Summary of
Symposium on the *Alexandrium fundyense* Red Tide of 2005

MIT Sea Grant
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Judith Pederson (chair)
MIT SeaGrant College Program

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Background

Alexandrium fundyense is a dinoflagellate that produces a toxin that can concentrate in the tissue of shellfish and cause paralytic shellfish poisoning (PSP) in humans who eat the shellfish. Animals such as marine mammals and birds can also be poisoned. *A. fundyense* and *A. tamarense* both occur in the Gulf of Maine, but for convenience, the name *A. fundyense* is commonly used for both (only specialized studies can differentiate them; they have similar toxicity). Also, for readability parts of this report may simply refer to the genus name *Alexandrium*. Blooms of *A. fundyense* are commonly called red tide, though the water rarely is discolored during blooms of this species.

Figure 1 depicts the life cycle of A. fundyense. A. fundyense cysts in sediments germinate to yield motile cells when environmental conditions are favorable. An internal clock also regulates *A. fundyense* germination. Motile cells divide in favorable conditions of light, temperature and nutrients, doubling every 1.5 – 2 days under optimal conditions. When conditions are unfavorable for growth, e.g. depleted nutrients, gametes are formed, fuse, develop into a zygote and then into a cyst. The cysts fall to the ocean floor where they may remain dormant for many years. In the Gulf of Maine, there appears to be a positive relationship between the number of cysts in the sediments and the size of the blooms.

A. fundyense has historically bloomed in the Bay of Fundy, but blooms were not known to occur in the southwestern Gulf of Maine, including Massachusetts Bay, until 1972 when a slow-moving tropical storm apparently transported cells down the coast, presumably from the Bay of Fundy. Following the 1972 bloom, recurrent annual outbreaks occurred in northern Massachusetts, New Hampshire, and western Maine through to the present. Farther south, in Massachusetts Bay, shellfish toxicity was frequent from 1972-1993 but nearly absent from 1994-2004 (despite recurrent toxicity in western Maine and New Hampshire).

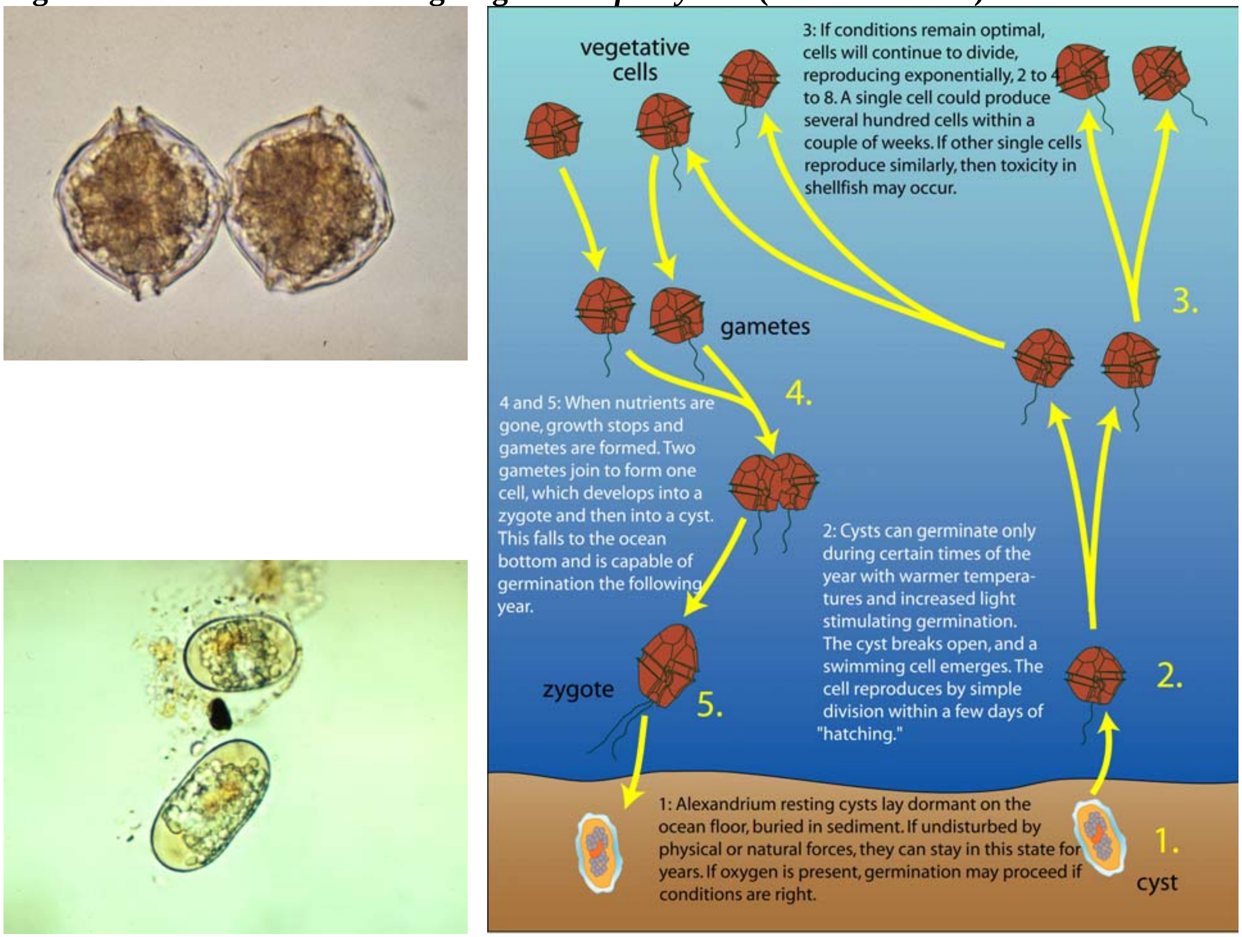
The Maine coastal current moves from the Bay of Fundy area south (see Figure 2), and into and around Massachusetts Bay (currents not shown in Figure 2). The presence or absence of *A. fundyense* blooms in the western part of the Gulf of Maine and western Massachusetts Bay is related, in part to: 1) upwelling and downwelling events that are driven by wind direction, duration, and strength (see Figure 3); 2) river runoff that brings freshwater, stratification, and nutrients; and 3) the abundance of cysts in sediments.

