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Late Spring and Summer Phytoplankton Community Dynamics on Georges Bank with Emphasis on Diatoms, Alexandrium SPP., and other Dinoflagellates

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LATE SPRING AND SUMMER PHYTOPLANKTON COMMUNITY DYNAMICS ON GEORGES BANK WITH EMPHASIS ON DIATOMS, *ALEXANDRIUM* SPP., AND OTHER DINOFLAGELLATES.

By

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An Abstract of the Thesis Presented
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Georges Bank is a highly productive continental shelf system in the Northwest Atlantic that has historically supported a rich fishery. Part of that productivity stems from annual spring diatom bloom, which is followed by post-bloom populations of flagellates, including the toxic dinoflagellate *Alexandrium* spp., responsible for paralytic shellfish poisoning. While the general oceanography of Georges Bank has been well studied, far less is known about phytoplankton community dynamics or even basic species distributions and abundance. This thesis is driven in part by the possible competitive interactions among species of phytoplankton which are thought to influence *Alexandrium* blooms on the Bank.

I examined the distribution, abundance, and succession patterns of the major species groups of diatoms, dinoflagellates, and nanoplankton on Georges Bank from late spring through summer 2008 (late April, May and June). Those results were related to dissolved inorganic nutrients, total and size-fractioned chlorophyll concentrations, and hydrography (temperature and salinity). The late April phytoplankton community was

predominantly diatoms, mainly *Skeletonema* spp., *Thalassiosira* spp., *Coscinodiscus* spp., and *Chaetoceros* spp. with cell densities of > 200,000 cells L^{-1}; reduced nutrient concentrations over most of the Bank, except the northern portions, indicated that this marked the end of the spring bloom. Lower nitrate (and silicate) concentrations in May, and patches of slightly elevated ammonium, were supporting a dinoflagellate population with high cell densities of *Alexandrium* spp. (up to 13,000 cells L^{-1}). Diatom cell densities were fewer than 40,000 cells L^{-1} and did not overlap spatially with the high cell densities of *Alexandrium* spp. Localized patches of elevated silicate (from regeneration) observed in late May cruise appeared to support a post-bloom, summer diatom community (> 180,000 cells L^{-1}), of species of *Leptocylindrus* spp., *Dactyliosolen* spp., and *Guinardia flaccida.* Continued reduction of nutrient concentrations in late June was accompanied by a shift in the phytoplankton community. The *Alexandrium* cell densities had dropped by late June, and species of heterotrophic and mixotrophic dinoflagellates, notably *Polykrikos* spp., *Gyrodinium* spp., *Gymnodinium* spp., and *Prorocentrum* spp. increased in abundance. Ingested cells were visible in the preserved samples of *Gyrodinium* spp. and *Polykrikos* spp. from late June, suggesting an interaction between the heterotrophic component of the phytoplankton community and the declining *Alexandrium* spp. bloom.

Multivariate statistical analyses of phytoplankton groups and sampling stations revealed distinct groupings of diatom and dinoflagellate taxa based on similarities in abundance and distribution on Georges Bank, throughout the late spring and summer, which could often be linked to particular oceanographic processes. Spatial and temporal trends with respect to these statistical groups suggest that interesting succession patterns

exist in the phytoplankton community on Georges Bank and may be the result of biological interactions between and among the major groups (i.e. diatoms and dinoflagellates).

Preliminary laboratory experiments using *Alexandrium fundyense* and the diatom *Ditylum brightwellii* suggested a competitive interaction between diatoms and dinoflagellates, which argues for further study.

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1. INTRODUCTION

Georges Bank is one of the most well known features of the northwest Atlantic continental shelf region. The Bank supports a rich fishery that is fueled by high rates of primary productivity, of particular importance is the pronounce winter-spring phytoplankton bloom. Additionally, Georges Bank, like the Gulf of Maine, is home to annual harmful algal blooms (HABs) of the genus *Alexandrium* spp. that occur during the late spring and summer months. Georges Bank is thus an important region to study, not only from a scientific perspective, but also from a social and economic standpoint.

The unique oceanographic properties of Georges Bank have been well studied as far back as the 1920's, when Bigelow (1927) first described the general circulation patterns on the Bank. A large portion of our present knowledge of the oceanography of Georges Bank comes as a result of an intensive series of studies (the GLOBEC program [Global Ecosystem Dynamics]), dedicated to better understanding the Bank's physical and biological oceanography (Townesned et al., 2006). As a result, Georges Bank is well described from physical and chemical perspectives; however, aside from chlorophyll measurements and patchy cell count data (prior to the 1950's), the biology of Georges Bank, with respect to primary producers, is poorly understood. Recent studies (Kemper, 2000; Townsend and Thomas, 2002) have identified general abundance and distribution patterns of some of the major phytoplankton functional groups (i.e., diatoms, dinoflagellates, and nanoplankton), however little is known about what particular species are present on Georges Bank throughout the spring and summer months, their abundance and distribution on the Bank, and the successional patterns of the major taxa. Ironically,

the focus of many of the studies in the Northwest Atlantic is on the toxic dinoflagellate *Alexandrium* spp. that can have dramatic impacts on the shellfish industry and public health. However, very little effort is directed at studying biological interactions and community dynamics in the phytoplankton, which may affect the timing and distribution of these annual *Alexandrium* blooms.

Although Georges Bank is well-studied oceanographically, our knowledge on phytoplankton community dynamics beyond chlorophyll concentration and distribution is severly lacking. This study is one of the first attempts to study the distribution, abundance, and successional patterns of the major phytoplankton taxa on Georges Bank from the late spring to summer months. In addition to providing some of the first comprehensive species lists of Georges Bank, this study also attempts to relate changes in the phytoplankton community (i.e. shifts in abundance and distribution) to the oceanography of the region, and to explain changes in the phytoplankton community from a competitive interaction perspective.

2. BACKGROUND

2.1. Georges Bank and the annual spring diatom bloom

Georges Bank, a shallow, but large submarine feature located in the Gulf of Maine (Fig. 2.1), spans approximately 150km by 200km, with an area of some 3400km^2 that is shallower than 100m deep. Georges Bank is known as one of the most productive continental shelf regions in the world ocean, with primary production rates exceeding 400 g C $m^{-2}y^{-1}$ (Backus, 1987 and O'Reilly, 1987). The dominant physical process at work on the bank is the strong tidal currents, which are especially important in the shallow central region, generating a well mixed water column throughout most of the year and helping to force an anti-cyclonic flow around the bank, first described by Bigelow (1927). Biological productivity is sustained throughout much of the year as a result of: 1. The bank's shallow depth, which facilitates phytoplankton growth without significant light limitation; 2. Nutrient-rich, deep waters that surround the bank and are readily available for mixing onto the bank; and 3. Strong tidal mixing and residual currents that allow upwelled nutrients to enter and drive biological productivity (Townsend et al., 2006).

Phytoplankton bloom conditions on Georges Bank become established in late fall-early winter, when upwelled nutrients accumulate during a time of slow phytoplankton growth due to light limitation. The annual diatom spring bloom can begin as early as January when nutrient levels are high, temperatures cool, tidal mixing fronts are

weakened, and the critical depth exceeds the water column depth (Townsend and Pettigrew, 1997; Townsend and Thomas, 2001; and Hu et al., 2008). Continual nutrient input to the system throughout the year maintains high rates of primary productivity across the shallow bank ecosystem and facilitates efficient transfer to higher trophic levels, including zooplankton and commercially exploited fish species (Townsend and Pettigrew, 1997). Strong frontal mixing and nutrient injections are especially important along the northern edge of the bank, which is often where the highest nutrient levels (in excess of 6 uM) are observed (Townsend and Thomas, 2002; Hu et al. 2008). This led Townsend et al. (2006) to propose the "donut" hypothesis of phytoplankton production, whereby greater nutrient flux to the northern flank generates high phytoplankton cell densities on the Northeast Peak, which are advected in a clockwise (anti-cyclonic) direction around the bank, resulting in increased secondary production on the southern half of the bank. High nutrient concentrations are delivered to the offshore Gulf of Maine and Georges Bank by slope waters from offshore, which historically have had lower silicate relative to nitrate, likely resulting in elevated N:Si ratios. While accounting for nearly 70% of primary productivity along the edges of the bank, nitrate fluxes via nutrient rich deep slope waters do not appear to be enough to support the relatively high productivity rates across the central portion of Georges Bank, therefore suggesting that recycled nitrogen in the form of ammonium supports about 80-90% of primary production across the central crest of the bank (Townsend and Pettigrew, 1997). Satellite images have confirmed this limited exchange of newly upwelled nutrient rich waters with the shallow central waters of Georges Bank (Townsend et al., 2006).

Although detailed studies on phytoplankton community dynamics on Georges Bank is lacking, a general successional pattern from spring-bloom diatoms to a community dominated by dinoflagellates has been observed (Backus, 1987; Townsend and Thomas, 2002). Sudies on diatom bloom formation and species succession in other regions have demonstrated that regardless of season and environmental variability, diatoms dominate the phytoplankton community as long as silicate remains in excess of 2 μM (Egge and Aksnes, 1992). This can most likely be attributed to the high growth rates of diatom species at non-limiting silicate concentrations, with growth rates often on the order of 5-50% higher than flagellate groups (Egge and Aksnes, 1992). Because the spring bloom on Georges Bank is composed primarily of diatoms, which take up nitrate and silicate in nearly equal proportions, silicate ultimately becomes limiting first and can lead to the decline and demise of the bloom as early as February, when silica concentrations begin to approach 2-4 μM, consistent with diatom half-saturation constants in the literature (Townsend et al., 2006). The excess nitrate in the system plays a key role in determining subsequent phytoplankton community composition, and tends to favor a post-bloom shift to dinoflagellates once silicate is depleted. For the remainder of the year, recycled nitrogen fuels primary production which causes dinoflagellate and microflagellate species to dominate the phytoplankton. One species of particular importance is toxic dinoflagellates belonging to *Alexandrium* spp. (Cura, 1987 and Kemper, 2000).

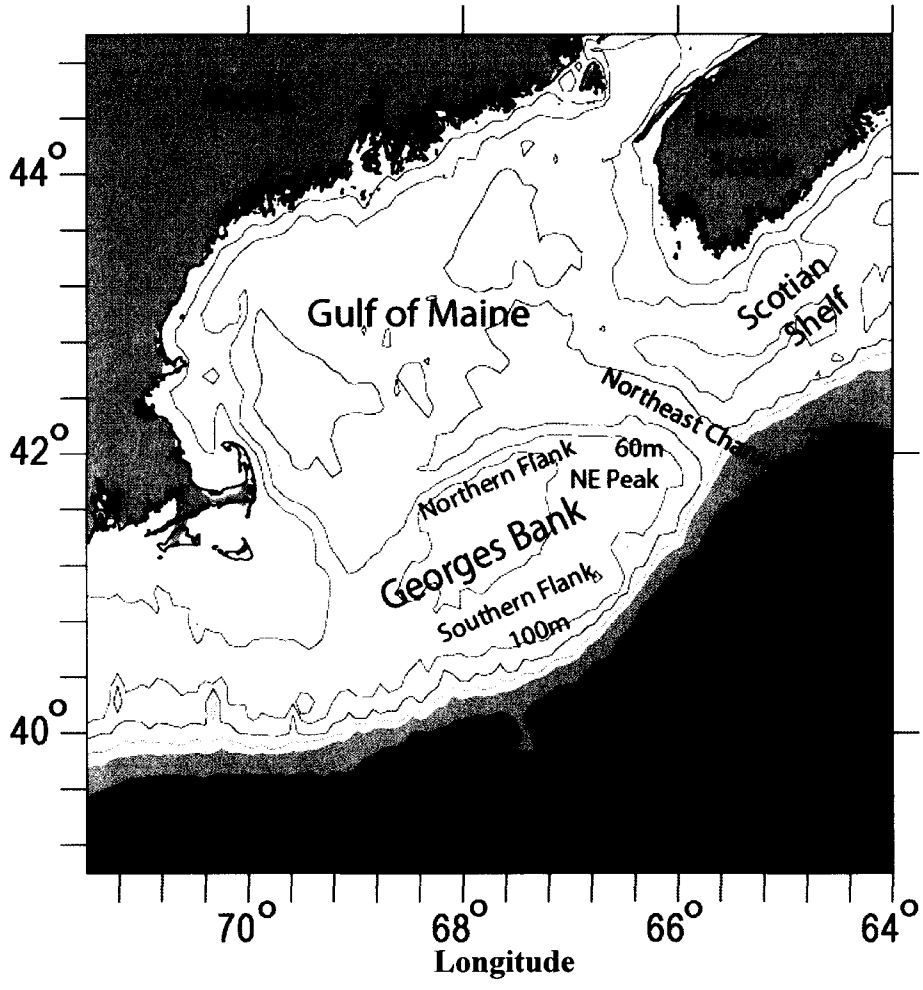

Figure 2.1. Map of the Georges Bank region.

2.2. The post-spring *Alexandrium* bloom

Alexandrium spp. are a harmful algal bloom (HAB) species responsible for Paralytic Shellfish Poisoning (PSP) outbreaks that occur on an annual basis in the Gulf of Maine and on Georges Bank (Anderson, 1997). Three toxic species of *Alexandrium* have been observed in the Northwest Atlantic: *Alexandrium tamarense*, *Alexandrium fundyense*, and *Alexandrium ostenfeldii*; the former two are considered to be different strains of the same species (Anderson, 1997; Gribble et al., 2005) and are hereafter referred to as *A. fundyense*, or just *Alexandrium*. This toxic dinoflagellate produces

potent neurotoxins known as saxitoxins, which accumulate in many filter feeding organisms and can be transferred to higher trophic levels. The toxin is effective at blocking sodium channels in marine animals and humans, resulting in severe illness and ultimately death if not immediately treated (Anderson, 1997; and Wyatt and Jenkinson, 1997). Surveys carried out in the late 1980s and early 1990's indicated an increase in these toxins on Georges Bank, reaching high enough levels in 1990 to poison eight fishermen who consumed toxic by-catch (Anderson, 1997). Due to the serious public health threat that exists each bloom season, significant research efforts have been dedicated to gaining a better understanding of bloom dynamics in the Northeast, including Georges Bank, as well as a greater knowledge about the causative organism itself.

Alexandrium spp. forms blooms each year following the spring diatom bloom in the Gulf of Maine and on Georges Bank. While at least three toxic strains of *Alexandrium* spp. have occur in the Northeast, in general, the taxonomy of *Alexandrium* spp. remains unresolved, with as many as ten toxic species described (Balech, 1995). *Alexandrium* spp. appears to have extended its range to many different regions in the United States and around the world, from the tropics to high latitudes in both hemispheres (Wyatt and Jenkinson, 1997). This armored dinoflagellate exhibits a complex life history, making the study and identification of the organism a challenge, and prompting Wyatt and Jenkinson (1997) to emphasize the need for researchers to consider the life histories and physiology of HAB species like *Alexandrium* in order to gain a better understanding of bloom development and population dynamics.

2.3. *Alexandrium* biology and life history

One aspect of the life history that contributes to its success is the ability to enter a dormant cyst life stage when environmental conditions become unfavorable (Figure 2.2, from Anderson et al., 1996).

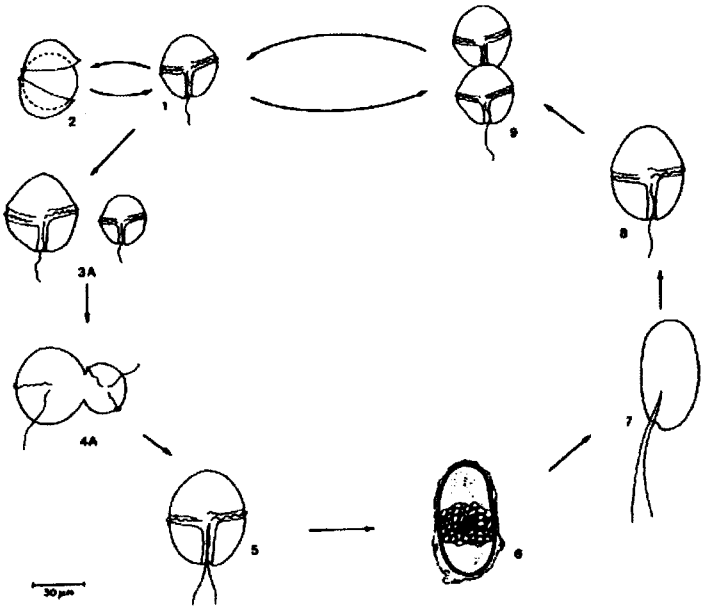

Fig. 1. Life cycle diagram of *Alexandrium tamarense*. Stages are identified as follows: (1) vegetative, motile cell; (2)temporary or pellicle cyst; (3) anisogamous "female" and "male" gametes; (4) fusing gametes; (5) swimming zygote or planozygote; (6) resting cyst or hypnozygote; (7&8) motile, germinated cell or planomeiocyte; and (9) pair of vegetative cells following division. Adapted from Anderson *et al.* 1996.

Figure 2.2 Life cycle diagram of *Alexandrium tamarense.* From Anderson et al., 1996.

Alexandrium spp. only spends a few weeks in the planktonic motile phase where the cells undergo vegetative growth and can become a threat to public health. Often, this phase is interrupted by a temporary, non-motile pellicle cyst phase as a result of environmental conditions unfavorable to support further growth. At this stage, the thecae are shed and the flagella lost. These particular cysts do not form from fertilization as do zygotic cysts.

Zygotic cysts form once cells complete the growth cycle and form gametes, with these producing diploid zygotes (planozygotes), via gametogenesis (Anderson, 1998). Planozygotes remain motile until they encyst to form hypnozygotes, or resting cysts, which sink to the bottom sediments and remain dormant for up to two years (Kirn et al., 2005). A fraction of cysts fromed in a previous growing year can germinate via response to an endogenous circannual clock when conditions permit, i.e. the following year (Anderson, 1980). Once germination occurs, cells begin the vegetative growth phase again, to achieve bloom-like densities, and progress through the life cycle to produce planozygotes and hypnozygotes (Anderson and Keafer, 1987). Encystment and sediment burial of *Alexandrium* cysts is also a focus of considerable research efforts. Encystment allows for a greater range of population development in areas that do not support year round growth of phytoplankton (Anderson, 1997). Despite the temperate climate of the Gulf of Maine and Georges Bank, the absence of vegetative *Alexandrium* cells in the winter suggests that the germination of benthic, hypnozygote cysts is crucial to the formation of blooms in the summer. The extent to which suspended and buried hypnozyotic cysts contribute to the bloom on Georges Bank, however, remains to be determined.

Whereas environmental conditions and *Alexandrium* physiology are crucial to the formation of blooms each year on Georges Bank, Townsend et al. (2005) suggested that there may also be some form of competitive interactions occurring between *Alexandrium* spp. and diatoms that lead to variability in both the timing and distribution of this toxic bloom species on Georges Bank, as well as throughout the Gulf of Maine. Several lines of evidence from previous surveys on Georges Bank and in the Gulf of Maine, as well as

previous research done on *Alexandrium* spp. interactions in laboratory studies further contribute to this hypothesis. Species distribution plots based on a 2006 survey of the Gulf of Maine revealed a coherent distinction between areas of high diatom and *Alexandrium* cell densities (Townsend et al., 2010). In addition, it is well known that the seasonal *Alexandrium* bloom starts after the spring diatom bloom each year. At the time of high *Alexandrium* cell densities, diatom cell densities appear to remain low despite significant regeneration of silicate in some regions. This suggests that although nutrient levels and other limiting resources determine the growth and success of a bloom species in the water column, competitive interactions between different phytoplankton may also play a role and can lead to shifts in community structure.

2.4. Phytoplankton community composition and succession

Investigation of species succession and community patterns of primary producers is becoming increasingly important. A better understanding of patterns in phytoplankton distribution and abundance can provide researchers insight into food web structure (i.e., carbon transfer to higher trophic levels which is important, for example, in fisheries). Identifying taxonomic groups that dominant at a particular time and under a given set of conditions is also crucial for public health, particularly with respect to safeguarding against species that can form nuisance and toxic blooms. On a much broader scale, observing changes in species community structure, in particular succession patterns, can be related to oceanographic changes in the water column not only on a seasonal cycle but also on an inter-annual basis, and is becoming increasingly important in assessing impacts of global warming on the world ocean. Long term changes or shifts in the

phytoplankton community can be linked to significant changes in the physical and chemical properties of water masses, which have been suggested to be the result of climate change in many regions, including the Gulf of Maine (Townsend et al., 2010). Although Georges Bank is an important and perhaps ideal location to study phytoplankton dynamics (i.e., almost year-round productivity and presence of a spring bloom and summer HAB), little research effort is given to investigating the biology on Georges Bank, in particular, the primary producers. Instead, chlorophyll measurements are used to provide a rough estimate of primary production; however, chlorophyll does not provide us with any knowledge of the phytoplankton community itself (i.e. species distribution, abundance, and successional patterns) which is becoming increasingly important because harmful algal blooms appear to be extending their geographical range and impacting coastal regions all over the world (Anderson, 1989; Hallegraeff, 1993).

Previous studies attempted to examine phytoplankton community dynamics by splitting up the bloom season into various phases, based on changes in the physical and chemical properties of the water column over time. Many studies examining species succession and distribution patterns on temporal and spatial scales were conducted in Mediterranean waters, the North and Baltic Sea regions, and in many bays, estuaries, and small bodies of water in Asia and Europe (Odate, 1987; Casas et al., 1999; Tilstone et al., 2000; Totti et al., 2000; Trigueros and Orive, 2001; Rousseau et al., 2002; Turkoglu and Koray, 2002; Ismael, 2003; Vadrucci et al., 2005; Daly Yahia-Kefi et al., 2005; Pilkaityte and Razinkovas, 2007; and Saadoun et al., 2008). General successional patterns in these different regions of the world reveal similar features, including succession from faster growing phytoplankton (e.g. diatoms), to species (i.e. dinoflagellates) better adapted to

grow in nutrient conditions that limit growth of diatoms. The general successional and community distribution of the major groups of phytoplankton, including diatoms, dinoflagellates, raphidophytes, and nanoplankton are determined by the physical and chemical changes from late winter through summer. Differences in nutrient requirements and uptake rates of essential nutrients by different phytoplankton species, and the physical properties of the water column including temperature and salinity, result in specific seasonal succession patterns and the dominance of taxa that are competitively superior under the given set of conditions at a particular point in space and time (Odate, 1987). In general, three phases exist that are typical of the spring and summer phytoplankton bloom seasons, characterized by the presence and/or absence of particular phytoplankton:

1. A late winter-early spring phase where an unlimited supply of nutrients and a well mixed water column result in dominance of phytoplankton species that are best able to exploit resources and grow at a faster rate to outcompete most other species in the water. In most cases, the late winter-early spring community is characterized by the presence of diatoms, in particular, large centric diatoms that appear in late winter, and pennate forms that grow faster than centric species when silicate is not limiting (Pilkaityte and Razinkovas, 2007). In addition to non-limiting nutrient conditions, a well-mixed, turbulent water column and lower irradiance levels characteristic of the late winter-early spring season is most beneficial to non-motile diatom species and makes for a spring bloom dominated by diatoms in many regions (Turkoglu and Koray, 2002; Pilkaityte and Razinkovas, 2007).

2. A late spring to early summer phase where excess nitrate often remains in the water column after silicate has been exhausted by diatoms. The relative excess nitrate to silicate, and lower nutrient levels overall results in a shift toward a community dominated by larger dinoflagellates, better adapted to grow in low nutrient conditions.

3. A late summer period characterized by depletion of nitrate and silicate, leaving a community dominated by smaller flagellates, mainly nanoplankton that are better equipped to take up recycled nutrients, at near-limiting levels. If silicate becomes available for uptake smaller, chain-forming centric diatoms can become abundant and represent a succession pattern from the larger single-celled centrics and pennates typical of the spring bloom (Trigueros and Orive, 2001). Depleted nutrient levels characteristic of the late summer in many regions often result in dominance of dinoflagellates that exhibit mixotrophic or heterotrophic feedings strategies. (Matsuyama et al., 1999; Stoecker et al., 1997; Bockstahler and Coats, 1993a, b; and Daly Yahia-Kefi et al., 2005).

The general successional patterns from spring through the summer appear to be influenced mainly by nutrient levels and stability of the water column, thus the phytoplankton group, taxa, or species that are competitively superior under the given set of environmental conditions in the water column will likely dominate the community. Whereas these general patterns are well observed in many coastal and offshore regions around the world, specific interactions between species of phytoplankton must also be considered and can likely result in the dominance of a particular diatom or dinoflagellate over another. These types of competitive interactions are important, for example, in

regions where a specific species can form noxious blooms that are a threat to public health (Smayda, 1997).

2.5. Phytoplankton competitive interactions

The study of phytoplankton community dynamics with respect to species interactions and competition for resources has been a challenge to researchers. In 1976, Levine stated that in order to "thoroughly describe a phytoplankton community, we must recognize that competing species interact within a whole complex of competition, predators, and resources, and the environmental background strongly influences the results of competition." Thirty-four years later, this challenge still remains and has become more important to study, as larger and more frequent phytoplankton blooms appear to occur each year around the world, many causing public health and economic threats. Smayda (2002) reminded us that the HAB phenomena and phytoplankton blooms in general must be analyzed from the "ecological perspective of species coexistence, community ecology, and habitat and resource spectra."

The annual spring and summer blooms on Georges Bank make it the ideal location to observe successional patterns between different phytoplankton groups, in particular diatoms and the dinoflagellate *Alexandrium* spp., which may exhibit a complex competitive relationship. A better understanding of phytoplankton ecology on Georges Bank, combined with our detailed knowledge of the physical processes and nutrient dynamics across the region, that were studied over the past two decades, could help explain and predict the distribution and abundance of *Alexandrium* spp. blooms each year.

Although the exact nature of species interactions is complex, researchers have grouped competitive interactions into two categories: interference competition and exploitation competition. The former describes a variety of strategies thought to be used by select phytoplankton species to improve their competitive rank, which often include: eating, killing by poisoning, and other interference mechanisms (Levine, 1976). This form of competitive interaction is generally observed in slower growing, flagellate species in order to "keep up" with relatively faster growing diatom species. Diatoms are well equipped to dominate the water column by the latter approach, whereby exploitation of resources ultimately denies their use by other phytoplankton. Thus, higher nutrient uptake affinities and faster growth rates allow diatoms to dominate a community rather quickly (Smayda, 1997).

The spring bloom on Georges Bank initiates in early winter and is dominated by diatoms until silicate becomes limiting, resulting in a species shift to a flagellate dominated community that becomes well established by the early and late summer months (Cura, 1987). Because silicate is not required by dinoflagellates, *Alexandrium* spp., in particular, can become numerically abundant along with other flagellate species and dominate the phytoplankton community. High dinoflagellate densities continue well through the summer months, despite the substantial regeneration of silicate (as a result of warming temperatures and subsequent diatom frustule dissolution) that begins to occur along the Northern Flank of Georges Bank in May and June (Townsend and Thomas, 2002). Whereas limiting resources appears to be the main cause for the demise of the diatom bloom on Georges Bank, it is unclear whether diatoms become the dominant group again when silicate concentrations are regenerated along some portions of the

bank. It is possible that an allelopathic or other form of interference competition occurs when *Alexandrium* spp. reach high enough concentrations to limit diatom growth despite higher nutrient uptake affinities and growth rates by diatoms. In addition, other dinoflagellate species that occur in high numbers on Georges Bank may also produce competitive interference to both diatoms and other flagellates.

Previous laboratory studies suggest that *Alexandrium* spp. exhibit a form of allelopathic interference on both diatom and other flagellate species that is unrelated to cell toxicity; rather, the negative effects on competing phytoplankton are associated with lytic compounds released by *Alexandrium* spp. (Simonsen et al., 1995; Arzul et al., 1999; and Tillmann and John, 2002). Fistarol et al. (2004) demonstrated such allelopathic capabilities of *Alexandrium* on natural community assemblages where decreases in growth rates and a change in the abundance and dominance of the phytoplankton population were observed in the presence of *Alexandrium* species. In addition, cell-free filtrate of various *Alexandrium* spp. strains, both toxic and non-toxic, negatively affected *Thalassiosira weissflogii* and *Rhodomonas* sp. in culture; the former species is observed on Georges Bank (Backus and Bourne, 1987). In addition to *Alexandrium* spp., similar allelopathic mechanisms were observed in a large suite of phytoplankton species, mainly from dinoflagellates such as *Karenia brevis* (Kubanek et al., 2005) and *Prorocentrum minimum* (Tameishah et al., 2009), and in some cases, by diatom species, notably *Skeletonema costatum* (Imada et al., 1991).

The benefit associated with production and release of allelochemicals is thought to be the reduction of competition in the immediate surrounding environment. Subsequently, reduced competition results in greater resource availability to support growth of the allelopathic cells. This theory appears relatively simple in the terrestrial world, with plants that remain fixed in space; however, in the aquatic environment, continuous movement of water disperses allelochemicals from their releasing cell, thereby diluting it rapidly (Lewis, 1986).

Much of the debate on allelopathic interactions between species of phytoplankton focuses on why the release of chemicals into the water column might be beneficial to a particular organism, especially in a body of water, where according to Lewis (1986), several issues arise: 1. Motile flagellates that commonly release chemicals will eventually leave the area where the substance was emitted, 2. Cells in the water column are separated by relatively large spatial distances (hundreds of cell diameters at times), 3. Viscous forces are present that make transmitting a substance inefficient, and 4. Releasing of a particular substance at one organism's expense can benefit another. It would appear that releasing chemicals into the water column would not only be of little advantage to a cell, but could also benefit different species at the same time. In addition, releasing inhiboratory substances might negatively affect the releasing cell and/or genetically related cells which would not support population increase. The question, therefore, remains: Why release an allelopathic chemical that is associated with some level of energetic cost to the cell?

Another consideration for the release of chemicals by a cell, in particular, by cells of a successional species like dinoflagellates, is that it serves as an environmental cue to target organisms rather than a defensive mechanism (Lewis, 1986). For example, the release of chemicals by *Alexandrium* spp. may signify a change in environmental conditions that mark the end of a growth period for the target organisms, in this case, the spring diatoms. As such, growth and success of dinoflagellates on Georges Bank may be a cue for a diatom population to end its growth phase, as nutrient levels tend to favor dinoflagellate growth (i.e., excess nitrate and low silicate levels), or due to another environmental factor. Lewis (1986) stated that "the allelochemical signal, based on the presence of certain critical quantities of other kinds of organisms may be the most reliable indicator of the position of the environment with respect to a particular organism's niche space." Chemical-releasing dinoflagellates may need to reach this "critical quantity" in order to fully suppress diatom growth.

2.6. Goals of thesis

1. To document the spatial and temporal patterns of the major phytoplankton taxa (i.e. diatoms and dinoflagellates), with respect to abundance and distribution on Georges Bank from the end of spring, through summer. This study will be one of the first to document, in detail, the community composition on Georges Bank in the months following the spring diatom bloom.

   A series of three survey cruises to Georges Bank in late April, May, and June 2008 allowed testing of the hypothesis that a succession from a spring diatom-dominated community to a dinoflagellate-dominated community takes place during

the summer months on Georges Bank. Further examination of phytoplankton distribution and abundance patterns within each survey allows testing of the hypothesis that interactions between diatoms and dinoflagellates, specifically *Alexandrium* spp., may exist in the field, and in addition to the unique oceanographic properties of Georges Bank, play a significant role in the distribution and timing of the *Alexandrium* bloom each year.

2. To compare phytoplankton community structure and successional patterns on Georges Bank with work done in other parts of the world, and on a broader scale, to increase understanding of phytoplankton community dynamics.

   Changes in community structure are crucial from both an economic and public health standpoint, particularly in the Gulf of Maine and Georges Bank' region, where toxic *Alexandrium* blooms are observed annually.

3. To document possible competitive interactions between *Alexandrium fundyense* and a diatom known to exist in the Gulf of Maine, *Ditylum brightwellii,* in a series of controlled, preliminary laboratory growth experiments.

3. MATERIALS AND METHODS

3.1. Oceanographic surveys

Hydrographic surveys of temperature, salinity, nutrients, total and size fractionated chlorophyll (>20 μm; <20 μm) measurements, and phytoplankton species abundance and distribution were conducted on Georges Bank during the summer of 2008: 28 April – 5 May (OC445) and 27 May – 4 June (OC447) on the R/V *Oceanus*, and 27 June-3 July (EN448) on the R/V *Endevaor*. These cruises were part of the Northeast ECOHAB-GOMTOX program. Water samples were collected from standard hydrocasts at each station using a SeaBird CTD and SeaBird carousel water sampler with 5-L Niskin bottles. Nutrient and chlorophyll measurements were taken at every station throughout each cruise. Water samples for nutrient analyses were taken from within a few meters of the bottom to the surface of each station; chlorophyll measurements were taken at 1m, 10 m, 20 m, 30 m, 40 m, and 50 m (when available); and surface (1m) water samples were collected and preserved for phytoplankton enumeration and community composition at every other station.

3.1.1. Nutrients and chlorophyll

Nutrient water samples were filtered through 0.45 μm Millipore cellulose acetate filters, immediately placed in a sea water ice bath for 5-10 minutes, and frozen at -18 C. Samples were analyzed at the University of Maine following each cruise for NO_3^- + NO_2^-, $Si(OH)_4$, PO_4^{-3}, and NH_4^+ using a Bran Luebbe AA3 Autoanalyzer and standard techniques.

To determine total chlorophyll a concentrations, a 100 mL water sample was filtered through a 25 mm GF/F glass fiber filter and placed in 10 mL of 90% acetone. The sample was kept in the dark at -18°C and extracted for a minimum of 12 hours. Size-fractionated chlorophyll (>20 μm and <20 μm) measurements were also obtained for this series of cruises. A second water sample at each station and depth of interest was first passed through a 20 μm filter and then processed according to the same protocol outlined above. Total and < 20 μm chlorophyll measurements were determined fluorometrically, using a Turner Model 10 fluorometer. The > 20 μm chlorophyll concentrations were calculated by subtracting < 20 μm chlorophyll from total chlorophyll values. For the purpose of this thesis, only the surface chlorophyll and nutrient measurements collected at stations where phytoplankton water samples were taken (i.e. every other station) were evaluated.

A total of 22-24 stations on Georges Bank were analyzed for each of the three cruises (Figure 3.1). Contour plots were generated using Surfer v.8.02 Mapping System, Golden Software, Inc. (www.goldensoftware.com) for the following: Salinity, temperature, $NO_3^- + NO_2^-$, $Si(OH)_4$, PO_4^{-3}, NH_4^+, nitrate minus silicate, total chlorophyll, >20μm chlorophyll, <20μm chlorophyll, diatom abundance (cells L^{-1}), dinoflagellate abundance (cells L^{-1}), *Alexandrium* spp. abundance (cells L^{-1}), and nanoplankton abundance (cells L^{-1}). Station maps for OC445, OC447, and EN448 were also constructed using Surfer 8.

3.1.2. Phytoplankton abundance

For analysis of the phytoplankton community on Georges Bank, 100 mL surface water samples were preserved in Lugol's iodine solution and transported back to the lab. Fifty mL of each sample was transferred into a 100 mL graduated cylinder following mixing, and allowed to settle for a minimum of 48 hours. The upper 40 mL of the settled sample was drawn off using a vacuum pump, leaving a five-fold concentrate of the water sample. For enumeration of each sample, the concentrate was shaken vigorously and a 1 mL sub-sample was placed on a Sedgwick-Rafter gridded cell chamber and examined under a Nikon compound light microscope, at a magnification of 100x or 200x . For enumeration of phytoplankton cells larger than 10 μm, the entire slide was counted, with each cell identified to the lowest taxon possible; in most instances, this was to genus, with several being identified to species. Identification of some preserved dinoflagellate cysts was not possible, and these cells were grouped together in a "Cysts" category. For nanoplankton and small flagellate species (<10 μm), a single transect on the slide was counted and an adjustment calculation made to represent the 1 mL subsample.

For two station transects on Georges Bank (late April and late May), triplicate counts were performed on 5 stations to evaluate error associated with cell counts (Fig. 3.1). Diatoms, dinoflagellates, *Alexandrium* spp., and nanoplankton were enumerated using the same methods as mentioned above for each triplicate. Uncertainty values were then calculated to observe counter variability as discussed in the next section.

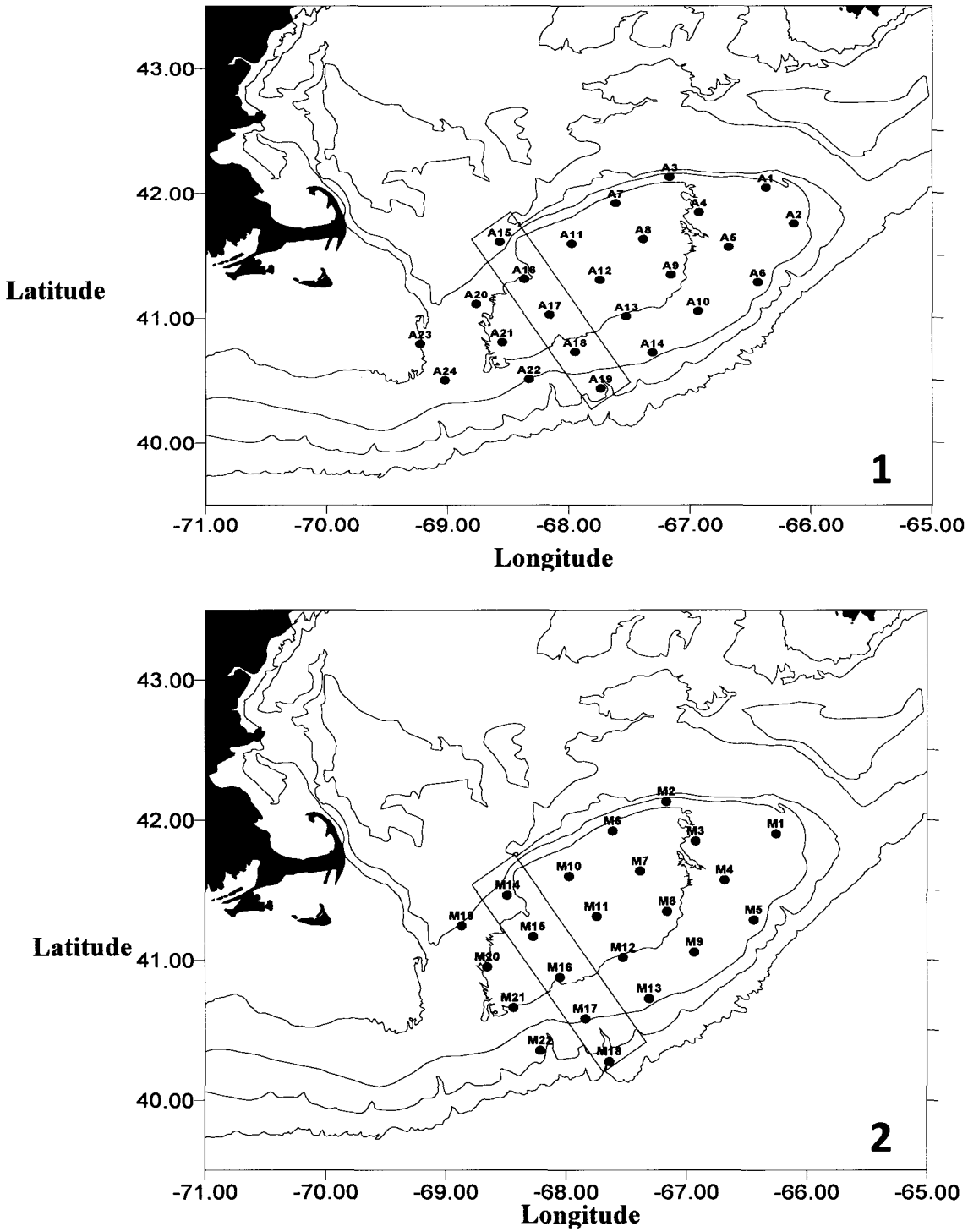

Figure 3.1. Station locations for summer 2008 cruises: Panel 1- OC445 (28 April – 5 May), Panel 2, OC447 (27 May – 4 June), both onboard the R/V *Oceanus*. Boxed area indicates stations where triplicate counts were performed.

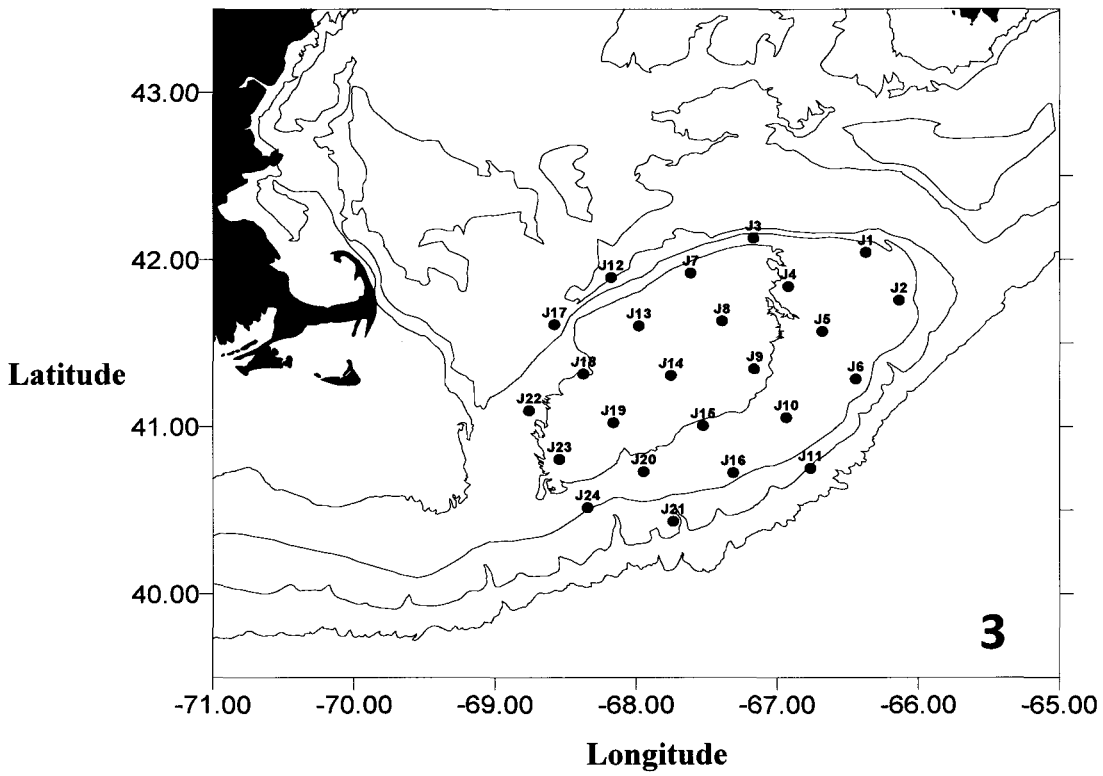

Figure 3.1 continued. Panel 3, EN448 (27 June-3 July), aboard the R/V *Endeavor*.

3.2. Statistical analyses

All statistical analyses were performed using MYSTAT 12, version 12.02.00, a student version of the SYSTAT 12 program software (http://www.systat.com/MystatProducts.aspx).

Cluster analysis is designed to provide meaningful groupings of entities based on similarities across a larger number of variables (McGarigal, 2000). Applying a cluster analysis to a large set of data can often help form smaller groups that are statistically similar, which can then be studied in greater detail and compared to one another. Two

different cluster analyses were performed in order to determine: 1) How the twenty-two most abundant diatom and dinoflagellate taxa observed on Georges Bank during the summer of 2008 relate to one another, based on their average abundance at the seventy stations sampled on the three survey cruises (n=70); and 2) How the seventy stations sampled on Georges Bank group together, based on the abundance of the twenty-two phytoplankton taxa. Observing groups of similar taxa and stations facilitates the identification of successional patterns and spatial trends.

Twenty-two species of diatoms and dinoflagellates were selected for the analysis, based on their average abundance at the seventy stations and also taking into account their percent presence across all three cruises. All but four of the twenty-two most abundant species were present in more than 30% of the stations. These remaining four were included in the analysis because of their significant contribution to the phytoplankton population, when present.

Taxa abundances were standardized prior to the analyses by removing the mean and standard deviation. By standardizing the data, the mean and standard deviation become zero and one respectively (Appendix H). This allows for better comparison between taxa that vary by orders of magnitudes in many cases, and prevents formation of clusters based on large differences in abundances, rather than similar abundances.

Hierarcheal techniques were used to calculate distances of each individual taxon in relation to the remaining taxa. In this case, there are x taxa, each of which has a value for n variables, represented as the top twenty-two taxa and the seventy sampling stations

across all three cruises, respectively. Distance (D) calculations between taxa were performed using the Euclidean distance formula generally written as:

$$D_{1,2} = \sqrt{\{ \sum_{i=1}^{n} (x_{1i} - x_{2i})^2 \}}$$

where, for example, 1 and 2 represent two taxa and *n* is equal to the number of variables the taxon abundance was measured for, in this case 70 stations (Manly, 1994). This produces a dendrogram representing how similar one particular taxon is to another, and is based on distances in ordinate space. By using relative abundances of the major phytoplankton taxa, rather than simply their absence or presence at a particular station, we can observe what particular diatoms and dinoflagellates tend to coexist with one another, and also those that exist at roughly similar cell densities.

Clusters were joined using the Ward linkage method (Ward, 1963) and groups were formed subjectively. After trial and error runs using a number of different linkage methods, including average, Ward, complete, centroid, and single linkages, no discernible changes in taxa grouping were observed, and the Ward method was chosen to link taxa groups. Ward linkage (Ward, 1963), sometimes termed the minimum-variance linkage, is similar to an analysis of variance (ANOVA) approach, whereby the groups are formed in an attempt to minimize an increase in within-group variance, which is ultimately less than if either of the two variables of interest were joined with a different cluster (McGarigal, 2000). In other words, Ward's method fuses groups based on a minimal

increase in the loss of information, which he terms error sums of squares (ESS), when making groups.

The second cluster analysis was performed in a similar manner, but here stations were grouped based on the abundances of the twenty-two taxa in an attempt to observe phytoplankton distribution and abundance trends in space and time on Georges Bank. The same approach to clustering was applied as above, and station clusters were again formed subjectively. Forming station clusters that contain similar abundances of taxa is useful for observing spatial trends both within and between the three cruises and aids in observing successional patterns in the plankton. In addition, it allows for comparison of the water properties (i.e. salinity, temperature, nutrients, etc) associated with each station cluster in an attempt to link oceanographic and biological characteristics on the Bank.

In addition to observing similarities in phytoplankton taxa using a clustering approach, a Principal Component Analysis (PCA) was also run using standardized abundances to observe similarities between phytoplankton taxa in 2-D space. This additional analysis was performed in order to observe orientation of phytoplankton in coordinate space and to find groups of phytoplankton taxa that appear to co-exist in a similar manner across a number of stations, again, in both space and time. Comparing the cluster analysis and PCA should reveal similar results with respect to the grouping of certain taxa based on their abundances. The PCA will then describe these similar groups in coordinate space. The goal of a PCA is to reduce the amount of variance in a group of data; in this particular case, the abundance of a number of taxa, to one or two principal components, which in general account for most of the variability in the samples (Manly,

1994). Observation of the factor loadings for each of these principal components can provide insight into what taxa or groups (diatoms or dinoflagellates) are accounting for most of the variability in our samples (stations).

A repeated measures' analysis of variance (ANOVA) was performed on the data from both laboratory growth experiments to determine whether *Alexandrium* and *Ditylum* cell densities, when co-culturing of the species was done, differed significantly from their abundance in control flasks. This method was chosen because the growth experiment contained replicated treatments measured over the course of fifteen days. Repeated measures' ANOVA considers differences in conditions throughout the course of an experiment when comparing means. For example, changes in *Alexandrium fundyense* cell density on one particular day is likely to be correlated with the abundance on prior days, and *Ditylum brightwellii* cell abundance will be correlated with cell densities on previous days. As such, unless we pick one sample day to compare means between treatments, a repeated measures' ANOVA approached should be used. This will account for the "within subjects factor", that is the measure of cell abundance for both subjects at each day, but also the "between subjects" factor, or the measurement of each individual subject across different conditions or days of the experiment in this case.

3.3. Laboratory competition experiments

Two controlled laboratory growth experiments were conducted during the summer of 2008 to examine whether the growth of on species can be inhibited by the presence of another. In this case, *Alexandrium fundyense*, a toxic dinoflagellate species suggested to be allelopathic in nature, and a diatom, *Ditylum brightwellii* were used as

target species. Both species occur in the Gulf Maine. The experiments were conducted approximately a month apart (June and July, 2008) using culture isolates from the Center for the Culture of Marine Phytoplankton (CCMP) that were kept in exponential growth phases in a culture incubator maintained at 17°C, with approximately 100 μmol photons of illumination and a 14:10 light: dark cycle.. Both cultures were isolated from the North Atlantic; *Alexandrium fundyense* (CCMP1978) from the Bay of Fundy in the North Atlantic, and *Ditylum brightwellii* (CCMP2227) from Avery Point, Conneticut USA. Replicate flasks containing 300 mL of sterile L1 media (Andersen, 2005) made with filtered Gulf of Maine seawater from the Darling Marine Center, were inoculated with three different treatments: (A) *Alexandrium fundyense* alone (control 1), (B) *Ditylum brightwellii* alone (control 2), and (C) *Alexandrium fundyense* and *Ditylum brightwellii* together (mixed). The nine flasks were maintained under the conditions described above, and were gently swirled by hand and rotated in the culture room each day, to avoid introducing biases in position. These growing conditions were maintained over the course of both experiments, while the initial concentrations of *Alexandrium fundyense* and *Ditylum brightwellii* varied between experiments. An initial microscopic count was done on exponential cultures in order to calculate the desired starting cell concentrations for each flask. Initial cell densities of *Alexandrium fundyense* were always higher than that of *Ditylum brightwellii* in order to compensate for relatively faster diatom growth rates.

A 10 mL sample was collected from each flask every 24 hours for the first 12 days of the experiment (without replacement of seawater), and again at day 15; after which the experiments were terminated.

The samples were fixed with a 1-2% formaldehyde-seawater mixture and enumerated within 30 days following the experiment. Cell counts were made by placing a 1 mL subsample on a Sedgwick-Rafter gridded cell chamber and enumerating the entire slide under a Nikon compound microscope. In order to account for counter error and variability, triplicate subsamples were counted on selected dates for each flask and averaged together. Triplicate flasks were then averaged for each day and standard deviation was calculated. Ten mL water samples were collected at day 9 and 16 of the first experiment to assess nutrient utilization and availability. Initial concentrations of NO_3, PO_4^{-3}, and SiO_3 in 1-L of L1 media are approximately: 882 μM, 36.2 μmM, and 106 μM, respectively (Andersen, 2005).

4. RESULTS

4.1. Sea surface temperature and salinity patterns

Near surface temperatures on Georges Bank during the summer of 2008 are presented as areal contour plots (Figs 4.1-4.3). Cooler surface temperatures were observed at the end of April and ranged from about 4 to 7 °C, with the coldest waters associated with the Northeast Peak, most likely the result of an influx of colder Scotian Shelf Water that was restricted to the eastern most part of the Bank (Fig. 4.1). The bank warmed over the remaining two cruises, with an increase in temperature of about 4-5°C observed by the end of May. Temperatures ranged from 7-12°C during this time, with the coldest water still confined to the eastern edge of the bank (Fig. 4.2). Warmest temperatures were observed at the end of the third cruise in June (EN448). By this time, temperatures reached a maximum of about 19°C around the outer edges of the Bank beyond the tidal mixing front separating the well-mixed waters, roughly confined within the 60 m isobath, and the thermally-stratified waters over deeper depths (EN448 2008 cruise, unpublished). Slightly cooler temperatures (10-12°C) were observed in the more central tidally mixed regions (Fig. 4.3).

The likely influence of colder and fresher Scotian Shelf Water was also evident in the salinity plots of Georges Bank. Relatively fresher water, with salinities of 32-32.6 PSU was observed along the entire eastern portion of the bank, while the western portions were saltier, with salinities of 32.8 to 33 PSU (Fig. 4.4). Salinities during the second cruise, OC447, ranged from 32-33 PSU, with warmer and saltier waters observed along the southeastern portion of the bank, with the remainder of the bank. (Fig. 4.5). By

the end of July, the lowest salinities, from 31.2-31.4 PSU were observed along the western-most edge of the bank, with the remainder of the Bank, including the Southern Flank, varying only from 32.5-32.8 PSU (Fig. 4.6).

