Red Tide Surveys of Massachusetts Bay, 1999

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Red Tide Surveys of Massachusetts Bay, 1999

by

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Introduction

Toxic or harmful algal blooms, commonly called "red tides", are a serious economic and public health problem throughout the U.S. and the world. In the New England region, the most serious problem in this context is paralytic shellfish poisoning (PSP), a potentially fatal neurological disorder caused by human ingestion of shellfish that accumulate toxins as they feed on dinoflagellates in the genus *Alexandrium*. Twenty-five years ago, PSP was virtually unknown in New England, yet now, significant portions of the region's intertidal shellfish resources are closed annually due to toxicity. A further expansion of the problem occurred recently when the offshore shellfish beds of Georges Bank and Nantucket Shoals were shown to contain dangerous levels of toxin.

The physiology and bloom dynamics of toxic *Alexandrium* have been the subject of sustained Sea Grant-supported research that has done much to increase our understanding of the patterns and dynamics of PSP outbreaks in the region. However, recent public controversy over the possible effects of a massive new sewage outfall that will release treated sewage from Boston into Massachusetts Bay have highlighted how little is known about the PSP phenomenon within the Bay.

Based on earlier SeaGrant/MWRA funded work, it was concluded that blooms of *Alexandrium* within Massachusetts Bay are largely formed from “source” populations to the north that are transported with the prevailing western Maine coastal current (WMCC) around Cape Ann and into the Bay. The timing of downwelling- and upwelling-favorable wind conditions are believed to be critical factors in the transport of the cells either into Massachusetts Bay (under downwelling favorable conditions) or offshore of Stellwagen Bank (during upwelling conditions). Physical-biological coupled circulation models of *Alexandrium* dynamics in the WMCC using real wind and runoff data from 1993 (see http://crusty.er.usgs.gov/wgulf/modeling.html) demonstrate that the bulk of the cells transported near Cape Ann will pass offshore of Stellwagen Bank during upwelling conditions (May 16-18, 1993), while other cells will enter the Bay during downwelling-favorable conditions (May 23-30). The shellfish toxicity pattern in 1993 generally agrees with this scenario, in that toxicity was first detected just north of Cape Ann on May 3, was detected within Massachusetts Bay a couple of weeks later, but did not increase immediately thereafter due to upwelling-favorable winds that kept the population offshore. By late May and early June however, toxicity was on the rise along the South Shore during the downwelling-favorable conditions at that time. In 1998, a year when toxicity was detected as far south as Cape Ann (Annisquam) but not within Massachusetts Bay, a satellite-tracked drifter, released in the Casco Bay region during the onset of shellfish toxicity there, tracked southward along the coast, but never entered the Bay. When it reached Cape Ann, the downwelling winds changed to upwelling-favorable and the drifter established an offshore trajectory beyond Stellwagen Bank. Had the downwelling winds persisted, the outcome for shellfish toxicity within the Bay might have been quite different.

This project represents in part a continuation of past red tide research within the region with the focus on the distribution of *Alexandrium* in the Bay in 1999. Sampling programs in Massachusetts Bay in recent years (ours and those associated with the Harbor Outfall Monitoring Program) have not detected high densities of *Alexandrium* within the Bay. The last time cells were sufficiently numerous in Massachusetts Bay to produce shellfish toxicity was during the spring of 1993 as noted above. However, even in years when no shellfish toxicity is detected in

the Bay, low densities of *Alexandrium* cells are present, usually offshore of the shellfish sites. Concurrent samples for nutrient analysis have not shown any relationship to the *Alexandrium* populations, other than that nutrients are generally low in surface waters during times when *Alexandrium* is present. This is presumably because nutrients in the surface waters have been depleted by prior diatom blooms. Our current thinking is that the *Alexandrium* population coming into Massachusetts Bay is nutrient limited in the WMCC, which may explain why populations in the WMCC are generally lower in abundance relative to waters to the north. To determine whether outfall nutrients will have an impact on the *Alexandrium* populations, it is important to understand the input and distribution of *Alexandrium* in the Bay and the nutrient status of these cells.

Objectives

The objectives of the 1999 survey for *Alexandrium* populations within Massachusetts Bay in 1999 were to:

- Provide background data on the distribution of *Alexandrium* within Massachusetts Bay to help characterize natural interannual variability of these populations before the new outfall is operational.

- Determine the meteorological and oceanographic mechanisms that regulate whether *Alexandrium* populations in the WMCC enter the Bay or are advected past the Bay along Stellwagen Bank.

Methods

The approach for the 1999 surveys for *Alexandrium* populations within Massachusetts Bay was to maintain several transects previously sampled, but also to add transects near Cape Ann to focus on the incoming populations (Fig. 1). A field operation was mounted in May and early June, 1999 to collect water samples and associated hydrographic data during the time most likely for *Alexandrium* bloom initiation within the Bay. Four cruises were scheduled in Massachusetts Bay, but the last cruise was cancelled due to lack of significant *Alexandrium* activity within the Bay, based on shellfish toxicity data and cell counts from the previous cruises. The dates of the completed cruises aboard the R/V Gulf Challenger (University of New Hampshire) were as follows:

Cruise 1	May 5-6
Cruise 2	May 17-18
Cruise 3	May 31- June 1

Hydrographic data was acquired using a Seabird SeaCat Profiler, while water samples were collected from Niskin bottles hung from the hydro-wire. Samples for both quantification of the toxic dinoflagellate population and nutrients were collected at the surface, 3.5m, and 7m. At 7 stations (about 1-2 stations per transect), additional water samples were collected at 10m and 20m so that vertical profiles of *Alexandrium* cells and nutrient concentrations could be obtained.