Circulation, wind, and river runoff were favorable to bloom development in 2005, including two or more Nor'easter storms that pushed waters onshore. In addition, cysts were very abundant in offshore sediments.

How widespread was the 2005 bloom relative to previous blooms?

Generally, PSP toxicity is initially observed in western Maine, and then Maine officials alert New Hampshire and Massachusetts agencies. Toxicity testing of shellfish begins throughout the region and closures of shellfish beds result when a toxicity threshold is reached (80 micrograms of toxin per 100 grams of shellfish tissue). Ensuring that PSP toxins are below this level protects humans from illness or death. For the first time ever, areas in Nantucket, Martha's Vineyard, and Buzzards Bay near the

Figure 1. Active and resting stages of *A. fundyense* (Anderson 2006)



Cape Cod Canal were closed to shellfishing following the direct detection of toxins in shellfish in these areas. (These areas had been closed in 1972 in a broad, state-wide closure, but not as a result of toxin tests.)

In 2005, record levels of PSP toxicity were measured at some locations, whereas other locations had detectable PSP toxicity for the first time ever. Record level cell concentrations were measured in southwestern Gulf of Maine. There was also a large closure of federal (offshore) waters. Disaster declarations were issued in Maine and Massachusetts, as shellfishermen were unable to harvest for prolonged periods over the affected areas. Losses to the shellfish industry are estimated at $50M in Massachusetts alone. Figure 4 shows the progression of shellfish closures in state and federal waters. Figure 5 compares the magnitude of the 2005 bloom to previous years in Massachusetts Bay.

In 2005, New Hampshire's coast experienced the highest PSP levels ever recorded. Other records were also broken: earliest toxicity, longest closures, and the largest area that was affected. Figure 6 shows how 2005 PSP toxin levels in Hampton, New Hampshire blue mussels compare to levels observed in 1993 (formerly the most severe PSP season on record for New Hampshire) and in 2000 (a PSP season with minor levels of toxicity).

Figure 2. Gulf of Maine circulation (Pettigrew 2006)

Summer mean Circulation in the Gulf of Maine (GoM) includes the Gulf of Maine Coastal Current (GMCC) in the shelf regions.

The two principal branches of the GMCC: Eastern Maine Coastal Current (EMCC) and the Western Maine Coastal Current (WMCC), both of which flow southwestward against the mean summer winds.

The transport of the EMCC is typically 2-3 times that of the WMCC. The alongshore decrease in transport is accomplished by offshore veering of the EMCC.

The connection between the EMCC and the WMCC, offshore of Penobscot Bay, is seasonal, variable, and is affected by wind forcing. The complex nature of this connection is a key to export of *A. fundyense* blooms from the perennial "hot" region in the EMCC to the shelf west of Penobscot Bay. GoMOOS buoys E and I are positioned to measure these currents.

