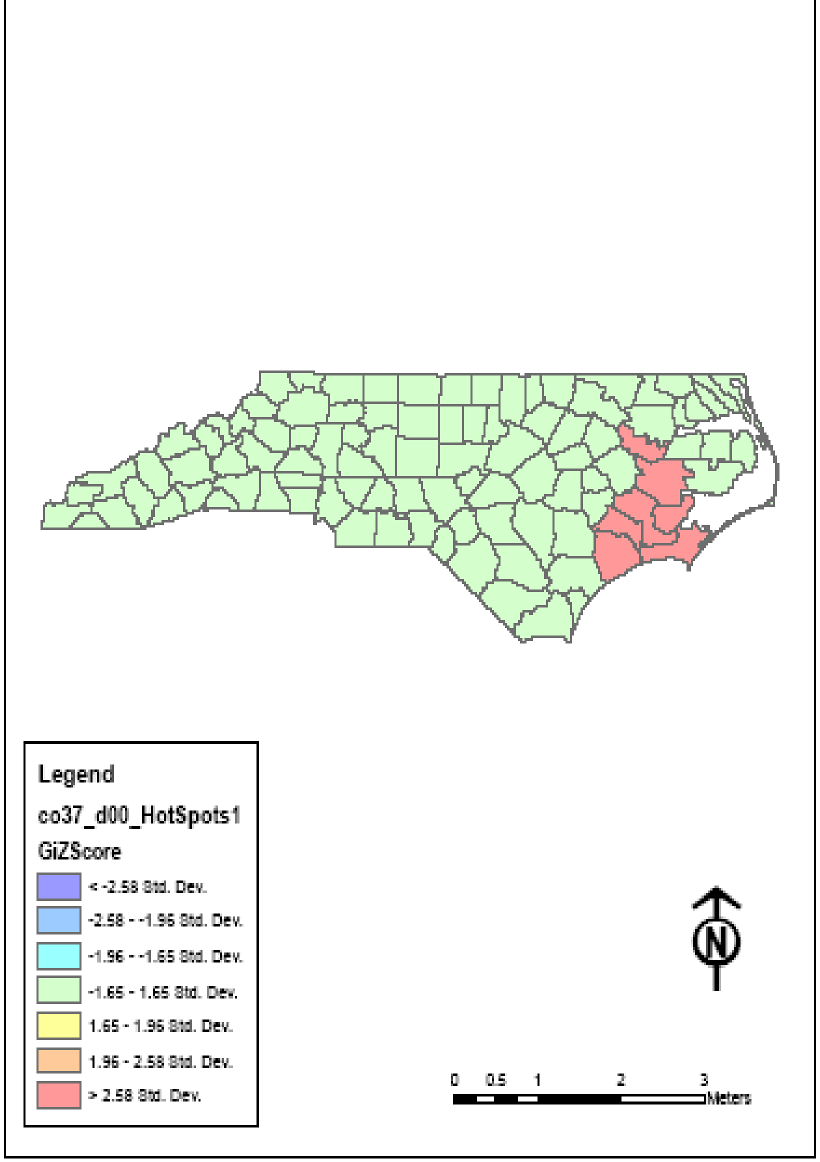


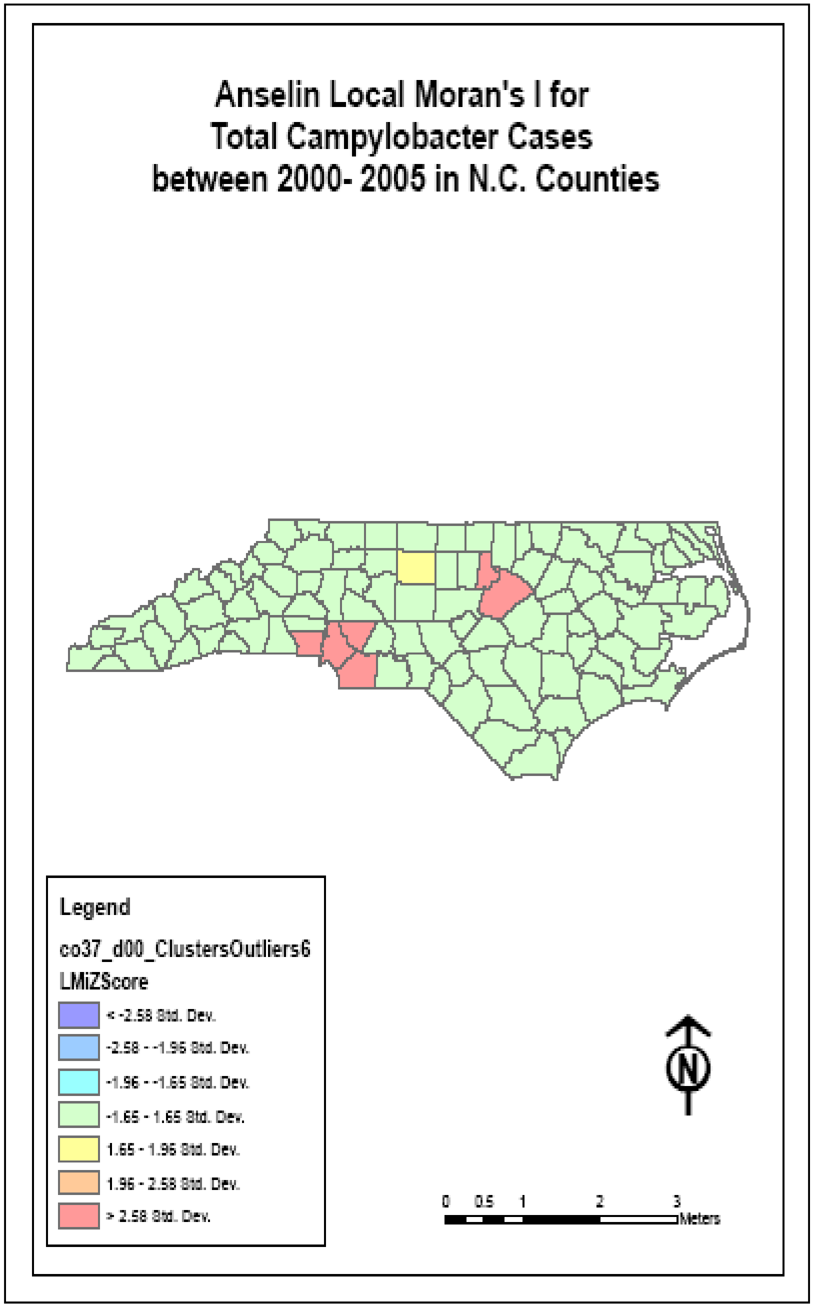
* **Note:** These numbers are largely dependent on reporting and surveillance activities in individual states and do not necessarily indicate the true incidence in a given state.

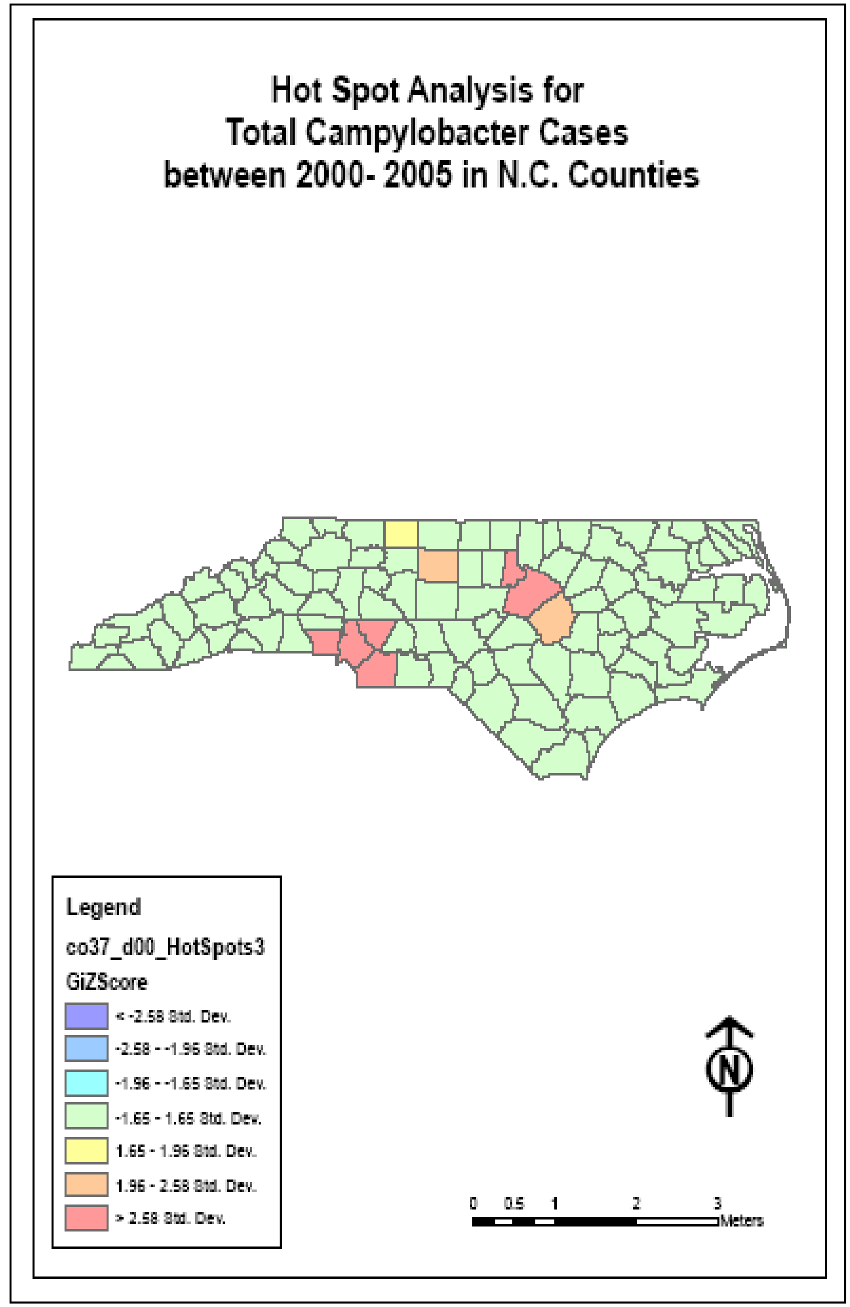
Anselin Local Moran's I for Total Vibrio vulnificus Cases between 2000- 2005 in N.C. Counties



Hot Spot Analysis for Total Vibrio vulnificus Cases between 2000- 2005 in N.C. Counties

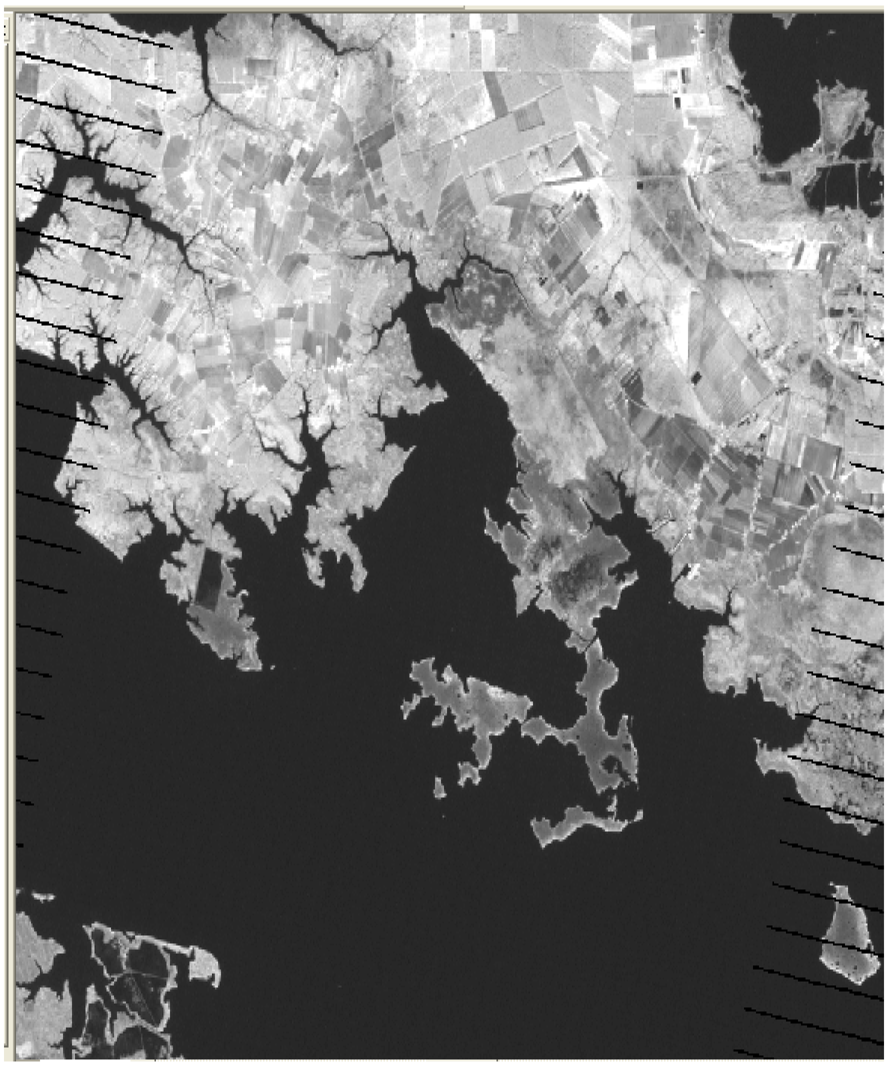



Anselin Local Moran's I for
Total Campylobacter Cases
between 2000- 2005 in N.C. Counties
Legend
co37_d00_ClustersOutliers6
LMiZScore
< -2.58 Std. Dev.
-2.58 - -1.96 Std. Dev.
-1.96 - -1.65 Std. Dev.
-1.65 - 1.65 Std. Dev.
1.65 - 1.96 Std. Dev.
1.96 - 2.58 Std. Dev.
> 2.58 Std. Dev.
N
0 0.5 1 2 3
Meters

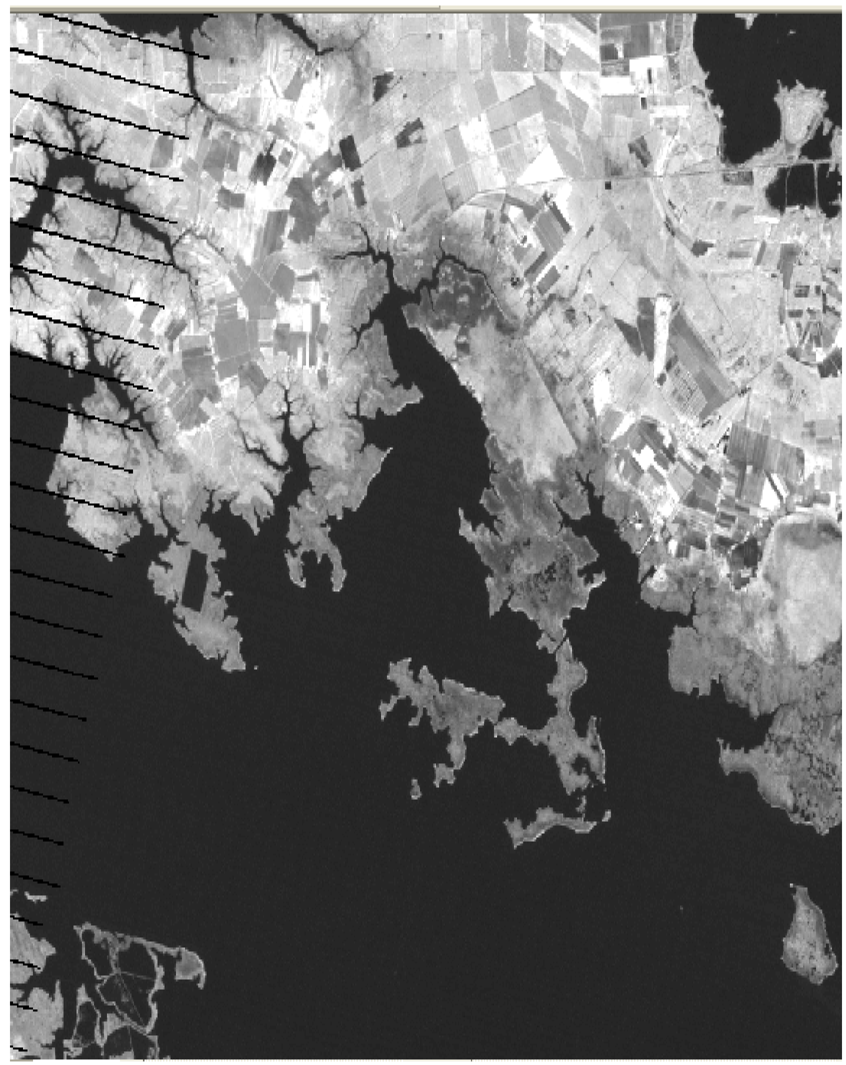

Hot Spot Analysis for
Total Campylobacter Cases
between 2000- 2005 in N.C. Counties
Legend
co37_d00_HotSpots3
GiZScore
< -2.58 Std. Dev.
-2.58 - -1.96 Std. Dev.
-1.96 - -1.65 Std. Dev.
-1.65 - 1.65 Std. Dev.
1.65 - 1.96 Std. Dev.
1.96 - 2.58 Std. Dev.
> 2.58 Std. Dev.
N
0 0.5 1 2 3
Meters

Results: Remote Sensing

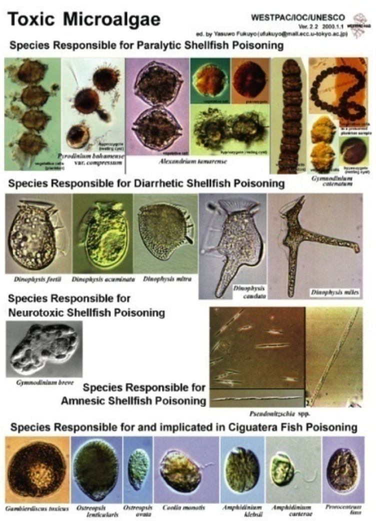
LANDSAT
07 Oct. 2003
Bands 4 (NIR)

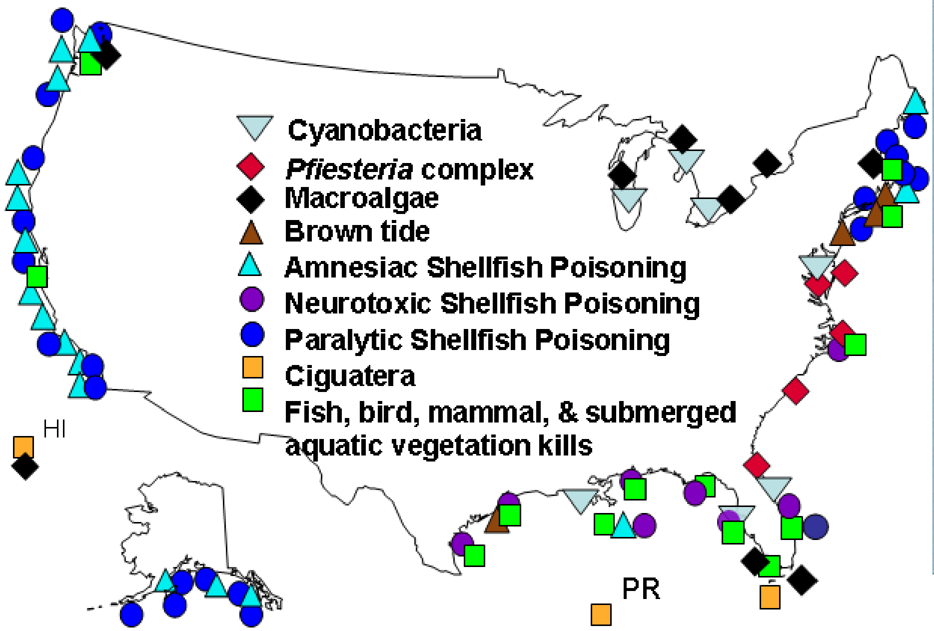


LANDSAT
20 Oct. 2010
Bands 4 (NIR)

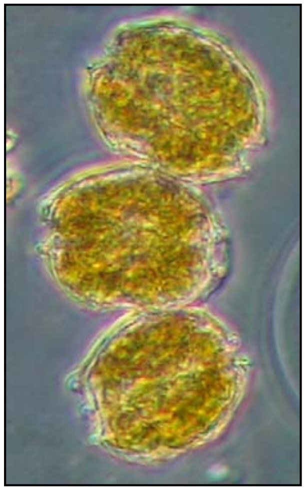


Harmful Algal Blooms (HABs)