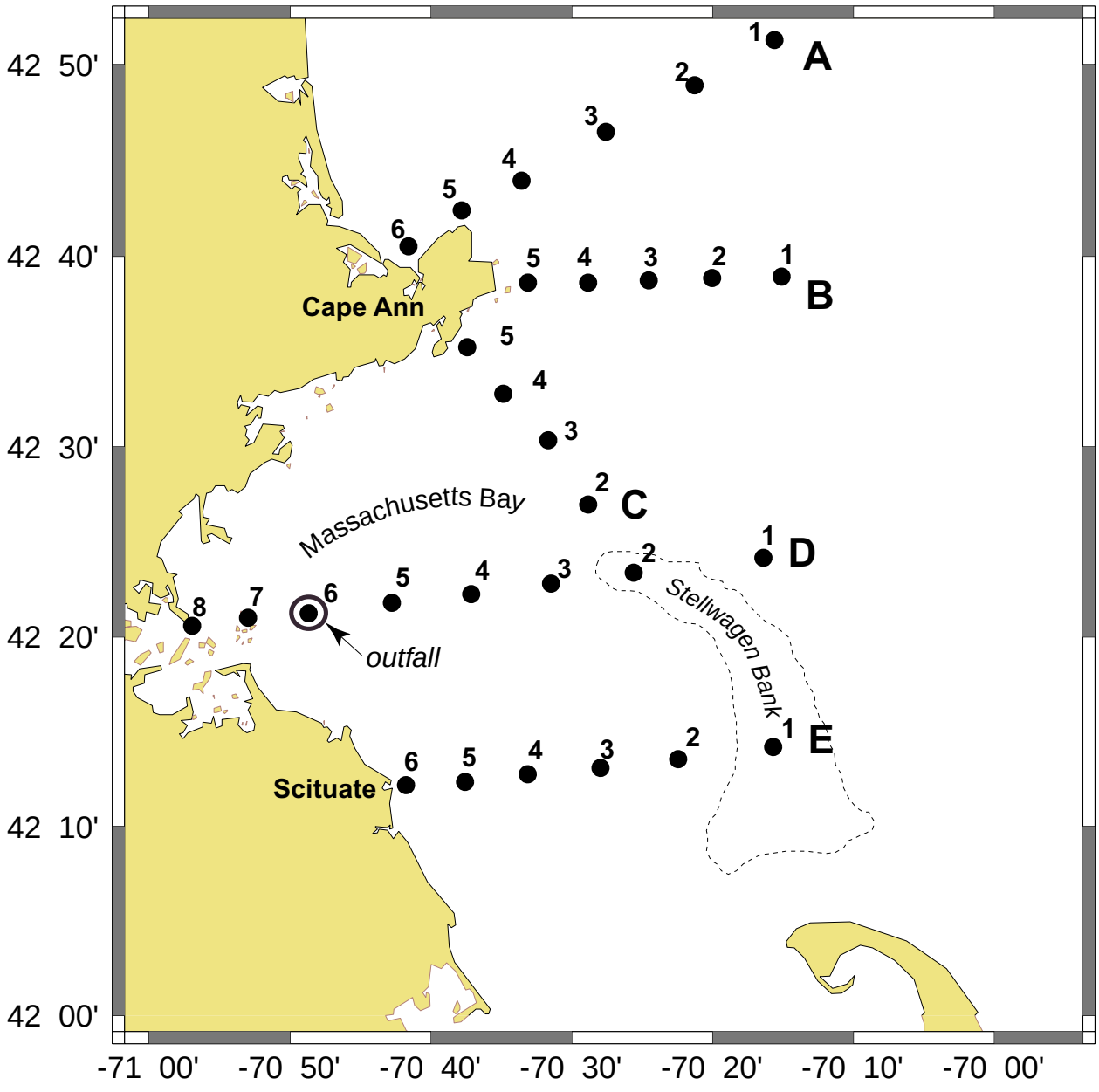

Fig. 1. Station locations in Massachusetts Bay and near Cape Ann for 3 survey cruises completed in May and early June, 1999.

Alexandrium water samples were sieved through 20 µm Nitex. Cells were backwashed off the sieve and preserved in borate-buffered formalin (5% final). The cells were filtered and stained using an indirect antibody-labeling method developed with prior Sea Grant/MWRA support. With this method, the target *Alexandrium* cells were labeled first with an *Alexandrium*-specific monoclonal antibody and then detected using a secondary antibody-fluorochrome tag (e.g. FITC). The target cells were then easily viewed using epifluorescent microscopy. This method is not only faster, but reduces the chance of mis-identification -- a very common problem using standard light microscope techniques when the concentration of *Alexandrium* is very low.

Samples for nutrient analyses were collected from the same Niskin bottles used for the *Alexandrium* collections. Aliquots of 50ml were filtered through 0.45 µm pore-size membrane filters to ensure that measured nutrients were dissolved. Chloroform was added to prevent degradation, and samples were stored frozen until analyzed (by J. Turner) using an Alpkem RFA 300 autoanalyzer to measure inorganic nutrients (ammonium, nitrate+nitrite, phosphate, silicate).

Results and Discussion

The hydrography of Massachusetts Bay during spring, 1999 was similar to previous years. The data consistently showed the influence of the less-saline WMCC and the Merrimack River on the hydrography of Massachusetts Bay. Surface salinities between 30 and 31 psu, indicative of the coastal current, were observed entering Massachusetts Bay near Cape Ann during all three cruises (Fig 2-4). Even lower salinities (<30 psu) were observed near Cape Ann and Boston Harbor, indicative of the broad influence of the Merrimack River and local influence from the Charles River, respectively. The WMCC, derived principally from the outflows of the Penobscot, Kennebec, and Merrimack Rivers, is believed to be the driving force for the transport of *Alexandrium* populations into Massachusetts Bay.

Surface temperatures had a weak correlation with the coastal current during the sampling periods. Surface temperatures ranged from about 7-9 ^{o}C on the first cruise in early May, with slightly higher temperatures recorded at the stations closest to the coast. Surface temperatures increased to 10-12 ^{o}C during the second cruise, and reached 12-16 ^{o}C by the final cruise in late May-early June. *Alexandrium* abundance was highest near Cape Ann in the slightly warmer waters of the WMCC during cruises 1 and 2 (see below) when temperatures were ca 8-12 ^{o}C. This pattern agrees with previous observations in the region.

Approximately 350 samples were collected during 1999 in order to characterize the *Alexandrium* distribution within Massachusetts Bay and near Cape Ann. *Alexandrium* was detected within the Bay at relatively low concentrations (<20 cells/liter) during all 3 cruises (Fig. 2-4). Although the cell densities were extremely low within the Bay, the concentrations were always slightly higher near Boston Harbor entrance and at the innermost stations near Scituate during each survey (Figs. 2 and 4; also see Appendix). It is not known if the slightly higher cell population was due to accumulation of toxic cells at the density fronts formed from the Harbor outflow or to enhanced growth due to higher nutrient concentrations. In our experience, these low cell concentrations are not sufficient for toxicity to reach detectable levels in shellfish.

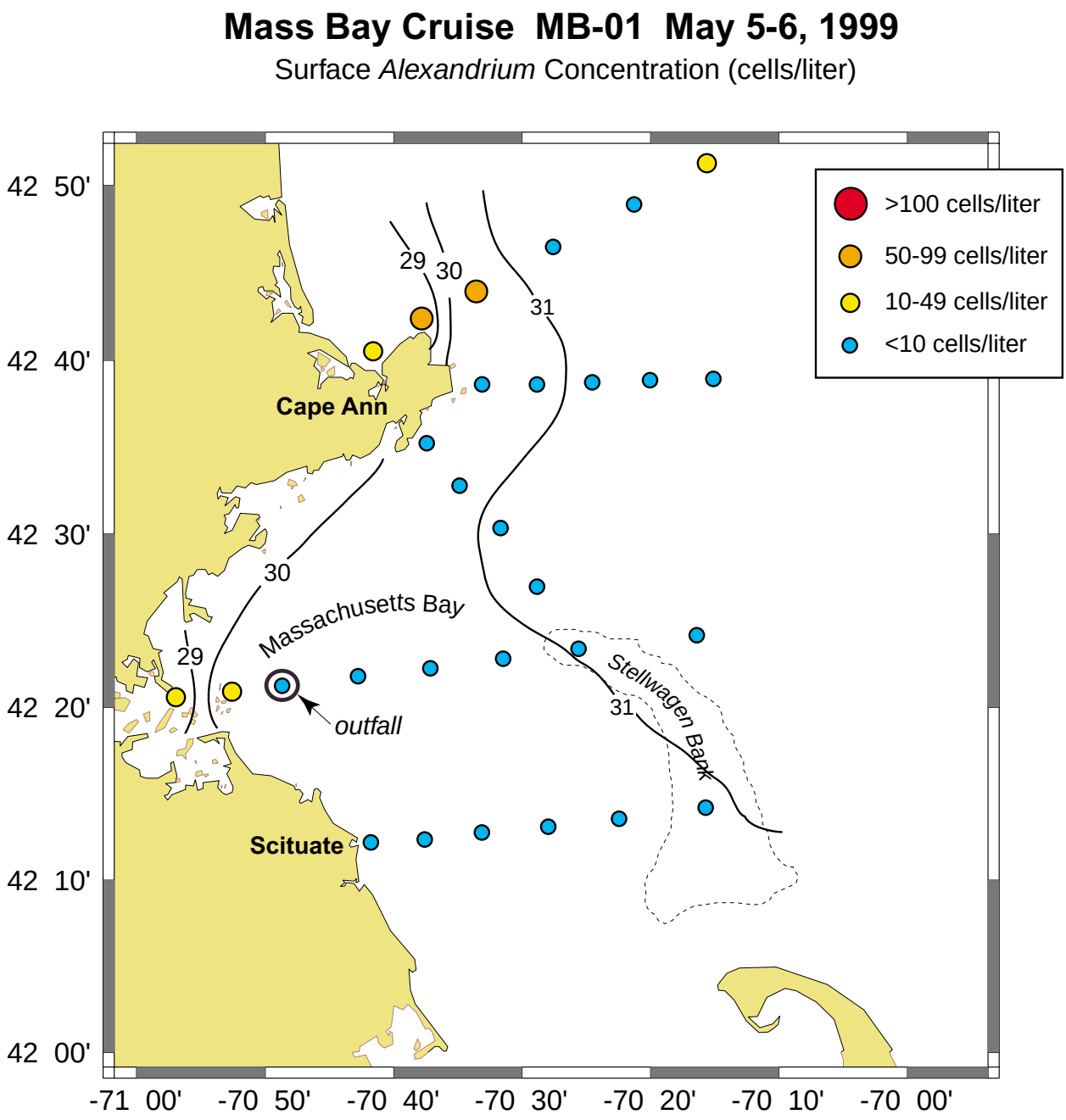

Fig. 2. Salinity and Alexandrium distribution during cruise 1. Cell abundances were low with slightly higher concentrations near frontal boundaries near Cape Ann and Boston Harbor.