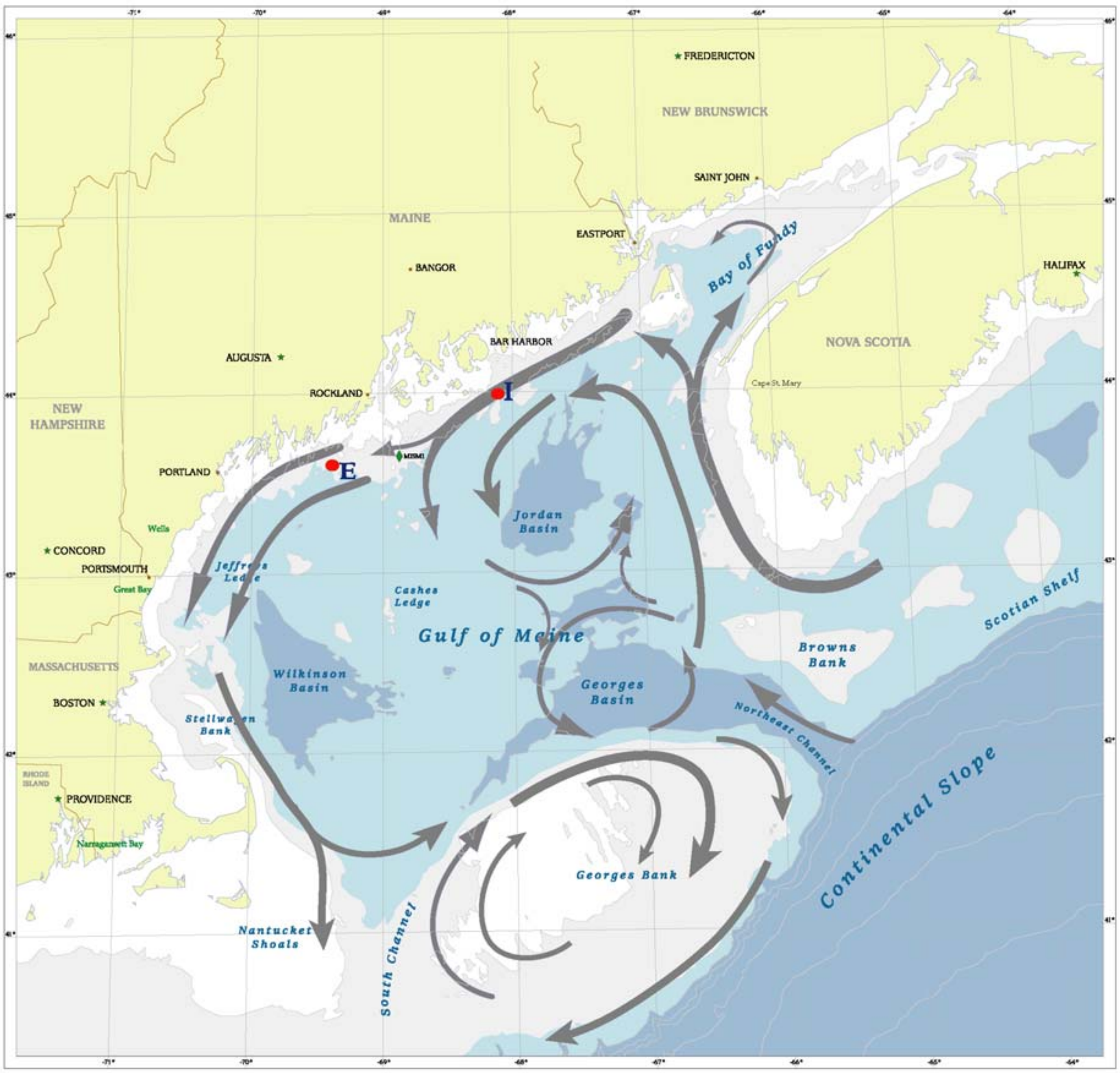
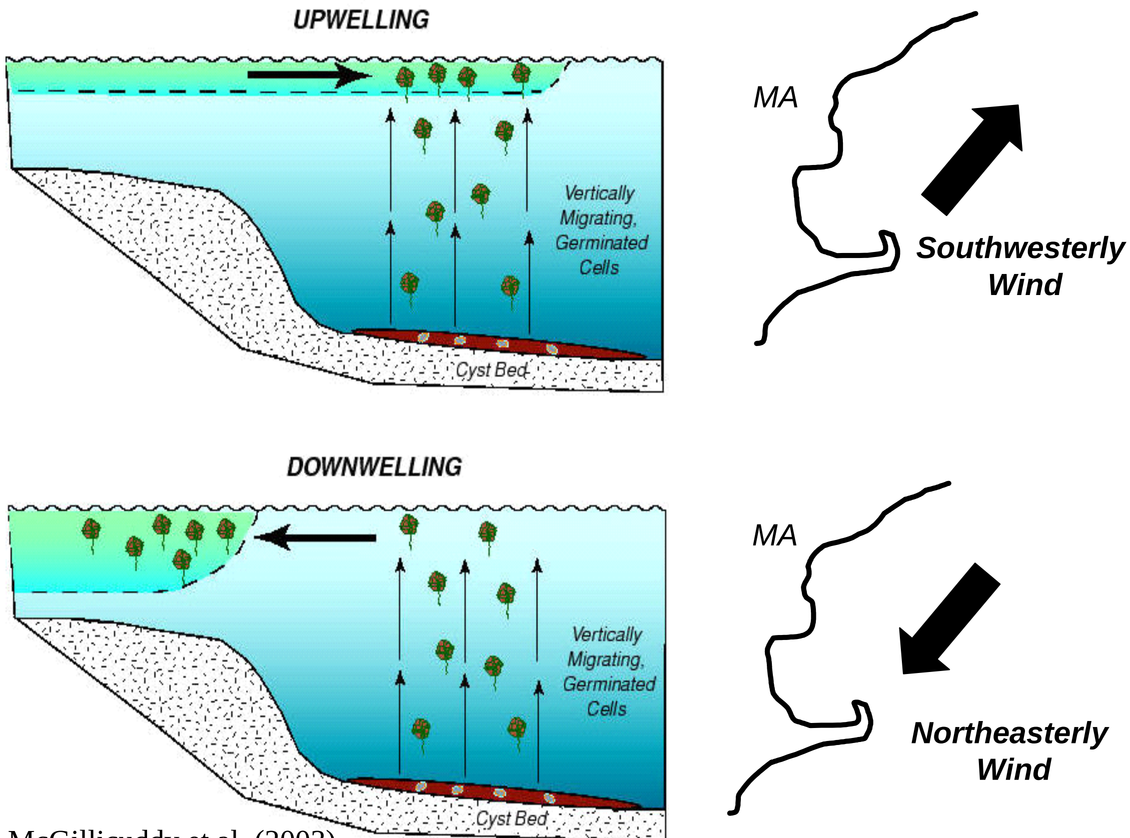


Figure 3. Downwelling winds concentrate cells near the coastline (He 2006)



McGillicuddy et al. (2003)

Maine also experienced a very large *A. fundyense* bloom in 2005. Figure 7 compares the magnitude of the 2005 bloom to previous blooms. In addition, some stations were found to have set new record highs of toxicity and species of bivalves were affected that had not been affected in previous years - American oyster (*Crassostrea virginica*) and Bay quahog (*Mercenaria mercenaria*).

The Bay of Fundy in 2005 had toxicity and cell abundance matching the highest levels seen in New England. This was, however, considered "normal" by local standards – because the Bay of Fundy, due to unique circulation patterns, is routinely a "hot spot" for *A. fundyense*. Much higher concentrations of cells and toxicity had been measured there in 2003 and 2004.

What lessons have we learned?

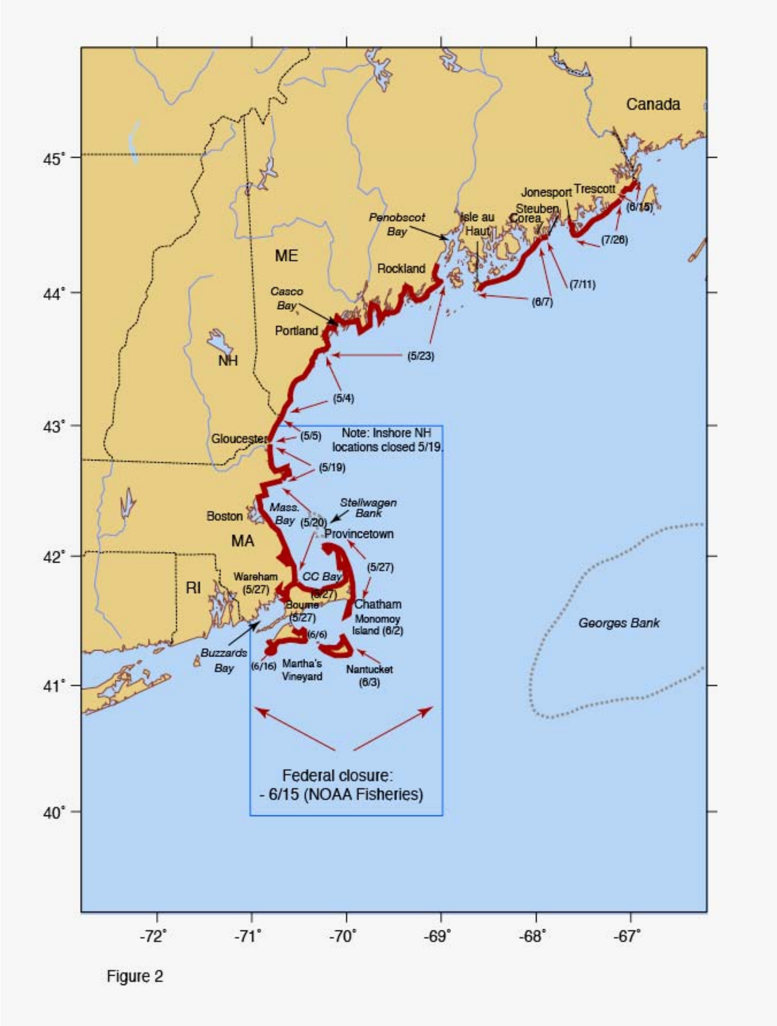
There were a number of lessons learned during the 2005 *A. fundyense* bloom. Below are responses to this question from several speakers at the Symposium.