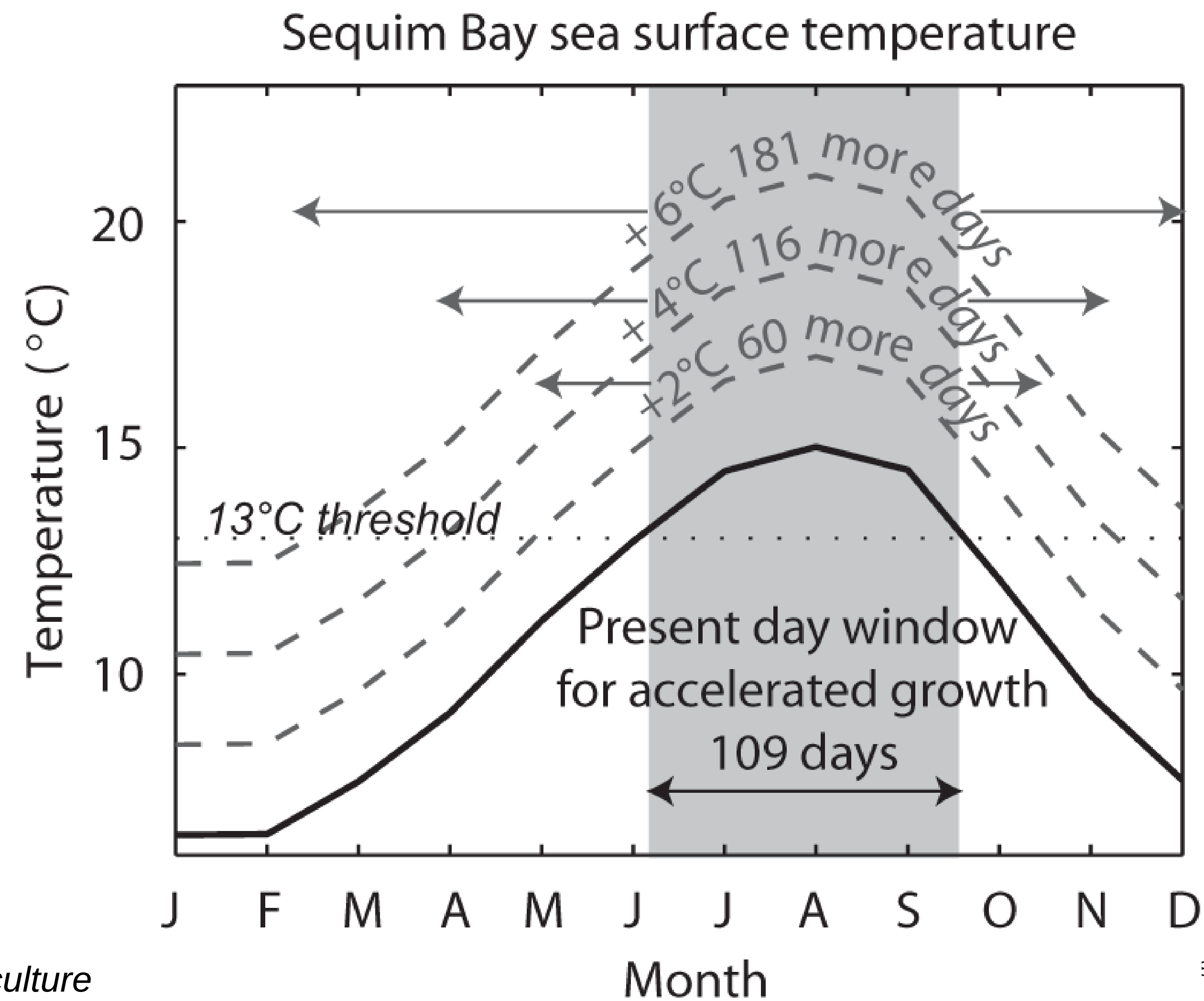
Case Study: Rising Temperatures Increase Window For HAB Growth In Puget Sound



Alexandrium catenella

- Evidence for accelerated growth when water temperatures >13° C

Nishitani and Chew (1984): Aquaculture



Moore et al. (in review): Environmental Health

Comparison of Leading Causes of Illness

Drinking Water

- **Total Cases US 1920-2002** – 10,646 cases/year
- Etiology of Disease Outbreaks, 1991-2001 in Drinking Water

  - Acute Gastroenteritis Infection (AGI) Unknown Origin 38%

  - Chemical Poisonings 16%

  - Giardiasis 12%

  -Cryptosporidiosis 7%

  - Norovirus 6%%

  - E. coli 0157:H7 5%

  - Shigellosis 4%

  -Legionella 3%

  -Campylobacterosis 3%

Surface Water

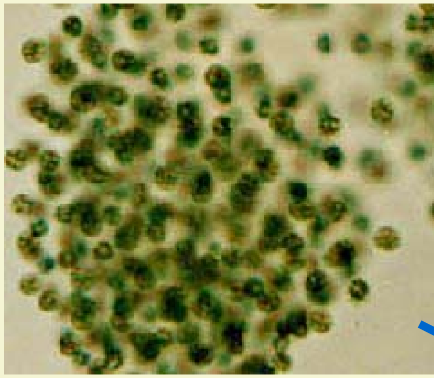
- **Total Cases US in 2004** –2,968 cases
- **Etiology of Disease Outbreaks in Surface Water**
- *Bacteria* (21% of all cases)- Pseudomonas sp.; Legionella; Shigella; *E. coli* & MRSA
- *Parasites* (53%)

  - Cryptosporidium and Giardia
- *Viruses* (13%)

  - Norovirus
- ***Chemical Toxins* (1%)**

  -Mycrosytin (toxin from blue-green algae)

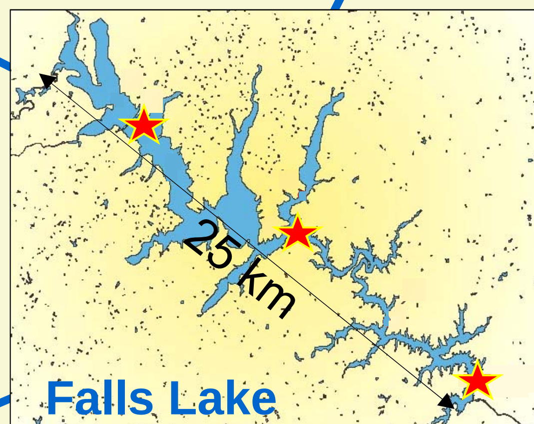
Potentially toxic cyanobacteria (max. abundance)



Microcystis aeruginosa

41,000 cells / mL

Anabaena spp.
87,000 cells / mL

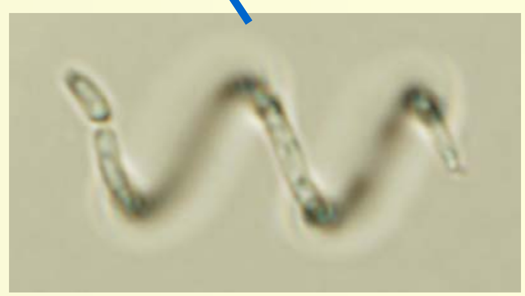


Drinking water for 0.5 million people

Cylindrospermopsis raciborskii

270,000 cells / mL

Raphidiopsis curvata
1,000 cells / mL



Cylindrospermopsis philippinensis

23,000 cells / mL

LMs: E. Allen

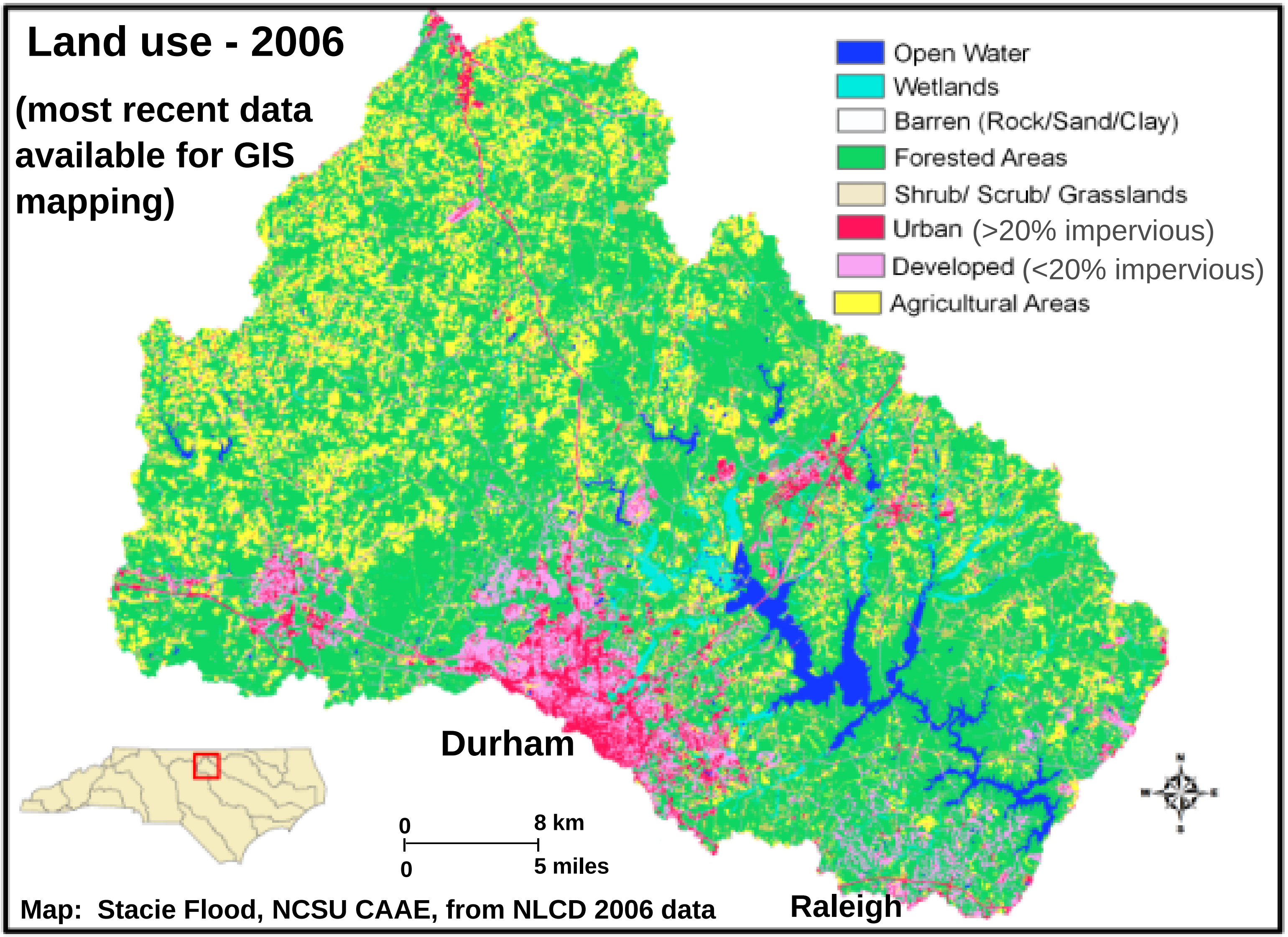
Freshwaters

Toxigenic Cyanobacteria in NC Potable Water Supply Reservoirs


Photos: M. Mallin and J. Burkholder

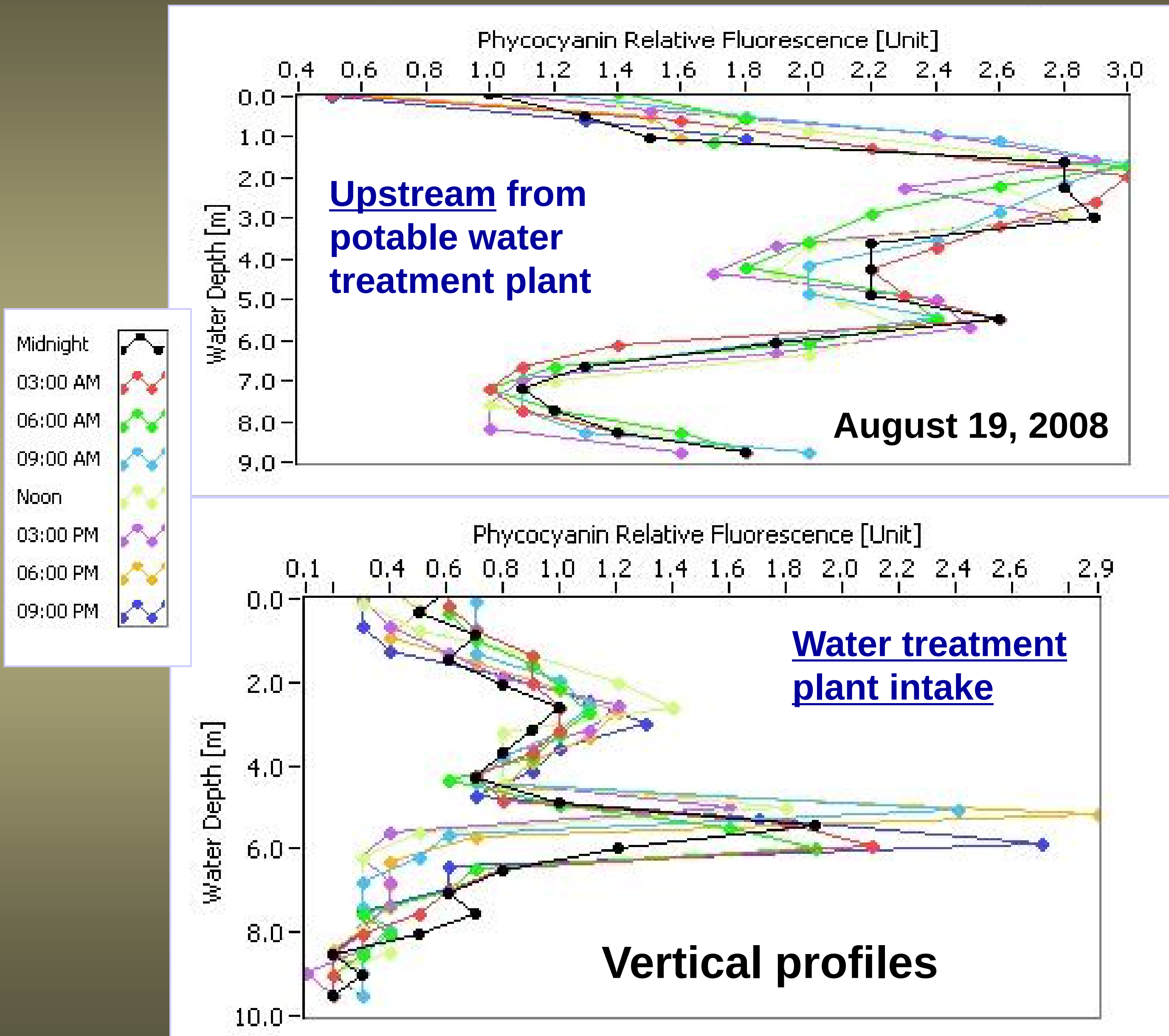
Since 2004 - RTRM, emphasizing three potable water supply reservoirs with blooms of potentially toxic cyanobacteria

Falls Lake Watershed, Raleigh, NC



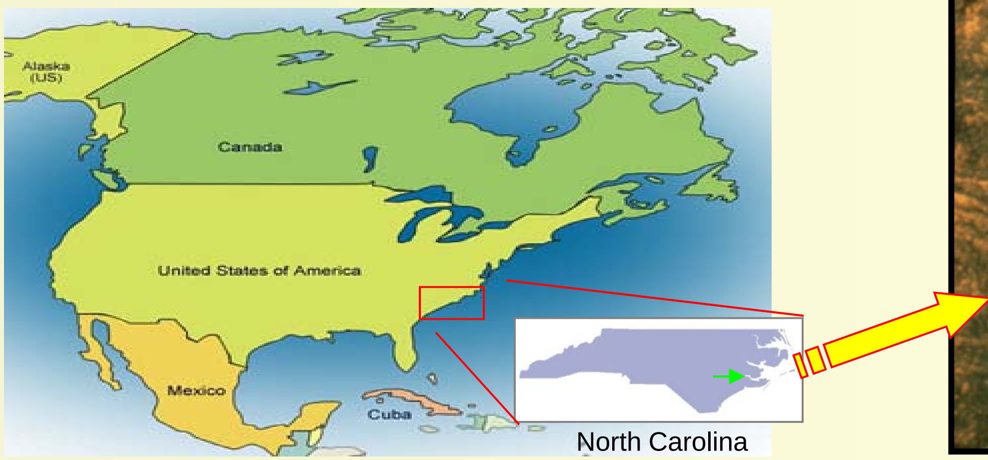
- **Nearly a decade of water quality data for trend analysis**
- **Planning to relate the findings to decadal changes in watershed land use**

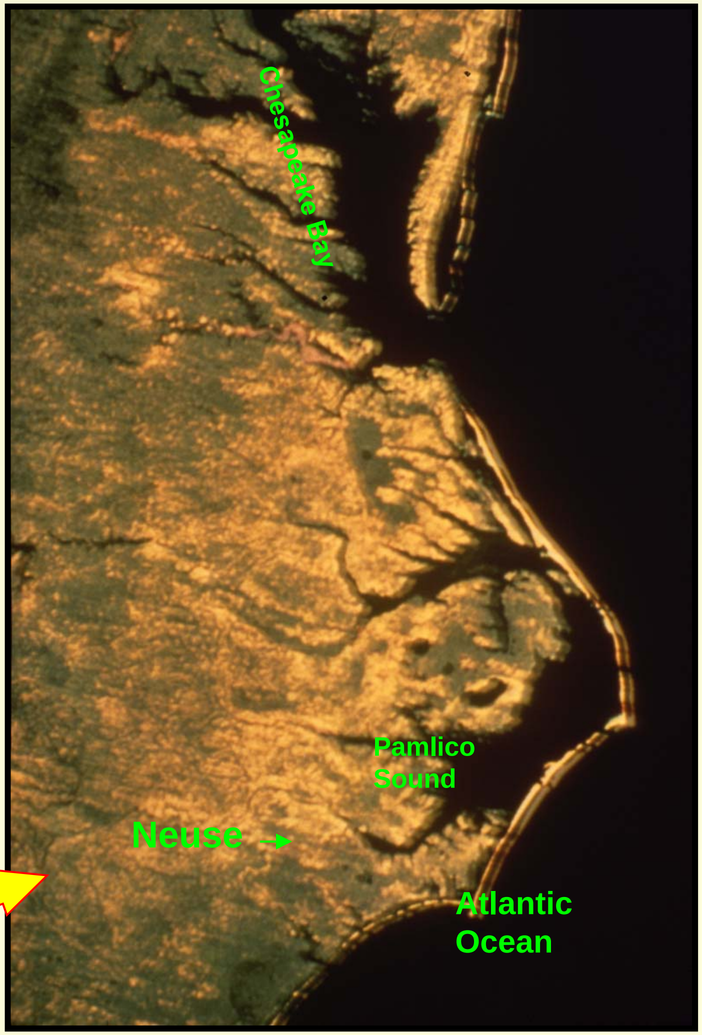
Cyanobacteria abundance (phycocyanin RF)



Severity of This Eutrophication/HAB Problem in NC

- **Estimated Restoration Costs**
  Falls Lake Reservoir - >$200M
- **Similar Problems** - Neuse, Yadkins & Other NC Watersheds
- **Restoration Cost Chesapeake Bay** - > $1-3 Billion





Maps: Travelblog.org , www.fhwaetis.com/

Albemarle-Pamlico Estuarine System - 2nd largest estuary on U.S. mainland

Phytoplankton Monitoring Network

Promoting a better understanding of Harmful Algal Blooms by way of Volunteer Monitoring

PMN Expansion

2001 — *South Carolina Phytoplankton Monitoring Network* (SCPMN)
+ South Carolina

2003 — *Southeast Phytoplankton Monitoring Network* (SEPMN)

2004 — + Georgia

2005 — + North Carolina

2006 — + Florida, US Virgin Islands, Hawaii

2007 — *Phytoplankton Monitoring Network* (PMN)
+ Massachusetts, Texas, Alabama

2008 — + Virginia, Alaska, Mississippi, Maryland, Rhode Island

2009 — + Washington, New York, Connecticut

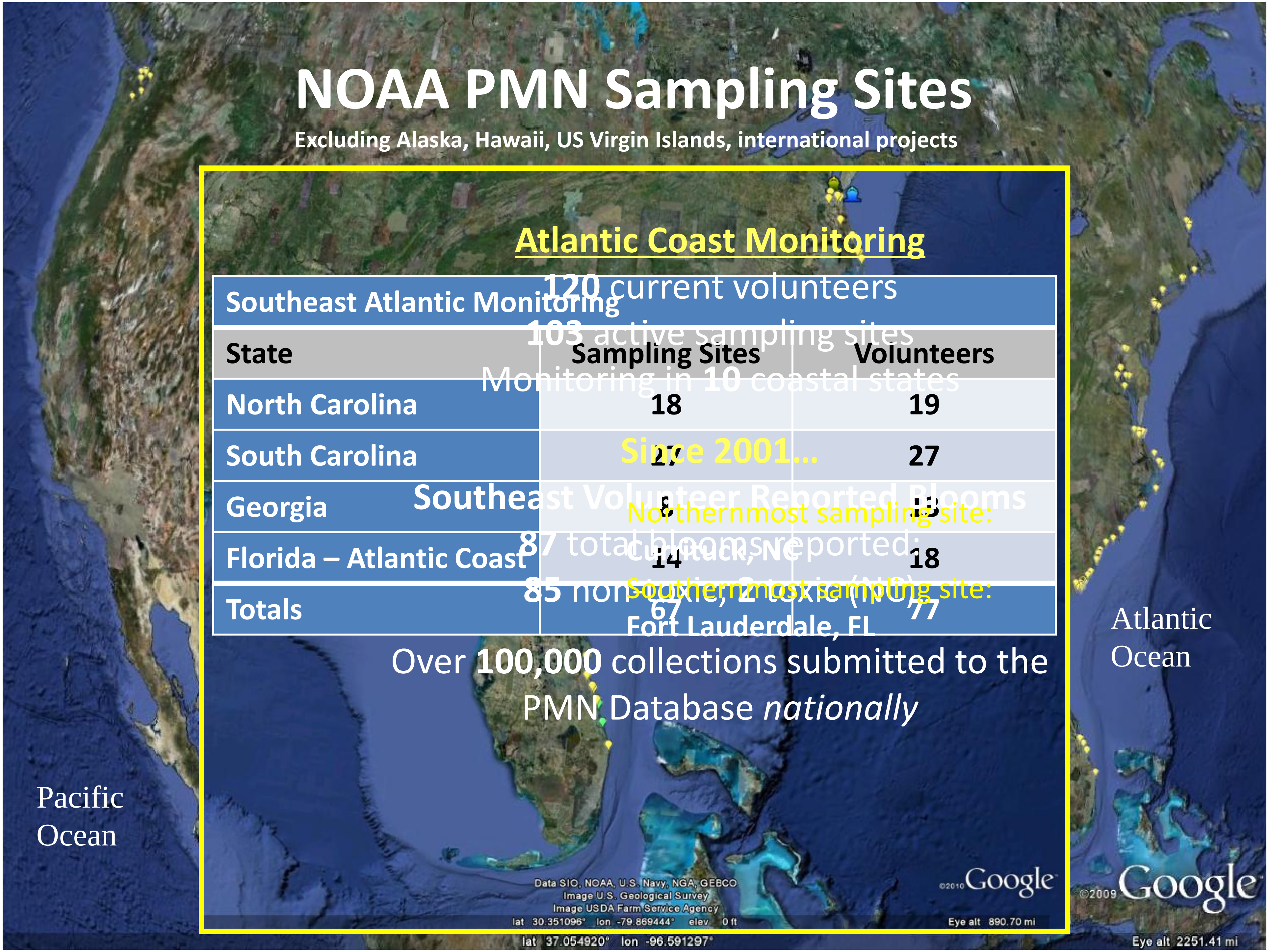
2010 — + Minnesota, Wisconsin, St. Johns River Basin