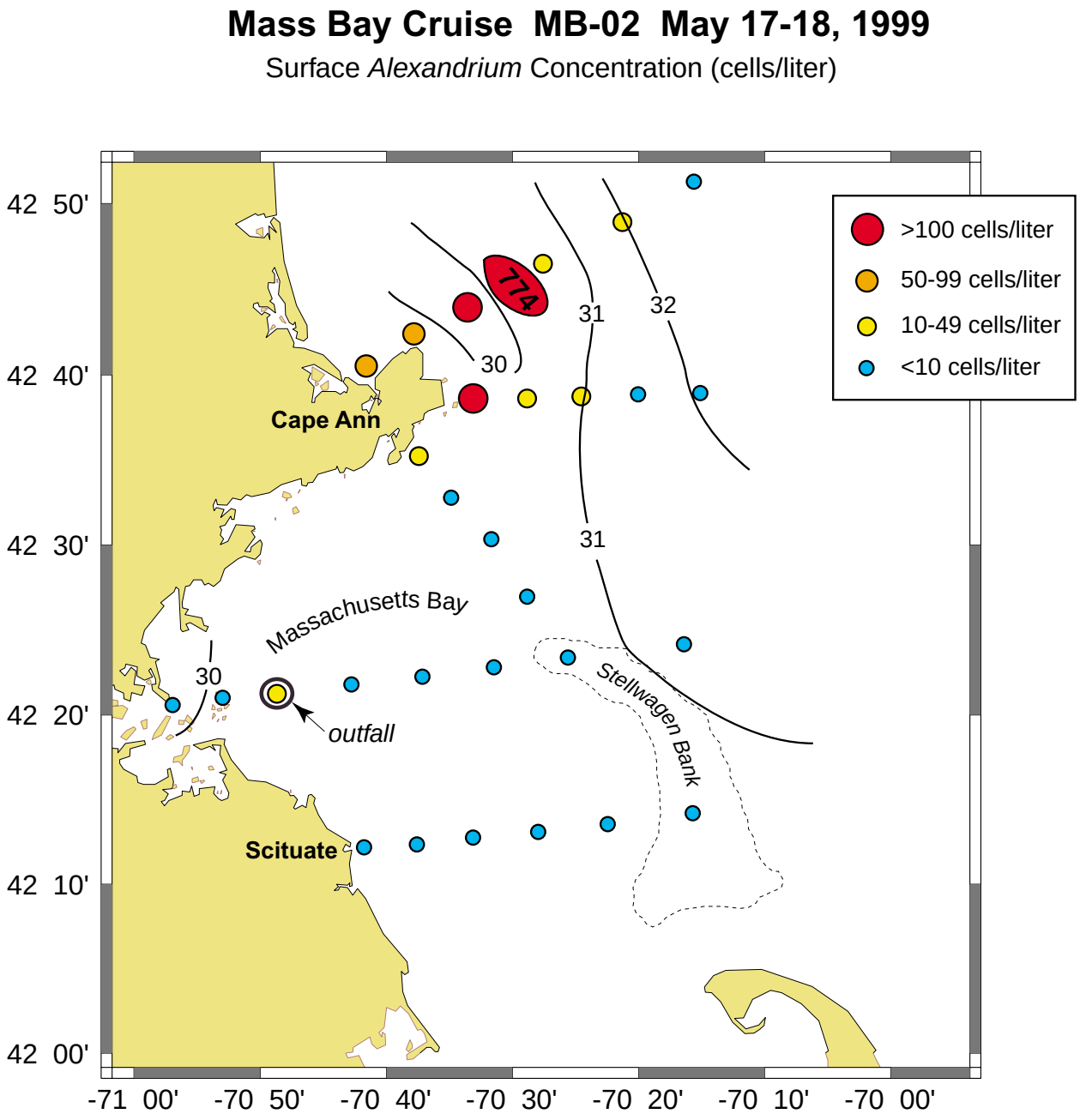

Fig. 3. Salinity and Alexandrium distribution during cruise 2. The highest concentrations of Alexandrium were observed northeast of Cape Ann. One isolated patch of toxic cells was >750 cells/liter.