Don Anderson, Woods Hole Oceanographic Institution

- Overall, this was a very well managed event. Despite the huge size of the bloom and the very high toxin levels, there were no reported illnesses or deaths. However, state staff and resources were pushed to the limit.

- There was an accurate and timely flow of information, and excellent cooperation and communication among state and federal managers and researchers.

Figure 4. Sequence of mussel beds closures in 2005 (Anderson 2006)



The 2005 event

- **Record levels of toxicity in some locations**
- **First-time ever records of toxicity in some locations**
- **Record high *A. fundyense* cell concentrations (for this southern region)**
- **Large closure of federal (offshore) waters**
- **$50M for shellfish industry in Massachusetts alone**
- **Maine and Massachusetts had disaster declarations**

- New tools and understanding developed during recent research programs proved very useful (e.g. conceptual models, molecular probes, sandwich hybridization assays, surface drifters, and numerical models).
- The bloom highlighted our ignorance of the link between surface blooms and toxicity in deep-water shellfish.
- The bloom also highlighted our ignorance of bloom transport pathways in the southern Gulf of Maine and its adjacent shelf waters.
- There are three working hypotheses to explain the magnitude and extent of the 2005 *A. fundyense* bloom:
  - High cyst abundance in western Gulf of Maine
  - Heavy snowmelt and rainfall
  - Northeast storms at critical times

- However, many unknowns remain:
  - Source of initial cells, transport pathways
  - Hydrographic pathways in southern waters, including the manner in which cells reach Nantucket Sound, Vineyard Sound, and southern Rhode Island waters
  - Factors leading to the termination of the bloom
  - Fate of cells, cysts and toxins

Figure 5. History of PSP in southern New England (Anderson 2006)

- **No PSP toxicity in western GOM prior to major "red tide" of *A. fundyense* in 1972**
- **Following 1972 bloom, recurrent annual outbreaks in northern MA, NH, and western Maine through to the present**
- **Shellfish toxicity frequent in Mass Bay from 1972 - 1993.**
- **Prior to 2005, almost no toxicity detected in Mass Bay over the last decade, despite recurrent toxicity in western Maine and NH.**

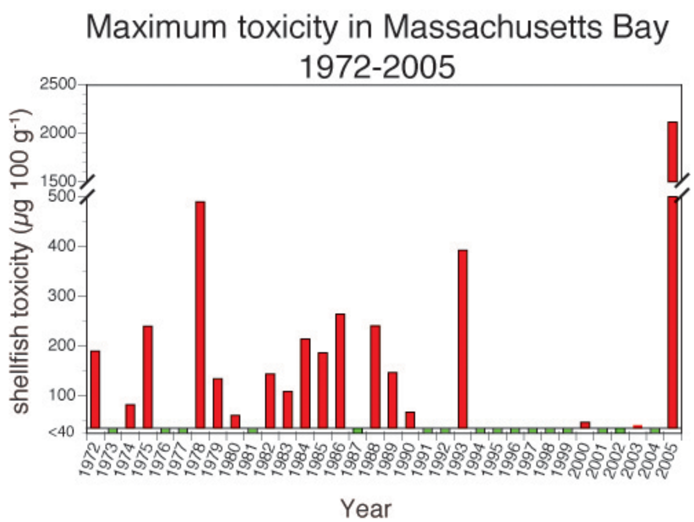


Figure 6. Hampton, New Hampshire blue mussel PSP toxin data (Nash 2006).