Phytoplankton Monitoring Network

Volunteer Sampling Sites

NOAA PMN Sampling Sites

Excluding Alaska, Hawaii, US Virgin Islands, international projects



Atlantic Coast Monitoring

120 current volunteers

103 active sampling sites

Monitoring in **10** coastal states

Over **100,000** collections submitted to the PMN Database *nationally*

Southeast Atlantic Monitoring		
State	**Sampling Sites**	**Volunteers**
North Carolina	**18**	**19**
South Carolina	**27**	**27**
Georgia	**8**	**13**
Florida – Atlantic Coast	**14**	**18**
Totals	**67**	**77**

Since 2001…

Southeast Volunteer Reported Blooms

87 total blooms reported:

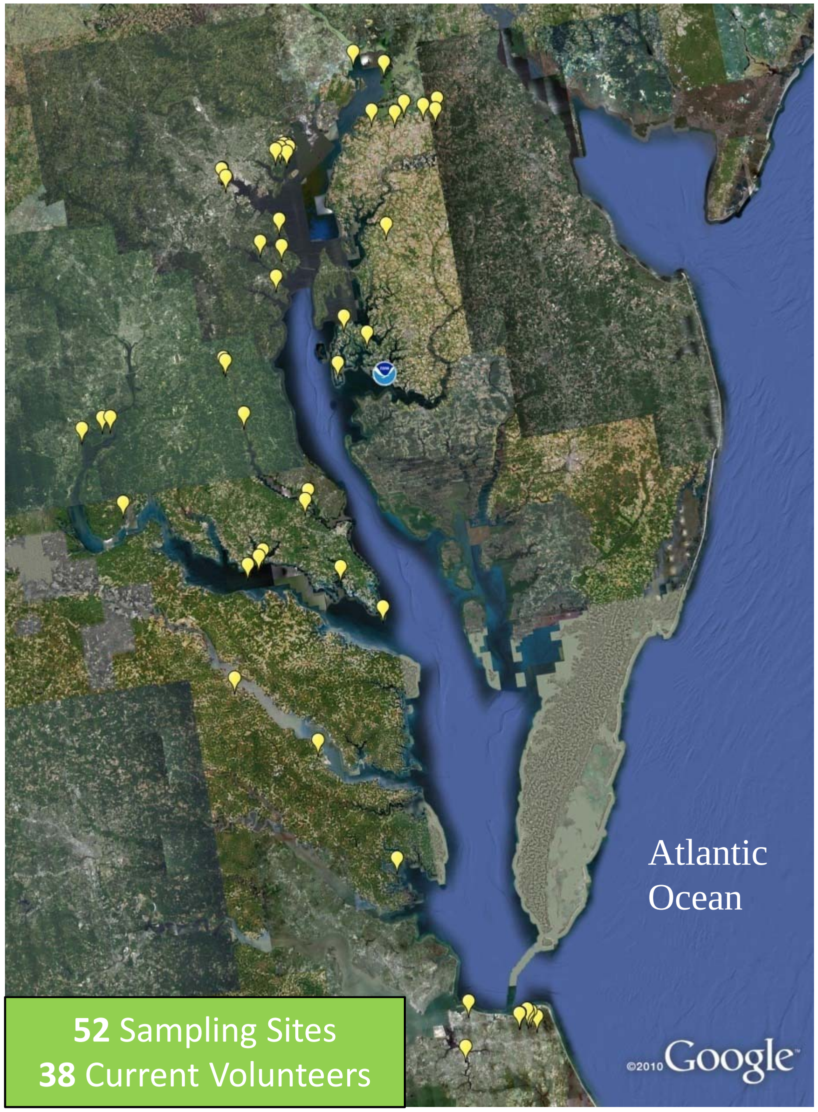
85 non-toxic, **2** toxic (NC)

Northernmost sampling site:
Currituck, NC

Southernmost sampling site:
Fort Lauderdale, FL

Chesapeake Bay PMN Monitoring

Including Virginia and Maryland



Phytoplankton monitoring a part of an Integrated Ecosystem Assessment

⇩

Investigating watershed health

Linking human activities to ecosystem services

★ **PMN monitoring a part of Virginia HAB Response Plan** ★

Partnerships

Agencies

Cooperative Oxford Laboratory
Virginia Department of Health

Universities

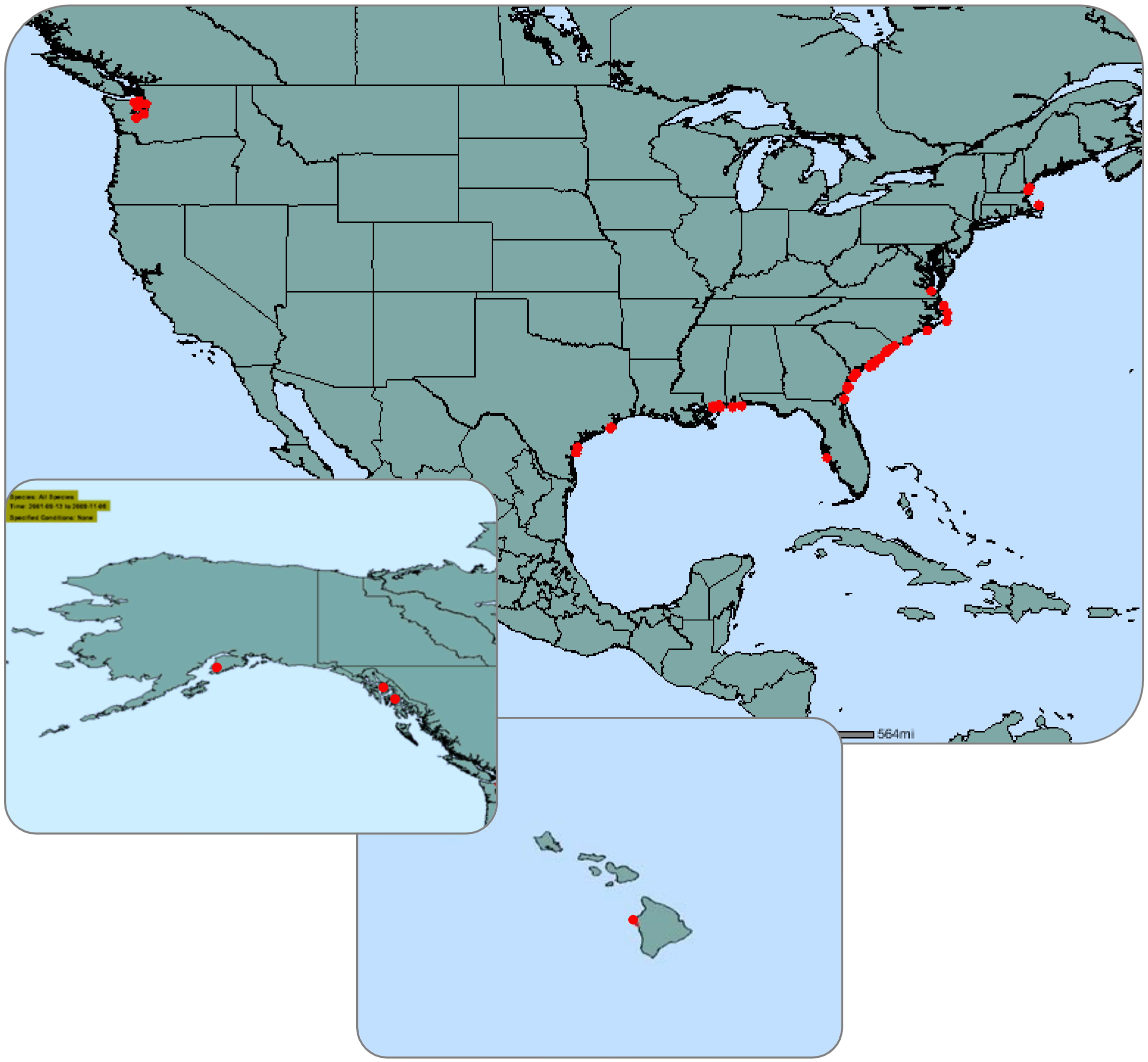
George Mason University
Morgan State University Estuarine Research Center

Environmental Organizations

Maryland Conservation Corps
Sassafras Riverkeeper
Lynnhaven River NOW

Phytoplankton Monitoring Network

Bloom Events from 2001 – 2009



Volunteer Reported Blooms: 200

Non-harmful species = 163

Potentially toxic species = 37

Confirmed toxic events = 7

- 6 Domoic Acid
  - Texas = 2
  - Mississippi = 2
  - North Carolina = 2
- 1 Okadaic Acid
  - Texas = 1

Maps created by NOAA Coastal Data Development Center (NCDDC)

Phytoplankton Monitoring Network

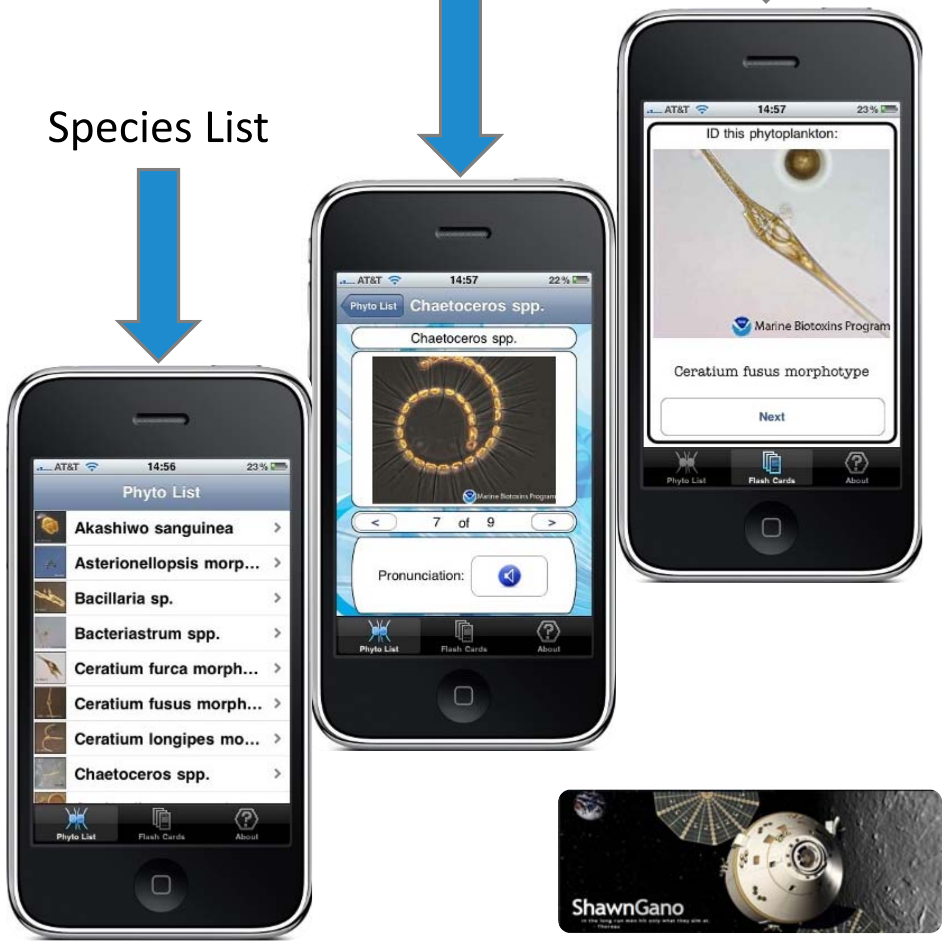
the "Phyto" iPhone Application

Developed by PMN volunteer Shawn Gano, to assist with and to improve volunteer's identification skills of marine phytoplankton and harmful algae in the Gulf of Mexico region.

Flash Card Game

Image Gallery & Pronunciations

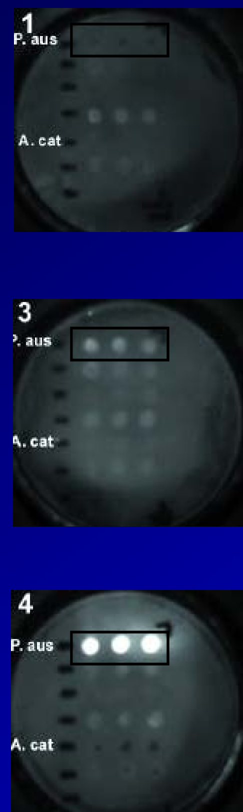
Species List



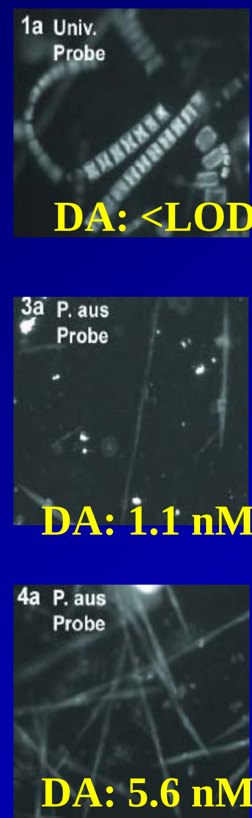
demonstration of this application can be viewed at http://www.gano.name/shawn/phyto/

In Situ Application of Toxin Assays for HAB Monitoring and Research

MBARI Environmental Sample Processor

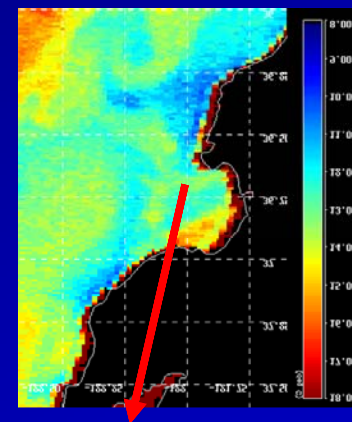


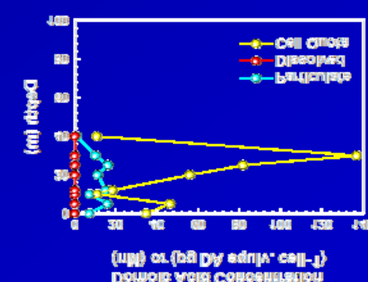
rRNA Probe Array



Domoic Acid Receptor Assay

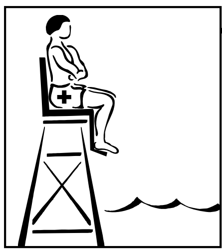
Monterey Bay, CA





Vertical profiling of DA in Pseudo-nitzschia australis bloom 2000

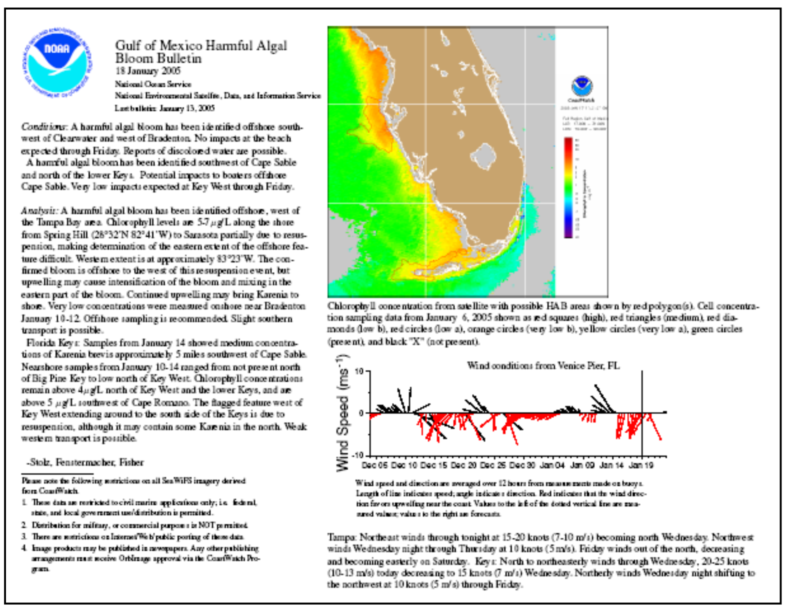
HAB Forecast System: Early Warning to Protect Human Health



Observations

Model Output

Synthesis
and Analysis



Gulf of Mexico Harmful Algal Bloom Bulletin
18 January 2005
National Ocean Service
National Environmental Satellite, Data, and Information Service
Last bulletin: January 13, 2005

Conditions: A harmful algal bloom has been identified offshore southwest of Clearwater and west of Bradenton. No impacts at the beach expected through Friday. Reports of discolored water are possible.

A harmful algal bloom has been identified southwest of Cape Sable and north of the lower Keys. Potential impacts to boaters offshore Cape Sable. Very low impacts expected at Key West through Friday.

Analysis: A harmful algal bloom has been identified offshore, west of the Tampa Bay area. Chlorophyll levels are 5-7 μg/L along the shore from Spring Hill (28°32'N 82°41'W) to Sarasota partially due to resuspension, making determination of the eastern extent of the offshore feature difficult. Western extent is at approximately 83°23'W. The confirmed bloom is offshore to the west of this resuspension event, but upwelling may cause intensification of the bloom and mixing in the eastern part of the bloom. Continued upwelling may bring Karenia to shore. Very low concentrations were measured onshore near Bradenton January 10-12. Offshore sampling is recommended. Slight southern transport is possible.

Florida Keys: Samples from January 14 showed medium concentrations of Karenia brevis approximately 5 miles southwest of Cape Sable. Nearshore samples from January 10-14 ranged from not present north of Big Pine Key to low north of Key West. Chlorophyll concentrations remain above 4 μg/L north of Key West and the lower Keys, and are above 5 μg/L southwest of Cape Romano. The flagged feature west of Key West extending around to the south side of the Keys is due to resuspension, although it may contain some Karenia in the north. Weak western transport is possible.

-Stolz, Fenstermacher, Fisher

Please note the following restrictions on all SeaWiFS imagery derived from CoastWatch.

1. These data are restricted to civil marine applications only; i.e. federal, state, and local government use/distribution is permitted.
2. Distribution for military, or commercial purposes is NOT permitted.
3. There are restrictions on Internet/Web/public posting of these data.
4. Image products may be published in newspapers. Any other publishing arrangements must receive OrbImage approval via the CoastWatch Program.

Chlorophyll concentration from satellite with possible HAB areas shown by red polygon(s). Cell concentration sampling data from January 6, 2005 shown as red squares (high), red triangles (medium), red diamonds (low b), red circles (low a), orange circles (very low b), yellow circles (very low a), green circles (present), and black "X" (not present).

Wind conditions from Venice Pier, FL

Wind Speed (ms⁻¹)

Dec 05 Dec 10 Dec 15 Dec 20 Dec 25 Dec 30 Jan 04 Jan 09 Jan 14 Jan 19

Wind speed and direction are averaged over 12 hours from measurements made on buoys. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

Tampa: Northeast winds through tonight at 15-20 knots (7-10 m/s) becoming north Wednesday. Northwest winds Wednesday night through Thursday at 10 knots (5 m/s). Friday winds out of the north, decreasing and becoming easterly on Saturday. Keys: North to northeasterly winds through Wednesday, 20-25 knots (10-13 m/s) today decreasing to 15 knots (7 m/s) Wednesday. Northerly winds Wednesday night shifting to the northwest at 10 knots (5 m/s) through Friday.

A harmful algal bloom has been identified in patches from southern Lee to central Collier County. Patchy very low impacts are possible from southern Lee County to central Collier County today through Thursday. No other impacts are expected.

