MORPHOLOGIC COMPARISONS OF SHALLOW AND DEEPWATER BENTHIC MARINE DIATOMS OF ONSLOW BAY, NORTH CAROLINA

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Consistent with the journal

Diatom Research

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ABSTRACT

In October 2003, *in-situ*, living benthic marine diatoms were recovered from sandy sediments from 67 m to 191 m depth in Onslow Bay, North Carolina, by a remotely operated vehicle tethered to the R/V *Cape Hatteras*. Fourteen stations were sampled, with surface incident irradiance flux ranging from 3.740% of the surface irradiance at the shallowest station to 0.028% at the deepest. Attenuation coefficients fluctuated with depth, averaging between 0.0443 (4.43% loss per meter) and 0.0842 (8.42% loss per meter). Bottom temperatures decreased with depth from 25.3 °C to 14.9°C. One hundred twenty-six species of 29 genera were identified from cleaned sediments from all 14 stations. Eleven live species from six genera were documented as live and identified from the shallowest and deepest of the fourteen stations (*Actinoptychus splendens*, *Amphora coffeaformis*, *Cocconeis disculus*, *Cocconeis distans*, *Cocconeis placentula*, *Diploneis chersonensis*, *Navicula* Sp. a, *Navicula digitoconvergens*, *Nitschia frustulum*, *Nitschia pellucida*, and *Nitschia panduriformis*), and analyzed morphometrically based on apical and transapical axis lengths, degree of frustal ornamentation, and surface area to volume ratios. These data were then compared to those for shallow water samples previously collected from intertidal marsh sediments on Masonboro Island, North Carolina. Though apical axis lengths were significantly larger in the shallow water samples ($p = 8.6 \times 10^{-6}$), transapical axis lengths and degree of ornamentation did not differ significantly between deepwater and shallow water regions. Surface area to volume ratios of three out of five live species found in both shallow water and deepwater were significantly lower in the deepwater stations ($p = 0.00045$ to 0.0088), indicating that differences in shape may affect the efficiency of light collection. The results of this study indicate taxonomic diversity and variety of frustal

morphology of benthic marine diatoms are greater shallow water; however, the presence of these microalgae in the deeper sediments of Onslow Bay may have far-reaching impacts on nutrient cycling and food web dynamics on the shelf and upper slope.

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I would also like to thank my committee members, Richard Laws, Larry Cahoon, and Patricia Kelley for their unwavering support and guidance in this project. I am indebted to them for the time, energy, and assistance they have provided over the past two years. Much appreciation is also extended to the Duke University/University of North Carolina Oceanographic Consortium for their use of the Research Vessel *Cape Hatteras* and its crew in collecting field samples in Onslow Bay and making our stay as enjoyable as nature would allow. I would like to thank Lance Horn of NOAA's National Undersea Research Center, UNCW's Coastal Ocean Research and Monitoring Program and Aquatic Ecology Lab for their technical assistance. Much gratitude is also extended to Cathy Morris and Anne Sutter for their logistical support.

The journey for answers is often more fulfilling than the answers themselves. Much love and thanks to those friends who've taught me about myself along the way: the DeLoach and CMS clan, the San Sal crew, and to Annie, Twinks, Rociel, Lisa F., and Lisa B, and Scott. Thanks to Steffi for the moral support and for showing me how to be strong in the face of opposition; to Greg for the wisdom and understanding, and for being there unconditionally; and last but not least, to my best friend Micól, with whom I've learned to be effortlessly, live happy, and enjoy the champagne highs.

DEDICATION

This thesis is dedicated to my family: To my Mom, who taught me how to persevere with grace; to my Aunt Gail for showing me what a little determination could accomplish; to Uncle Jim for being my geological muse; to Sarah, Matt, Luke, Uncle Jack, and Aunt Lynn for their support (despite the rock jokes); and the zoo crew Jasmine, Maako, Saba, Minerva, Rasta, and Inca, as well as Tommy, Gandalf, and Julep (who didn’t see the completion of this project but aided me in getting there nonetheless).

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INTRODUCTION

Overview

Benthic marine diatoms live in a variety of environments ranging from marshes to the outer continental shelf. Due to their photosynthetic nature, the primary limiting factor governing their distribution is light availability. Distribution of benthic diatoms should therefore be light-limited. To date, the maximum depth at which live benthic marine diatoms have been found is 83 m, off the coast of Madagascar (Plant-Cuny, 1978). However, during a recent research cruise aboard the R/V *Cape Hatteras*, live benthic diatoms were found at the continental shelf-break region of Onslow Bay, North Carolina, at depths up to 191 m, the lower limit of the photic zone of open water (~200 m). Benthic diatoms have been previously documented living *in-situ* in sediments in Onslow Bay at depths of 63 m (Cahoon et al. 1992; Cahoon and Laws, 1993); therefore, physical transport of these frustules via currents and wave energy from shallower regions to this depth is unlikely. Though the possibility of physical transport of diatoms beyond the 63 m depth cannot be eliminated, there are several lines of reason suggesting their *in-situ* growth at the depths sampled in this study. First, the distance from land (>50 km) and virtual absence of planktonic and tychopelagic species from the sample sediments reduces the likelihood of transport from shore or settling from surface waters, where such species are common. Second, wave energy and strong currents rarely reach these depths except during strong storms and hurricanes, thus keeping sediment transport in these regions to a minimum. Third, live species were found continuously at each of the fourteen stations sampled as opposed to being found in patches, lessening the likelihood that transport is occurring at depth. The absence of warmer bottom water temperatures in the deeper of stations sampled in Onslow Bay (such as those recorded in the shallower of these stations) also suggests that transport is not occurring between stations.

The purpose of this project is to compare species composition and morphologies of benthic marine diatoms of the continental shelf to those of the back-barrier marsh zone of Onslow Bay, North Carolina, using light and scanning electron microscopy in order to determine what, if any, differences exist between the assemblages from these contrasting habitats.

Diatom Biology

Diatoms are single-celled marine and freshwater microalgae encased in a heterovalvar, siliceous shell called the frustule (Figure 1). The larger of the two valves, the epitheca, fits over the smaller valve, the hypotheca, and the two are held together by a girdle band. Frustules range in size from 1 micron to 1 millimeter, can be simple to ornate in structure, and have frustule morphologies loosely reflecting their life habitat. Forms are usually classified as centric or pennate. Centric diatoms are radially symmetric and may have a discoid or cylindrical shape and are typically planktonic, but may also adhere to substrates. Pennate diatoms are usually solitary, are bilaterally symmetrical, and elongate in shape. Pennates may have one or more raphe, or valve slit, running the length of the frustule. Monoraphid diatoms such as the genus *Cocconeis* have one raphe on the hypothecal valve, while biraphid diatoms such as the genus *Navicula* have a raphe on both valves. Raphes are believed to secrete a mucilaginous layer, allowing diatoms to adhere and move on a chosen substratum. Hence most raphid diatoms are considered to be benthic.