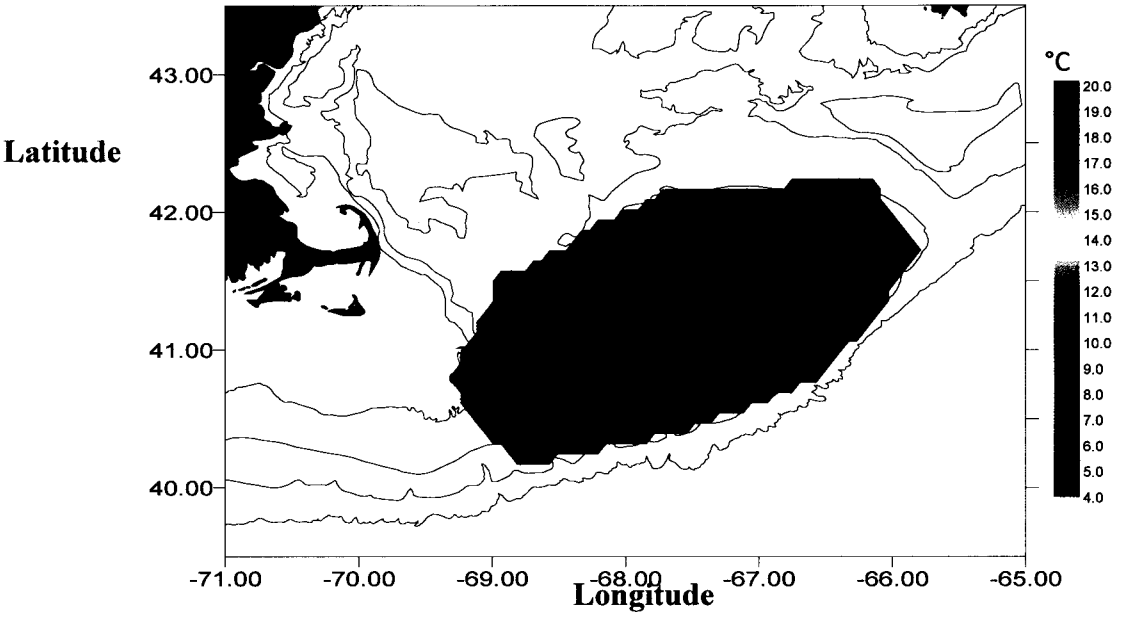

Figure 4.1. OC445 (28 April to 5 May 2008) near-surface *in situ* water temperatures (°C).

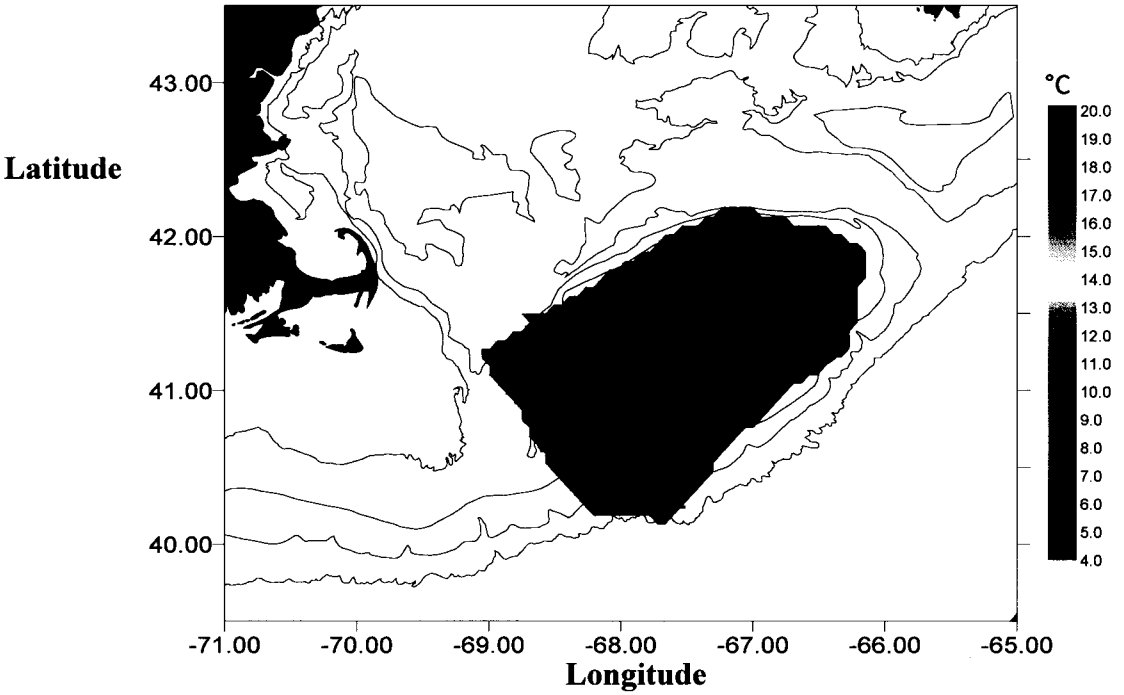

Figure 4.2. OC447 (27 May to 3 June 2008) near-surface *in situ* water temperatures (°C).

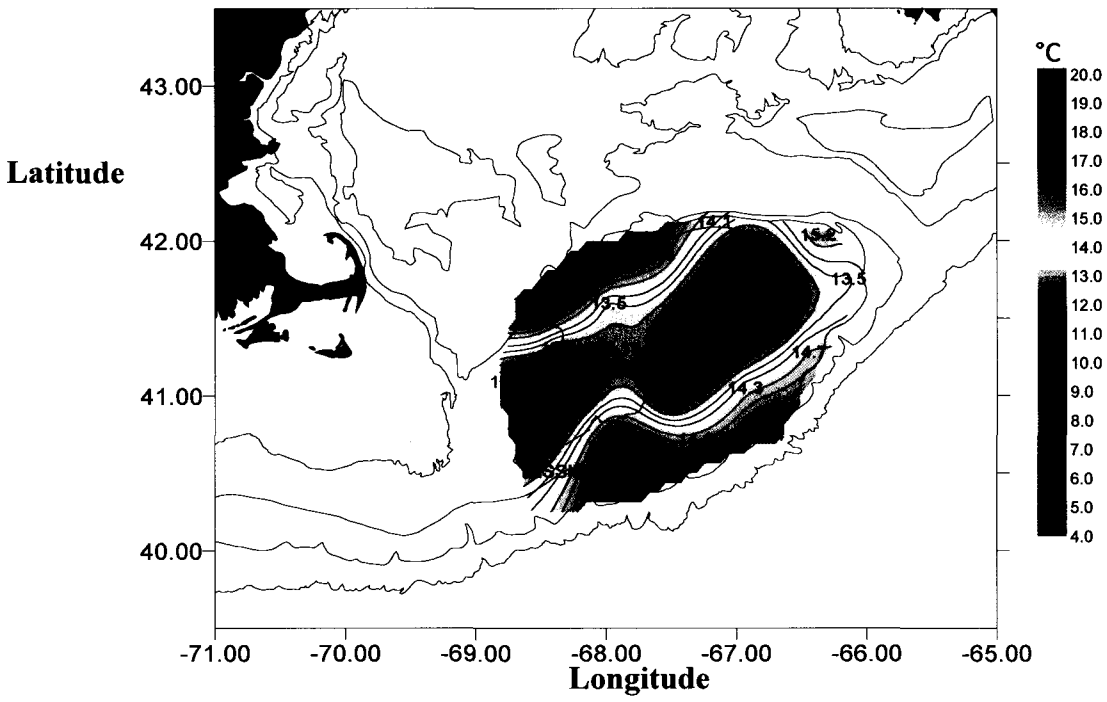

Figure 4.3. EN448 (27 June to 3 July 2008) near-surface *in situ* water temperatures (°C).

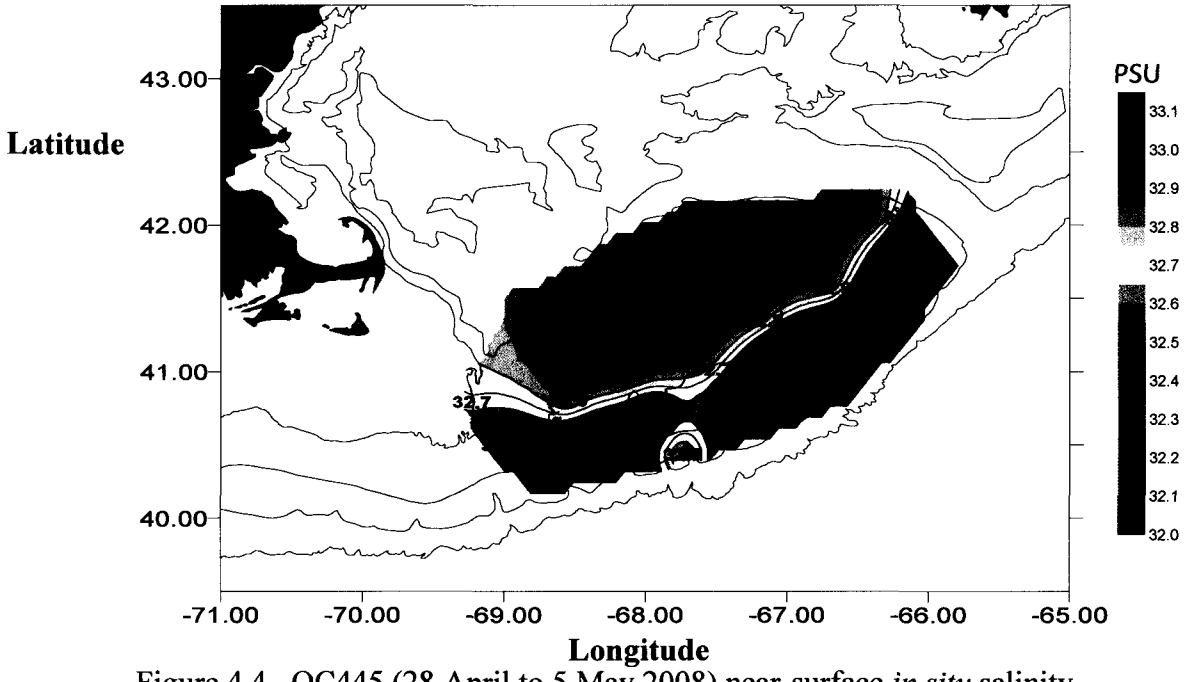

Figure 4.4. OC445 (28 April to 5 May 2008) near-surface *in situ* salinity.

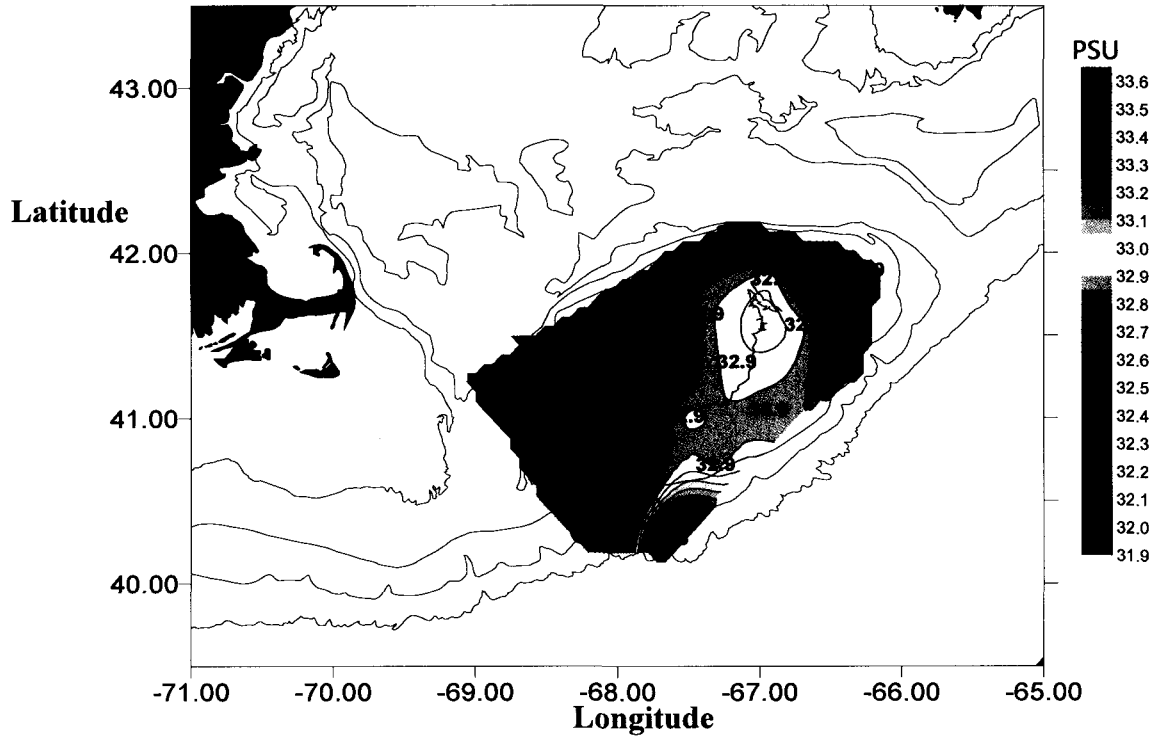

Figure 4.5. OC447 (27 May to 3 June 2008) near-surface *in situ* salinity.

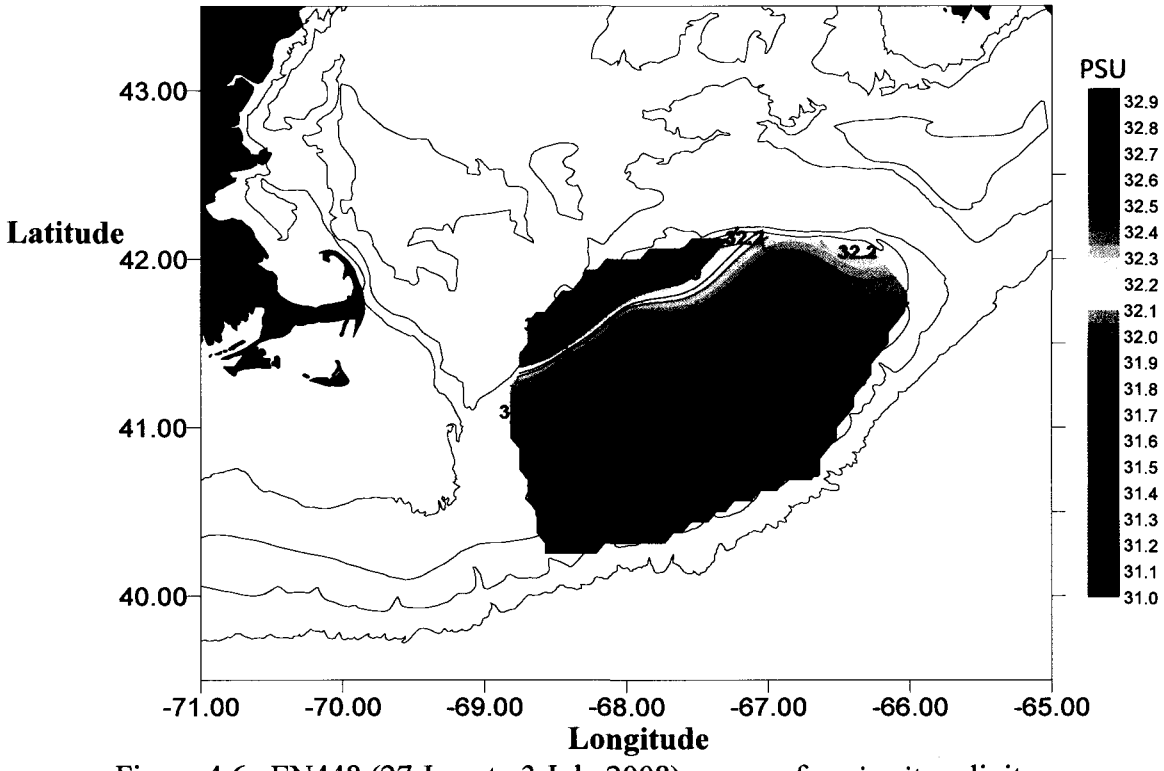

Figure 4.6. EN448 (27 June to 3 July 2008) near-surface *in situ* salinity.

4.2. Dissolved inorganic nutrient concentrations

In general, the surface nutrient concentrations on Georges Bank throughout the summer months were low, having been drawn down during and following the annual spring phytoplankton bloom. Nitrate and nitrite ($NO_3^- + NO_2^-$) concentrations on all three cruises were less than 3.5 μM, and were only in excess of 2.0 μM during OC445 on May 2, 2008, where slightly elevated levels were observed along the north-west edge of the Bank, most likely the result of localized upwelling and nutrient injection (Hu et al., 2008; Fig. 4.7). Surface concentrations of $NO_3^- + NO_2^-$ in May and June were depleted to less than 1 μM and were near the lower limit of detection in some locations (Figs. 4.8 and 4.9).

Surface silicate ($Si(OH)_4$) concentrations were also depleted, likely the result of the spring diatom bloom, with the exception of a patch in excess of 5 μM observed along the southeast portion of the Bank (Fig. 4.10). Those elevated surface concentrations are most likely the result of localized regeneration of biogenic silicate at the end of May, because levels increased to 2-5 μM at several stations (Fig. 4.11). Because there were no apparent concomitant increases in $NO_3^- + NO_2^-$ concentration, it is likely that increased pulses of $Si(OH)_4$ occurred as a result of increasing temperatures and subsequent dissolution of biogenic silica (diatom frustules from the previous spring bloom), as observed in earlier cruises (Townsend and Thomas, 2002), rather than a localized upwelling event. Silicate levels dropped again during EN448 from late June to early July, to levels less than 2 μM across most of the Bank (Fig. 4.12).

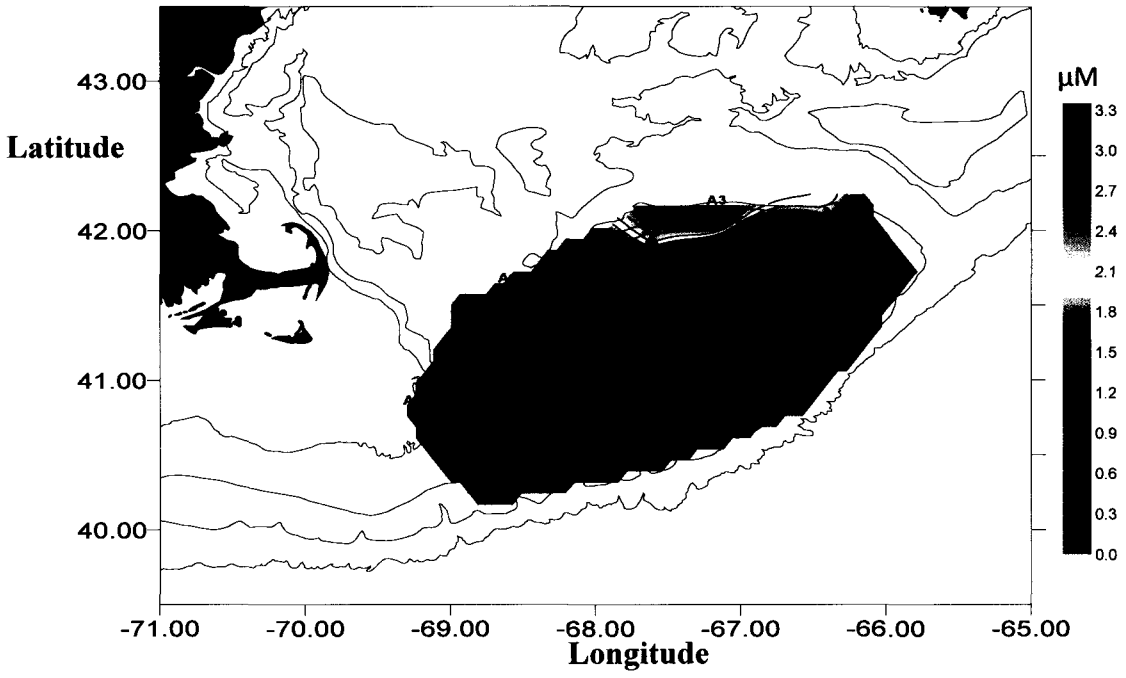

Figure 4.7. OC445 (28 April – 5 May 2008) surface $NO_3^- + NO_2^-$ concentrations.

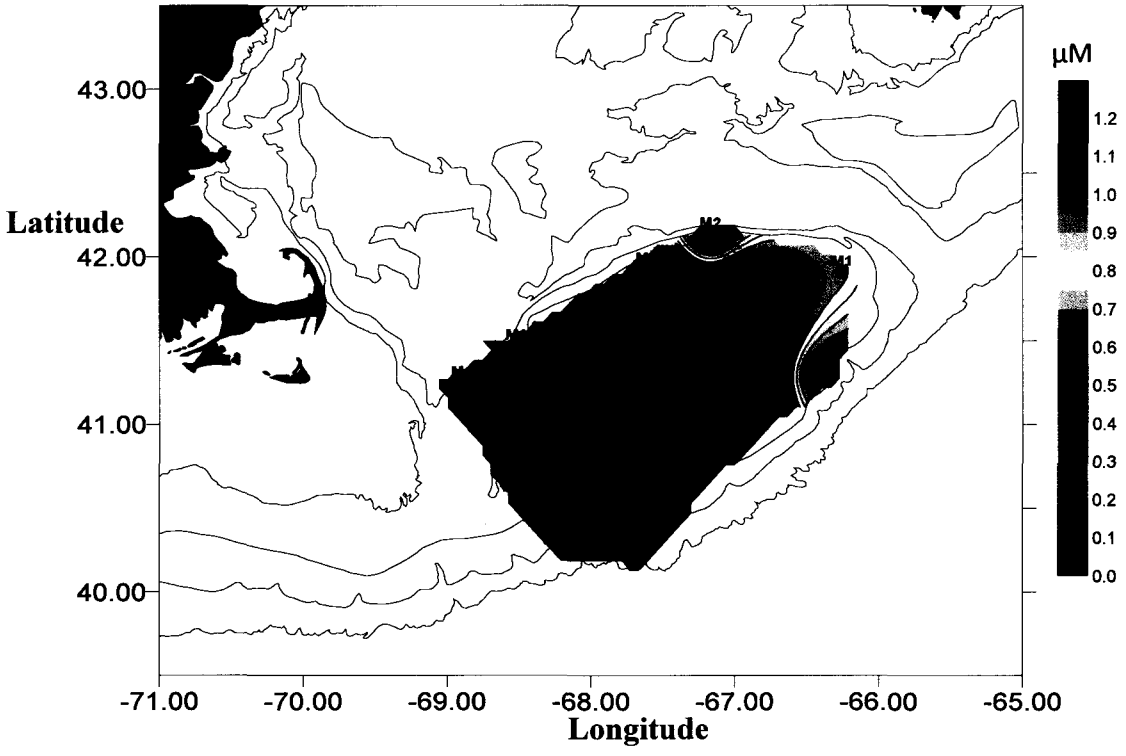

Figure 4.8. OC447 (27 May-4 June 2008) surface $NO_3^- + NO_2^-$ concentrations.

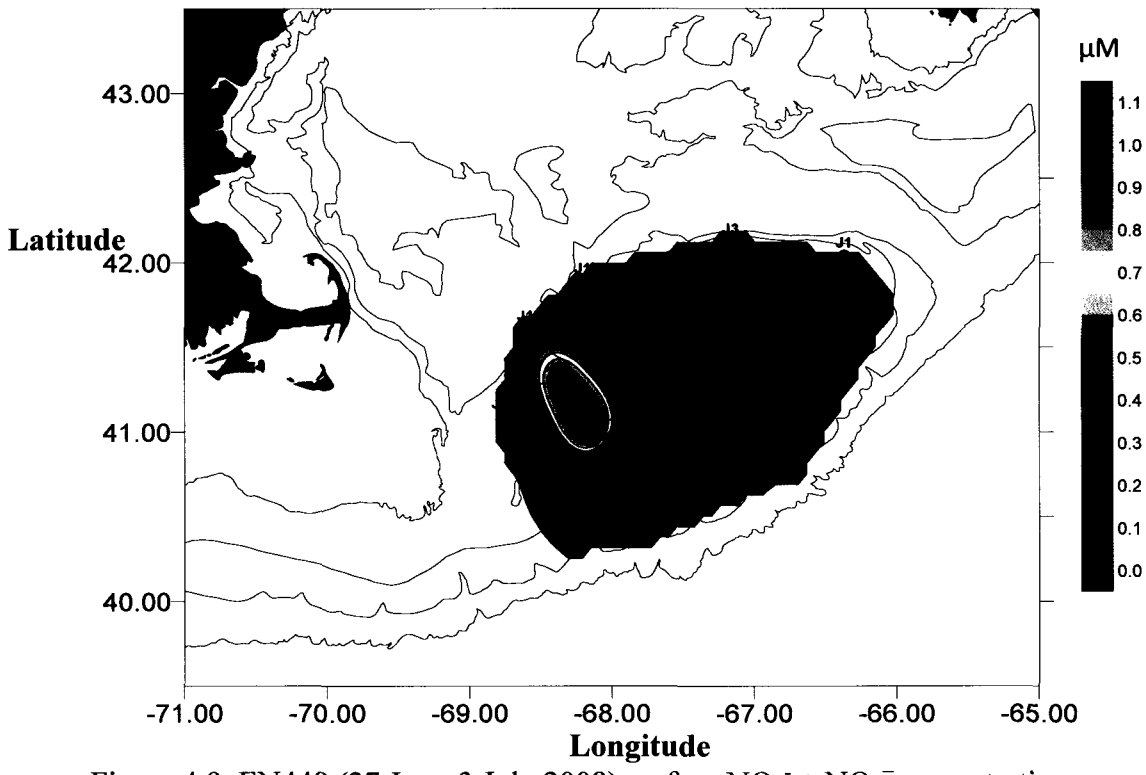

Figure 4.9. EN448 (27 June-3 July 2008) surface NO_3^- + NO_2^- concentrations.

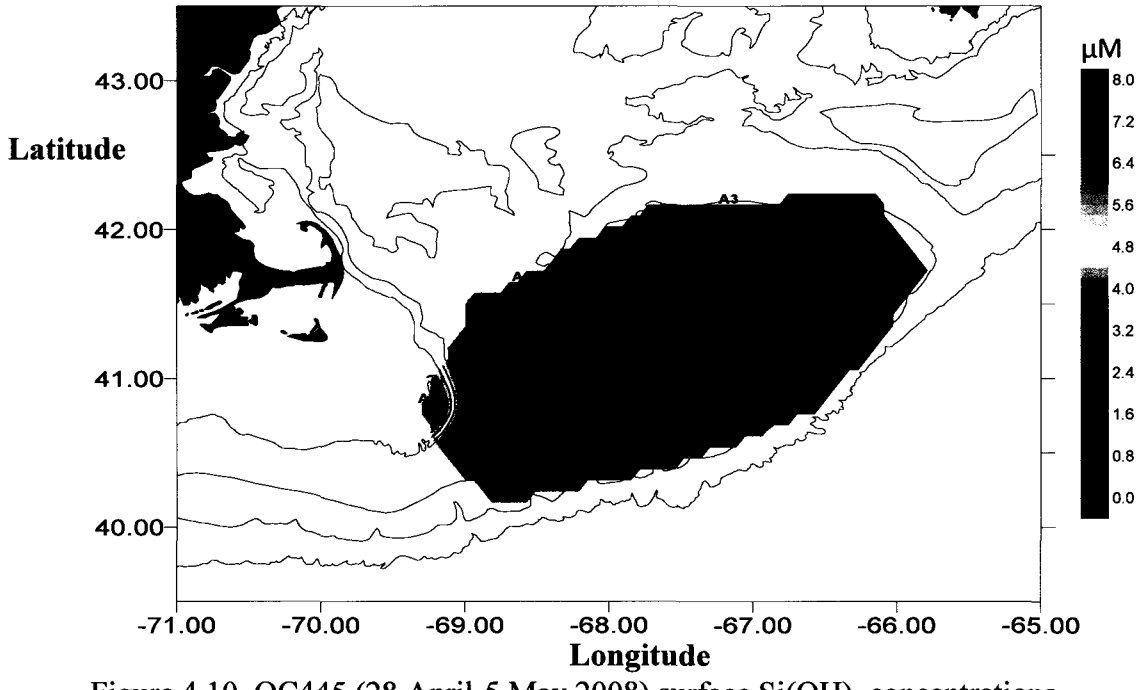

Figure 4.10. OC445 (28 April-5 May 2008) surface $Si(OH)_4$ concentrations.

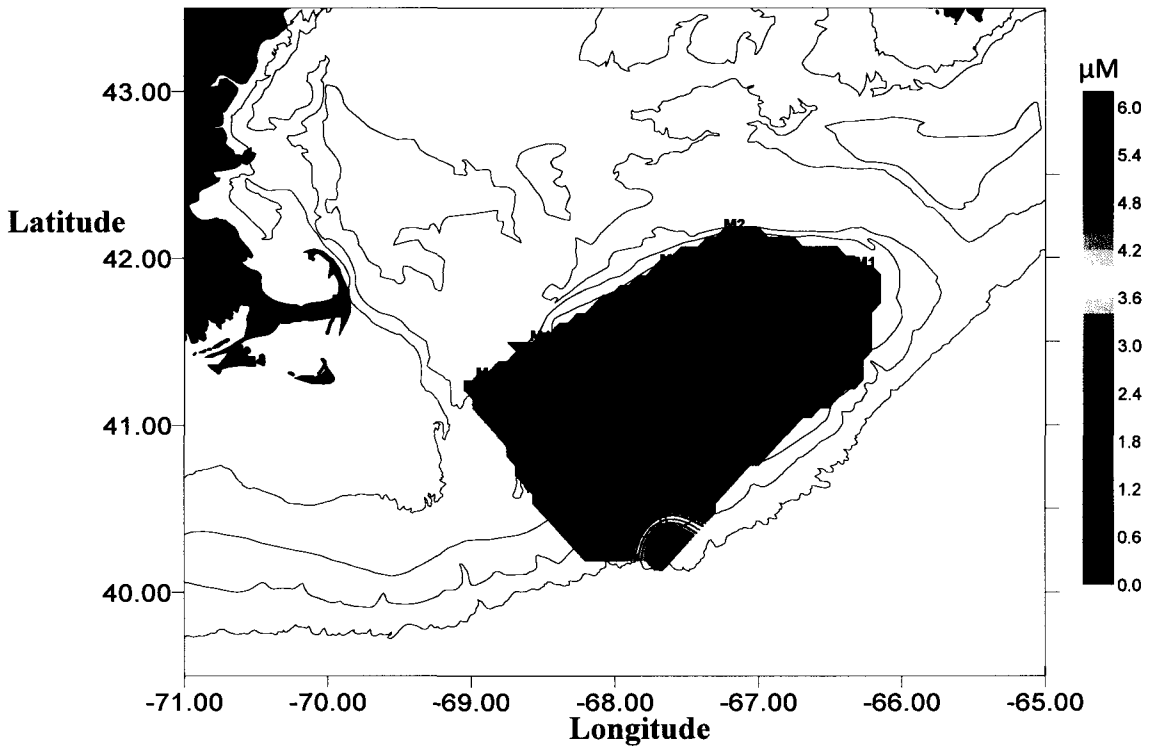

Figure 4.11. OC447 (27 May-4 June 2008) surface $Si(OH)_4$ concentrations.

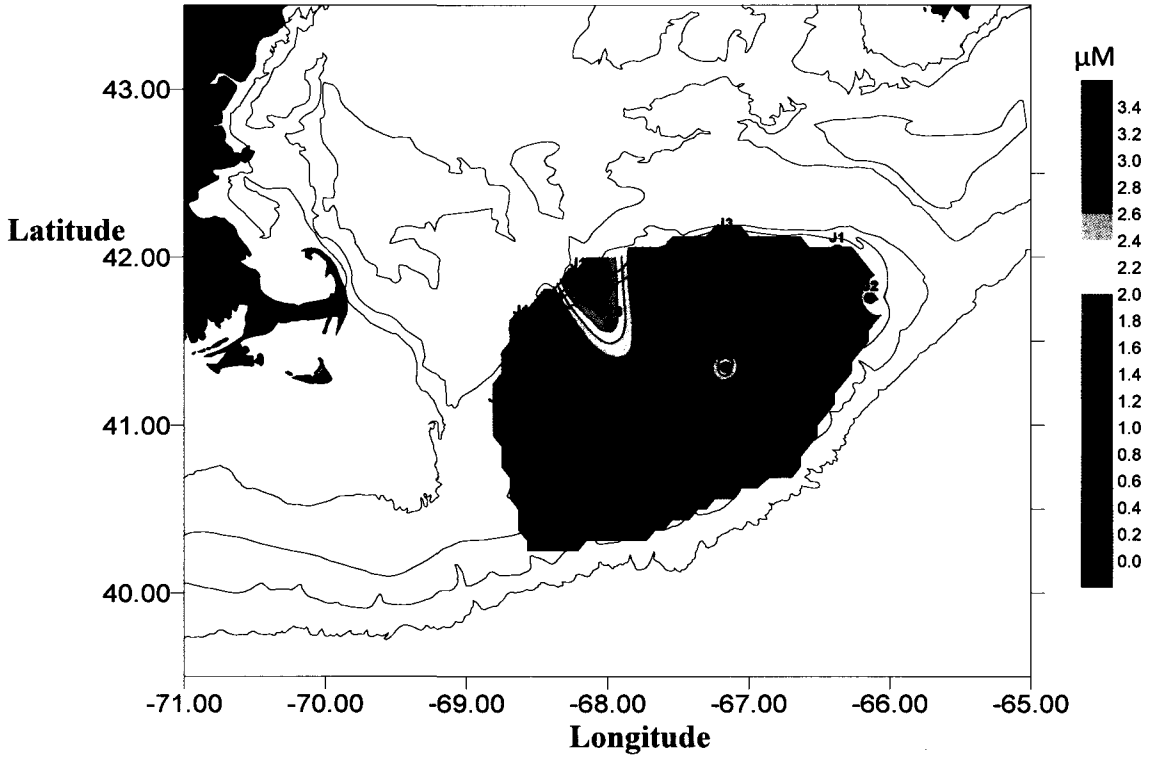

Figure 4.12. EN448 (27 June-3 July 2008) surface $Si(OH)_4$ concentrations.

Surface phosphate (PO_4^{-3}) concentrations were higher along the northern flank at the end of April, but did not exceed 1.5 μM anywhere on the Bank (Fig. 4.13). Increased levels of PO_4^{-3} (>1 μM) were observed along the eastern-most edges of Georges Bank during OC447 and EN448 (27 May-3 June and 27 June-3 July; Figs. 4.14 and 4.15). Despite some localized patches, PO_4^{-3} levels remained low and often undetectable throughout most of the Bank for the remainder of the summer. A plot of all $NO_3^- + NO_2^-$ surface concentrations versus PO_4^{-3} for each of the three cruises shows that it was nitrogen, not phosphorus that was limiting on the Bank in the summer (Fig. 4.16). All but only one or two data pairs fell to the behind the 16:1 line representing the Redfield ratio.

Surface ammonium (NH_4^+) levels displayed an interesting pattern during the summer months on Georges Bank. Whereas concentrations rarely exceed 2.0 μM, increased concentrations of NH_4^+were observed on different portions of the Bank throughout the summer, with higher levels generally present on the Northeast Peak during OC445 (2, May 2008; Fig. 4.17). Patches of higher concentrations of NH_4^+at the end of May and June were generally observed along the southern portions of the Bank , and may be the result of higher grazer activity on the Southern Flank, following the spring bloom (Townsend et al., 2006; Figs. 4.18 and 4.19).

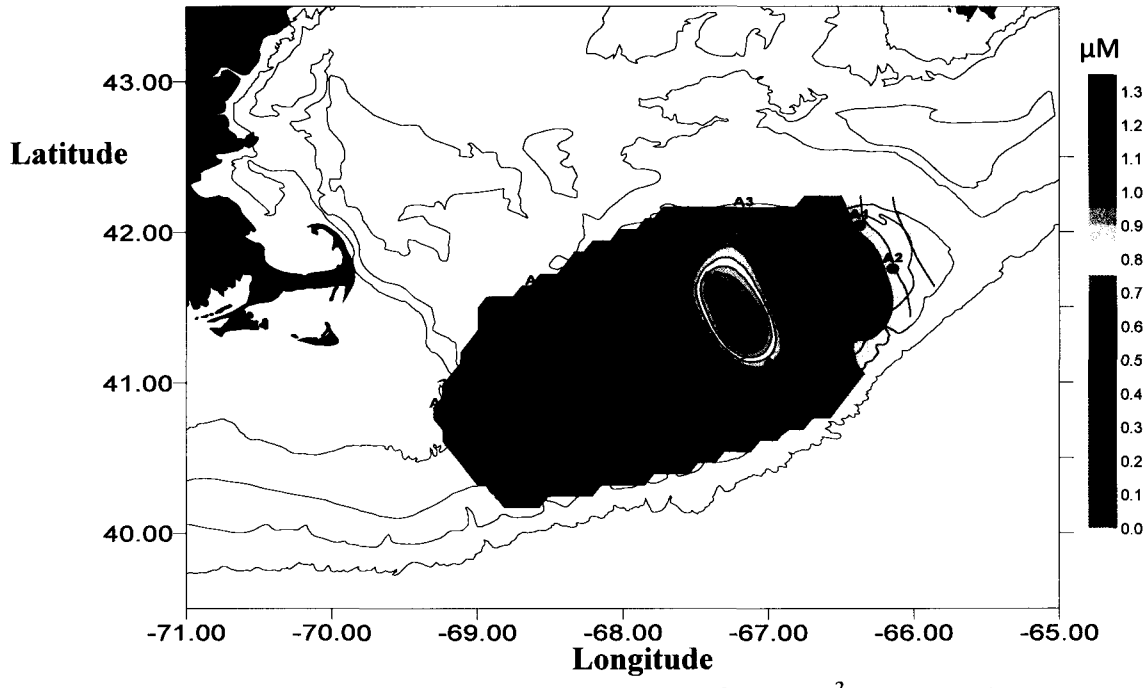

Figure 4.13. OC445 (28 April-5 May 2008) surface PO_4^{-3} concentrations.

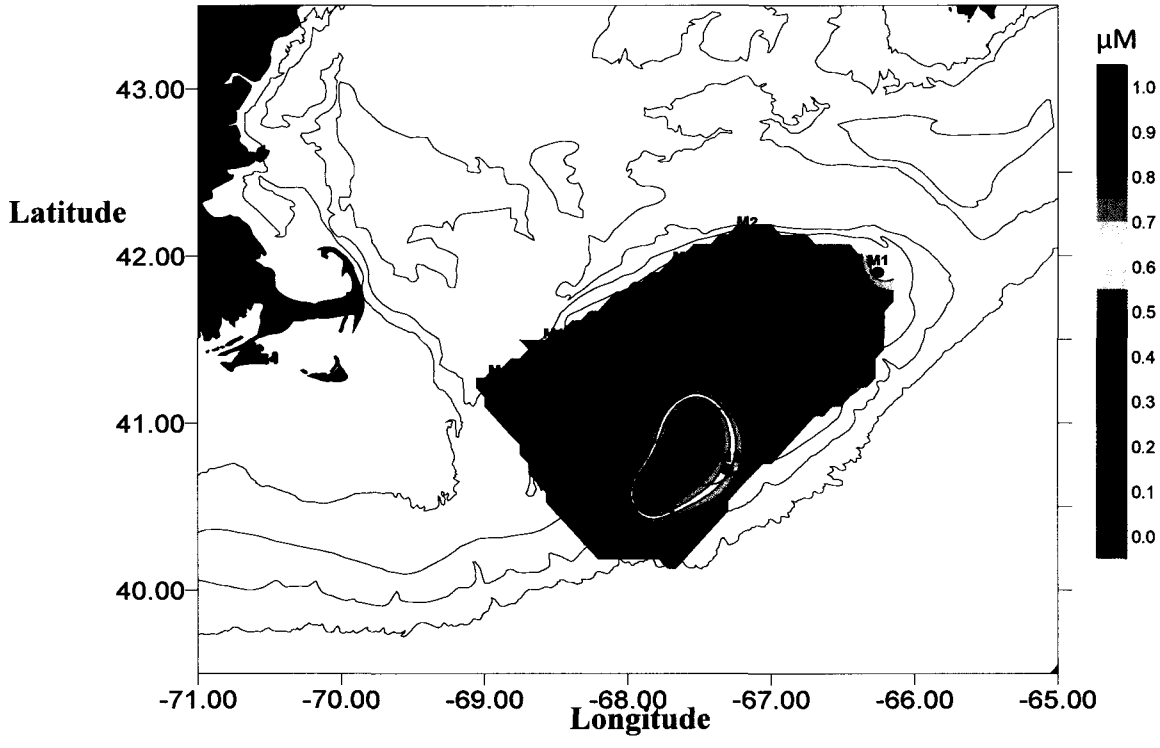

Figure 4.14. OC447 (27 May-4 June 2008) surface PO_4^{-3} concentrations.

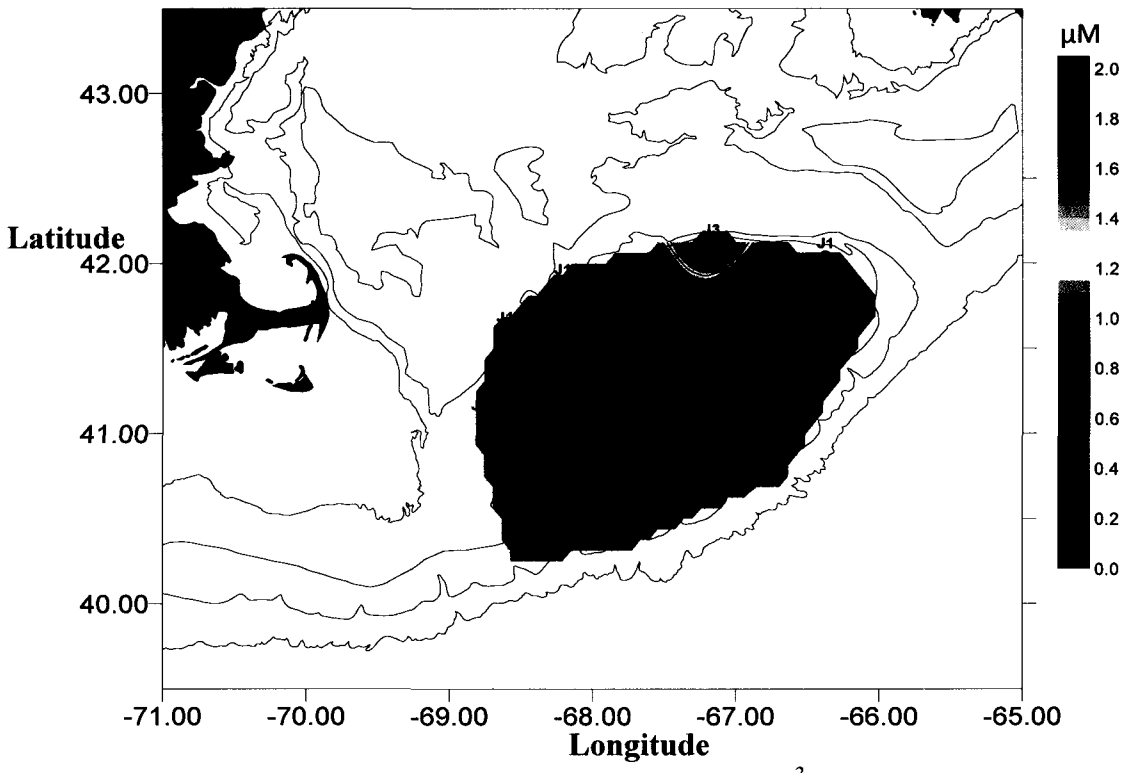

Figure 4.15. EN448 (27 June-3 July 2008) surface PO_4^{-3} concentrations.

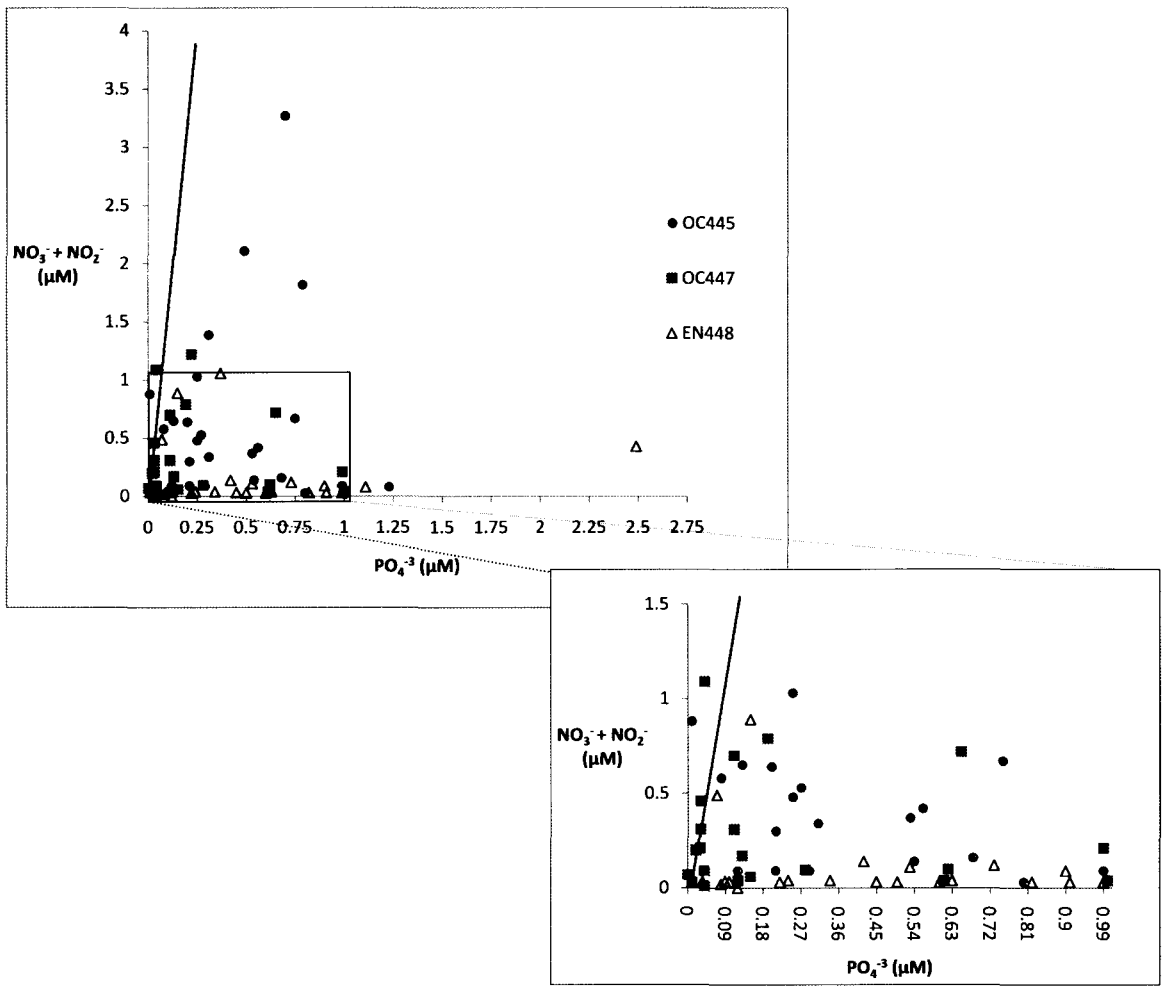

Figure 4.16. $NO_3^- + NO_2^-$ versus PO_4^{-3} concentrations (µM) for OC445 (28 April-5 May 2008), OC447 (27 May-4 June 2008), and EN448 (27 June-3 July 2008) cruises, with 16:1 Redfield line inserted.

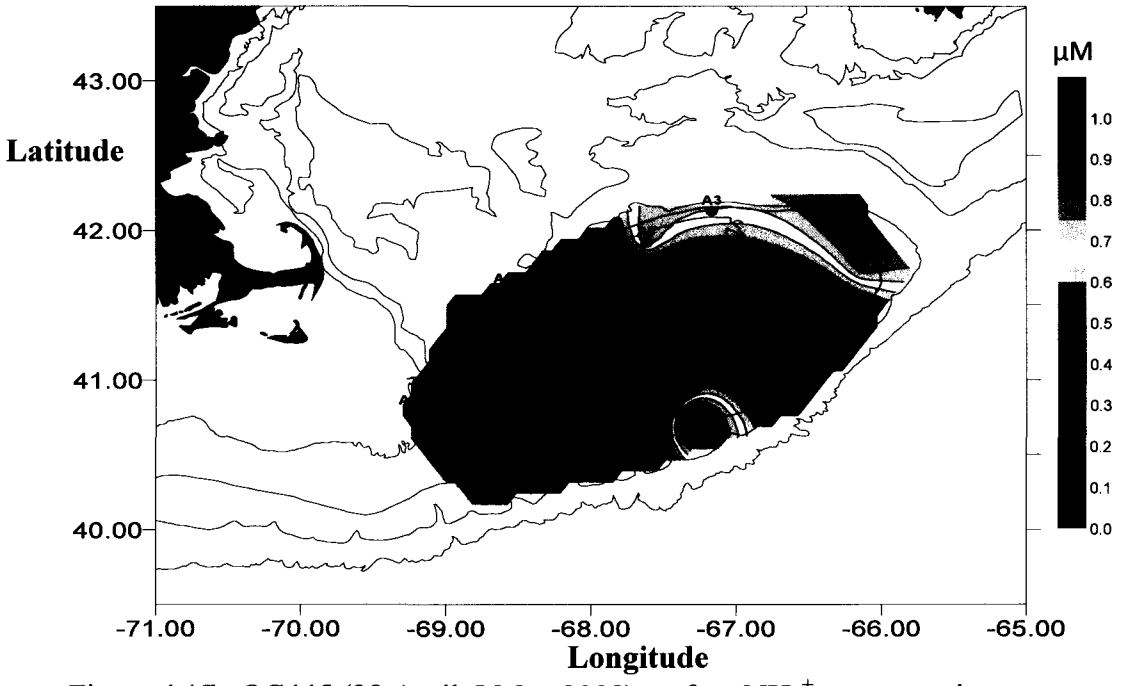

Figure 4.17. OC445 (28 April-5 May 2008) surface NH_4^+ concentrations.

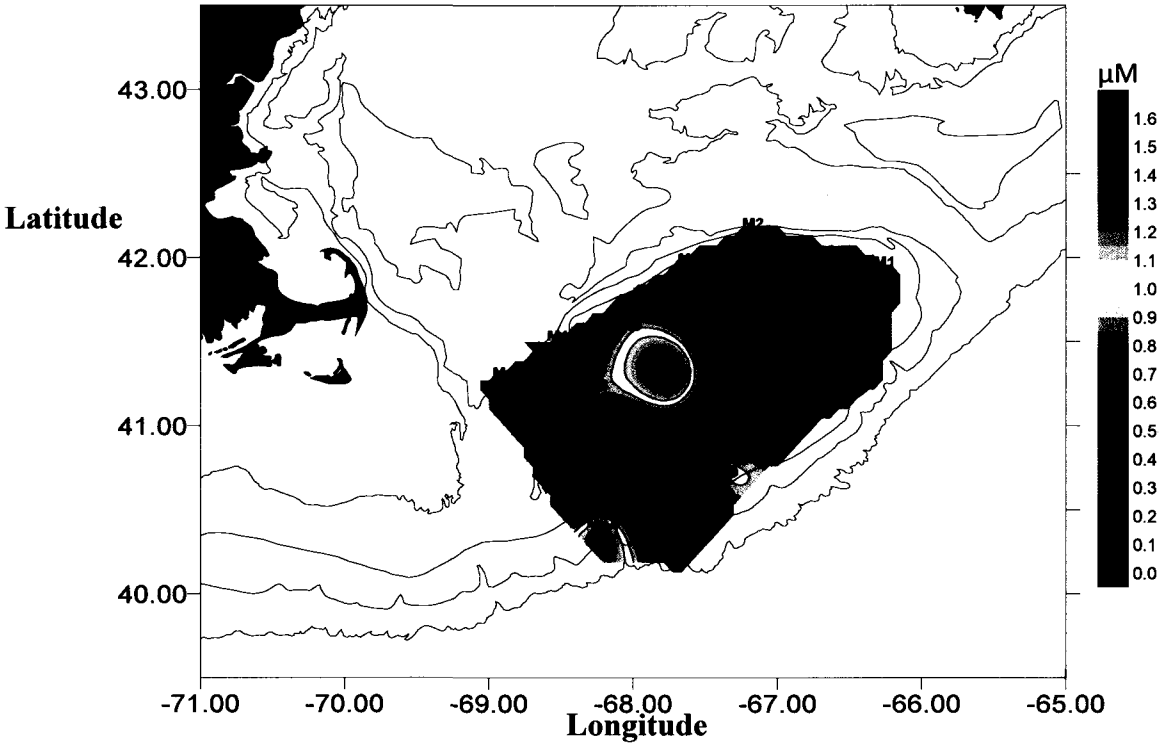

Figure 4.18. OC447 (27 May-4 June 2008) surface NH_4^+ concentrations.