Conditions Report (public)

HAB Bulletin (managers)

http://www.csc.noaa.gov/crs/habf

Increased Sea Level Rise

Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Sea Level Rise	Increased coastal flooding and subsidence	Destruction of coastal property/commerce, including infrastructure such as drinking water supplies and waste water treatment facilities
Extreme Weather	Increased runoff and drought	Enhanced exposure of marine organisms and humans to chemical contaminants, microbes and nutrients
		Greater number of shellfish and beach closures
		Greater susceptibility of older coastal population
Altered Salinity Regimens	Increased osmoregulation stress	Enhanced toxicity of many EECs

Global Climate Change:
Sea Level Rise Effects

- **Sea Level Rise**

  - Normal Eustatic Sea Level Rise – 10-20 cm/100 years (4-8 inches)

  -With 1.5-4.5 Degree F Increase – 70-100cm/100 year rise (28-40 inches)

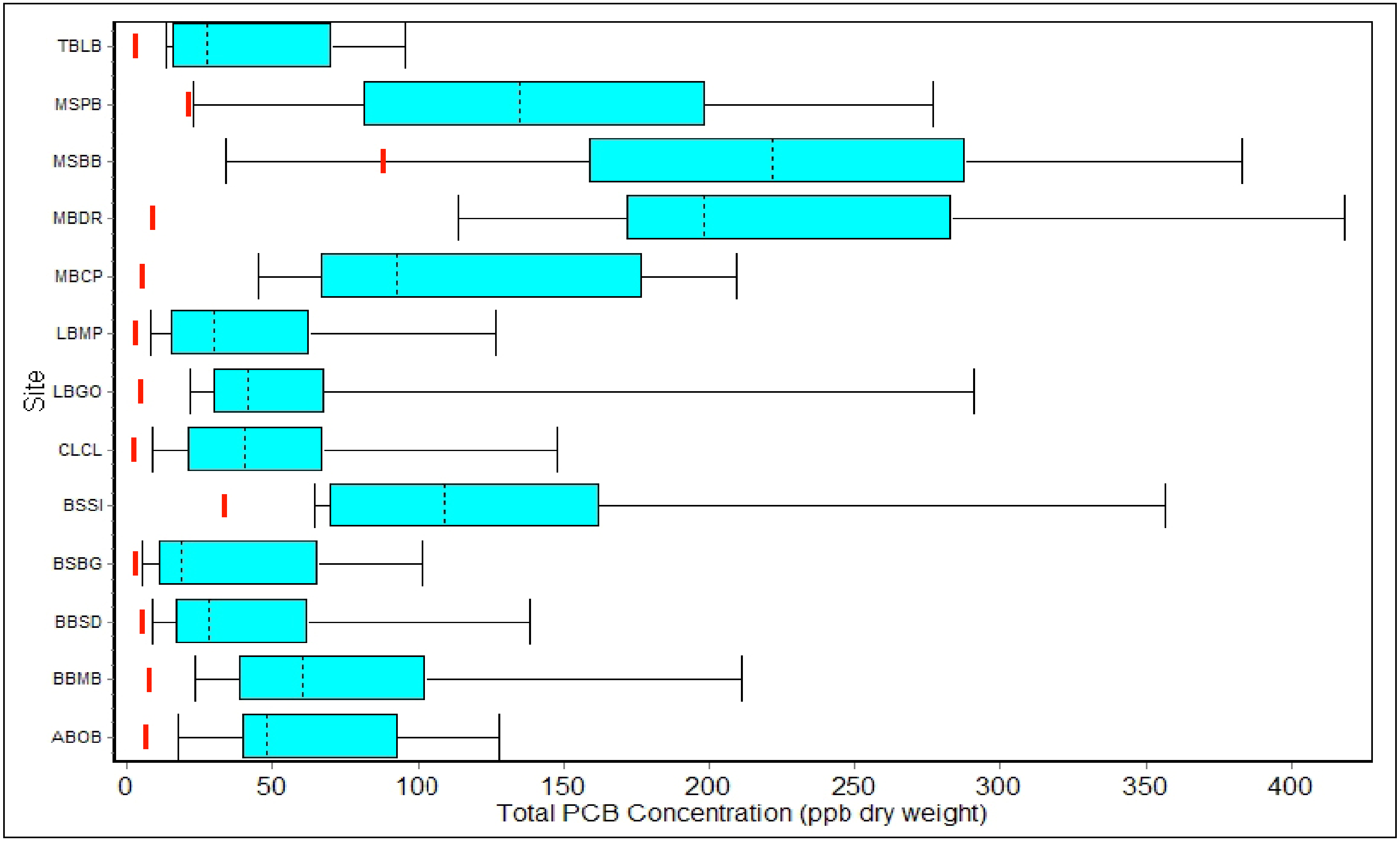
- **Coastal Land Use Vulnerable to Flooding**

Commercial Land Use

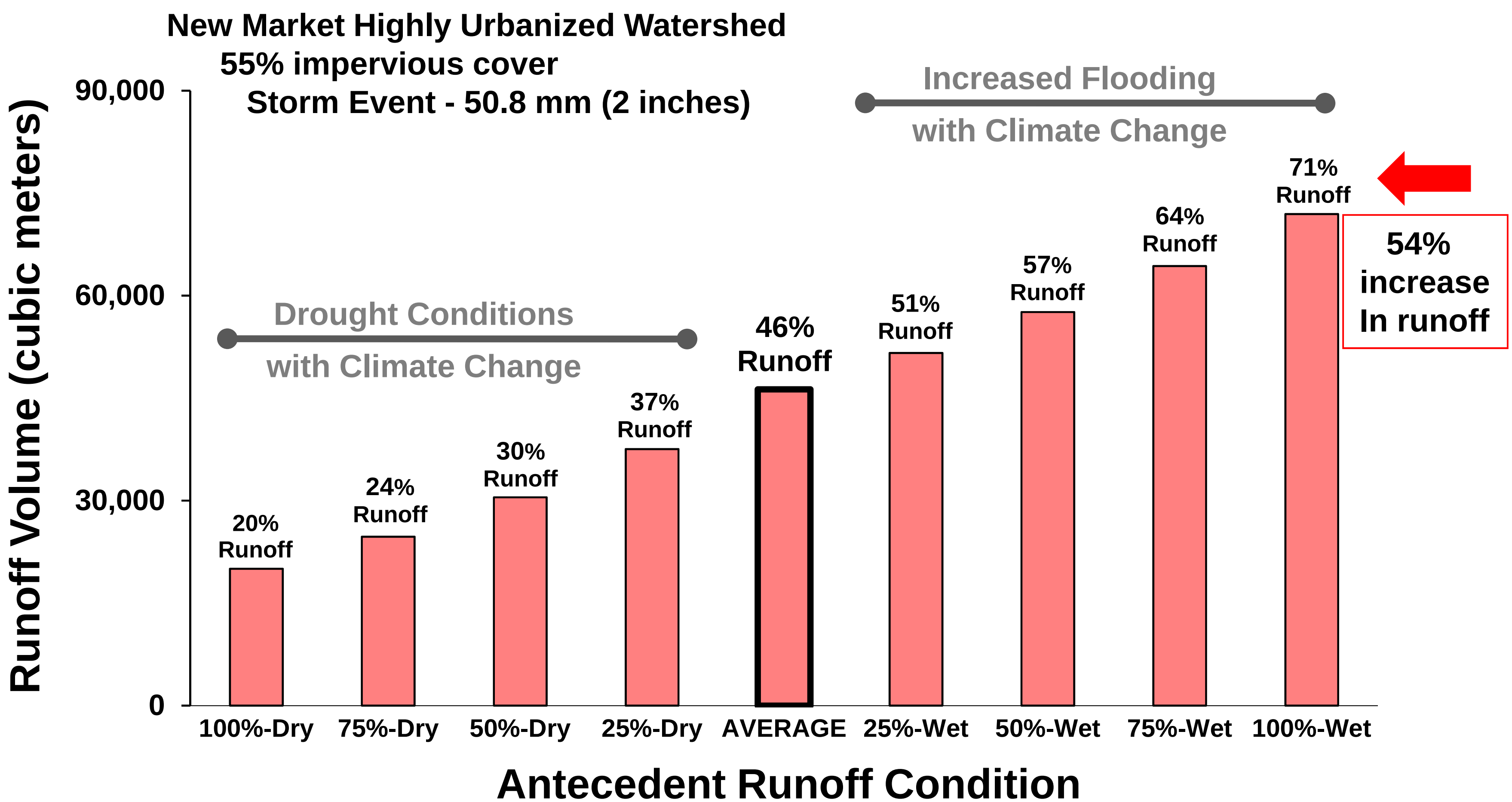
Urban/Industrial Land Use

Suburban Land Use

Hurricane and Floods: Katrina PCB Levels in Oysters



The 'dryer dry' periods and 'wetter wet' periods of climate change will dramatically impact stormwater runoff in developed watersheds as sea level rise will affect soil moisture conditions to enhance runoff

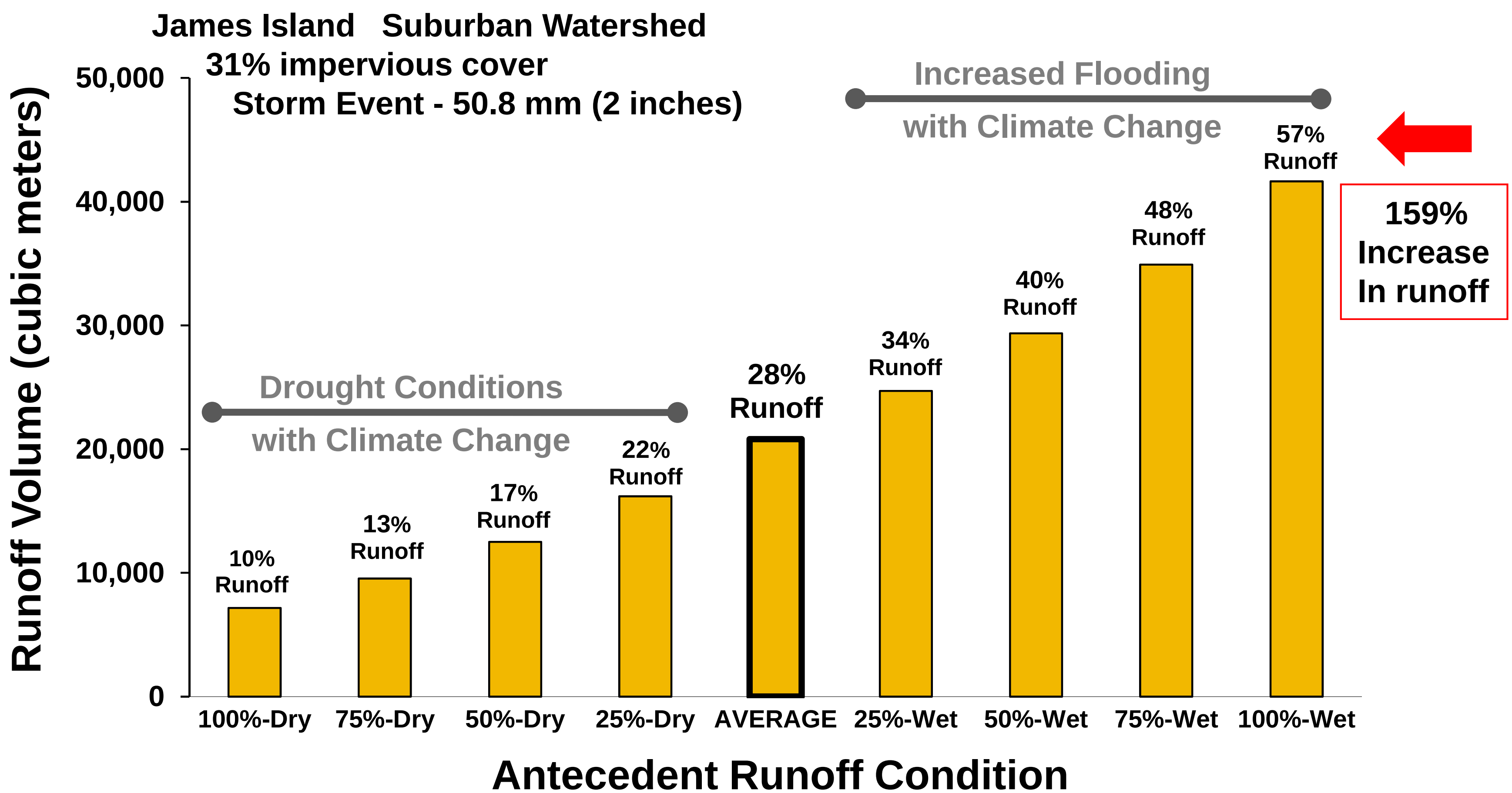


Courtesy of Anne Blair, NOAA Hollings Marine Laboratory, Charleston, SC

Center for Human Health Risk at the Hollings Marine Laboratory

Center for Coastal Environmental Health and Biomolecular Research

The 'dryer dry' periods and 'wetter wet' periods of climate change will dramatically impact stormwater runoff in developed watersheds as sea level rise will affect soil moisture conditions to enhance runoff



Courtesy of Anne Blair, NOAA Hollings Marine Laboratory, Charleston, SC

Center for Human Health Risk at the Hollings Marine Laboratory

Center for Coastal Environmental Health and Biomolecular Research

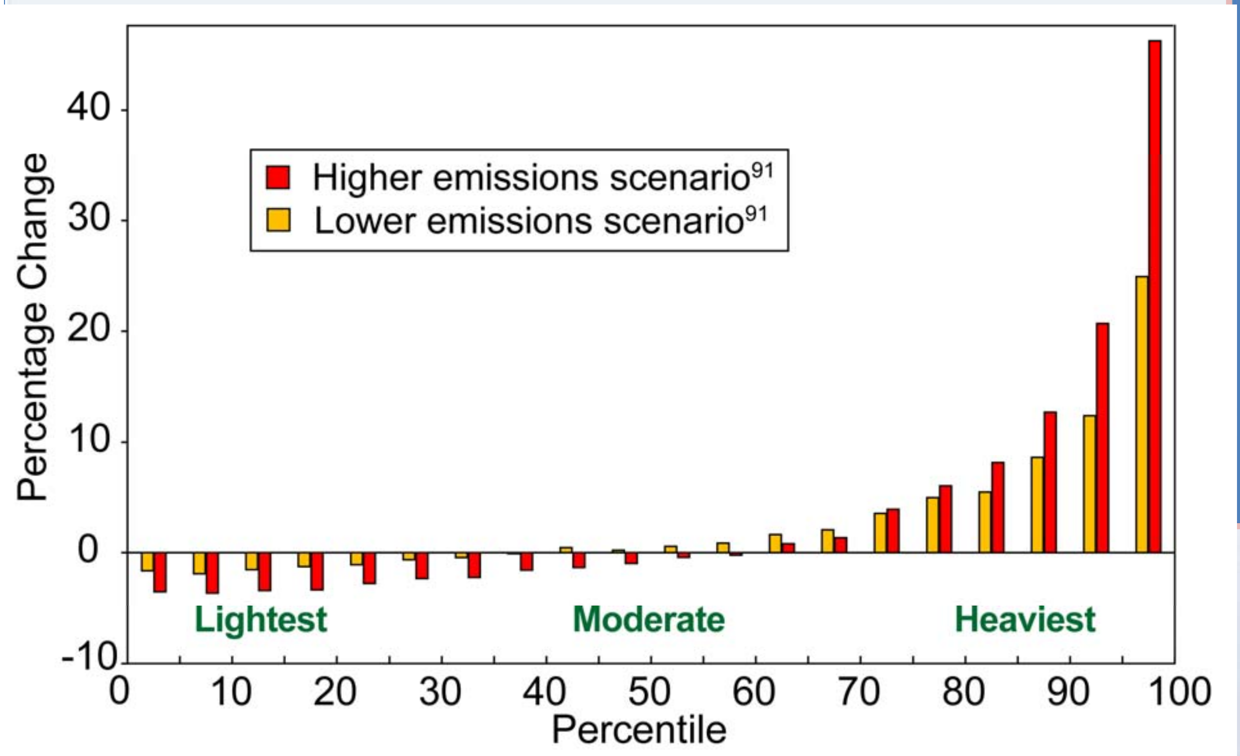
Increased Runoff and Drought

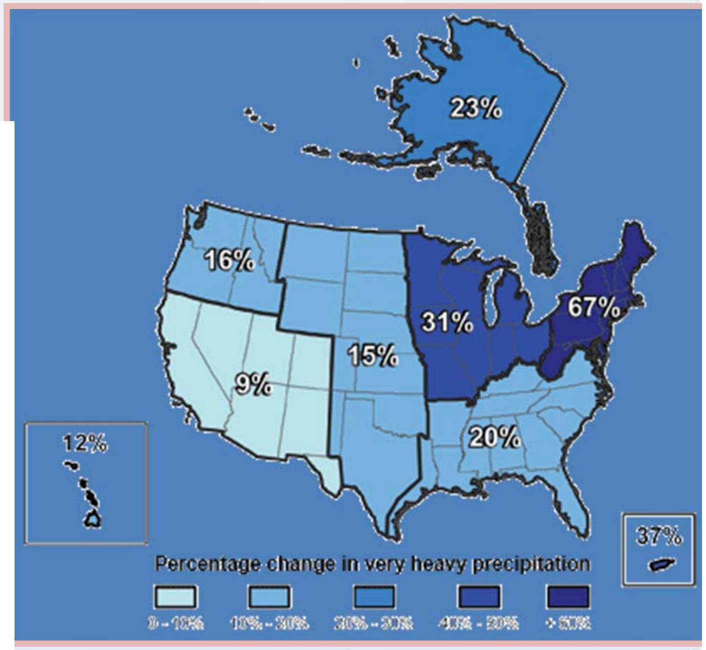
Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Sea Level Rise	Increased coastal flooding and subsidence	Destruction of coastal property/commerce, including infrastructure such as drinking water supplies and waste water treatment facilities
Extreme Weather	Increased runoff and drought	Enhanced exposure of marine organisms and humans to chemical contaminants, microbes and nutrients
		Greater number of shellfish and beach closures
		Greater susceptibility of older coastal population
Altered Salinity Regimens	Increased osmoregulation stress	Enhanced toxicity of many EECs

Heavy precipitation events have been increasing and are projected to continue to increase

Observed Increases in Very Heavy Precipitation (1958 to 2007)

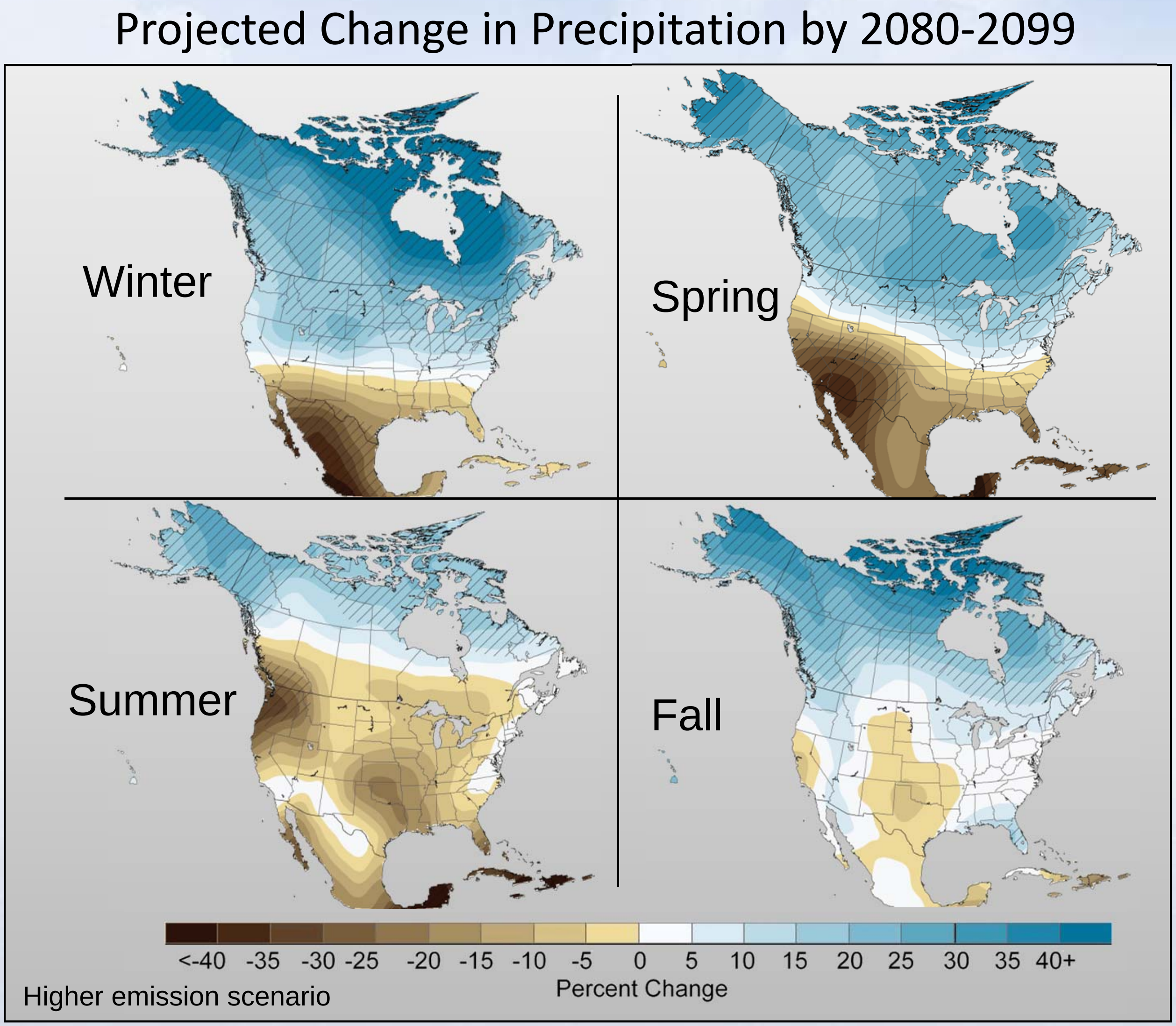
Projected Change in Precipitation Intensity (2080-2099)



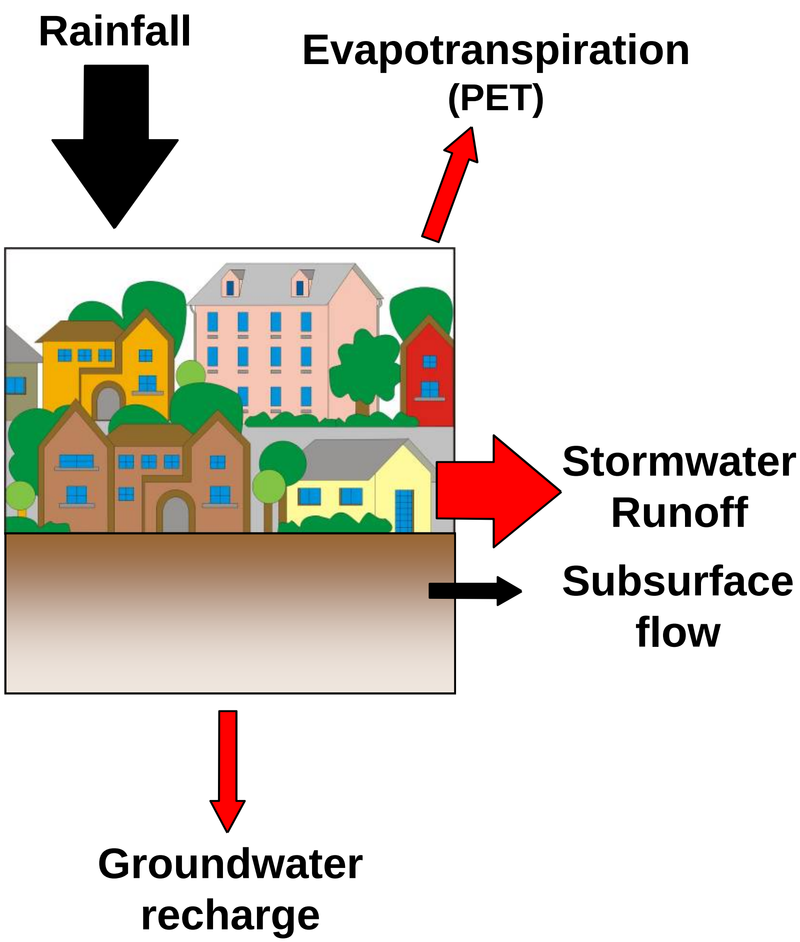


Projected decrease in precipitation in the south, increases in the north

- These are projections for the end of the century
- Uncertainty – disagreement between models is large
- Hashing is where agreement between models is greater
- Uncertainty over the next few decades is large



