“Ecological and Human Health Threats Related to Drought in Coastal Ecosystems”

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- Centre for Atmospheric Research Experiments, Environment Canada
  
  Terry Biddleman

- NOAA, National Climate Data Center
  
  Thomas C. Peterson
Five Domains for Climate Change Impacts (NAS, 2010)

- **Food:** Climate change impacts may result in competition for declining food resources (both fisheries and agriculture) as well as shifting patterns of harvest. This could lead to food shortages and famines in less developed countries, as well as a variety of economic ramifications.

- **Water:** Climate change stands to affect future water distribution, quantity, and quality. This could lead to lack of water, water of poor quality, or too much water at the wrong time in many locations around the globe.

- **Energy:** Anthropogenic input of CO2 to the atmosphere is well established as a cause of climate change. The pressure to “decarbonize” over the next few decades will inevitably result in new approaches to energy use, which will, in turn, have potentially unforeseen environmental impacts.

- **Shelter:** Humans need shelter as a basic element for quality of life. Natural disasters such as flood, drought, and wildfire both threaten existing shelter and increase the need for shelter. Many of these extreme events may be exacerbated by climate change.

- **Health:** A changing climate may affect any health outcome that is influenced by environmental conditions, such as an increase in mosquito- and water-borne diseases.
Climate Change Impacts to Coastal Ecosystem
(Marques et al. 2010. Climate change and seafood safety)
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
IPCC PREDICTED ECOSYSTEM IMPACTS OF GLOBAL CLIMATE CHANGE: Drought Implications

- 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

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Over most land areas, warmer and fewer cold days and nights</td>
<td>Virtually certain</td>
<td>Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Warm spells/heat waves. Frequency increases over most land areas</td>
<td>Very likely</td>
<td>Reduced yields in warmer regions due to heat stress; increased danger of wildfire</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Heavy precipitation events. Frequency increases over most areas</td>
<td>Very likely</td>
<td>Damage to crops; soil erosion; inability to cultivate land due to waterlogging of soils</td>
<td></td>
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</tr>
<tr>
<td>Area affected by drought increases</td>
<td>Likely</td>
<td>Low crop damage and failure; increased livestock deaths; increased risk of wildfire</td>
<td></td>
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<tr>
<td>Intense tropical cyclone activity increases</td>
<td>Likely</td>
<td>Damage to crops; windthrow (uprooting) of trees; damage to coral reefs</td>
<td></td>
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</tr>
<tr>
<td>Increased incidence of extreme high sea level [excluding tsunamis]*</td>
<td>Likely</td>
<td>Salinization of irrigation water, estuaries and freshwater systems</td>
<td>Decreased freshwater availability due to saltwater intrusion</td>
<td>Increased risk of deaths and injuries by drowning in floods; migration-related health effects</td>
<td>Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above</td>
</tr>
</tbody>
</table>

- See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions.
- 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.
- For a given 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.
Health Impacts of Drought (CDC, 2010)

- Compromised Water Quantity and Quality (e.g. increased effluent dominated streams)
- Compromised Food and Nutrition
- Compromised Air Quality (increased particulates, HABs)
- Diminished Living Conditions (Temperature)
- Increased Recreational Risks (e.g. *Naegleria fowleri*)
- Increased Disease Incidence for Infectious (e.g. *E. coli* & Salmonella), Chronic (e.g. Asthma) and Vector-Borne/Zoonotic Disease
Ecosystem Impacts of Drought

- Altered Water Quantity, Delivery and Water Quality
  - Temperature
  - Salinity
  - pH Changes
  - Increased Pollution Loading during Rain Events

- Altered Air Quality
  - Increasing Wildfires
  - Increased Particulate Loads
  - HAB Events
Drought: Health Effects

- **Ecosystem Health**
  - *Increased Salinity*
  - Increased Temperature
  - Altered pH
  - Increased periods of dry deposition and pollution loading when it does rain