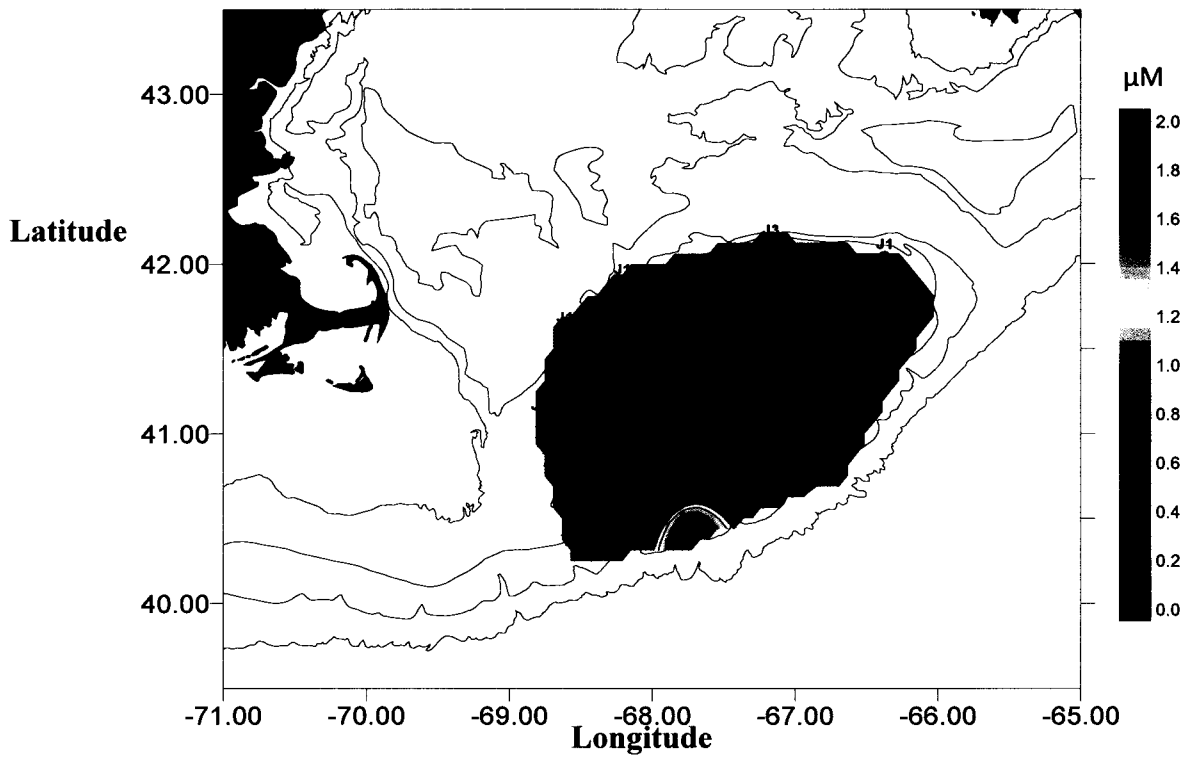

Figure 4.19. EN448 (27 June-3 July 2008) surface NH_4^+ concentrations.

4.3. Chlorophyll analyses

Total and size-fractionated (> 20 µm and < 20 µm) chlorophyll-a concentrations were measured on each of these cruises to determine whether they might be useful in assessing differences in the community structure. In general, chlorophyll present in material > 20 µm was similar in areal distributions to those of total chlorophyll on all three cruises, suggesting that the larger phytoplankton account for the majority of the phytoplankton biomass on Georges Bank. This is evident during OC445 in late April and early May, where total and > 20 µm chlorophyll levels reached 5-10 µg L^{-1} on some parts of the bank, in particular along the central-southwestern portions (Figs. 4.20 and 4.21). Less than 20 µm chlorophyll concentrations were much lower across Georges Bank at the

end of April, only exceeding 4 μg L^{-1} at a few stations along the Southern Flank (Fig. 4.22).

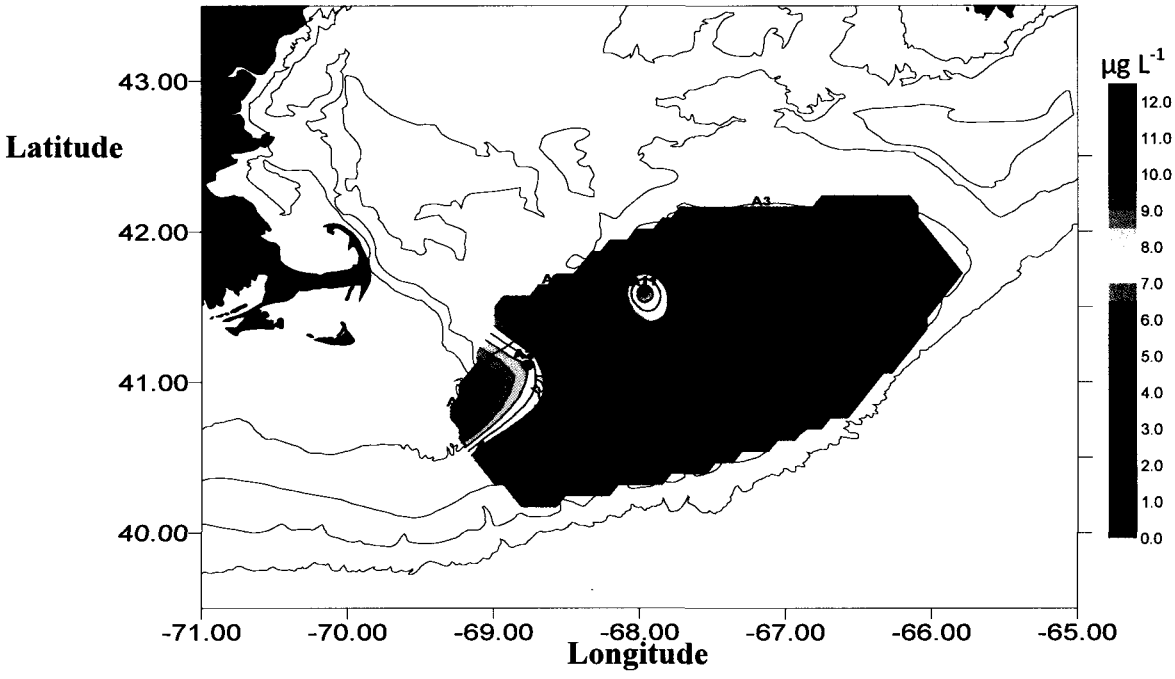

Figure 4.20. OC445 (28 April-5 May 2008) total surface chlorophyll a concentrations.

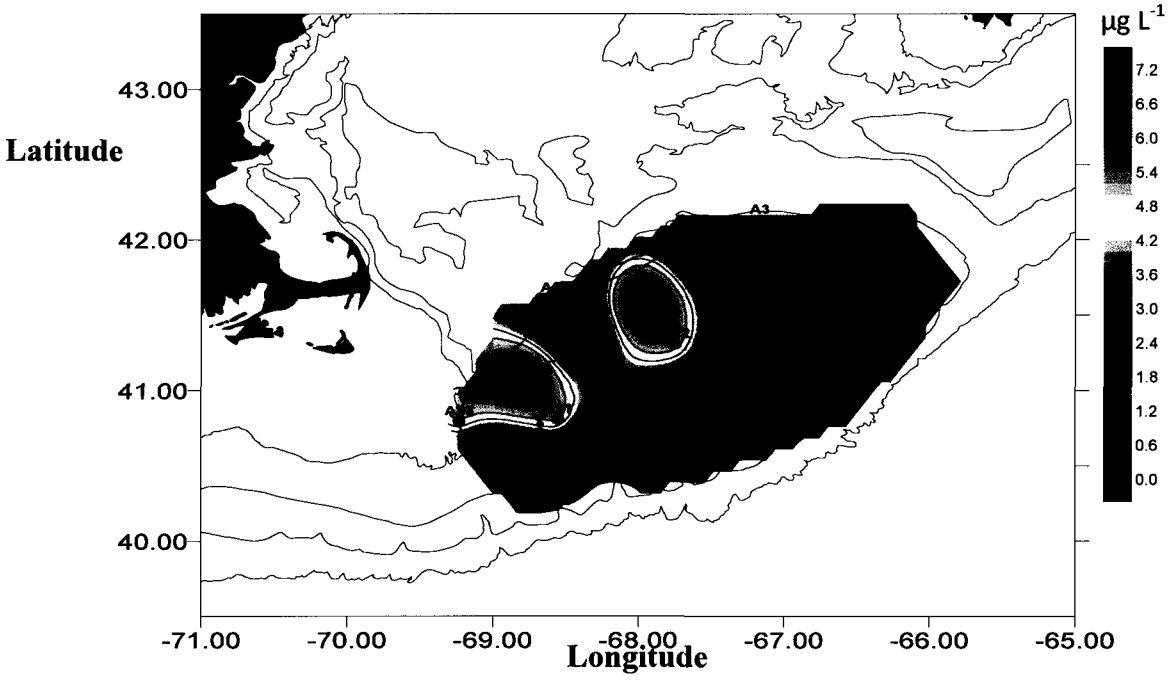

Figure 4.21.OC445 (28 April-5 May 2008) > 20 μm surface chlorophyll a concentrations.

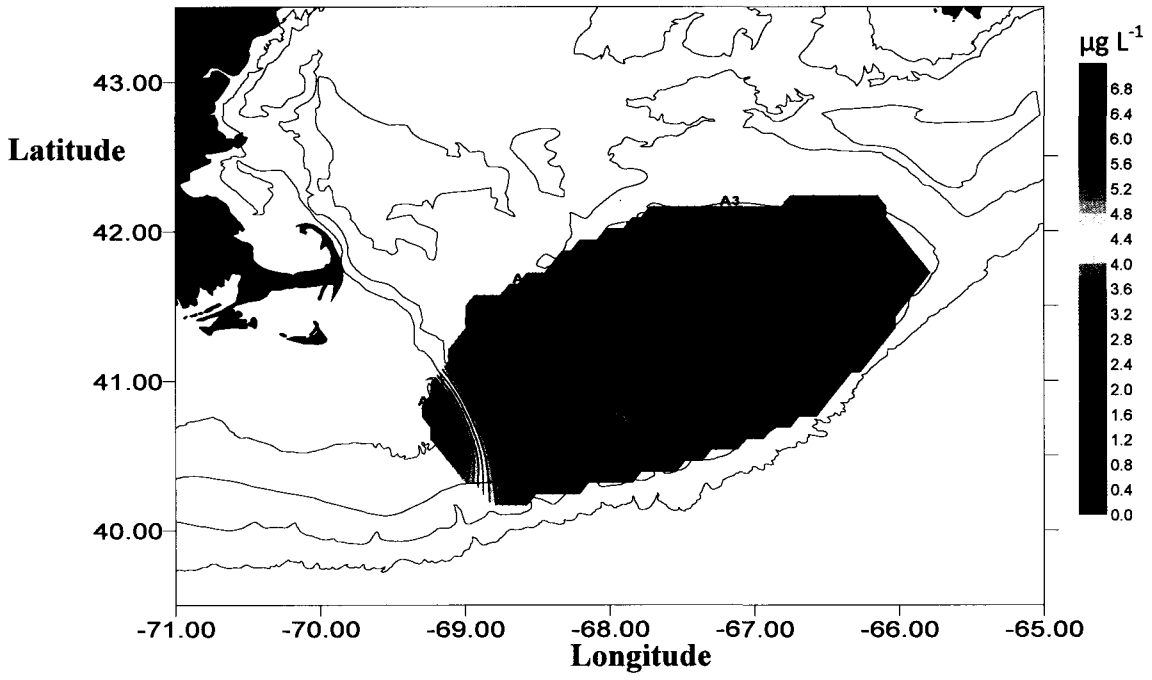

Figure 4.22.OC445 (28 April-5 May 2008) < 20 μm surface chlorophyll a concentrations.

Total and > 20 μm chlorophyll levels were relatively low (< 2 μg L^{-1}) across much of the Bank in late May, except for a patch at the northern peak of the Bank where concentrations exceeding 10 μg L^{-1} were observed at some stations (Figs. 4.23 and 4.24). The < 20 μm chlorophyll size fraction again remained at less than 2 μg L^{-1} throughout the Bank, with the exception of slightly higher concentrations (ca. 3-4 μg L^{-1}) on the Northeast Peak (Fig. 4.25).

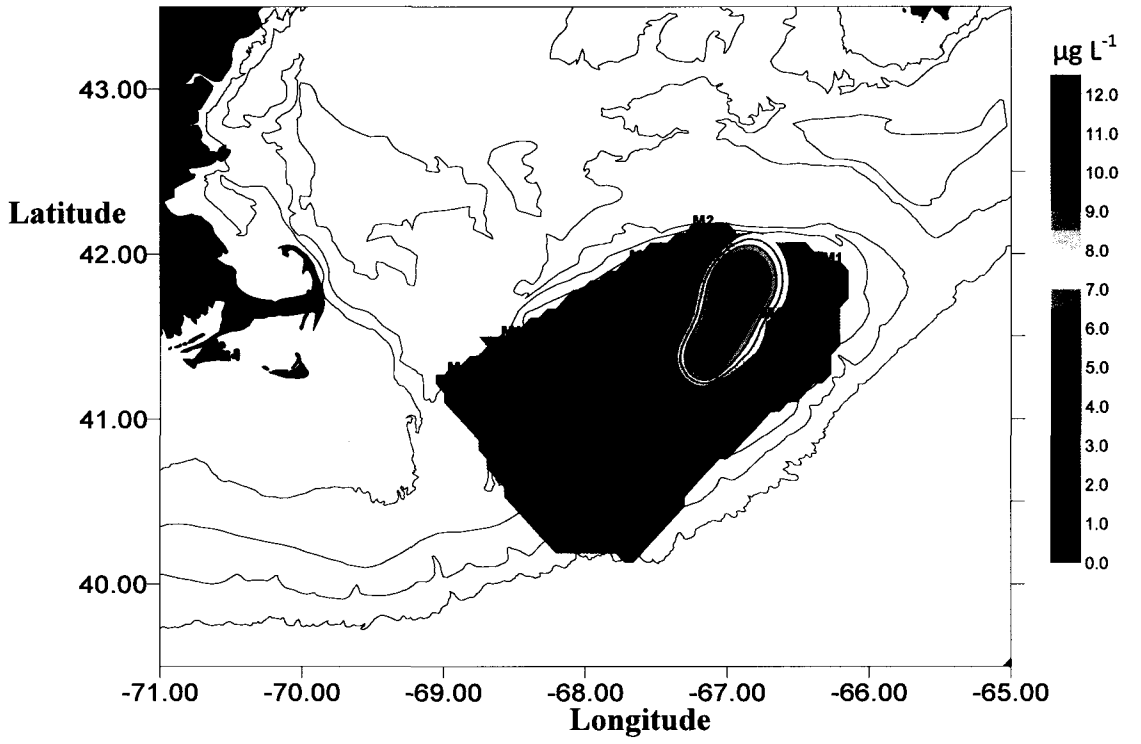

Figure 4.23. OC447 (27 May-4 June 2008) total surface chlorophyll a concentrations.

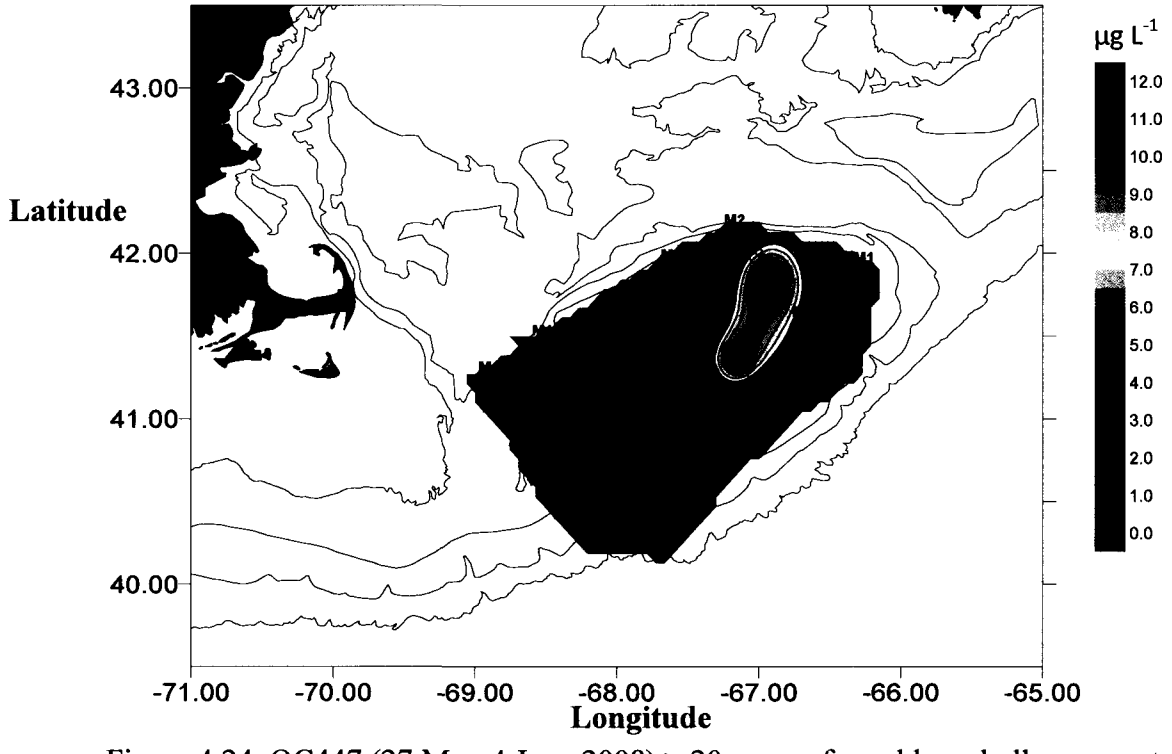

Figure 4.24. OC447 (27 May-4 June 2008) > 20 μm surface chlorophyll a concentrations.

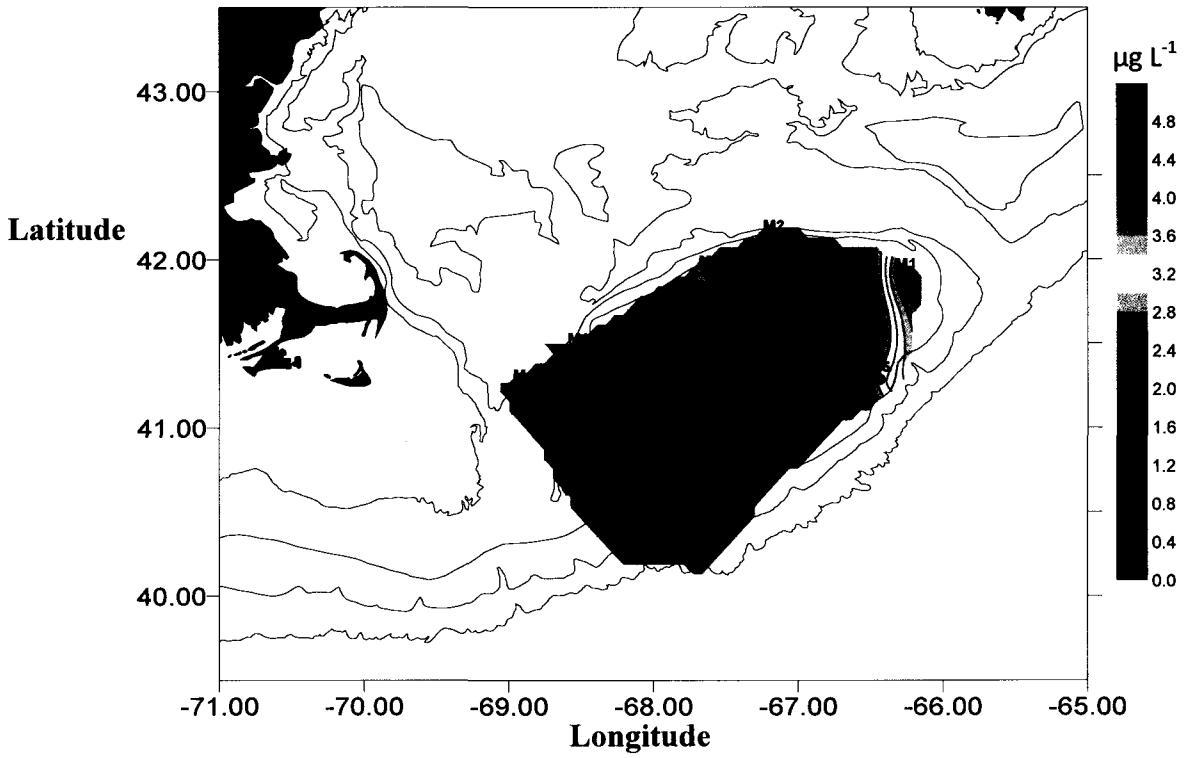

Figure 4.25. OC447 (27 May-4 June 2008) < 20 µm surface chlorophyll a concentrations.

By late June, total and > 20 µm chlorophyll levels had decreased, and did not exceed 8.0 µg L^{-1} anywhere on Georges Bank. Slightly higher concentrations were evident along some of the inner-Bank stations, while the outer edges were low, with concentrations less than 1 µg L^{-1} (Figs. 4.26 and 4.27). The < 20 µm phytoplankton population appeared to contribute slightly more to the chlorophyll a concentrations during late June and early July on the central crest of the Bank, with concentrations increasing to 3-4 µg L^{-1} at some stations (Fig. 4.28).

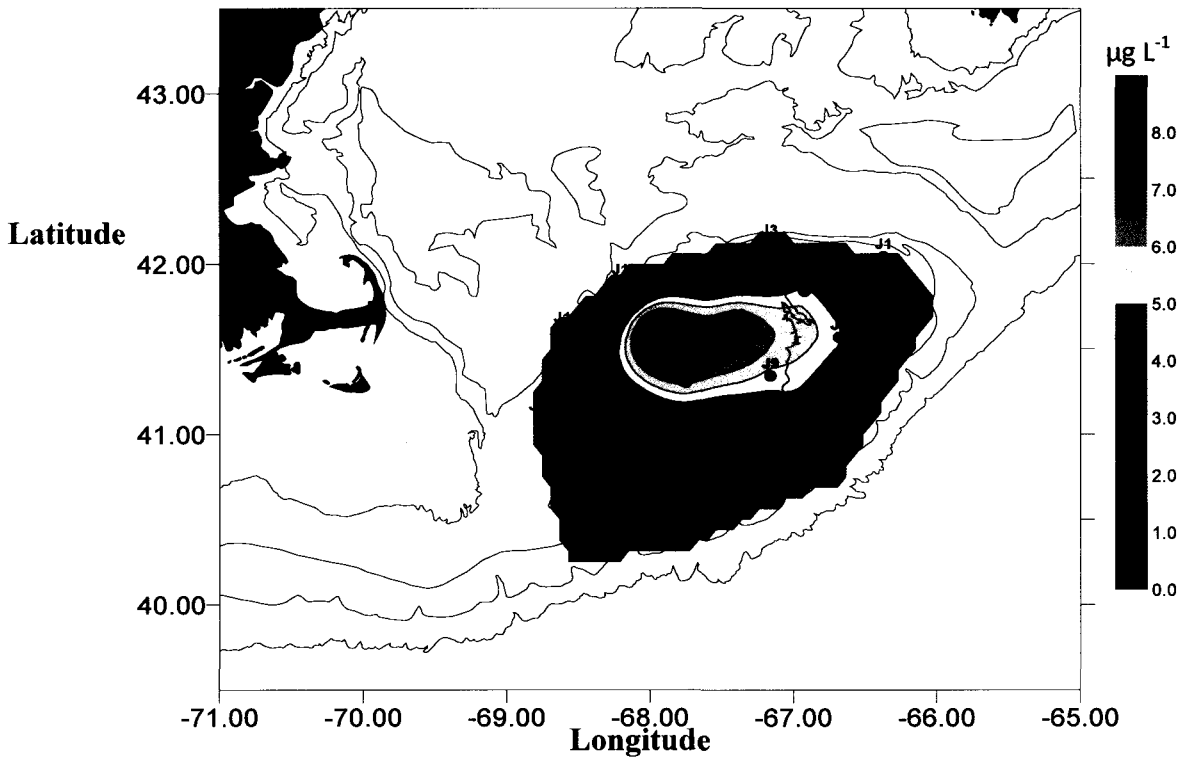

Figure 4.26. EN448 (27 June-3 July 2008) total surface chlorophyll a concentrations.

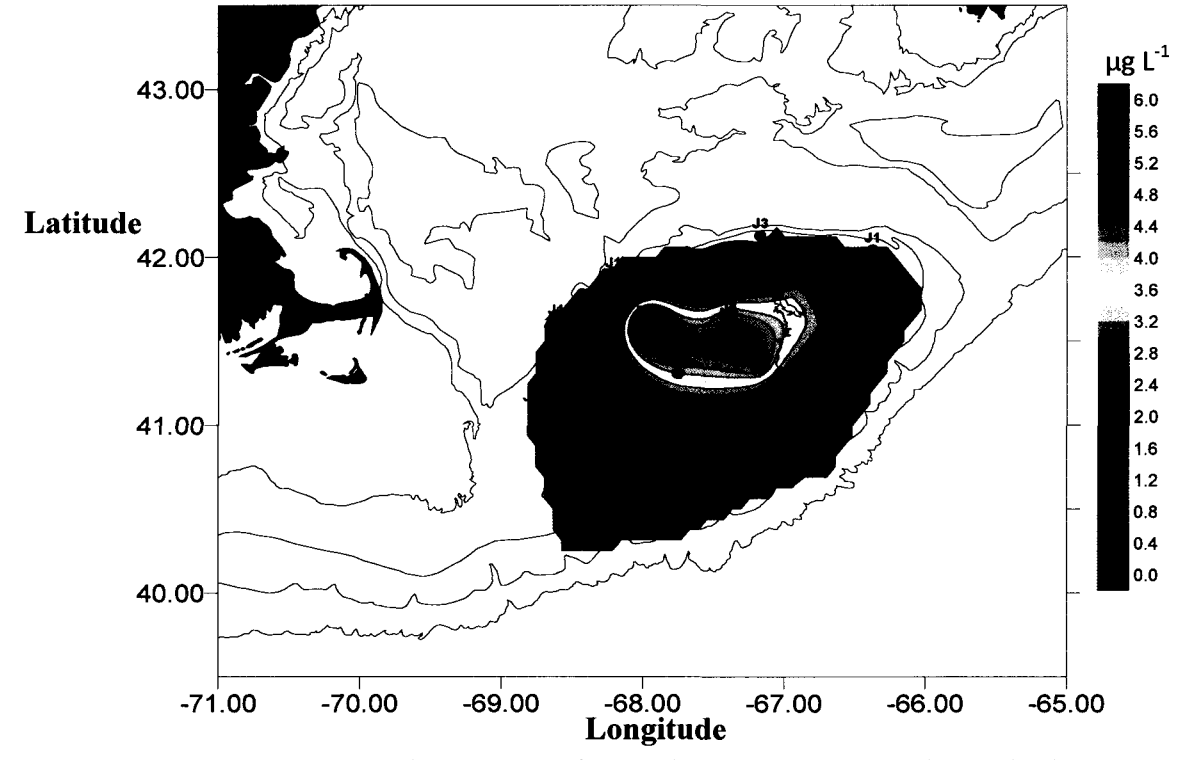

Figure 4.27. EN448 (27 June-3 July 2008) > 20 μm surface chlorophyll a concentrations.

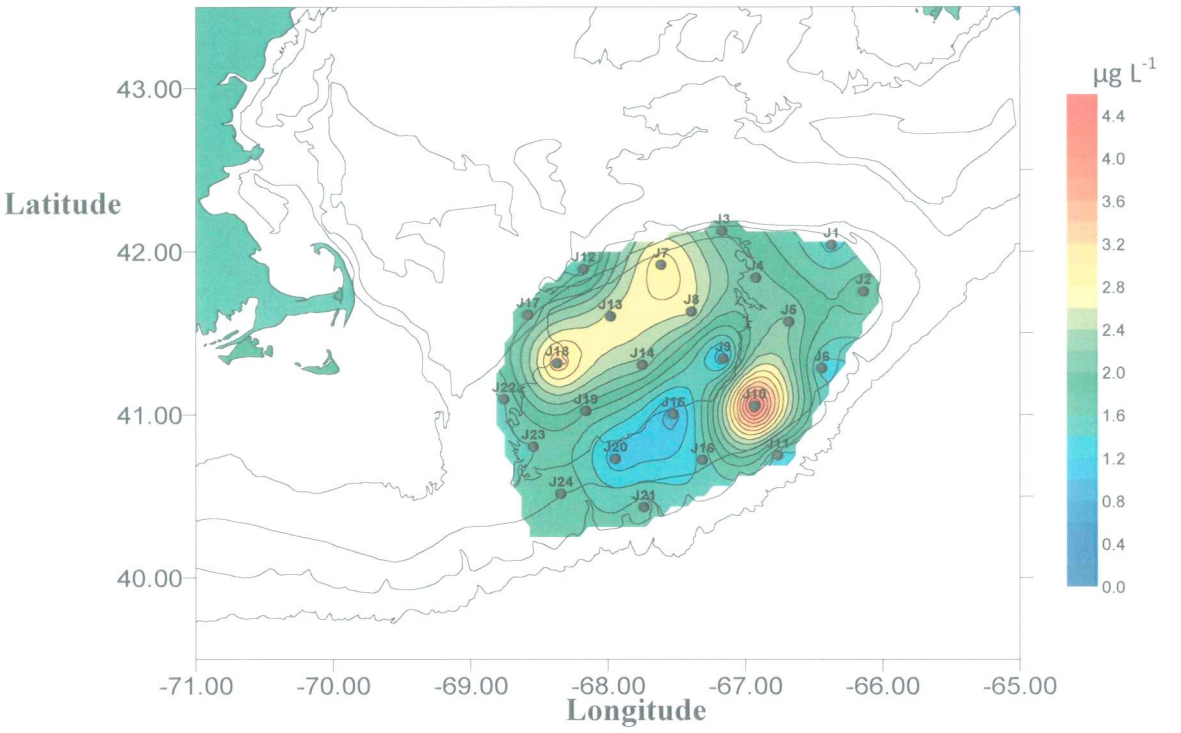

Figure 4.28. EN448 (27 June-3 July 2008) < 20 µm surface chlorophyll a concentrations.

4.4. Phytoplankton community structure

A total of 31 phytoplankton taxa were identified on Georges Bank during the summer of 2008, including 16 dinoflagellates, 13 diatoms, and 2 nanoplankton taxa. Of the 31 taxa, eight were identified to species (Appendices E, F, and G). *Phaeocystis* spp., *Cryptomonas* spp., and other unidentified nanoplankton were by far the most abundant taxa observed on Georges Bank during all three survey cruises. Diatoms were present in high cell concentrations (> 100,000 cells L^{-1}) at some stations; however, their presence was patchy, leaving the summer community dominated largely by dinoflagellates and nanoplankton (Appendix D). Replication of single transects (Fig 3.1) for each of the first two cruises revealed some variability between station cell counts, in which the major phytoplankton groups (and *Alexandrium* spp.) were enumerated. However, in general,

abundances of diatoms, dinoflagellates, and *Alexandrium* spp. for each count were within one standard deviation of the mean (Figs. 4.29 and 4.30; Appendix L).

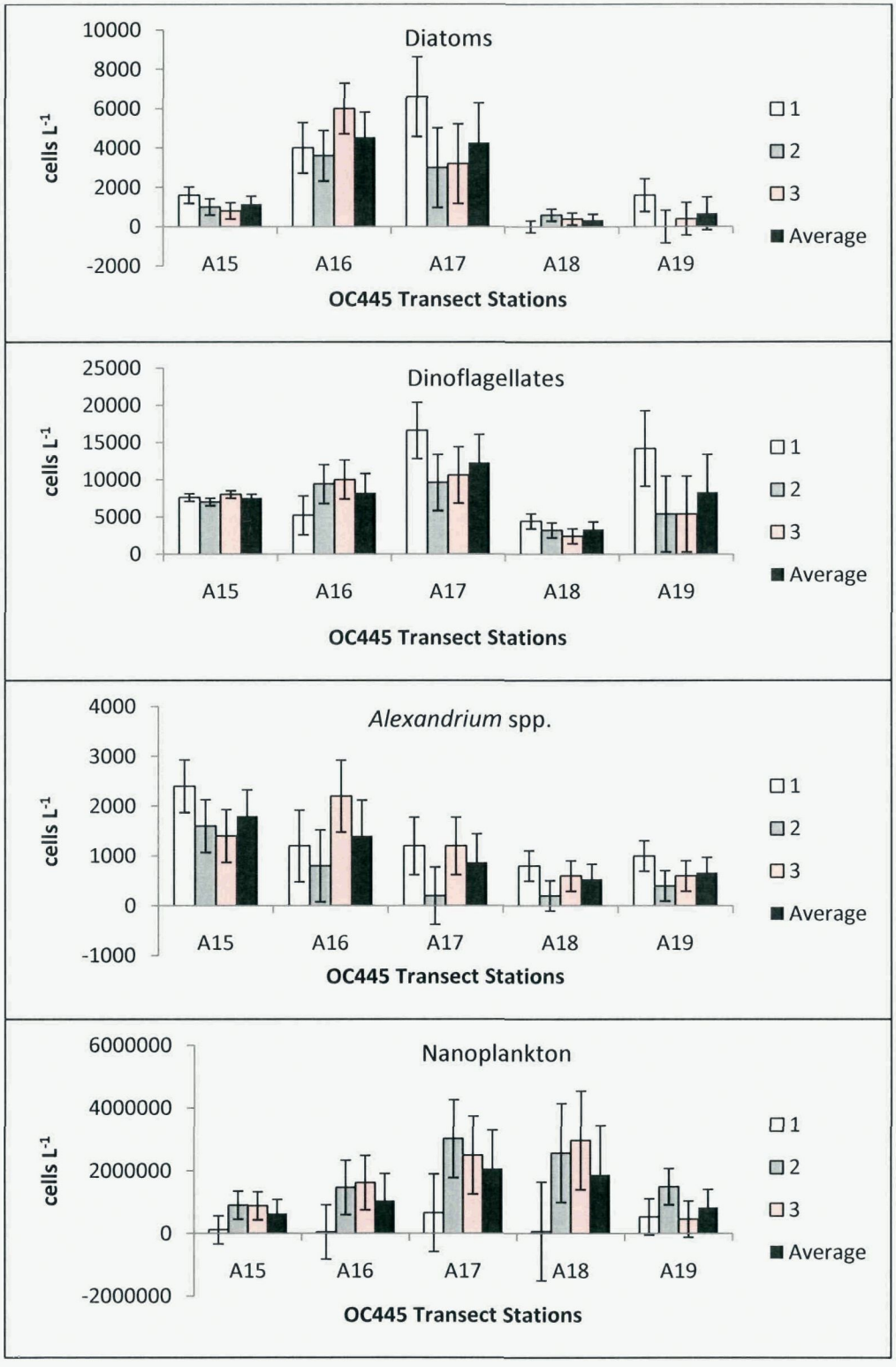

Figure 4.29. Triplicate counts of diatoms, dinoflagellates, *Alexandrium* spp., and nanoplankton for OC445 (28 April-5 May 2008) cruise transect. (See Fig. 1, panel 1). Error bars represent standard deviations.

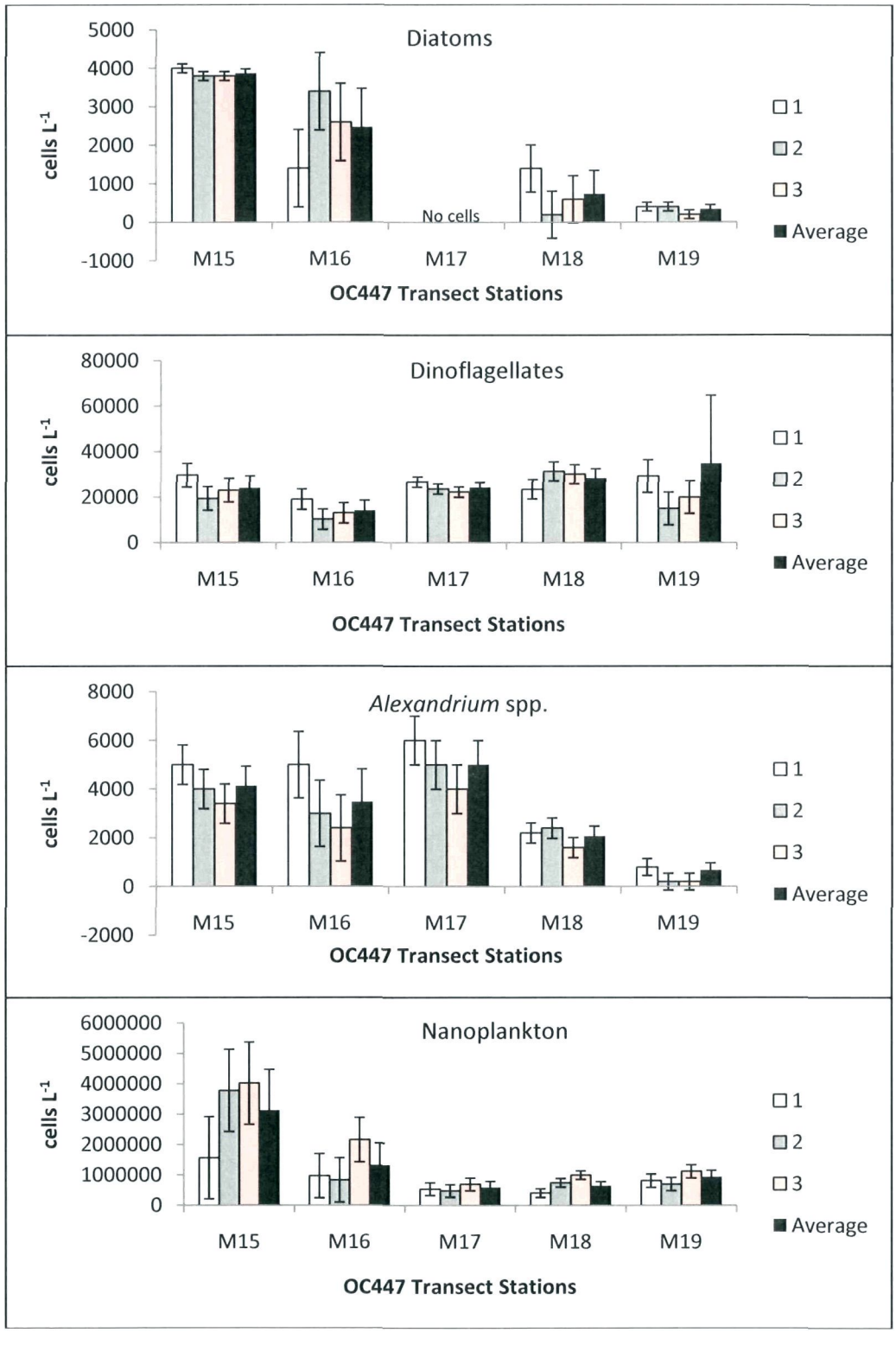

Figure 4.30. Triplicate counts of diatoms, dinoflagellates, *Alexandrium* spp., and nanoplankton for OC447 (27 May-4 June 2008) cruise transect (See Fig. 1, Panel 1). Error bars represent standard deviations.

The curtailment of the annual spring diatom bloom on Georges Bank was apparent by April, as diatom cell densities were relatively low throughout most of the Bank, most likely the result of depleted nutrient levels, in particular silicate (Fig. 4.31). Because our three cruises began well after the spring phytoplankton bloom, the presence of high cell densities of diatoms on the Northeast Peak of Georges Bank (in excess of 200,000 cells L^{-1}, mainly comprised of *Coscinodiscus* spp., *Thalassiosira* spp., and *Skeletonema* spp.) would suggest that increased nutrient injections there stimulated continued diatom growth (Appendix E, Table E.1). Whereas slightly elevated total chlorophyll levels (4-6 μg L^{-1}) were associated with the diatom-dominated Northeast Peak, in general, the highest total and > 20 μm chlorophyll levels were not associated with the highest densities of diatoms (Figs 4.20, 4.21, 4.31).

While cell densities were relatively low, compared with the Northeast Peak, the phytoplankton community in late April was still dominated by diatoms, which made up the majority of the top 25 most abundant taxa during OC445, excluding nanoplankton (Table 4.1). Dinoflagellate densities, including *Alexandrium* spp. were relatively low at the end of April, and did not exceed 20,000 cells L^{-1} (Figs. 4.32 and 4.33), leaving only six major dinoflagellate taxa and a group of unidentified flagellate cysts as part of the top 25 taxa observed in April (Table 4.1). However, a number of dinoflagellate taxa including: *Alexandrium* spp., *Gyrodinium* spp., *Protoperidinium* spp., and unidentified dinoflagellate cysts, were present at nearly every station during the OC445 cruise, indicating the seasonal increase in the dinoflagellate population (Table 1). Nanoplankton abundance was relatively low in comparison to the remaining two cruises, with cell densities less than 1,000,000 cells L^{-1} on the Bank (Fig. 4.34).

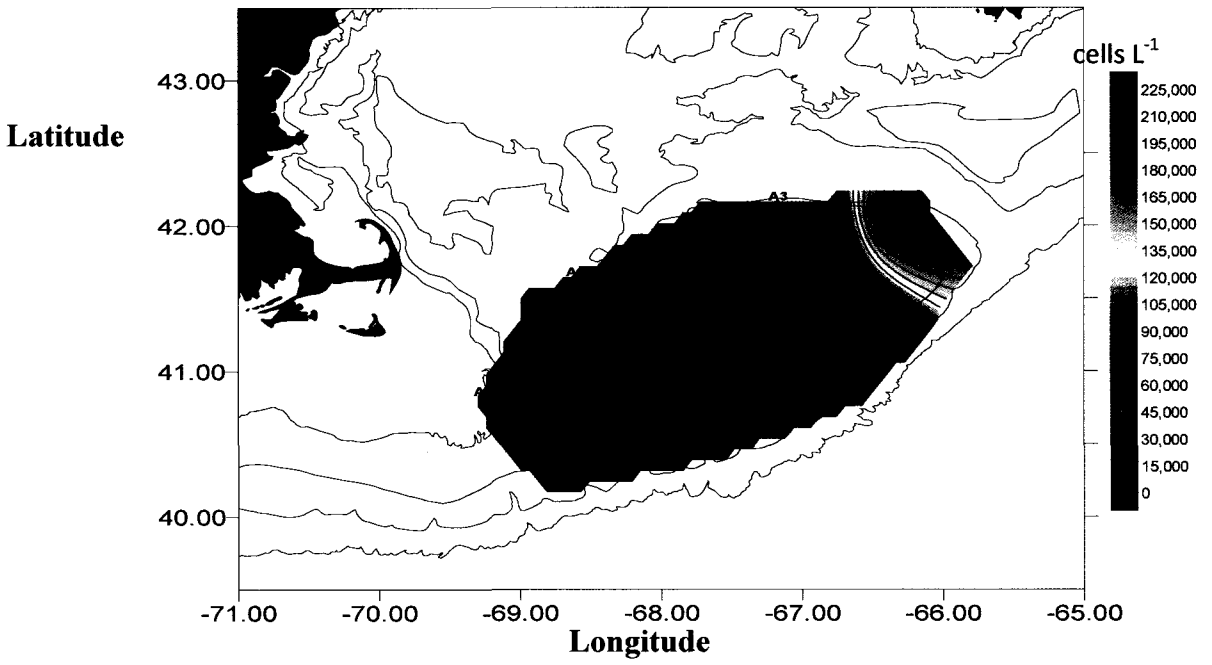

Figure 4.31. OC445 (28 April-5 May 2008) surface diatom cell densities.

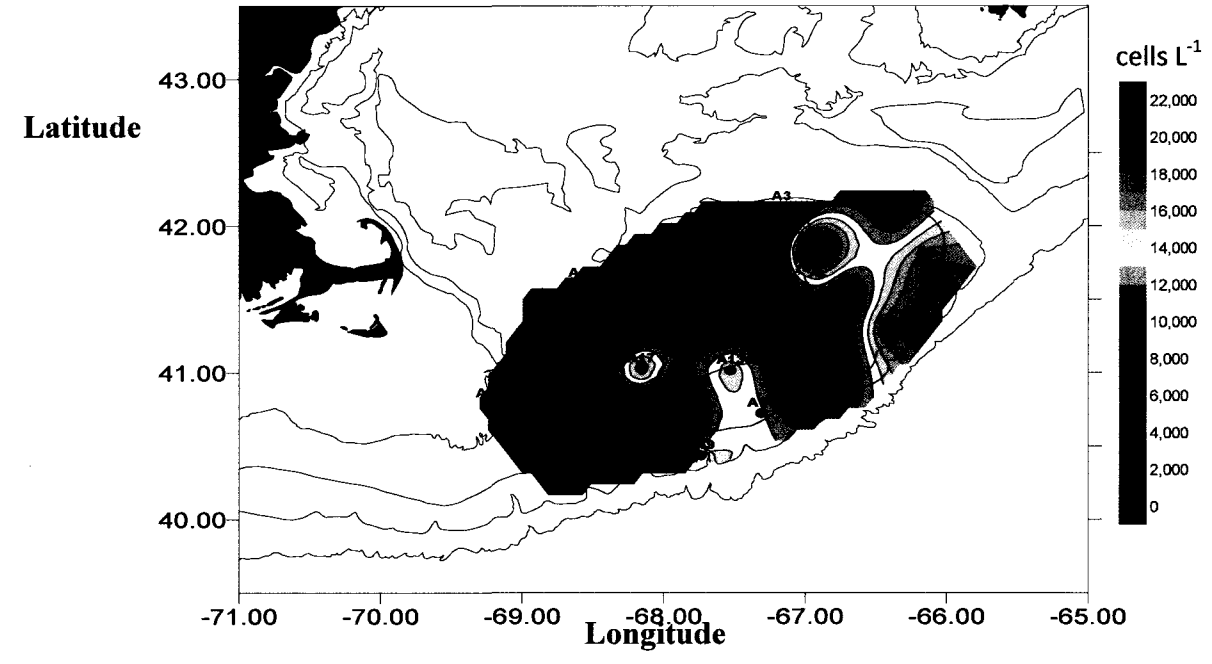

Figure 4.32. OC445 (28 April-5 May 2008) surface dinoflagellate cell densities.

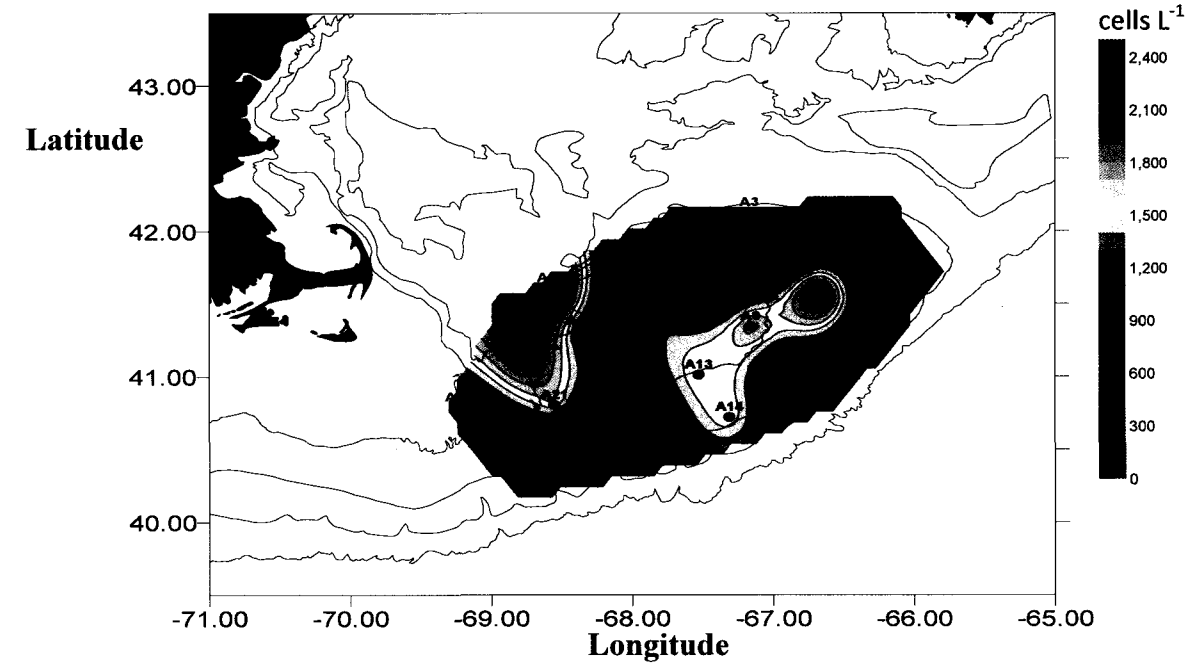

Figure 4.33. OC445 (28 April-5 May 2008) surface *Alexandrium* spp. cell densities.

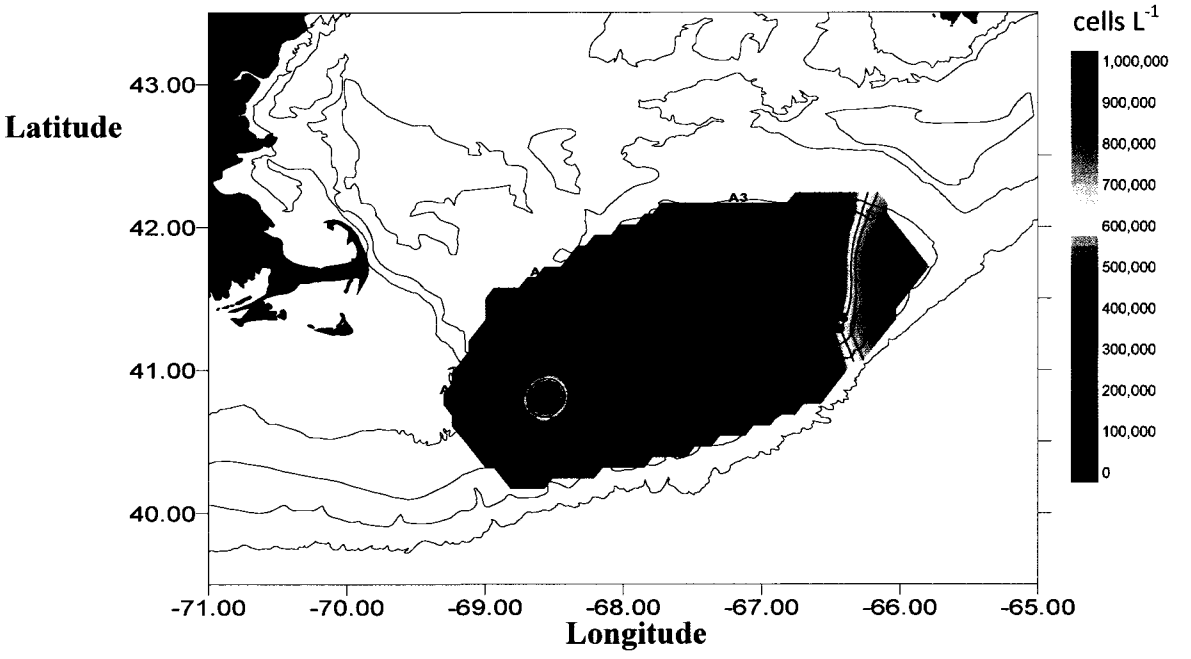

Figure 4.34. OC445 (28 April- 5 May 2008) surface nanoplankton cell densities.

Table 4.1. OC445 (28 April- 5 May 2008) rank order of the 25 most abundant phytoplankton taxa observed and rank order of the number of samples in which found (n=24). Dinoflagellate and raphidophyte taxa are highlighted in grey.

Taxon	Class	Rank order of average abundance per sample	Rank order of number of samples observed
Phaeocystis spp.	Prymnesiophyceae	1	4
other nanoplankton		2	4
Cryptomonas spp.	Cryptophyceae	3	3
Coscinodiscus spp.	Coscinodiscophyceae	4	5
Skeletonema spp.	Coscinodiscophyceae	5	10
Leptocylindrus spp.	Coscinodiscophyceae	6	7
Thalassiosira spp.	Coscinodiscophyceae	7	7
Amphidinium spp.	Dinophyceae	8	8
Scrippsiella spp.	Dinophyceae	9	6
Chaetoceros spp.	Coscinodiscophyceae	10	11
Pseudo-nitzschia spp.	Bacillariophyceae	11	13
cysts		12	3
Gryodinium spp.	Dinophyceae	13	4
Alexandrium spp.	Dinophyceae	14	1
Dactyliosolen spp.	Coscinodiscophyceae	15	12
Stephanopyxis spp.	Coscinodiscophyceae	16	15
Protoperidinium spp.	Dinophyceae	17	2
Gymnodinium spp.	Dinophyceae	18	7
Guinardia striata	Coscinodiscophyceae	19	14
Ceratium spp.	Dinophyceae	20	9
Dinophysis spp.	Dinophyceae	21	7
Paralia sulcata	Coscinodiscophyceae	22	16
Prorocentrum spp.	Dinophyceae	23	11
Rhizosolenia spp.	Coscinodiscophyceae	24	17
Gonyaulax spp.	Dinophyceae	25	18

By late May, an apparent shift in phytoplankton community structure had occurred. Diatom cell densities were lower (<60,000 cells L^{-1}) across the bank, including the Northeast Peak, where cell densities in excess of 200,000 cells L^{-1} were observed in April (Figs. 4.35 and 4.31). Dinoflagellate densities increased, especially along the Southern Flank of Georges Bank, as the annual *Alexandrium* bloom ensued, with dinoflagellate densities reaching as high as 70,000 cells L^{-1} at some stations (Fig. 4.36). It was during the late May survey that the highest *Alexandrium* spp. densities were observed, often exceeding 7,000 cells L^{-1} along the southeast edge (Fig. 4.37). Highest total and > 20 μm chlorophyll concentrations did not appear to coincide with increased dinoflagellate densities. In addition to high numbers of *Alexandrium* spp., increased densities of *Scrippsiella* spp., *Heterosigma* spp., and *Amphdinium* spp. were also observed during the May cruise, with 13 dinoflagellates making up part of the top twenty-five taxa (Appendix F, Table F.1; and Table 4.2). Slight increases in the nanplankton community were detected in the central and southwest regions of the ank, where the dinoflagellate population was relatively low (Fig. 4.38).