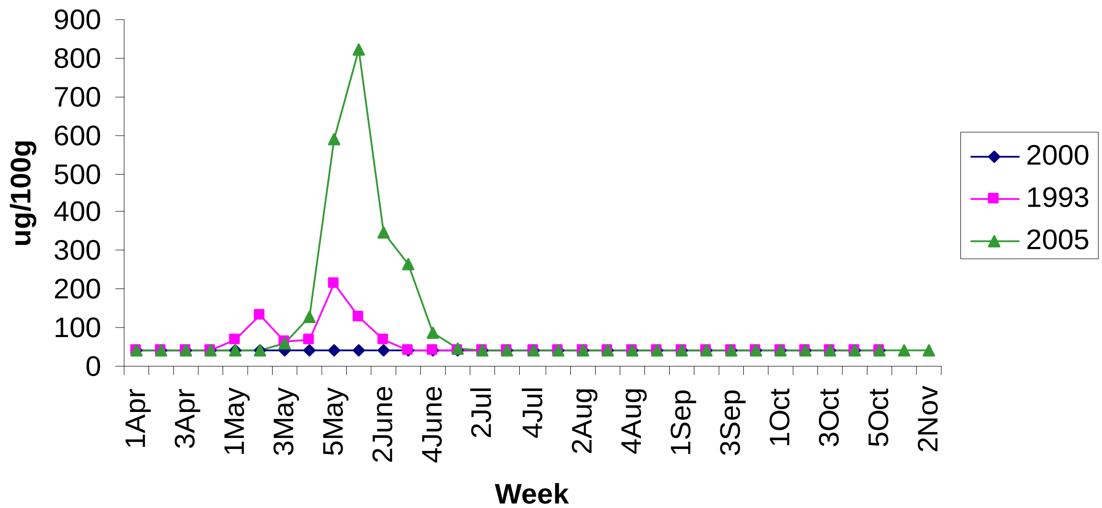
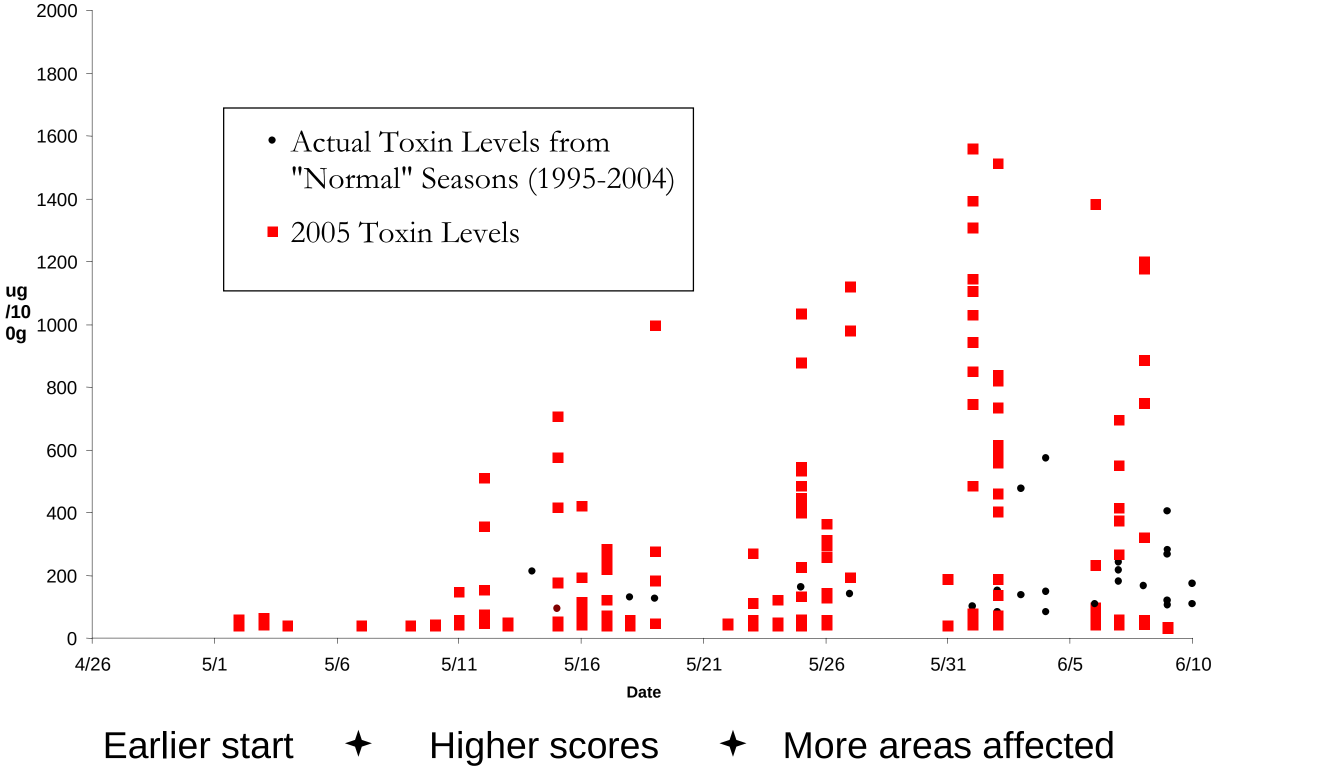


Figure 7. **Ten-year analysis of early season trends in Maine (Couture 2006).**



David Whittaker, Massachusetts Division of Marine Fisheries

- Accelerated sampling and/or processing
- Identified and sampled new sites
- Enlisted assistance from towns, and commercial vessels
- Received and/or processed samples from industry and or federal agencies
- Increased nearshore phytoplankton sampling
- Wide-spread closures by designated shellfish growing areas by species
- Developed and outreach program including closure notices, maps and e-mails; closure calls
- Massachusetts Division of Marine Fisheries Website included a red tide white paper and maps and notices of openings and closings.
- Communicated with state agencies and programs and externally with local government, federal agencies, academia, industry, other states, and the Massachusetts Water Resources Authority
- Worked with the press
- Provided description of red tide and impacts
- Described open and closed areas
- Provided information on symptoms
- Shared sampling and analysis methods
- Emphasized safety of seafood!

Darcie Couture, Maine Department of Marine Resources

- Provided 1-800 Hotline information
- Broadcast weekly updates
- Collaborated with poison control
- Collaborated with Maine Bureau of Health
- Used volunteer vessels for offshore monitoring (created a special license)

What preparations are being done for 2006?

States more severely affected by the 2005 *A. fundyense* bloom are preparing in the event of a severe bloom in 2006:

Massachusetts plans to:

- Predefine secondary and tertiary stations
- Prepare list of commercial vessels
- Coordinate with non-state sampling
- Prepare dealer and processor list
- Post real-time updates on website
- Distribute daily internal updates
- Revised list of outside parties to be notified
- Prepare statements for the press

New Hampshire plans to:

- Begin Star Island sampling in April
- Conduct offshore plankton tows with Great Bay Coast Watch volunteers