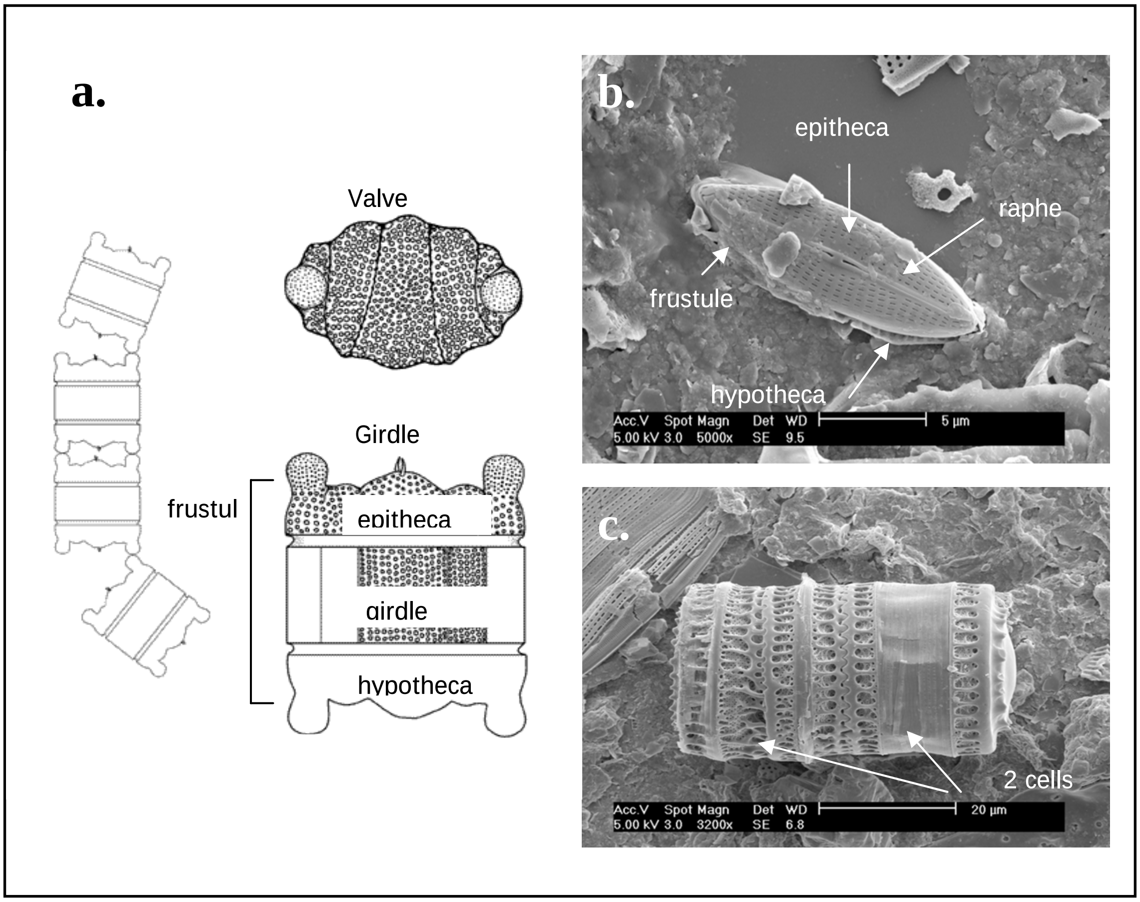


Figure 1. a) Valve and girdle views of *Biddulphia* sp. (*by Denise Eaton*).
b) Valve view of the solitary pennate diatom *Navicula salinarum*.
c) Girdle view of the colonial centric diatom *Paralia sulcata*.

Previous Work

Frequent taxonomic reorganization of diatoms leaves a confused trail of classification schemes, though the Round et al. (1990) classification is the commonly utilized system. Diatoms compose the division Bacillariophyta and include three classes based on frustule structure: Coscinodiscophyceae (centric forms), Fragilariophyceae (araphid pennate forms), and Bacillariophyceae (raphid pennate forms). Round et al. (1990) provides the most complete and detailed reference for distinguishing genera based on morphological characteristics, as revealed by light and scanning electron microscopy. This reference also includes an extensive introduction highlighting diatom morphology and biological processes. A more complete biological description of diatoms can be found in Werner (1977). Differentiation at the species level relies upon the descriptions and light microscopy of numerous authors. Cleve-Euler (1952), Hustedt (1977), and John (1983) each provide extensive morphological and life-mode descriptions accompanied by detailed species-level photographs and line drawings. Hartley (1996) includes hundreds of line drawings of species, but does not provide descriptions.

Hustedt (1955) pioneered the characterization of marine diatoms native to the North Carolina coast by examining mud samples previously collected by Dr. Harold Humm of the Duke University Marine Laboratory. These samples originated from littoral muds at the beach and in the harbor of Beaufort and contained numerous novel species that until that time had not been described. Marshall (1982) characterized the composition of phytoplankton in this region by identifying taxa from surface-water samples collected along a 600 mile stretch of coastline from Cape Lookout, North Carolina, to Cape Canaveral, Florida, during fall cruises in 1973 and 1978. Ninety-one stations were sampled total, ranging in depths from 9 m on the upper shelf to 318 m near the slope. Depths at 35 of these stations were less than 35 m, 45 stations were between 44 m and 200 m, and 4 stations were deeper than 200 m. Taxonomic groups and their constituent species were identified and sorted based on their distance from shore (<35 km from shore being near shore, >35 km from shore being far shore). Concentrations were measured in number of individuals per liter, and the average number of taxonomic groups and their concentrations were slightly higher in near shore areas. Diatoms were one of five dominant taxonomic groups and included 194 total species. Fifty-six percent of these species existed in near shore and far shore areas, 17% were found in near shore areas only, and the remaining 27% were found in far shore areas only. Stations closer to shore had higher concentrations of larger centric diatom forms; however, most near shore individuals were smaller than far shore individuals.

Cahoon et al. (1992, 1993) furthered diatom research for the North Carolina area and began characterizing modern benthic assemblages of species living on inner to slope regions of Onslow Bay. They found that planktonic species of this region were often centric in form, though some centric species may be tychopelagic (benthic dwellers dislodged and temporarily suspended). Most benthic species were pennate in form and classed as epipsammic (living on sand grains) or epilithic (living on hard bottom). The differing assemblages between planktonic and benthic environments suggested the benthic colonies were established and not displaced from other environments. Benthic communities engaging in active photosynthesis were documented to depths of 63 m, with high fucoxanthin: chlorophyll *a* ratios, indicating either a fucoxanthin-rich community or an adaptive strategy to lower wavelengths (400-550 nm). Chlorophyll *a* was also documented in decreasing quantities from sediment samples at depths up to 222 m. Because light flux calculations and pigment data for North Carolina coastal waters indicated that benthic species may live at depths up to 90 m, it was hypothesized that microalgae in deeper areas may be inactive, perhaps shifting into resting spore stages. It was noted, however, that a previous study by Palmisano et al. (1985) documented active benthic diatom cells at approximately 110 m in Antarctica.