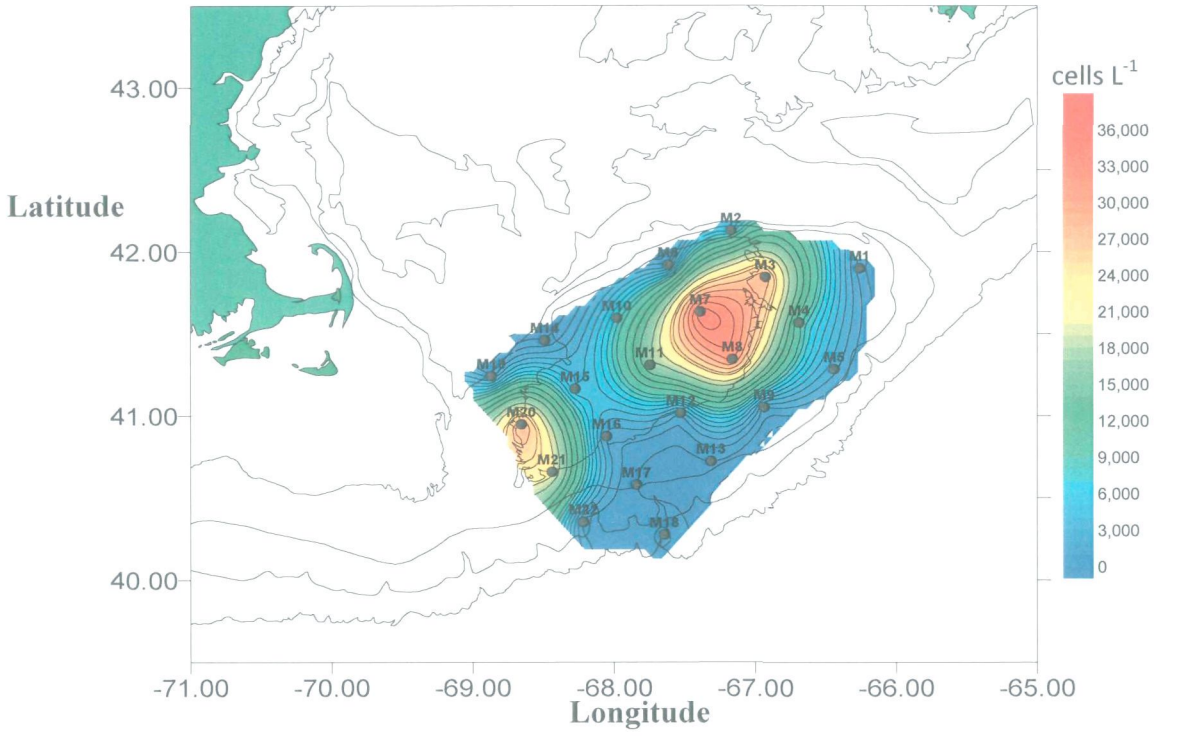

Figure 4.35. OC447 (27 May-4 June 2008) surface diatom cell densities.

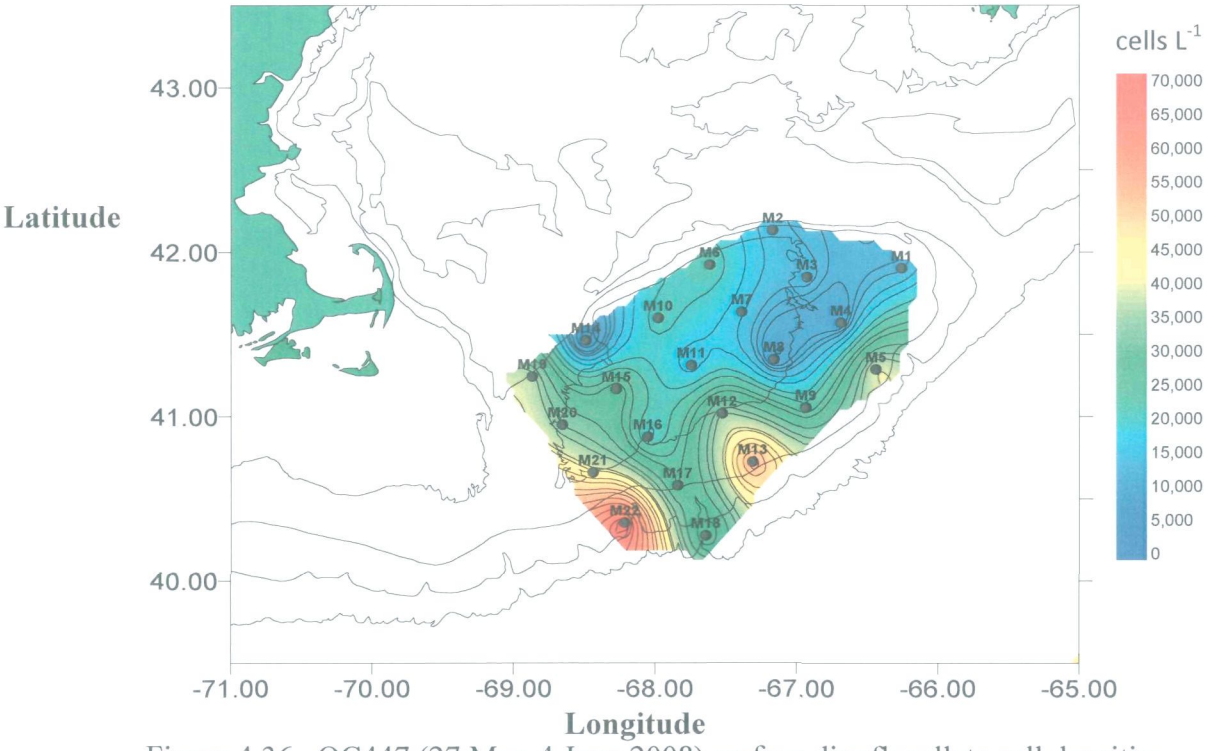

Figure 4.36. OC447 (27 May-4 June 2008) surface dinoflagellate cell densities.

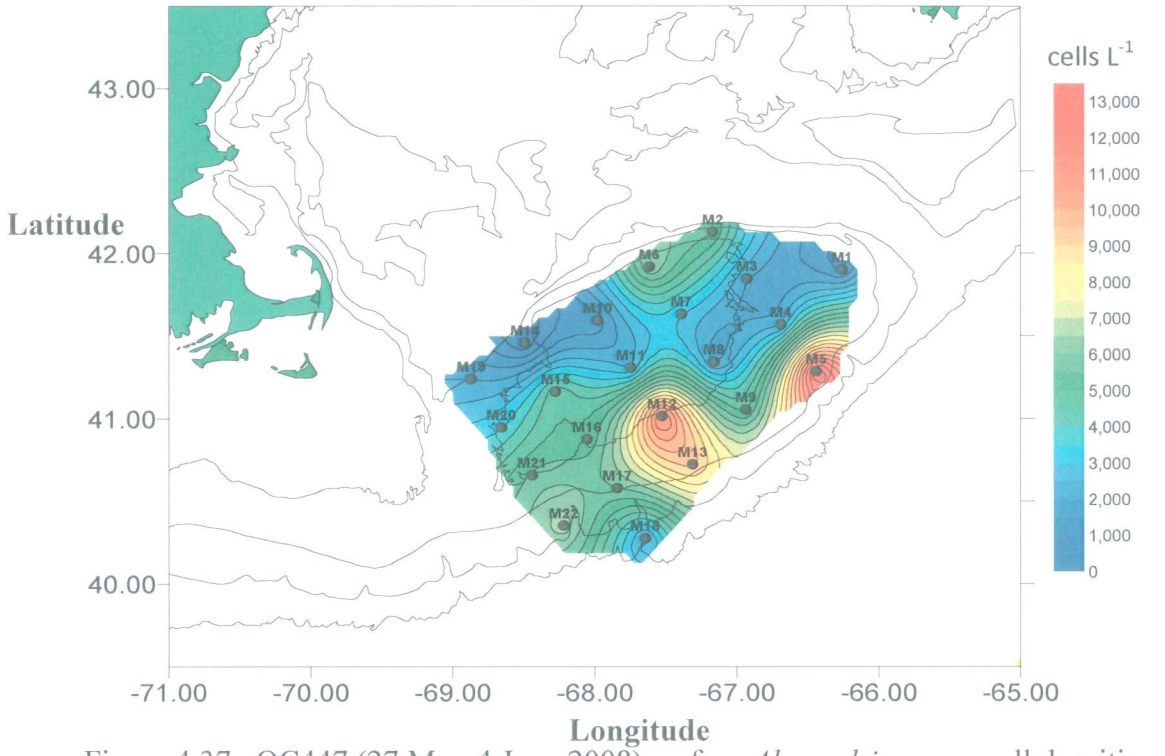

Figure 4.37. OC447 (27 May-4 June 2008) surface *Alexandrium* spp. cell densities.

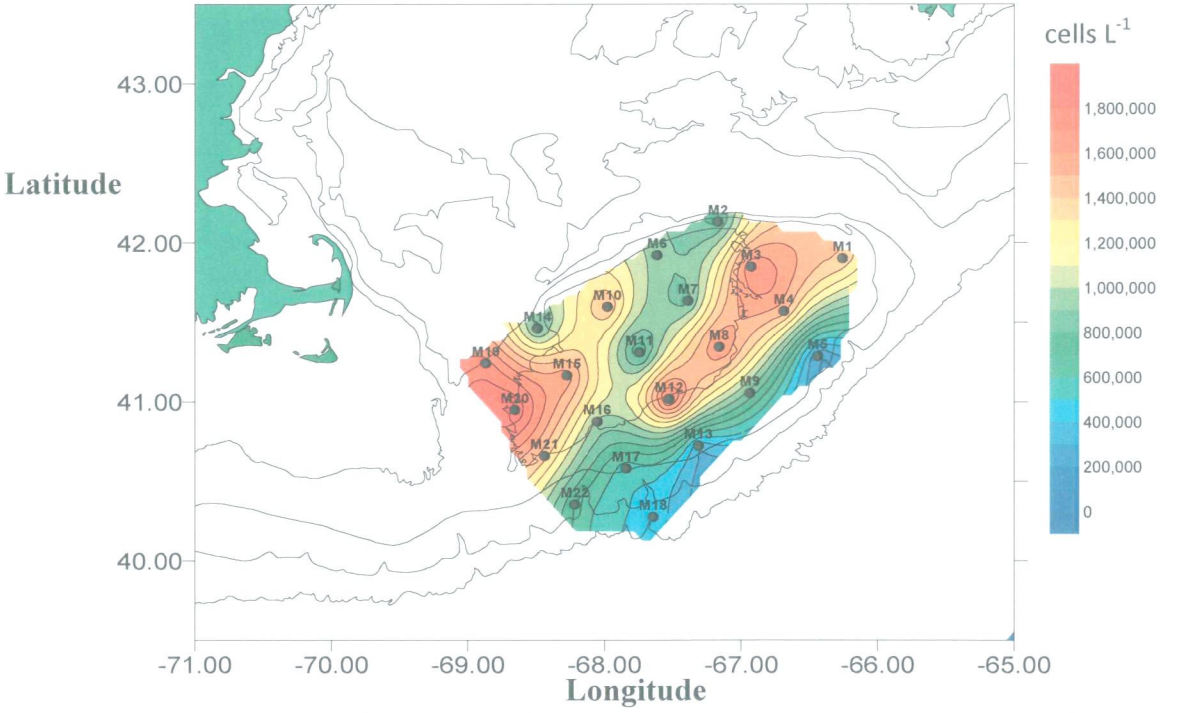

Figure 4.38. OC447 (27 May-4 June 2008) surface nanoplankton cell densities.

Table 4.2. OC447 (27 May-4 June 2008) rank order of the 25 most abundant phytoplankton taxa observed and rank order of the number of samples in which found (n=22). Dinoflagellate and Raphidophyte taxa are highlighted in grey.

Taxon	Class	Rank order of average abundance per sample	Rank order of number of samples observed
Phaeocystis spp.	Prymnesiophyceae	1	1
other nanoplankton		2	4
Cryptomonad spp.	Cryptophyceae	3	1
Alexandrium spp.	Dinophyceae	4	2
Amphidinium spp.	Dinophyceae	5	1
Guinardia flaccida	*Coscinodiscophyceae*	6	12
Scrippsiella spp.	Dinophyceae	7	3
Heterosigma spp.	Raphidophyceae	8	9
cysts		9	1
Heterocapsa spp.	Dinophyceae	10	6
Pseudo-nitzschia spp.	Bacillariophyceae	11	12
Gymnodinium spp.	Dinophyceae	12	2
Protoperidinium spp.	Dinophyceae	13	3
Coscinodiscus spp.	Coscinodiscophyceae	14	5
Gryodinium spp.	Dinophyceae	15	1
Ceratium spp.	Dinophyceae	16	5
Dactyliosolen spp.	Coscinodiscophyceae	17	13
Dinophysis spp.	Dinophyceae	18	8
Gonyaulax spp.	*Dinophyceae*	19	7
Prorocentrum spp.	Dinophyceae	20	10
Leptocylindrus spp.	Coscinodiscophyceae	21	14
Thalassiosira spp.	Coscinodiscophyceae	22	11
Chaetoceros spp.	Coscinodiscophyceae	23	12
Paralia sulcata	Coscinodiscophyceae	24	13
Guinardia striata	Coscinodiscophyceae	25	13

By the end of June, the peak of the *Alexandrium* spp. bloom was apparently passed, with cell concentrations now less than 2,000 cells L^{-1}; the general dinoflagellate population had also decreased across much of the Bank, leaving only a few stations along the eastern edge with cell concentrations in excess of 60,000 cells L^{-1} (Figs. 4.39 and 4.40). The dinoflagellate community was dominated by *Ceratium* spp., *Gyrodinium* spp., *Gymnodinium* spp., unidentified flagellate cysts, and the presence of *Polykrikos* spp., a heterotrophic dinoflagellate that was not observed during the April and May cruises (Appendix G, Tables G.1 and G.2; and Table 4.3). An interesting increase in diatom abundance occurred in the central portion of Georges Bank during this last cruise (EN448), with diatom cell numbers greater than 180,000 cells L^{-1} at some stations (Fig. 4.41), perhaps in response to the regeneration of silicate discussed above. The diatom composition at the end of June included high densities of *Leptocylindrus* spp., *Pseudo-nitzschia* spp., and *Guinardia flaccida* (Appendix G, Table G1). Highest densities of nanoplankton were observed during the last cruise, with densities greater than 8,000,000 cells L^{-1} present at the northeastern portion of the Bank (Fig. 4.42). This was evident in the < 20 μm chlorophyll data as well with some stations increasing to 4-5 μg L^{-1} (Fig. 4.28).

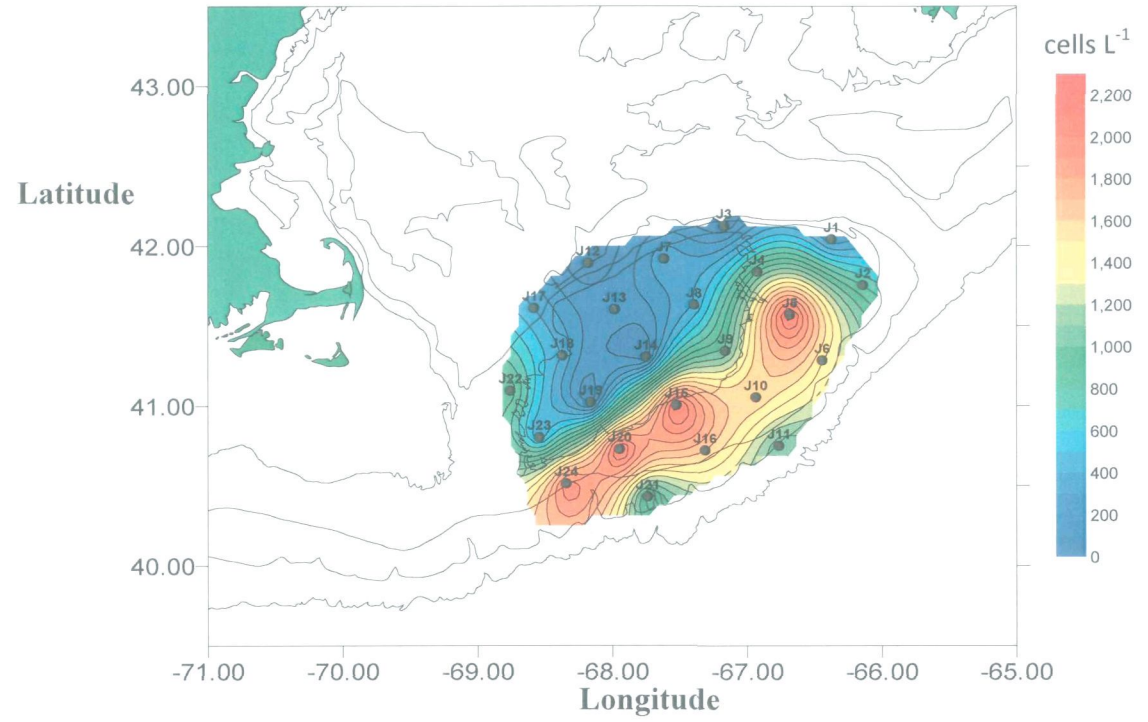

Figure 4.39. EN448 (27 June-3 July 2008) surface *Alexandrium* spp. cell densities.

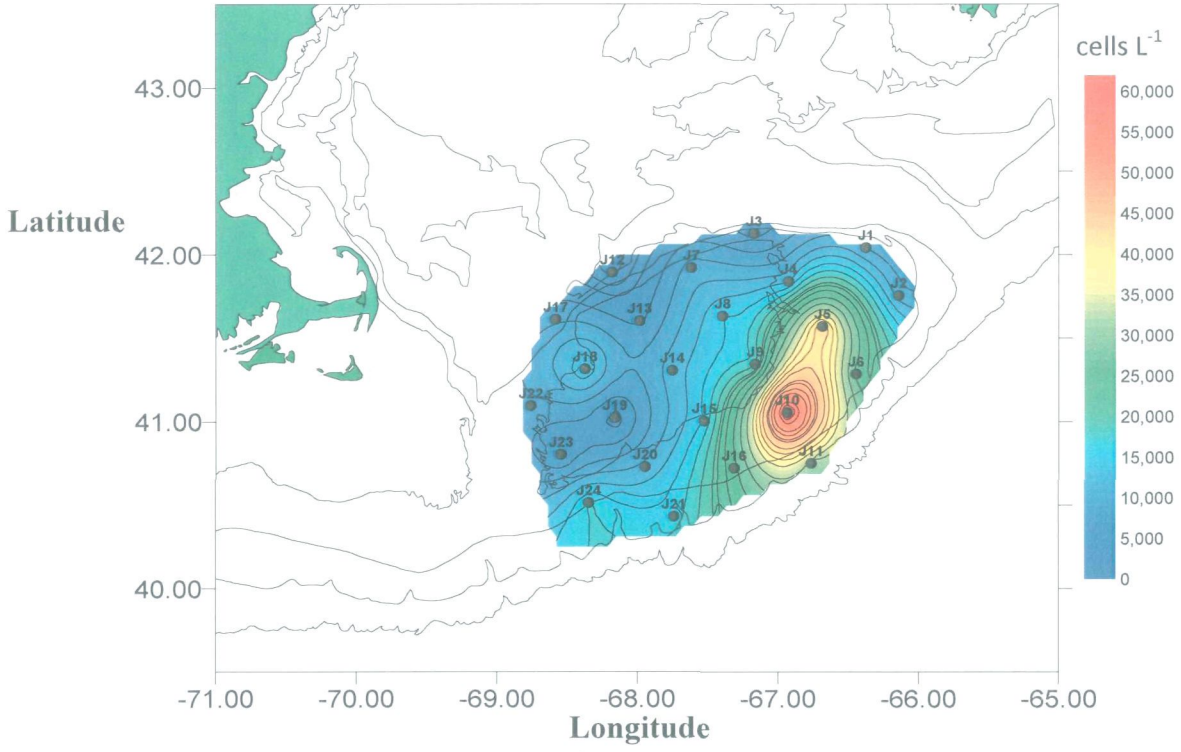

Figure 4.40. EN448 (27 June-3 July 2008) surface dinoflagellate cell densities.

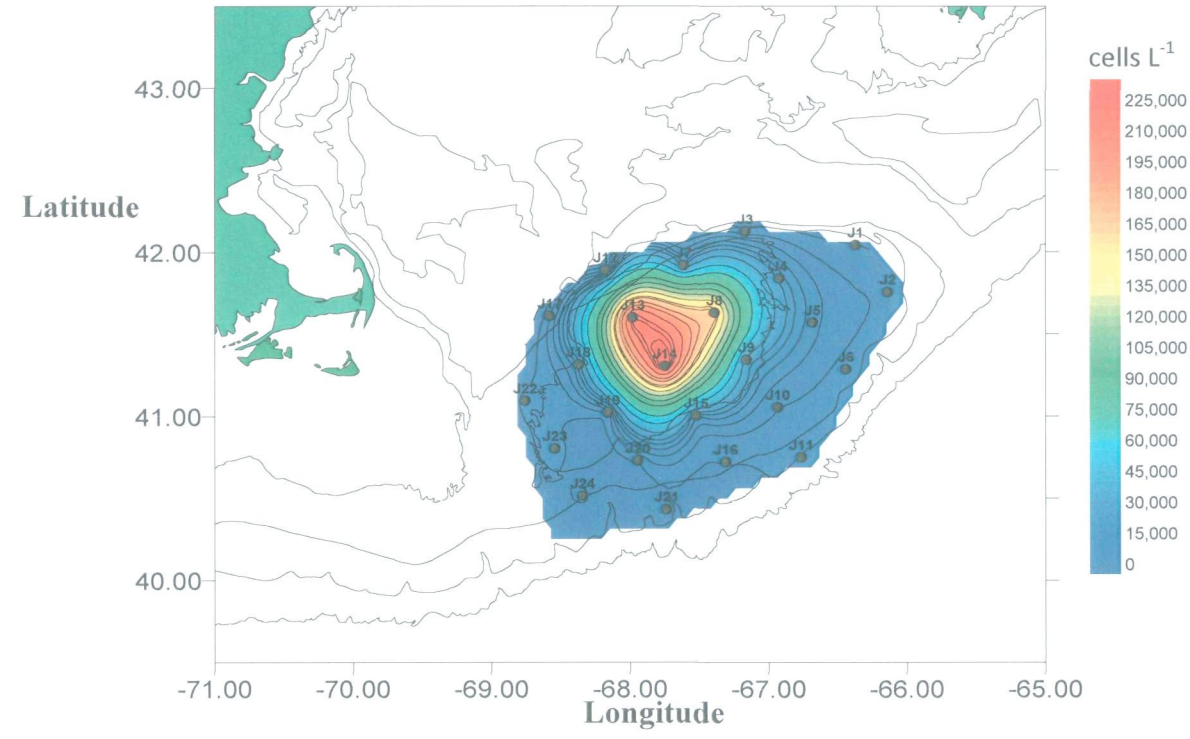

Figure 4.41. EN448 (27 June-3 July 2008) surface diatom cell densities.

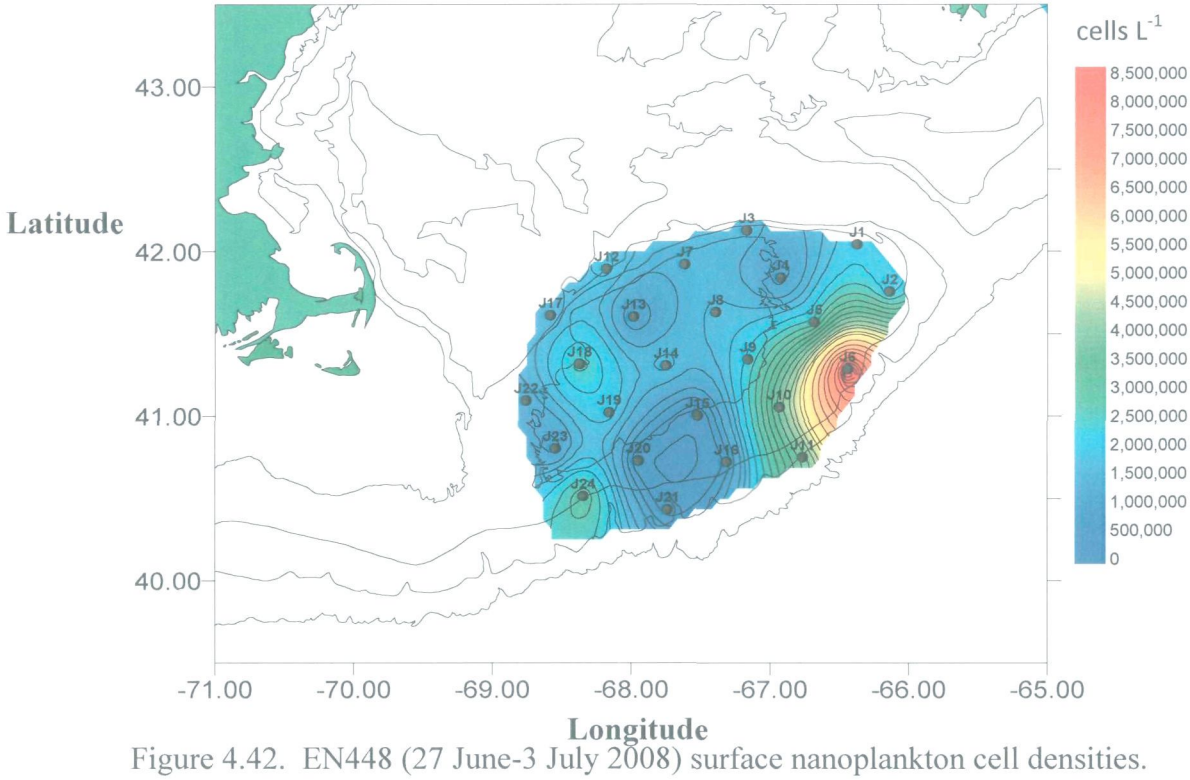

Figure 4.42. EN448 (27 June-3 July 2008) surface nanoplankton cell densities.

Table 4.3. EN448 (27 June- 3 July, 2008) rank order of the 25 most abundant phytoplankton taxa observed and rank order of the number of samples in which found (n=24). Dinoflagellate and Raphidophyte taxa are highlighted in grey.

Taxon	Class	Rank order of average abundance per sample	Rank order of number of samples observed
Phaeocystis spp.	Prymnesiophyceae	1	1
other nanoplankton		2	1
Cryptomonad spp.	Cryptophyceae	3	2
Leptocylindrus spp.	Coscinodiscophyceae	4	8
Heterosigma spp.	Raphidophyceae	5	2
Cysts		6	2
Gryodinium spp.	Dinophyceae	7	5
Gymnodinium spp.	Dinophyceae	8	6
Scrippsiella spp.	Dinophyceae	9	3
Guinardia flaccida	Coscinodiscophyceae	10	12
Ceratium spp.	Dinophyceae	11	4
Heterocapsa spp.	Dinophyceae	12	4
Amphidinium spp.	Dinophyceae	13	4
Pseudo-nitzschia spp.	Bacillariophyceae	14	11
Coscinodiscus spp.	Coscinodiscophyceae	15	7
Polykrikos spp.	Dinophyceae	16	9
Skeletonema spp.	Coscinodiscophyceae	17	10
Alexandrium spp.	Dinophyceae	18	4
Prorocentrum spp.	Dinophyceae	19	6
Chaetoceros spp.	Coscinodiscophyceae	20	11
Protoperidinium spp.	Dinophyceae	21	6
Paralia sulcata	Coscinodiscophyceae	22	14
Gonyaulax spp.	Dinophyceae	23	11
Guinardia striata	Coscinodiscophyceae	24	13
Dactyliosolen spp.	Coscinodiscophyceae	25	13

4.5. Statistical analyses of phytoplankton community

4.5.1. Cluster Analysis

A cluster analysis was used to analyze similarities among phytoplankton taxa based on their abundance, and it revealed four distinct groups of taxa (Fig. 4.43). The first group (Group 1) was comprised of all diatom taxa including: *Coscinodiscus* spp., *Thalassiosira* spp., *Stephanopyxis* spp., *Skeletonema* spp., and *Chaetoceros* spp. All of the Group 1 taxa were centric diatoms and were present in highest cell densities (>150,000 cells L^{-1}) on the Northeast Peak during the April cruise (Appendix I, Fig. 4.44). Cluster Group 1 became less abundant as the summer progressed, with fewer than 15,000 cells L^{-1} in May and June. The highest densities of this diatom group did shift from the Northern Peak of Georges Bank in late April, to a more central location (Figs. 4.45 and 4.46). Phytoplankton Cluster Group 2 was also made entirely of diatoms, including: *Pseudo-nitzschia* spp., *Leptocylindrus* spp., *Guinardia flaccida*, and *Dactyliosolen* spp. Group 2 exhibited similar spatial patterns to Group 1, with highest concentrations on the Northeast Peak; in addition, a population of cells was observed at stations A11 and A12 near the center of the Bank (Fig. 4.47). While both cluster Groups 1 and 2 were observed at similar locations on the Bank, cell densities of cluster Group 2 were lower in April, with a maximum density of only about 20,000 cells L^{-1} (Appendix I). Cluster Group 2 density increased slightly in May, with a localized patch (>20,000 cells $^{L-1}$) at stations M4, M7, and M8 (Appendix I, Fig. 4.48). Cluster Group 2 reached highest densities of approximately 220,000 cells L^{-1} in late June, again associated with a small localized patch, near stations J8, J13, and J14 (Fig. 4.49).

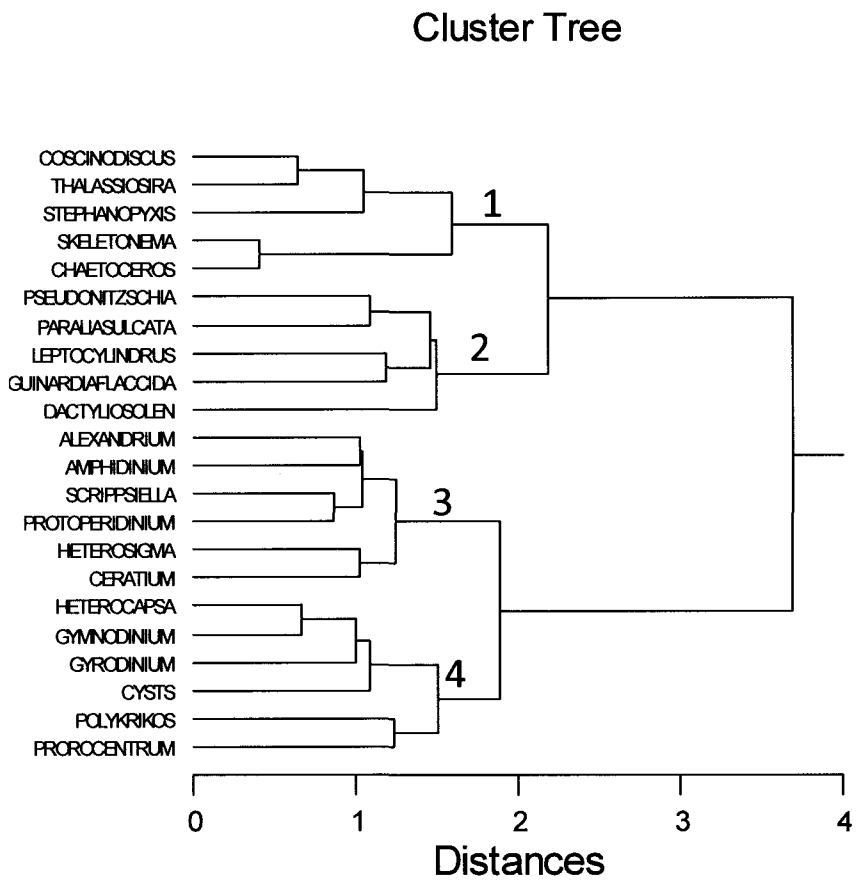

Figure 4.43. Dendrogram from cluster analysis of the twenty-two most abundant taxa using Euclidean distances. Four groups were formed subjectively using Ward linkage.

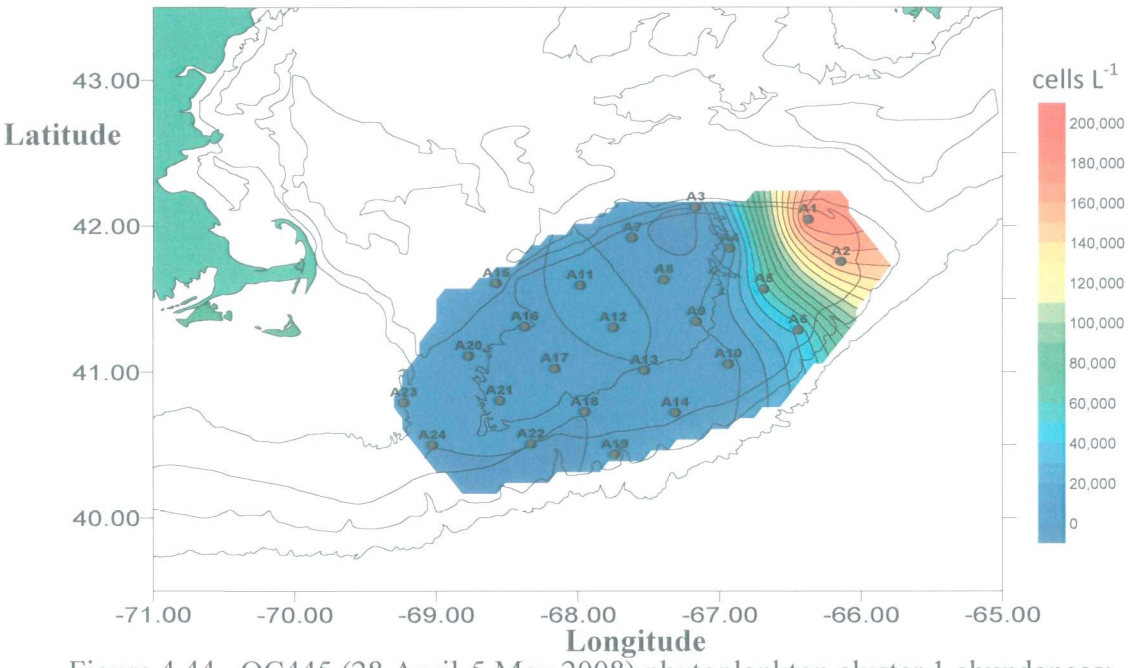

Figure 4.44. OC445 (28 April-5 May 2008) phytoplankton cluster 1 abundances; *Coscinodiscus* spp., *Thalassiosira* spp., *Stephanopyxis* spp., *Skeletonema* spp., and *Chaetoceros* spp.

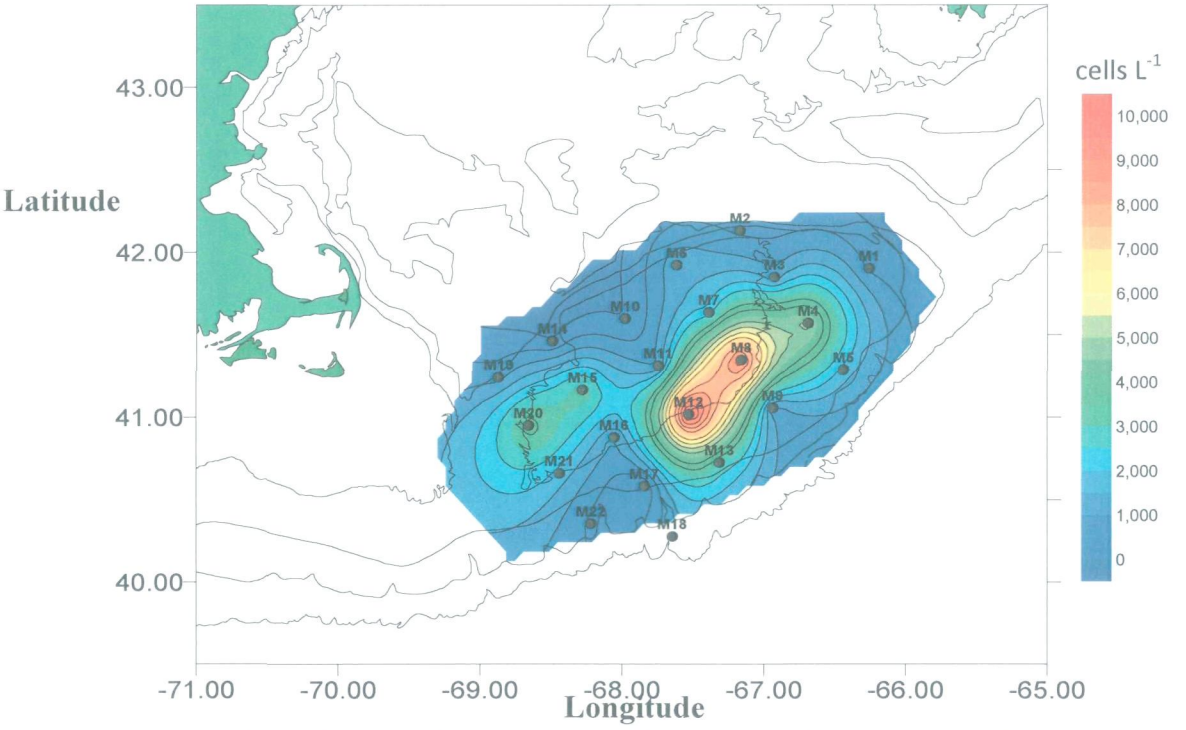

Figure 4.45. OC447 (27 May-4 June 2008) phytoplankton cluster 1 abundances; *Coscinodiscus* spp., *Thalassiosira* spp., *Stephanopyxis* spp., *Skeletonema* spp., and *Chaetoceros* spp.

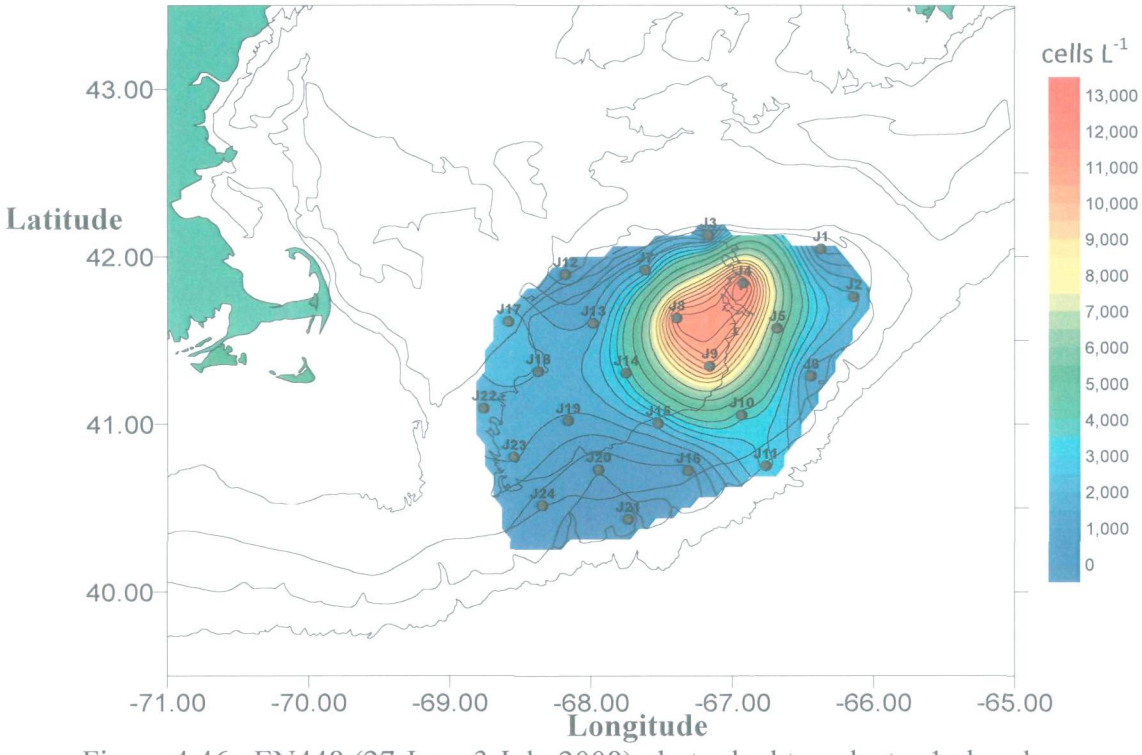

Figure 4.46. EN448 (27 June-3 July 2008) phytoplankton cluster 1 abundances; *Coscinodiscus* spp., *Thalassiosira* spp., *Stephanopyxis* spp., *Skeletonema* spp., and *Chaetoceros* spp.

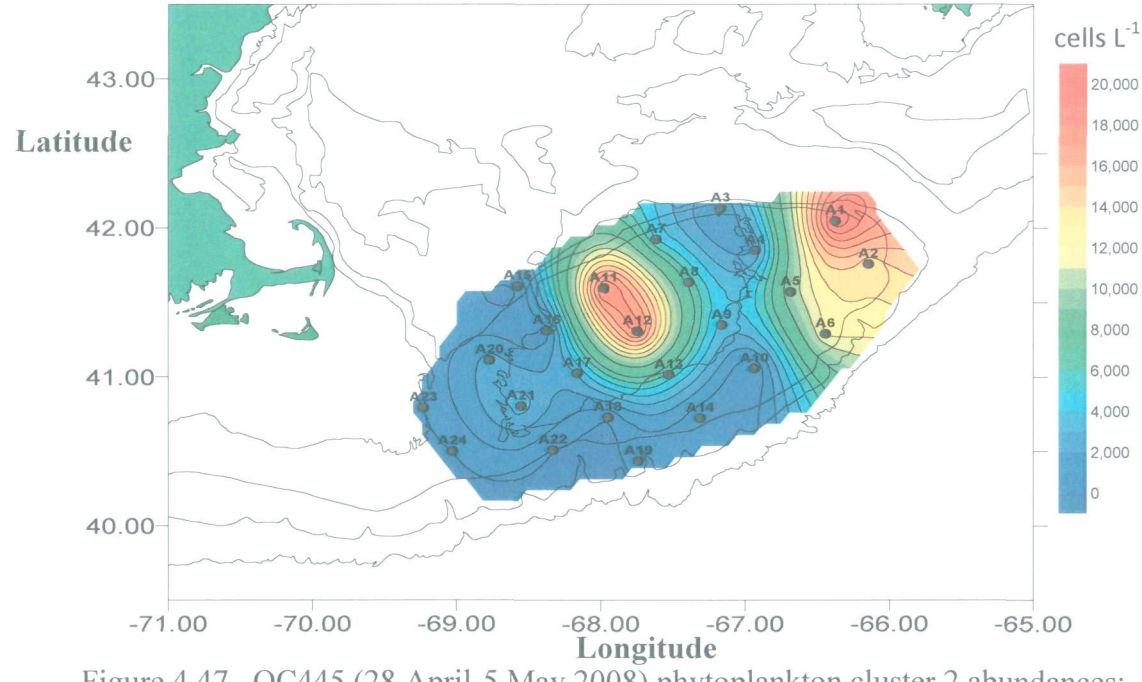

Figure 4.47. OC445 (28 April-5 May 2008) phytoplankton cluster 2 abundances; *Pseudo-nitzschia* spp., *Paralia sulcata*, *Leptocylindrus* spp., *Guinardia flaccida*, *Dactyliosolen* spp.

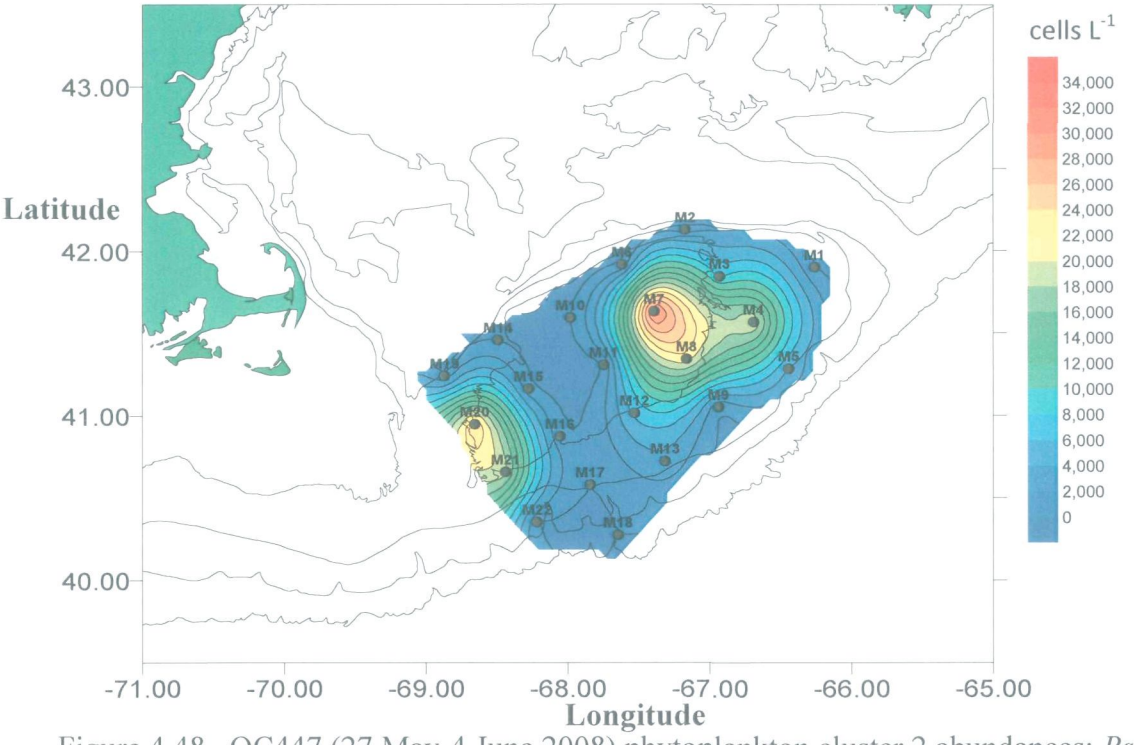

Figure 4.48. OC447 (27 May-4 June 2008) phytoplankton cluster 2 abundances; *Pseudo-nitzschia* spp., *Paralia sulcata*, *Leptocylindrus* spp., *Guinardia flaccida*, *Dactyliosolen* spp.

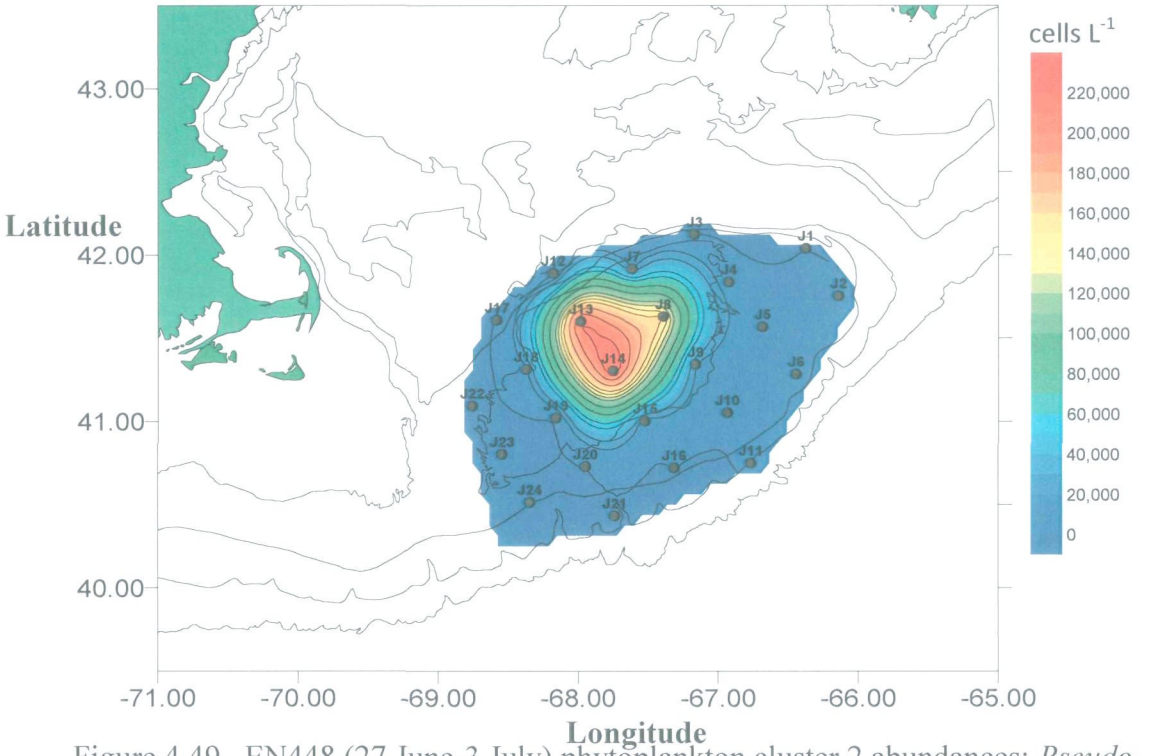

Figure 4.49. EN448 (27 June-3 July) phytoplankton cluster 2 abundances; *Pseudo-nitzschia* spp., *Paralia sulcata*, *Leptocylindrus* spp., *Guinardia flaccida*, *Dactyliosolen* spp.

Phytoplankton cluster Groups 3 and 4, all dinoflagellates, except for *Heterosigma* spp., a raphidophyte in group 3, occupied a much broader spatial distribution across the three cruises. Cluster Group 3 included *Alexandrium* spp., *Amphidinium* spp., *Scrippsiella* spp., *Protoperidinium* spp., *Heterosigma* spp., and *Ceratium* spp.; their cell densities were relatively low in April, and were located primarily on the eastern edge of the Bank (Fig. 4.50). By late May, cluster Group 3 cell densities had increased to greater than 40,000 cells L^{-1} at some stations, and were still located at the eastern edge of the Bank, in particular along the 100 m isobath (Fig. 4.51). Cluster Group 3 densities dropped down at the end of June, to a maximum of only 24,000 cells L^{-1} (Appendix I, Fig. 4.52).

Dinoflagellate cluster Group 4, which included: *Heterocapsa* spp., *Gymnodinium* spp., *Gyrodinium* spp., unidentified flagellate cysts, *Polykrikos* spp., and *Prorocentrum* spp., was generally less abundant than cluster Group 3 taxa during the summer on Georges Bank. Cluster Group 4 cell densities were less than 15,000 cells L^{-1} in late April, and, interestingly, the highest cell densities of this group were observed on the Northeast Peak, coinciding with high densities of diatom cluster Group 1 (Fig. 4.53). During late May, Group 4 densities remained relatively low compared to Group 3, with a maximum of about 13,000 cells L-1 along the eastern edge. Their distribution was patchy in nature and did not appear to coincide with any particular frontal features (Fig. 4.54). By late June however, maximum cell densities for cluster Group 4 increased to about 45,000 cells L^{-1}, with higher densities again associated with the 100 m isobath on the eastern edge of the bank, where cluster Group 3 was also abundant (Fig. 4.55). The dinoflagellates of cluster Group 4 reached their highest densities of the summer during late June and exhibited similar spatial trends as Group 3 (Figs 4.52 and 4.54).

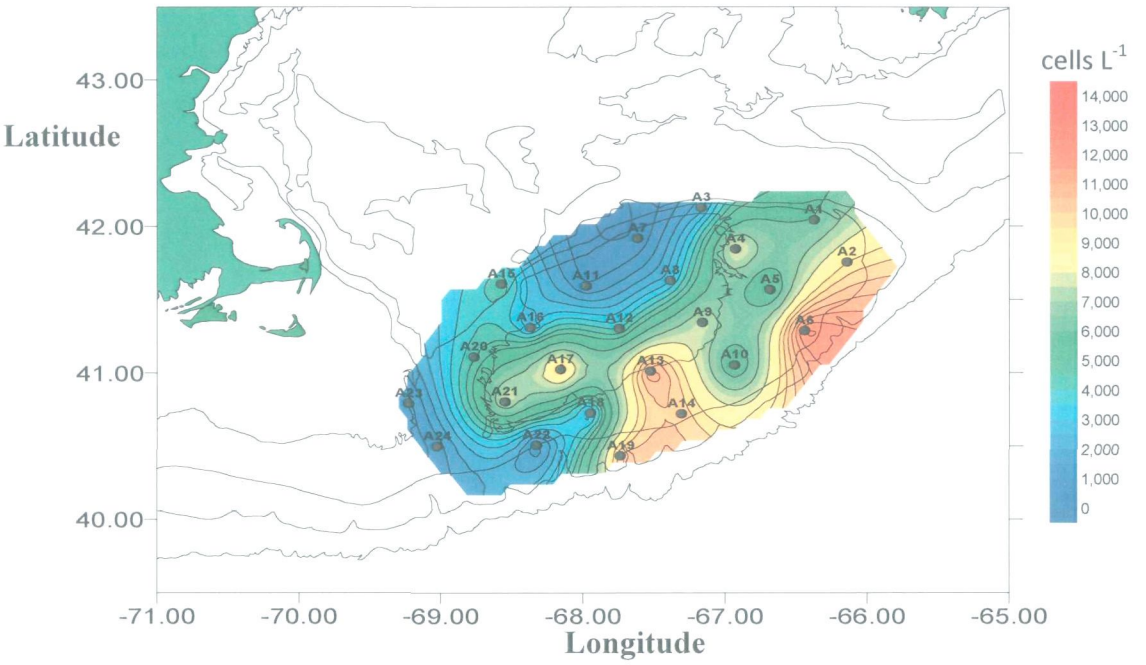

Figure 4.50. OC445 (28 April-5 May 2008) phytoplankton cluster 3 abundances; *Alexandrium* spp., *Amphidinium* spp., *Scrippsiella* spp., *Protoperidinium* spp., *Heterosigma* spp., *Ceratium* spp.