- **Human Health**
  - Reduced Water Quality (Altered microbes and HABs) and Quantity
Impacts of upstream drought and water withdrawals on the health and survival of downstream estuarine oyster populations

(Petes et al. 2012. Ecology & Evolution)
Oyster Survival to Drought (Petes et al. 2012)

Oyster Mortality Associated with Parasite *Perkinsis marinus* that Thrives in High Salinities and Temperatures
Drought: Health Effects

- **Ecosystem Health**
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  - *Increased Temperature*
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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
Increased Salinity Stress: *Chlorthalonil*

**High Temp. & High Salinity = 2.4 - 4.5X more toxic in Shrimp**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Larvae LC50</th>
<th>Adult LC50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (25°C/20ppt)</td>
<td>257.6</td>
<td>279.5</td>
</tr>
<tr>
<td>High Salinity (25°C/30ppt)</td>
<td>469.5</td>
<td>477.1</td>
</tr>
<tr>
<td>High Temperature (35°C/20ppt)</td>
<td>117.2</td>
<td>124.6</td>
</tr>
<tr>
<td>High Temp. &amp; High Salinity (35°C/30ppt)</td>
<td>108.3</td>
<td>103.8</td>
</tr>
</tbody>
</table>

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.

Marques et al. (2010) Climate Change and Seafood Safety

Organics

Trace Metals

Biota Response to Climate Change (Temperature/Salinity) and Pollution
<table>
<thead>
<tr>
<th>Fate/process</th>
<th>Impact of climate change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Death</td>
<td>Drier summers increase death rate; temperature extremes increase death rate; higher UV radiation levels increase death; flooding and anaerobic conditions increase death</td>
</tr>
<tr>
<td>Growth</td>
<td>Increased temperature and wetness increase growth</td>
</tr>
<tr>
<td>Lost of active genes</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Gene transfer</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Adherence</td>
<td>No expected impact</td>
</tr>
<tr>
<td>Chemical Hydrolysis</td>
<td>Not expected impact</td>
</tr>
<tr>
<td>Photolysis</td>
<td>Increases as UV increase rate</td>
</tr>
<tr>
<td>Biodegradation/transformation</td>
<td>Higher temperature increase rate; wetter winters increase rate; drier summers decrease rate</td>
</tr>
<tr>
<td>Sequestration</td>
<td>Lower for contaminants that sorb to soil organic matter</td>
</tr>
<tr>
<td>Volatilization</td>
<td>Increases with increasing temperature</td>
</tr>
<tr>
<td>Bioconcentration</td>
<td>Increases with increasing temperature and decrease in salinity</td>
</tr>
<tr>
<td>Biomagnification</td>
<td>No expected impact</td>
</tr>
<tr>
<td>Dilution</td>
<td>Increases in periods of high rainfall; decreases in prolonged dry periods</td>
</tr>
</tbody>
</table>
Drought: Health Effects

- **Ecosystem Health**
  - Increased Salinity
  - Increased Temperature
  - *Altered pH*
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CO$_2$ and pH time series in the North Pacific Ocean

- Atmospheric CO$_2$ (ppmv)
- Seawater pCO$_2$ (µatm)
- Seawater pH
Drought: Health Effects

- **Ecosystem Health**
  - Increased Salinity
  - Increased Temperature
  - Altered pH
  - *Increased periods of dry deposition and pollution loading when it does rain*

- **Human Health**
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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
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.