Cahoon (1999) synthesized data from a variety of resources in a meta-analysis assessing the biases of benthic microalgal production and the function of benthic microalgae in the relatively unstudied regions of the neritic zone (i.e. continental shelf ecosystems). Estimates of production by benthic microalgae are likely skewed as sampling is biased both by geography and depth, with the majority of research taking place in shallow coastal waters of temperate regions and in areas where funding for such research is available (i.e. east and west coasts of the United States and Canada, and the western coasts of Europe). Furthermore, the variety of techniques used in measuring chlorophyll *a*, as well as the differing concentrations of chlorophyll *a* between light- and shade-adapted species, likely lead to estimates of production that are somewhat removed from actual values. Though minimum light intensity data are scarce, they clearly indicate that benthic microalgae are capable of living in conditions where irradiance and surface incident radiation is lower than traditionally accepted values. A study by Falkowski (1988) cited in this paper, reduces the average light compensation value for algal growth from 1% to 0.1% surface incident radiation. Because oligotrophic waters are generally clearer than coastal waters, compensation values of 0.1% with 0.07% attenuation per meter would yield compensation depths of 100 m based on the equation $I_D = I_0 e^{-kd}$, where I_D equals irradiance at a certain depth D, I_0 equals irradiance at the surface, and k_d equals the extinction coefficient at depth D. Because benthic microalgae are more concentrated at the sediment-water interface than in the water column, extracellular polymeric substances (mucilage) tend to accumulate, which increase stabilization of the sediments and benefit the species by minimizing turbidity and resuspension.

Their position at the sediment-water interface also places benthic microalgae at the “gate” of nutrient transport both in and out of the sediments, making it highly likely that nutrient and other biochemical concentrations are altered by their presence. Finally, benthic microalgae are known food sources for a variety of grazers from zooplankton to bivalves and crabs, implying that ranges of grazers may be wider should benthic microalgae distribution be underestimated.

Hudson and Legendre (1987) studied the morphologies of five species of diatoms native to Point Mitis and Baie des Sables, Quebec, to characterize their ecologic implications. Based on differences in form, mobility, solitary or colonial growth preferences, and position on the sediment surface (prostrate/parallel to the bottom versus erect, or extending into the water column), each species was expected to be distinct in behavior and niche occupation. Using five species of diatoms (a raphid and non-raphid colonial, non-mobile species; two raphid non-colonial slow-moving species; and one raphid non-colonial fast-moving species), distribution and settling analyses took place by studying their individual aggregation patterns and mobility both in a natural setting and under laboratory conditions. As the number of individuals overall increased, non-mobile and slow-moving species tended to aggregate in increasingly fewer patches with high concentrations of cells. At the same time, faster-moving species displayed the opposite behavior, aggregating in numerous patches of lower concentrations of cells. Because the distributions were correlated to the speed of the movement of the species, the life habit of the species (colonial or solitary) and the presence of a raphe did not seem to impact the results. Likewise, the similar distributions between non-mobile and slow-moving species indicated that movement as a whole for this group did not appear to be advantageous. Though mobility would appear to be useful in maintaining an orientation towards a light source, it was implied that either slow-moving species may not be able to move at a rate sufficient enough to be advantageous under these circumstances, or that they were not limited by light availability. Furthermore, colonial diatom species tended to be larger in size than solitary species, reducing their surface-area-to-volume ratio and making them less efficient at light absorption. This feature would require a more upright posture in the water column, effectively increasing their risk of predation by grazers. The collective ecological implications from these results indicate that simply extrapolating behavior and niche occupation by valve morphology alone is insufficient, and that species of various growth forms can coexist in the same niche due to a more complex set of behavioral variables.

Kudo et al. (2000) quantified the effects of temperature and iron supply on the growth rates of the marine planktonic diatom *Phaeodactylum tricornutum*. Cell cultures were grown in artificial seawater under various temperatures and were either supplied with iron manually or made dependent on trace amounts of iron from the seawater. Iron-replete and depleted cells both grew best at 20 °C. Their growth rates decreased gradually below this temperature and decreased sharply above. Iron-depleted cells grew at half the rate of iron-replete cells at 20 °C, and at less than half the rate below 20 °C. These results specifically defined and supported more general observations of the same phenomenon by the authors. An increase in temperature leads to an increase in metabolism to an optimum level, after which the cost of high metabolic activity (respiration) outweighs the benefits (growth rate). Plant metabolism, including photosynthesis, nitrate assimilation, and respiratory electron transport, is highly dependent on iron.

Nayar et al. (2005) studied the effects of dredging and light attenuation on size fractionation of the planktonic diatom *Skeletonema costatum*. They found that the size of cells increased between high light (undredged) and low light (dredged) waters, suggesting that larger cell sizes were advantageous under low-light conditions. To test this hypothesis, light experimentation took place over a four day period by mixing two samples of *S. costatum*, one collected from both the surface and subsurface layers, in each of four mesocosms made from 25 L carboys floated in the surface waters of a nearby marina. Two carboys were wrapped in black netting to reduce the light to 10% of that in the remaining two carboys, which were artificially lit to maintain constant irradiance. Wave activity from marina traffic was used as an agitant to keep the mesocosms evenly mixed. Daily samples were taken and filtered through progressively smaller millipore filters to obtain size fractioning of cells. End results showed a turnover in size fractions, with smaller sizes (2 µm – 20 µm) becoming dominant in the high-light mesocosms, and larger sizes (20 µm – 200 µm) becoming dominant in the low-light conditions.

Werner (1977) synthesized the research of several scientists to characterize the reactions of diatoms to various intensities and qualities of light. Adaptations to changes in light intensity vary between species and include decreases in cell volume and chloroplast numbers at low light, increased chlorophyll content at low light, and increases in photosynthesis rate at high light. For example, *Cyclotella nana* cultured in blue, green, and white light demonstrated the highest photosynthesis rate in blue light of any intensity due to the increase in chlorophyll *a* and *c* in the cell. Upward and downward migration cycles in the sediment by benthic diatoms also vary between species, indicating variations in tolerance for light exposure. While some species migrate up through the sediment column to the surface in morning hours and migrate downward at noon on sunny days, others remain on the surface throughout the day, migrating down only at dusk. Hopkins (1969) demonstrated that some species failed to surface at all when light intensities associated with seasonality were too high. Diatoms in that study did not surface when light intensities surpassed 650 lux in the summer and 800 lux in the winter. Finally, as red light penetrates further than blue light in turbid water and in muds (Sverdrup et al., 1942), it was suggested that benthic diatoms of low latitudes with high light intensities may exhibit a higher photosynthesis rate just below the surface, as high light intensities at the surface may inhibit photosynthesis.

Jochem (1999) examined changes in metabolic activity of marine phytoplankton, including diatoms, during extended periods of darkness. For ten to twelve days, batch cultures of these phytoplankton were exposed to total darkness and sampled once daily for cytometric analysis. Unlike the chlorophytes and most primnesiophytes in the culture, the diatoms present in this experiment (*Bacteriastrum* sp. and an unidentified *Nitschia*-like species) showed no change in metabolic activity during the darkness exposure, and nearly all cells began rapid population growth upon re-entry into light following the experiment. This response was considered odd as the observed response of most diatoms is a reduction of metabolism or formation of resting spores when exposed to extended periods of darkness. Peters and Thomas (1996) and Peters (1996) hypothesized that heterotrophy may allow diatoms to survive months of darkness. Jochem reported the absence of this phenomenon in his experiment, but concluded the duration of his experiments may not have been long enough to induce a heterotrophic response. Finally, though *Bacteriastrum* is a planktonic species and the habit of the *Nitschia*-like species is unknown, it has not been shown that this behavior cannot be attributable to benthic species.