Maine

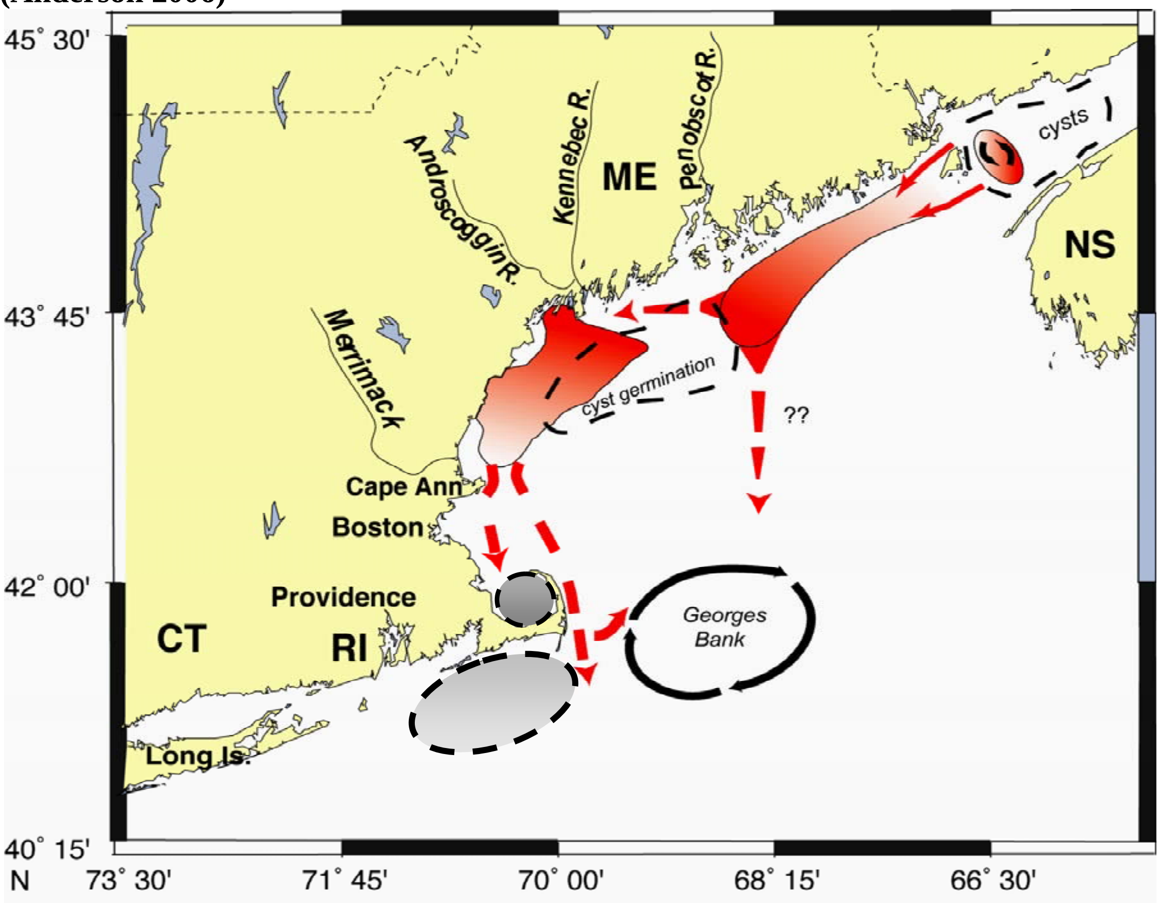
- Have had successful discussions with Maine Legislature have lead to an increased Department of Marine Resources budget and seven new seasonal positions (although this was subsequently cut from the budget).
- Plans to augment training for Phytoplankton Monitoring Network.
- Plans to continue to collaborate with the Casco Bay Estuary Program and MER Assessment Corporation for intensive, fine scale sampling by boat. If successful, this collaborative approach could be used as a model for managing other areas in Maine.

Are there new cyst fields in Massachusetts Bay and Nantucket Sound?

Massachusetts staff were very concerned that the bloom of 2005 would produce and deposit large numbers of over-wintering cysts on the sea floor in Massachusetts Bay and southern waters (Figure 8), and be available in greater abundance to cause problems in 2006.

Recent sampling found that the cysts were unexpectedly sparse in southern waters impacted by the 2005 red tide event, although cyst concentrations were still historically high in the offshore waters of the western Gulf of Maine. It is therefore unlikely that there will be substantial *in situ* germination of cysts and localized bloom development in Massachusetts Bay. Delivery of cells from the north is still possible with proper conditions and a large, regional bloom is also possible (i.e. cysts to the north are nearly as abundant as they were in 2004).

Figure 8. An expansion of the *A. fundyense* cyst distribution, which may lead to new patterns of PSP (Anderson 2006)



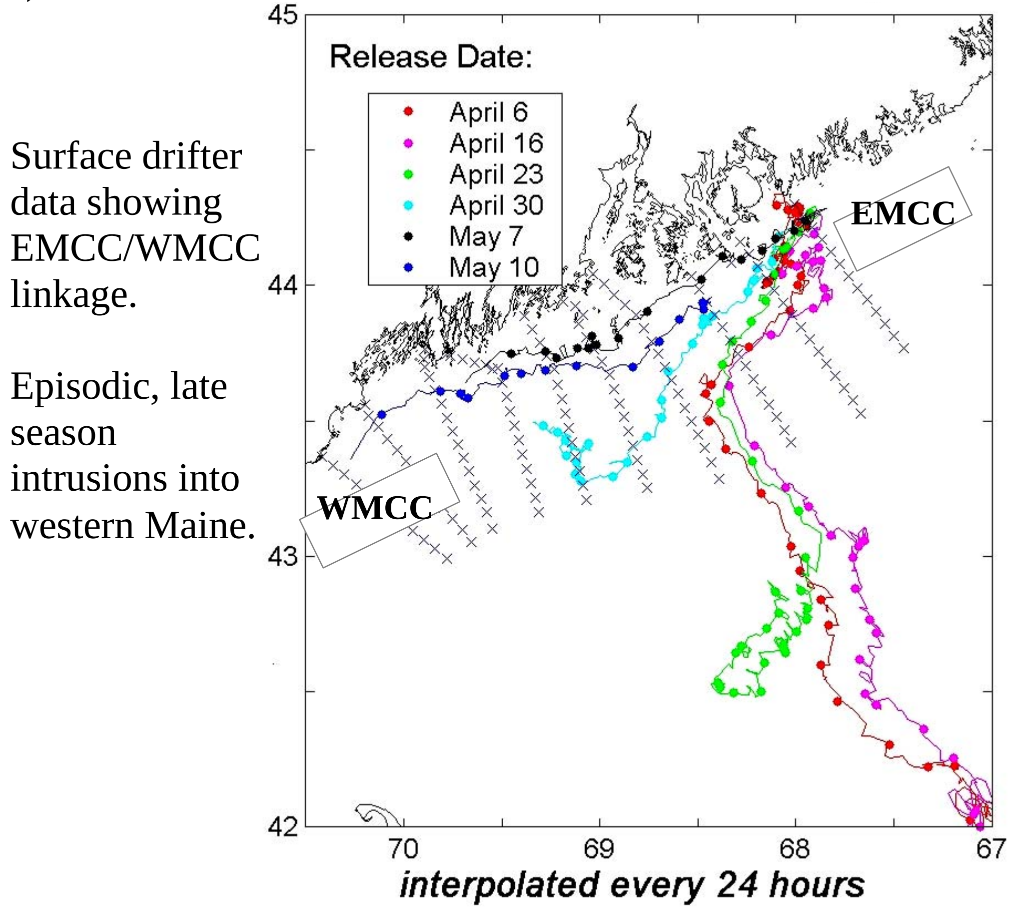
Can we predict blooms?