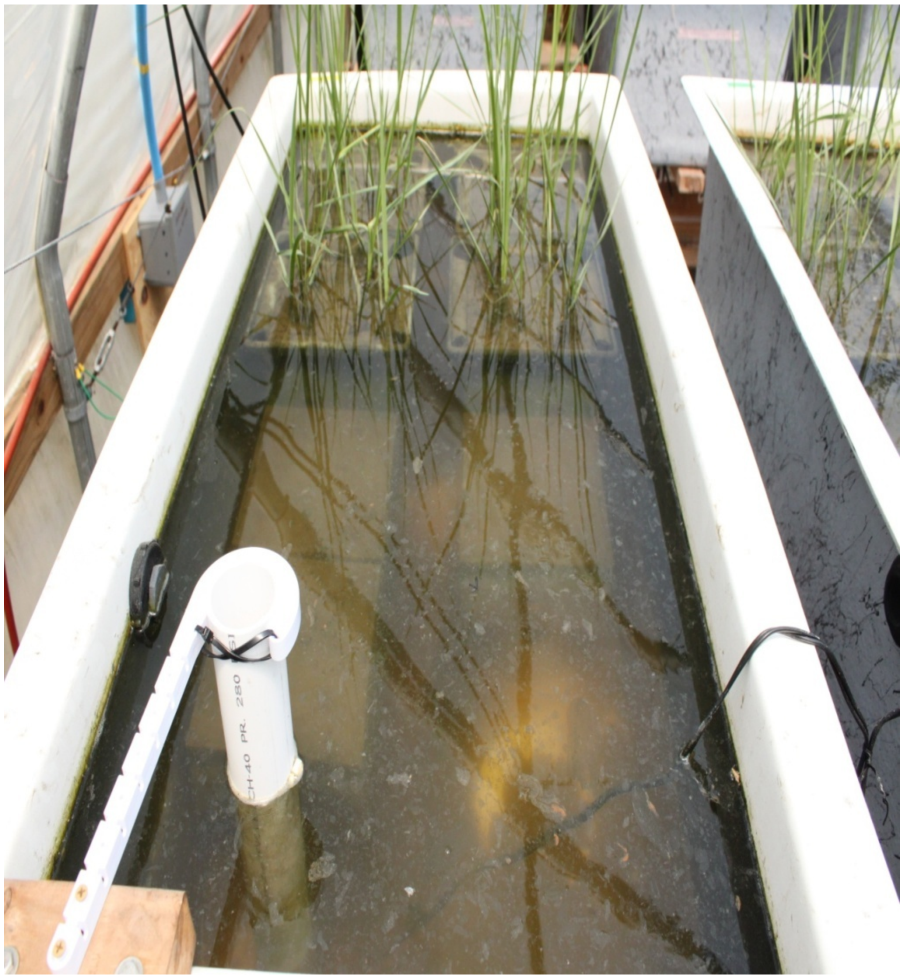
Developed Watershed



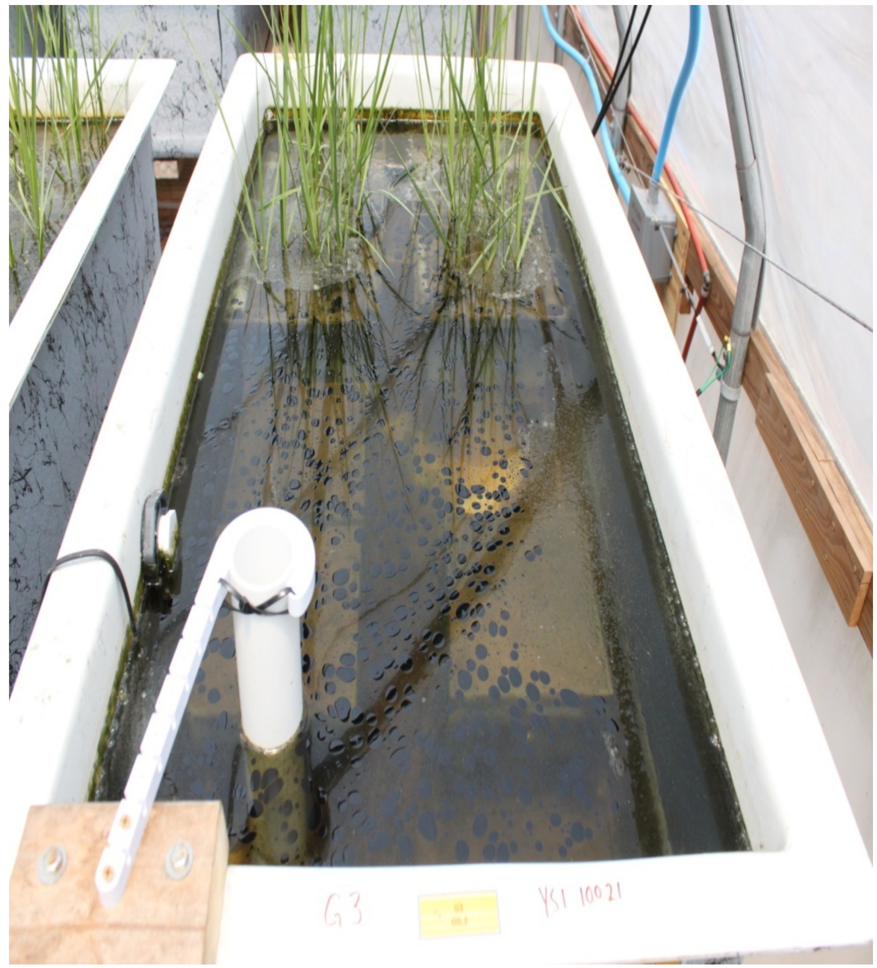
PAH Urban Runoff

- National Academy of Sciences (NRC, 2002) reported that polycyclic aromatic hydrocarbon (PAHs) and other petroleum products running off of roadways, parking lots and driveways in the U.S. cumulatively account for more than **10.9 million gallons of petroleum pollution in an 8 month period**, which is the the equivalent to the volume of oil spilled in the EXXON VALDEZ Oil Spill.

DWH Oil Spill Mesocosm Study

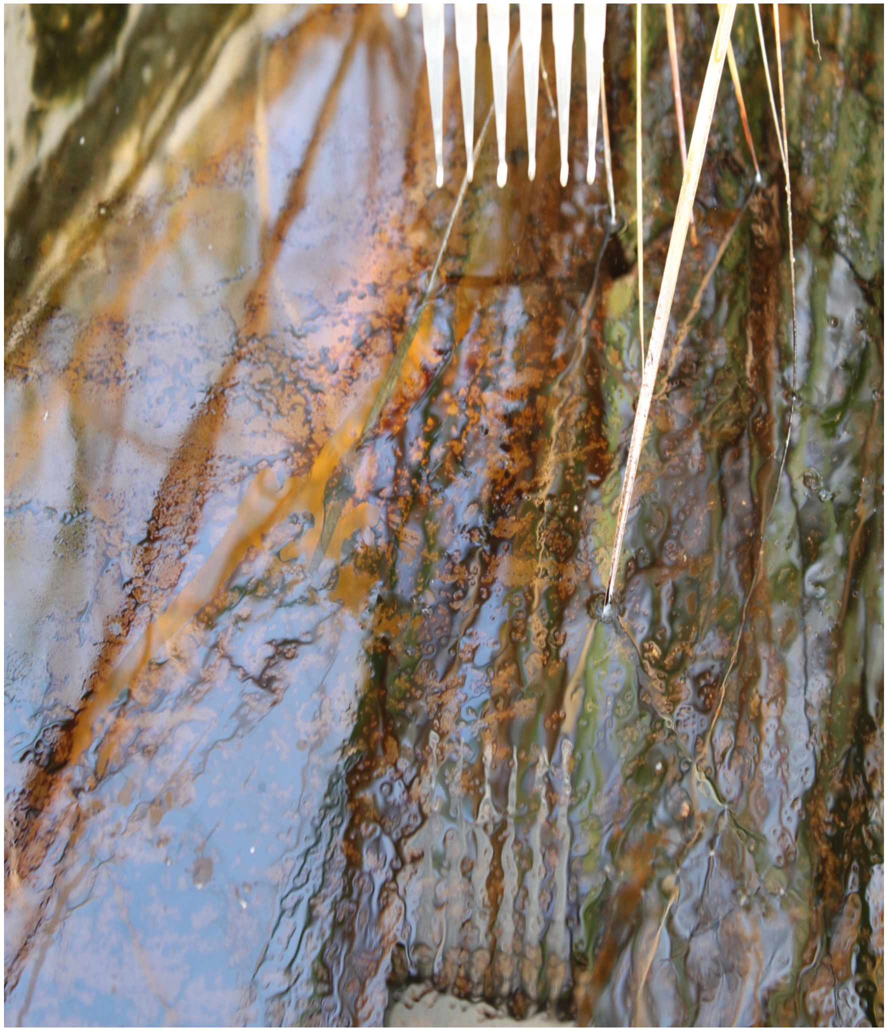


Pre-Spill



Post Spill

DWH Oil Spill:
Dispersant Application HT vs LT



Post Dispersant Application: HT

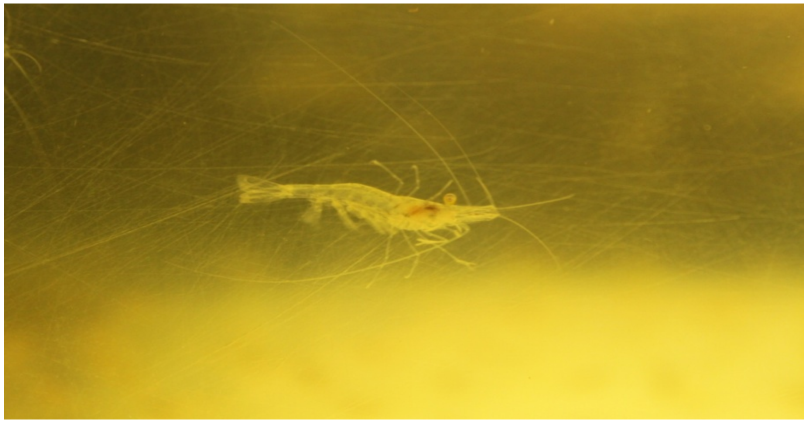
Post Dispersant Application: LT

DWH Oil Spill Mesocosm Study: Low Tide, Salt Marsh Comparisons

Oil

Oil and Dispersant

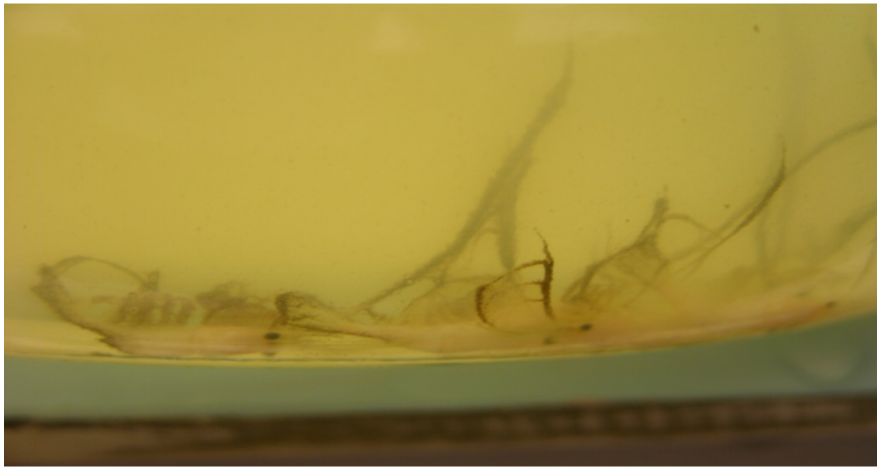
Species of Concern



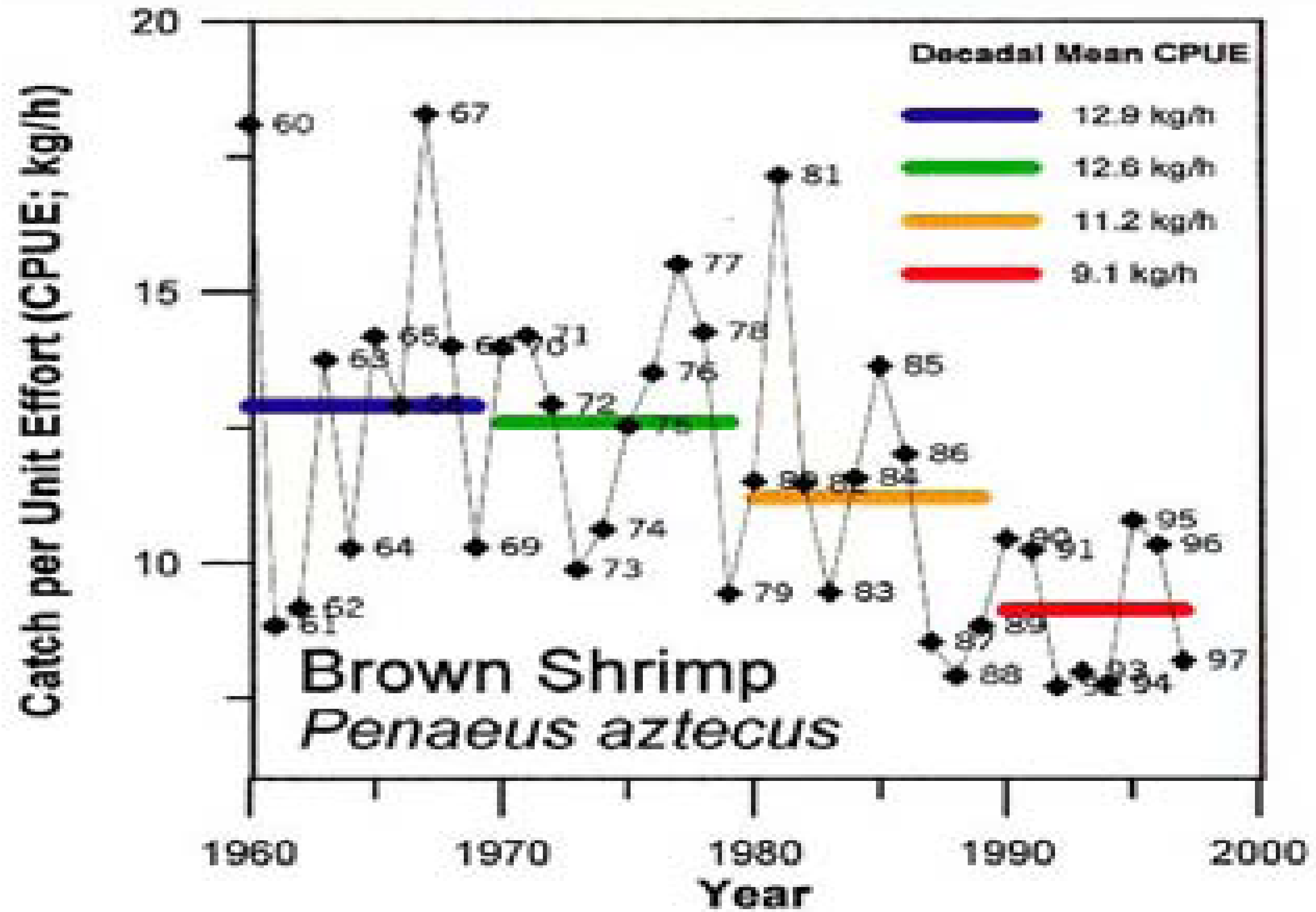
Grass Shrimp: ***P. pugio (56%)***

Mummichog: ***F. heteroclitus (30%)***

- Grass Shrimp and Mummichogs are the dominant in stream macrofauna in estuarine tidal creeks/salt marshes

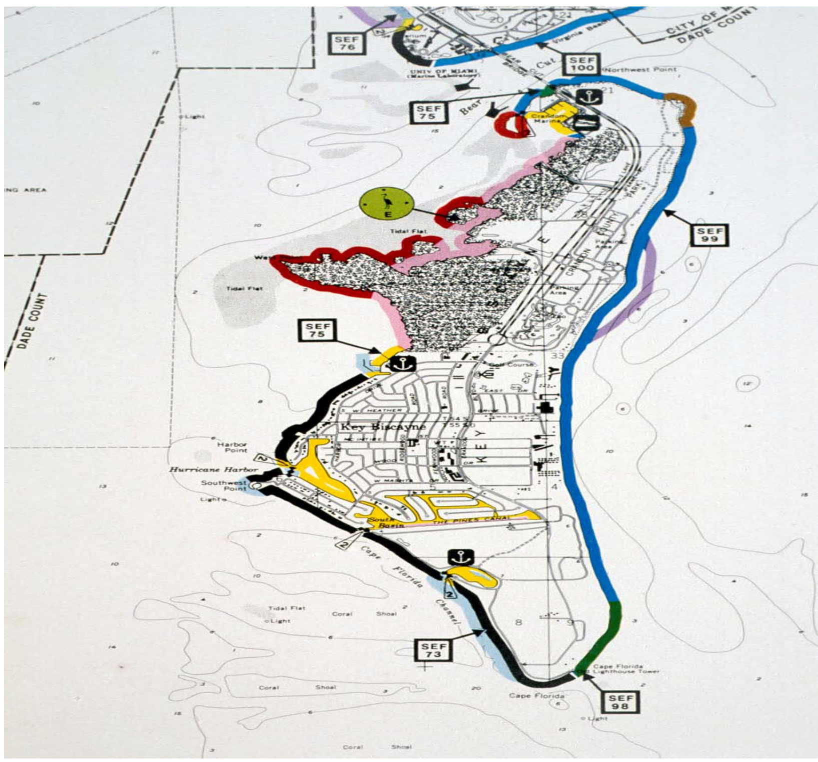


SHRIMP LANDING NORTHERN GOM
1960-1997

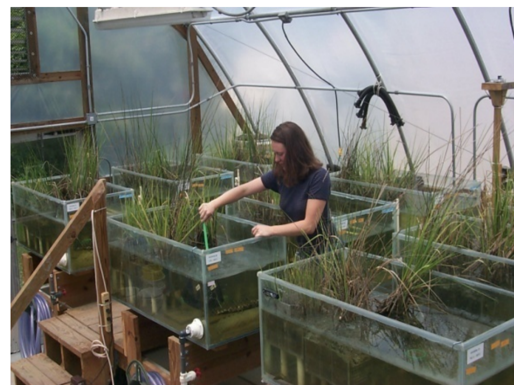


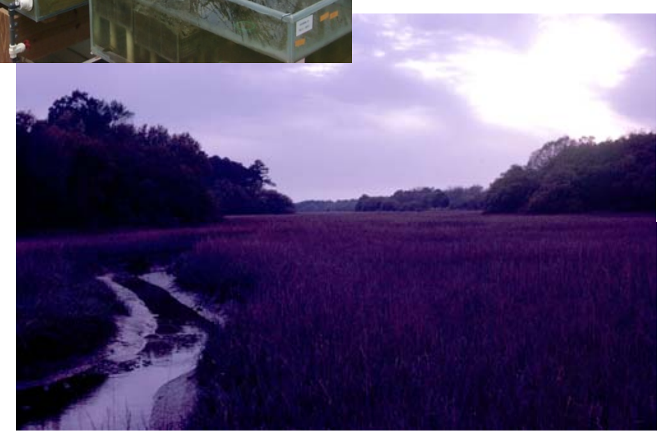
Relevance of Mesocsom Study

NOAA's Environmental Sensitivity Index
Predicts oil spill vulnerability – salt marshes, mangroves and sheltered tidal flats are most Vulnerable Habitats

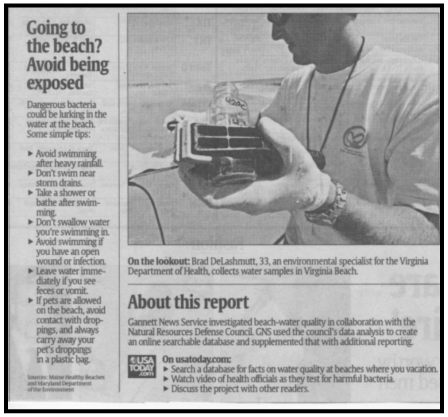


Mesocosm Studies – will document predicted fate of oil (water-sediments -biota) and document impacts to salt marsh and sheltered tidal flat communities – complementing NOAA's ESI and damage assessment studies





Getting Sick at the Beach?



Going to the beach? Avoid being exposed

Dangerous bacteria could be lurking in the water at the beach. Some simple tips:

- Avoid swimming after heavy rainfall.
- Don't swim near storm drains.
- Take a shower or bathe after swimming.
- Don't swallow water you're swimming in.
- Avoid swimming if you have an open wound or infection.
- Leave water immediately if you see feces or vomit.
- If pets are allowed on the beach, avoid contact with droppings, and always carry away your pet's droppings in a plastic bag.

Sources: Maine Healthy Beaches and Maryland Department of the Environment

On the lookout: Brad DeLashmutt, 33, an environmental specialist for the Virginia Department of Health, collects water samples in Virginia Beach.

About this report

Gannett News Service investigated beach-water quality in collaboration with the Natural Resources Defense Council. GNS used the council's data analysis to create an online searchable database and supplemented that with additional reporting.