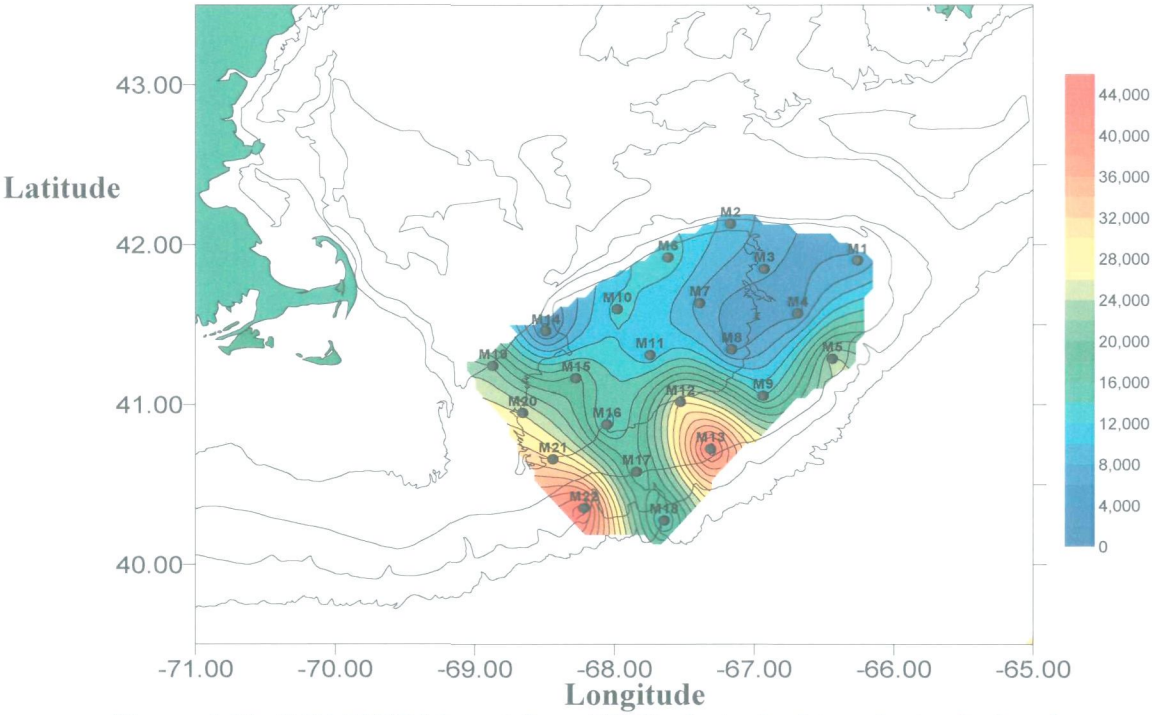

Figure 4.51. OC447(27 May- 4 June 2008) phytoplankton cluster 3 abundances; *Alexandrium* spp., *Amphidinium* spp., *Scrippsiella* spp., *Protoperidinium* spp., *Heterosigma* spp., *Ceratium* spp.

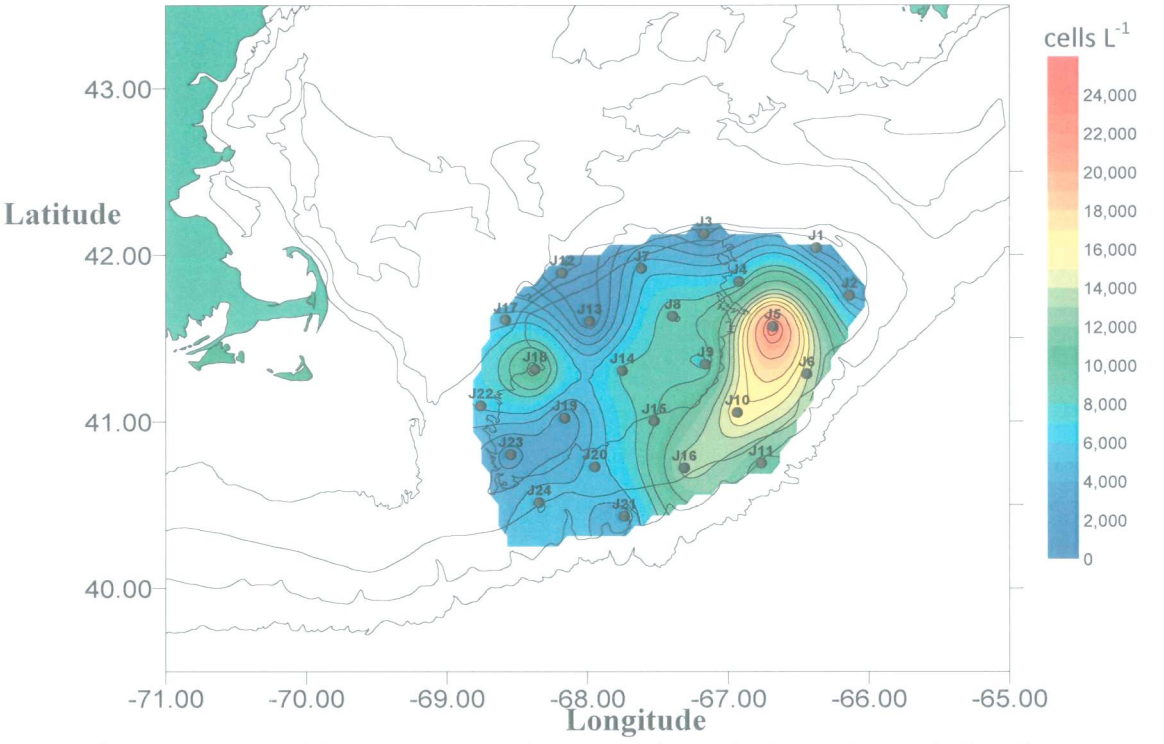

Figure 4.52. EN448 (27 June-3 July 2008) phytoplankton cluster 3 abundances; *Alexandrium* spp., *Amphidinium* spp., *Scrippsiella* spp., *Protoperidinium* spp., *Heterosigma* spp., *Ceratium* spp.

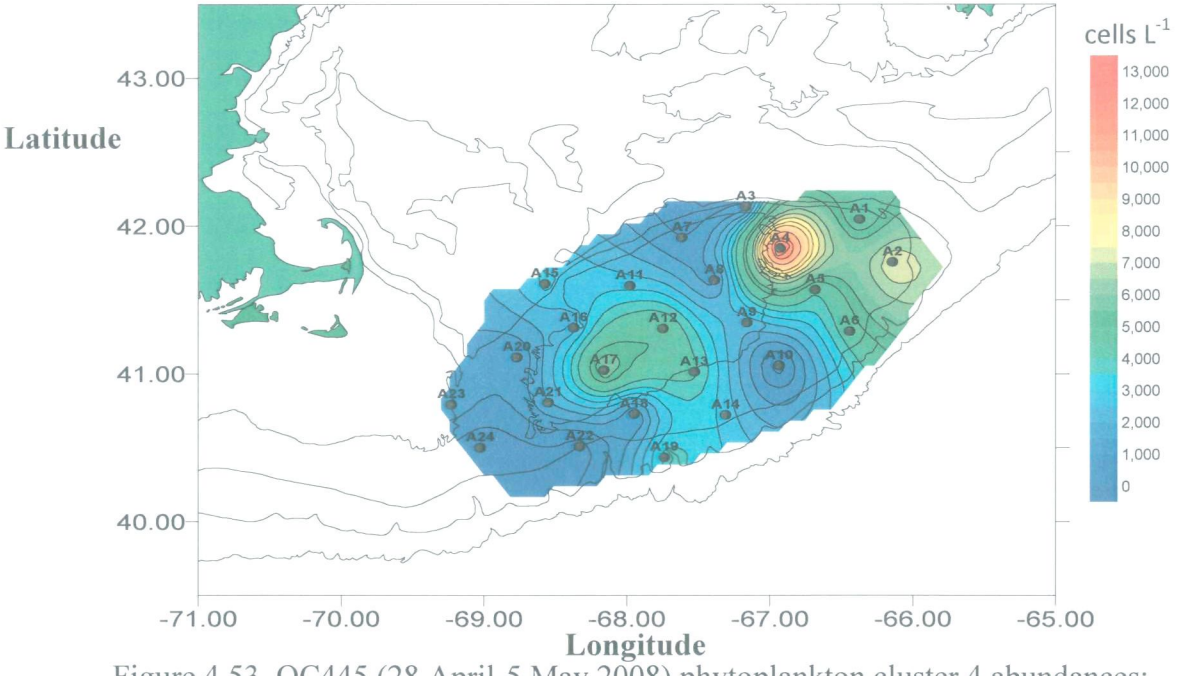

Figure 4.53. OC445 (28 April-5 May 2008) phytoplankton cluster 4 abundances; *Heterocapsa* spp., *Gymnodinium* spp., *Gyrodinium* spp., unidentified cysts, *Polykrikos* spp., *Prorocentrum* spp.

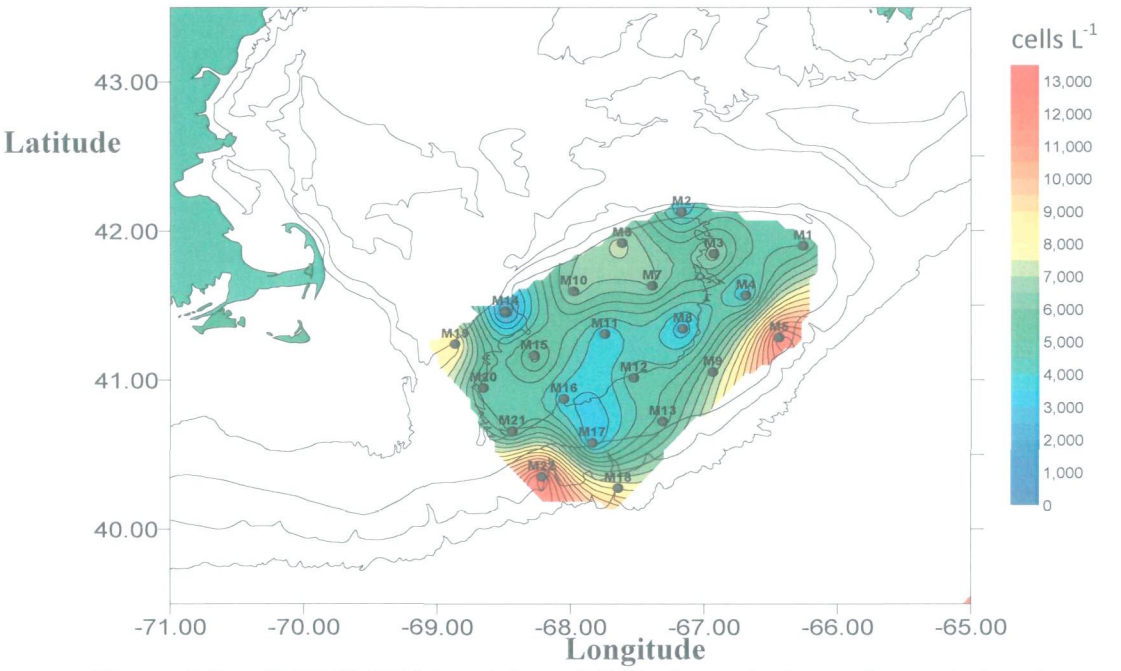

Figure 4.54. OC447 (27 May-4 June 2008) phytoplankton cluster 4 abundances; *Heterocapsa* spp., *Gymnodinium* spp., *Gyrodinium* spp., unidentified cysts, *Polykrikos* spp., *Prorocentrum* spp.

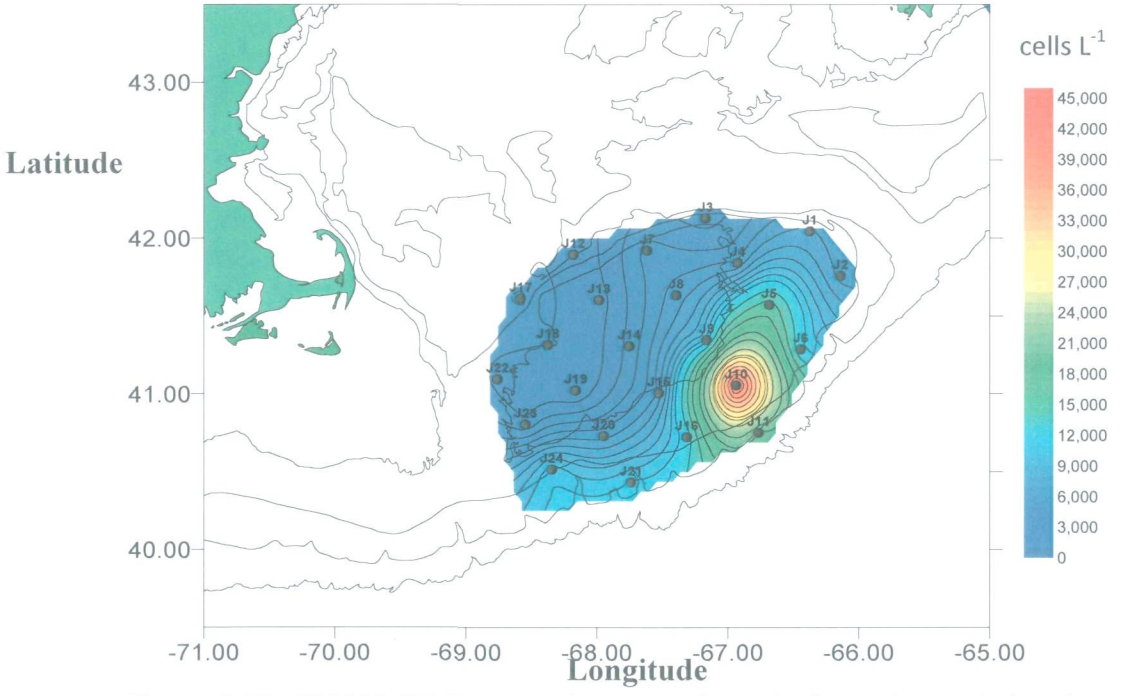

Figure 4.55. EN448 (27 June-3 July 2008) phytoplankton cluster 4 abundances; *Heterocapsa* spp., *Gymnodinium* spp., *Gyrodinium* spp., unidentified cysts, *Polykrikos* spp., *Prorocentrum* spp.

Temporal and spatial differences existed with respect to cell densities and distribution of the major diatoms and dinoflagellates on Georges Bank in summer 2008. Localized patches of high cell densities from diatom clusters Groups 1 and 2 appeared to be spatially distinct from regions of the Bank where dinoflagellate cluster Group 3 dominated (Figs. 4.39-4.50). Cluster Group 4 appeared to coexist with diatoms in cluster Group 1 during the late April cruise; and with Group 3 dinoflagellates at the end of the summer.

4.5.2. Principal Component Analysis

Principal Component Analysis performed on the standardized abundances of the top 22 phytoplankton taxa displayed similar results to that just discussed when plotted using principal components 1 and 2, which accounted for 39% of the variance in the samples (Table 4.4). The taxa making up the diatom cluster Group 1 tended to group close together in coordinate space, while all taxa in cluster Group 2 lied close together in space, except for *Pseudo-nitzschia* spp., which happened to be the only pennate form included in the analyses (Fig. 4.56). Cluster Groups 3 and 4 did not form distinct groups in the PCA, however they did tend to separate from the diatom species of cluster Groups 1 and 2. Further breakdown of the component loadings revealed that the dinoflagellates used in the analysis were responsible for most of the variance for principal component 1, suggesting that differences in dinoflagellate abundances accounted for most of the variability in the data (Table 4.5). Diatom taxa accounted for most of the variability in principal component 2, which is not surprising as diatoms tended to be relatively low in abundance, only exhibiting a few localized patches of increased abundance throughout

the summer (Table 4.5). Shifts within the dinoflagellate community appeared to be less dramatic versus changes with respect to the diatom community (often on the order of hundreds of thousands of cells), and could be the reason dinoflagellates tended to associate together in the PCA with no discernable groups among them. This was also evident in the cluster analysis where all dinoflagellate taxa were grouped together initially (Fig. 4.43), whereas Group 1 and 2 diatoms were less closely related and revealed a more obvious separation (Fig 4.43).

Table 4.4. Variance and percent variance explained by the first six principal components. **Principal components 1 and 2 account for approximately 39.2% of the total variance.

Variance explained by principal components					
1	**2**	**3**	**4**	**5**	**6**
5.001	3.617	2.168	1.555	1.336	1.222
Percent of variance explained					
1	**2**	**3**	**4**	**5**	**6**
* 22.731	* 16.44	9.853	7.07	6.074	5.557

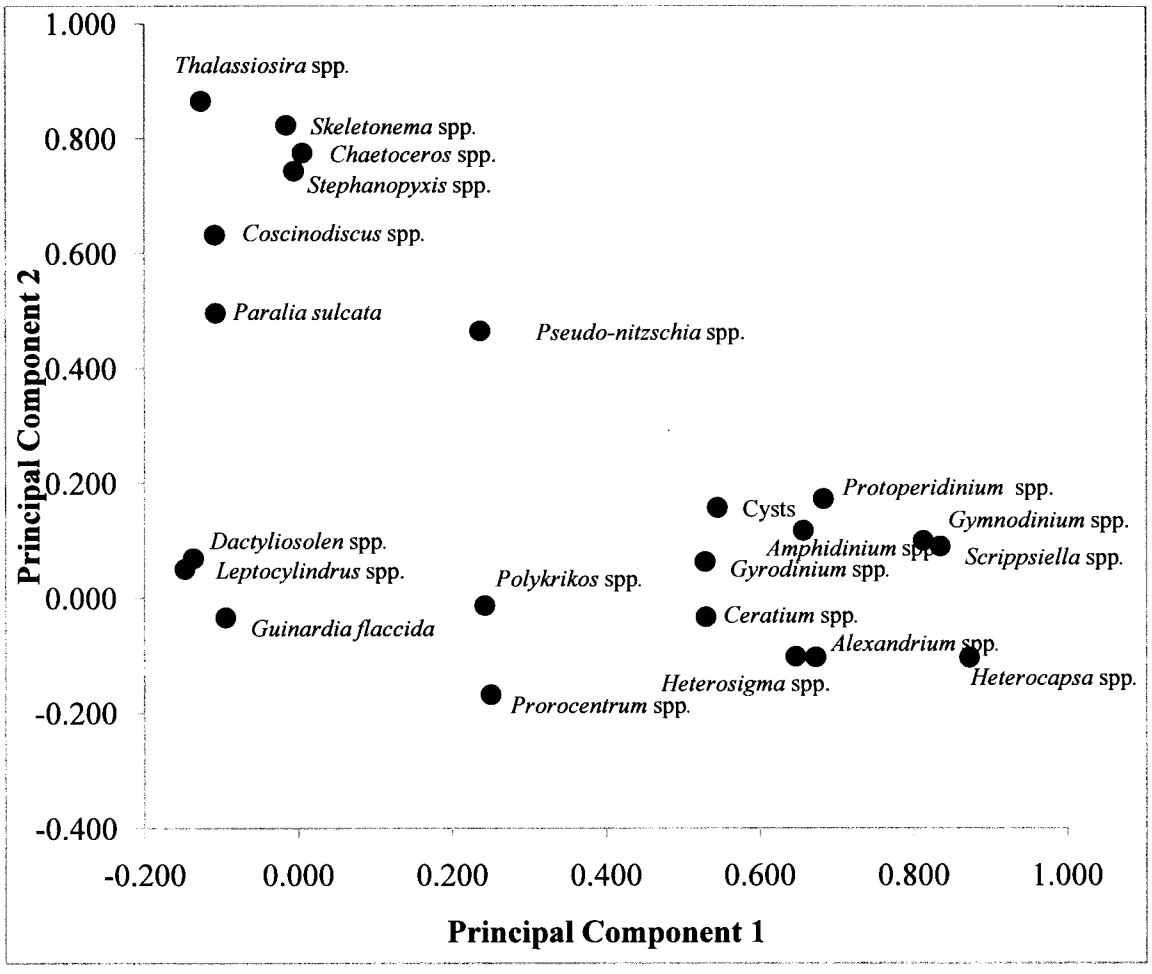

Figure 4.56. Twenty-two phytoplankton taxa plotted using principal components 1 and 2 from the Principal Component Analysis.

Table 4.5. Component loadings for each of the twenty-two taxa used in the Principal Component Analysis.
*Only principal components 1 and 2 were considered for further analysis.

Diatom/ Dinoflagellate	Taxa	Component Loadings					
		1	2	3	4	5	6
Dinoflagellate	*Alexandrium* spp.	0.646	-0.102	0.124	-0.382	-0.233	-0.018
Dinoflagellate	*Protoperidinium* spp.	0.682	0.172	2.237	-0.312	0.050	-0.008
Dinoflagellate	*Scrippsiella* spp.	0.834	0.089	0.074	-0.177	0.031	-0.032
Dinoflagellate	*Amphidinium* spp.	0.656	0.117	0.051	-0.271	-0.227	0.052
Raphidophyte	*Heterosigma* spp.	0.672	-0.103	0.388	0.042	0.319	0.078
Dinoflagellate	*Ceratium* spp.	0.529	-0.033	0.503	0.228	0.012	-0.186
Dinoflagellate	*Heterocapsa* spp.	0.872	-0.104	0.047	0.119	0.029	0.027
Dinoflagellate	*Gymnodinium* spp.	0.812	0.099	-0.273	0.272	-0.084	0.030
Dinoflagellate	*Gyrodinium* spp.	0.528	0.063	-0.456	0.388	-0.021	0.190
Dinoflagellate	Cysts	0.544	0.157	-0.437	0.179	-0.437	-0.044
Dinoflagellate	*Prorocentrum* spp.	0.250	-0.168	-0.375	0.207	0.401	0.044
Dinoflagellate	*Polykrikos* spp.	0.242	-0.013	-0.406	0.430	0.240	0.117
Diatom	*Coscinodiscus* spp.	-0.109	0.632	0.092	0.038	0.005	0.621
Diatom	*Thalassiosira* spp.	-0.127	0.865	-0.058	-0.084	-0.014	0.284
Diatom	*Stephanopyxis* spp.	-0.006	0.743	-0.258	-0.078	0.080	-0.141
Diatom	*Skeletonema* spp.	-0.016	0.823	-0.175	-0.014	0.094	-0.449
Diatom	*Chaetoceros* spp.	0.005	0.775	-0.148	0.027	0.067	-0.428
Diatom	*Pseudo-nitzschia* spp.	0.236	0.465	0.492	0.030	0.041	0.036
Diatom	*Paralia sulcata*	-0.108	0.496	0.465	0.331	0.068	0.304
Diatom	*Leptocylindrus* spp.	-0.148	0.050	0.514	0.638	-0.094	-0.191
Diatom	*Guinardia flaccida*	-0.095	-0.034	0.194	0.349	-0.552	-0.231
Diatom	*Dactyliosolen* spp.	-0.137	0.069	-0.113	-0.012	-0.606	0.260

4.5.3. Additional statistical analyses

A second cluster analysis was performed to examine how stations from the three cruises group together based on the abundances of the top 22 phytoplankton taxa; such groupings might be useful in linking oceanographic features with the distributions of phytoplankton. This analysis formed six clusters of stations ranging from as few as four stations in a cluster, to as many as approximately thirty in another cluster (Fig. 4.57). The first cluster joined four stations from the late April survey, all located on the Northeast Peak of Georges Bank (Figs. 4.57, 4.58, and 4.59). Further breakdown of the percentages of each of the four phytoplankton cluster groups revealed the dominance of diatom cluster Group 1 at this set of stations (Fig. 4.60). The small station cluster that formed appeared to be the result of the high cell-density patch of diatoms on the crest of the Bank in April. Station cluster Groups 2 and 3 contained a mix of stations from the three cruises; however, they were dominated by OC447 (late May) and EN448 (late June) stations, respectively, comprising greater than sixty percent of the cluster (Figs. 4.57 and 4.58). Station cluster Group 2 was not present during the first cruise, appearing only in May and June, and was dominated by dinoflagellate cluster Group 3, which accounted for greater than fifty percent of the phytoplankton abundance (Figs. 4.58, 4.59, and 4.60). Dinoflagellate cluster Group 4 was also observed in higher cell densities, making up approximately thirty percent of the abundance (Fig. 4.60). Cluster Group 2 stations were found along the western and southern regions of the bank at the end of May (OC447) and along the eastern edge in late June (EN448) (Fig. 4.59). Station cluster 3 was comprised of nearly 50% diatoms and 50% dinoflagellate clusters (Fig. 4.60). Breakdown of the station cluster 3, which contained 16 stations, revealed that the majority of these stations

were from the late April survey, and those remaining were part of the late June cruise; only one station from the late May survey (OC447) was included in this cluster (Fig. 4.58). The lack of dominance of a single phytoplankton group (i.e. the diatoms or dinoflagellates of cluster groups 1-4) is possibly the result of the shift in the phytoplankton community in April. The transition from a diatom to dinoflagellate dominated community could explain why diatoms and dinoflagellates were seen in relatively equal proportions at this time on the Bank. Station cluster 4, like the first cluster, was small, grouping only three stations, all part of the late June cruise and located in a small patch in the central part of the Bank (Figs. 4.57, 4.58, and 4.59). Similar to cluster 1, cluster 4 appeared to be grouped together based on the high densities (> 100,000 cells L^{-1}) of diatoms; however, diatom cluster Group 2 dominated at these stations (Fig. 4.57). The switch in dominance from diatom cluster Group 1 in late April, to diatom cluster Group 2 in late June suggests that a significant successional pattern from one type of diatom group to another occurred from late spring to late summer. Station cluster 5, was additionally, only made up of EN448 (late June) stations and, interestingly, occupied the eastern half of the Bank, suggesting these stations may be associated with a frontal feature (Figs. 4.58 and 4.59). It was this station cluster that contained the highest percentage of phytoplankton cluster Group 4, which exhibited the highest cell densities during the end of the summer (Figs. 4.55 and 4.60). Station cluster 6 was the largest cluster, containing forty-one stations, spanning all three months (Fig. 4.57). The distribution of the stations from this cluster on the bank did not appear to have any oceanographic significance (Fig. 4.59); however, in general, these stations contained higher densities of the dinoflagellate cluster, in particular cluster Group 3 (Fig. 4.60).

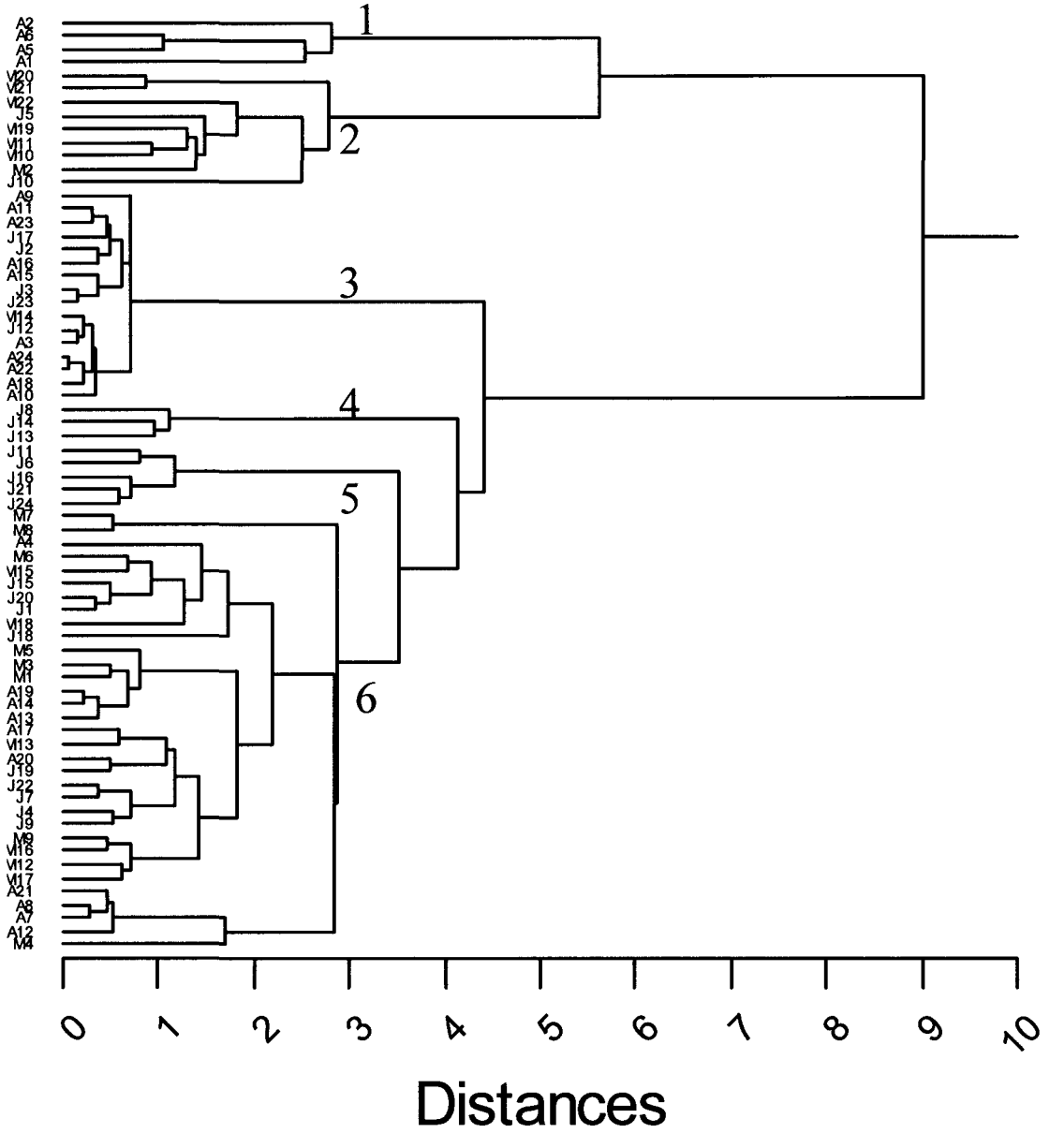

Figure 4.57. Dendrogram of 70 stations sampled during OC445 (28 April- 5 May 2008), OC447 (27 May- 4 June 2008), and EN448 (27 June-3 July 2008) using Euclidean distances. Six groups were subjectively formed using Ward linkage

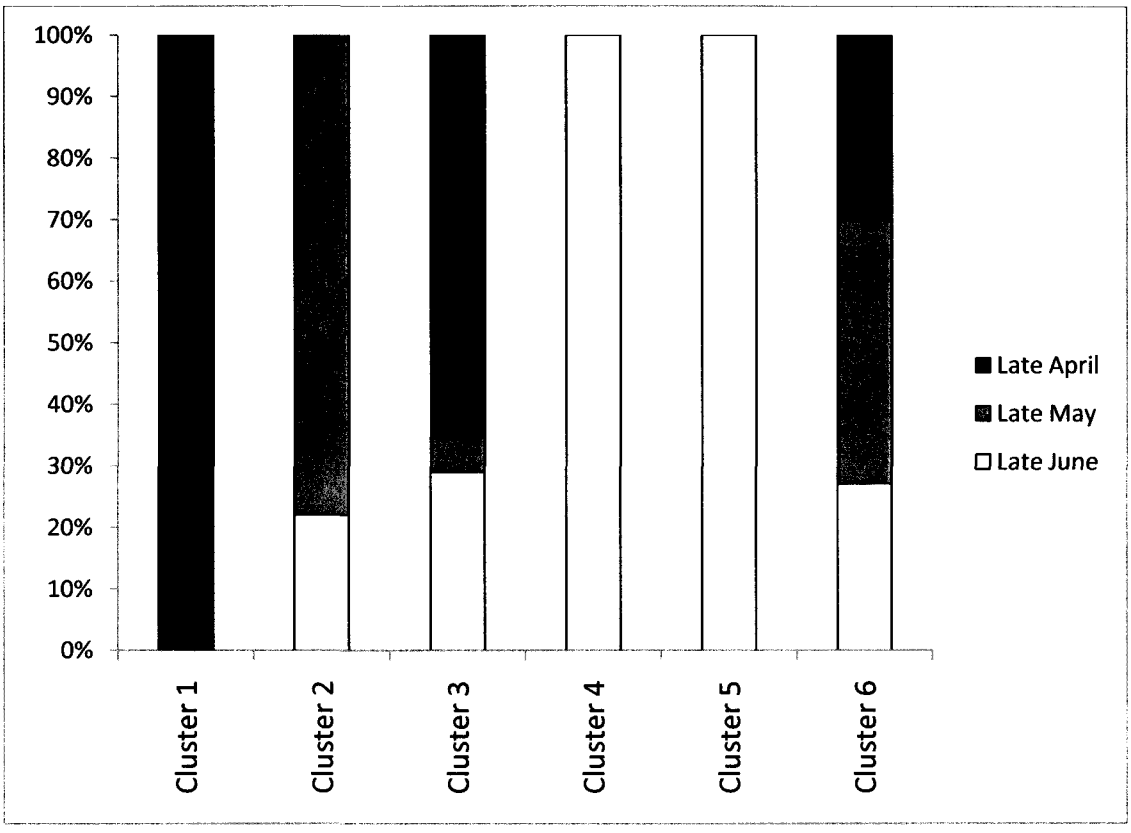

Figure 4.58. Percentage of stations from OC445 (28 April-5 May 2008), OC447 (27 May-4 June 2008), and EN448 (27 June-3 July 2008) for each station cluster formed. Cruises termed late April, late May, and late June, respectively.

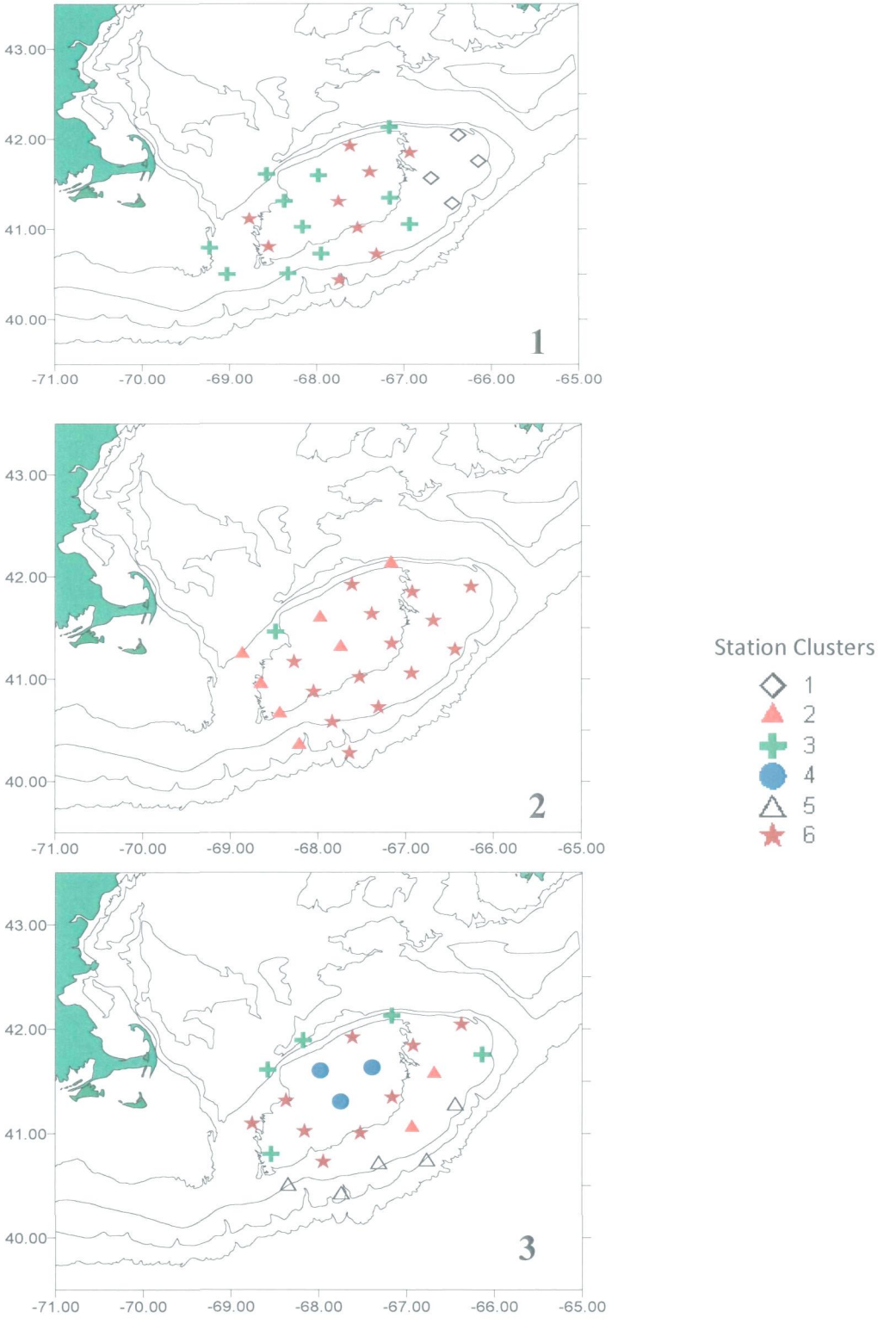

Figure 4.59. Locations of station clusters on Georges Bank. 1. OC445 (28 April-5 May 2008), 2. OC447 (27 May-4 June 2008), and 3. EN448 (27 June-3 July 2008).

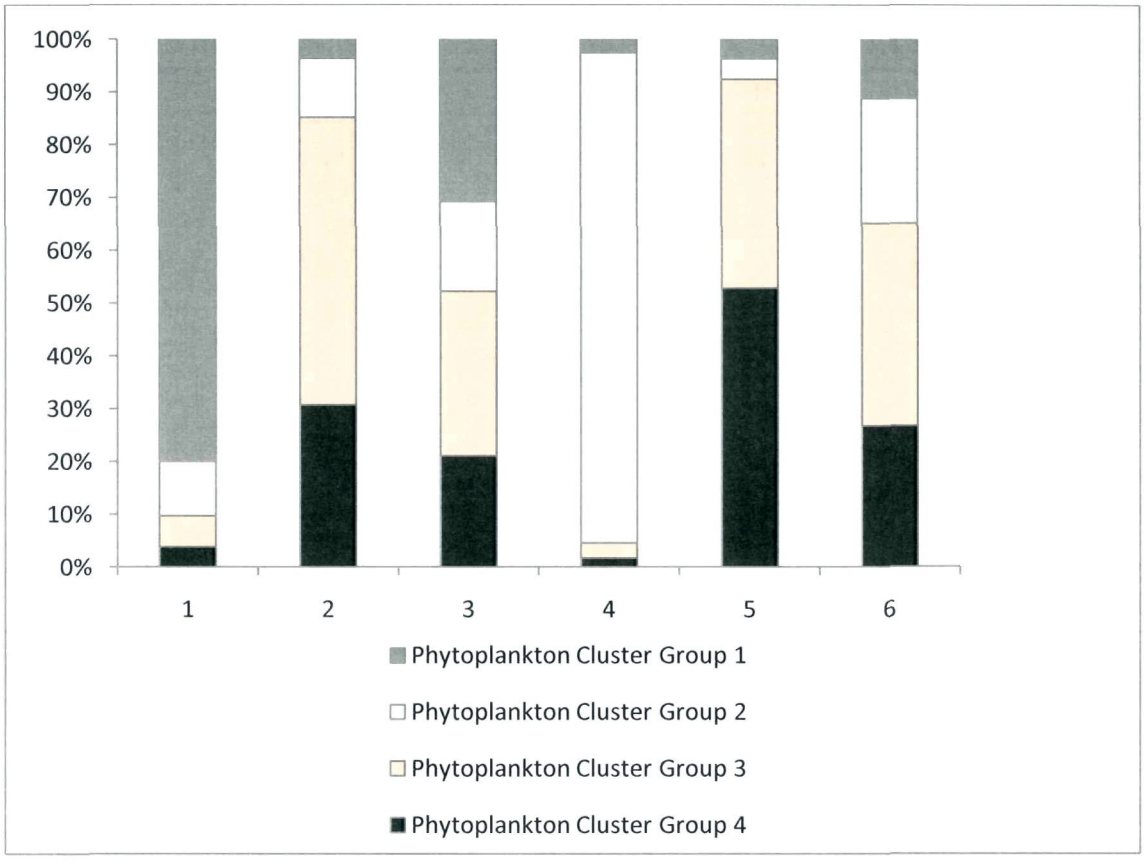

Figure 4.60. Average percentage of phytoplankton clusters 1-4 for each station cluster.

4.6. Laboratory competition experiments

Alexandrium fundyense growth rates were lower than *Ditylum brightwellii* in mixed cultures and controls, for both experiments, which was expected as dinoflagellates tend to have relatively slower growth rates compared to diatom species. In the first experiment, initial *Alexandrium* concentrations were ten times greater than starting *Ditylum* concentrations, at approximately 500 cells mL^{-1} and 10 cells mL^{-1}, respectively. High variability between replicate flasks of each treatment was often observed; however, triplicate subsample counts on selected days revealed that variability associated with counter error was generally less than 10% (Appendix J). When initial *Alexandrium* cell densities were higher, there was no significant difference in growth between mixed cultures and control flasks; average growth rates during the first week of the experiment were 0.16 ± 0.03 and 0.21 ± 0.10 respectively (Fig. 4.62, Tables 4.6 and 4.7). Although *Alexandrium* growth rates decreased during the second week of the experiment, average growth rates for mixed and control treatments were not statistically different, at 0.11 ± 0.09 and 0.13 ± 0.03 respectively (Fig. 4.62, Tables 4.6 and 4.7).

In the second growth experiment, *Alexandrium fundyense* initial cell concentrations were slightly lower (approximately 50 cells mL^{-1}) but were again higher than initial *Ditylum* concentrations (approximately 10 cells mL-1) by a factor of 5. During the first week of the experiment, average *Alexandrium* growth rates were not significantly different between mixed and control treatments, and were similar to growth rates during experiment 1, with rates of 0.12± 0.04 and 0.14 ± 0.04 respectively (Fig. 4.61, Tables 4.6 and 4.7). During week two, average growth rates for *Alexandrium* in the control remained positive at 0.21 ±0.04, while average growth rates of cells in culture

with *Ditylum* became negative (-0.02 ± 0.007). This resulted in significantly higher *Alexandrium* concentrations in control flasks at the end of the experiment compared to mixed cultures (Fig. 4.61).

Average growth of *Ditylum* in the first experiment (higher initial *Alexandrium* concentrations), was significantly different between treatments, with rates of 0.55 ± 0.13 and 1.10 ± 0.05 for mixed and control flasks during the first week of the experiment (Fig. 4.62, Tables 4.6 and 4.7). *Ditylum* appeared to be inhibited by the presence of high concentrations of *Alexandrium* and did not exhibit an exponential growth phase when grown in mixed cultures. *Ditylum* growth became negative at the end of experiment, however average growth rates were not significantly different between mixed and control treatments during this time (Table 4.7). Control flasks of *Ditylum* displayed exponential growth during days 4-8, reaching an average maximum cell density of 11,840 ± 731 cells mL^{-1} at day 9; after which cell densities decreased and growth rates were negative.

When initial concentrations of *Alexandrium* were ten-fold lower (Experiment 2), no apparent affect on the growth of *Ditylum* was observed in mixed treatments. Average growth rates for *Ditylum* during week 1 of the experiment were 0.93 ± 0.05 and 1.08 ± 0.03 for mixed and controls, respectively, which were not significantly different (Fig. 4.61, Tables 4.6 and 4.7). *Ditylum* grew exponentially from day 7 to day 11, with average maximum cell densities of 8,030 ± 1,985 cells mL^{-1} and 9,483 ± 1,150 cells mL^{-1} for mixed and control treatments, both observed on day 11 (Appendix J). Growth of *Ditylum* in mixed and control flasks became negative after day 12, and cell densities decreased to less than 6,000 cells L^{-1} at the time the experiment was terminated (Fig. 4.61).

Triplicate samples of culture water were collected for nutrient analysis at days 9 and 16 for experiment 1, which contained the highest initial starting concentrations of cells, in order to confirm that nutrients were not limiting throughout the course of the experiment. Nutrient levels remained replete in all flasks for both days, with NO_3^- + NO_2^-, $Si(OH)_4$, and PO_4^{-3} levels in excess of 500 µM, 50 µM, and 4µM, respectively (Appendix K and Fig. 4.63).

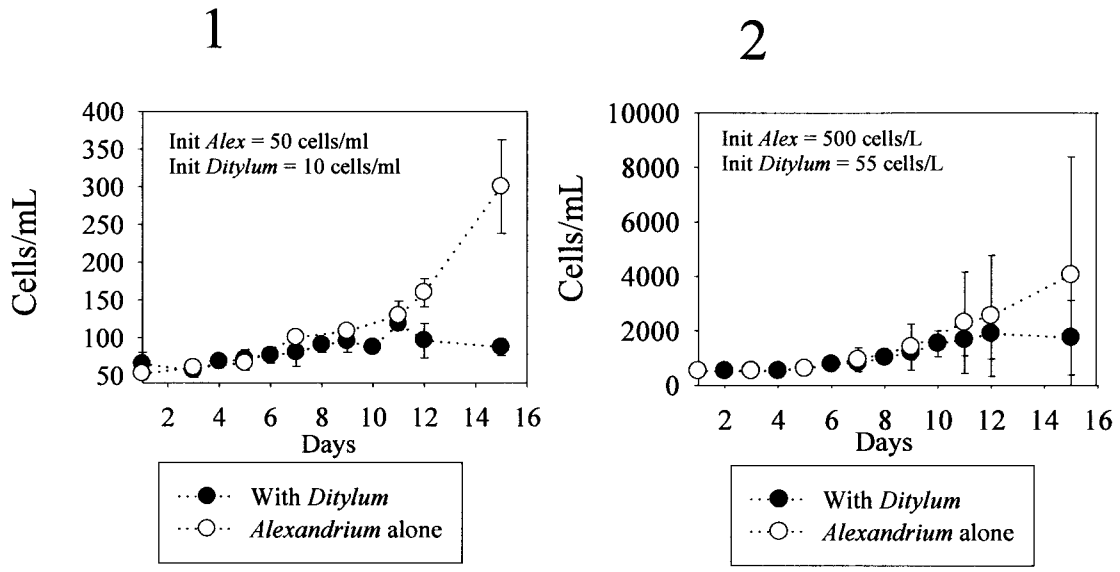

Figure 4.61. Average *Alexandrium* cell densities. 1. Experiment with "low" initial *Alexandrium* concentrations and 2. Experiment with "high" initial *Alexandrium* concentrations. Full circles represent average *Alexandrium* cell densities in mixed cultures with *Ditylum,* and open circles represent average *Alexandrium* cell densities in the control flasks.

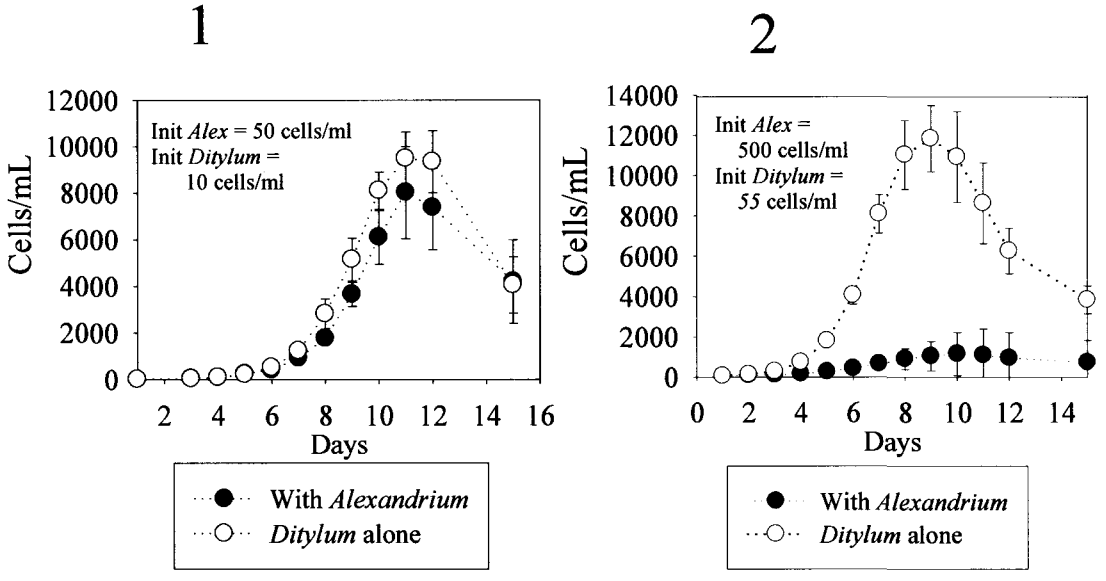

Figure 4.62. Average *Ditylum* cell densities. 1. Experiment with "low" initial *Alexandrium* concentrations and 2. Experiment with "high" Initial *Alexandrium* concentrations. Full circles represent average *Ditylum* cell densities in mixed cultures with *Alexandrium,* and open circles represent average *Ditylum* cell densities in the control flasks.

Table 4.6. Average growth rates of *Alexandrium fundyense* and *Ditylum brightwellii* in mixed and control treatments for days 2-8 and 9-15. Standard deviations included.

Alexandrium fundyense	**Mixed**		**Control**	
Experiment 1	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Days 2-8	0.16	0.03	0.22	0.10
Days 9-15	0.11	0.09	0.13	0.03
Experiment 2	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Days 2-8	0.12	0.04	0.14	0.03
Days 9-15	-0.02	0.01	0.21	0.04
***Ditylum* brightwellii**	**Mixed**		**Control**	
Experiment 1	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Days 2-8	0.55	0.13	1.07	0.05
Days 9-15	-0.26	0.24	-0.21	0.05
Experiment 2	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Days 2-8	0.93	0.05	1.08	0.03
Days 9-15	0.02	0.06	-0.05	0.10

Table 4.7. Repeated Measures Analysis and ANOVA for growth rates. 1. Results of repeated measures analysis using cell densities for both experiments. 2. Results of an analysis of variance (ANOVA) on growth rates for days 2-8 and 9-15 for both experiments. Analyses are comparing differences in species abundance and growth in mixed cultures and controls, respectively.