Moisan and Mitchell (2001) hypothesized that mycosporine-like amino acids (MAAs) found in a variety of phytoplankton including diatoms, dinoflagellates, and cyanobacteria served as sunscreens, protecting them from ultraviolet-B (UV-B) radiation. Moisan and Mitchell cultured the planktonic Antarctic prymnesiophyte species *Phaeocystis antarctica* in f/2 medium and exposed samples of these cultures to various intensities of photosynthetically active radiation (PAR) from a tungsten-halogen light source. They found an increase in overall concentrations of

MAA and a decrease in photosynthetic pigment with increasing irradiance. Because fluxes in UV absorption lessened with an increase in MAA and because MAAs were not linked to photosynthesis, it was concluded that MAAs served as effective sunscreens for this species. *Phaeocystis antarctica* would be allowed to carry on photosynthesis uninhibited during increased light intensities of austral spring in Antarctica resulting from the presence of an ozone hole, giving it a distinct advantage. Because MAAs are present in other phytoplankton species, the results of this study suggest similar reactions may take place in other taxa, though the precise role of MAAs in these taxa is as yet unknown. It may be hypothesized that the concentration of MAAs in deepwater benthic diatom species may be less than those concentrations in shallow-water species as UVB radiation is typically absorbed in the upper meter of water (shallower in turbid conditions), lessening the need for MAAs as sunscreens in deepwater assemblages.

Hypothesis

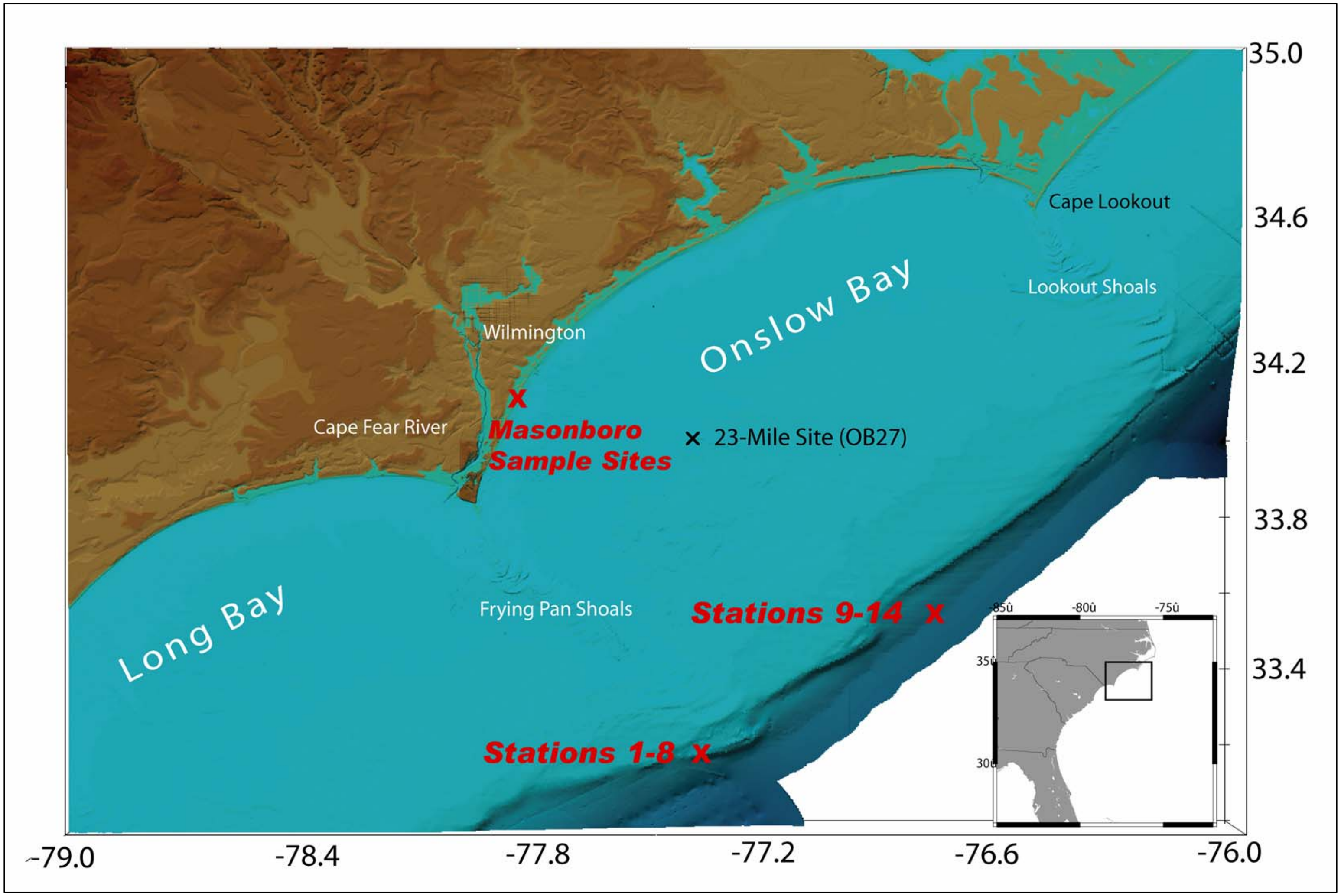
My hypothesis states that external morphological features of the diatom frustule may exert significant control on light collection and absorption, and therefore should vary between species in higher light level shallow coastal regions versus species from the lower light level outer-shelf regions. Species that live in the relatively deeper outer-shelf waters would be expected to collect, absorb, and use light more efficiently than species that live in shallower coastal areas. One possibility is that outer-shelf species may have frustal variations that enhance their ability to absorb light (i.e., complex ornamentation, and differing frustal size and shape compared to shallow water floras) Conversely, diatoms of the shallower back-barrier marsh zone would have frustal variations suited to high-light habitats (simple or no ornamentation, differing frustal size and shape compared to deepwater assemblages). Ornamental features on the valve such as spines, nodules, sterna, and ocelli, can increase the surface area of the frustule, allowing more area for light absorption, and may even aid in deflecting back toward the valve surface any photons that may inadvertently have been reflected away. Variation in size and shape of the frustule may also contribute to efficiency of light absorption. Apical and transapical axes may grow proportionally larger than the pervalvar axis (thickness) as a means of increasing their surface area and taking on a discoid shape, as irradiance decreases. In this way, benthic diatoms increase the amount of surface area on the valve face, and decrease their overall frustal thickness, thereby increasing their potential for light absorption and its penetration through the frustule. Likewise, as irradiance increases, the apical and transapical axis lengths may shrink proportionately smaller than the pervalvar axis, giving the frustule a more cylindrical shape (perhaps as safeguard against overexposure). On the other hand, the pervalvar axis may grow in proportion to apical and transapical axes as a means of increasing cell volume for housing larger chloroplasts. Therefore, some fluctuation in surface area and/or volume ratio is expected between diatoms that are light limited and those that are not. Finally, benthic species compositions should become less diverse with depth and be composed mainly of pennate forms. If the hypothesis is rejected, community differences and frustal morphologies of shallow and deepwater species will not be significantly different despite habitat depth. Because very little is known about diatom functional morphology, this study will answer basic questions of habitat preference of benthic diatom species and differences in taxonomic composition between the assemblages from the two habitats by making possible correlations to exterior features of the frustule.