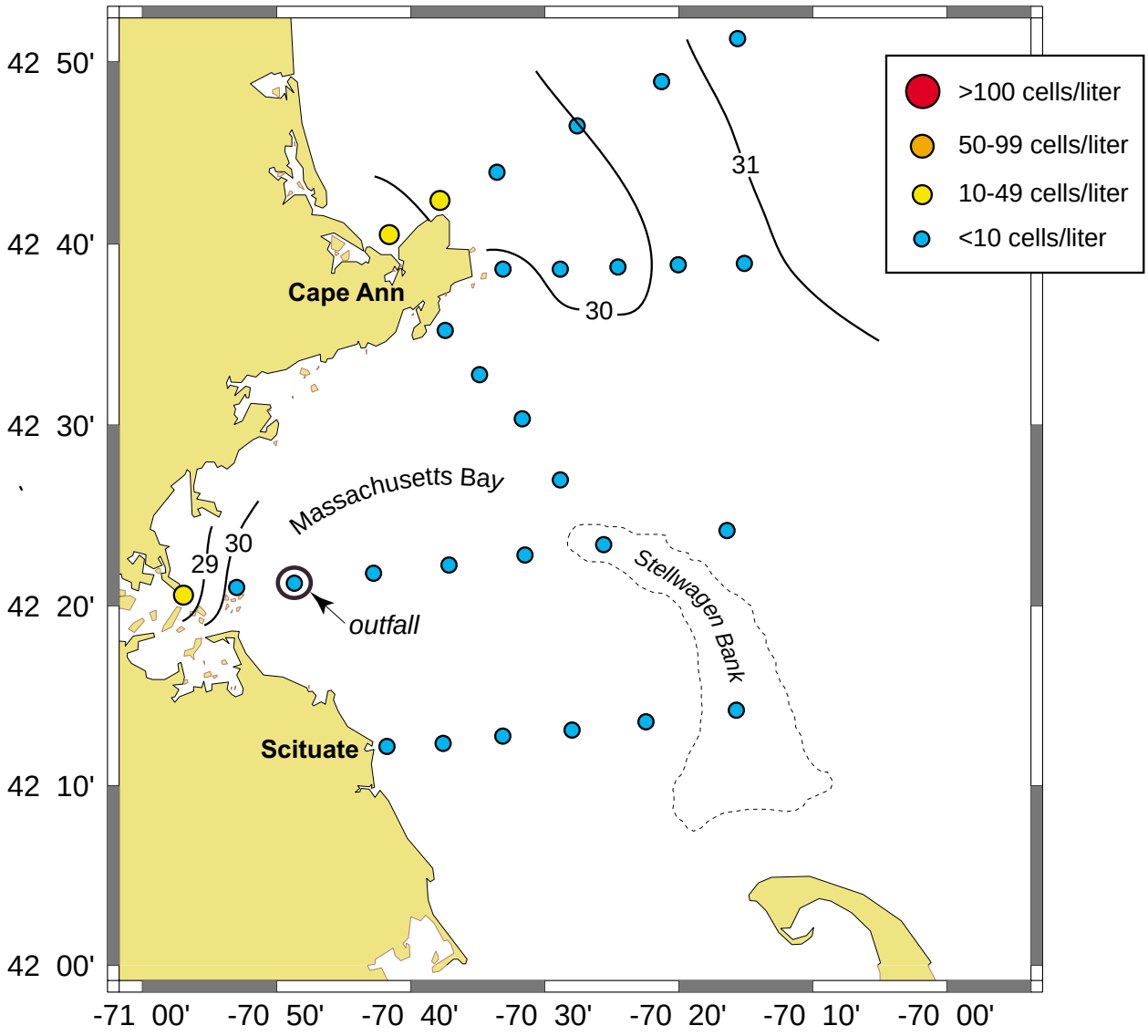

Fig. 4. Salinity and Alexandrium distribution during cruise 3. Very few toxic cells were observed within the study area during this time. The higher Alexandrium populations detected in earlier May near Cape Ann were never detected within Massachusetts Bay.

The highest concentrations of *Alexandrium* were always found just outside the Bay at the northernmost stations near Cape Ann, notably during the second cruise in May (May 17-18), when concentrations at several stations reached slightly more than 100 cells liter^{-1} (Fig. 3; also see Appendix). This concentration was also too low to cause toxicity in shellfish. Coincidentally, a concentration of >750 cells liter $^{-1}$ was detected at an underway surface station along the northernmost transect, indicating that there was a potential for patches of higher cell densities to enter the Bay (Fig. 3). However, higher densities were not observed within the Bay in subsequent cruises. Both shipboard measurements (Fig. 3) and satellite imagery (Fig. 5) indicate that the observed patch was located at the outer frontal boundary of the Merrimack River plume. The toxic cells were likely coming from the northern source waters via the WMCC, and accumulated at the outside edge of the Merrimack plume front along the strong density gradient.

Examination of two vertical profiles of *Alexandrium* along the northernmost transect during cruise 2 revealed that the cells were not only in the surface waters, but were also present at least as deep as 20m at both the offshore station (A1) and a station within the plume (A4). Concentrations underneath the plume at the A4 site were equal to the surface concentration (Fig. 6). This suggests that toxic cells can be transported into Massachusetts Bay both within the surface waters of the WMCC (including the Merrimack River plume) and in colder, more saline layers underneath the plume. The accumulation of cells in the surface waters near the frontal boundary may reflect the behavior of the organism as it swims towards the light while the colder, more saline water is subducted underneath the plume at the convergent front. The origin of the colder, more saline waters may be the Eastern Maine Coastal Current (EMCC) system, known to be rich in *Alexandrium* cells during May and June (unpublished ECOHAB data). This colder feature is commonly observed in AVHRR satellite imagery as far south as Cape Ann and can be seen adjacent to the coast in eastern Maine in Fig. 5.

An alternative explanation for the observed subsurface populations is that some *Alexandrium* cells can vertically migrate when nutrients are depleted in the surface waters. When nutrients are in short supply, the cells may swim to greater depths at night to acquire nutrients, then return to the surface during the day to photosynthesize. However, the nutrient concentrations were not significantly higher at depth when subsurface populations were observed. We did not sample below 20m and thus never reached the peak of the subsurface populations. The subsurface populations that we observed may be an important indication of the organism's nutrient and light behavior or a clue that deeper populations are advected from the north at (or below) the pycnocline.

The Massachusetts Division of Marine Fisheries was notified of our observations since the cell concentration in the patch observed during cruise 2 was sufficient to cause shellfish toxicity. However, the MA DMF shellfish monitoring program did not detect any toxicity within the Bay during the subsequent sampling period, and thus no closures were necessary throughout the spring and summer (Fig. 7). The state of Maine did have a brief shellfish closure in May, but toxicity levels were not high or prolonged. This result is consistent with the generally low *Alexandrium* abundance observed during the period, excepting the one isolated patch. Although a slight amount of shellfish toxicity was detected in Maine in mid-May near the “upstream” source waters, that event was short-lived due to upwelling conditions. Thus, most of the cells were probably transported offshore and never progressed into the “downstream” study area of Massachusetts Bay. Therefore, 1999 can be characterized as a relatively "light" year with respect

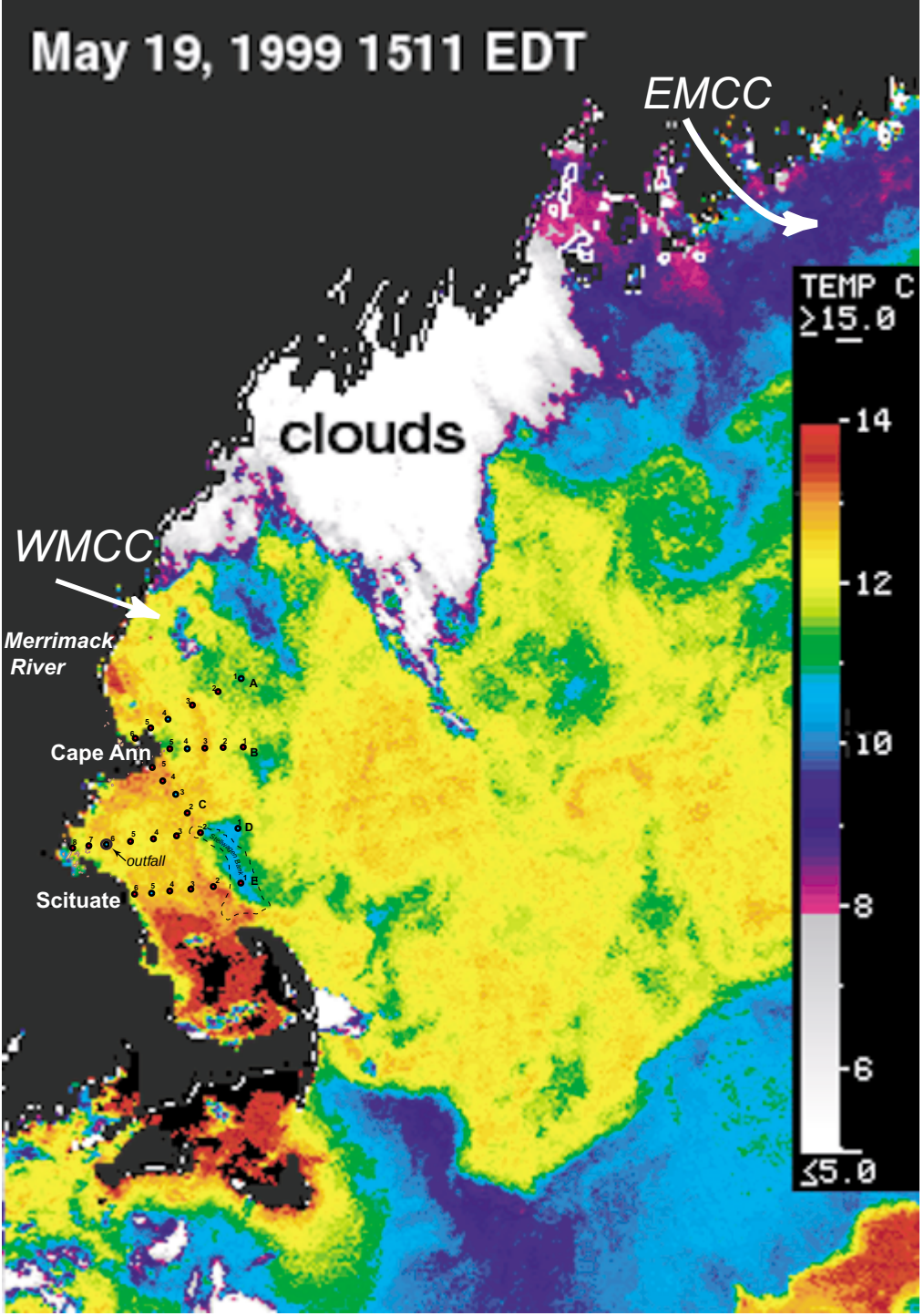

Fig. 5. NOAA Coastwatch image of sea surface temperature acquired 1 day after cruise 2. The highest concentrations of Alexandrium were observed northeast of Cape Ann (Transect A), near the front formed by the warmer waters of the Merrimack River plume.