1. Repeated Measures		**2. ANOVA**		**2. ANOVA**	
Experiment 1		**Experiment 1; 1-8**		**Experiment 1; 9-15**	
Species	**p-value**	**Species**	**p-value**	**Species**	**p-value**
A. fundyense	0.153	*A. fundyense*	0.388	*A. fundyense*	0.834
D. brightwellii	0.005*	*D. brightwellii*	0.003*	*D. brightwellii*	0.728
Experiment 2		**Experiment 2; 1-8**		**Experiment 2; 9-15**	
Species	**p-value**	**Species**	**p-value**	**Species**	**p-value**
A. fundyense	0.115	*A. fundyense*	0.431	*A. fundyense*	0.001*
D. brightwellii	0.833	*D. brightwellii*	0.015	*D. brightwellii*	0.348

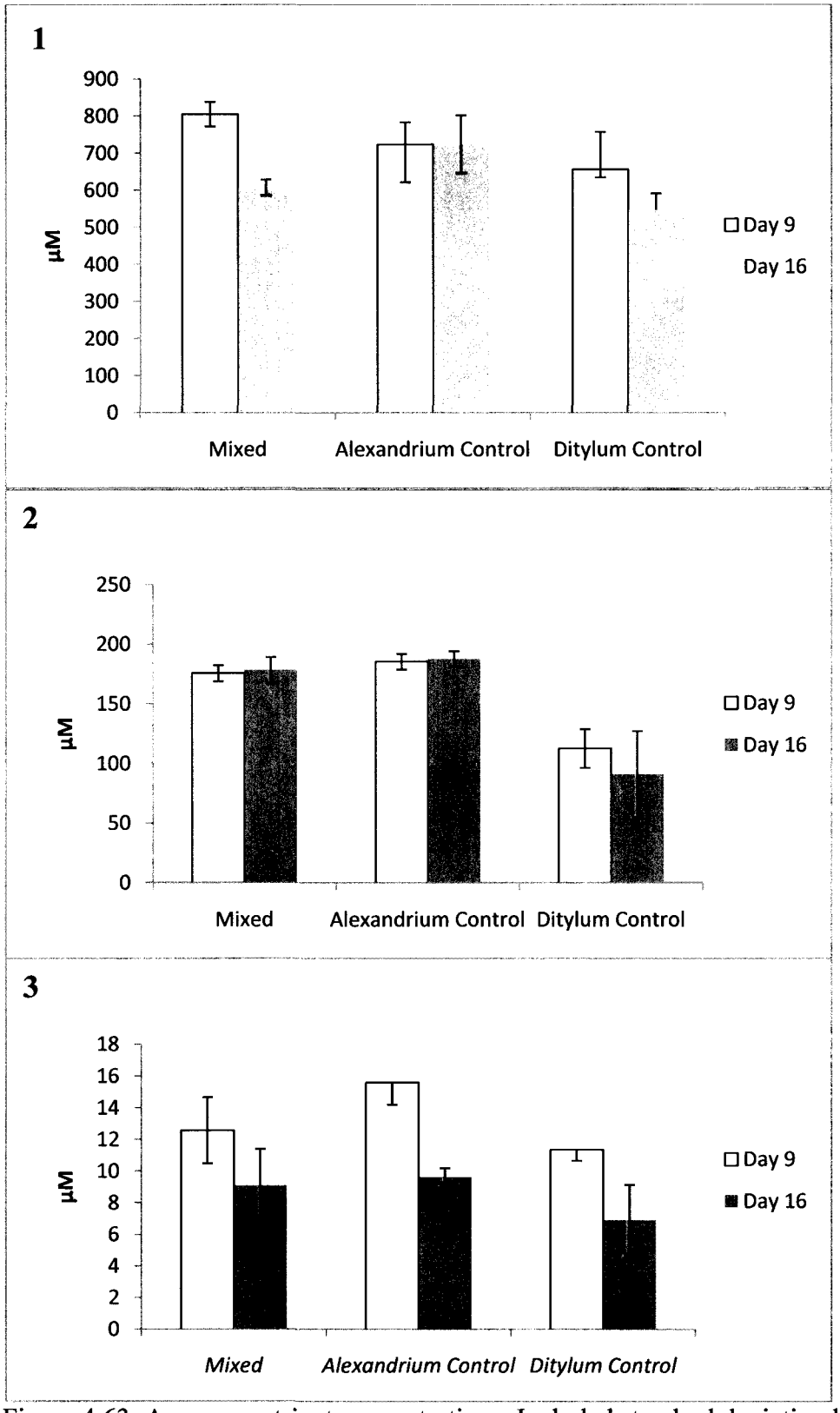

Figure 4.63. Average nutrient concentrations. Included standard deviation bars for each treatment at Days 9 and 16. 1: $NO_3^- + NO_2^-$, 2: $Si(OH)_4$, and 3: PO_4^{-3}

5. DISCUSSION

Whereas the focus of my research on the phytoplankton community structure of Georges Bank was on the months that followed the annual spring diatom bloom, it was that bloom that likely shaped the oceanographic conditions that followed it. Riley (1946) described the conditions required for the onset of the spring bloom on Georges Bank each year (i.e. increasing irradiance coupled with winter mixing events). Upwelling of nutrients from cold deeper waters in the fall and winter permit growth of plankton once light conditions are adequate usually in late winter and spring. These conditions appear to be ideal for faster growing, centric diatom species, which remain above the thermocline, where nutrients and light are plentiful. Previous studies on Georges Bank reported the dominance of species such as *Skeletonema debile* and S. *decipens* in March and April, with concentrations exceeding 500,000 cells L^{-1} in some locations on the Bank (Sears, 1941). Additional studies observed species of *Thalassiosira* (*T. nordenskioldii* and *T. gravida*), *Coscinodiscus* sp., and *Navicula* sp. making up the majority of the phytoplankton community from as early as January through late April (Lillick, 1940; Bigelow, 1926; Sears, 1941; and Falkowski and Von Bock, 1979). Growth of diatom species occurs over the course of the spring until late March-early April when nutrients, in particular silicate, become depleted. A coupling of depleted nutrient levels and increased stability of the water column from increasing temperatures prohibits diatoms from accessing nutrients below the thermocline (outside the tidally mixed crest of Georges Bank), resulting in termination of the spring bloom by late April (Riley, 1946). Diatoms generally take up nitrate and silicate in a 1:1 ratio, leaving excess nitrate available in the system once silicate becomes limiting (Turner et al., 1998). The excess

nitrate allows a post-spring bloom of slower growing, motile dinoflagellates to occur. Dinoflagellates do not require silicate and their ability to move vertically throughout the water column and access increased nitrate levels (relative to silicate) results in a shift in community, because diatoms are no longer able to maintain high population numbers in a nutrient-depleted upper water column. My results from April, May, and June surveys of Georges Bank in 2008, well after the spring bloom, revealed interesting successional patterns from late spring to summer, not only between phytoplankton functional groups (dinoflagellates, diatoms, etc.), but within these groups as well.

5.1. Late April-early May phytoplankton community

The somewhat unique and well-studied oceanographic properties of Georges Bank influence primary production and phytoplankton distribution throughout its area (Riley, 1946). Strong tidal currents interacting with the steep topography across the shallow parts of the bank are crucial to maintaining a well mixed water column, with vertical pumping and advection of nutrients onto the Bank driving primary production through the spring and summer months (Flagg, 1987; Townsend and Pettigrew, 1997; and Hu et al., 2008). The well mixed water column is separated from offshore waters by these tidal fronts, which appear stronger at the Northern Flank of the Bank compared to the southern region, which is characterized by a gentler slope (Chen et al., 1995). The Northern Flank receives a greater nutrient flux than the rest of the Bank, resulting in patches of increased phytoplankton abundance, especially on the Northeast Peak, which I also observed during the summer 2008 surveys. The highest abundances of diatoms (especially) and dinoflagellates were located at the northern stations on Georges Bank at

the end of April, consistent with nutrient input into the system from deep slope waters (Townsend and Pettigrew, 1997). Greater phytoplankton abundance, in particular diatom taxa, on the Northeast Peak is evident in the areal plots of nitrate and silicate, which are both depleted by late April (Figs. 10 and 13) suggesting that diatoms have taken up most of the silicate entering the Bank in this region. Phosphate concentrations were among the highest at the Northern Flank relative to the remainder of the Bank in late April, suggesting Georges Bank is a nitrate, not phosphate, limited region in the summer (Figs. 4.13 and 4.16).

The most abundant diatom taxa at the Northern Flank of Georges Bank in late April may be remnants of a spring bloom, because Group 1 diatoms, including *Coscinodiscus* spp., *Skeletonema* spp., *Chaetoceros* spp., and *Thalassiosira* spp., were present in high abundances (> 180,000 cells L^{-1}). The chain-forming centrics like *Skeletonema* spp. and *Chaetoceros* spp. are frequently the dominant diatoms at the end of the spring bloom on Georges Bank, notably in April and May, as reviewed above. The presence of these taxa in high abundances is often typical during late spring conditions in other regions of the world, when the majority of silicate has been taken up (Trigueros and Olive, 2001). Colonial diatoms of the genera *Chaetoceros*, *Skeletonema*, and *Thalassiosira* have rapid growth rates and can still outgrow dinoflagellates when silicate is near limiting in late spring and early summer (Grenny et al., 1973 and Parsons et al., 1978). Increased > 20 μm chlorophyll levels at the Northern Flank are likely the result of these chain-forming diatoms (Fig. 4.21). Cluster analyses grouped the northern-most stations together during the late April cruise based on the presence of these Group 1

diatoms, which I observed in higher abundances on the Northern Flank than elsewhere on the Bank, consistent with increased nutrient delivery to this region (Fig. 4.59).

The presence of Group 4 dinoflagellates in increasing abundance (still lower densities relative to diatoms) at the Northern Flank suggests that a shift in community structure might occur by late April. Unidentified dinoflagellate cysts (intact) made up a significant portion of Group 4 and likely represent the developing dinoflagellate population that becomes dominant after diatom growth subsides. Stations with increased Group 3 dinoflagellates, *Alexandrium* spp. included, were located in the central and southeast portions of the bank, not along the Northern Flank. Dinoflagellates, in general, have slower growth rates than diatoms, which can quickly exploit available resources and dominate the phytoplankton community (Banse, 1982; and Yang, 1996). When nutrients are available, as is often the case at the Northern Flank, diatoms remain abundant. It would appear that the dinoflagellates of Group 3 cannot grow fast enough to compete successfully with the faster growing chain-formers of the Group 1 diatoms. *Alexandrium fundyense*, a Group 3 dinoflagellate, displayed significantly lower growth rates than *Ditylum brightwellii* in my culture experiments with non-limiting nutrient levels (Tables 4.6 and 4.7). Therefore, it is likely that the presence of elevated silicate on the Northern Flank allowed Group 1 diatoms to remain dominant, or otherwise prevent successional replacement by dinoflagellate populations. Highest abundances of Group 3 dinoflagellates were present at the eastern-most edge of the Bank, consistent with an area of relatively lower salinity in late April (Fig. 4.50), which suggests the possibility of an intrusion of colder and fresher Scotian Shelf water onto the Bank may have transported a population of Group 3 dinoflagellates to this region. Also, Group 4 dinoflagellates

overlapped with Group 1 diatoms at the northern stations in Late April. The ability of Group 4 dinoflagellates to exist at relatively higher abundances there compared to the rest of the Bank may be a result of alternative nutritional strategies often employed by members of Group 4. Species of *Prorocentrum* and *Polykrikos* for example, have both mixotrophic and heterotrophic capabilities and may be coexisting with diatoms and perhaps ingesting them in order to subsist (Jacobson, 1996; Matsuyama, 1999). Previous studies have observed heterotrophic dinoflagellates coinciding with increased diatom biomass and in some cases are suggested to be important in the termination of diatom blooms, often when nutrients are not limiting (Hansen, 1991; Bralewska and Witek; Tiselius and Kuylenstierna, 1996). In addition, unidentified dinoflagellate cysts made up a significant portion of the Group 4 dinoflagellates (Appendix I) and may represent a temporary cyst population that can enter a vegetative growth phase to exploit resources once diatoms are no longer present.

It has been suggested that that regeneration of silicate and recycled nitrogen are the main sources of nutrients to the central part of the Bank where there is limited exchange with colder upwelled water from sources waters, and are important to maintaining increased production during the summer months (Townsend et al., 2006). Continuous supply of both new and recycled nutrients, combined with a generally well-mixed water column create adequate conditions for phytoplankton production, which are often patchy in nature (Franks and Chen, 1996). By late April, warming of the surface waters in the central, shallow portions of the Bank is evident (Fig. 4.1). Nutrient concentrations, in particular nitrate and silicate are depleted at the central and southern stations of the Bank, and phytoplankton populations in these regions are not in a position

to benefit from increased inputs of new nutrients that flux onto the bank along the steeper sloped Northern Flank. With little input of new or regenerated nutrients, diatom growth ceases in late April across most of the Bank. During the late April cruise, I observed relatively high abundances of Group 3 and 4, in particular *Alexandrium* spp. and Group 3 dinoflagellates and a raphidophyte at the central and southern stations on Georges Bank, where increasing temperature, stratification of the surface layer outside the tidal mixing front, and low nutrient levels are ideal conditions for the dinoflagellate population to become established, or for the diatom community to subside (Spector, 1984 and Taylor, 1987). Increases in > 20 um and total chlorophyll at these central-southern stations may be the result of new growth, particularly dinoflagellate growth, as the larger taxa like *Alexandrium* spp., *Amphidinium* spp., and *Scrippsiella* are photoautotrophic.

5.2. Late May-early June phytoplankton community

Limited exchange of upwelled waters along the edges of Georges Bank with the shallow central region results in a summer community that uses recycled nitrogen, in the form of ammonium, and regenerated biogenic silica (Draxler et al., 1985; Horne et al., 1989; and Townsend and Thomas, 2002). The cruise in late May appeared to support these conclusions, as I observed increases in silicate, often patchy in nature, at several stations on the Bank during OC447, which did not coincide with increased nitrate levels. This led me to believe that the silicate was regenerated, perhaps as a result of increasing temperatures and increasing dissolution of diatom frustules, remnants of the spring bloom. Nitrate and phosphate levels remained relatively low in late May, however slightly elevated concentrations of ammonium (NH_4^+) were observed at some stations

throughout the Bank (Figs. 4.8, 4.14, and 4.18). Organic nitrogen sources appear to fuel dinoflagellate production, in particular the *Alexandrium* spp. population, which became well established across the Bank (Fig. 4.37) by late May. Previous studies on Georges Bank suggest that diatoms grow in the presence of new nitrogen sources (nitrate), while dinoflagellates can grow well when nitrogen is near limiting to diatoms and organic nitrogen sources are available (Townsend and Pettigrew, 1997). I observed the highest abundances of *Alexandrium* during the May survey (12,600 cells L^{-1}) and an increase in the remaining dinoflagellates and raphidophye of Group 3, which together formed the majority of the phytoplankton community in late May. Group 1 diatoms were no longer present in the high abundances observed in April at the Northeast Peak, and still remained low throughout the rest of Georges Bank, not exceeding 10,000 cells L^{-1} anywhere (Fig. 4.45). The absence of Group 1 diatoms in high abundance (> 100,000 cells L^{-1}) suggests that nutrient levels were limiting to diatom growth, causing termination of the spring bloom community. Group 2 diatom abundances increased slightly; however, they were not near the typical bloom-forming concentrations observed in the spring on Georges Bank (Backus 1987). Group 4 dinoflagellates were essentially background taxa, not reaching cell numbers as high as Group 3, and exhibited an overall patchy distribution throughout the Bank in late May. The inability of Group 4 dinoflagellates to become equally well-established, despite increased abundances at several stations during the late April survey, suggests that these taxa grow at a slower rate, and are therefore competitively inferior to the dinoflagellates and raphidophyte of Group 3, and cannot become dominant once a Group 3 population is established. However, their patchy distribution and presence at nearly every station on Georges Bank

during late May suggests that the Group 4 taxa may be feeding on dinoflagellates and other phytoplankton cells, and therefore would be able to maintain limited population numbers with the dinoflagellates of Group 3. *Alexandrium* spp. distributions did not overlap with localized areas of increased diatom abundance as did the dinoflagellates in general, which displayed spatially distinct distribution patterns with respect to diatoms.

The relatively high abundance of Group 2 diatoms in late May-early June, likely the result of regenerated biogenic silica to the system represents a succession from the fast-growing, chain-forming diatoms of Group 1, which dominate the spring bloom community, to a group that may be competitively superior at lower nutrient levels. Group 2 taxa, notably species of *Leptocylindrus* and *Guinardia,* are often a major component of summer communities in other regions of the world (Casas et al., 1999;Trigueros and Orive, 2001; Gayoso, 1999; Schapira et al., 2008). The localized patch of increased Group 2 diatoms at stations where dinoflagellates (i.e., Group 3 taxa), were lower in abundance suggests that diatoms did not allow significant growth of the dinoflagellate population, perhaps because of resource exploitation or some form of competitive interaction. Alternatively, if the dinoflagellate bloom remained confined in a frontal feature, a secondary diatom population could become dominant outside of this region where the dinoflagellate population is not established but where limited silicate is available for uptake. Limited temporal sampling of stations on Georges Bank (i.e., one per month) makes it difficult to comment on the nature of these distributional patterns, whereby high abundances of *Alexandrium* spp. and the dinoflagellates and raphidophyte of Group 3 remain separated from increased densities of the successor Group 2 diatoms. However, regeneration of silica as observed on the late May cruise would suggest that the

diatoms of Group 2 could become numerically dominant and establish late-summer populations until nutrients become limited again. What remains curious is the apparent inability of Group 2 diatoms to maintain higher cell concentrations (relative to dinoflagellates) at more than a few localized patches on the Bank despite significant biogenic silica regeneration. Smayda (2003) suggests that it is not the ability of dinoflagellates to be competitively superior and exploit light and nutrients, but rather their tolerance of stress that allows them to precede diatoms in summer months. Warming temperatures along with increased light levels and low concentrations of inorganic nutrients on Georges Bank in the summer may explain in part why the dinoflagellate population is able to persist at higher abundances than diatoms, which are still present in relatively low numbers.

5.3. Late June- early July phytoplankton community

Perhaps the most interesting results were observed during the late June survey of Georges Bank in 2008, which was characterized by the decline of the *Alexandrium* bloom and a shift toward a Group 4 dinoflagellate-dominated community. *Alexandrium* spp. abundances dropped to less than 3,000 cells L^{-1}, but the highest cell numbers in late June were still observed around the 100 m isobath on the eastern edge of the Bank (Fig. 4.39). The remaining dinoflagellates and raphidophyte of Group 3 remained confined to the eastern region and dropped to less than 25,000 cells L^{-1}, accompanied by an increase in Group 4 dinoflagellates along the same spatial gradient, often to greater than 40,000 cells L^{-1} in some locations (Figs. 4.52 and 4.55). The demise of the Group 3 bloom, or at least the decrease in relative cell numbers from the previous cruise, is likely the result of

severe depletion of inorganic nitrogen sources, which were less than 0.5 μM at all but two stations in late June (Fig. 4.9). The increase in Group 4 dinoflagellates despite nearly undetectable levels of nitrogen suggests that these particular taxa are utilizing recycled ammonium or employing alternative feeding strategies, i.e. heterotrophic or mixotrophic behavior that provides adequate nutrition to maintain and even increase population numbers in late summer. The similar spatial patterns of Group 4 and Group 3 dinoflagellates in late June support this hypothesis, because species of *Prorocentrum*, *Polykrikos*, and *Gyrodinium* are known to ingest larger dinoflagellate cells, characteristic of the Group 3 bloom taxa (Hansen, 1992; Nakamura et al., 1995; Jeong et al., 2003; Kim and Jeong, 2004; Sherr and Sherr, 2007). *Polykrikos* spp. was not observed at any station during the first two cruises to Georges Bank in summer 2008. The general presence and increased abundance of these largely heterotrophic taxa suggests that the late summer community on Georges Bank is possible because of a shift from photoautotrophy to heterotrophy or mixotrophy; in many instances, I observed what appeared to be ingested flagellate cells within *Polykrikos* spp. and *Gyrodinium* spp. cells (Fig. 5.1).

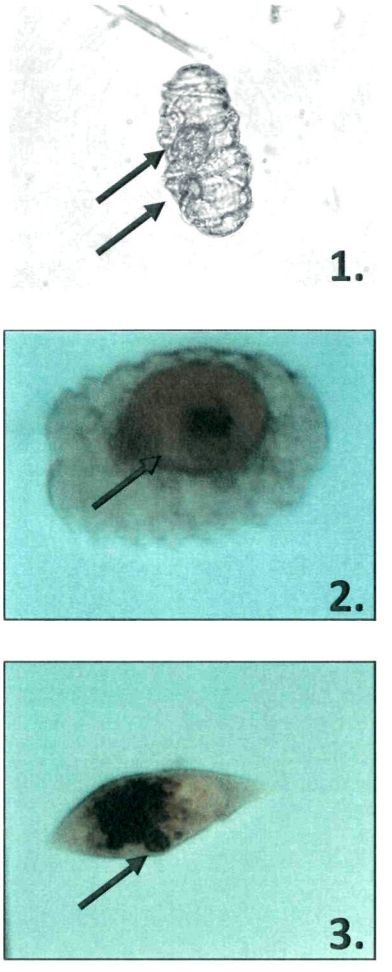

Figure 5.1. Heterotrophic Dinoflagellate microscope images. 1.Live *Polykrikos* spp.; 2: Preserved *Polykrikos* spp., and 3: *Gyrodinium* spp. observed during EN448 (27 May-3 July 2008) with ingested cells inside (arrows).

Previous studies of *Polykrikos* spp. in other bodies of water reported similar abundance and spatial distributions of this heterotrophic dinoflagellate with bloom forming dinoflagellates, including *Gymnodinium* spp., also a Group 4 dinoflagellate in this study (Matsuyama et al., 1999). Supporting laboratory experiments also reveal that *Polykrikos* spp. is capable of feeding on *Gymnodinium* and other red tide species, including species from the common taxa I observed on Georges Bank: *Scrippsiella* spp., *Amphidinium* spp.,

Ceratium furca, *Gyrodinium* spp., and *Gymnodinium* spp., and can thus be important in controlling their population numbers in the field (Sampayo, 1998; Matsuyama et al., 1999; and Jeong et al., 2001)

Unidentified dinoflagellate cysts of Group 4 also increased in abundance from the late June survey (Fig. 5.2).

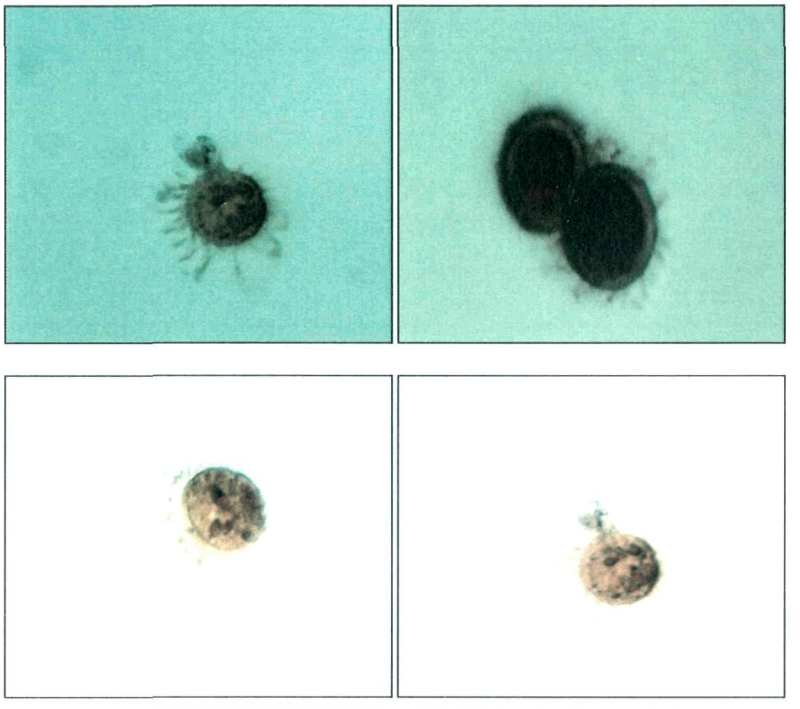

Figure 5.2. Dinoflagellate cyst microscope images. Preserved unidentified dinoflagellate cysts observed during EN448 (27 May-3 July 2008).

The higher numbers of cysts in late June can be attributed to the demise of the Group 3 bloom, as unfavorable environmental conditions, i.e. nutrient limitation, can lead to encystment of the dinoflagellate population (Anderson et al., 1985; Kremp and Heiskanen, 1999; Nagai et al., 2004). The number of unidentified cysts increased substantially from the late May cruise and even late April survey, becoming the 6th most

abundant (average) category in late June, versus the top 12th and 9th in OC445 and OC447, respectively (Tables 4.1 and 4.2). Increased encystment in late June supports the hypothesis that dinoflagellate populations will cease growth and enter into a cyst life stage in order to avoid adverse growth conditions, and to preserve the population for future growth when conditions permit.

The decrease in *Alexandrium* spp. cell abundances from late May to late June is likely the combination of adverse growing conditions in the upper water column and, perhaps, ingestion by zooplankton and/or other heterotrophic dinoflagellates. The members of the Group 3 dinoflagellates include *Protoperidinium* spp. and *Amphidinium* spp., species of which are capable of grazing down bloom-like conditions of harmful algal blooms. For example, observations of high numbers of *Protoperidinium* spp., co-occurring with red tide species in other parts of the world, and laboratory evidence of feeding on red tide species by *Protoperidinium* spp. support this theory (Jeong and Latz, 1994; and Buskey, 1997). Additional laboratory studies have observed preferential feeding of *Protoperidinium* on species of *Ceratium*, which were also a part of the Group 3 population on Georges Bank, occurring in similar abundances (Olseng et al., 2002). The grouping of *Protoperidinium* and *Ceratium* spp. with *Alexandrium* spp., based on similar abundance patterns at each station, suggests that heterotrophic feeding may need to be considered, at least not ruled out, as a means by which the *Alexandrium* bloom, and other toxic blooms, are controlled and even suppressed.

5.4. Competitive interactions on Georges Bank: A Perspective

Reynolds (1988) suggested that [freshwater] phytoplankton have developed three adaptive strategies to survive in their habitat, which frequently has high levels of disturbance and stress: 1. Be good competitors; 2. Be stress tolerant; and 3. Be disturbance-tolerant. It is not the ability of dinoflagellates to be competitively superior and exploit light and nutrients from the water column, but rather it is their tolerance of stress (i.e. higher light levels, increased stratification/limited nutrient exchange, and low nutrient levels) that likely allows them to succeed and dominate in the summer months in many regions of the world, including Georges Bank. Before further discussion of community dynamics with respect to diatom and dinoflagellate interactions, it is necessary to comment on the term "bloom", which is used often, but does not always describe similar events. For example, the annual diatom spring "bloom" on Georges Bank and in most other continental shelf regions in characterized by a sudden increase in cell abundance, to anywhere from 500,000 cells L^{-1} to as high as 1-2 million cells L^{-1}, following favorable environmental conditions. Subsequent to the annual spring bloom on Georges Bank is an increase in *Alexandrium* spp. abundance, as well as dinoflagellates in general, constituting a summer "bloom", specifically, a harmful algal bloom when referring to an *Alexandrium* spp. population. However, average cell densities of *Alexandrium* spp. generally peak at less than 15,000 cells L^{-1}, and are more often on the order of 4,000 cells L^{-1} in the surface waters. The remaining summer dinoflagellate population does not appear to exceed greater than 100,000 cells L^{-1}, at least during these summer 2008 cruises. Both phenomena are termed a bloom, even though there is more than an order of magnitude difference in maximum cell densities. The term "bloom" is

often used to describe an increase in a particular phytoplankton functional group or harmful species of interest that is out of the ordinary. What remains a challenge is to define what "out of the ordinary" is; for example: 500,000 cells L^{-1} of diatoms in late June on Georges Bank might be considered unusually high, however that concentration would be considered average or slightly lower than average during the spring season. A question that can be formed from a discussion on what the term "bloom" really means is why the late summer population on Georges Bank, consisting of mainly dinoflagellates, does not reach densities similar to the spring diatom bloom? The most commonly understood reason is that nutrient levels in summer are significantly lower than in spring. But it may also be that dinoflagellates, while well suited to withstand environmental stressors like increased light and limiting nutrients, may not be good enough competitors to maintain higher cell densities characteristic of the diatom bloom species. Simply developing a population of cells, increasing slightly in abundance, and providing a population of cysts for future generations may be the extent to which dinoflagellates extend their abundance on Georges Bank and throughout most of the world. In that case, being a good competitor for light and nutrients may not be sufficient in the presence of faster growing, nutrient exploiting diatoms. Dinoflagellates instead invest energy into adapting to conditions that are generally unfavorable for species of diatoms, by a number of strategies.

Biological interactions, specifically competitive interactions, between species of diatoms and dinoflagellates in natural assemblages is not well understood or studied, perhaps because dinoflagellate populations generally follow diatom blooms, and lack of sufficient sampling often prevents further investigation into community changes on the

time scales of days, rather than months. The general successional trend from fast growing diatoms to dinoflagellates and smaller nanoplankton does not address the variability in the timing and distribution of the annual *Alexandrium* blooms on Georges Bank each year. It is likely that the dinoflagellate bloom occurs once nutrient and light levels limit growth of diatoms (good competitors); however, the ability or inability of *Alexandrium* and dinoflagellate populations to become established in certain regions of the Bank relative to another is unknown and cannot be solely attributed to physical and chemical forcing, which is often the case for other taxa. Drouet and Zielinski (1994) stated that "Phytoplankton population dynamics is usually modeled as though the phytoplankton were a bulk property of seawater, and as if all component species of the community behaved in the same way in response to physical forcing. According to this view, all phytoplankton species simply track environmental variables, grow when they can, and succumb to circumstances when they cannot. The 'species' of this approach are usually 'chlorophyll' or 'carbon'. Phytoplankton, for example, is 'a dynamically passive physical quantity'.

In addition to differences in diatom and dinoflagellate abundance and distribution, differences within each of the functional groups identified in this study were observed during the summer 2008 cruise season to Georges Bank, which leads one to believe that coupled with physical and chemical drivers, biological interactions, in particular competitive interactions, are occurring and are determining succession and abundance of particular phytoplankton taxa. Competitive interference from phytoplankton, in particular dinoflagellates by methods other than fast nutrient uptake capability and growth rates, might be a strategy employed to comepensate for slower

growth, or at least rid the water column of the good competitors (i.e. resource exploiters), in this case, the diatom population (Roy and Chattopadhyay, 2006; Roy, 2009). Termination of bloom-like concentrations of diatoms will allow increases in dinoflagellate cell populations that were previously unable to compete with spring taxa. Conversely, persistence of diatoms, or a return to favorable growing conditions for diatoms, can prevent increases in the dinoflagellate population, which is likely the case in late June on Georges Bank, where a group of summer diatom taxa dominated a few regions on the Bank, perhaps keeping dinoflagellate abundance low. Recent studies have suggested that some species of diatoms are capable of undermining allelopathic interference by dinoflagellates which can also alter the phytoplankton community (Prince et al., 2008). This could be proposed as a means by which Group 2 diatoms on Georges Bank persist during a red tide bloom, in particular *Guinardia flaccida*, which was often co-occurring with *Alexandrium* spp.

Competitive interactions between dinoflagellates and other groups of phytoplankton are often suggested to be the result of releases of chemical compounds or substances that essentially limit diatom growth. This has been demonstrated in laboratory culture work for various species of *Alexandrium* that are observed annually on Georges Bank and in the Gulf of Maine (Arzul et al., 1999; Fistarol et al., 2004). The reasons for the release of such chemicals are unknown. Many believe the chemical substances released into the water column contain hemolytic compounds that cause lysis and eventual cell death or encystment when in close contact. However, the ability of the target species to still maintain low numbers of cells and lower growth rates, often observed in previous culture studies and my preliminary work, could suggest that the

release of these chemicals serves as more of an environmental cue; perhaps the presence of stress-tolerant dinoflagellates means environmental conditions are not favorable for diatom growth. A question that is then asked, is: At what concentrations of cells do we see such interactions occurring?

Varying the initial concentrations of *Alexandrium fundyense* and *Ditylum brightwellii* in my two laboratory growth experiments yielded different results, and suggests that a threshold concentration of *Alexandrium fundyense* is required to impact diatom growth significantly (Figs 64a and 64b). Adjusting the initial cell concentrations is relatively easy in a laboratory setting, whereas it is unclear in the natural environment what might allow a population of potentially allelopathic dinoflagellates, such as a species of *Alexandrium,* to become well enough established to limit diatom growth. It is likely that a combination of variables is responsible for the succession from diatoms to toxic dinoflagellates. The cyst phase in the life history of *Alexandrium* spp. and many other dinoflagellates creates viable cells that can remain dormant until conditions become suitable for growth once again. The presence of unidentified cysts in the late April cruise likely represents a population of dinoflagellates from the previous season. As nutrients and water column conditions become unfavorable for diatom growth, a decrease in bloom like conditions characteristic of early spring months occurs. A decrease in relative population numbers of diatoms, coupled with background abundances of dinoflagellates and the presence of cysts, may bring dinoflagellates, including *Alexandrium* spp., to a critical threshold concentration that impedes further diatom growth. By late May and June, the presence of spring blooming taxa like *Skeletonema* spp., *Coscinodiscus* spp., *Chaetoceros* spp., and *Thalassiosira* spp. were minimal. Despite regeneration of silicate

in late May and recycling of nitrogen, the phytoplankton community in June was still dominated by dinoflagellates and other smaller flagellate taxa. Diatoms remained in low abundance at most stations, except for a localized patch of increased abundances of *Leptocylindrus* spp., *Guinardia flaccida, Dactyliosolen*, and *Pseudo-nitzchia* spp. in excess of 200,000 cells L^{-1}; the dinoflagellate abundance at those particular stations was lower than across most of the Bank. Because densities only increased at a few stations, the presence of dinoflagellates and subsequent release of chemicals may serve as a cue to remaining diatoms that unfavorable conditions for growth exist; combined with close to limiting nutrient levels, this may suffice to limit the diatom population to one or two stations with localized increased abundance.

In the preliminary growth experiments, control flasks of the diatom *Ditylum brightwellii* had significantly higher growth rates than *Alexandrium fundyense*, which is often the case when comparing diatom and dinoflagellate growth rates (Banse, 1982; Tang, 1995). Non-limiting nutrient concentrations and resources should then favor growth of competitively superior species in culture, in this case a diatom that can take up nutrients quicker and grow faster. This was the case in Experiment 2, where initial concentrations of *Alexandrium* were lower (relative to Experiment 1); *Ditylum*, despite being five times less abundant than *A. fundyense* at the start of the experiment, experienced exponential growth with no significant difference in growth rate when compared to control flasks (Tables 4.6 and 4.7). *Alexandrium fundyense* cells were not able to compete for resources in an environment that exhibited favorable growing conditions for diatoms (replete nutrients, adequate light, etc). By the end of the experiment, *Alexandrium fundyense* growth had become negative, and was unable to

establish a growing population in the presence of *Ditylum brightwellii.* Increasing the initial concentration of *Alexandrium* so that a 10-fold difference existed in starting cell numbers between *Ditylum* and *Alexandrium* yielded different results. Despite running Growth Experiment 1 under identical growth conditions, with replete nutrient concentrations, and an increase in the initial diatom concentration by 5 –fold (relative to the Experiment 2), *Ditylum brightwellii* did not outcompete the dinoflagellate. Growth during days 1-8 was significantly lower than growth of *D. brightwellii* in control flasks without *Alexandrium fundyense* present. The ability of *Alexandrium* to grow with *Ditylum brightwellii* at a rate similar to control flasks suggests that higher initial numbers of *A. fundyense* cells may release enough chemical deterrents to result in significantly lower growth rates of diatoms coexisting in culture. The presence of *Alexandrium* at higher initial concentrations did not, however, completely suppress growth of *D. brightwellii*, rather it lowered the growth rate and subsequent cell densities enough for *Alexandrium* to establish and maintain increased population numbers. Growth rates of *A. fundyense* in mixed cultures and in control flasks for Experiment 1 were not significantly different, suggesting that limiting diatom growth maintained relatively average growth rates for *A. fundyense* in this particular culture.

These similar scenarios can be compared with results observed in the field on Georges Bank. If nutrients and resources are not limiting, i.e. in the early-late spring period on Georges Bank, *Alexandrium* spp. are not able to outcompete faster growing diatoms like *Skeletonema*, *Chaeotoceros*, *Thalasssiosira*, *Coscinodiscus*, etc., which make up the annual spring diatom bloom each year. As late-spring, early-summer approaches, nutrients become depleted from diatom uptake, which, along with increasing

temperatures, creates unfavorable growth conditions. Diatom abundance begins to decrease and growth of the numerous unidentified cysts observed in this study mark the beginning of a succession to a dinoflagellate dominated community. Increases in dinoflagellate abundance, including *Alexandrium* spp., whether by vegetative growth or germination of cysts, ensues across most of the Bank, except for the Northern Flank, where nutrient pumping appears to fuel the diatom bloom into late April. Dinoflagellate cells increase in abundance, but they do not generally exceed 100,000 cells L^{-1} anywhere on the Bank. The *Alexandrium* spp. bloom reaches a peak in late May, with lower cell densities than is typical for laboratory experiments, but densities equal to these blooms in the waters of the Gulf of Maine to the north. Regeneration of silicate occurs on the Bank between late April and late May, while near-limiting levels of inogranic nitrogen persists through late June. By this point, the *Alexandrium* spp. bloom is near its end, however dinoflagellates, and other nanoplankton remain the dominate groups on Georges Bank; in particular the presence of several heterotrophic taxa suggests that ingestion of *Alexandrium* spp. and the late May blooming dinoflagellates could be occurring. Several stations exhibit increased abundances of what appear to be a later summer diatom community. However, these localized patches of higher diatom numbers coincide with relatively low dinoflagellate abundances, thus allowing growth and uptake of any remaining silicate and nitrate in the system without interference by dinoflagellates.

A common criticism of laboratory experiments is the use of unrealistic (high) concentrations of cells, as is the case with the preliminary experiments reported here. While *Alexandrium* spp. is present in much lower concentrations on Georges Bank, even at the peak of a bloom, nutrients are not replete (versus Growth Experiments where

nutrients were not limiting) but rather appear to be close to limiting at this time. Because nutrients are not limiting at any time during the growth experiments and diatoms in general have higher growth rates, a much higher initial concentration of *Alexandrium fundyense* needs to be added to inflict any significant changes in the growth of *Ditylum brightwellii*. If *Alexandrium*, even in high concentrations, can significantly impede the growth of a faster growing and competitively superior diatom in the presence of ideal growing conditions, it should not be ruled out that lower concentrations of *Alexandrium* spp. could impede growth of diatoms when nutrients become close to limiting in a natural setting.

Studying competitive interactions among phytoplankton taxa is a challenging task and much more work needs to be done in this particular line of research, not only on Georges Bank, but throughout the entire Gulf of Maine and in coastal and open ocean ecosystems around the world. The ability to observe the competition between bloom forming species, in particular diatoms and dinoflagellates, which often comprise the spring and summer phytoplankton community in many coastal and continental shelf regions, can only be done by making improvements in field and laboratory research methods. Monitoring changes in a phytoplankton community need to be done on the time scales of days and weeks, not months, which will provide more insight into shifts in the community beyond just changes from diatom to dinoflagellate communities.

In order to advance our understanding of succession patterns and distribution and abundances of a particular species or functional plankton group in space and time, laboratory studies need to be improved. Isolating natural phytoplankton communities and

conducting experiments at similar and variable physical and chemical conditions are crucial to linking laboratory and field data. Competitive interactions, in particular allelopathic capabilities of *Alexandrium* spp. and other dinoflagellates cannot be ruled out as a mechanism by which this group of phytoplankton occupies a particular spatial and temporal niche on Georges Bank. Sufficient evidence on these types of interactions in the field is lacking and the extent to which competitive interactions between the phytoplankton species affect the timing and distribution of *Alexandrium* blooms on Georges Bank each year is yet to be determined.

Results from the 2008 summer cruises to Georges Bank also highlight the need to consider other adaptations by dinoflagellates to be competitive in the water column, specifically alternative nutritional strategies, such as heterotrophy and mixotrophy. Studies of the spring and summer phytoplankton community in other regions provide evidence of heterotrophic and mixotrophic feeding by dinoflagellates that not only decrease diatom abundance, but can also lead to shifts in the dinoflagellate community, which was apparent on Georges Bank from late May to late June. The presence of heterotrophic dinoflagellates on Georges Bank may play a much bigger role in the demise of the diatom and *Alexandrium* spp. blooms each year that previously thought.

6. CONCLUSION

Ecological interactions between phytoplankton species is suggested to play a key role in phytoplankton community dynamics, however this area of research is just emerging in greater detail, as examining the nature of competitive interactions in the field still remains a challenge. Whereas my study is one of the first to identify the abundance and distribution of major phytoplankton taxa present on Georges Bank during late spring and summer, one can only speculate on the nature of these successional patterns until sampling methods are enhanced. Improvements that need to be made in this area of research center on the need for more real-time sampling in order to link changes in community structure with changes in the environment (i.e. nutrient availability, temperature, light levels, water column stability, etc). Addtionally, microscopy, while beneficial, is time consuming and provides only limited temporal and spatial resolution. The level of error associated with cell counts from field samples is difficult to determine and can vary depending on the type and number of cells being counted (Andersen, 2005). Replication of cell counts to assess counter error and variability in sampling will be crucial, and combining traditional methods with newly designed instruments like flow cytometers will make this process less labor-intensive. Whereas this study identified the phytoplankton community on Georges Bank beyond the major functional groups (i.e. diatoms and dinoflagellates) to genus (only sometimes to species), it will be important in future studies to identify to species level, which is necessary to study competitive interactions between phytoplankton in laboratory studies and possibly link these findings with species distribution and successional patterns in the field.

Results from my preliminary laboratory experiment suggest that competitive interactions exist between diatoms and a harmful bloom forming dinoflagellate; however, I cannot conclude with any degree of certainty that phytoplankton species distributions in the field are the direct results of competitive interactions seen in my laboratory studies. Differences in nutrient availability, light, temperature, and other oceanographic processes can have a strong affect on the nature of competitive interactions between diatoms and *Alexandrium*. In the laboratory studies, nutrients were kept replete and cells were grown under constant, identical growing conditions, with much higher initial cell concentrations than are often observed in nature.

Allelopathic interference by *Alexandrium* spp. may play a role in this species' ability to outcompete faster growing diatoms and even impede diatom growth when present in high enough concentrations. Whereas previous studies (Fistarol et al., 2004a; and Tillmann and John, 2002) have demonstrated such an effect by *Alexandrium*, the nature of this mechanism in the field has yet to be tested and cannot necessarily be stated with any degree of certainty as a major factor in the formation of high densities of *Alexandrium* after the diatom spring bloom. In addition, my laboratory studies used non-axenic cultures of both *Alexandrium* and our diatom species of interest, therefore I cannot completely rule out the possible contribution of bacteria to what was observed throughout the course of the experiment. I examined the nature of competitive interactions between *Alexandrium fundyense* and only one particular species of diatom, *Ditylum brightwellii*, which is common in the Gulf of Maine; however, *Dityum spp.* is not considered to be a dominant diatom on Georges Bank. In future studies, many different species of diatoms, in particular, species of interest on Georges Bank, need to be grown in culture with

Alexandrium in order to observe any increased sensitivity or resilience of some species relative to another. One must also consider the release of inhibitory compounds by certain species of diatoms, (for example *Pseudo-nizschia* spp. and *Rhizosolenia* spp.) which, in addition to their relatively faster growth rates, may also help to gain a competitive advantage when allelochemical-producing dinoflagellates are present (Legrand et al., 2003).

In my study, *Alexandrium* was the toxic dinoflagellate of interest due to heath threats associated with PSP in the northeast, however many different species of dinoflagellates have been shown to exhibit growth inhibitory and cyst promoting effects on other cells, some such species are observed in high numbers on Georges Bank, including *Amphidinium* spp., *Ceratium* sp., *Dinophysis* spp., *Gymnodinium* spp., and *Heterocapsa* spp. (Sugg and VanDolah, 1999; Legrand et al., 2003; Kubanek et al., 2005; Ahmed et al., 1995; and Uchida, 2001). Thus, competitive interactions between different species of both diatoms and dinoflagellates need to be investigated in greater detail.

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APPENDICES

Appendix A. OC445, OC447, and EN448 2008 sampling locations and dates, bottom depth, temperature and salinity.

Table A.1. OC445, OC447, and EN448 2008 sampling locations and dates, bottom depth, temperature and salinity.

Station	Sample Date	Latitude	Longitude	Bottom Depth (m)	Temperature (°C)	Salinity (PSU)
A1	2-May-08	42 2.7	66 22.5	82	5.95	32.84
A2	2-May-08	41 45.4	66 8.7	86	4.94	32.20
A3	2-May-08	42 7.8	67 10.2	75	6.71	32.92
A4	1-May-08	41 50.9	66 55.8	58	6.28	33.01
A5	1-May-08	41 34.1	66 41.1	76	6.00	32.80
A6	1-May-08	41 17.3	66 26.6	95	5.43	32.24
A7	1-May-08	41 55.3	67 37.0	35	6.59	32.92
A8	1-May-08	41 38.0	67 23.4	42	6.79	33.00
A9	1-May-08	41 20.8	67 9.7	56	6.50	32.78
A10	1-May-08	41 3.3	66 56.2	72	5.59	32.05
A11	30-Apr-08	41 35.8	67 58.8	28	7.55	32.97
A12	30-Apr-08	41 18.4	67 44.9	33	7.27	33.06
A13	30-Apr-08	41 0.9	67 31.8	60	7.38	32.73
A14	30-Apr-08	40 43.4	67 18.7	95	6.44	32.32
A15	29-Apr-08	41 36.6	68 34.5	139	6.69	32.80
A16	29-Apr-08	41 18.8	68 22.4	44	6.90	32.90
A17	30-Apr-08	41 1.6	68 9.7	47	7.05	32.96
A18	30-Apr-08	40 43.7	67 57.0	77	7.11	32.46
A19	30-Apr-08	40 26.2	67 44.3	130	6.89	32.85
A20	29-Apr-08	41 6.7	68 46.2	67	6.82	32.82
A21	29-Apr-08	40 48.4	68 33.1	53	6.85	32.83
A22	29-Apr-08	40 30.6	68 19.9	93	6.05	32.35
A23	28-Apr-08	40 47.6	69 13.8	52	6.08	32.69
A24	29-Apr-08	40 30.1	69 1.6	70	7.02	32.46
M1	30-May-08	41 54.1	66 15.5	80	6.94	31.97
M2	30-May-08	42 7.9	67 10.3	71	7.77	32.64
M3	30-May-08	41 50.9	66 55.7	59	8.15	32.94
M4	30-May-08	41 34.2	66 41.3	72	7.84	32.91
M5	30-May-08	41 17.2	66 26.5	95	8.58	32.72
M6	31-May-08	41 55.3	67 37.0	37	8.89	32.79
M7	31-May-08	41 38.1	67 23.4	38	9.06	32.88
M8	31-May-08	41 20.8	67 9.7	52	8.27	32.93
M9	31-May-08	41 3.3	66 56.2	71	9.26	32.87
M10	31-May-08	41 35.8	67 58.8	35	9.64	32.64
M11	31-May-08	41 18.7	67 44.8	36	8.43	32.58

Table A.1. Continued.

M12	31-May-08	41	1.1	67	31.7	61	9.40	32.91
M13	31-May-08	40	43.5	67	18.8	95	10.04	32.87
M14	1-Jun-08	41	27.7	68	29.5	83	10.84	32.07
M15	1-Jun-08	41	10.0	68	16.6	45	9.28	32.82
M16	1-Jun-08	40	52.6	68	3.2	58	8.55	32.73
M17	1-Jun-08	40	34.9	67	50.5	91	9.69	32.63
M18	1-Jun-08	40	16.6	67	38.7	500	12.22	33.55
M19	2-Jun-08	41	14.6	68	52.2	98	9.65	32.64
M20	2-Jun-08	40	57.0	68	39.4	49	8.35	32.67
M21	2-Jun-08	40	39.6	68	26.4	64	9.11	32.81
M22	2-Jun-08	40	21.3	68	13.1	141	11.09	31.96
J1	2-Jul-08	42	2.6	66	22.5	88	15.24	32.22
J2	2-Jul-08	41	45.4	66	8.5	90	13.48	32.43
J3	2-Jul-08	42	7.7	67	10.3	68	14.13	32.17
J4	2-Jul-08	41	50.5	66	55.5	63	10.96	32.57
J5	1-Jul-08	41	34.3	66	41.1	75	11.26	32.58
J6	1-Jul-08	41	17.2	66	26.6	96	14.67	32.52
J7	1-Jul-08	41	55.2	67	37.0	36	15.76	32.00
J8	1-Jul-08	41	38.0	67	23.7	46	12.51	32.47
J9	1-Jul-08	41	20.7	67	9.8	47	11.13	32.68
J10	1-Jul-08	41	3.3	66	56.2	70	14.30	32.63
J11	1-Jul-08	40	45.1	66	46.0	270	16.37	32.57
J12	30-Jun-08	41	53.6	68	10.8	200	18.28	31.39
J13	30-Jun-08	41	36.2	67	59.1	37	13.50	32.58
J14	30-Jun-08	41	18.4	67	45.2	41	13.20	32.68
J15	30-Jun-08	41	0.3	67	31.6	67	11.65	32.74
J16	30-Jun-08	40	43.4	67	18.8	98	14.89	32.51
J17	29-Jun-08	41	36.7	68	35.0	145	18.09	31.24
J18	29-Jun-08	41	18.9	68	22.4	49	12.78	32.80
J19	29-Jun-08	41	1.4	68	9.7	45	12.22	32.84
J20	30-Jun-08	40	43.8	67	56.9	78	16.28	32.63
J21	30-Jun-08	40	25.9	67	44.3	142	17.89	32.64
J22	29-Jun-08	41	5.7	68	45.6	69	11.63	32.73
J23	29-Jun-08	40	48.2	68	32.7	58	11.17	32.85
J24	29-Jun-08	40	30.9	68	20.7	96	MISSING	MISSING

Appendix B. OC445, OC447, and EN448 2008 nutrient concentrations.

Table B.1. OC445, OC447, and EN448 2008 nutrient concentrations.

Station	Latitude	Longitude	$NO_3^- + NO_2^-$ (μm)	$Si(OH)_4$ (μm)	PO_4^{-3} (μm)	NH_4^+ (μm)
A1	42 2.7	66 22.5	1.82	-0.28	0.79	0.79
A2	41 45.4	66 8.7	0.03	0.07	0.80	0.80
A3	42 7.8	67 10.2	3.27	0.37	0.70	0.70
A4	41 50.9	66 55.8	0.14	0.37	0.54	0.54
A5	41 34.1	66 41.1	0.88	0.03	0.01	0.38
A6	41 17.3	66 26.6	0.67	0.32	0.75	0.01
A7	41 55.3	67 37.0	2.11	1.76	0.49	0.75
A8	41 38.0	67 23.4	0.09	0.08	0.99	0.21
A9	41 20.8	67 9.7	0.08	0.03	1.23	0.50
A10	41 3.3	66 56.2	0.16	0.03	0.68	0.38
A11	41 35.8	67 58.8	0.53	1.74	0.27	0.01
A12	41 18.4	67 44.9	0.30	0.03	0.21	0.02
A13	41 0.9	67 31.8	0.09	0.03	0.12	0.02
A14	40 43.4	67 18.7	0.48	0.87	0.25	1.04
A15	41 36.6	68 34.5	0.64	1.24	0.20	0.01
A16	41 18.8	68 22.4	0.65	0.73	0.13	0.01
A17	41 1.6	68 9.7	0.37	0.41	0.53	0.36
A18	40 43.7	67 57.0	0.42	2.34	0.56	0.02
A19	40 26.2	67 44.3	1.39	0.80	0.31	0.00
A20	41 6.7	68 46.2	0.34	0.36	0.31	0.16
A21	40 48.4	68 33.1	0.58	0.19	0.08	0.01
A22	40 30.6	68 19.9	1.03	0.44	0.25	0.65
A23	40 47.6	69 13.8	0.09	7.27	0.29	0.01
A24	40 30.1	69 1.6	0.09	1.58	0.21	0.09
M1	41 54.1	66 15.5	0.72	2.39	0.65	0.71
M2	42 7.9	67 10.3	1.22	3.23	0.22	0.17
M3	41 50.9	66 55.7	0.31	2.19	0.11	0.04
M4	41 34.2	66 41.3	0.46	0.25	0.03	0.26
M5	41 17.2	66 26.5	1.09	2.66	0.04	0.65
M6	41 55.3	67 37.0	0.20	2.20	0.02	0
M7	41 38.1	67 23.4	0.17	2.50	0.13	0.09
M8	41 20.8	67 9.7	0.01	0.30	0.04	0
M9	41 3.3	66 56.2	0.10	0.75	0.28	0.64

Table B.1. Continued.

Station	Latitude	Longitude	$NO_3^- + NO_2^-$ (µm)	$Si(OH)_4$ (µm)	PO_4^{-3} (µm)	NH_4^+ (µm)
M10	41 35.8	67 58.8	0.03	1.45	0.01	0.92
M11	41 18.7	67 44.8	0.79	3.37	0.19	1.62
M12	41 1.1	67 31.7	0.21	0.48	0.99	0.45
M13	40 43.5	67 18.8	0.10	0.98	0.62	1.01
M14	41 27.7	68 29.5	0.04	2.62	0.12	0.26
M15	41 10.0	68 16.6	0.04	1.02	0.61	0.92
M16	40 52.6	68 3.2	0.31	3.26	0.03	0.03
M17	40 34.9	67 50.5	0.04	1.95	1	0.12
M18	40 16.6	67 38.7	0.06	5.52	0.15	0.42
M19	41 14.6	68 52.2	0.21	2.02	0.03	0.04
M20	40 57.0	68 39.4	0.07	0.54	0	0.7
M21	40 39.6	68 26.4	0.09	0.32	0.04	0.06
M22	40 21.3	68 13.1	0.70	0.34	0.11	1.4
J1	42 2.6	66 22.5	0.03	1.17	0.04	0.29
J2	41 45.4	66 8.5	0.12	2.26	0.73	0.35
J3	42 7.7	67 10.3	0.43	1.62	2.49	0.48
J4	41 50.5	66 55.5	0.03	0.51	0.10	0.28
J5	41 34.3	66 41.1	0.03	0.84	0.45	0.46
J6	41 17.2	66 26.6	0.03	0.57	0.91	0.24
J7	41 55.2	67 37.0	0.03	0.69	0.22	0.21
J8	41 38.0	67 23.7	0.14	0.28	0.42	0.07
J9	41 20.7	67 9.8	0.03	2.58	0.50	0.50
J10	41 3.3	66 56.2	0.03	0.00	0.82	0.09
J11	40 45.1	66 46.0	0.04	0.03	0.09	0.23
J12	41 53.6	68 10.8	0.11	3.34	0.53	0.39
J13	41 36.2	67 59.1	0.00	2.56	0.12	0.52
J14	41 18.4	67 45.2	0.08	1.89	1.11	0.03
J15	41 0.3	67 31.6	0.03	0.46	0.99	0.06
J16	40 43.4	67 18.8	0.09	0.19	0.90	0.29
J17	41 36.7	68 35.0	0.49	0.03	0.07	0.48
J18	41 18.9	68 22.4	0.89	0.81	0.15	0.41
J19	41 1.4	68 9.7	1.06	1.13	0.37	0.00
J20	40 43.8	67 56.9	0.03	0.03	0.60	0.06
J21	40 25.9	67 44.3	0.04	0.38	0.24	1.95
J22	41 5.7	68 45.6	0.02	0.96	0.08	0.49
J23	40 48.2	68 32.7	0.04	0.53	0.34	0.05
J24	40 30.9	68 20.7	0.04	1.72	0.63	0.01

Appendix C. OC445, OC447, and EN448 2008 chlorophyll concentrations

Table C.1. OC445, OC447, and EN448 2008 chlorophyll concentrations

Station	Latitude	Longitude	Total Chlorophyll a ($\mu g\ L^{-1}$)	>20μm Chlorophyll a ($\mu g\ L^{-1}$)	<20μm Chlorophyll a ($\mu g\ L^{-1}$)
A1	42 2.7	66 22.5	3.94	1.19	1.54
A2	41 45.4	66 8.7	4.03	1.22	0.10
A3	42 7.8	67 10.2	0.61	1.21	3.64
A4	41 50.9	66 55.8	1.71	1.15	0.51
A5	41 34.1	66 41.1	MISSING	MISSING	MISSING
A6	41 17.3	66 26.6	3.43	2.18	1.25
A7	41 55.3	67 37.0	2.71	1.75	0.96
A8	41 38.0	67 23.4	3.58	2.50	1.08
A9	41 20.8	67 9.7	2.00	1.01	0.99
A10	41 3.3	66 56.2	1.55	1.00	0.55
A11	41 35.8	67 58.8	8.74	7.57	1.17
A12	41 18.4	67 44.9	6.19	5.12	1.07
A13	41 0.9	67 31.8	MISSING	MISSING	MISSING
A14	40 43.4	67 18.7	1.95	0.01	2.62
A15	41 36.6	68 34.5	1.85	0.89	0.96
A16	41 18.8	68 22.4	2.34	1.52	0.83
A17	41 1.6	68 9.7	5.33	3.91	1.42
A18	40 43.7	67 57.0	4.36	0.01	4.58
A19	40 26.2	67 44.3	1.87	0.26	1.61
A20	41 6.7	68 46.2	8.07	6.91	1.17
A21	40 48.4	68 33.1	6.18	5.02	1.16
A22	40 30.6	68 19.9	1.32	0.01	1.49
A23	40 47.6	69 13.8	11.17	4.86	6.31
A24	40 30.1	69 1.6	5.45	0.01	5.46
M1	41 54.1	66 15.5	4.22	4.09	0.13
M2	42 7.9	67 10.3	3.42	3.65	0.00
M3	41 50.9	66 55.7	11.99	0.91	11.09
M4	41 34.2	66 41.3	6.53	0.72	5.81
M5	41 17.2	66 26.5	6.38	3.13	3.26
M6	41 55.3	67 37.0	2.06	3.03	0.00
M7	41 38.1	67 23.4	4.06	1.82	2.24
M8	41 20.8	67 9.7	10.98	0.57	10.41
M9	41 3.3	66 56.2	1.62	0.85	0.76
M10	41 35.8	67 58.8	1.69	1.94	0.00

Table C.1. Continued.