METHODS

Sample Collection

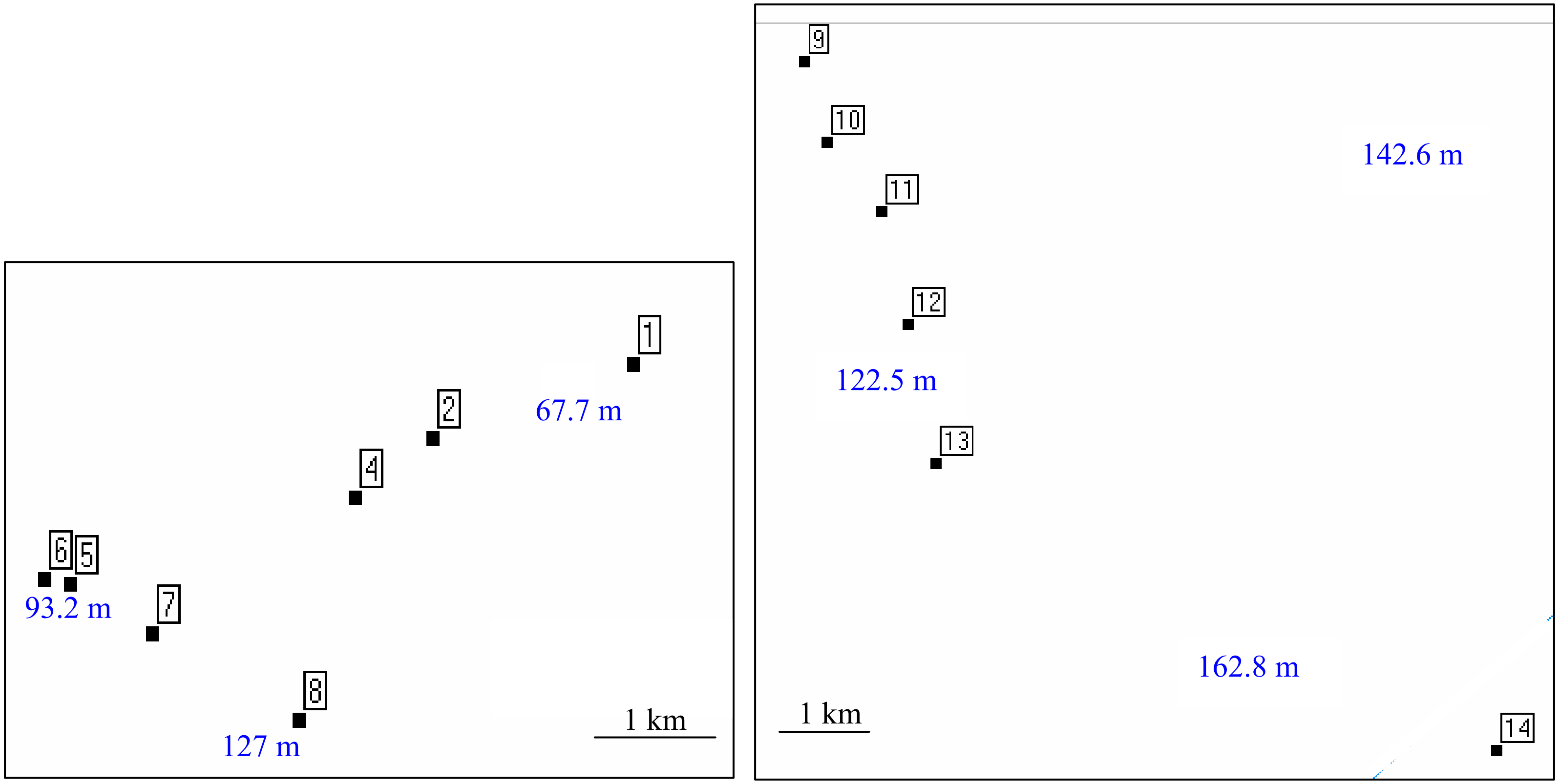
Bottom sediment samples were collected during a five-day cruise aboard the Duke University/University of North Carolina Oceanographic Consortium's research vessel R/V *Cape Hatteras* on October 13-18, 2003. Samples were taken from the soft bottom sediments of 14 stations on the continental shelf-break region of Onslow Bay. These stations were arbitrarily chosen to produce two transects of increasing depth (Figure 2, Appendix A). Transect 1, sampled on October 16, 2003, included Stations 1-8 and was situated on the lower shelf near the shelf break, with depths increasing from 67.2 m to 121.0 m. Transect 2, sampled on October 17, 2003, included Stations 9-14 and was situated on the upper slope, with depths increasing from 93.6 m to 191.1 m. Three sediment grabs per station were collected using a Tri-Scoop 1000 rotating sampler affixed to a Phantom S2 remotely operated vehicle (ROV) (Figure 3). CTD casts using a Seabird SBE 911*plus* affixed with a Paroscientific digiquartz pressure transducer and a Biospherical QSP-200L light sensor were also taken to measure fluxes in temperature and irradiance (photosynthetically active radiation, or PAR) with depth at a scan rate of 24 Hz (Figure 3). Sediment samples were analyzed immediately after collection using a light microscope to determine the presence or absence of live benthic diatoms, then bagged and refrigerated for further lab analysis on shore.

Depth measurements were taken using pressure transducers on the CTD and the ROV. Though the CTD depth accuracy was 0.008%, because CTD casts were halted 10 m from the bottom to prevent damage to the rosette, ROV depths were more representative of sample collection depth, despite their 0.25 % accuracy. In addition, the



a.

Figure 2 a) Onslow Bay and Masonboro sample collection locations
(Courtesy of Matthew Head, UNCW MS Marine Science, 2004).



b.

c.

Figure 2. b) Transect 1 (Station 3 located at same site as Station 4).
c) Transect 2.

a. b. c.

Figure 3. a) ROV Phantom S2.
b) Tri-Scoop 1000 sediment scoop (circled).
c) Seabird SBE 911*plus* CTD rosette.

pressure transducer on the ROV is located 1 foot (0.3048 m) above the bottom of the crash frame, requiring this addition of depth to that shown on the display when the ROV reached bottom. However, because the ROV made a full descent to the bottom, these factors became less important as the CTD depth would be compromised by the 10 m halting distance and ship movement via wave motion at the sea surface. Therefore, any references to total depth from surface to bottom will use depth recordings made by the ROV, while references to salinity, temperature, and light, will use depth recordings made by the CTD.