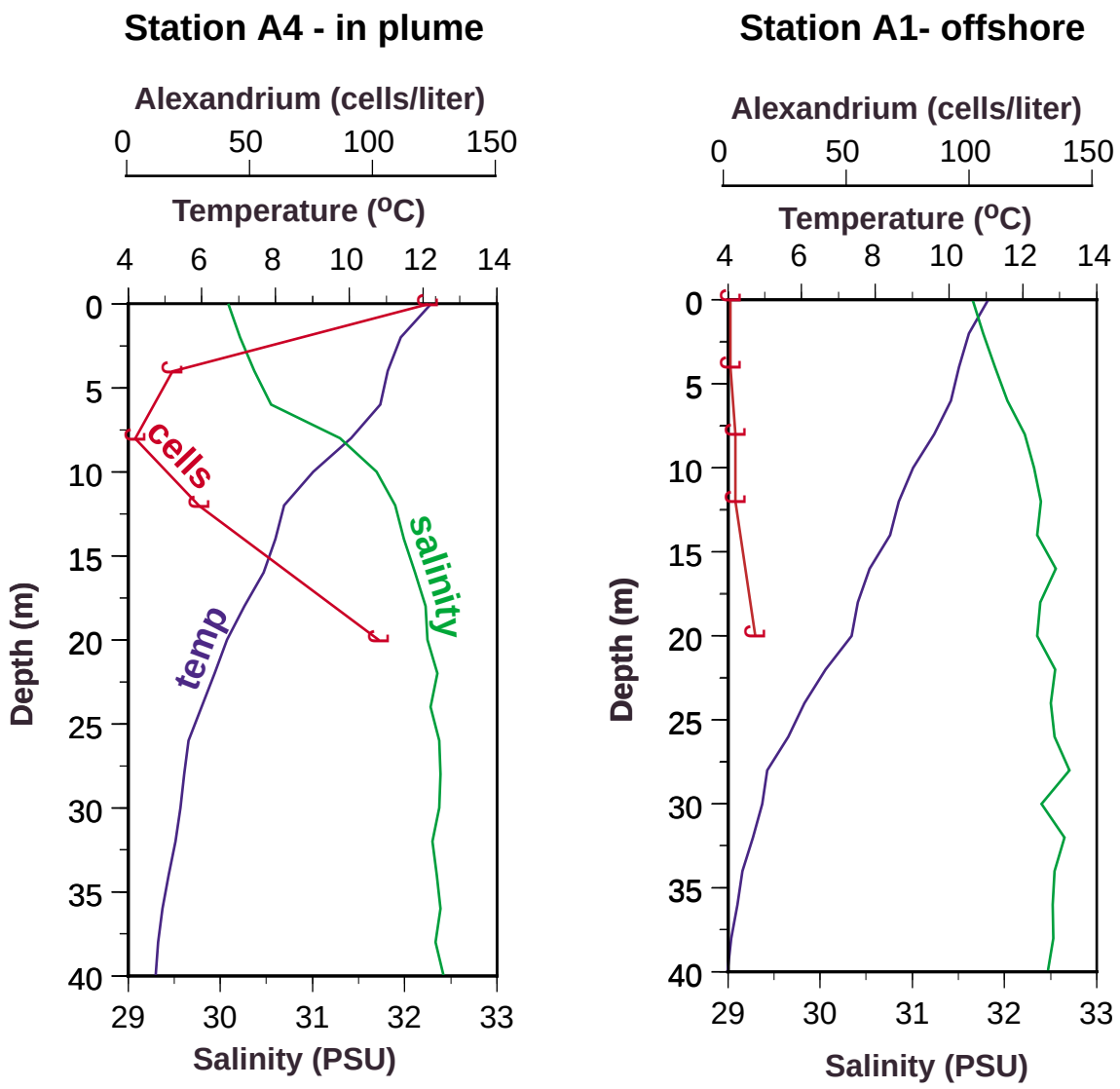

Fig. 6. Vertical distribution of temperature, salinity, and Alexandrium cells at 2 stations along the northernmost transect (Transect A) of the field study. Station A4 (left panel) shows the influence of the Western Maine Coastal Current and/or the Merrimack River on the surface waters. Station A1 (right panel), the outermmost station, shows very little influence. Alexandrium populations were observed in both the warmer, less-saline waters of the surface as well as in the colder, more saline waters.

to shellfish toxicity along the western Gulf of Maine shoreline and a "non-bloom" year in Massachusetts Bay.

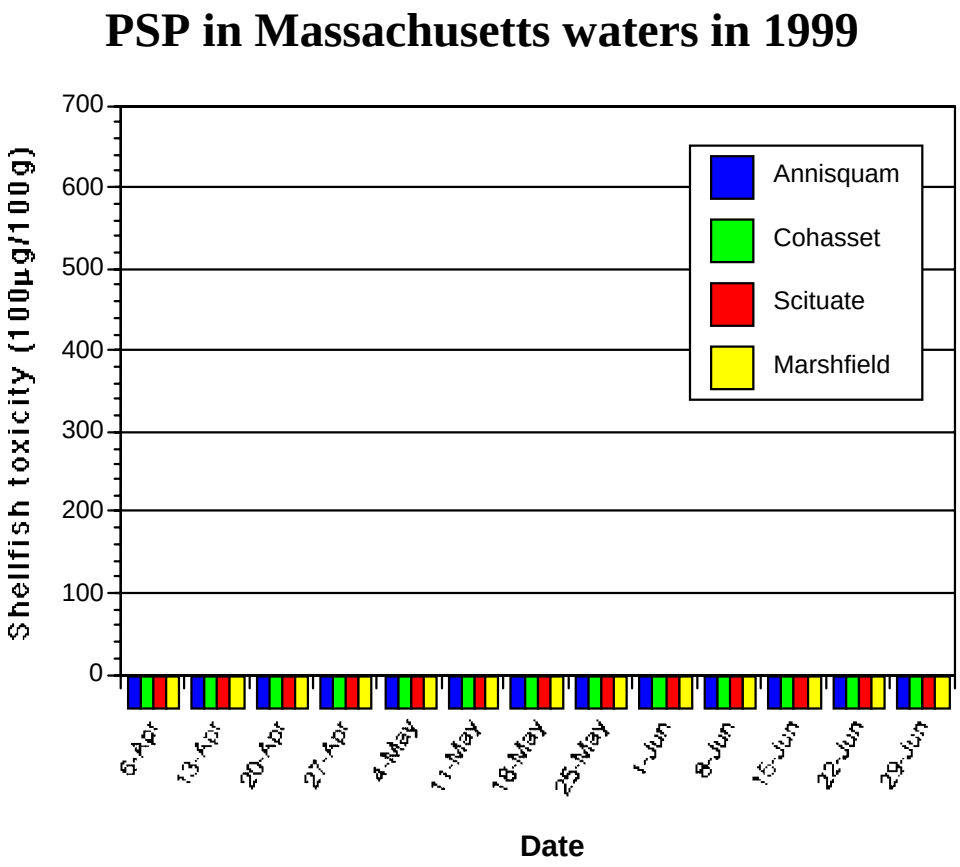

Fig. 7. Shellfish toxicity at four primary monitoring stations in Massachusetts coastal waters for spring 1999. All mouse bioassay measurements using the mussel, *Mytilus edulis*, as the indicator species were below detection in 1999 (i.e. bars shown below zero). (Data supplied by David Whitaker of the Massachusetts Division of Marine Fisheries.)