Currently, long-term prediction of blooms (i.e., annual forecasts) is not possible in the Gulf of Maine, although it is becoming clear that knowledge of cyst abundance can be a useful indicator. The physical-biological model developed for *A. fundyense* in the Gulf of Maine has demonstrated a good capability to hindcast past blooms, and now is being evaluated for forecasts. This model, however, is initiated by regional cyst map, and at present, there are no sources of *A. fundyense* cell abundance observations that can be used in data assimilation mode to update the model's forecasts. Nevertheless, the model is providing a regional picture of bloom development that has been remarkably accurate. Coupled with weather forecasts and data from ocean observing systems (especially those that provide data specific for *A. fundyense*), short-term forecasts should be available.

Empirical and conceptual models can also be used to make forecasts and predictions. For example, as shown in Figure 9, the episodic nature of the connections between the Eastern Maine Coastal Current (EMCC) and the Western Maine Coastal Current (WMCC) are very important in the transport of cells and water into western Maine. These intrusions of EMCC water can be detected by satellite remote sensing, and thus can be used to predict outbreaks of toxicity in western Maine.

Some confined areas such as the Nauset estuary, Massachusetts and Lumbo's Hole, Maine have regular annual blooms, apparently seeded from within. Although the timing of these blooms is quite predictable, their magnitude is not.

Figure 9. 2001 Drifter tracks as of May 24, 2001 interpolated every 24 hours (Anderson 2006)



What were the economic costs of the 2005 bloom?

The impact on Massachusetts' shellfish industry was estimated using a landed value of $10.2 million and a multiplier of 4.5 (the ratio of total economic cost to landed value). The estimated impact of the 2005 *A. fundyense* bloom on the Massachusetts shellfish industry was therefore $46 million.

What is an appropriate level of monitoring?

Appropriate monitoring enables us to minimize risk while permitting appropriate use. Given that protecting human health during red tide events is the highest priority, monitoring during the 2005 bloom can be considered to have been at an appropriate level because there were no reported illnesses due to PSP. However, state personnel were stretched far too thin, and the story might have been very different. As one participant noted, "we were just one illness or death away from failure". Continued vigilance, dedicated monitoring programs, and communication within and between states are important. Of great concern are visitors or those unaware of the ban on shellfish harvesting

Does the outfall play a role in the frequency and extent of the blooms?

One of the pressing questions in the public's mind is, did the Massachusetts Water Resources (MWRA) outfall stimulate nearby cells? The MWRA added additional sampling to comply with its commitments in its Contingency Plan and discharge permit, and to assist with the research and management actions during the event. Even with additional monitoring, the question of whether the outfall has an impact is difficult to assess considering the size of the bloom area, the complexity of mixing during the storms, and intensity of the bloom. However, it is evident that the 2005 red tide event was a regional bloom – with high levels of toxicity well upstream of the outfall. In addition, when the bloom was ending, cell abundances dropped just as steeply in the region of the outfall as elsewhere, and there was no apparent outfall effect causing a localized increase in growth and duration.

MWRA and Battelle (the consultant conducting the field sampling program) intend to address the following questions with further data analysis:

- What did the deep mixing from storms do to the nitrogen pool from the outfall?
- How did the nitrogen pool change through time as it was dispersed, diluted, and transported to the south?
- Does knowing the contribution of the outfall discharge to the total nitrogen budget of the bay help to understand observed cell abundances?

Numerical modeling will be of great help in exploring these linkages. Currently there is no definitive evidence for outfall effects. Data analyses are ongoing and sampling during future red tide events will focus on evaluating whether the outfall plays a role in *A. fundyense* bloom dynamics.