Irradiance/PAR was measured in units of $\mu E\ m^{-2}\ s^{-1}$. The percentage of surface incident irradiance transmitted to the bottom was calculated by dividing the mean bottom irradiance by the mean surface irradiance, and then multiplied by 100. Attenuation coefficients (kD), used as a proxy for water clarity, were calculated using the attenuation formula $I_D = I_O\, e^{-kD}$, where I_D equals irradiance at the bottom of the water column, and I_O equals irradiance at the surface. Mean irradiance values for the surface and bottom were used for this formula. Raw kD values were reported here; however, these values must be multiplied by 100 to obtain the percent attenuation per meter of water, with lower values indicating higher water clarity.

Sample Preparation

Immediately following collection, wet strewn slides of bulk sediment were made and examined on board the ship to determine the presence or absence of living diatoms. The remaining bulk sediment was refrigerated in the dark and transported to the on shore lab for immediate documentation of these live species, again using wet strewn slides. Individuals were photographed using a Nikon Coolpix 995 digital camera affixed to an Olympus BH2 microscope at 1250x magnification. Species were identified based on size, shape, and position of plastids within the cell using a variety of texts including Hustedt (1930, 1955), Hendey (1964), John (1983), and Round et al. (1990). A portion of each sample was processed using the following methods to produce cleaned material suitable for species identification by light and scanning electron microscopy: Five cc of each sample were placed in a 400 mL beaker filled with 50 mL deionized water. Ten mL of 30 percent hydrogen peroxide (H_2O_2) and 0.1 g potassium dichromate were added to remove any organics in the sample. After each sample was decanted and rinsed three times with deionized water, excess deionized water was decanted until 50 mL of the sample solution remained. Seven mL of 37% hydrochloric acid (HCl) was added to remove any carbonates present. Following the reaction, each sample was again rinsed and decanted three times, then diluted to 400 mL with deionized water. The final solution was thoroughly mixed, then halved for light microscope and scanning electron microscope sample preparation.

Cover slip preparation for light microscope (LM) slides followed the settling technique used by Laws (1983). Three 22-mm cover slips were made for each sample and were mounted on slides using a naphrax/toluene solution and were progressively heated until evaporation of the toluene was complete. Excess naphrax was pressed out from under the mounted slip to remove bubbles and later scraped off.

To prepare scanning electron microscope mounts, a portion of each sample was vacuum-filtered through two Whatman 0.4-µm millipore discs and one Whatman 5-µm millipore disc. After drying for 24 hours in a Thelco-130 drying oven at 75°F, the discs were cut into rectangular pieces and mounted on standard aluminum stubs. Three stubs were made using the 4-µm millipore cellulose nitrate membrane discs, and one stub was made using the 5-µm millipore cellulose nitrate membrane disc. This combination of discs was used to ensure good scanning electron microscope analysis. The 0.4 µm millipore disc was the preferred size as any small diatoms would not be filtered through. In the event excess fine material obstructed frustule visibility, 5-μm millipore discs served as a backup, eliminating the need to refilter the samples. Once mounted, the stubs were sputter-coated with platinum palladium using a Cressington 208 HR sputter coater and Cressington MTM 20 thickness controller to a thickness of 6 nm. Samples were then viewed using a Philips 1L XL-305 FEG scanning electron microscope.

Shallow-water samples were obtained by randomly selecting two archived intertidal marsh samples from stations on Masonboro Island, North Carolina. These samples were collected by a former graduate student, Heather Reesey, during the summer of 2000 as part of a Cooperative Institute for the Coastal and Estuarine Environmental Technology (CICEET) program (Figure 4). Station samples included bulk sediment, previously cleaned material, and previously prepared light microscope slides. Cleaned material was processed a second time using the procedure mentioned above to ensure removal of carbonate and organic matter.

Microscope Analysis

All microscope analysis of each sample took place using one light microscope slide and one scanning electron stub. The remaining slides and stubs served as reserves in the event a particular slide or stub was damaged, or a stub displayed poor image resolution due to charging by the electron microscope. Taxonomic identification was done with both LM and SEM analysis using a ribbon-transecting method. Light microscope slides were analyzed at 1250x using ribbon transects traversing the entire area of the cover-slip. Photographs were taken at the magnification necessary to identify individual diatoms and document their morphologic features. Twenty-one ribbon transects (seven at the top, middle, and bottom of the filter discs) on the SEM stubs were analyzed at 1250x. Again, photographs of individuals were taken at the