Station	Latitude	Longitude	Total Chlorophyll a ($\mu g\ L^{-1}$)	>20μm Chlorophyll a ($\mu g\ L^{-1}$)	<20μm Chlorophyll a ($\mu g\ L^{-1}$)
M11	41 18.7	67 44.8	4.32	0.56	3.76
M12	41 1.1	67 31.7	2.11	1.14	0.97
M13	40 43.5	67 18.8	1.61	0.97	0.64
M14	41 27.7	68 29.5	1.22	0.96	0.26
M15	41 10.0	68 16.6	1.41	1.31	0.11
M16	40 52.6	68 3.2	1.88	0.78	1.10
M17	40 34.9	67 50.5	1.61	1.46	0.15
M18	40 16.6	67 38.7	1.15	1.02	0.13
M19	41 14.6	68 52.2	0.94	0.82	0.12
M20	40 57.0	68 39.4	2.08	1.00	1.08
M21	40 39.6	68 26.4	1.75	0.54	1.21
M22	40 21.3	68 13.1	1.53	0.68	0.85
J1	42 2.6	66 22.5	1.35	0.06	1.29
J2	41 45.4	66 8.5	2.32	0.33	1.99
J3	42 7.7	67 10.3	1.40	-0.59	1.99
J4	41 50.5	66 55.5	5.25	3.18	2.07
J5	41 34.3	66 41.1	5.22	2.99	2.23
J6	41 17.2	66 26.6	1.95	0.65	1.30
J7	41 55.2	67 37.0	3.28	0.29	2.99
J8	41 38.0	67 23.7	7.04	4.40	2.64
J9	41 20.7	67 9.8	5.27	4.31	0.96
J10	41 3.3	66 56.2	4.50	0.05	4.45
J11	40 45.1	66 46.0	1.33	0.07	1.26
J12	41 53.6	68 10.8	1.46	0.01	1.45
J13	41 36.2	67 59.1	8.23	5.55	2.68
J14	41 18.4	67 45.2	6.15	3.81	2.33
J15	41 0.3	67 31.6	2.87	2.01	0.86
J16	40 43.4	67 18.8	1.70	0.24	1.46
J17	41 36.7	68 35.0	1.74	0.00	1.91
J18	41 18.9	68 22.4	3.73	0.50	3.24
J19	41 1.4	68 9.7	2.18	0.38	1.80
J20	40 43.8	67 56.9	2.24	1.19	1.06
J21	40 25.9	67 44.3	1.19	0.00	1.73
J22	41 5.7	68 45.6	1.75	0.16	1.59
J23	40 48.2	68 32.7	1.87	0.28	1.59
J24	40 30.9	68 20.7	2.27	0.45	1.81

Appendix D. OC445, OC447, and EN448 2008 phytoplankton group abundances.

Table D.1. OC445, OC447, and EN448 2008 phytoplankton group abundances.

Station	Latitude	Longitude	Diatoms cells L^{-1}	Dinoflagellates cells L^{-1}	Nanoplankton cells L^{-1}
A1	42 2.7	66 22.5	203,200	10,400	532,000
A2	41 45.4	66 8.7	165,400	17,200	952,000
A3	42 7.8	67 10.2	800	4,000	5,600
A4	41 50.9	66 55.8	13,800	21,400	23,000
A5	41 34.1	66 41.1	67,200	9,400	17,800
A6	41 17.3	66 26.6	55,200	17,000	616,000
A7	41 55.3	67 37.0	6,600	1,600	24,800
A8	41 38.0	67 23.4	13,400	4,600	15,200
A9	41 20.8	67 9.7	13,800	10,000	11,400
A10	41 3.3	66 56.2	7,400	5,400	8,200
A11	41 35.8	67 58.8	40,800	4,000	14,200
A12	41 18.4	67 44.9	34,800	9,200	26,400
A13	41 0.9	67 31.8	15,400	15,200	216,000
A14	40 43.4	67 18.7	1,200	13,200	336,000
A15	41 36.6	68 34.5	1,600	7,600	117,000
A16	41 18.8	68 22.4	4,000	5,200	47,600
A17	41 1.6	68 9.7	6,600	16,600	66,100
A18	40 43.7	67 57.0	0	4,400	7,000
A19	40 26.2	67 44.3	1,600	14,200	53,200
A20	41 6.7	68 46.2	5,600	6,200	14,200
A21	40 48.4	68 33.1	6,200	10,000	992,000
A22	40 30.6	68 19.9	0	1,600	2,800
A23	40 47.6	69 13.8	5,000	2,800	12,200
A24	40 30.1	69 1.6	0	1,200	7,000
M1	41 54.1	66 15.5	400	12,400	1,388,000
M2	42 7.9	67 10.3	2,400	40,600	184,000
M3	41 50.9	66 55.7	9,200	8,800	1,452,000
M4	41 34.2	66 41.3	27,600	14,200	1,700,000
M5	41 17.2	66 26.5	5,600	13,600	772,000
M6	41 55.3	67 37.0	1,800	22,400	956,000
M7	41 38.1	67 23.4	35,800	15,400	852,000
M8	41 20.8	67 9.7	31,000	8,400	1,628,000
M9	41 3.3	66 56.2	800	22,800	856,000
M10	41 35.8	67 58.8	0	53,400	312,600

Table D.1. Continued.

Station	Latitude	Longitude	Diatoms cells L^{-1}	Dinoflagellates cells L^{-1}	Nanoplankton cells L^{-1}
M11	41 18.7	67 44.8	1,800	36,600	1,784,000
M12	41 1.1	67 31.7	17,400	15,200	684,000
M13	40 43.5	67 18.8	7,200	21,800	1,416,000
M14	41 27.7	68 29.5	0	5,000	840,000
M15	41 10.0	68 16.6	4,000	29,600	1,564,000
M16	40 52.6	68 3.2	1,400	19,000	972,000
M17	40 34.9	67 50.5	0	26,600	536,000
M18	40 16.6	67 38.7	1,400	23,400	2,200
M19	41 14.6	68 52.2	400	69,200	692,000
M20	40 57.0	68 39.4	21,000	41,200	1,340,000
M21	40 39.6	68 26.4	28,600	33,800	1,896,000
M22	40 21.3	68 13.1	1,000	37,600	1,752,000
J1	42 2.6	66 22.5	200	8,800	2,080,000
J2	41 45.4	66 8.5	4,600	10,000	1,892,000
J3	42 7.7	67 10.3	1,400	4,400	1,552,000
J4	41 50.5	66 55.5	22,800	12,400	948,000
J5	41 34.3	66 41.1	12,000	42,400	2,472,000
J6	41 17.2	66 26.6	3,600	25,800	8,460,000
J7	41 55.2	67 37.0	21,800	10,000	1,500,000
J8	41 38.0	67 23.7	164,200	15,000	1,672,000
J9	41 20.7	67 9.8	29,000	17,600	2,168,000
J10	41 3.3	66 56.2	5,200	60,400	4,060,000
J11	40 45.1	66 46.0	5,000	31,600	4,036,000
J12	41 53.6	68 10.8	200	2,600	1,896,000
J13	41 36.2	67 59.1	222,400	6,600	808,000
J14	41 18.4	67 45.2	230,200	12,200	1,716,000
J15	41 0.3	67 31.6	14,400	15,200	464,000
J16	40 43.4	67 18.8	600	26,200	752,000
J17	41 36.7	68 35.0	3,800	8,600	1,460,000
J18	41 18.9	68 22.4	19,400	15,000	2,564,000
J19	41 1.4	68 9.7	3,000	3,800	1,932,000
J20	40 43.8	67 56.9	0	11,600	460,000
J21	40 25.9	67 44.3	0	16,000	580,000
J22	41 5.7	68 45.6	1,800	8,600	1,260,000
J23	40 48.2	68 32.7	2,000	4,400	936,000
J24	40 30.9	68 20.7	1,000	17,200	3,032,000

Appendix E. OC445 2008 phytoplankton taxa abundance and absence/presence data.

Table E.1. OC445 phytoplankton abundance in cells L^{-1}.

Station #	A1	A2	A3	A4	A5	A6	A7
Alexandrium spp.	600	400	200	400	2,200	1,000	400
Scrippsiella spp.	2,000	3,000	1,000	5,400	200	5,600	0
Gymnodinium spp.	1,200	2,200	0	400	1,200	1,400	0
Amphidinium spp.	2,400	3,400	800	1,400	400	3,800	0
Heterosigma spp.	0	0	0	0	0	0	0
Gonyaulax spp.	0	400	800	0	0	0	0
Gyrodinium spp.	1,400	1,200	200	8,800	1,400	600	0
Protoceratium spp.	0	0	0	0	0	0	0
Prorocentrum spp.	0	400	0	1,400	200	0	0
Heterocapsa spp.	0	0	0	0	0	0	0
Dinophysis spp.	200	200	0	400	800	200	0
Cysts	1,600	3,800	800	2,000	1,200	2,600	1,000
Dictyocha spp.	0	0	0	0	0	0	0
Ceratium tripos	200	200	0	0	0	200	0
Ceratium fusus	0	200	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0
Ceratium lineatum	0	200	0	0	200	200	0
Ceratium longipes	0	0	0	0	0	0	0
Total *Ceratium* spp.	200	600	0	0	200	600	0
Protoperidinium spp.	800	1,600	200	1,200	1,600	1,200	200
Pyrophacus spp.	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0
Guinardia flaccid	0	0	0	0	0	0	0
Guinardia striata	200	200	0	0	600	0	0
Dactyliosolen spp.	1,000	0	200	1,000	200	1,200	4,600
Leptocylindrus spp.	8,800	4,600	600	800	7,200	6,000	0
Coscinodiscus spp.	146,400	16,200	0	3,800	27,200	3,000	1,000
Thalassiosira spp.	13,200	7,600	0	600	10,800	5,200	800
Stephanopyxis spp.	1,400	4,800	0	1,800	7,200	5,200	0
Chaetoceros spp.	3,600	22,600	0	0	1,800	0	0
Skeletonema spp.	16,000	99,400	0	5,200	8,800	29,600	0
Paralia sulcata	2,600	1,400	0	0	0	0	0
*Pseudo-nitzchia*spp.	7,600	7,200	0	0	2,800	5,000	200
Navicula spp.	0	0	0	0	0	0	0
Rhizosolenia spp.	2,200	1,200	0	0	200	0	0
Ditylum spp.	200	200	0	600	400	0	0
Phaeocystis spp.	464,000	812,000	1,000	6,600	1,800	544,000	0
"other" nanoplankton	16,000	0	2,800	11,600	14,000	16,000	0
Cryptomonad spp.	52,000	140,000	1,400	4,800	2,000	56,000	0

Table E.1. Continued.

Station #	A8	A9	A10	A11	A12	A13	A14
Alexandrium spp.	600	1,800	800	600	1,400	1,600	1,600
Scrippsiella spp.	1,000	5,200	2,400	400	400	2,400	2,000
Gymnodinium spp.	200	0	0	1,200	1,000	600	400
Amphidinium spp.	600	0	600	0	1,400	6,000	5,400
Heterosigma spp.	0	0	0	0	0	0	0
Gonyaulax spp.	0	0	0	0	0	0	0
Gyrodinium spp.	600	800	200	600	2,800	800	400
Protoceratium spp.	400	0	0	0	0	0	0
Prorocentrum spp.	0	0	0	0	600	400	200
Heterocapsa spp.	0	0	0	0	0	0	0
Dinophysis spp.	200	0	400	200	400	0	400
Cysts	400	1,400	0	1,000	600	2,400	1,800
Dictyocha spp.	0	0	0	0	0	0	0
Ceratium tripos	0	200	400	0	0	200	200
Ceratium fusus	0	0	200	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0
Ceratium lineatum	0	0	200	0	0	0	400
Ceratium longipes	0	0	0	0	0	0	0
Total *Ceratium* spp.	0	200	800	0	0	200	600
Protoperidinium spp.	600	600	200	0	600	800	200
Pyrophacus spp.	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0
Guinardia striata	1,000	200	1,200	3,400	3,000	0	0
Dactyliosolen spp.	4,000	0	0	0	4,800	0	0
Leptocylindrus spp.	2,600	1,600	0	18,400	13,000	2,000	200
Coscinodiscus spp.	1,400	2,600	0	3,200	2,600	600	400
Thalassiosira spp.	1,200	400	0	2,600	1,200	0	0
Stephanopyxis spp.	0	0	0	0	0	0	400
Chaetoceros spp.	2,400	400	0	1,800	200	600	200
Skeletonema spp.	800	6,600	6,200	11,200	10,000	8,600	0
Paralia sulcata	0	0	0	0	0	0	0
*Pseudo-nitzchia*spp.	0	2,000	0	200	0	3,600	0
Navicula spp.	0	0	0	0	0	0	0
Rhizosolenia spp.	0	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0	0
Phaeocystis spp.	9,400	0	0	6,000	9,600	160,000	296,000
"other" nanoplankton	2,800	7,400	3,600	7,600	14,400	28,000	32,000
Cryptomonas spp.	3,000	2,000	4,400	600	2,200	28,000	8,000

Table E.1. Continued.

Station #	A15	A16	A17	A18	A19	A20	A21
Alexandrium spp.	2,400	1,200	1,200	800	1,000	2,000	1,600
Scrippsiella spp.	0	0	2,200	0	3,600	400	2,400
Gymnodinium spp.	0	200	1,000	0	400	200	200
Amphidinium spp.	1,400	0	5,200	0	5,000	0	2,800
Heterosigma spp.	0	0	0	0	0	0	0
Gonyaulax spp.	0	0	0	0	0	0	0
Gyrodinium spp.	1,400	1,000	4,000	400	400	0	600
Protoceratium spp.	0	0	0	0	0	0	0
Prorocentrum spp.	800	0	600	0	200	400	0
Heterocapsa spp.	0	0	0	0	0	0	0
Dinophysis spp.	0	400	400	1,200	200	400	0
Cysts	1,000	1,000	800	400	2,800	400	1,200
Dictyocha spp.	0	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	200	200	0
Ceratium fusus	0	0	0	200	200	0	200
Ceratium azoricum	0	0	0	0	0	0	0
Ceratium lineatum	0	0	0	0	0	0	0
Ceratium longipes	0	0	0	1,200	0	0	0
Total *Ceratium* spp.	0	0	0	1,400	400	200	200
Protoperidinium spp.	600	1,400	1,200	200	200	1,800	1,000
Pyrophacus spp.	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0
Guinardia striata	0	0	0	0	0	0	0
Dactyliosolen spp.	0	0	2,200	0	0	0	3,400
Leptocylindrus spp.	0	400	0	0	400	800	200
Coscinodiscus spp.	1,400	1,600	3,400	0	200	2,400	2,400
Thalassiosira spp.	0	800	200	0	200	400	200
Stephanopyxis spp.	0	400	0	0	0	0	0
Chaetoceros spp.	0	0	0	0	0	400	0
Skeletonema spp.	0	0	0	0	800	0	0
Paralia sulcata	0	0	600	0	0	1,600	0
*Pseudo-nitzchia*spp.	0	0	200	0	0	0	0
Navicula spp.	0	0	0	0	0	0	0
Rhizosolenia spp.	200	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0	0
Phaeocystis spp.	29,400	44,600	253,600	400	420,000	14,000	396,800
"other" nanoplankton	54,800	2,600	151,400	6,000	84,000	0	400,000
Cryptomonas spp.	32,800	400	256,000	600	28,000	5,000	195,200

Table E.1. Continued.

Station #	A22	A23	A24	Mean
Alexandrium spp.	200	800	600	**1,058**
Scrippsiella spp.	200	0	0	**1,658**
Gymnodinium spp.	0	600	0	**517**
Amphidinium spp.	0	0	0	**1,692**
Heterosigma spp.	0	0	0	**0**
Gonyaulax spp.	0	0	0	**50**
Gyrodinium spp.	0	600	0	**1,175**
Protoceratium spp.	0	0	0	**17**
Prorocentrum spp.	0	200	0	**225**
Heterocapsa spp.	0	0	0	**0**
Dinophysis spp.	200	0	0	**258**
Cysts	200	0	0	**1,183**
Dictyocha spp.	0	0	0	**0**
Ceratium tripos	200	0	0	**92**
Ceratium fusus	200	0	0	**50**
Ceratium azoricum	0	0	0	**0**
Ceratium lineatum	0	0	0	**50**
Ceratium longipes	0	0	400	**67**
Total *Ceratium* spp.	400	0	400	**267**
Protoperidinium spp.	200	0	200	**692**
Pyrophacus spp.	200	0	0	**8**
Polykrikos spp.	0	0	0	**0**
Guinardia flaccida	0	0	0	**0**
Guinardia striata	0	0	0	**408**
Dactyliosolen spp.	0	0	0	**942**
Leptocylindrus spp.	0	0	0	**2,817**
Coscinodiscus spp.	0	2,400	0	**9,258**
Thalassiosira spp.	0	2,000	0	**1,975**
Stephanopyxis spp.	0	0	0	**883**
Chaetoceros spp.	0	200	0	**1,425**
Skeletonema spp.	0	400	0	**8,483**
Paralia sulcata	0	0	0	**258**
*Pseudo-nitzchia*spp.	0	0	0	**1,200**
Navicula spp.	0	0	0	**0**
Rhizosolenia spp.	0	0	0	**158**
Ditylum spp.	0	0	0	**58**
Phaeocystis spp.	2,800	0	1,200	**144,717**
"other" nanoplankton	0	12,200	4,800	**36,333**
Cryptomonas spp.	0	0	1,000	**34,308**

Table E.2. OC445 phytoplankton absence/presence
1 = Present; 0 = Absent

Station #	A1	A2	A3	A4	A5	A6	A7	A8	A9
Alexandrium spp.	1	1	1	1	1	1	1	1	1
Scrippsiella spp.	1	1	1	1	1	1	0	1	1
Gymnodinium spp.	1	1	0	1	1	1	0	1	0
Amphidinium spp.	1	1	1	1	1	1	0	1	0
Heterosigma spp.	0	0	0	0	0	0	0	0	0
Gonyaulax spp.	0	1	1	0	0	0	0	0	0
Gyrodinium spp.	1	1	1	1	1	1	0	1	1
Protoceratium spp.	0	0	0	0	0	0	0	1	0
Prorocentrum spp.	0	1	0	1	1	0	0	0	0
Heterocapsa spp.	0	0	0	0	0	0	0	0	0
Dinophysis spp.	1	1	0	1	1	1	0	1	0
Cysts	1	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	0	0	0	0	0	0	0
Ceratium tripos	1	1	0	0	0	1	0	0	1
Ceratium fusus	0	1	0	0	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0	0	0
Ceratium lineatum	0	1	0	0	1	1	0	0	0
Ceratium longipes	0	0	0	0	0	0	0	0	0
Total *Ceratium* spp.	1	1	0	0	1	1	0	0	1
Protoperidinium spp.	1	1	1	1	1	1	1	1	1
Pyrophacus spp.	0	0	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0	0	0
Guinardia striata	1	1	0	0	1	0	0	1	1
Dactyliosolen spp.	1	0	1	1	1	1	1	1	0
Leptocylindrus spp.	1	1	1	1	1	1	0	1	1
Coscinodiscus spp.	1	1	0	1	1	1	1	1	1
Thalassiosira spp.	1	1	0	1	1	1	1	1	1
Stephanopyxis spp.	1	1	0	1	1	1	0	0	0
Chaetoceros spp.	1	1	0	0	1	0	0	1	1
Skeletonema spp.	1	1	0	1	1	1	0	1	1
Paralia sulcata	1	1	0	0	0	0	0	0	0
*Pseudo-nitzchia*spp.	1	1	0	0	1	1	1	0	1
Navicula spp.	0	0	0	0	0	0	0	0	0
Rhizosolenia spp.	1	1	0	0	1	0	0	0	0
Ditylum spp.	1	1	0	1	1	0	0	0	0
Phaeocystis spp.	1	1	1	1	1	1	0	1	0
"other" nanoplankton	1	0	1	1	1	1	0	1	1
Cryptomonas spp.	1	1	1	1	1	1	0	1	1

Table E.2. Continued.

Station #	A10	A11	A12	A13	A14	A15	A16	A17	A18
Alexandrium spp.	1	1	1	1	1	1	1	1	1
Scrippsiella spp.	1	1	1	1	1	0	0	1	0
Gymnodinium spp.	0	1	1	1	1	0	1	1	0
Amphidinium spp.	1	0	1	1	1	1	0	1	0
Heterosigma spp.	0	0	0	0	0	0	0	0	0
Gonyaulax spp.	0	0	0	0	0	0	0	0	0
Gyrodinium spp.	1	1	1	1	1	1	1	1	1
Protoceratium spp.	0	0	0	0	0	0	0	0	0
Prorocentrum spp.	0	0	1	1	1	1	0	1	0
Heterocapsa spp.	0	0	0	0	0	0	0	0	0
Dinophysis spp.	1	1	1	0	1	0	1	1	1
Cysts	0	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	0	0	0	0	0	0	0
Ceratium tripos	1	0	0	1	1	0	0	0	0
Ceratium fusus	1	0	0	0	0	0	0	0	1
Ceratium azoricum	0	0	0	0	0	0	0	0	0
Ceratium lineatum	1	0	0	0	1	0	0	0	0
Ceratium longipes	0	0	0	0	0	0	0	0	1
Total *Ceratium* spp.	1	0	0	1	1	0	0	0	1
Protoperidinium spp.	1	0	1	1	1	1	1	1	1
Pyrophacus spp.	0	0	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0	0	0
Guinardia striata	1	1	1	0	0	0	0	0	0
Dactyliosolen spp.	0	0	1	0	0	0	0	1	0
Leptocylindrus spp.	0	1	1	1	1	0	1	0	0
Coscinodiscus spp.	0	1	1	1	1	1	1	1	0
Thalassiosira spp.	0	1	1	0	0	0	1	1	0
Stephanopyxis spp.	0	0	0	0	1	0	1	0	0
Chaetoceros spp.	0	1	1	1	1	0	0	0	0
Skeletonema spp.	1	1	1	1	0	0	0	0	0
Paralia sulcata	0	0	0	0	0	0	0	1	0
*Pseudo-nitzchia*spp.	0	1	0	1	0	0	0	1	0
Navicula spp.	0	0	0	0	0	0	0	0	0
Rhizosolenia spp.	0	0	0	0	0	1	0	0	0
Ditylum spp.	0	0	0	0	0	0	0	0	0
Phaeocystis spp.	0	1	1	1	1	1	1	1	1
"other" nanoplankton	1	1	1	1	1	1	1	1	1
Cryptomonas spp.	1	1	1	1	1	1	1	1	1

Table E.2. Continued.

Station #	A19	A20	A21	A22	A23	A24	Total	Percent
Alexandrium spp.	1	1	1	1	1	1	**24**	**100**
Scrippsiella spp.	1	1	1	1	0	0	**18**	**75**
Gymnodinium spp.	1	1	1	0	1	0	**16**	**67**
Amphidinium spp.	1	0	1	0	0	0	**15**	**63**
Heterosigma spp.	0	0	0	0	0	0	**0**	**0**
Gonyaulax spp.	0	0	0	0	0	0	**2**	**8**
Gyrodinium spp.	1	0	1	0	1	0	**20**	**83**
Protoceratium spp.	0	0	0	0	0	0	**1**	**4**
Prorocentrum spp.	1	1	0	0	1	0	**11**	**46**
Heterocapsa spp.	0	0	0	0	0	0	**0**	**0**
Dinophysis spp.	1	1	0	1	0	0	**16**	**67**
Cysts	1	1	1	1	0	0	**21**	**88**
Dictyocha spp.	0	0	0	0	0	0	**0**	**0**
Ceratium tripos	1	1	0	1	0	0	**10**	**42**
Ceratium fusus	1	0	1	1	0	0	**6**	**25**
Ceratium azoricum	0	0	0	0	0	0	**0**	**0**
Ceratium lineatum	0	0	0	0	0	0	**5**	**21**
Ceratium longipes	0	0	0	0	0	1	**2**	**8**
Total *Ceratium* spp.	1	1	1	1	0	1	**14**	**58**
Protoperidinium spp.	1	1	1	1	0	1	**22**	**92**
Pyrophacus spp.	0	0	0	1	0	0	**1**	**4**
Polykrikos spp.	0	0	0	0	0	0	**0**	**0**
Guinardia flaccida	0	0	0	0	0	0	**0**	**0**
Guinardia striata	0	0	0	0	0	0	**8**	**33**
Dactyliosolen spp.	0	0	1	0	0	0	**10**	**42**
Leptocylindrus spp.	1	1	1	0	0	0	**16**	**67**
Coscinodiscus spp.	1	1	1	0	1	0	**19**	**79**
Thalassiosira spp.	1	1	1	0	1	0	**16**	**67**
Stephanopyxis spp.	0	0	0	0	0	0	**7**	**29**
Chaetoceros spp.	0	1	0	0	1	0	**11**	**46**
Skeletonema spp.	1	0	0	0	1	0	**13**	**54**
Paralia sulcata	0	1	0	0	0	0	**4**	**17**
*Pseudo-nitzchia*spp.	0	0	0	0	0	0	**9**	**38**
Navicula spp.	0	0	0	0	0	0	**0**	**0**
Rhizosolenia spp.	0	0	0	0	0	0	**4**	**17**
Ditylum spp.	0	0	0	0	0	0	**4**	**17**
Phaeocystis spp.	1	1	1	1	0	1	**20**	**83**
"other" nanoplankton	1	0	1	0	1	1	**20**	**83**
Cryptomonas spp.	1	1	1	0	0	1	**21**	**88**

Appendix F. OC447 2008 phytoplankton taxa abundance and absence/presence data.

Table F.1. OC447 phytoplankton abundance in cells L^{-1}.

Station	M1	M2	M3	M4	M5	M6	M7
Alexandrium spp.	800	12,600	2,400	2,000	5,600	6,600	3,000
Scrippsiella spp.	800	3,400	0	200	400	1,200	1,400
Gymnodinium spp.	0	4,000	200	1,000	600	2,000	2,200
Amphidinium spp.	4,600	5,000	2,600	3,600	3,600	5,200	1,600
Heterosigma spp.	0	0	0	0	0	0	0
Gonyaulax spp.	1,000	400	0	0	0	600	1,000
Gyrodinium spp.	600	1,400	200	1,000	200	2,000	1,000
Protoceratium spp.	0	0	0	0	0	0	0
Prorocentrum spp.	0	1,000	0	0	0	1,200	400
Heterocapsa spp.	0	2,600	0	0	0	1,000	400
Dinophysis spp.	200	400	200	600	400	0	0
Cysts	4,400	6,000	3,000	5,000	2,800	2,000	3,000
Dictyocha spp.	0	0	0	0	0	0	200
Ceratium tripos	0	800	0	200	0	200	0
Ceratium fusus	0	400	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0
Ceratium lineatum	0	0	0	0	0	200	200
Ceratium longipes	0	0	0	0	0	0	0
Total *Ceratium* spp.	0	1,200	0	200	0	400	200
Protoperidinium spp.	0	2,400	200	600	0	200	1,000
Pyrophacus spp.	0	200	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0
Guinardia flaccida	0	0	7,000	3,800	0	200	25,200
Guinardia striata	0	0	0	0	0	0	1,600
Dactyliosolen spp.	0	0	400	11,200	1,400	0	600
Leptocylindrus spp.	0	0	200	3,000	0	0	5,600
Coscinodiscus spp.	200	0	600	2,200	1,200	1,200	1,200
Thalassiosira spp.	0	200	400	1,800	0	200	0
Stephanopyxis spp.	0	0	200	0	0	0	0
Chaetoceros spp.	200	200	0	1,200	600	0	1,000
Skeletonema spp.	0	0	0	0	0	0	0
Paralia sulcata	0	0	0	1,000	1,200	0	0
*Pseudo-nitzschia*spp.	0	1,200	0	1,000	1,200	0	0
Navicula spp.	0	0	0	0	0	0	600
Rhizosolenia spp.	0	0	400	2,400	0	200	0
Ditylum spp.	0	0	0	0	0	0	0
Phaeocystis spp.	784,000	164,000	1,256,000	1,512,000	600,000	900,000	844,000
"other" nanoplankton	60,000	0	32,000	44,000	52,000	20,000	0
Cryptomonas spp.	544,000	20,000	164,000	144,000	120,000	36,000	8,000

Table F.1. Continued.

Station	M8	M9	M10	M11	M12	M13	M14
Alexandrium spp.	1,800	4,800	9,200	11,400	2,400	1,200	0
Scrippsiella spp.	0	2,400	9,800	4,400	2,400	1,000	200
Gymnodinium spp.	600	2,200	2,600	1,400	800	1,600	400
Amphidinium spp.	2,600	3,200	7,600	2,200	1,800	4,200	1,200
Heterosigma spp.	0	0	8,000	6,000	1,400	4,000	1,200
Gonyaulax spp.	0	800	600	200	200	1,200	0
Gyrodinium spp.	800	1,200	800	1,600	400	3,400	1,000
Protoceratium spp.	0	0	0	0	0	0	0
Prorocentrum spp.	0	200	200	0	0	200	200
Heterocapsa spp.	0	1,600	3,800	2,200	1,200	1,000	200
Dinophysis spp.	0	0	1,600	1,000	0	0	0
Cysts	1,600	3,200	1,600	2,000	2,200	1,600	200
Dictyocha spp.	0	0	0	0	0	0	0
Ceratium tripos	0	2,000	1,800	800	200	0	200
Ceratium fusus	0	200	800	600	0	200	0
Ceratium azoricum	0	0	0	0	0	0	0
Ceratium lineatum	0	400	2,800	1,400	0	400	0
Ceratium longipes	0	0	0	0	0	0	0
Total *Ceratium* spp.	0	2,600	5,400	2,800	200	600	200
Protoperidinium spp.	1,000	600	2,200	1,400	2,200	1,800	200
Pyrophacus spp.	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0
Guinardia flaccida	21,200	0	0	0	6,600	800	0
Guinardia striata	600	0	0	800	600	200	0
Dactyliosolen spp.	0	0	0	0	0	0	0
Leptocylindrus spp.	0	0	0	0	0	600	0
Coscinodiscus spp.	6,200	800	0	200	9,600	600	0
Thalassiosira spp.	2,800	0	0	800	400	0	0
Stephanopyxis spp.	0	0	0	0	0	0	0
Chaetoceros spp.	0	0	0	0	0	1,600	0
Skeletonema spp.	0	0	0	0	0	800	0
Paralia sulcata	0	0	0	0	0	1,200	0
*Pseudo-nitzschia*spp.	0	0	0	0	0	800	0
Navicula spp.	200	0	0	0	200	0	0
Rhizosolenia spp.	0	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0	0
Phaeocystis spp.	1,584,000	820,000	312,000	1,724,000	664,000	1,264,000	788,000
"other" nanoplankton	0	16,000	600	20,000	20,000	52,000	20,000
Cryptomonas spp.	44,000	20,000	0	40,000	0	100,000	32,000

Table F.1. Continued.

Station	M15	M16	M17	M18	M19
Alexandrium spp.	5,000	5,000	6,000	2,200	2,000
Scrippsiella spp.	3,200	2,600	3,400	2,600	3,600
Gymnodinium spp.	1,600	800	1,200	2,000	2,400
Amphidinium spp.	3,200	1,200	1,000	1,000	7,200
Heterosigma spp.	5,200	1,400	2,400	2,600	7,200
Gonyaulax spp.	400	0	400	1,400	400
Gyrodinium spp.	400	600	400	400	3,800
Protoceratium spp.	0	0	0	0	0
Prorocentrum spp.	1,600	200	0	3,200	1,200
Heterocapsa spp.	2,000	1,200	4,400	1,200	6,400
Dinophysis spp.	1,800	1,000	800	800	200
Cysts	2,800	2,000	1,400	1,200	1,200
Dictyocha spp.	0	0	0	0	0
Ceratium tripos	600	800	0	0	1,000
Ceratium fusus	400	400	0	0	0
Ceratium azoricum	0	0	0	0	0
Ceratium lineatum	400	200	0	1,000	0
Ceratium longipes	0	0	400	0	0
Total *Ceratium* spp.	1,400	1,400	400	1,000	1,000
Protoperidinium spp.	1,000	1,600	3,000	3,800	1,000
Pyrophacus spp.	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0
Guinardia flaccida	200	400	0	0	0
Guinardia striata	0	0	0	0	0
Dactyliosolen spp.	0	0	0	0	200
Leptocylindrus spp.	0	0	0	0	0
Coscinodiscus spp.	800	1,000	0	200	400
Thalassiosira spp.	600	0	0	200	0
Stephanopyxis spp.	0	0	0	0	0
Chaetoceros spp.	1,400	0	0	200	400
Skeletonema spp.	600	0	0	800	0
Paralia sulcata	400	0	0	0	0
*Pseudo-nitzschia*spp.	0	0	0	0	0
Navicula spp.	0	0	0	0	0
Rhizosolenia spp.	0	0	0	0	0
Ditylum spp.	0	0	0	0	0
Phaeocystis spp.	1,440,000	724,000	504,000	428,000	1,308,000
"other" nanoplankton	56,000	20,000	4,000	32,000	196,000
Cryptomonas spp.	68,000	22,800	28,000	16,000	248,000

Table F.1. Continued.

Station	M20	M21	M22	Mean
Alexandrium spp.	3,400	5,600	6,800	**4,536**
Scrippsiella spp.	4,200	6,000	11,400	**2,936**
Gymnodinium spp.	2,000	1,400	6,400	**1,700**
Amphidinium spp.	7,400	4,400	7,000	**3,700**
Heterosigma spp.	6,200	5,200	11,200	**2,818**
Gonyaulax spp.	400	1,400	600	**500**
Gyrodinium spp.	1,600	1,400	2,800	**1,227**
Protoceratium spp.	0	0	0	**0**
Prorocentrum spp.	0	0	400	**455**
Heterocapsa spp.	1,400	3,200	12,600	**2,109**
Dinophysis spp.	1,600	2,000	0	**573**
Cysts	1,000	2,000	3,200	**2,427**
Dictyocha spp.	0	0	0	**9**
Ceratium tripos	0	1,600	400	**482**
Ceratium fusus	200	800	200	**191**
Ceratium azoricum	200	0	0	**9**
Ceratium lineatum	1,000	1,200	2,000	**509**
Ceratium longipes	200	0	0	**27**
Total *Ceratium* spp.	1,600	3,600	2,600	**1,218**
Protoperidinium spp.	3,000	5,000	4,200	**1,655**
Pyrophacus spp.	0	0	0	**9**
Polykrikos spp.	0	0	0	**0**
Guinardia flaccida	0	0	0	**2,973**
Guinardia striata	0	0	0	**173**
Dactyliosolen spp.	0	0	0	**627**
Leptocylindrus spp.	0	0	0	**427**
Coscinodiscus spp.	1,800	1,000	200	**1,336**
Thalassiosira spp.	400	800	0	**391**
Stephanopyxis spp.	0	0	0	**9**
Chaetoceros spp.	1,600	0	0	**382**
Skeletonema spp.	0	0	200	**109**
Paralia sulcata	1,200	0	0	**227**
*Pseudo-nitzschia*spp.	23,000	18,800	0	**2,091**
Navicula spp.	600	400	0	**91**
Rhizosolenia spp.	0	0	0	**136**
Ditylum spp.	0	0	0	**0**
Phaeocystis spp.	1,592,000	1,192,000	584,000	**954,000**
"other" nanoplankton	32,000	24,000	72,000	**35,118**
Cryptomonas spp.	272,000	124,000	36,000	**94,855**

Table F.2. OC447 phytoplankton taxa absence/presence
1 = Present; 0 = Absent

Station	M1	M2	M3	M4	M5	M6	M7	M8
Alexandrium spp.	1	1	1	1	1	1	1	1
Scrippsiella spp.	1	1	0	1	1	1	1	0
Gymnodinium spp.	0	1	1	1	1	1	1	1
Amphidinium spp.	1	1	1	1	1	1	1	1
Heterosigma spp.	0	0	0	0	0	0	0	0
Gonyaulax spp.	1	1	0	0	0	1	1	0
Gyrodinium spp.	1	1	1	1	1	1	1	1
Protoceratium spp.	0	0	0	0	0	0	0	0
Prorocentrum spp.	0	1	0	0	0	1	1	0
Heterocapsa spp.	0	1	0	0	0	1	1	0
Dinophysis spp.	1	1	1	1	1	0	0	0
Cysts	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	0	0	0	0	1	0
Ceratium tripos	0	1	0	1	0	1	0	0
Ceratium fusus	0	1	0	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0	0
Ceratium lineatum	0	0	0	0	0	1	1	0
Ceratium longipes	0	0	0	0	0	0	0	0
Total *Ceratium* spp.	0	1	0	1	0	1	1	0
Protoperidinium spp.	0	1	1	1	0	1	1	1
Pyrophacus spp.	0	1	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	1	1	0	1	1	1
Guinardia striata	0	0	0	0	0	0	1	1
Dactyliosolen spp.	0	0	1	1	1	0	1	0
Leptocylindrus spp.	0	0	1	1	0	0	1	0
Coscinodiscus spp.	1	0	1	1	1	1	1	1
Thalassiosira spp.	0	1	1	1	0	1	0	1
Stephanopyxis spp.	0	0	1	0	0	0	0	0
Chaetoceros spp.	1	1	0	1	1	0	1	0
Skeletonema spp.	0	0	0	0	0	0	0	0
Paralia sulcata	0	0	0	1	1	0	0	0
*Pseudo-nitzschia*spp.	0	1	0	1	1	0	0	0
Navicula spp.	0	0	0	0	0	0	1	1
Rhizosolenia spp.	0	0	1	1	0	1	0	0
Ditylum spp.	0	0	0	0	0	0	0	0
Phaeocystis spp.	1	1	1	1	1	1	1	1
"other" nanoplankton	1	0	1	1	1	1	0	0
Cryptomonas spp.	1	1	1	1	1	1	1	1

Table F.2. Continued.

Station	M9	M10	M11	M12	M13	M14	M15	M16
Alexandrium spp.	1	1	1	1	1	0	1	1
Scrippsiella spp.	1	1	1	1	1	1	1	1
Gymnodinium spp.	1	1	1	1	1	1	1	1
Amphidinium spp.	1	1	1	1	1	1	1	1
Heterosigma spp.	0	1	1	1	1	1	1	1
Gonyaulax spp.	1	1	1	1	1	0	1	0
Gyrodinium spp.	1	1	1	1	1	1	1	1
Protoceratium spp.	0	0	0	0	0	0	0	0
Prorocentrum spp.	1	1	0	0	1	1	1	1
Heterocapsa spp.	1	1	1	1	1	1	1	1
Dinophysis spp.	0	1	1	0	0	0	1	1
Cysts	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	0	0	0	0	0	0
Ceratium tripos	1	1	1	1	0	1	1	1
Ceratium fusus	1	1	1	0	1	0	1	1
Ceratium azoricum	0	0	0	0	0	0	0	0
Ceratium lineatum	1	1	1	0	1	0	1	1
Ceratium longipes	0	0	0	0	0	0	0	0
Total *Ceratium* spp.	1	1	1	1	1	1	1	1
Protoperidinium spp.	1	1	1	1	1	1	1	1
Pyrophacus spp.	0	0	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	1	1	0	1	1
Guinardia striata	0	0	1	1	1	0	0	0
Dactyliosolen spp.	0	0	0	0	0	0	0	0
Leptocylindrus spp.	0	0	0	0	1	0	0	0
Coscinodiscus spp.	1	0	1	1	1	0	1	1
Thalassiosira spp.	0	0	1	1	0	0	1	0
Stephanopyxis spp.	0	0	0	0	0	0	0	0
Chaetoceros spp.	0	0	0	0	1	0	1	0
Skeletonema spp.	0	0	0	0	1	0	1	0
Paralia sulcata	0	0	0	0	1	0	1	0
Pseudo-nitzschia spp.	0	0	0	0	1	0	0	0
Navicula spp.	0	0	0	1	0	0	0	0
Rhizosolenia spp.	0	0	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0	0	0
Phaeocystis spp.	1	1	1	1	1	1	1	1
"other" nanoplankton	1	1	1	1	1	1	1	1
Cryptomonas spp.	1	1	1	1	1	1	1	1

Table F.2. Continued.

Station	M17	M18	M19	M20	M21	M22	Total	Percent
Alexandrium spp.	1	1	1	1	1	1	**21**	**95**
Scrippsiella spp.	1	1	1	1	1	1	**20**	**91**
Gymnodinium spp.	1	1	1	1	1	1	**21**	**95**
Amphidinium spp.	1	1	1	1	1	1	**22**	**100**
Heterosigma spp.	1	1	1	1	1	1	**13**	**59**
Gonyaulax spp.	1	1	1	1	1	1	**16**	**73**
Gyrodinium spp.	1	1	1	1	1	1	**22**	**100**
Protoceratium spp.	0	0	0	0	0	0	**0**	**0**
Prorocentrum spp.	0	1	1	0	0	1	**12**	**55**
Heterocapsa spp.	1	1	1	1	1	1	**17**	**77**
Dinophysis spp.	1	1	1	1	1	0	**14**	**64**
Cysts	1	1	1	1	1	1	**22**	**100**
Dictyocha spp.	0	0	0	0	0	0	**1**	**5**
Ceratium tripos	0	0	1	0	1	1	**13**	**59**
Ceratium fusus	0	0	0	1	1	1	**10**	**45**
Ceratium azoricum	0	0	0	1	0	0	**1**	**5**
Ceratium lineatum	0	1	0	1	1	1	**12**	**55**
Ceratium longipes	1	0	0	1	0	0	**2**	**9**
Total *Ceratium* spp.	1	1	1	1	1	1	**18**	**82**
Protoperidinium spp.	1	1	1	1	1	1	**20**	**91**
Pyrophacus spp.	0	0	0	0	0	0	**1**	**5**
Polykrikos spp.	0	0	0	0	0	0	**0**	**0**
Guinardia flaccida	0	0	0	0	0	0	**9**	**41**
Guinardia striata	0	0	0	0	0	0	**5**	**23**
Dactyliosolen spp.	0	0	1	0	0	0	**5**	**23**
Leptocylindrus spp.	0	0	0	0	0	0	**4**	**18**
Coscinodiscus spp.	0	1	1	1	1	1	**18**	**82**
Thalassiosira spp.	0	1	0	1	1	0	**11**	**50**
Stephanopyxis spp.	0	0	0	0	0	0	**1**	**5**
Chaetoceros spp.	0	1	1	1	0	0	**10**	**45**
Skeletonema spp.	0	1	0	0	0	1	**4**	**18**
Paralia sulcata	0	0	0	1	0	0	**5**	**23**
Pseudo-nitzschia spp.	0	0	0	1	1	0	**6**	**27**
Navicula spp.	0	0	0	1	1	0	**5**	**23**
Rhizosolenia spp.	0	0	0	0	0	0	**3**	**14**
Ditylum spp.	0	0	0	0	0	0	**0**	**0**
Phaeocystis spp.	1	1	1	1	1	1	**22**	**100**
"other" nanoplankton	1	1	1	1	1	1	**19**	**86**
Cryptomonas spp.	1	1	1	1	1	1	**22**	**100**

Appendix G. EN448 2008 phytoplankton taxa abundance and absence/presence data.
Table G.1. EN448 phytoplankton abundance in cells L^{-1}.

Station	J1	J2	J3	J4	J5	J6
Alexandrium spp.	200	800	0	1,000	2,200	1,400
Scrippsiella spp.	200	1,400	400	1,800	9,400	5,000
Gymnodinium spp.	1,000	2,000	800	1,800	3,800	3,000
Amphidinium spp.	1,200	400	600	1,400	2,800	2,400
Heterosigma spp.	600	0	400	1,000	1,400	3,800
Gonyaulax spp.	0	200	0	0	2,200	400
Gyrodinium spp.	1,200	2,000	600	1,200	3,200	1,400
Protoceratium spp.	0	0	0	0	0	0
Prorocentrum spp.	2,000	200	600	0	600	200
Heterocapsa spp.	400	600	0	800	4,200	2,000
Dinophysis spp.	0	0	0	200	600	0
Cysts	1,600	800	600	1,200	1,800	800
Dictyocha spp.	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	0	0
Ceratium fusus	0	200	0	0	200	0
Ceratium azoricum	0	0	0	0	0	0
Ceratium lineatum	0	400	400	1,400	6,200	200
Ceratium longipes	0	0	0	0	0	0
Total *Ceratium* spp.	0	600	400	1,400	6,400	200
Protoperidinium spp.	400	800	0	600	1,400	1,400
Pyrophacus spp.	0	200	0	0	0	0
Polykrikos spp.	0	0	0	0	2,400	3,800
Guinardia flaccid	0	0	0	3,200	2,800	0
Guinardia striata	0	0	0	200	200	0
Dactyliosolen spp.	0	0	0	2,200	2,200	200
Leptocylindrus spp.	0	1,600	200	4,000	1,000	1,600
Coscinodiscus spp.	200	1,000	600	4,600	1,400	0
Thalassiosira spp.	0	0	0	1,600	800	0
Stephanopyxis spp.	0	0	0	0	0	0
Chaetoceros spp.	0	1,200	0	1,600	600	200
Skeletonema spp.	0	0	0	4,600	2,800	800
Paralia sulcata	0	0	0	0	0	0
*Pseudo-nitzschia*spp.	0	800	0	0	200	800
Navicula spp.	0	0	200	0	0	0
Rhizosolenia spp.	0	0	400	0	0	0
Ditylum spp.	0	0	0	0	0	0
Phaeocystis spp.	1,444,000	1,100,000	1,424,000	784,000	2,176,000	5,872,000
"other" nanoplankton	604,000	736,000	100,000	96,000	192,000	2,544,000
Cryptomonas spp.	32,000	56,000	28,000	68,000	104,000	44,000

Table G.1. Continued.

Station	J7	J8	J9	J10	J11	J12
Alexandrium spp.	400	400	1,000	3,200	1,000	0
Scrippsiella spp.	0	1,000	800	4,800	2,400	200
Gymnodinium spp.	1,800	1,600	2,800	10,200	3,200	0
Amphidinium spp.	800	1,400	1,400	2,800	2,600	0
Heterosigma spp.	1,200	2,200	1,800	2,400	3,200	800
Gonyaulax spp.	0	0	400	1,600	1,000	0
Gyrodinium spp.	600	1,400	2,800	12,400	6,800	200
Protoceratium spp.	0	0	0	0	0	0
Prorocentrum spp.	0	0	1,000	1,400	400	0
Heterocapsa spp.	600	1,400	1,400	8,400	1,200	400
Dinophysis spp.	0	200	0	400	400	0
Cysts	1,000	1,200	1,600	8,000	2,800	800
Dictyocha spp.	0	0	0	0	200	0
Ceratium tripos	200	0	0	0	0	0
Ceratium fusus	0	0	200	200	200	0
Ceratium azoricum	0	0	0	0	0	0
Ceratium lineatum	2,400	3,600	1,600	1,800	0	0
Ceratium longipes	0	0	0	0	0	0
Total *Ceratium* spp.	2,600	3,600	1,800	2,000	200	0
Protoperidinium spp.	600	600	600	1,000	800	0
Pyrophacus spp.	0	0	0	0	0	0
Polykrikos spp.	400	0	200	1,800	5,400	0
Guinardia flaccid	200	5,200	5,000	0	0	0
Guinardia striata	0	0	0	0	0	0
Dactyliosolen spp.	0	0	1,200	0	0	0
Leptocylindrus spp.	19,600	132,800	10,000	0	200	0
Coscinodiscus spp.	400	4,400	4,800	0	0	200
Thalassiosira spp.	0	0	0	0	0	0
Stephanopyxis spp.	0	0	0	1,000	600	0
Chaetoceros spp.	0	800	4,000	800	200	0
Skeletonema spp.	1,600	6,200	1,200	1,800	2,400	0
Paralia sulcata	0	2,600	0	0	0	0
*Pseudo-nitzschia*spp.	0	11,600	1,800	1,600	1,600	0
Navicula spp.	0	200	0	0	0	0
Rhizosolenia spp.	0	200	0	0	0	0
Ditylum spp.	0	200	0	0	0	0
Phaeocystis spp.	896,000	1,432,000	2,016,000	3,504,000	3,216,000	1,596,000
"other" nanoplankton	332,000	68,000	80,000	388,000	388,000	136,000
Cryptomonas spp.	272,000	172,000	720,000	168,000	432,000	164,000

Table G.1. Continued.

Station	J13	J14	J15	J16	J17	J18
Alexandrium spp.	200	0	2,200	1,600	400	400
Scrippsiella spp.	0	200	1,200	3,200	400	200
Gymnodinium spp.	0	0	600	600	1,200	0
Amphidinium spp.	0	0	2,000	5,400	2,200	0
Heterosigma spp.	400	3,000	1,400	3,000	2,200	10,200
Gonyaulax spp.	0	0	200	400	0	200
Gyrodinium spp.	0	0	1,200	1,200	0	200
Protoceratium spp.	0	0	0	0	0	0
Prorocentrum spp.	0	200	1,200	1,000	0	1,400
Heterocapsa spp.	400	1,800	1,600	2,200	800	400
Dinophysis spp.	400	400	0	200	0	600
Cysts	800	1,400	800	3,400	1,200	0
Dictyocha spp.	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	0	0
Ceratium fusus	0	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0
Ceratium lineatum	0	5,200	1,000	0	0	1,400
Ceratium longipes	0	0	0	0	200	0
Total *Ceratium* spp.	0	5,200	1,000	0	200	1,400
Protoperidinium spp.	200	0	1,000	600	0	0
Pyrophacus spp.	0	0	0	0	0	0
Polykrikos spp.	400	0	800	3,400	0	0
Guinardia flaccid	3,800	11,800	1,800	0	200	0
Guinardia striata	5,200	400	0	0	0	600
Dactyliosolen spp.	800	0	0	0	0	0
Leptocylindrus spp.	205,800	209,600	8,000	400	0	13,600
Coscinodiscus spp.	1,400	1,800	1,000	0	0	1,200
Thalassiosira spp.	0	0	0	0	200	800
Stephanopyxis spp.	200	0	0	0	0	0
Chaetoceros spp.	0	0	1,000	0	200	0
Skeletonema spp.	0	1,800	200	200	2,000	0
Paralia sulcata	800	800	0	0	0	2,400
*Pseudo-nitzschia*spp.	2,800	3,800	2,200	0	1,000	0
Navicula spp.	1,600	200	200	0	200	800
Rhizosolenia spp.	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0
Phaeocystis spp.	764,000	1,572,000	384,000	564,000	1,232,000	2,404,000
"other" nanoplankton	0	24,000	32,000	164,000	176,000	148,000
Cryptomonas spp.	44,000	120,000	48,000	24,000	52,000	12,000

Table G.1. Continued.

