Future Scenarios for Environmental Conditions Favoring the Accumulation of Paralytic Shellfish Toxins in Puget Sound Shellfish

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Harmful Algal Blooms (HABs)

- Natural phenomena caused by the proliferation of algae, resulting in damage to the environment and/or risk to human health
- Many produce toxins that cause illness or death if contacted/consumed by humans and marine wildlife

“Florida red tide”

Image from NOAA website courtesy of P. Schmidt, Charlotte (FL) Sun
Foodborne HAB-Related Illnesses

Diarrhetic Shellfish Poisoning

- Okadaic acid
- Dinophysis spp.
- Prorocentrum spp.

Amnesic Shellfish Poisoning

- Domoic acid
- Pseudo-nitzschia spp.

Paralytic Shellfish Poisoning

- Saxitoxin
- Alexandrium spp.
- Gymnodinium spp.
- Pyrodinium spp.

Neurotoxic Shellfish Poisoning

- Brevetoxins
- Karenia brevis

Ciguatera Fish Poisoning

- Ciguatoxins
- Gambierdiscus toxicus

Images from Florida Fish and Wildlife Conservation Commission; NOAA CORIS; Oceanography Vol.18, No.2, June 2005: Images courtesy NOAA Fisheries, Seattle, WA, the Center for Integrated Marine Technology, T. Moita, and F. Figueiras.
50% of the Economic Impacts of HABs in the U.S. are Associated with Public Health Costs

Economic effects of HABs in the U.S. are at least $82 million/year*

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Commercial Fisheries Impacts</td>
<td>$38 million/year</td>
</tr>
<tr>
<td>Public Health Costs of Illnesses</td>
<td>$37 million/year</td>
</tr>
<tr>
<td>Recreation and Tourism Impacts</td>
<td>$4 million/year</td>
</tr>
<tr>
<td>Coastal Monitoring and Management</td>
<td>$3 million/year</td>
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</tbody>
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Source: NOAA CSCOR Economic Impacts Fact Sheet
The annual value of the shellfish industry in Washington State is $108 million.
HABs are Increasing in the United States and Around the World

Sources:


Climate Change has been Implicated in this Global Increase

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

Impacts of climate variability and future climate change on harmful algal blooms and human health

Stephanie K Moore, Vera L Trainer, Nathan J Mantua, Micaela S Parker, Edward A Laws, Lorraine C Backer, and Lora E Fleming

doi:10.1016/S1146-695X(03)00092-3
Cite or Link Using DOI

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Original article

Climate change and harmful algal blooms in the North Sea

Louis Peperzak

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DOI: 10.1111/j.1529-8817.2010.08815.x

REVIEW

OCEAN CLIMATE CHANGE, PHYTOPLANKTON COMMUNITY RESPONSES, AND HARMFUL ALGAL BLOOMS: A FORMIDABLE PREDICTIVE CHALLENGE

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28 Climate Change and Harmful Algal Blooms

B. Dale, M. Edwards, and P.C. Reid
Observed Warming in Puget Sound

SST from 1921-2007
Department of Fisheries and Oceans, Canada

Race Rocks lighthouse

Photo credit: E. B. Bartels
How will HABs change in the future as a result of climate change?

Can we anticipate changes and mitigate impacts?
**Alexandrium catenella**

- *Alexandrium* produce **saxitoxin** that accumulates in filter-feeding shellfish during blooms, or “**red tides**”
- Consumption of contaminated shellfish causes **paralytic shellfish poisoning**
Alexandrium life cycle

1. cyst
2. germination
3. vegetative cells
4. gametes
5. zygote

Vegetative cells
Cyst

Photo credit: Woods Hole Oceanographic Institute 2007, Dr. Don Anderson Director
[Photo credit: B. Bill]
Window of Opportunity Approach

1. Is there a “window of opportunity” for HABs in Puget Sound that is determined by weather and environmental conditions?

2. Has the window of opportunity changed in the past?

3. Will the window of opportunity change in a future warmer climate?
A period of time with weather and environmental conditions that increase risk for HAB development and shellfish toxicity

A window of opportunity for *Alexandrium* in Puget Sound was identified using the five most toxic events on record at “hot spot sites”

Moore et al. (2009): Harmful Algae
Five most toxic HAB events at hot spot sites

What did the weather and environmental parameters look like during these events?
Five most toxic HAB events at hot spot sites

A window of opportunity exists when all eight of the parameters are within 1.5 SD from the mean of values calculated during the 20 days leading up to the most toxic events

The window of opportunity for *Alexandrium* in Puget Sound is primarily driven by warm air and water temperatures, weak winds, low streamflow and small tidal variability
“Windows of Opportunity” correspond with historical **Shellfish Toxicity** records in Puget Sound.

= Windows of Opportunity, i.e. days with ideal weather and environmental conditions for toxic HAB development

Moore et al. (2009): Harmful Algae
Has the Window of Opportunity Changed in the Past?

The window of opportunity for HABs of Alexandrium in Puget Sound has increased in duration since 1967.

Moore et al. (2011): Harmful Algae
Has the Window of Opportunity Changed in the Past?

These increases occurred in “steps” in 1977 and 1991 marking new ceilings for values attained by the window of opportunity.

Moore et al. (2011): Harmful Algae
Frequency of toxic *Alexandrium* bloom events in Puget Sound

Closures only in Northwest basin and Strait

First Central and Whidbey basin closures

First South basin closures

Closures in most of Sound

Will the Window of Opportunity Change in a Future Warmer Climate?

- Explore future scenarios for the window of opportunity for *Alexandrium* using climate change projections for the Puget Sound region.