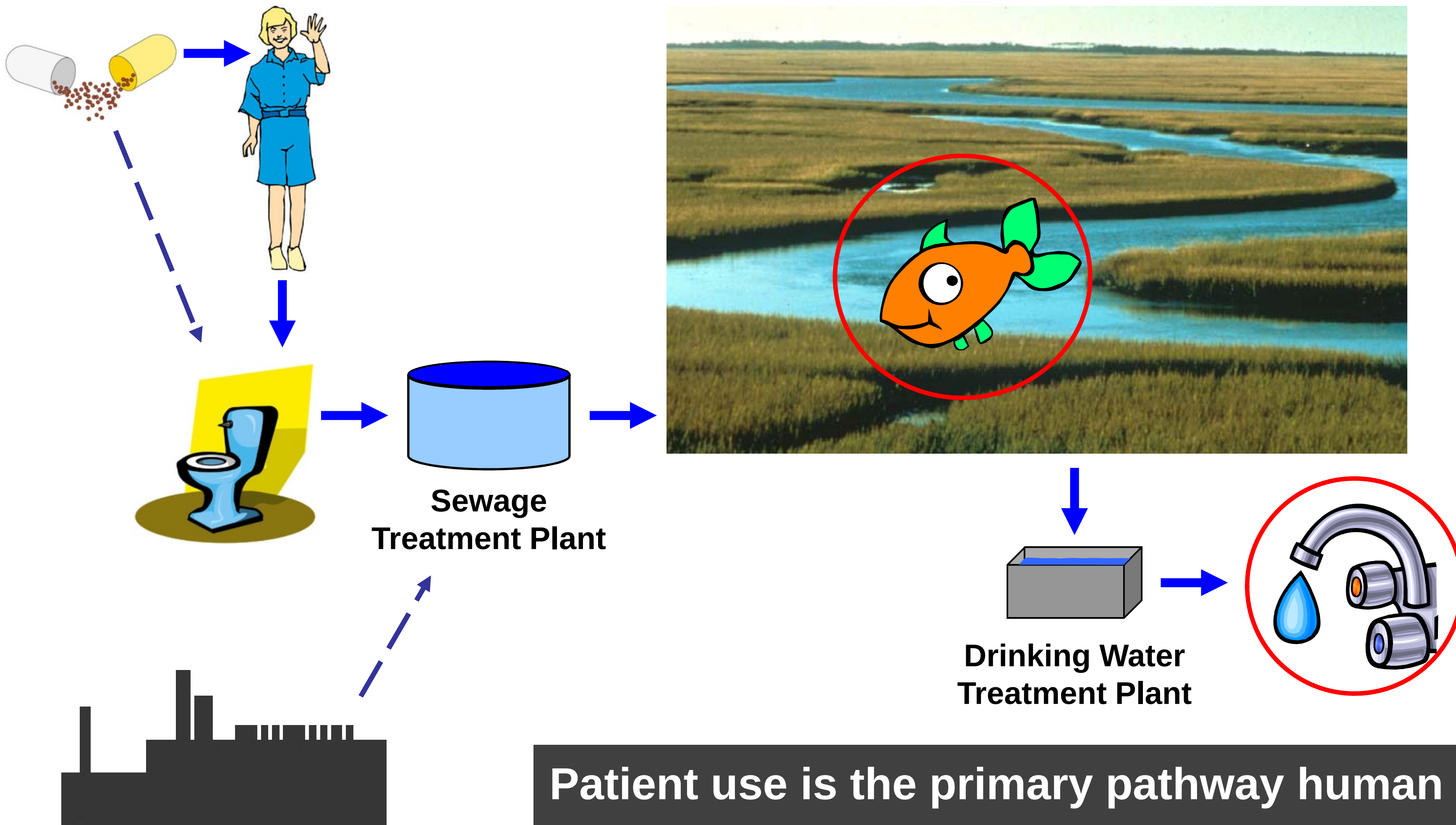
On usatoday.com:

- Search a database for facts on water quality at beaches where you vacation.
- Watch video of health officials as they test for harmful bacteria.
- Discuss the project with other readers.

- In 2006 alone, the US had ~ 34,358 days of beach closures/advisories, due to the presence of pathogens (bacteria, viruses or other disease-causing microbes) and HABs
- NRDC estimates 10% of beachgoers contract GI illness for >7,000,000 cases annually
- Estimated annual public health costs in just two counties in California were $21 – $51 M - extrapolate to the U.S., potentially huge

Emerging Chemical Contaminants (ECCs)

Pharmaceuticals in the Environment



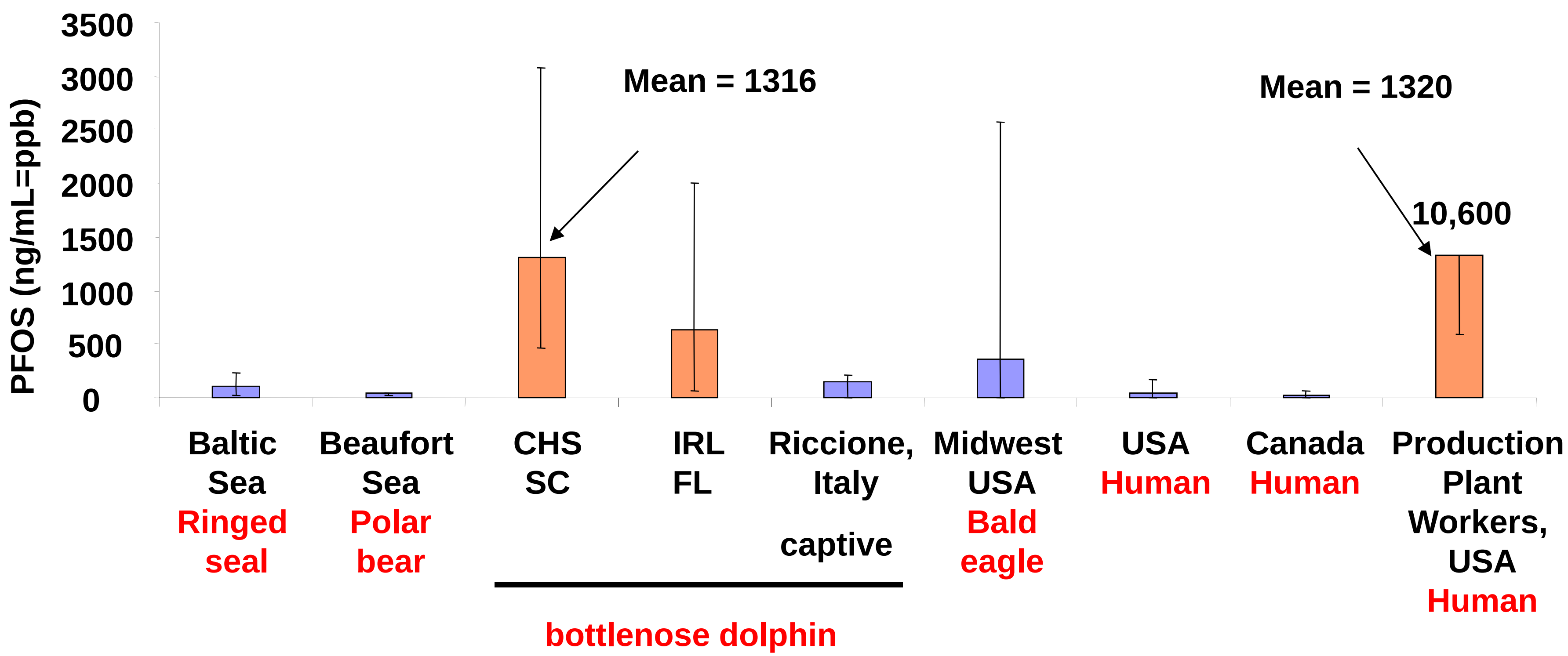
Patient use is the primary pathway human pharmaceuticals enter the environment

Pharmaceuticals in US Surface Waters: Frequency of Detection

Drug	% Frequency of Detection
Steroids	89
Nonprescription Dugs	81
Insect Repelllent	74
Detergents	69
Disinfectants	66
Plasticizers	64
Fire Retardants	***60***
Antibiotics	***48***
Insecticides	45
PAHs	44
Hormones	37
Other Prescription Drugs	32
Antioxidants	29
Fragrances	27
Solvents	24

USGS: 1999-2000 Survey of 139 US Waterways

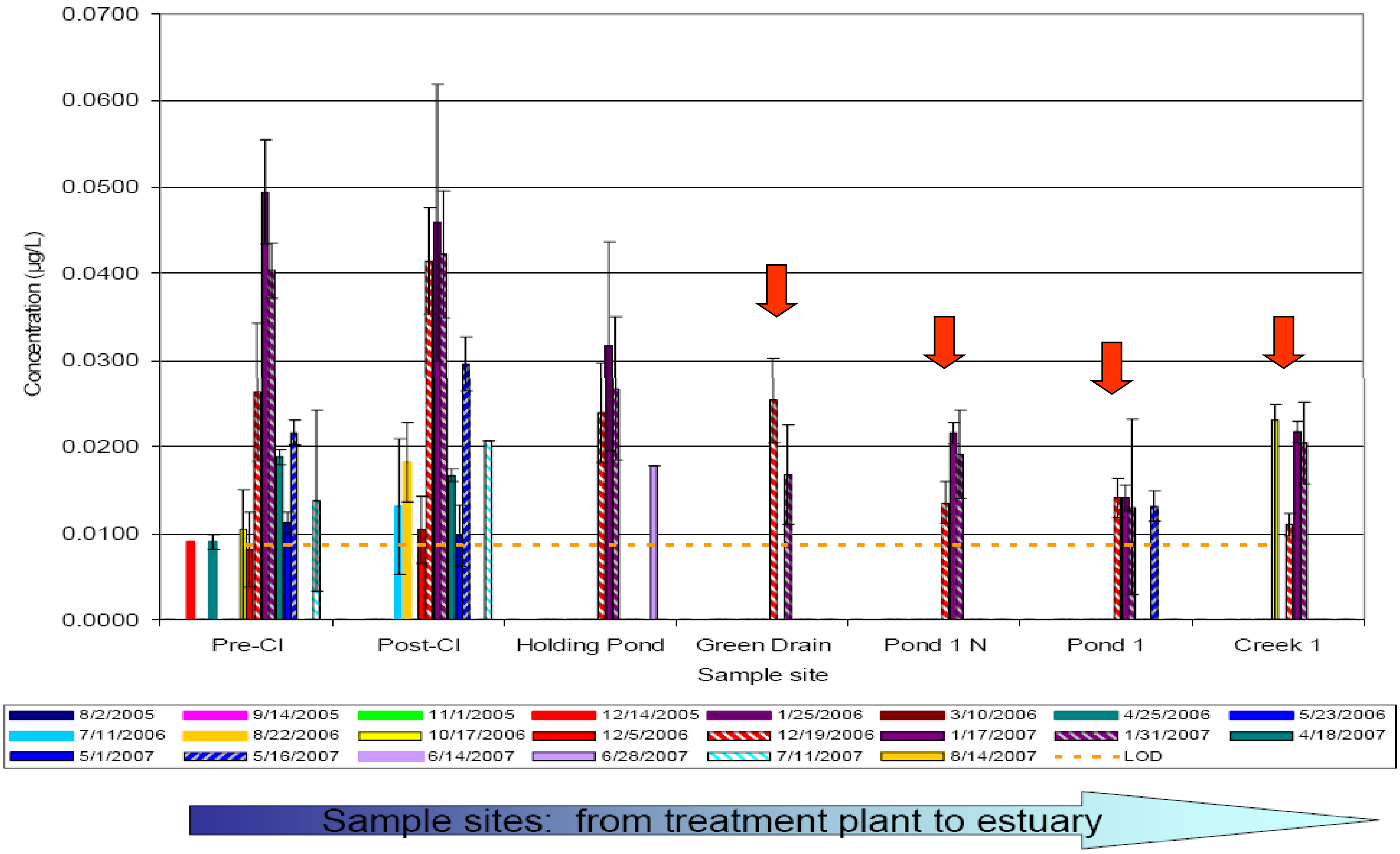
Concentrations of Perfluorinated Chemicals in Wildlife & Humans



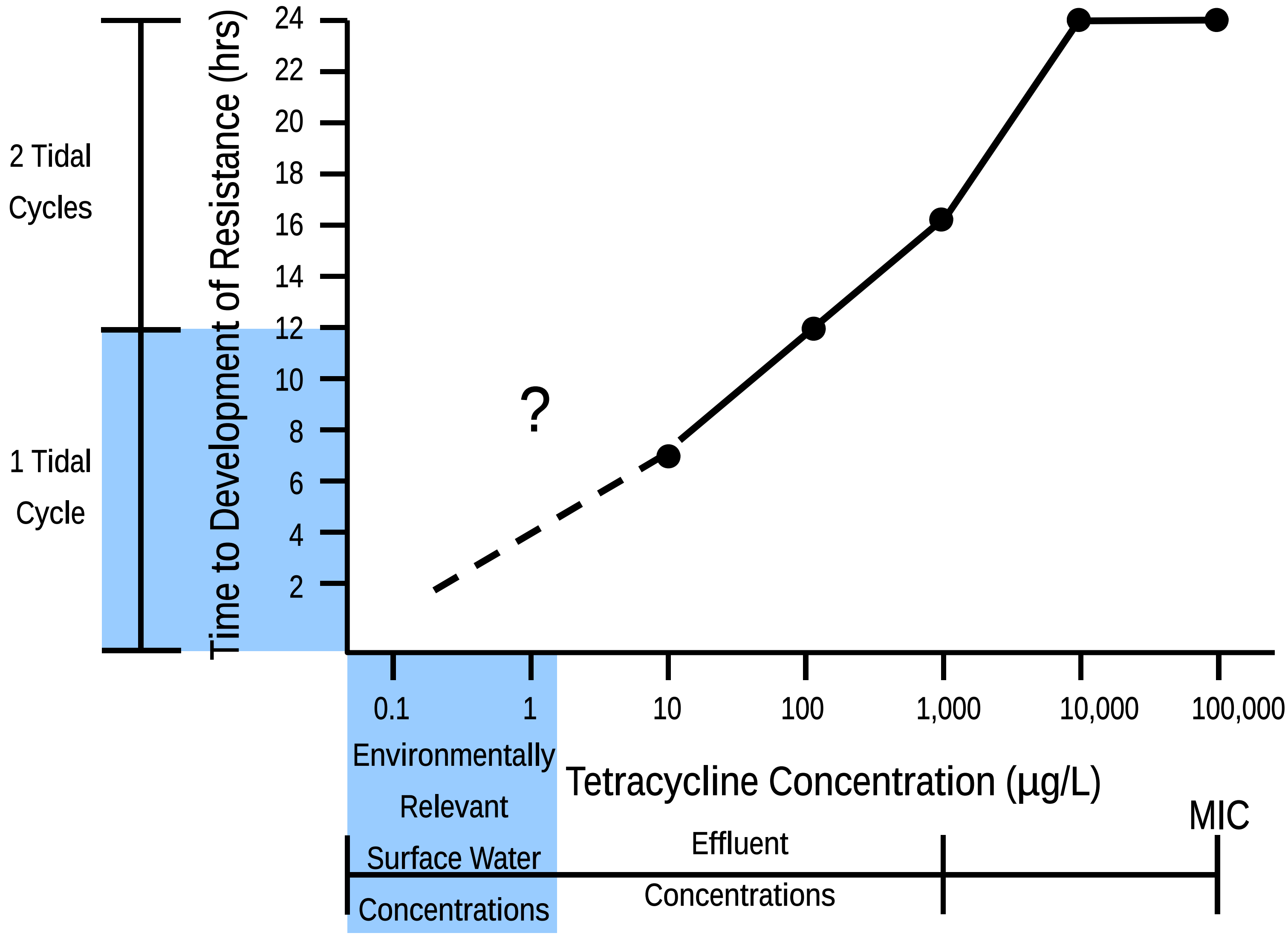
Summary of Antibiotic Resistance Issues in the US

Watershed	Effects Measured	Reference
	Rates of Microbial Antibiotic Resistance	
MD (Ches. Bay)	MAR *E.coli* = 2.8 - 9% in marine waters	Kaspar et al. 1990
FL	MAR *E.coli* = 13 - 25% in marine waters	Parveen et al. 1997
SC[3]	MAR *E.coli* = 0.9-3.9% in FW & MW	NOAA. 2011
SC[4]	MAR *E.coli* = 1-3% in coastal waters	Van Dolah et al.
SC STPs	MAR *E.coli* = 5-22% in effluent	Webster et al. 2004
SC CAFOs	MAR *E.coli* = 12-16% in effluent	NOAA, 2011
SC Dolphins	MAR *E.coli measured in* 39% of dolphins	NOAA, 2011
FL Dolphins	MAR *E.coli measured in* 8% of dolphins	NOAA, 2011
	Detectable Levels of Antibiotics in Surface Waters or Pollution Sources	
US Watersheds	48% of the sites had detectable levels of	USGS, 2002
SC Golf Course	1 - 61 ng/L Tetracycline in effluent effluent used for golf course irrigation	NOAA, 2011

Oxytetracycline Findings



Induction of *E. coli* Antibiotic Resistance



Anti-biotic Resistance in Ocean and Coastal Waters

61% of sick and stranded marine wildlife sampled exhibited resistance to one to as many as ten common antibiotics.


Courtesy of NOAA

Bacteria isolated from 39% of wild-caught dolphins in the Charleston, SC area were resistant to $\geq$ 3 common antibiotics (Amp-Amx-Cf-P).

Average Antibiotic Resistance Rates Of Digestive Tract Bacterial Microflora in Grass Shrimp, *P. pugio*

	Mean Resistance (MR)		Minimum Inhibitory Concentration	Ratio (MR/MIC)	
Antibiotic	Digestive Tract	PBS Wash	(MIC)	Digestive Tract	PBS Wash
Amikacin	64	64	64	1	1
Amoxicillin	32	32	32	1	1
Ampicillin	32	32	32	1	1
Apramycin	32	32	32	1	1
Azithromycin	8	8	8	1	1
Cefoxitin	32	32	32	1	1
Cephalexin	60.04	51.64	32	1.87	1.61
Cephalothin	59.4	41.9	32	1.86	1.31
Erythromycin	66.46	64	32	2.07	2
Gentamicin	16	16	16	1	1
Nitrofurantoin	128	128	128	1	1
Oxytetracycline	31.56	32	16	0.99	1
Penicillin	117.07	123.73	64	1.83	1.93
Streptomycin	74.26	90.18	64	1.16	1.41
Sulfathiazole	500	500	500	1	1
Tetracycline	23.75	32	16	1.48	2
Trimethoprim	16	16	16	1	1
Trimethoprim/Sulfamethoxazole	4/76	4/76	4/76	1	1

Antibiotics of Concern: Compounds in the Environment

- **SC Effluent**– Triclosan, Tetracyclines (COT), Ampicillin, Penicillin,
- **Ches. Bay Effluent**- Erythromycin, Sulfamethoxale & Trimethoprim
- **Southern CA Water** - Sulfamethoxazole, Calrithramycin, Sulfamethizole, Trimethoprim
- **Southern CA Sediments** – Ciproflaxin, Erythromycin, Tricarbam, Sulfamethoxazole, Trimethoprim
- **Southern CA Mussels** – Sulfamethizole, Erythromycin, Triclocarban

Antibiotic Resistance

- How bacteria develop resistance:
- **Mutations** - Mutations are relatively rare, occurring in only 1 event per 10^7–10^{10} bacteria
- **Plasmids** – packets of DNA that exist outside of the microbe that contain the genetic code for developing resistance. Plasmids may be exchanged between different microbes
- WWTP treatment may select for more resistance and enhances plasmid production as a result (Uyaguari et al, 2011)

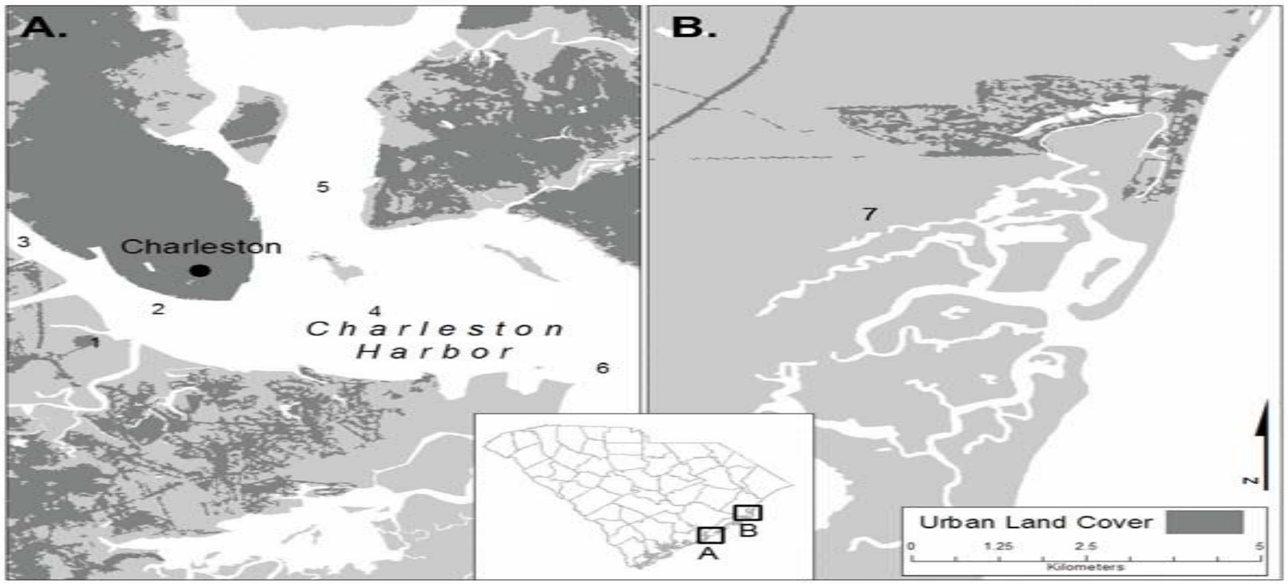


FIG. 1. Sampling site locations: A) WWTP and Charleston Harbor sites. The WWTP, site 1 (principal effluent) is located in Charleston, SC. Environmental collection sites were labeled as follows: site 2 (outfall/discharge site), Site 3 (Ashley River); site 4 (Ashley and Cooper River mixing zone); site 5 (Cooper River); site 6 (Charleston Harbor mouth). B) Site 7 (North Inlet control site). Dark gray shaded zones represent areas of urban land cover.