Station	J19	J20	J21	J22	J23	J24	Mean
Alexandrium spp.	0	2,200	800	1,000	400	2,000	**983**
Scrippsiella spp.	0	1,000	1,200	1,000	200	600	**1,583**
Gymnodinium spp.	0	1,000	200	0	400	2,000	**1,609**
Amphidinium spp.	200	400	200	1,000	200	1,200	**1,278**
Heterosigma spp.	600	1,000	1,800	800	1,000	1,400	**1,957**
Gonyaulax spp.	0	200	400	0	0	0	**313**
Gyrodinium spp.	0	400	1,400	0	200	200	**1,626**
Protoceratium spp.	0	0	0	0	0	0	**0**
Prorocentrum spp.	200	1,400	1,200	400	1,000	2,200	**635**
Heterocapsa spp.	0	400	1,000	0	0	800	**1,322**
Dinophysis spp.	0	200	0	600	0	200	**191**
Cysts	800	2,000	3,200	1,200	600	3,200	**1,704**
Dictyocha spp.	0	0	0	0	0	0	**9**
Ceratium tripos	0	0	0	0	0	0	**9**
Ceratium fusus	0	0	0	0	0	0	**43**
Ceratium azoricum	0	0	0	0	0	0	**0**
Ceratium lineatum	1,800	800	200	2,200	400	400	**1,365**
Ceratium longipes	0	0	0	0	0	0	**9**
Total *Ceratium* spp.	1,800	800	200	2,200	400	400	**1,426**
Protoperidinium spp.	200	200	200	200	0	600	**478**
Pyrophacus spp.	0	0	0	0	0	0	**9**
Polykrikos spp.	0	400	4,200	200	0	2,400	**1,122**
Guinardia flaccida	0	0	0	0	0	0	**1,478**
Guinardia striata	0	0	0	0	0	0	**287**
Dactyliosolen spp.	0	0	0	0	0	0	**287**
Leptocylindrus spp.	400	0	0	0	0	0	**26,470**
Coscinodiscus spp.	1,400	0	0	600	1,600	200	**1,157**
Thalassiosira spp.	0	0	0	0	0	0	**148**
Stephanopyxis spp.	0	0	0	0	0	0	**78**
Chaetoceros spp.	0	0	0	1,200	0	0	**513**
Skeletonema spp.	0	0	0	0	0	0	**1,113**
Paralia sulcata	1,200	0	0	0	0	0	**339**
Pseudo-nitzschia spp.	0	0	0	0	0	0	**1,226**
Navicula spp.	0	0	0	0	400	800	**200**
Rhizosolenia spp.	0	0	0	0	0	0	**26**
Ditylum spp.	0	0	0	0	0	0	**9**
Phaeocystis spp.	1,340,000	364,000	300,000	1,104,000	920,000	2,800,000	**1,641,913**
"other" nanoplankton	560,000	96,000	244,000	76,000	8,000	68,000	**289,391**
Cryptomonas spp.	32,000	0	36,000	80,000	8,000	164,000	**123,826**

Table G.2. EN448 phytoplankton taxa absence/presence
1 = Present; 0 = Absent

Station	J1	J2	J3	J4	J5	J6	J7	J8
Alexandrium spp.	1	1	0	1	1	1	1	1
Scrippsiella spp.	1	1	1	1	1	1	0	1
Gymnodinium spp.	1	1	1	1	1	1	1	1
Amphidinium spp.	1	1	1	1	1	1	1	1
Heterosigma spp.	1	0	1	1	1	1	1	1
Gonyaulax spp.	0	1	0	0	1	1	0	0
Gyrodinium spp.	1	1	1	1	1	1	1	1
Protoceratium spp.	0	0	0	0	0	0	0	0
Prorocentrum spp.	1	1	1	0	1	1	0	0
Heterocapsa spp.	1	1	0	1	1	1	1	1
Dinophysis spp.	0	0	0	1	1	0	0	1
Cysts	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	0	0	1	0
Ceratium fusus	0	1	0	0	1	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0	0
Ceratium lineatum	0	1	1	1	1	1	1	1
Ceratium longipes	0	0	0	0	0	0	0	0
Total *Ceratium* spp.	0	1	1	1	1	1	1	1
Protoperidinium spp.	1	1	0	1	1	1	1	1
Pyrophacus spp.	0	1	0	0	0	0	0	0
Polykrikos spp.	0	0	0	0	1	1	1	0
Guinardia flaccida	0	0	0	1	1	0	1	1
Guinardia striata	0	0	0	1	1	0	0	0
Dactyliosolen spp.	0	0	0	1	1	1	0	0
Leptocylindrus spp.	0	1	1	1	1	1	1	1
Coscinodiscus spp.	1	1	1	1	1	0	1	1
Thalassiosira spp.	0	0	0	1	1	0	0	0
Stephanopyxis spp.	0	0	0	0	0	0	0	0
Chaetoceros spp.	0	1	0	1	1	1	0	1
Skeletonema spp.	0	0	0	1	1	1	1	1
Paralia sulcata	0	0	0	0	0	0	0	1
Pseudo-nitzschia spp.	0	1	0	0	1	1	0	1
Navicula spp.	0	0	1	0	0	0	0	1
Rhizosolenia spp.	0	0	1	0	0	0	0	1
Ditylum spp.	0	0	0	0	0	0	0	1
Phaeocystis spp.	1	1	1	1	1	1	1	1
"other" nanoplankton	1	1	1	1	1	1	1	1
Cryptomonas spp.	1	1	1	1	1	1	1	1

Table G.2. Continued.

Station	J9	J10	J11	J12	J13	J14	J15	J16	J17
Alexandrium spp.	1	1	1	0	1	0	1	1	1
Scrippsiella spp.	1	1	1	1	0	1	1	1	1
Gymnodinium spp.	1	1	1	0	0	0	1	1	1
Amphidinium spp.	1	1	1	0	0	0	1	1	1
Heterosigma spp.	1	1	1	1	1	1	1	1	1
Gonyaulax spp.	1	1	1	0	0	0	1	1	0
Gyrodinium spp.	1	1	1	1	0	0	1	1	0
Protoceratium spp.	0	0	0	0	0	0	0	0	0
Prorocentrum spp.	1	1	1	0	0	1	1	1	0
Heterocapsa spp.	1	1	1	1	1	1	1	1	1
Dinophysis spp.	0	1	1	0	1	1	0	1	0
Cysts	1	1	1	1	1	1	1	1	1
Dictyocha spp.	0	0	1	0	0	0	0	0	0
Ceratium tripos	0	0	0	0	0	0	0	0	0
Ceratium fusus	1	1	1	0	0	0	0	0	0
Ceratium azoricum	0	0	0	0	0	0	0	0	0
Ceratium lineatum	1	1	0	0	0	1	1	0	0
Ceratium longipes	0	0	0	0	0	0	0	0	1
Total *Ceratium* spp.	1	1	1	0	0	1	1	0	1
Protoperidinium spp.	1	1	1	0	1	0	1	1	0
Pyrophacus spp.	0	0	0	0	0	0	0	0	0
Polykrikos spp.	1	1	1	0	1	0	1	1	0
Guinardia flaccida	1	0	0	0	1	1	1	0	1
Guinardia striata	0	0	0	0	1	1	0	0	0
Dactyliosolen spp.	1	0	0	0	1	0	0	0	0
Leptocylindrus spp.	1	0	1	0	1	1	1	1	0
Coscinodiscus spp.	1	0	0	1	1	1	1	0	0
Thalassiosira spp.	0	0	0	0	0	0	0	0	1
Stephanopyxis spp.	0	1	1	0	1	0	0	0	0
Chaetoceros spp.	1	1	1	0	0	0	1	0	1
Skeletonema spp.	1	1	1	0	0	1	1	1	1
Paralia sulcata	0	0	0	0	1	1	0	0	0
Pseudo-nitzschia spp.	1	1	1	0	1	1	1	0	1
Navicula spp.	0	0	0	0	1	1	1	0	1
Rhizosolenia spp.	0	0	0	0	0	0	0	0	0
Ditylum spp.	0	0	0	0	0	0	0	0	0
Phaeocystis spp.	1	1	1	1	1	1	1	1	1
"other" nanoplankton	1	1	1	1	1	1	1	1	1
Cryptomonas spp.	1	1	1	1	1	1	1	1	1

Table G.2. Continued.

Station	J18	J19	J20	J21	J22	J23	J24	Total	Percent
Alexandrium spp.	1	0	1	1	1	1	1	**20**	**83**
Scrippsiella spp.	1	0	1	1	1	1	1	**21**	**88**
Gymnodinium spp.	0	0	1	1	0	1	1	**18**	**75**
Amphidinium spp.	0	1	1	1	1	1	1	**20**	**83**
Heterosigma spp.	1	1	1	1	1	1	1	**23**	**96**
Gonyaulax spp.	1	0	1	1	0	0	0	**11**	**46**
Gyrodinium spp.	1	0	1	1	0	1	1	**19**	**79**
Protoceratium spp.	0	0	0	0	0	0	0	**0**	**0**
Prorocentrum spp.	1	1	1	1	1	1	1	**18**	**75**
Heterocapsa spp.	1	0	1	1	0	0	1	**20**	**83**
Dinophysis spp.	1	0	1	0	1	0	1	**12**	**50**
Cysts	0	1	1	1	1	1	1	**23**	**96**
Dictyocha spp.	0	0	0	0	0	0	0	**1**	**4**
Ceratium tripos	0	0	0	0	0	0	0	**1**	**4**
Ceratium fusus	0	0	0	0	0	0	0	**5**	**21**
Ceratium azoricum	0	0	0	0	0	0	0	**0**	**0**
Ceratium lineatum	1	1	1	1	1	1	1	**18**	**75**
Ceratium longipes	0	0	0	0	0	0	0	**1**	**4**
Total *Ceratium* spp.	1	1	1	1	1	1	1	**20**	**83**
Protoperidinium spp.	0	1	1	1	1	0	1	**18**	**75**
Pyrophacus spp.	0	0	0	0	0	0	0	**1**	**4**
Polykrikos spp.	0	0	1	1	1	0	1	**13**	**54**
Guinardia flaccida	0	0	0	0	0	0	0	**9**	**38**
Guinardia striata	1	0	0	0	0	0	0	**5**	**21**
Dactyliosolen spp.	0	0	0	0	0	0	0	**5**	**21**
Leptocylindrus spp.	1	1	0	0	0	0	0	**15**	**63**
Coscinodiscus spp.	1	1	0	0	1	1	1	**17**	**71**
Thalassiosira spp.	1	0	0	0	0	0	0	**4**	**17**
Stephanopyxis spp.	0	0	0	0	0	0	0	**3**	**13**
Chaetoceros spp.	0	0	0	0	1	0	0	**11**	**46**
Skeletonema spp.	0	0	0	0	0	0	0	**12**	**50**
Paralia sulcata	1	1	0	0	0	0	0	**5**	**21**
*Pseudo-nitzschia*spp.	0	0	0	0	0	0	0	**11**	**46**
Navicula spp.	1	0	0	0	0	1	1	**9**	**38**
Rhizosolenia spp.	0	0	0	0	0	0	0	**2**	**8**
Ditylum spp.	0	0	0	0	0	0	0	**1**	**4**
Phaeocystis spp.	1	1	1	1	1	1	1	**24**	**100**
"other" nanoplankton	1	1	1	1	1	1	1	**24**	**100**
Cryptomonas spp.	1	1	0	1	1	1	1	**23**	**96**

Appendix H. Standardized abundances for twenty-two phytoplankton taxa used in statistical analyses.

Table H.1. Standardized abundances for twenty-two phytoplankton taxa used in statistical analyses.

Station	A1	A2	A3	A4	A5	A6	A7	A8
Taxa								
Alexandrium spp.	-0.59	-0.67	-0.75	-0.67	0.03	-0.44	-0.67	-0.59
Protoperidinium spp.	-0.12	0.66	-0.70	0.27	0.66	0.27	-0.70	-0.31
Scrippsiella spp.	-0.01	0.41	-0.42	1.41	-0.75	1.49	-0.84	-0.42
Amphidinium spp.	0.10	0.58	-0.65	-0.37	-0.84	0.77	-1.03	-0.75
Heterosigma spp.	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62
Ceratium spp.	-0.55	-0.25	-0.70	-0.70	-0.55	-0.25	-0.70	-0.70
Heterocapsa spp.	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53
Gymnodinium spp.	-0.03	0.59	-0.78	-0.53	-0.03	0.09	-0.78	-0.66
Gyrodinium spp.	0.03	-0.07	-0.57	3.73	0.03	-0.37	-0.67	-0.37
Cysts	-0.11	1.44	-0.67	0.18	-0.39	0.60	-0.53	-0.95
Prorocentrum spp.	-0.71	-0.09	-0.71	1.47	-0.40	-0.71	-0.71	-0.71
Polykrikos spp.	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
Coscinodiscus spp.	8.04	0.69	-0.22	-0.01	1.31	-0.06	-0.17	-0.15
Thalassiosira spp.	5.42	2.96	-0.37	-0.11	4.37	1.91	-0.02	0.15
Stephanopyxis spp.	0.88	3.69	-0.27	1.21	5.67	4.02	-0.27	-0.27
Skeletonema spp.	1.01	7.67	-0.26	0.15	0.44	2.10	-0.26	-0.20
Chaetoceros spp.	1.02	7.88	-0.28	-0.28	0.37	-0.28	-0.28	0.59
Pseudo-nitzschia spp.	1.56	1.46	-0.37	-0.37	0.34	0.90	-0.32	-0.37
Paralia sulcata	3.71	1.80	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43
Leptocylindrus spp.	-0.03	-0.14	-0.24	-0.24	-0.07	-0.10	-0.26	-0.19
Guinardia flaccid	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33
Dactyliosolen spp.	0.23	-0.37	-0.25	0.23	-0.25	0.35	2.38	2.02

Table H.1. Continued.

Station	A9	A10	A11	A12	A13	A14	A15	A16
Taxa								
***Alexandrium* spp.**	-0.12	-0.52	-0.59	-0.28	-0.20	-0.20	0.11	-0.36
***Protoperidinium* spp.**	-0.31	-0.70	-0.90	-0.31	-0.12	-0.70	-0.31	0.47
***Scrippsiella* spp.**	1.33	0.16	-0.67	-0.67	0.16	-0.01	-0.84	-0.84
***Amphidinium* spp.**	-1.03	-0.75	-1.03	-0.37	1.81	1.52	-0.37	-1.03
***Heterosigma* spp.**	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62
***Ceratium* spp.**	-0.55	-0.11	-0.70	-0.70	-0.55	-0.25	-0.70	-0.70
***Heterocapsa* spp.**	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53
***Gymnodinium* spp.**	-0.78	-0.78	-0.03	-0.16	-0.41	-0.53	-0.78	-0.66
***Gyrodinium* spp.**	-0.27	-0.57	-0.37	0.73	-0.27	-0.47	0.03	-0.17
Cysts	-0.25	-1.23	-0.53	-0.81	0.46	0.03	-0.53	-0.53
***Prorocentrum* spp.**	-0.71	-0.71	-0.71	0.22	-0.09	-0.40	0.54	-0.71
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
***Coscinodiscus* spp.**	-0.08	-0.22	-0.04	-0.08	-0.19	-0.20	-0.15	-0.13
***Thalassiosira* spp.**	-0.20	-0.37	0.77	0.15	-0.37	-0.37	-0.37	-0.02
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	0.06	-0.27	0.06
***Skeletonema* spp.**	0.26	0.23	0.63	0.53	0.42	-0.26	-0.26	-0.26
***Chaetoceros* spp.**	-0.14	-0.28	0.37	-0.21	-0.06	-0.21	-0.28	-0.28
***Pseudo-nitzschia* spp.**	0.13	-0.37	-0.32	-0.37	0.54	-0.37	-0.37	-0.37
Paralia sulcata	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43
***Leptocylindrus* spp.**	-0.22	-0.26	0.23	0.08	-0.21	-0.25	-0.26	-0.25
Guinardia flaccid	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	2.50	-0.37	-0.37	-0.37	-0.37

Table H.1. Continued.

Station	A17	A18	A19	A20	A21	A22	A23	A24
Taxa								
***Alexandrium* spp.**	-0.36	-0.52	-0.44	-0.04	-0.20	-0.75	-0.52	-0.59
***Protoperidinium* spp.**	0.27	-0.70	-0.70	0.86	0.08	-0.70	-0.90	-0.70
***Scrippsiella* spp.**	0.08	-0.84	0.66	-0.67	0.16	-0.75	-0.84	-0.84
***Amphidinium* spp.**	1.43	-1.03	1.33	-1.03	0.29	-1.03	-1.03	-1.03
***Heterosigma* spp.**	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62
***Ceratium* spp.**	-0.70	0.34	-0.40	-0.55	-0.55	-0.40	-0.70	-0.40
***Heterocapsa* spp.**	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53
***Gymnodinium* spp.**	-0.16	-0.78	-0.53	-0.66	-0.66	-0.78	-0.41	-0.78
***Gyrodinium* spp.**	1.33	-0.47	-0.47	-0.67	-0.37	-0.67	-0.37	-0.67
Cysts	-0.67	-0.95	0.74	-0.95	-0.39	-1.09	-1.23	-1.23
***Prorocentrum* spp.**	0.22	-0.71	-0.40	-0.09	-0.71	-0.71	-0.40	-0.71
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
***Coscinodiscus* spp.**	-0.03	-0.22	-0.21	-0.09	-0.09	-0.22	-0.09	-0.22
***Thalassiosira* spp.**	-0.28	-0.37	-0.28	-0.20	-0.28	-0.37	0.51	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.26	-0.26	-0.20	-0.26	-0.26	-0.26	-0.23	-0.26
***Chaetoceros* spp.**	-0.28	-0.28	-0.28	-0.14	-0.28	-0.28	-0.21	-0.28
***Pseudo-nitzschia* spp.**	-0.32	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
Paralia sulcata	0.52	-0.43	-0.43	2.12	-0.43	-0.43	-0.43	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.25	-0.24	-0.25	-0.26	-0.26	-0.26
Guinardia flaccid	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33
***Dactyliosolen* spp.**	0.95	-0.37	-0.37	-0.37	1.66	-0.37	-0.37	-0.37

Table H.1. Continued.

Station	M1	M2	M3	M4	M5	M6	M7
Taxa							
***Alexndrium* spp.**	-0.52	4.12	0.11	-0.04	1.37	1.76	0.35
***Protoperidinium* spp.**	-0.90	1.45	-0.70	-0.31	-0.90	-0.70	0.08
***Scrippsiella* spp.**	-0.51	0.58	-0.84	-0.75	-0.67	-0.34	-0.26
***Amphidinium* spp.**	1.15	1.33	0.20	0.67	0.67	1.43	-0.27
***Heterosigma* spp.**	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62
***Ceratium* spp.**	-0.70	0.19	-0.70	-0.55	-0.70	-0.40	-0.55
***Heterocapsa* spp.**	-0.53	0.72	-0.53	-0.53	-0.53	-0.05	-0.34
***Gymnodinium* spp.**	-0.78	1.72	-0.66	-0.16	-0.41	0.47	0.59
***Gyrodinium* spp.**	-0.37	0.03	-0.57	-0.17	-0.57	0.33	-0.17
Cysts	1.86	2.99	0.88	2.29	0.74	0.18	0.88
***Prorocentrum* spp.**	-0.71	0.85	-0.71	-0.71	-0.71	1.16	-0.09
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
***Coscinodiscus* spp.**	-0.21	-0.22	-0.19	-0.10	-0.16	-0.16	-0.16
***Thalassiosira* spp.**	-0.37	-0.28	-0.20	0.42	-0.37	-0.28	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.11	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26
***Chaetoceros* spp.**	-0.21	-0.21	-0.28	0.15	-0.06	-0.28	0.08
***Pseudo-nitzschia* spp.**	-0.37	-0.07	-0.37	-0.12	-0.07	-0.37	-0.37
Paralia sulcata	-0.43	-0.43	-0.43	1.16	1.48	-0.43	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.25	-0.18	-0.26	-0.26	-0.11
Guinardia flaccid	-0.33	-0.33	1.30	0.55	-0.33	-0.28	5.52
***Dactyliosolen* spp.**	-0.37	-0.37	-0.13	6.32	0.47	-0.37	-0.01

Table H.1. Continued.

Station	M8	M9	M10	M11	M12	M13	M14
Taxa							
***Alexndrium* spp.**	-0.12	1.05	2.78	3.64	0.11	-0.36	-0.83
***Protoperidinium* spp.**	0.08	-0.31	1.25	0.47	1.25	0.86	-0.70
***Scrippsiella* spp.**	-0.84	0.16	3.24	0.99	0.16	-0.42	-0.75
***Amphidinium* spp.**	0.20	0.48	2.57	0.01	-0.18	0.96	-0.46
***Heterosigma* spp.**	-0.62	-0.62	2.62	1.81	-0.06	1.00	-0.14
***Ceratium* spp.**	-0.70	1.23	3.30	1.37	-0.55	-0.25	-0.55
***Heterocapsa* spp.**	-0.53	0.24	1.30	0.53	0.05	-0.05	-0.43
***Gymnodinium* spp.**	-0.41	0.59	0.84	0.09	-0.28	0.22	-0.53
***Gyrodinium* spp.**	-0.27	-0.07	-0.27	0.13	-0.47	1.03	-0.17
Cysts	-0.11	1.02	-0.11	0.18	0.32	-0.11	-1.09
***Prorocentrum* spp.**	-0.71	-0.40	-0.40	-0.71	-0.71	-0.40	-0.40
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
***Coscinodiscus* spp.**	0.13	-0.18	-0.22	-0.21	0.32	-0.19	-0.22
***Thalassiosira* spp.**	0.86	-0.37	-0.37	-0.02	-0.20	-0.37	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.26	-0.26	-0.26	-0.26	-0.26	-0.20	-0.26
***Chaetoceros* spp.**	-0.28	-0.28	-0.28	-0.28	-0.28	0.30	-0.28
***Pseudo-nitzschia* spp.**	-0.37	-0.37	-0.37	-0.37	-0.37	-0.17	-0.37
Paralia sulcata	-0.43	-0.43	-0.43	-0.43	-0.43	1.48	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.26	-0.26	-0.26	-0.24	-0.26
Guinardia flaccid	4.60	-0.33	-0.33	-0.33	1.20	-0.14	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37

Table H.1. Continued.

Station	M15	M16	M17	M18	M19	M20	M21
Taxa							
***Alexndrium* spp.**	1.13	1.13	1.53	0.03	-0.04	0.50	1.37
***Protoperidinium* spp.**	0.08	0.66	2.03	2.81	0.08	2.03	3.99
***Scrippsiella* spp.**	0.49	0.24	0.58	0.24	0.66	0.91	1.66
***Amphidinium* spp.**	0.48	-0.46	-0.56	-0.56	2.38	2.47	1.05
***Heterosigma* spp.**	1.49	-0.06	0.35	0.43	2.30	1.89	1.49
***Ceratium* spp.**	0.34	0.34	-0.40	0.04	0.04	0.49	1.97
***Heterocapsa* spp.**	0.43	0.05	1.59	0.05	2.55	0.14	1.01
***Gymnodinium* spp.**	0.22	-0.28	-0.03	0.47	0.72	0.47	0.09
***Gyrodinium* spp.**	-0.47	-0.37	-0.47	-0.47	1.23	0.13	0.03
Cysts	0.74	0.18	-0.25	-0.39	-0.39	-0.53	0.18
***Prorocentrum* spp.**	1.78	-0.40	-0.71	4.28	1.16	-0.71	-0.71
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
***Coscinodiscus* spp.**	-0.18	-0.17	-0.22	-0.21	-0.20	-0.12	-0.17
***Thalassiosira* spp.**	-0.11	-0.37	-0.37	-0.28	-0.37	-0.20	-0.02
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.22	-0.26	-0.26	-0.20	-0.26	-0.26	-0.26
***Chaetoceros* spp.**	0.22	-0.28	-0.28	-0.21	-0.14	0.30	-0.28
***Pseudo-nitzschia* spp.**	-0.37	-0.37	-0.37	-0.37	-0.37	5.47	4.41
Paralia sulcata	0.20	-0.43	-0.43	-0.43	-0.43	1.48	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26
Guinardia flaccida	-0.28	-0.24	-0.33	-0.33	-0.33	-0.33	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	-0.37	-0.25	-0.37	-0.37

Table H.1. Continued.

Station	M22	J1	J2	J3	J4	J5	J6
Taxa							
***Alexndrium* spp.**	1.84	-0.75	-0.52	-0.83	-0.44	0.03	-0.28
***Protoperidinium* spp.**	3.20	-0.51	-0.12	-0.90	-0.31	0.47	0.47
***Scrippsiella* spp.**	3.90	-0.75	-0.26	-0.67	-0.09	3.07	1.24
***Amphidinium* spp.**	2.28	-0.46	-0.84	-0.75	-0.37	0.29	0.10
***Heterosigma* spp.**	3.92	-0.38	-0.62	-0.46	-0.22	-0.06	0.92
***Ceratium* spp.**	1.23	-0.70	-0.25	-0.40	0.34	4.04	-0.55
***Heterocapsa* spp.**	5.53	-0.34	-0.24	-0.53	-0.15	1.49	0.43
***Gymnodinium* spp.**	3.21	-0.16	0.47	-0.28	0.34	1.59	1.09
***Gyrodinium* spp.**	0.73	-0.07	0.33	-0.37	-0.07	0.93	0.03
Cysts	1.02	-0.11	-0.67	-0.81	-0.39	0.03	-0.67
***Prorocentrum* spp.**	-0.09	2.41	-0.40	0.22	-0.71	0.22	-0.40
***Polykrikos* spp.**	-0.34	-0.34	-0.34	-0.34	-0.34	1.90	3.20
***Coscinodiscus* spp.**	-0.21	-0.21	-0.17	-0.19	0.04	-0.15	-0.22
***Thalassiosira* spp.**	-0.37	-0.37	-0.37	-0.37	0.33	-0.02	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.25	-0.26	-0.26	-0.26	0.10	-0.04	-0.20
***Chaetoceros* spp.**	-0.28	-0.28	0.15	-0.28	0.30	-0.06	-0.21
***Pseudo-nitzschia* spp.**	-0.37	-0.37	-0.17	-0.37	-0.37	-0.32	-0.17
Paralia sulcata	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.22	-0.25	-0.15	-0.23	-0.22
Guinardia flaccida	-0.33	-0.33	-0.33	-0.33	0.41	0.32	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	-0.37	0.95	0.95	-0.25

Table H.1. Continued.

Station	J7	J8	J9	J10	J11	J12	J13
Taxa							
***Alexndrium* spp.**	-0.67	-0.67	-0.44	0.43	-0.44	-0.83	-0.75
***Protoperidinium* spp.**	-0.31	-0.31	-0.31	0.08	-0.12	-0.90	-0.70
***Scrippsiella* spp.**	-0.84	-0.42	-0.51	1.16	0.16	-0.75	-0.84
***Amphidinium* spp.**	-0.65	-0.37	-0.37	0.29	0.20	-1.03	-1.03
***Heterosigma* spp.**	-0.14	0.27	0.11	0.35	0.67	-0.30	-0.46
***Ceratium* spp.**	1.23	1.97	0.63	0.78	-0.55	-0.70	-0.70
***Heterocapsa* spp.**	-0.24	0.14	0.14	3.51	0.05	-0.34	-0.34
***Gymnodinium* spp.**	0.34	0.22	0.97	5.59	1.22	-0.78	-0.78
***Gyrodinium* spp.**	-0.37	0.03	0.73	5.53	2.73	-0.57	-0.67
Cysts	-0.53	-0.39	-0.11	4.40	0.74	-0.67	-0.67
***Prorocentrum* spp.**	-0.71	-0.71	0.85	1.47	-0.09	-0.71	-0.71
***Polykrikos* spp.**	0.03	-0.34	-0.16	1.34	4.69	-0.34	0.03
***Coscinodiscus* spp.**	-0.20	0.02	0.05	-0.22	-0.22	-0.21	-0.15
***Thalassiosira* spp.**	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	0.55	0.22	-0.27	-0.11
***Skeletonema* spp.**	-0.14	0.23	-0.17	-0.12	-0.07	-0.26	-0.26
***Chaetoceros* spp.**	-0.28	0.01	1.16	0.01	-0.21	-0.28	-0.28
***Pseudo-nitzschia* spp.**	-0.37	2.58	0.08	0.03	0.03	-0.37	0.34
Paralia sulcata	-0.43	3.71	-0.43	-0.43	-0.43	-0.43	0.84
***Leptocylindrus* spp.**	0.26	3.25	0.01	-0.26	-0.25	-0.26	5.18
Guinardia flaccida	-0.28	0.88	0.83	-0.33	-0.33	-0.33	0.55
***Dactyliosolen* spp.**	-0.37	-0.37	0.35	-0.37	-0.37	-0.37	0.11

Table H.1. Continued.

Station	J14	J15	J16	J17	J18	J19	J20
Taxa							
***Alexndrium* spp.**	-0.83	0.03	-0.20	-0.67	-0.67	-0.83	0.03
***Protoperidinium* spp.**	-0.90	0.08	-0.31	-0.90	-0.90	-0.70	-0.70
***Scrippsiella* spp.**	-0.75	-0.34	0.49	-0.67	-0.75	-0.84	-0.42
***Amphidinium* spp.**	-1.03	-0.09	1.52	0.01	-1.03	-0.94	-0.84
***Heterosigma* spp.**	0.59	-0.06	0.59	0.27	3.51	-0.38	-0.22
***Ceratium* spp.**	3.15	0.04	-0.70	-0.55	0.34	0.63	-0.11
***Heterocapsa* spp.**	0.34	0.24	0.53	-0.15	-0.34	-0.53	-0.34
***Gymnodinium* spp.**	-0.78	-0.41	-0.41	-0.03	-0.78	-0.78	-0.16
***Gyrodinium* spp.**	-0.67	-0.07	-0.07	-0.67	-0.57	-0.67	-0.47
Cysts	-0.25	-0.67	1.16	-0.39	-1.23	-0.67	0.18
***Prorocentrum* spp.**	-0.40	1.16	0.85	-0.71	1.47	-0.40	1.47
***Polykrikos* spp.**	-0.34	0.40	2.83	-0.34	-0.34	-0.34	0.03
***Coscinodiscus* spp.**	-0.12	-0.17	-0.22	-0.22	-0.16	-0.15	-0.22
***Thalassiosira* spp.**	-0.37	-0.37	-0.37	-0.28	-0.02	-0.37	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.12	-0.25	-0.25	-0.10	-0.26	-0.26	-0.26
***Chaetoceros* spp.**	-0.28	0.08	-0.28	-0.21	-0.28	-0.28	-0.28
***Pseudo-nitzschia* spp.**	0.59	0.19	-0.37	-0.12	-0.37	-0.37	-0.37
Paralia sulcata	0.84	-0.43	-0.43	-0.43	3.39	1.48	-0.43
***Leptocylindrus* spp.**	5.28	-0.05	-0.25	-0.26	0.10	-0.25	-0.26
Guinardia flaccida	2.41	0.09	-0.33	-0.28	-0.33	-0.33	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37

Table H.1. Continued.

Station	J21	J22	J23	J24
Taxa				
***Alexndrium* spp.**	-0.52	-0.44	-0.67	-0.04
***Protoperidinium* spp.**	-0.70	-0.70	-0.90	-0.31
***Scrippsiella* spp.**	-0.34	-0.42	-0.75	-0.59
***Amphidinium* spp.**	-0.94	-0.56	-0.94	-0.46
***Heterosigma* spp.**	0.11	-0.30	-0.22	-0.06
***Ceratium* spp.**	-0.55	0.93	-0.40	-0.40
***Heterocapsa* spp.**	-0.05	-0.53	-0.53	-0.15
***Gymnodinium* spp.**	-0.66	-0.78	-0.53	0.47
***Gyrodinium* spp.**	0.03	-0.67	-0.57	-0.57
Cysts	1.02	-0.39	-0.81	1.02
***Prorocentrum* spp.**	1.16	-0.09	0.85	2.72
***Polykrikos* spp.**	3.58	-0.16	-0.34	1.90
***Coscinodiscus* spp.**	-0.22	-0.19	-0.13	-0.21
***Thalassiosira* spp.**	-0.37	-0.37	-0.37	-0.37
***Stephanopyxis* spp.**	-0.27	-0.27	-0.27	-0.27
***Skeletonema* spp.**	-0.26	-0.26	-0.26	-0.26
***Chaetoceros* spp.**	-0.28	0.15	-0.28	-0.28
***Pseudo-nitzschia* spp.**	-0.37	-0.37	-0.37	-0.37
Paralia sulcata	-0.43	-0.43	-0.43	-0.43
***Leptocylindrus* spp.**	-0.26	-0.26	-0.26	-0.26
Guinardia flaccid	-0.33	-0.33	-0.33	-0.33
***Dactyliosolen* spp.**	-0.37	-0.37	-0.37	-0.37

Appendix I. Phytoplankton cluster group abundances.

Table I.1. Phytoplankton cluster group abundances in cells L^{-1}.

Station	Cluster 1	Cluster 2	Cluster 3	Cluster 4
A1	180,600	20,000	6,000	4,200
A2	150,600	13,200	9,000	7,600
A3	0	800	2,200	1,000
A4	11,400	1,800	8,400	12,600
A5	55,800	10,200	4,600	4,000
A6	43,000	12,200	12,200	4,600
A7	1,800	4,800	600	1,000
A8	5,800	6,600	2,800	1,200
A9	10,000	3,600	7,800	2,200
A10	6,200	0	4,800	200
A11	18,800	18,600	1,000	2,800
A12	14,000	17,800	3,800	5,000
A13	9,800	5,600	11,000	4,200
A14	1,000	200	9,800	2,800
A15	1,400	0	4,400	3,200
A16	2,800	400	2,600	2,200
A17	3,600	3,000	9,800	6,400
A18	0	0	2,400	800
A19	1,200	400	10,200	3,800
A20	3,200	2,400	4,400	1,000
A21	2,600	3,600	8,000	2,000
A22	0	0	1,000	200
A23	5,000	0	800	1,400
A24	0	0	1,200	0
M1	400	0	6,200	5,000
M2	400	1,200	24,600	15,000
M3	1,200	7,600	5,200	3,400
M4	5,200	20,000	6,600	7,000
M5	1,800	3,800	9,600	3,600
M6	1,400	200	13,600	8,200
M7	2,200	31,400	7,200	7,000
M8	9,000	21,200	5,400	3,000
M9	800	0	13,600	8,400
M10	0	0	42,200	9,000
M11	1,000	0	28,200	7,200
M12	10,000	6,600	10,400	4,600
M13	3,000	3,400	12,800	7,800

Table I.1. Continued.

M14	0	0	3,000	2,000
M15	3,400	600	19,000	8,400
M16	1,000	400	13,200	4,800
M17	0	0	16,200	7,400
M18	1,400	0	13,200	8,000
M19	800	200	22,000	15,000
M20	3,800	24,200	25,800	6,000
M21	1,800	18,800	29,800	8,000
M22	400	0	43,200	25,400
J1	200	0	2,600	6,200
J2	2,200	2,400	4,000	5,600
J3	600	200	1,800	2,600
J4	12,400	9,400	7,200	5,000
J5	5,600	6,200	23,600	16,000
J6	1,000	2,600	14,200	11,200
J7	2,000	19,800	5,600	4,400
J8	11,400	152,200	9,200	5,600
J9	10,000	18,000	7,400	9,800
J10	3,600	1,600	16,200	42,200
J11	3,200	1,800	10,200	19,800
J12	200	0	1,000	1,400
J13	1,600	214,000	800	1,600
J14	3,600	226,000	8,400	3,400
J15	2,200	12,000	8,800	6,200
J16	200	400	13,800	11,800
J17	2,400	1,200	5,400	3,200
J18	2,000	16,000	12,200	2,000
J19	1,400	1,600	2,800	1,000
J20	0	0	5,600	5,600
J21	0	0	4,400	11,200
J22	1,800	0	6,200	1,800
J23	1,600	0	2,200	2,200
J24	200	0	6,200	10,800

Appendix J. Growth Experiment Raw Data.

Table J.1. Experiment 1 ("low" *Alexandrium fundyense*) raw data. Average and standard deviation for each treatment included. Counts represent cells mL^{-1}. *Samples not collected

Day	Mixed A		Mixed B		Mixed C		Avg		Std. Dev.	
	Alex.	*Dity*	*Alex.*	*Dity*	*Alex.*	*Dity*	*Alex.*	*Dity*	*Alex*	*Dity*
1	81	6	63	8	52	6	65	7	15	1
2										
3	59	33	62	46	46	32	56	37	9	8
4	59	85	69	84	75	77	68	82	8	4
5	60	187	69	197	85	334	71	239	13	82
6	71	383	87	436	70	393	76	404	10	28
7	69	962	101	974	69	795	80	910	18	100
8	80	1,980	100	1,750	90	1,540	90	1,757	10	220
9	79	3,930	100	3,960	107	3,050	95	3,647	15	517
10	81	6,700	87	6,830	92	4,780	87	6,103	6	1148
11	122	8,540	122	9,710	109	5,840	118	8,030	8	1985
12	91	7,310	122	9,230	76	5,600	96	7,380	23	1816
13*	*	*	*	*	*	*	*		*	*
14*	*	*	*	*	*	*	*		*	*
15	75	3,870	92	6,130	95	2,600	87	4,200	11	1788

Day	Control A	Control B	Control C	Average	Std. Dev.	Control A	Control B	Control C	Average	Std. Dev.
	Alex.	*Alex.*	*Alex.*	*Alex*	*Alex.*	*Dity*	*Dity*	*Dity*	*Dity*	*Dity*
1	59	53	44	52	8	9	10	3	7	4
2						14				
3	67	50	63	60	9	33	31	28	31	3
4						106	87	70	88	18
5	58	75	66	66	9	244	215	176	212	34
6						617	434	486	512	94
7	103	99	99	100	2	1,500	1,140	1,040	1,227	242
8						3,500	2,680	2,260	2,813	631
9	112	104	108	108	4	6,030	5,200	4,210	5,147	911
10						8,180	8,870	7,270	8,107	803
11	112	124	150	129	19	9,830	10,420	8,200	9,483	1150
12	142	157	179	159	19	8,970	10,830	8,250	9,350	1331
13*	*	*	*	*	*	*	*	*	*	*
14*	*	*	*	*	*	*	*	*	*	*
15	246	287	367	300	62	2,680	4,950	4,520	4,050	1206

Table J.2. Experiment 2 ("high" *Alexandrium fundyense*). Average and standard deviation for each treatment included. Counts represent cells mL^{-1}.
***Samples not collected**

Day	Mixed A		Mixed B		Mixed C		Avg		Std. Dev.	
	Alex	*Dity*	*Alex*	*Dity*	*Alex*	*Dity*	*Alex*	*Dity*	*Alex*	*Dity*
1	550	48	557	59	440	62	516	56	66	7
2	496	86	568	77	490	84	518	82	43	5
3	554	89	548	116	485	110	529	105	38	14
4	493	138	564	167	507	167	521	157	38	17
5	614	224	647	251	543	287	601	254	53	32
6	667	344	813	396	812	522	764	421	84	92
7	727	459	899	577	813	910	813	649	86	234
8	852	500	1,247	696	942	1,480	1,014	892	207	519
9	909	439	1,407	822	1,305	1,858	1,207	1,040	263	734
10	975	353	1,756	723	1,847	2,366	1,526	1,147	479	1071
11	1,044	231	1,773	308	2,174	2,594	1,664	1,044	573	1343
12	1,041	140	1,746	308	2,887	2,402	1,891	950	932	1260
13*	*	*	*	*	*	*	*	*	*	*
14*	*	*	*	*	*	*	*	*	*	*
15	1,128	55	2,033	140	3,820	2,006	2,327	734	1370	1103

Day	Control A	Control B	Control C	Avg	Std. Dev.	Control A	Control B	Control C	Avg	Std Dev.
	Alex	*Alex.*	*Alex.*	*Alex*	*Alex*	*Dity*	*Dity*	*Dity*	*Dity*	*Dity*
1	501	531	509	514	16	56	52	54	54	1
2						137	119	128	128	5
3	468	613	466	516	84	246	287	289	274	8
4						716	747	731	731	9
5	553	746	523	607	121	1,700	1,810	1,880	1,797	45
6						3,560	4,170	4,440	4,057	197
7	712	1,444	646	934	443	6,990	8,500	8,780	8,090	347
8						9,120	11,560	12,410	11,030	696
9	1,009	2,373	825	1,402	846	10,030	12,240	13,260	11,843	731
10						8,470	11,390	12,920	10,927	1043
11	1,273	4,442	1,174	2,296	1,859	6,640	8,600	10,650	8,630	1175
12	1,342	5,106	1,198	2,549	2,216	4,970	7,060	6,770	6,267	401
13*	*	*	*	*	*	*	*	*	*	*
14*	*	*	*	*	*	*	*	*	*	*
15	1,637		1,442	1,540	138	4,610	4,610	3,800	4,340	412

Table J.3. Triplicate counts on selected dates for Experiment 1 ("low" *Alexandrium fundyense*). Standard deviations are expressed as percentages.
***no replication**

Day	Mixed A		Mixed B		Mixed C	
	Alex.	*Ditylum*	*Alex.*	*Ditylum*	*Alex.*	*Ditylum*
6	71	383	87	436	70	393
6	*	338	*	417	*	327
6	*	374	*	420	*	320
Avg	—	**365**	—	**424**	—	**347**
Std Dev %	—	**6.5**	—	**2.4**	—	**11.6**
7	69	962	101	974	69	795
7	80	935	105	948	90	815
7	61	999	83	982	88	789
Avg	**70**	**965**	**96**	**968**	**82**	**800**
Std Dev %	**13.6**	**3.3**	**12.2**	**1.8**	**14.1**	**1.7**
8	80	1,980	100	1,750	90	1,540
8	*	1,970	*	1,900	*	1,530
8	*	2,130	*	1,910	*	1,690
Avg	—	**2027**	**100**	**1853**	**90**	**1587**
Std Dev %	—	**4.4**	—	**4.8**	—	**5.6**
9	79	3,930	100	3,960	107	3,050
9	92	3,720	95	4,020	98	2,650
9	82	3,540	86	3,550	78	2,810
Avg	**84**	**3730**	**94**	**3843**	**94**	**2837**
Std Dev %	**8.1**	**5.2**	**7.6**	**6.7**	**15.7**	**7.1**
10	81	6,700	87	6,830	92	4,780
10	*	6,020	*	6,210	*	4,310
10	*	6,140	*	6,240	*	3,810
Avg	—	**6287**	—	**6427**	—	**4300**
Std Dev %	—	**5.8**	—	**5.4**	—	**11.3**
15	75	3,870	92	6,130	95	2,600
15	88	*	95	*	87	*
15	81	*	90	*	92	*
Avg	**81**	—	**92**	—	**91**	—
Std Dev %	**8.0**	—	**2.7**	—	**4.4**	—

Day	Control A	Control B	Control C	Control A	Control B	Control C
	Alex.	*Alex.*	*Alex.*	*Ditylum*	*Ditylum*	*Ditylum*
6	*	*	*	617	434	486

Table J.3. Continued.

6	*	*	*	566	447	490
6	*	*	*	531	493	447
Avg	—	—	—	**571**	**458**	**474**
Std Dev %	—	—	—	**7.6**	**6.8**	**5.0**
7	103	99	99	1,500	1,140	1,040
7	83	97	66	1,040	780	930
7	75	89	64	1,130	1,020	860
Avg	**87**	**95**	**76**	**1223**	**980**	**943**
Std Dev %	**16.6**	**5.6**	**25.7**	**19.9**	**18.7**	**9.6**
8	*	*	*	3,500	2,680	2,260
8	*	*	*	2,680	2,360	2,260
8	*	*	*	2,950	2,270	2,390
Avg	—	—	—	**3043**	**2437**	**2303**
Std Dev %	—	—	—	**13.7**	**8.8**	**3.3**
9	112	104	108	6,030	5,200	4,210
9	86	105	81	3,480	3,440	3,930
9	95	109	87	3,430	3,580	4,190
Avg	**98**	**106**	**92**	**4313**	**4073**	**4110**
Std Dev %	**13.5**	**2.5**	**15.4**	**34.5**	**24.0**	**3.8**
10	*	*	*	8,180	8,870	7,270
10	*	*	*	6,830	7,820	5,950
10	*	*	*	7,020	8,240	5,640
Avg	—	—	—	**7343**	**8310**	**6287**
Std Dev %	—	—	—	**10.0**	**6.4**	**13.8**
15	246	287	367	2,680	4,950	4,520
15	*	*	*	*	*	*
15	*	*	*	*	*	*
Avg	—	—	—	—	—	—
Std Dev %	—	—	—	—	—	—

Table J.4. Triplicate counts on selected dates for Experiment 2 ("high" *Alexandrium fundyense*). Standard deviations are expressed as percentages. *no replication

Day	Mixed A		Mixed B		Mixed C	
	Alex.	*Ditylum*	*Alex.*	*Ditylum*	*Alex.*	*Ditylum*
7	727	459	899	577	813	910
7	805	439	933	544	808	922
7	765	455	915	596	851	907
Avg	**766**	**451**	**916**	**572**	**824**	**913**
Std Dev %	**5.1**	**2.3**	**1.9**	**4.6**	**2.9**	**0.9**
9	909	439	1,407	822	1,305	1,858
9	972	250	1,702	592	1,476	2,302
9	981	324	1,684	715	1,382	1,967
Avg	**954**	**338**	**1598**	**710**	**1388**	**2042**
Std Dev %	**4.1**	**28.2**	**10.4**	**16.2**	**6.2**	**11.3**
11	1,044	231	1,773	308	2,174	2,594
11	968	225	1,680	420	1,930	2,990
11	1,006	242	1,710	436	2,240	2,850
Avg	**1006**	**233**	**1721**	**388**	**2115**	**2811**
Std Dev %	**3.8**	**3.7**	**2.8**	**18.0**	**7.7**	**7.1**
15	1,128	55	2,033	140	3,820	2,006
15	1,080	56	2,040	129	3,650	2,000
15	1,149	47	1,996	113	3,910	1,980
Avg	**1119.0**	**52.7**	**2023.0**	**127.3**	**3793.3**	**1995.3**
Std Dev %	**3.2**	**9.4**	**1.2**	**10.7**	**3.5**	**0.7**

Day	Control A	Control B	Control C	Control A	Control B	Control C
	Alex.	*Alex.*	*Alex.*	*Ditylum*	*Ditylum*	*Ditylum*
7	712	1,444	646	6,990	8,500	8,780
7	775	1,330	619	7,930	7,410	8,020
7	710	1,406	623	6,770	8,230	8,470
Avg	**732**	**1,393**	**629**	**7,230**	**8,047**	**8,423**
Std Dev %	**5.0**	**4.2**	**2.3**	**8.5**	**7.1**	**4.5**
9	1,009	2,373	825	10,030	12,240	13,260
9	1,008	2,277	815	8,930	11,790	12,820
9	1,016	2,212	825	9,640	12,300	12,470
Avg	**1011**	**2287**	**822**	**9533**	**12110**	**12850**
Std Dev %	**0.4**	**3.5**	**0.7**	**5.9**	**2.3**	**3.1**

Table J.4. Continued.

11	1,273	4,442	1,174	6,640	8,600	10,650
11	1,303	4,260	1,308	6,540	8,900	9,310
11	1,286	4,387	1,219	6,710	8,790	9,420
Avg	**1287**	**4363**	**1234**	**6630**	**8763**	**9793**
Std Dev %	**1.2**	**2.1**	**5.5**	**1.3**	**1.7**	**7.6**
15	1,637	9,060	1,442	3,240	4,610	3,800
15	1,450	7,400	1,360	3,280	4,460	3,740
15	1,520	8,290	1,568	3,190	4,650	3,710
Avg	**1536**	**8250**	**1457**	**3237**	**4573**	**3750**
Std Dev %	**6.2**	**10.1**	**7.2**	**1.4**	**2.2**	**1.2**

Appendix K. Growth experiment 2 ("high" *Alexandrium fundyense*) nutrient concentrations.

Table K.1. Nutrient concentrations of $NO_3^- + NO_2^-$, $Si(OH)_4$, and PO_4^{-3} at days 9 and 16 for Growth Experiment 2 ("high" *Alexandrium fundyense*). Average and standard deviations were calculated for each treatment.

Day 9	$NO_3^- + NO_2^-$ µM	$Si(OH)_4$ µM	$PO4^{-3}$ µM
Mixed A	843.0	180.1	10.3
Mixed B	783.0	179.0	14.4
Mixed C	789.0	167.9	13.0
Average	**805.0**	**175.7**	**12.6**
Std. Dev.	**33.0**	**6.7**	**2.1**
Alexandrium Control A	770.0	192.9	17.0
Alexandrium Control B	655.0	181.5	14.2
Alexandrium Control C	744.0	181.8	15.6
Average	**723.0**	**185.4**	**15.6**
Std. Dev.	**60.3**	**6.5**	**1.4**
Ditylum Control A	732.0	131.1	11.5
Ditylum Control B	696.0	106.2	12.0
Ditylum Control C	541.0	100.5	10.6
Average	656.3	112.6	11.4
Std. Dev.	101.5	16.3	0.7
Day 16	**$NO_3^- + NO_2^-$ µM**	**$Si(OH)_4$ µM**	**$PO4^{-3}$ µM**
Mixed A	584.0	189.1	9.3
Mixed B	613.0	178.5	9.8
Mixed C	625.0	167.5	5.6
Average	**607.3**	**178.4**	**9.1**
Std. Dev.	**21.1**	**10.8**	**2.3**
Alexandrium Control A	769.0	183.3	9.1
Alexandrium Control B	634.0	195.0	9.6
Alexandrium Control C	770.0	185.2	10.2
Average	**724.3**	**187.8**	**9.6**
Std. Dev.	**78.2**	**6.3**	**0.6**
Ditylum Control A	528.0	123.7	8.7
Ditylum Control B	520.0	96.9	7.6
Ditylum Control C	598.0	52.0	4.4
Average	**548.7**	**90.9**	**6.9**
Std. Dev.	**42.9**	**36.2**	**2.2**

Appendix L: Triplicate cell count data for diatoms, dinoflagellates, *Alexandrium* spp., and nanoplankton for 5-station transects.

Table L.1. OC445 triplicate cell counts in cells L^{-1}. Averages and standard deviations included.

Station	Diatoms (cells L^{-1})	Dinoflagellates (cells L^{-1})	Alexandrium spp. (cells L^{-1})	Nanoplankton (cells L^{-1})
A15	1,600	7,600	2,400	117,000
A15	1,000	7,000	1,600	904,000
A15	800	8,000	1,400	884,000
Avg	**1,133**	**7,533**	**1,800**	**635,000**
Std Dev.	**416**	**503**	**529**	**448,713**
A16	4,000	5,200	1,200	47,600
A16	3,600	9,400	800	1,472,000
A16	6,000	10,000	2,200	1,620,000
Avg	**4,533**	**8,200**	**1,400**	**1,046,533**
Std Dev.	**1,286**	**2,615**	**721**	**868,261**
A17	6,600	16,600	1,200	661,000
A17	3,000	9,600	200	3,024,000
A17	3,200	10,600	1,200	2,500,000
Avg	**4,267**	**12,267**	**867**	**2,061,667**
Std Dev.	**2,023**	**3,786**	**577**	**1,240,985**
A18	0	4,400	800	70,000
A18	600	3,200	200	2,572,000
A18	400	2,400	600	2,972,000
Avg	**333**	**3,333**	**533**	**1,871,333**
Std Dev.	**306**	**1,007**	**306**	**1,572,769**
A19	1,600	14,200	1,000	532,000
A19	0	5,400	400	1,500,000
A19	400	5,400	600	464,000
Avg	**667**	**8,333**	**667**	**832,000**
Std Dev.	**833**	**5,081**	**306**	**579,503**

Table L.2. OC447 triplicate cell counts in cells L^{-1}. Averages and standard deviations included.

Station	Diatoms (cells L^{-1})	Dinoflagellates (cells L^{-1})	Alexandrium spp. (cells L^{-1})	Nanoplankton (cells L^{-1})
M15	4,000	29,600	5,000	1,564,000
M15	3,800	19,400	4,000	3,780,000
M15	3,800	23,000	3,400	4,020,000
Avg	**3,867**	**24,000**	**4,133**	**3,121,333**
Std Dev.	**115**	**5,173**	**808**	**1,354,018**
M16	1,400	19,000	5,000	972,000
M16	3,400	10,200	3,000	832,000
M16	2,600	13,000	2,400	2,160,000
Avg	**2,467**	**14,067**	**3,467**	**1,321,333**
Std Dev.	**1,007**	**4,496**	**1,361**	**729,672**
M17	0	26,600	6,000	536,000
M17	0	23,600	5,000	476,000
M17	0	22,200	4,000	692,000
Avg	**0**	**24,133**	**5,000**	**568,000**
Std Dev.	**0**	**2,248**	**1,000**	**111,499**
M18	1,400	23,400	2,200	40,400
M18	200	31,200	2,400	744,000
M18	600	30,000	1,600	996,000
Avg	**733**	**28,200**	**2,067**	**593,467**
Std Dev.	**611**	**4,200**	**416**	**495,266**
M19	400	69,200	2,000	812,000
M19	400	30,000	200	700,000
M19	200	26,000	200	1,120,000
Avg	**333**	**41,733**	**800**	**877,333**
Std Dev.	**115**	**23,871**	**1,039**	**217,489**

Biography of the Author

Rachel Gettings was born in Watervliet, New York in 1985, where she graduated from Watervliet High School in 2003. She received her Bachelor's of Science degree in Marine Biology at the University of Maine in 2007. She played Division 1 Ice Hockey and earned Scholar Athlete awards during her four years of play. She stayed at the University of Maine and continued her Master's work in the spring of 2008. She is a candidate for the Master of Science degree in Marine Biology from the University of Maine in May, 2010.