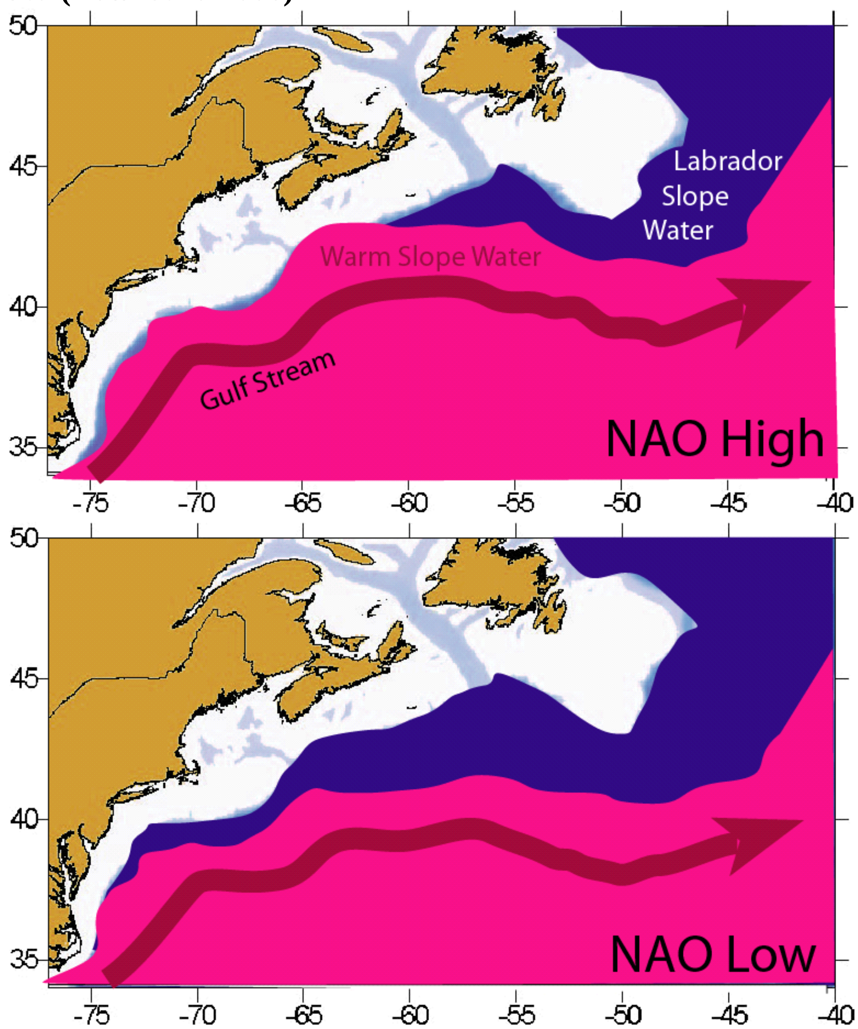
Does the North Atlantic Oscillation (NAO) play a role in bloom dynamics?

The North Atlantic Oscillation (NAO) is an atmospheric pressure oscillation between the Icelandic Low pressure and the Azores High pressure. This affects the westerly winds that in turn affect ocean currents (Figure 10) and weather patterns. D. Townsend presented research on the influence of the NAO on nutrient concentrations entering the Gulf of Maine through the Northeast Channel. Greater inputs of inorganic nitrogen relative to silicate may have coincided with greater offshore blooms of *A. fundyense*.

Figure 10. NAO and the Slope Sea (Townsend 2006)

NAO Influences:

- Position of the North Wall of the Gulf Stream;
- Labrador Slope Water extends southwest during NAO Low.



Future Work

Continued funding of research, monitoring, and management programs is important.

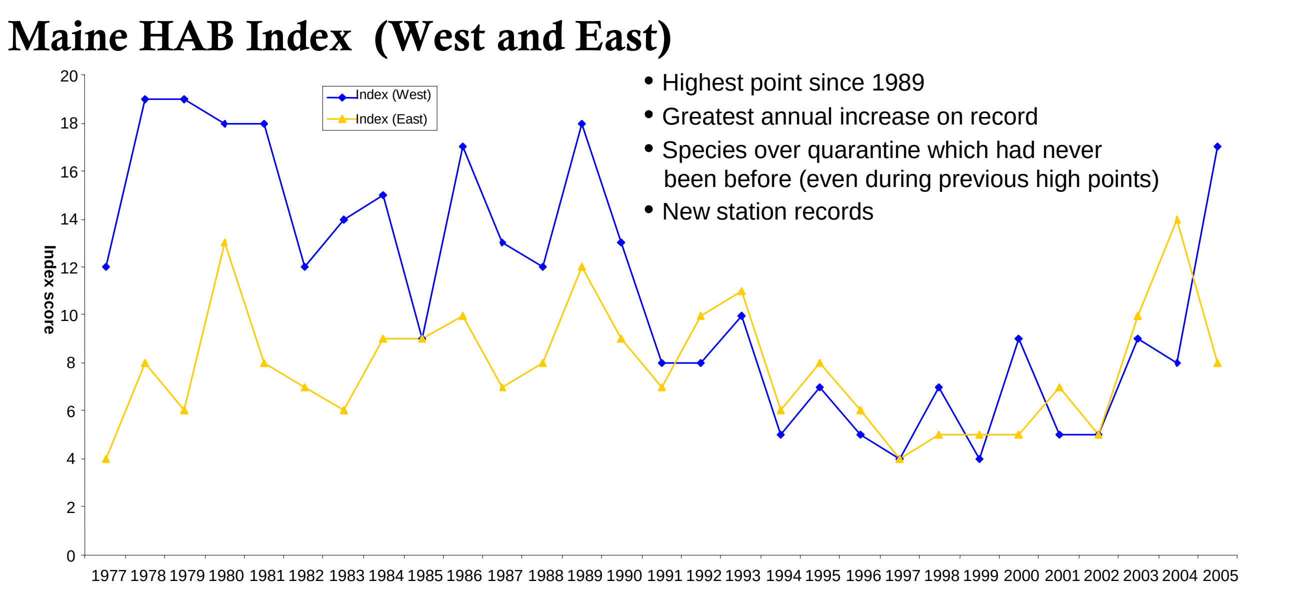
Potential research topics

- Continued investigation of the dynamics of cyst bed formation
- Continued investigation of the extent to which *A. fundyense* blooms in the Bay of Fundy influence blooms in western Maine and Massachusetts Bay
- Modeling *A. fundyense* bloom termination

Monitoring and management issues

- Develop protocols for analyzing carnivorous snails that may accumulate toxin from feeding on contaminated bivalves and in turn be eaten by other animals or humans.
- Establish new sampling stations (shellfish and phytoplankton) where needed
- Develop analysis and management methods to deal with sea scallops, ocean quahogs, and surf clams in deep, offshore waters
- Develop sampling/analysis opportunities among agencies
- Continue to improve communication among agencies
- Develop protocol and funding sources for on-going deep-water sampling
- Establish funding source for field sampling and lab analyses to supplement state shellfish monitoring efforts. Emergency funds were obtained for the 2005 bloom from federal (NOAA) sources, but such funds will not be available on a routine basis for future blooms.
- Ensure timely postings of area closures
- Improve communication with the public
- Investigate long-term toxicity trends [for example, D. Couture's "Maine Harmful Algal Bloom Index" (Figure 11) which shows that we are currently in a more active phase of red tide blooms].

Figure 11. Maine HAB Index indicates recent upswing in severity of toxic blooms (Couture 2006)



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