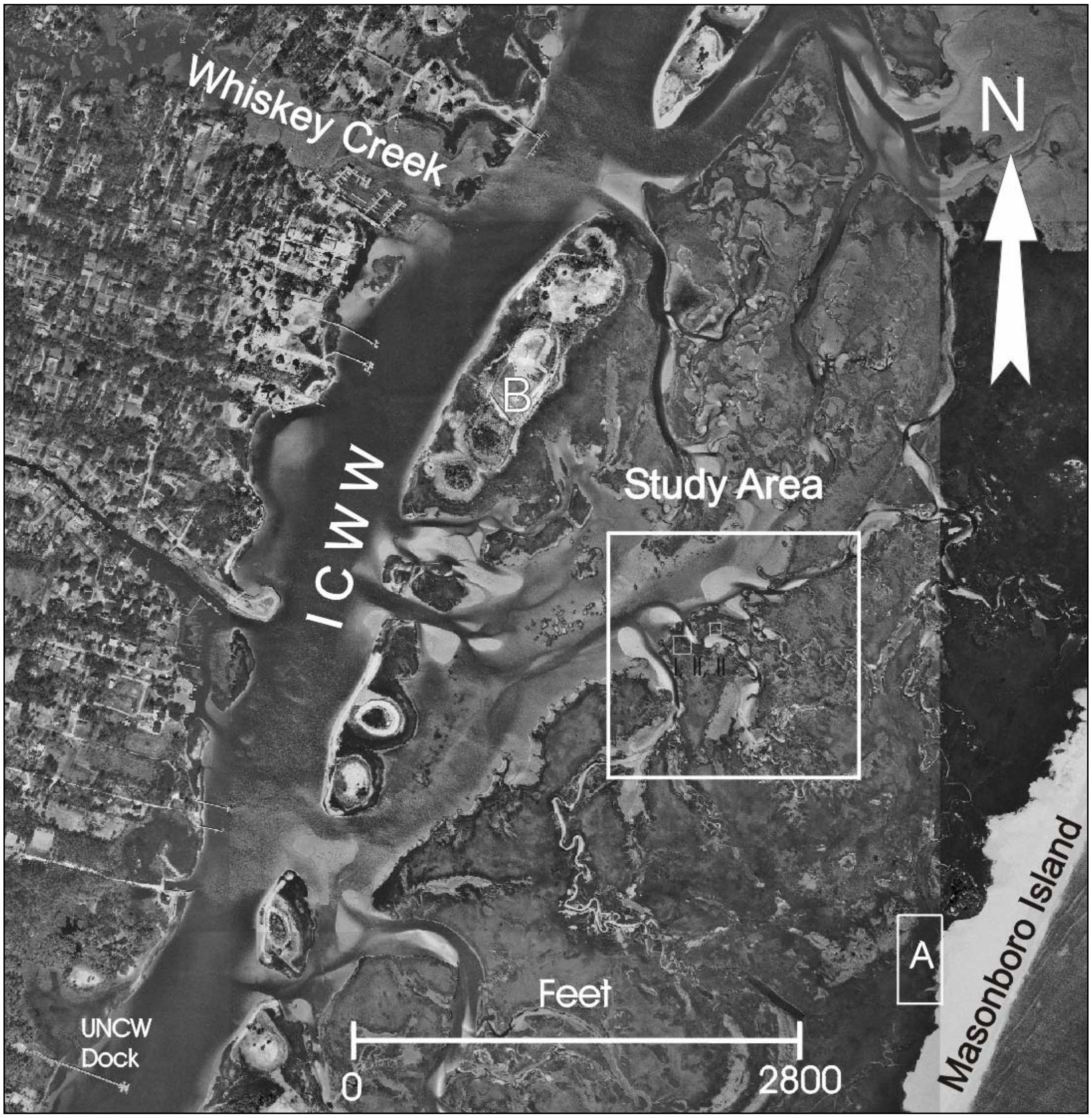


Figure 4. Masonboro Island, North Carolina sample locations *(courtesy of R. Laws)*.

magnification necessary for taxonomic identification and documentation of morphologic features.

In some cases, particularly for the genus *Navicula*, the chloroplasts of live diatoms viewed in the light microscope obstructed the view of frustal ornamentation, making it difficult to identify the diatom on the species level. In such instances, valves found in the SEM which bore the same overall size and shape, and any similarities in ornamentation that might have been visible in the LM specimen, were used.

Quantitative/Morphometric Analysis

Quantitative analysis took place by documenting, in cleaned material, the taxonomy and frustal morphology of the species previously documented as live in the wet slides at the shallowest and deepest of the 14 Onslow Bay stations, Stations 1 and 14. This ensured that only species known to be alive at these areas were included in the study, as dead frustules could have either settled from the photic zone or been carried in by currents from other areas. Omitting the analysis of stations 2-13 was necessary due to limitations in time. Marsh samples from Masonboro Island were analyzed using the same documentation methods; however, because all species present were considered native to the area (Hustedt 1955, Hilterman, 1998), differentiating between live and dead frustules was unnecessary. Using the light microscope, relative species abundances were established by counting 500 frustules of species previously documented as live from Station 1 in Onslow Bay, 59 species from Station 14, and 500 frustules each from both Masonboro Island stations. To delineate between unidentified species of both areas, Roman numerals were assigned following the genus name for Onslow Bay species, and capital letters were assigned following the genus name for Masonboro Island species (Appendix E-G, K, M). If a particular unidentified species was present in both locations, a lower-case letter was assigned.

Using the scanning electron microscope stubs, 200 valves from each of the two Masonboro Island sites, 200 valves of species previously documented as live from Stations 1, and 59 valves of species previously documented as live from Station 14 were measured and coded morphometrically using the following guide (Figure 5):

- Apical axis size
    - <10 μ
    - $10\ \mu m \leq n < 20\ \mu m$
    - $20\ \mu \leq n < 30\ \mu$
    - $30\ \mu \leq n < 40\ \mu$
    - > 40 μ
- Symmetry
    - Radial
        - Discoid shape
            - Intervalve distance less than valve diameter
        - Cylindrical shape
            - Intervalve distance greater than valve diameter
    - Bilateral
        - Raphe present
            - Monoraphid
            - Biraphid
        - Raphe absent (araphid)
        - Symmetry about axis
- Ornamentation
    - Hyaline – Index 1 (<5% of valve surface covered by ornamentation)
    - Hyaline to complex – Index 2 (>5% but <50% valve surface covered by ornamentation)
    - Complex – Index 3
        - Stria-dominant (>50% valve surface striate with areolae)
            - Unoccluded areolae-dominant
            - Occluded areolae-dominant
                - Cribera
                - Rotae
                - Volae
                - Hymenes
                - Other
        - Sterna-dominant (>50% valve surface covered with raised sterna)

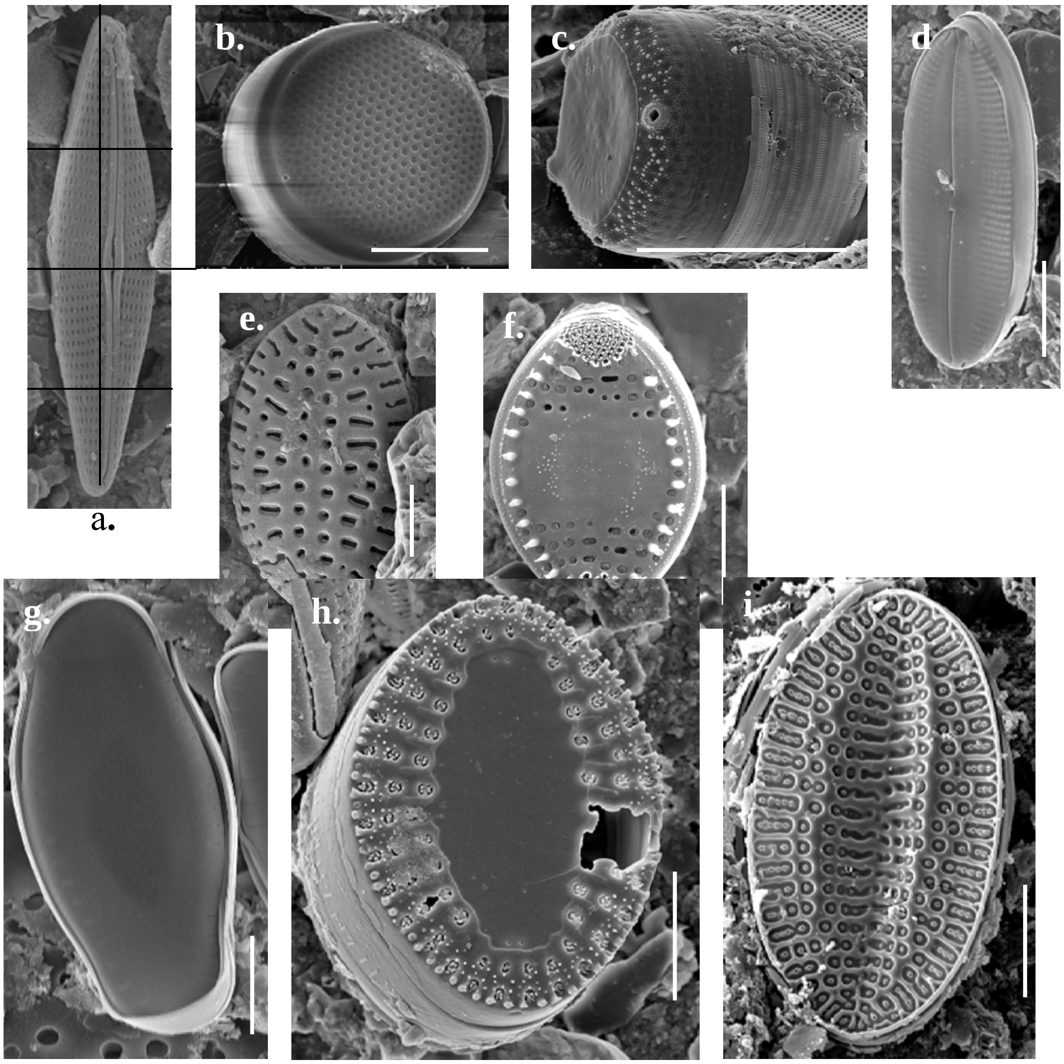


Figure 5.
a) Division of diatom frustule into sectors.
b) Radial discoid symmetry (scale = 10 μm).
c) Radial cylindrical symmetry (scale = 10 μm).
d) Bilateral symmetry, biraphid (scale = 5 μm).
e) Bilateral symmetry, monoraphid (scale = 2 μm).
f) Bilateral symmetry, araphid (scale = 5 μm).
g) Hyaline ornamentation, Index 1 (scale = 2 μm).
h) Hyaline to complex ornamentation, Index 2 (scale = 2 μm).
i) Complex ornamentation, Index 3 (scale = 5 μm).