Samples were also taken from the identical depths where *Alexandrium* was collected and analyzed for inorganic nutrients (see Appendix for values at each station for ammonium, nitrate+nitrite, phosphate, and silicate). Levels of inorganic nutrients were generally higher in or near Boston Harbor than elsewhere. On Cruise 1, ammonium levels were >10 uM at Station D8 near the Deer Island outfall, but elsewhere were mostly 1-3 uM. On Cruise 2, ammonium levels were very high (>50 uM) near the Deer Island outfall (Station D8), but elsewhere were only slightly higher than the first cruise, with values ranging from 1-5 uM. On cruise 3, ammonium levels were also high near the surface (>30 uM) at the Deer Island station (D8) and generally decreased offshore to ambient levels. Levels of nitrate + nitrite were very low, never exceeding 1 uM. Phosphate was also very low (<1 uM), except at the Deer Island outfall where levels were elevated to about 3 uM. Silicates were higher in the Bay (about 10-15 uM), during cruise 1, especially nearshore and decreased during subsequent cruises. This decrease with time likely reflects the utilization of silicates by the dominant spring diatom population.

There was no apparent correspondence between the higher abundance of *Alexandrium* near Cape Ann and the nutrient distribution. During cruise 2, when the *Alexandrium* concentrations were highest, all nutrient concentrations were low. This supports our hypothesis that *Alexandrium* is nutrient-limited within the WMCC, especially later in the spring and further south during transport as the nutrients are stripped from the surface waters by preceding diatom blooms. When the population is resupplied with high nutrients, e.g. near the Deer Island outfall, the cells responded only slightly, if at all, during the period of our observations and did not develop into a significant bloom.

Summary

This project adds to our understanding of the distribution and dynamics of *Alexandrium* in Massachusetts Bay. Generally, the concentrations of *Alexandrium* were low in 1999, only exceeding 100 cells liter^{-1} at a few stations. These levels were not unlike other years when no toxicity was detected (e.g., 1994, 1995, 1996, and 1997). There were two consistent features observed during all 3 cruises in May, 1999 that have also been observed during previous years: higher concentrations of *Alexandrium* near Cape Ann and slightly elevated, but very low concentrations near Boston Harbor and the South Shore, relative to stations in the Bay. These patterns do not appear to be strongly related to the nutrient field, since the highest *Alexandrium* concentrations (only 100 cells liter^{-1}) occurred in low nutrient waters. Furthermore, the high nutrient concentrations observed near Deer Island did not cause significant development of the *Alexandrium* population. Fronts found near Cape Ann and the Boston Harbor entrance are more likely to be responsible for the physical accumulation of cells in these areas. The occurrence of subsurface populations of *Alexandrium* noted at several stations near Cape Ann is a new observation revealed by high resolution vertical sampling. The data suggest that either *Alexandrium* cells were nutrient-limited near their entry point into Massachusetts Bay and migrated into deeper waters to acquire nutrients, or were advected into the Bay in subsurface waters originating offshore and underneath the WMCC. These questions will be addressed in a recently funded Sea Grant/MWRA-funded project planned for 2001 and 2002.

The data collected in 1999 supplement our earlier data sets, yielding a better understanding of the interannual variability of the abundance of the causative organism for PSP outbreaks along the New England coast. Data suggest that low concentrations (<100 cells l^{-1}) of *Alexandrium* are observed in Massachusetts Bay every year even when no shellfish toxicity has been detected in the nearshore shellfish. The bulk of the *Alexandrium* population in the Western GOM is confined to the waters north of Cape Ann during most years, as Cape Ann acts as a natural barrier to the dispersal of cells into the Bay. The larger the population of *Alexandrium* north of Cape Ann, the greater the chance that population and its associated shellfish toxicity has of reaching Massachusetts Bay. The chances are even greater under downwelling conditions that will transport surface water and its associated cells into Massachusetts Bay. Perhaps, more importantly, downwelling may also bring offshore populations, possibly originating as far north as eastern Maine, closer to the shore where they can be concentrated at frontal boundaries such as the those formed by the Kennebec and Merrimack Rivers.

APPENDIX

Table of *Alexandrium* counts and Nutrient Data

- Cruise 1 May 5-6
- Cruise 2 May 17-18
- Cruise 3 May 31-June 1

98-MB-1
Massachusetts Bay Alexandrium Cells and Nutrients 1999
Cruise 1: 5 and 6 May, 1999

			Cells/liter	CONCENTRATION (uM)			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
A	**1**	1	10	2.13	0.11	0.45	0.11
		3.5	5	1.85	0.11	0.45	0.08
		7	4	1.57	0.11	0.19	0.11
		10	6	1.67	0.11	0.19	0.14
		20	1	1.76	0.22	5.75	0.88
A	**2**	1	2	2.04	0.11	3.73	0.14
		3.5	0	1.85	0.14	2.46	0.11
		7	2	1.57	0.14	2.21	0.14
A	**3**	1	4	1.48	0.08	3.22	0.14
		3.5	2	1.57	0.11	2.46	0.14
		7	6	1.39	0.14	0.95	0.08
A	**4**	1	96	1.57	0.14	7.01	0.18
		3.5	50	1.48	0.14	5.75	0.11
		7	35	1.39	0.20	6.00	0.14
		10	21	1.39	0.20	5.49	0.11
		20	16	1.30	0.14	3.47	0.28
A	**5**	1	57	1.85	0.17	15.08	0.28
		3.5	13	2.04	0.11	10.04	0.18
		7	6	2.59	0.08	8.52	0.18
A	**6**	1	20	2.04	0.17	16.09	0.24
		3.5	NA	1.85	0.14	12.81	0.08
		7	NA	1.76	0.14	11.55	0.11
B	**1**	1	0	1.94	0.08	1.24	0.18
		3.5	0	2.50	0.08	0.38	0.14
		7	0	1.94	0.08	0.67	0.14
B	**2**	1	1	2.31	0.11	3.82	0.11
		3.5	0	2.69	0.08	4.39	0.14
		7	0	2.78	0.11	2.67	0.11
B	**3**	1	1	3.24	0.08	3.24	0.14
		3.5	0	3.06	0.17	3.82	0.21
		7	0	2.78	0.11	2.96	0.14
B	**4**	1	9	2.87	0.14	12.12	0.28
		3.5	4	2.87	0.17	7.82	0.24
		7	4	2.87	0.11	6.39	0.24
		10	10	2.78	0.11	4.96	0.21
		20	3	3.24	0.11	1.53	0.21
B	**5**	1	0	3.06	0.08	11.83	0.28