(Uyaguari, M., S. Norman, J. Gooch, K. Jackson and G. I. Scott. 2011. The Discovery of Novel Bacterial Antibiotic Resistance Genes in Activated Sludge Using a Metagenomic Approach. *Journal of Applied Env. Microbiology* 77: 8226–8233)

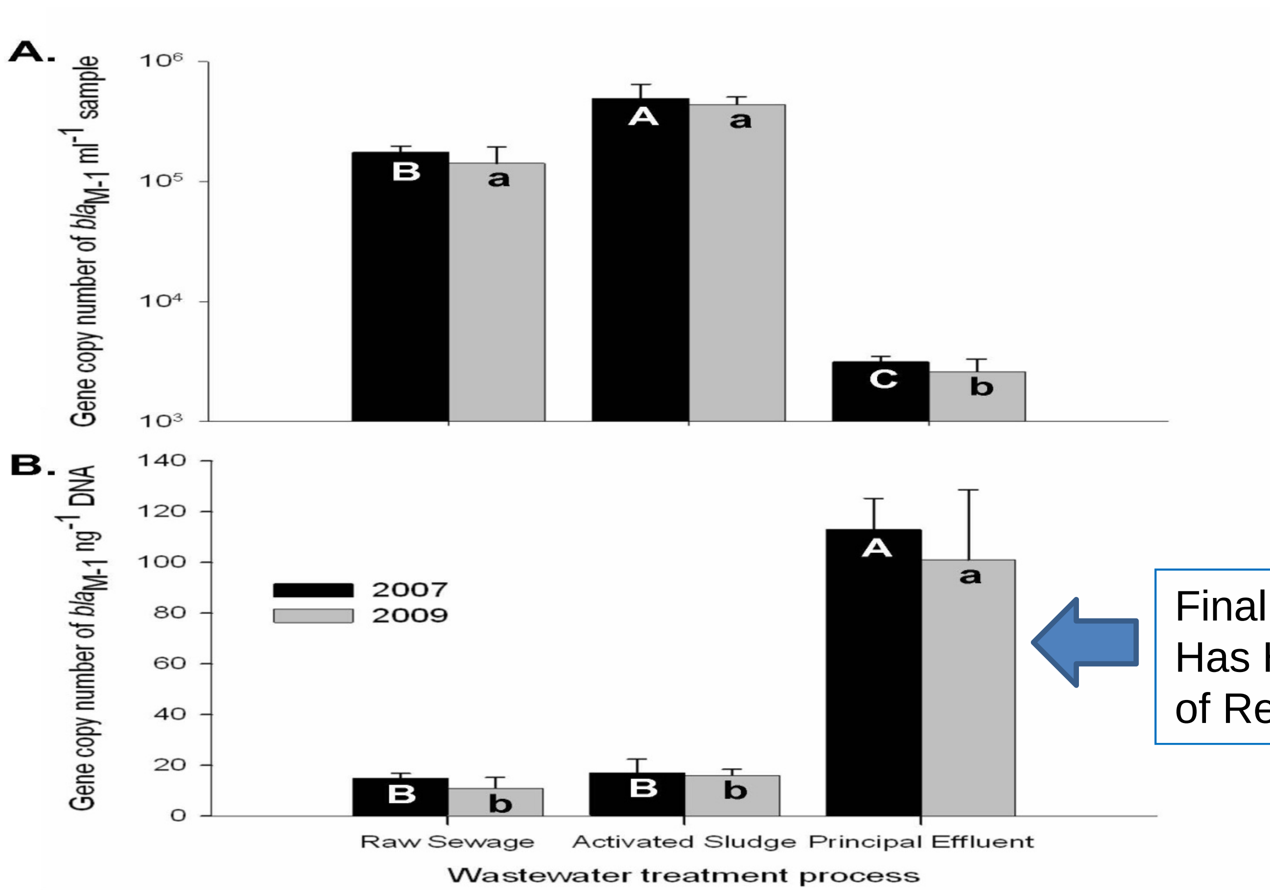


FIG. 3. Copy number of the bla_{M-1} gene ml^{-1} of sample (A), and ng^{-1} of DNA (B). Copy numbers were quantified by qPCR using metagenomic DNA extracted from 3 stages in the WWTP: Raw sewage (RS), Activated sludge (AS), and Principal effluent (PE). Black/gray bars represent GCN means for each treatment (n=3) during years 2007 and 2009 respectively. Error bars indicate standard deviations. Means with different upper and lower case letters indicate significant differences across treatment for years 2007 and 2009, respectively.

Final Effluent
Has Highest Levels
of Resistance

(Uyaguari et L., 2011. *Journal of Applied Env. Microbiology* 77: 8226–8233)

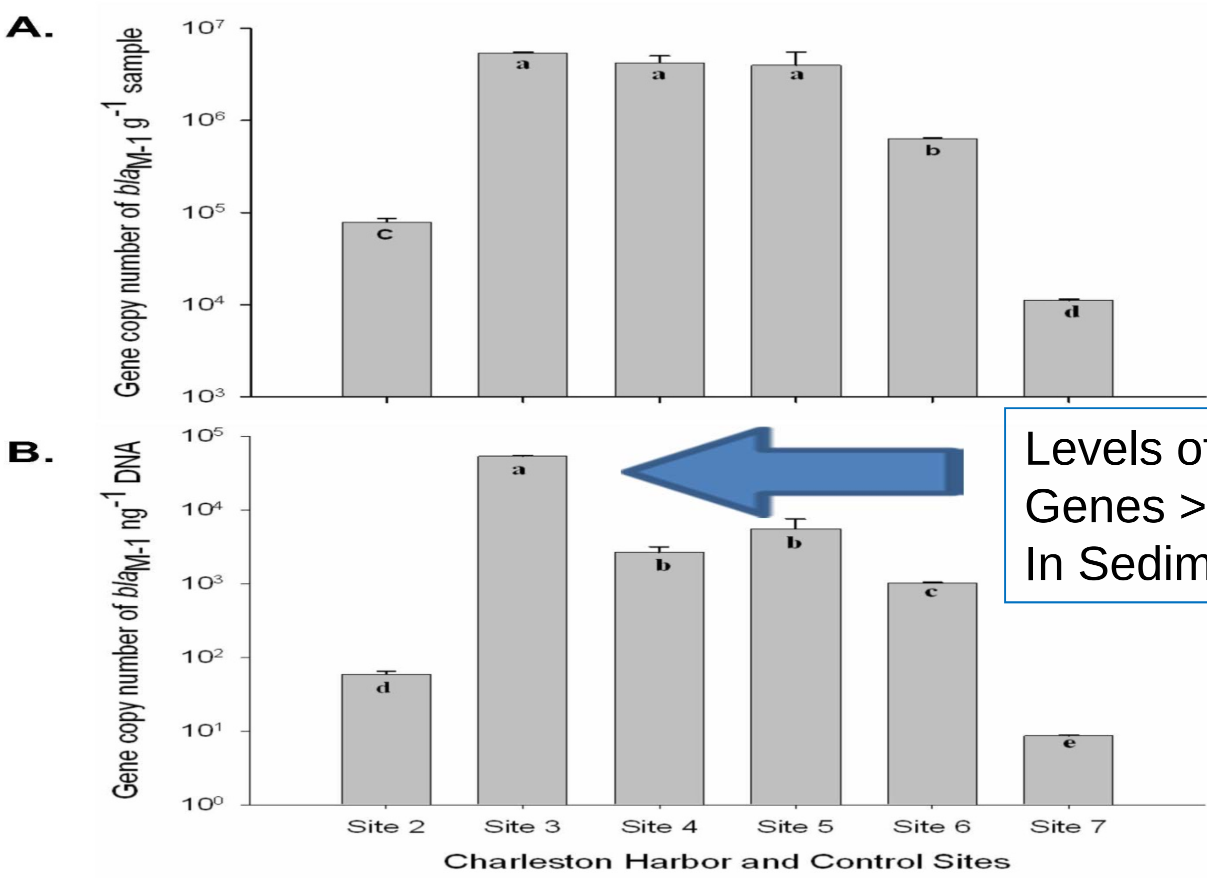
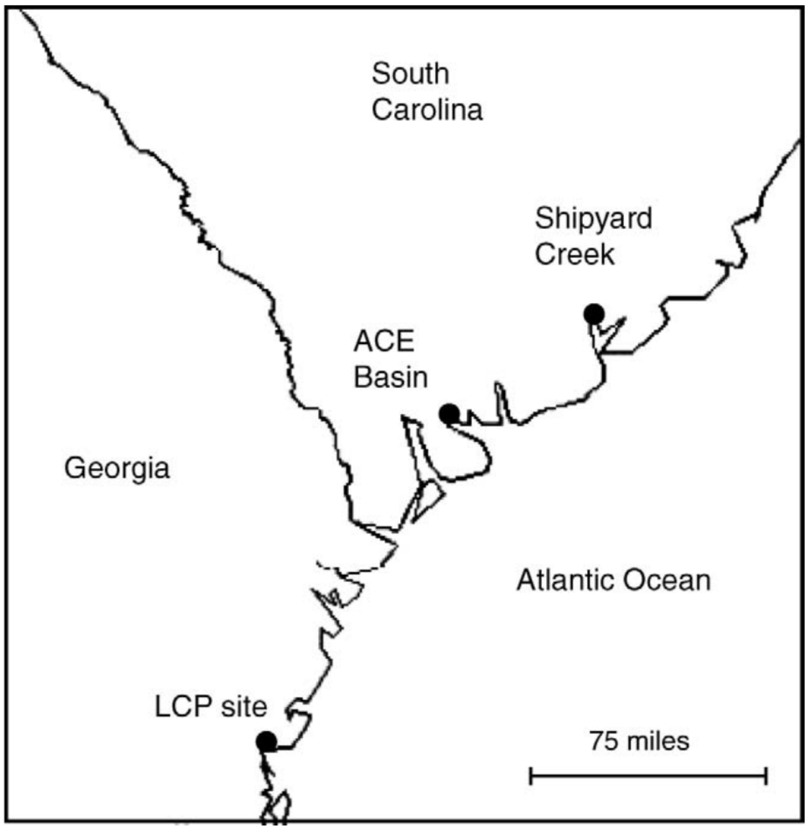


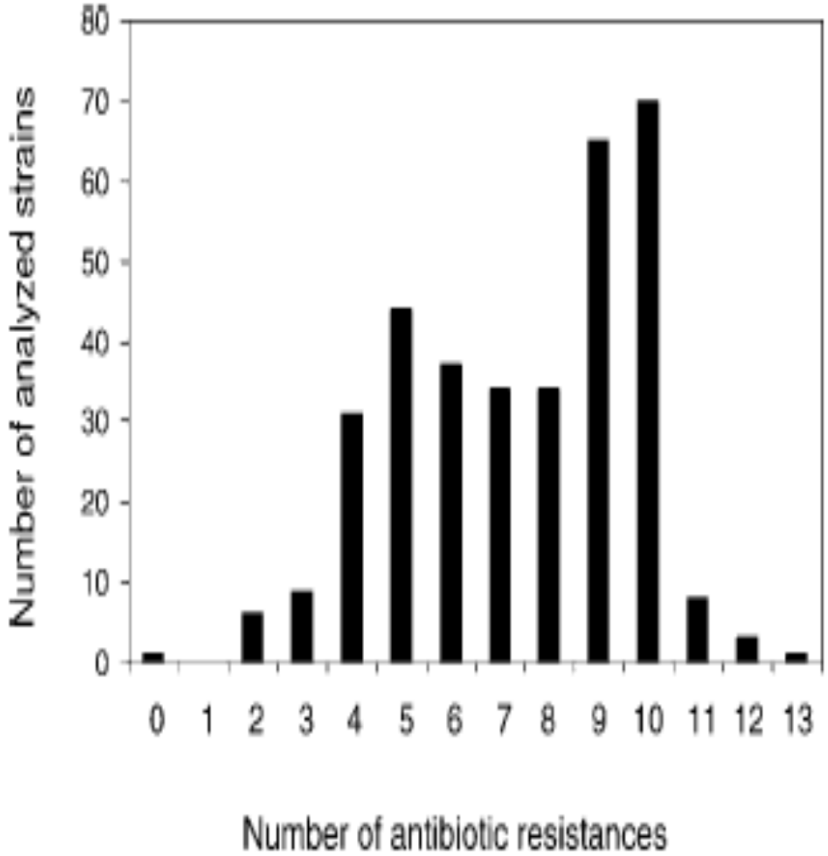
FIG. 4. Copy number of the *bla*$_{M-1}$ gene in sediments g^{-1} of sample (A), and ng^{-1} of DNA (B). Copy numbers were quantified by qPCR using metagenomic DNA extracted from 5 different sites in the Charleston Harbor area: Site 2 (WWTP outfall), Site 3 (Ashley River), Site 4 (Ashley and Cooper River mixing zone), Site 5 (Cooper River), Site 6 (Charleston Harbor mouth), and Site 7 (NI control site). Bars represent the mean for each treatment (n=3). Error bars indicate standard deviations. Means with different letters indicate statistical significance at the 0.05 level.

Levels of Resistance Genes >1,000X Higher In Sediment Than Effluent

(Uyaguari et L., 2011. *Journal of Applied Env. Microbiology* 77: 8226–8233)

Antibiotic Resistance in *Vibrio parahaemolyticus*

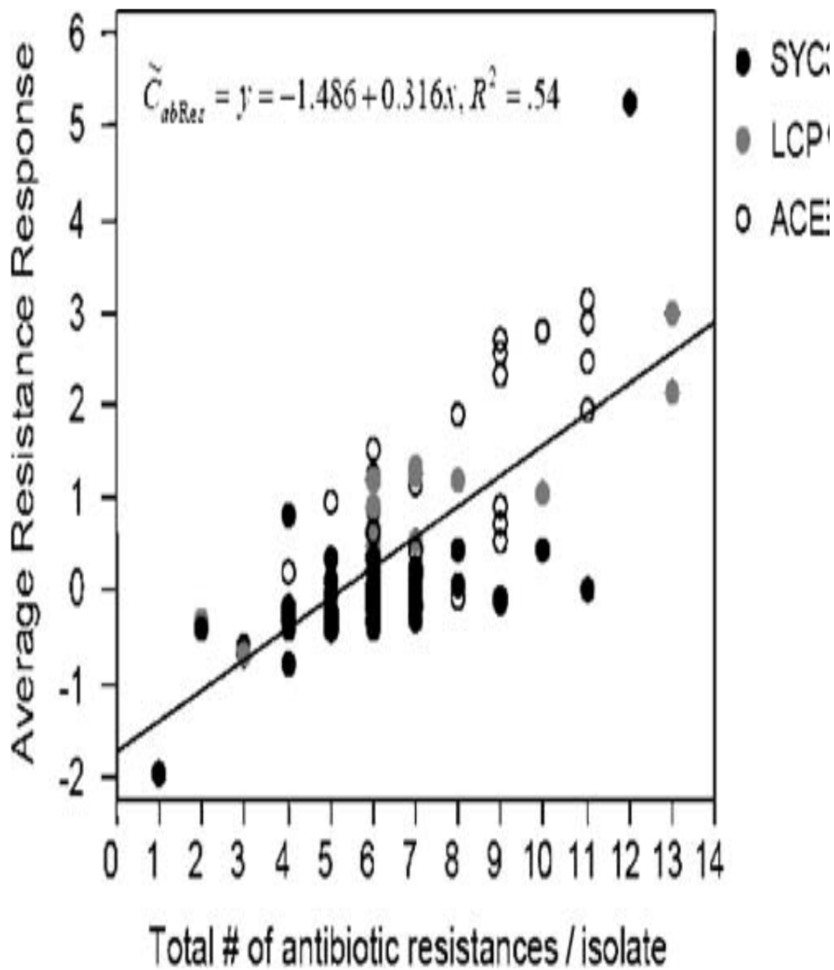




(Baker–Austin et al., 2008. Journal of Food Protection 71:2552)

Antibiotic Resistance in *Vibrio vulnificus*

- The frequency of multiple resistances to antibiotics from all sources was unexpectedly high, particularly during summer months, and **a substantial proportion of isolates (17.3%) were resistant to eight or more antimicrobial agents.**
- Numerous isolates demonstrated resistance to antibiotics routinely prescribed for *V. vulnificus* infections, such as doxycycline, tetracycline, aminoglycosides and cephalosporins
- This report is the first to demonstrate prevalent antibiotic resistance in a human pathogen with no clinical reservoirs (importance of Env. Factors such as climate)

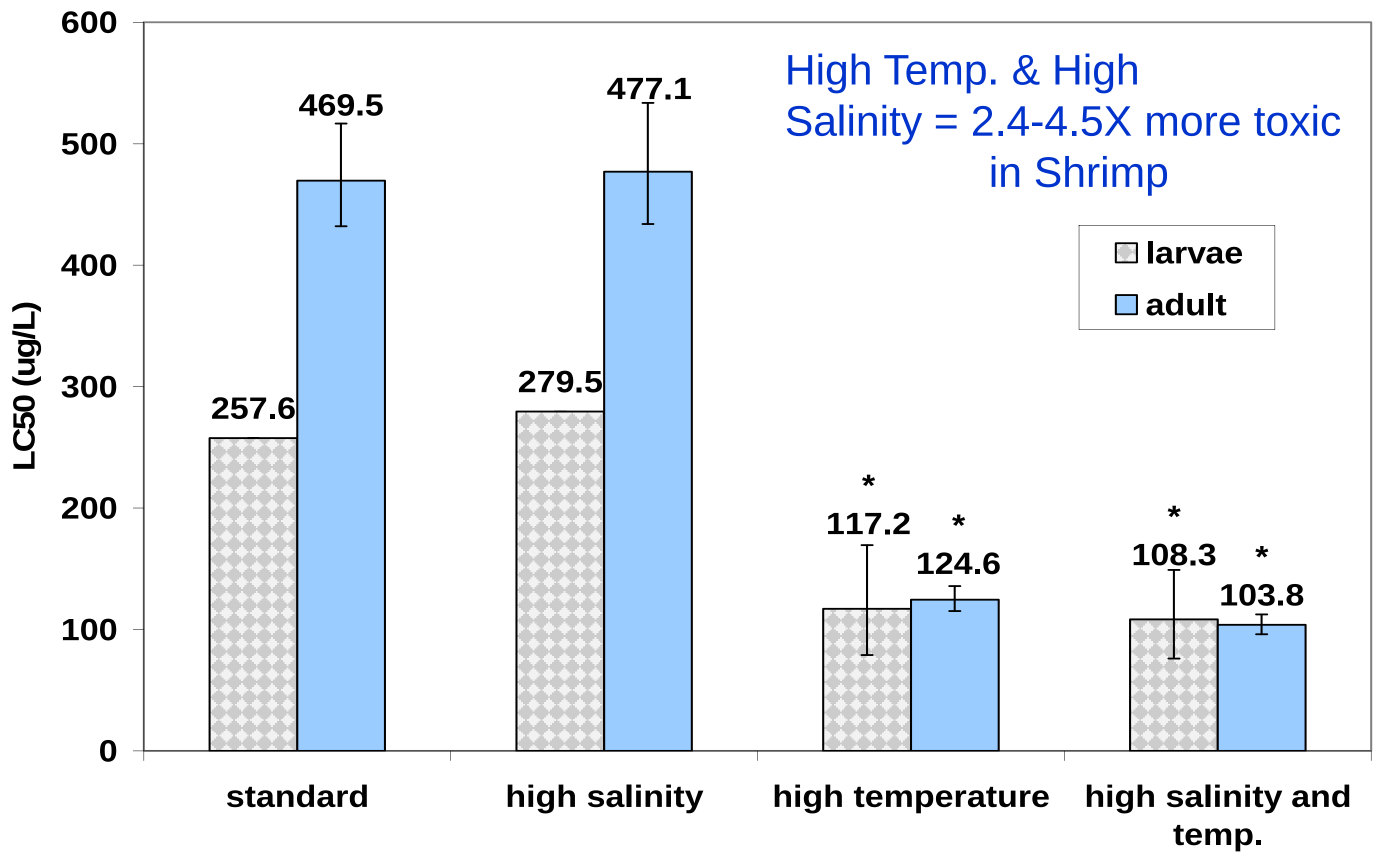


(Baker Austin et al. 2009 Microb. Ecol. 57:151–159)

Altered Salinity Stress

Global Warming Effects	Ecosystem/Ecological Response	Interactions with Known Coastal Urbanization Effects
Sea Level Rise	Increased coastal flooding and subsidence	Destruction of coastal property/commerce, including infrastructure such as drinking water supplies and waste water treatment facilities
Extreme Weather	Increased runoff and drought	Enhanced exposure of marine organisms and humans to chemical contaminants, microbes and nutrients
		Greater number of shellfish and beach closures
		Greater susceptibility of older coastal population
Altered Salinity Regimens	Increased osmoregulation stress	Enhanced toxicity of many EECs

Increased Salinity Stress: *Chlorthalonil*



Standard = 25°C/20ppt, High Salinity = 25°C/30ppt, High Temperature = 35°C/20ppt, High Temperature & High Salinity = 35°C/30ppt.

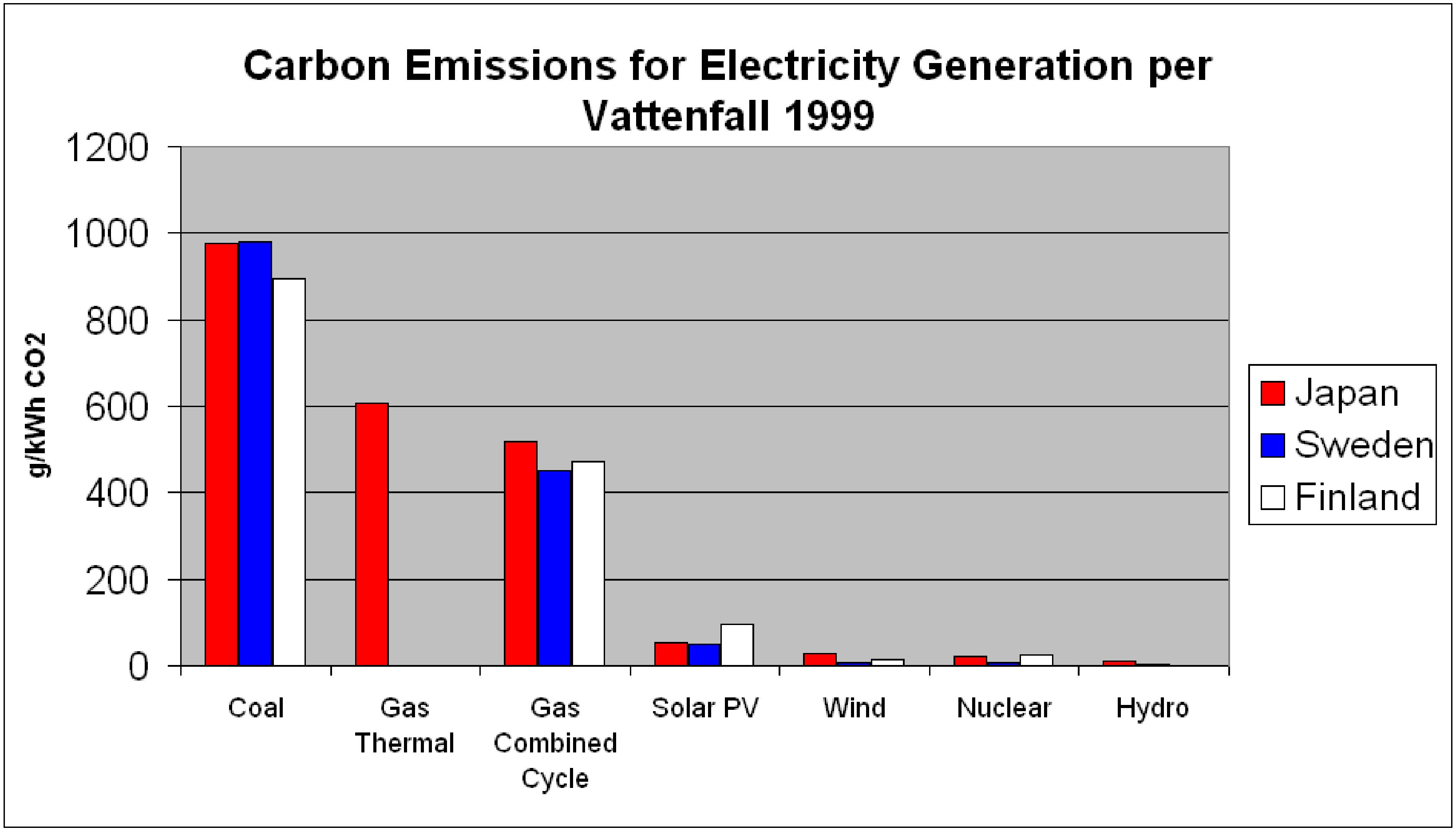
Bars indicate 24& 96h LC50 values and error bars indicate 95% confidence intervals.