New Market Highly Urbanized Watershed
55% impervious cover
Storm Event - 50.8 mm (2 inches)

Runoff Volume (cubic meters)

<table>
<thead>
<tr>
<th>Antecedent Runoff Condition</th>
<th>Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%-Dry</td>
<td>20%</td>
</tr>
<tr>
<td>75%-Dry</td>
<td>24%</td>
</tr>
<tr>
<td>50%-Dry</td>
<td>30%</td>
</tr>
<tr>
<td>25%-Dry</td>
<td>37%</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>46%</td>
</tr>
<tr>
<td>25%-Wet</td>
<td>51%</td>
</tr>
<tr>
<td>50%-Wet</td>
<td>57%</td>
</tr>
<tr>
<td>75%-Wet</td>
<td>64%</td>
</tr>
<tr>
<td>100%-Wet</td>
<td>71%</td>
</tr>
</tbody>
</table>

230% Decrease In Runoff

Increased Flooding with Climate Change

Drought Conditions with Climate Change

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
Drought: Health Effects

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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

Kolkata, India

Matlib, Bangladesh

Cholera
CHL
SST
Rain

Guillaume Constantin de Magny et al. (in prep)
Vibrios: Naturally Occurring Harmful Bacteria

- **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)
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 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.
Hot Spot Analysis for Total Campylobacter Cases between 2000-2005 in N.C. Counties

Legend
- < -2.58 Std. Dev.
-2.58 - -1.96 Std. Dev.
-1.96 - -1.66 Std. Dev.
-1.66 - -1.35 Std. Dev.
-1.35 - -1.05 Std. Dev.
-1.05 - -0.75 Std. Dev.
0.75 - 0.25 Std. Dev.
0.25 - 0.55 Std. Dev.
0.55 - 0.95 Std. Dev.
0.95 - 1.35 Std. Dev.
1.35 - 1.95 Std. Dev.
1.95 - 2.55 Std. Dev.
> 2.55 Std. Dev.

Legend
- < -2.58 Std. Dev.
-2.58 - -1.96 Std. Dev.
-1.96 - -1.66 Std. Dev.
-1.66 - -1.35 Std. Dev.
-1.35 - -1.05 Std. Dev.
-1.05 - -0.75 Std. Dev.
0.75 - 0.25 Std. Dev.
0.25 - 0.55 Std. Dev.
0.55 - 0.95 Std. Dev.
0.95 - 1.35 Std. Dev.
1.35 - 1.95 Std. Dev.
1.95 - 2.55 Std. Dev.
> 2.55 Std. Dev.

(Weis et al., 2011. Epidemiol. Infect. 139: 591-598)
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)
Case Study: Rising Temperatures Increase Window For HAB Growth In Puget Sound

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

Nishitani and Chew (1984): Aquaculture

Moore et al. (in review): Environmental Health
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

Bloom Events from 2001 – 2009
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%
    - Campylobacteriosis 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
- **Cylindrospermopsis raciborskii**: 270,000 cells / mL
- **Raphidiopsis curvata**: 1,000 cells / mL
- **Cylindrospermopsis philippinensis**: 23,000 cells / mL

Falls Lake

Drinking water for 0.5 million people

LMs: E. Allen
Since 2004 - RTRM, emphasizing three potable water supply reservoirs with blooms of potentially toxic cyanobacteria
Cyanobacteria abundance (phycocyanin RF)

Upstream from potable water treatment plant

Water treatment plant intake

Vertical profiles

August 19, 2008
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


Albemarle-Pamlico Estuarine System - 2nd largest estuary on U.S. mainland
Conclusions: Ecosystem Impacts of Drought

- Increased Temperature and Salinity and altered pH that may affect the survival of marine organisms
- Altered water delivery and increased pollution loading during subsequent rain events due to increased dry deposition period
- Increased amount of effluent dominated streams during drought may increase pollution loads
- Interactions of pollution, temperature, salinity and pH
- Altered degradation rates and partitioning of pollutants during drought
- These altered ecosystem conditions may enhance microbes and increase HAB events
Drought and Human Health

- Increased microbial and HAB threats during drought may affect drinking water safety, food quality and reduce recreational activities.
- The linkages between climate change including drought and shifting patterns of health threats and outcomes are complicated by factors such as wealth, distribution of income, status of public health infrastructure, provision of preventive and acute medical care, and access to and appropriate use of health care information.
- The severity of future health impacts will be influenced by adaptive strategies to limit and adapt to climate change (NRC, 2010).