		3.5	1	3.06	0.14	11.55	0.41
		7	1	3.15	0.17	9.83	0.31
C	**1**	1	not sampled				
		3.5					
		7					
C	**2**	1	0	2.13	0.08	10.36	0.31
		3.5	0	1.67	0.08	9.06	0.21
		7	0	1.94	0.11	7.23	0.31
			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
C	**3**	1	0	1.67	0.17	4.36	0.21
		3.5	0	1.67	0.17	5.66	0.28
		7	0	1.57	0.11	5.66	0.24
		10	0	1.39	0.11	5.66	0.21
		20	0	1.67	0.14	6.97	0.21
C	**4**	1	1	1.39	0.20	7.23	0.28
		3.5	1	1.67	0.20	7.23	0.14
		7	0	1.30	0.17	6.71	0.11
C	**5**	1	0	1.57	0.11	13.49	0.28
		3.5	0	1.39	0.11	13.49	0.28
		7	0	1.67	0.14	8.53	0.24
D	**1**	1	0	1.34	0.13	12.83	0.23
		3.5	0	0.76	0.13	8.98	0.20
		7	0	0.67	0.13	7.96	2.46
		10	0	1.34	0.13	6.42	0.29
		20	0	1.43	0.16	7.70	0.29
D	**2**	1	0	1.15	0.13	6.67	0.23
		3.5	0	1.24	0.16	6.67	0.23
		7	0	1.24	0.16	9.50	0.32
D	**3**	1	2	0.96	0.13	13.34	0.20
		3.5	0	0.76	0.10	12.83	0.17
		7	NA	0.57	0.10	8.98	0.20
D	**4**	1	1	1.05	0.10	11.55	0.20
		3.5	NA	1.15	0.13	12.06	0.23
		7	NA	0.86	0.13	10.26	0.26
D	**5**	1	0	0.67	0.13	12.83	0.14
		3.5	NA	1.05	0.10	11.55	0.14
		7	NA	0.96	0.16	10.26	0.14
D	**6**	1	0	1.72	0.16	12.83	0.20
		3.5	0	1.24	0.13	13.09	0.17
		7	0	1.15	0.13	12.83	0.14
		10	0	1.24	0.16	13.09	0.14
		20	2	1.15	0.13	11.80	0.20
D	**7**	1	16	4.59	0.20	6.67	0.53
		3.5	NA	1.91	0.13	6.67	0.26
		7	NA	1.15	0.16	8.47	0.17

D	**8**	1	12	13.38	0.29	20.53	2.95
		3.5	NA	10.99	0.16	8.47	1.59
		7	NA	8.13	0.16	8.47	0.98
E	**1**	1	0	2.15	0.16	10.01	0.26
		3.5	NA	2.24	0.09	11.55	0.34
		7	NA	2.15	0.09	9.75	0.30
E	**2**	1	2	2.15	0.13	12.57	0.30
		3.5	NA	2.91	0.16	12.32	0.30
		7	NA	2.05	0.16	12.32	0.34
E	**3**	1	0	1.86	0.09	12.83	0.30
		3.5	NA	1.96	0.13	12.83	0.30
		7	NA	1.96	0.09	13.60	0.34

			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
E	**4**	1	0	1.86	0.09	13.60	0.26
		3.5	NA	1.86	0.09	13.60	0.26
		7	NA	1.86	0.09	13.60	0.26
E	**5**	1	0	1.86	0.09	16.94	0.30
		3.5	0	1.76	0.09	16.94	0.30
		7	0	1.76	0.13	16.68	0.30
		10	0	1.86	0.13	15.91	0.26
		20	0	2.15	0.13	15.40	0.45
E	**6**	1	6	1.96	0.23	9.75	0.60
		3.5	NA	1.96	0.27	9.75	0.60
		7	NA	1.76	0.27	12.83	0.45

98-MB-2
Massachusetts Bay Nutrients
Cruise 2: 17and 18 May, 1999

			Cells/liter	CONCENTRATION (uM)			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
A	**1**	1	1	2.72	0.20	0.86	0.15
		3.5	1	3.04	0.20	0.86	0.12
		7	3	2.83	0.18	3.43	0.21
		10	3	2.28	0.18	2.00	0.18
		20	11	3.80	0.22	0.86	0.15
A	**2**	1	15	2.72	0.14	0.86	0.12
		3.5	2	1.96	0.16	1.43	0.15
		7	2	2.07	0.16	0.86	0.15
A	**3**	1	42	1.74	0.16	0.86	0.09
		3.5	8	1.41	0.14	0.86	0.18
		7	5	1.74	0.14	0.86	0.12
A	**4**	1	122	1.74	0.18	2.00	0.09
		3.5	18	1.85	0.16	2.00	0.12
		7	3	2.07	0.16	2.58	0.24
		10	29	2.39	0.16	1.43	0.21
		20	102	2.50	0.20	1.43	0.27
A	**5**	1	83	1.74	0.16	0.86	0.06
		3.5	10	1.52	0.16	0.86	0.09
		7	18	1.85	0.14	0.86	0.15
A	**6**	1	77	1.63	0.18	1.14	0.15
		3.5	26	1.63	0.16	0.86	0.15
		7	45	2.17	0.16	0.86	0.21
B	**1**	1	0	3.04	0.20	2.62	0.39
		3.5	0	2.72	0.18	1.31	0.35
		7	0	3.37	0.18	1.05	0.24
B	**2**	1	0	3.37	0.18	1.31	0.32
		3.5	0	3.59	0.16	1.05	0.24
		7	0	3.59	0.18	0.79	0.24
B	**3**	1	14	2.83	0.16	0.79	0.13
		3.5	0	3.59	0.22	1.31	0.13
		7	5	3.59	0.22	4.72	0.35
B	**4**	1	21	3.59	0.31	2.36	0.24
		3.5	2	3.37	0.18	1.57	0.05
		7	7	3.37	0.18	1.57	0.09
		10	11	3.26	0.18	1.31	0.09
		20	48	4.57	0.16	1.05	0.17
B	**5**	1	122	1.96	0.20	0.79	0.09
		3.5	NA	2.50	0.20	2.36	0.20
		7	33	5.54	0.20	1.83	0.24

C	**1**	1	2	4.87	0.16	1.34	0.21
		3.5	0	6.69	0.24	2.15	0.27
		7	4	5.51	0.26	4.29	0.39
C	**2**	1	5	4.60	0.24	0.81	0.15
		3.5	1	5.33	0.24	1.34	0.33
		7	1	4.60	0.24	0.81	0.18
			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
C	**3**	1	1	3.96	0.19	1.07	0.15
		3.5	2	3.68	0.19	0.81	0.12
		7	2	4.14	0.21	0.81	0.15
		10	3	5.23	0.24	3.49	0.51
		20	30	4.14	0.21	6.17	0.60
C	**4**	1	1	3.78	0.19	0.81	0.18
		3.5	2	3.78	0.26	0.81	0.15
		7	6	3.78	0.21	0.81	0.15
C	**5**	1	15	4.41	0.24	0.81	0.18
		3.5	7	4.41	0.26	0.81	0.21
		7	11	4.87	0.26	1.61	0.30
D	**1**	1	0	2.61	0.14	3.85	0.35
		3.5	0	2.03	0.14	5.88	0.44
		7	0	4.70	0.14	3.45	0.29
		10	0	2.61	0.18	4.66	0.44
		20	0	2.61	0.22	10.34	0.88
D	**2**	1	6	1.78	0.16	0.61	0.29
		3.5	1	1.86	0.18	3.45	0.32
		7	1	1.86	0.18	1.82	0.29
D	**3**	1	3	2.28	0.16	1.62	0.24
		3.5	2	2.44	0.18	1.62	0.26
		7	0	2.11	0.11	2.43	0.24
D	**4**	1	1	2.03	0.11	3.04	0.26
		3.5	1	2.03	0.11	2.43	0.26
		7	2	1.69	0.14	1.42	0.26
D	**5**	1	NA	1.61	0.12	1.62	0.29
		3.5	0	1.86	0.18	1.62	0.38
		7	1	1.61	0.16	0.81	0.26
D	**6**	1	11	1.36	0.16	0.41	0.15
		3.5	7	2.03	0.16	0.81	0.15
		7	4	3.03	0.22	1.22	0.15
		10	4	1.69	0.17	0.61	0.26
		20	1	2.28	0.18	13.18	0.88
D	**7**	1	4	4.78	0.18	2.43	0.62
		3.5	7	4.36	0.18	2.43	0.53
		7	7	4.28	0.22	2.03	0.53
D	**8**	1	8	56.13	0.32	12.16	2.97
		3.5	5	24.22	0.26	6.49	2.64