Significant differences (LC50 ratio test) from standard exposure conditions are indicated with an asterisk.

Global Climate Change: Energy Policy Options

- Improved Energy Efficiencies in cars and other facets of energy production (i.e. car mileage of 45 mpg = reduce CO_2 levels by 40%)
- Replace fossil fuels with “Soft Path (renewable) Technologies” such as solar, wind power & biofuels
- Replace all coal fired power plants – 14 % reduction in CO_2 but will cost $144B/year & would require building a new plant every 2.5 days until 2025
- Reverse Forest Loss (absorbs CO_2)
- Reduce CFC Emissions
- Tax Fossil Fuels (Coal> Oil > Natural Gas)
- Diversification of Energy Production including Nuclear Options

Comparison of CO2 Footprint for Different Energy Sources



CO_2 Emissions by Commercial Sector

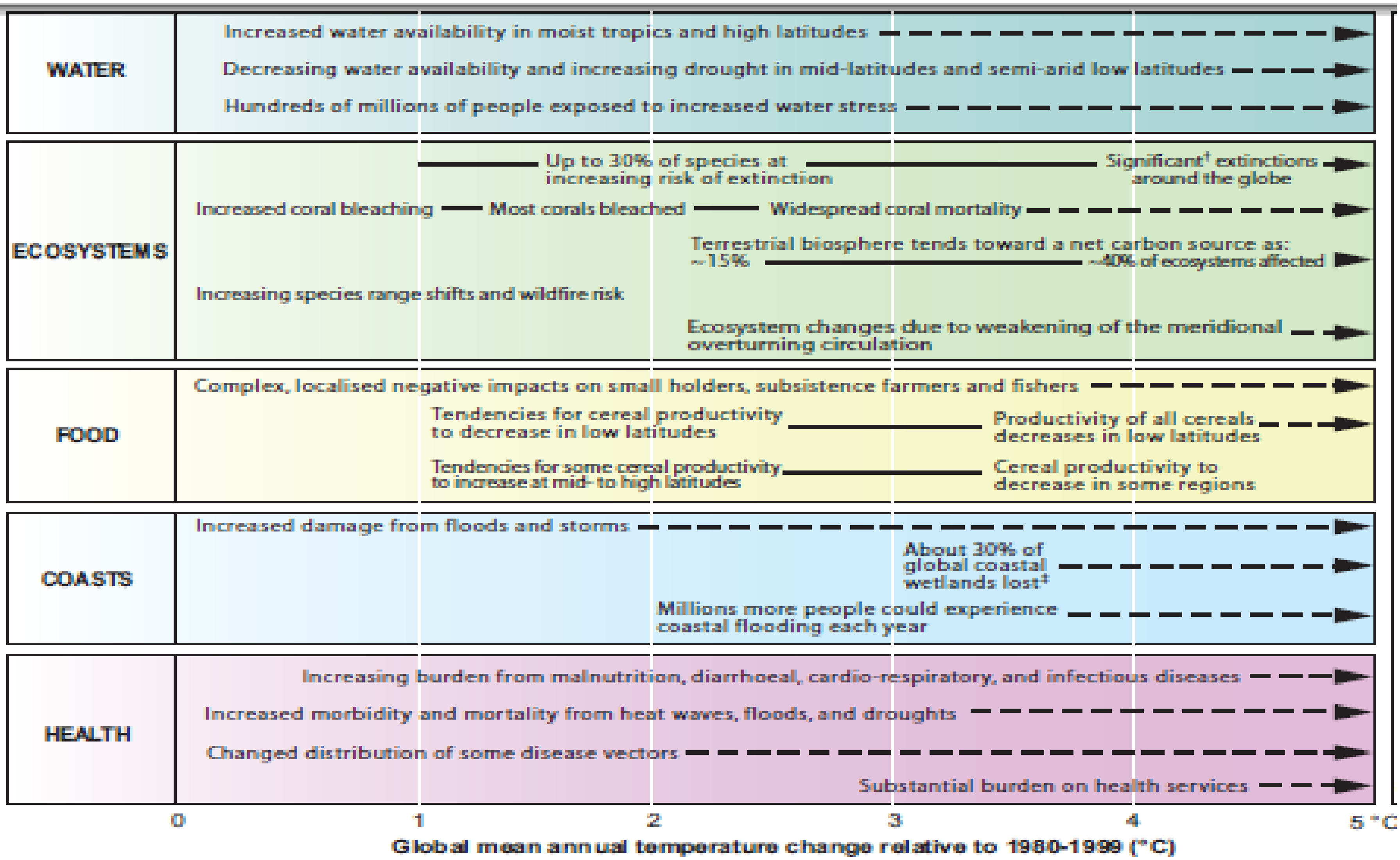
Sector	SC	US
Transportation	34%	27%
Electricity Consumption	35%	34%
Industrial Fuel	15%	14%
Industrial Processes	4%	4%
Residential/Commercial Fuel Use	4%	8%
Agriculture	3%	7%
Fossil Fuel Industry	1%	3%
Waste	3%	3%

Possible Effects of Global Warming on Known Urbanization Effects on Coastal Ecosystems

Stressor	Exposure	Ecological Response	Human Response
Coastal Development Activities	**Physical-Chemical Changes**	**Living Resources**	**Health and Welfare**
↓ Increased Population Density	↑ Impaired Water Quality & Hydrography	? Altered Biological Productivity	↑ Beach and Shellfish Bed Closures
↑ Altered Land Cover	↑ Microbial and Pathogen Contamination	? Altered Food Webs	↑ Vulnerability to Flooding
? Increased Impervious Cover	↑ Chemical Contamination	↑ Impaired Animal Health to Certain Diseases	↑ Public Health Risk
			↓ Quality of Place

Global Warming may greatly impact Coastal Ecosystem Sustainability

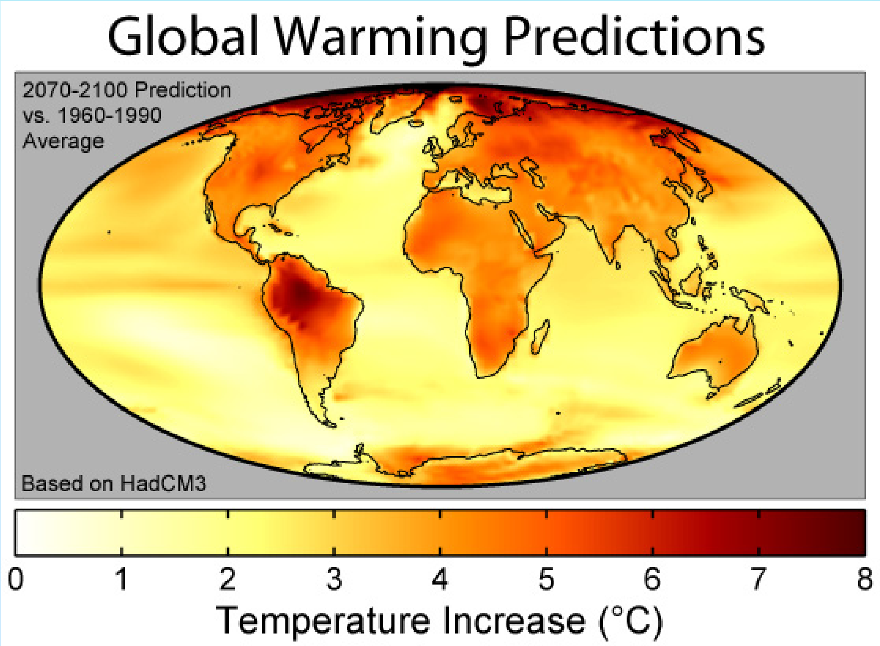
PREDICTED ECOSYSTEM IMPACTS OF GLOBAL CLIMATE CHANGE



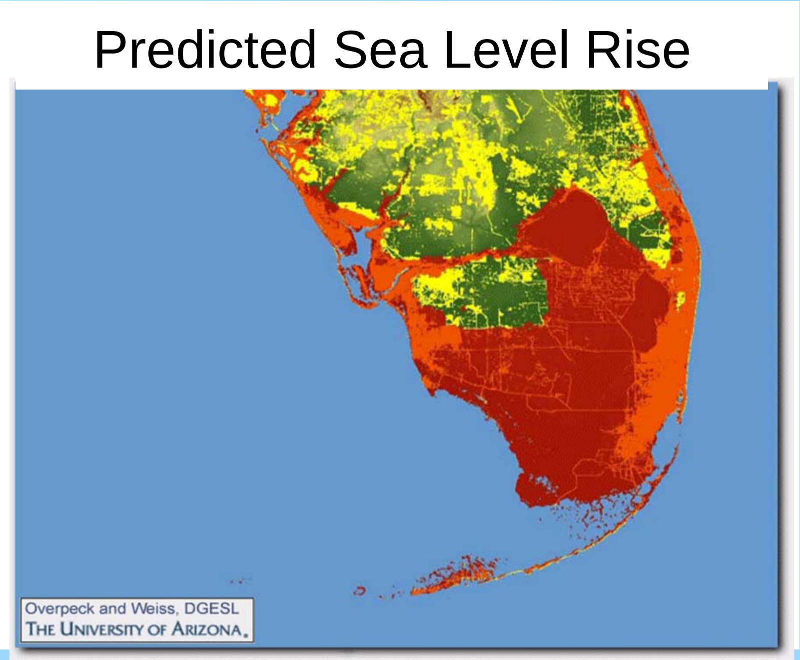
† Significant is defined here as more than 40%.

How Will Climate Change Affect Estuaries?

- Temperatures are expected to rise
- Sea level is expected to rise (salinity may increase)
- Physiology of organisms may change
- Pollution exposures may change
- The response of organisms to pollution may be altered



http://naturematters.files.wordpress.com/2006/11/global_warming_predictions_map_2.jpg



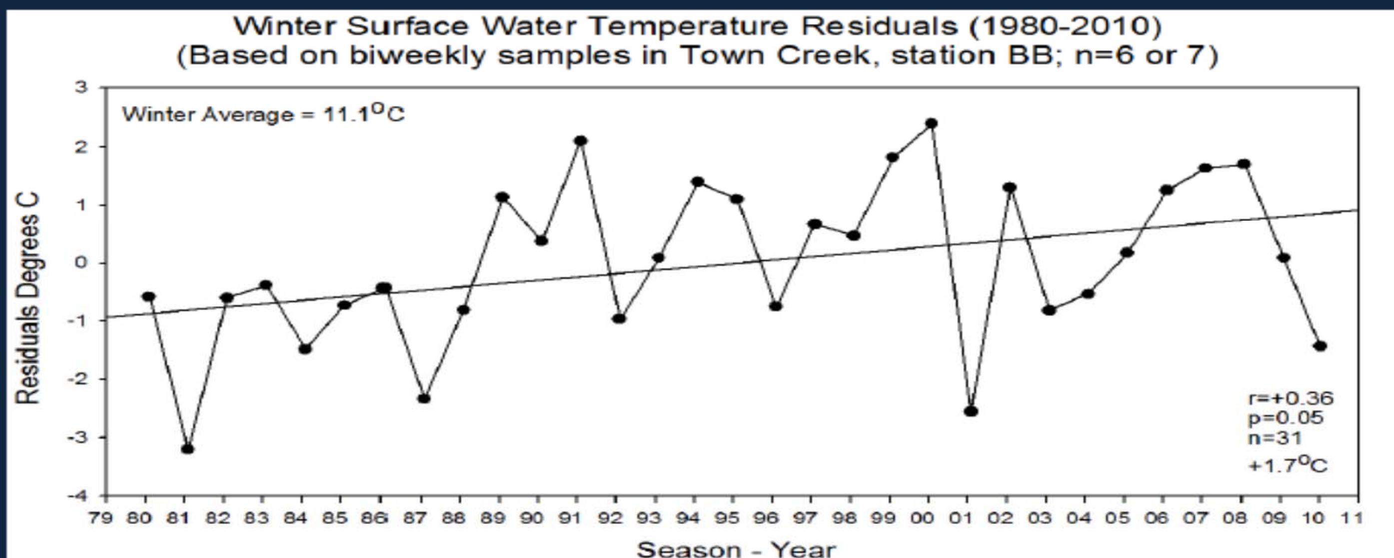
www.geo.arizona.edu/.../southernflorida.gif

Temperature Change in North Inlet

Dr. Dennis Alan reports increased water temperatures at North Inlet: 1980-2008

Winter water temperature at North Inlet estuary, SC 1980 – 2010

Long-term increase: r = 0.36, p = 0.05
estimated change: +1.7° C



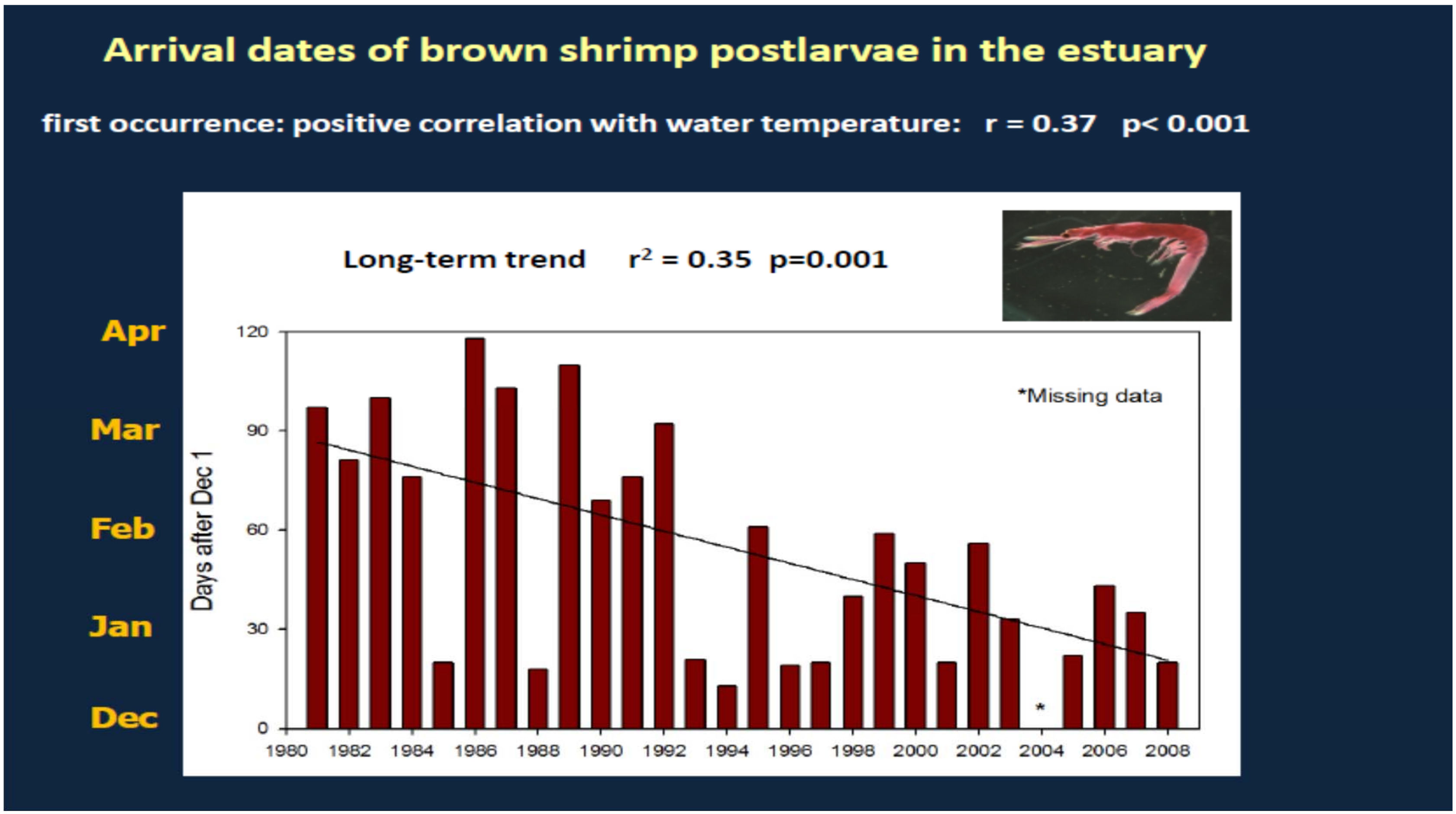
Winter water temperature correlated with winter NAO index, r= 0.60. p= 0.002

Center for Human Health Risk at the Hollings Marine Laboratory
Center for Coastal Environmental Health and Biomolecular Research

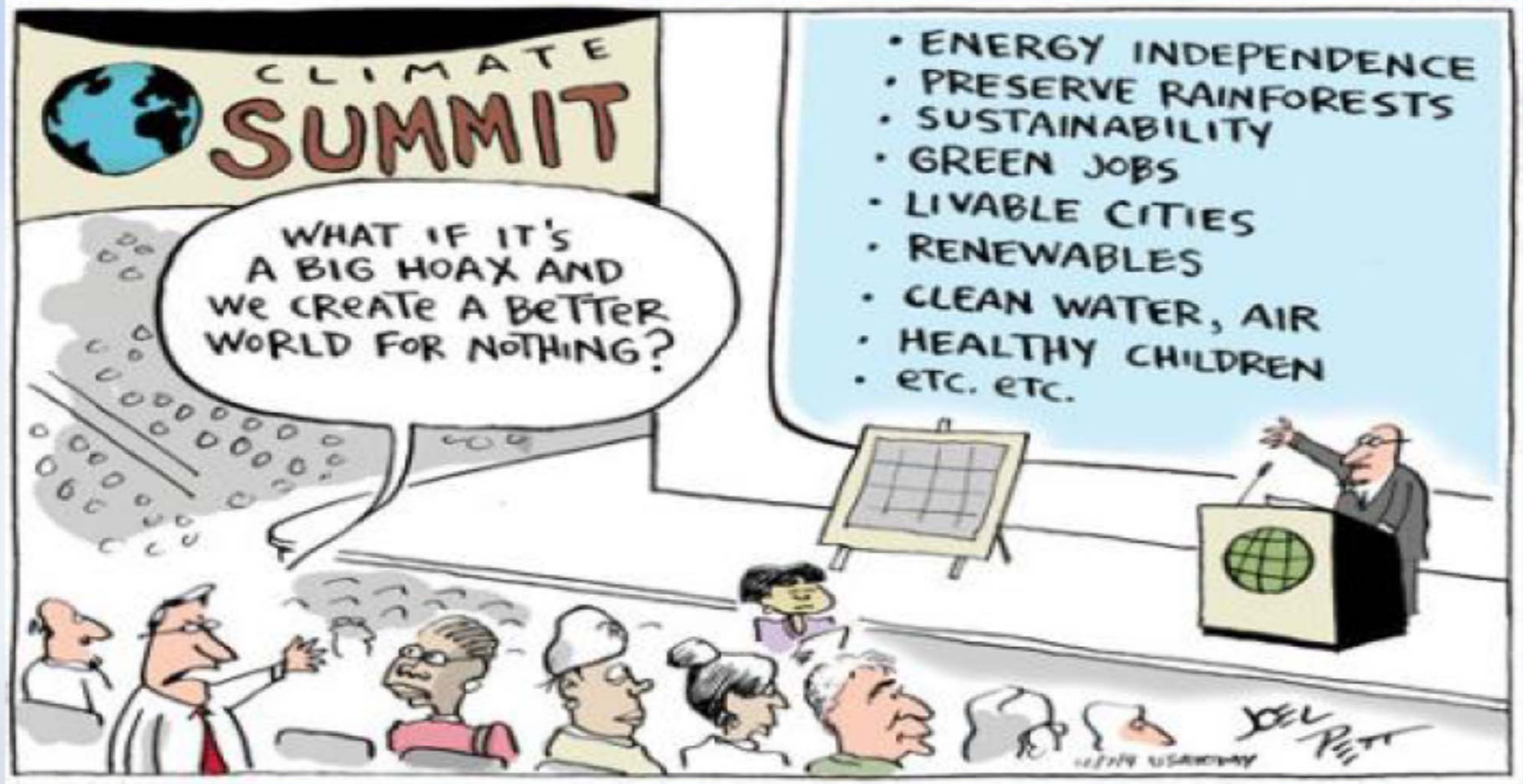
NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE
NATIONAL OCEAN SERVICE

Brown Shrimp in North Inlet: Earlier Arrival

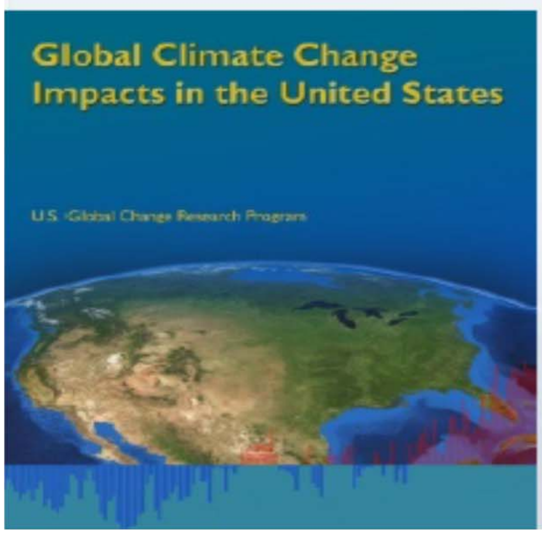
Dr. Dennis Alan reports earlier arrival dates
For brown shrimp at North Inlet: 1980-2008



CONCLUSION: Climate Change



CONCLUSIONS: Climate Change



The full report is available from www.globalchange.gov/usimpacts