Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions

Michalak et al. 2013

Lake Erie and HABs

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Context and History

• Lake Erie is shallow and warm relative to other Great Lakes
• Water supply for > 10 million people
• Major pollution and eutrophication issues through 50s, 60s, and 70s
  • Detergent bans and point source reduction of P
• Many invasive species from St. Lawrence shipping channels
• More HABs from 1990s – today
Blue-green Algae

**Microcystis**
- Toxins: Microcystin (hepatotoxic)
- Cannot fix N
- Rapid growth
- Rapid vertical migration

**Anabaena**
- Toxins: Anatoxins (neurotoxic)
- Microcystin (hepatotoxic)
- Can fix N in **heterocysts**
- Slow vertical migration
The 2011 Blooms

- July 2011 – *Microcystis* blooms in western basin
  - ~600 km², 2.4x larger than previous record
- Sept. 2011 – *Anabaena* bloom in western basin
  - *Microcystis* decline from N-lmitation
- Oct. 2011 – *Microcystis* bloom in central basin
  - ~5,000 km², 3.3x larger than previous record
- Max measured (column integrated sample):
  - 8.7 µg/L
- Max estimated Microcystin concentration:
  - 4500+ µg/L
- WHO guideline: 20 µg/L
Goals

• Identify causes of the 2011 bloom
• Assess potential for future blooms

Hypothesized Causes:
• Phosphorus inputs from agriculture
• Unusually calm pre-bloom conditions
• Weak lake circulation
Methods – P Loading and Land use

• P loading data from USGS and National Center for Water Quality Research
  • Data from 1995 – 2011

• Land use and fertilizer application data from USDA databases

• Used the USDA’s Soil and Water Assessment Tool (SWAT) to model P loads
  • Based on: meteorology, hydrology, vegetation, and agricultural practices
Methods – Meteorological Conditions

- *Microcystis* especially effective in calm, warm waters
  - Buoyancy regulation to outcompete others
- Authors designated favorable and unfavorable bloom conditions:
  - Wind stress < 0.05 Pa and Temperature > 15°C → favorable
- Wind stress based on air velocity, air density, and drag coefficients
Methods – Flow Modeling and Particle Tracking

• Used a finite difference model with irregular grid
  • Flow accounts for roughness and tributaries
• Particle tracking used to estimate particle residence times
  • Simulated particle releases from Detroit and Maumee Rivers
Causes – P Loading

- High-intensity tile-drained agriculture in western basin watershed (OH, IN, MI)
- Three management practices:
  1) Autumn Fertilization
  2) Surface Fertilization
  3) Conservation Tillage
- Steadily increasing soil P
  - Highest in surface layers
- Reduced TP losses, but
- 218% increase in dissolved reactive P (DRP, SRP) loading of Maumee River since 1995
Causes – Spring Rains

• Autumn/Winter 2010 had perfect conditions for harvesting and fertilizer application
• A series of storms in spring
• **Massive** storm on May 25
  • 99.8\textsuperscript{th} percentile discharge at Maumee River gage station
• Record-setting P exports from Maumee River
Causes – Pre-bloom conditions

- Pre-bloom weather conditions were calm, but not unusually so
  - Favorable conditions typical of other years, but...
- Maumee River: 50% of P loading, 5% of discharge
- Detroit River: 50% of P loading, >90% of discharge
  - Very little mixing between the two
- ~80 day residence time of water at Maumee outlet following May 25th storm
Causes – Post-bloom lake conditions

- Calm, warm conditions persist
  - Limited vertical mixing of water column
- Detroit River short-circuits western basin channels
  - No dilution of Maumee River outflow
- Perfect conditions for *Microcystis* growth
MODIS Progression Images

June 1: Post-storm

July 19: Bloom begins

July 31: Detroit River short circuits

Aug 11: Mixing/eastward drift

Sept 3: Migration into central basin

Oct 9: Secondary bloom in central basin
Summary of causes

- Increased DRP loading from Maumee River/agricultural areas
- Big storm in May – released tons of P to western basin
- High residence time of water at Maumee River outlet
- No dilution from Detroit River (short-circuits system)
- Calm, warm weather conditions prevent mixing and promote bloom
It will happen again (and already did)

- Incentives for ethanol production → continuing corn agriculture in region
  - Production expected to plateau in 2015-2020
  - Continuing or increased P loading
- Increased use of Glyphosate herbicide
  - Contains phosphate
- Climate models predict:
  - Warmer, calmer lake conditions in summer
  - More major spring storms
- In 2014, Toledo, OH shut off water for ~500,000 people
What is being done?

• Strategic fertilization programs and education (SUSTAIN)
  • Operated by industrial agriculture companies

• USDA grants to MI, IN, and OH ($57 million since 2009)
  • Soil chemistry adjustments
  • Improving water management systems

• 2014 Farm Bill Program ($17.5 million)
  • Regional Conservation Partnership Program
  • Cooperation between Federal and State Ag. Depts, farm organizations
Questions:

• What potential farming practices or engineering solutions may reduce DRP export?
  • How might tile drainage complicate or simplify?

• What consequences might HABs have for the aquatic food web?