		7	0	6.53	0.26	4.05	1.76
E	**1**	1	5	5.11	0.11	2.57	0.45
		3.5	1	2.61	0.11	6.18	0.56
		7	2	2.44	0.15	10.29	0.82
E	**2**	1	1	2.69	0.16	2.06	0.37
		3.5	0	2.11	0.18	2.06	0.37
		7	0	2.44	0.18	1.29	0.37
E	**3**	1	0	2.28	0.20	1.03	0.22
		3.5	0	2.44	0.18	0.77	0.15
		7	3	2.61	0.20	1.29	0.22

			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
E	**4**	1	1	3.00	0.47	0.51	0.17
		3.5	3	2.00	0.32	1.29	0.19
		7	3	2.40	0.38	1.03	0.21
E	**5**	1	5	2.40	0.38	2.32	0.26
		3.5	0	2.40	0.38	1.80	0.26
		7	0	1.60	0.25	1.80	0.26
		10	2	3.00	0.47	1.80	0.26
		20	0	3.00	0.47	1.29	0.34
E	**6**	1	6	2.40	0.38	5.66	0.37
		3.5	1	3.00	0.47	12.87	0.82
		7	1	3.00	0.47	3.09	0.49

98-MB-3
Massachusetts Bay Nutrients
Cruise 3: 31 May and 1 June, 1999

			Cells/liter	CONCENTRATION (uM)			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
A	**1**	1	0	1.32	0.09	1.08	0.52
		3.5	0	1.76	0.09	1.08	0.29
		7	0	1.03	0.09	1.08	0.29
		10	0	2.06	0.09	1.29	0.29
		20	0	2.21	0.09	1.51	0.29
A	**2**	1	1	1.62	0.08	1.08	0.19
		3.5	0	2.50	0.08	0.43	0.19
		7	0	1.47	0.08	0.43	0.23
A	**3**	1	1	1.91	0.09	5.17	0.13
		3.5	0	2.06	0.09	4.52	0.16
		7	0	1.76	0.11	0.86	0.19
A	**4**	1	0	2.50	0.09	5.82	0.13
		3.5	0	2.50	0.09	2.58	0.10
		7	0	3.68	0.11	2.37	0.19
		10	0	2.79	0.09	0.65	0.26
		20	0	3.24	0.09	0.86	0.48
A	**5**	1	16	3.97	0.09	4.74	0.19
		3.5	2	2.94	0.08	3.23	0.19
		7	3	2.94	0.09	4.09	0.32
A	**6**	1	32	2.50	0.11	6.46	0.26
		3.5	7	3.24	0.12	5.82	0.29
		7	8	3.24	0.12	4.09	0.39
B	**1**	1	0	3.17	0.09	0.67	0.29
		3.5	0	2.83	0.09	0.45	0.29
		7	0	3.28	0.09	1.12	0.32
B	**2**	1	0	1.94	0.09	2.02	0.26
		3.5	0	1.94	0.12	0.90	0.29
		7	0	1.94	0.12	0.90	0.29
B	**3**	1	0	1.38	0.10	4.71	0.19
		3.5	0	2.28	0.12	4.03	0.19
		7	0	2.28	0.12	1.57	0.23
B	**4**	1	0	1.27	0.10	2.69	0.19
		3.5	0	2.28	0.12	2.91	0.16
		7	0	2.05	0.12	1.79	0.26
		10	0	1.72	0.10	0.90	0.26
		20	0	2.83	0.19	0.90	0.48
B	**5**	1	4	2.05	0.09	2.24	0.26
		3.5	0	2.16	0.12	1.34	0.26
		7	0	2.61	0.10	1.57	0.42

C	**1**	1	1	1.49	0.12	0.85	0.09
		3.5	0	2.28	0.10	0.64	0.06
		7	0	1.83	0.10	1.06	0.09
C	**2**	1	0	1.72	0.09	2.98	0.14
		3.5	0	1.94	0.09	1.91	0.14
		7	NA	1.94	0.09	0.85	0.14
			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
C	**3**	1	0	1.16	0.09	0.85	0.09
		3.5	0	2.28	0.10	0.85	0.14
		7	0	1.72	0.10	1.49	0.14
		10	0	2.05	0.12	1.49	0.17
		20	0	0.60	0.12	1.49	0.46
C	**4**	1	0	1.05	0.10	1.70	0.12
		3.5	0	1.05	0.12	2.34	0.12
		7	0	1.16	0.12	1.70	0.12
C	**5**	1	1	1.49	0.10	1.70	0.09
		3.5	0	1.49	0.10	1.49	0.14
		7	0	1.72	0.14	3.19	0.32
D	**1**	1	0	1.30	0.22	0.79	0.12
		3.5	0	1.01	0.16	0.79	0.09
		7	0	1.01	0.13	2.37	0.18
		10	0	1.15	0.10	1.05	0.24
		20	0	1.30	0.10	2.37	0.36
D	**2**	1	0	1.15	0.16	1.05	0.06
		3.5	N/A	1.30	0.13	1.05	0.09
		7	0	1.44	0.13	1.05	0.12
D	**3**	1	0	1.73	0.19	2.10	0.09
		3.5	0	1.15	0.16	2.10	0.09
		7	0	1.73	0.19	1.31	0.06
D	**4**	1	0	2.16	0.22	1.05	0.06
		3.5	0	3.30	0.13	1.05	0.09
		7	0	4.02	0.16	1.05	0.06
D	**5**	1	3	4.02	0.16	0.79	0.06
		3.5	2	3.88	0.19	0.79	0.06
		7	0	3.45	0.22	1.05	0.24
D	**6**	1	6	2.87	0.16	0.79	0.12
		3.5	11	2.87	0.19	0.79	0.09
		7	1	3.02	0.16	0.79	0.12
		10	1	3.16	0.16	1.31	0.18
		20	0	6.89	0.16	11.83	0.98
D	**7**	1	5	5.46	0.16	2.63	0.33
		3.5	4	5.74	0.19	3.42	0.36
		7	1	3.73	0.16	6.31	0.51
D	**8**	1	10	33.55	0.19	23.65	3.33
		3.5	5	13.46	0.25	9.72	1.93

		7	3	8.76	0.25	6.31	1.04
E	**1**	1	2	1.58	0.13	0.79	0.15
		3.5	0	1.58	0.10	1.05	0.15
		7	0	1.44	0.10	1.05	0.12
E	**2**	1	5	0.87	0.10	1.84	0.12
		3.5	0	1.01	0.13	2.37	0.12
		7	1	1.01	0.16	1.31	0.12
E	**3**	1	0	0.87	0.10	1.05	0.12
		3.5	0	1.01	0.13	0.79	0.18
		7	0	1.15	0.13	1.05	0.15

			Cells/liter	**CONCENTRATION (uM)**			
LINE	**STATION**	**DEPTH (m)**	**Alexandrium**	**NH4**	**NO3/NO2**	**SiO2**	**PO4**
E	**4**	1	0	0.87	0.16	0.79	0.12
		3.5	0	1.44	0.16	0.79	0.21
		7	0	1.44	0.13	1.84	0.21
E	**5**	1	8	1.15	0.13	1.84	0.12
		3.5	3	1.15	0.10	2.37	0.09
		7	2	1.58	0.13	1.84	0.15
		10	0	1.58	0.13	1.05	0.18
		20	0	1.44	0.13	1.84	0.33
E	**6**	1	9	1.73	0.13	6.31	0.33
		3.5	NA	2.59	0.13	6.57	0.33
		7	NA	2.59	0.16	11.30	0.56

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