- Greenhouse gas emissions scenario A1B
  - Characterized by rapid economic growth, a global population that peaks in the mid-21st century, and rapid adoption of new technologies.

- Modified the time series of environmental parameters using the mean changes in air and water temperature, precipitation, and streamflow from 20 global climate models.
Future Average Changes to Parameters

Relative to the present-day (i.e., 1980s)

** Perturbations to (i) air temperature and precipitation calculated using the mean values of 20 GCMs with simulations for SRES A1B (Mote and Salathé, In press), (ii) streamflow calculated from the variable infiltration capacity regional hydrological model (Elsner et al. 2009), and (iii) sea surface temperature using a regression relationship with surface air temperature (Moore et al. 2011)
Projected Window of Opportunity for *Alexandrium* in Puget Sound

Managers can watch these months more closely and put mitigation measures in place ahead of time instead of being caught off guard by an unexpected bloom.

Moore et al. (2011): Harmful Algae
Compared to the Present day

2020s
- Blooms may begin 1 month earlier
- Blooms may last up to 14 days longer
- Average increase of 6 days

2040s
- Blooms may begin 1 month earlier
- Blooms may last up to 15 days longer
- Average increase of 9 days

2080s
- Blooms may begin 2 months earlier
- Blooms may last up to 19 days longer
- Average increase of 13 days
We now know that...

- A window of opportunity exists for HABs of *Alexandrium* and can significantly increase the risk for toxic blooms in Puget Sound.

- This window has been widening since at least the late 1960s.

- Under a moderate greenhouse gas emissions scenario, we project that blooms may begin up to 2 months earlier in the year and persist for up to 1 month later.

- Changes will be felt within 30 years, and maybe felt as early as next decade.
### Pros

- Considers effects of multiple environmental parameters
- Identifies seasonal time periods of increased risk

### Cons

- No **spatial** information on where blooms might be more likely to occur
- Limited mechanistic understanding of causative factors

...of the window of opportunity approach
Favorable habitat areas in Puget Sound for *Alexandrium* growth


**Shellfish were too toxic to eat only at sites with >40 d optimal T&S conditions**

T = 13-17°C  
S = 20-37 ppt
Puget Sound Alexandrium: Harmful Algal Blooms (PS-AHAB)

Supported by NOAA's ECOHAB Program

thou all-destroying but unconquering cell from hell's heart I stab at thee for hate's sake I spit my last breath at thee Sink all coffins and all hearse to one common pool! and since neither can be mine, let me then tow to pieces, while still chasing thee, though tied to thee, thou damned cell!

PS-AHAB

All that most madders and torments; all that stirs up the lees of things; all that cracks the sinews and cakes the brain; all the subtle demonisms of life and thought; all evil, to crazy Ahab, were visibly personified, and made practically assailable in Alexandrium. He piled upon the cell’s thecal plates the sum of all the general rage and hate felt by his whole race from Adam down; and then, as if his chest had been a mortar, he burst his hot heart's shell upon it.
Compare the influences of the **OCEAN**, **WATERSHED**, and **ATMOSPHERE** on Puget Sound oceanography

Explore future scenarios for favorable habitat areas for *Alexandrium* and develop management applications
Downscaled climate information is used to force an ocean model and evaluate future scenarios

- **MoSSea**: Modeling the Salish Sea
  http://www.faculty.washington.edu/pmacc/MoSSea

  [Snapshot of MoSSea SST May 15, 2006]([Credit: MoSSea website])
Downscaling relates the “LARGE” to the “SMALL”

Our downscaling approach uses global climate simulations from CCSM3 to force the lateral boundary conditions of the finer scale regional WRF model.

Slide courtesy of Eric Salathé
Preliminary low resolution (i.e., 3 km) MoSSea results for 1988, 2006, and 2047.
CCSM3-WRF South Sound temperature profiles

Year: 1988
Seasonal warming occurring earlier in the year

Year: 2047
Surface intensified warming

Banas et al., Unpublished
CCSM3-WRF: South Sound temperature in the upper 30 m

Temperature \( (^\circ C) \) vs. Yearday

Optimal temperature range for *A. catenella*

Earlier and longer lasting bloom season

Banas *et al.*, Unpublished
CCSM3-WRF: South Sound temperature in the upper 30 m

Optimal temperature range for A. catenella

Too warm?

Banas et al., Unpublished
Next steps: PS-AHAB and beyond

• Run the MoSSea model at high resolution using the downscaled climate information from an ensemble of models and for an ensemble of years in the future
  – Identify differences in favorable habitat areas for *A. catenella*

• Couple a biological model for *Alexandrium* to the ocean model and evaluate scenarios for future bloom dynamics in Puget Sound
Vision for the Future

• Incorporate climate and weather information into early warning systems for HAB events
  – ↑ capacity to adapt and mitigate the impacts of future climate change because a framework will already exist for considering climate and weather forecasts in risk assessments

As climate changes, management and monitoring practices will be better able to change along with it!
Acknowledgments

• NOAA, Northwest Fisheries Science Center
  – Vera Trainer
  – Brian Bill

• University of Washington
  – Barbara Hickey
  – Nathan Mantua
  – Eric Salathé
  – Neil Banas
  – Dave Sutherland

• Puget Sound Alexandrium Harmful Algal Bloom (PS-AHAB) Research Team
  Trainer, Bill, Mantua, Salathé, Banas, John Stein, Cheryl Greengrove, Julie Masura, Don Anderson

• Funding
  – NOAA’s Oceans and Human Health Program
  – NOAA’s ECOHAB Program