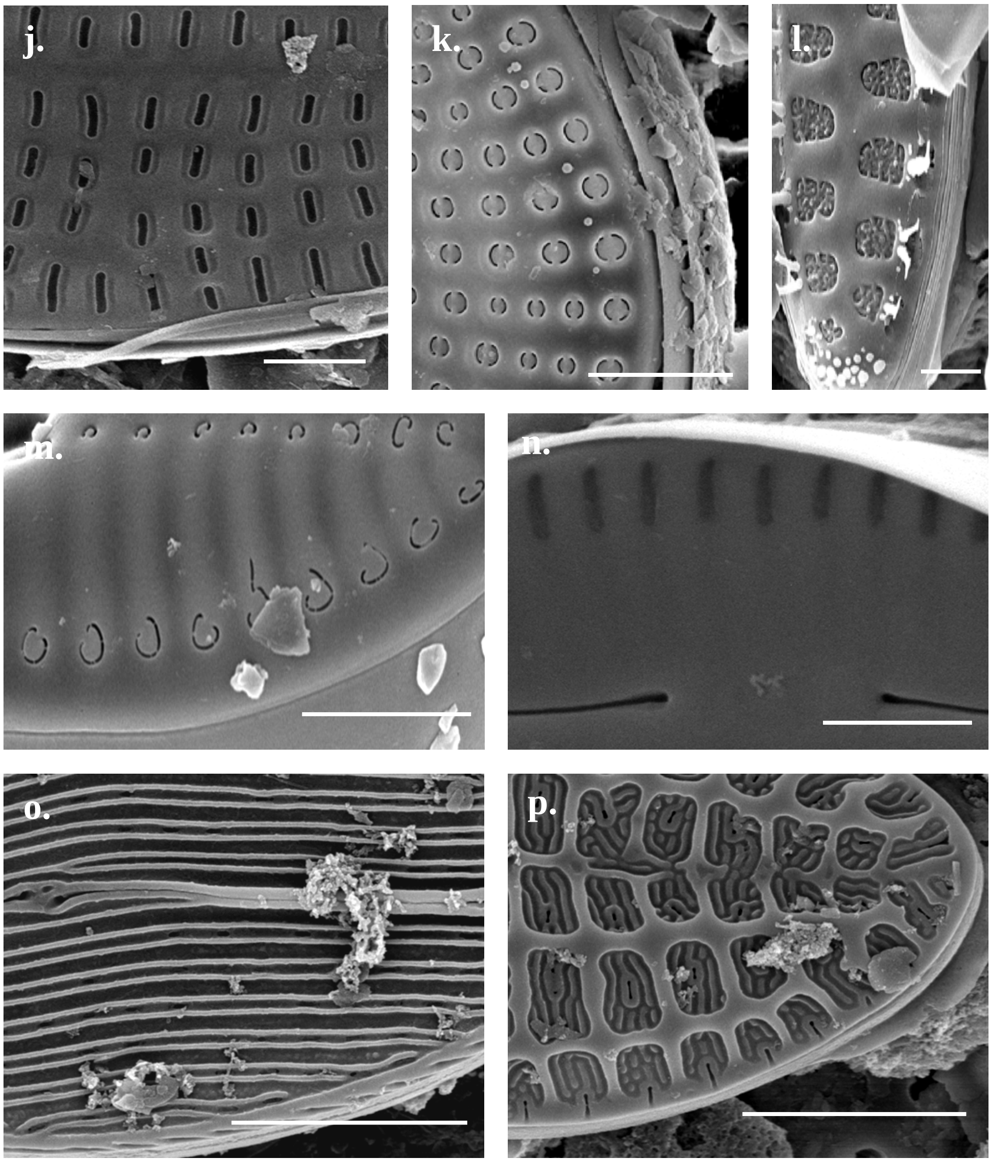


Figure 5.
j) Striae-dominant, unoccluded areolae (scale = 1 μm).
k) Striae-dominant, occluded areolae, rotae (scale = 2 μm).
l) Striae-dominant, occluded areolae, cribera (scale = 1 μm).
m) Striae-dominant, occluded areolae, volae (scale = 2 μm).
n) Striae-dominant, occluded areolae, hymenes (scale = 2 μm).
o) Sterna-dominant (scale = 2 μm).
p) Multiple ornamentation (scale = 2 μm).

- Multiple ornamentation types (>50% of surface ornamented by a combination of aforementioned types)

Inequality of valves sampled between the deepwater and shallow water localities were due to the paucity of valves present in the sediments collected from Station 14, despite the higher volume of sediment examined. Even after a full scan of 8 SEM stubs (4 to 8 times more than was required for the other three samples), only 59 valves of species previously documented as live from that station were found. Complete valves and fragments of valves were present in this sample, but were also very scarce. Due to the 57.6 m difference in depth between Station 13 and Station 14, valves from Station 13 could not be used to supplement the Station 14 sample size. However, because the variety of habitats in the shallow water region is larger than the deepwater, and a more diverse assemblage has been previously documented there by Hustedt (1955) and Hilterman (1999), the diversity of taxa should be higher shallow water, thus alleviating any biases introduced by differences in sample size.

Apical axes were measured from the valve margins, not including the thickness of the girdle band. Ornamentation was assessed by printing scanning electron images of the individuals, dividing the valve surface into a grid of eight sectors (for better qualitative estimation of percent valve cover), and visually classifying it into an ornamentation type based on the percentage of the valve surface covered by ornamentation. Because only three ornamentation classes were used in this study and valve ornamentation was rarely irregular in distribution on the valve itself, qualitatively assessing the percent valve cover by ornamentation in this way was sufficient. An ornamentation index was established for quantification purposes with an index of 1 applying to valves of the hyaline category, an index of 2 applying to valves of the hyaline to complex category, and an index of 3 applying to valves of the complex category. Ornamentation terminology was used in accordance with Round, et al. (1990). Whenever possible for the genus *Cocconeis*, quantification was done on the external side of dorsal valves, except in individuals in which the dorsal and ventral sides bore the same ornamentation. This method would ensure that the majority of valves measured were those valves most responsible for light collection. With the exception of a few genera, namely *Amphora* and *Nitschia*, which seem to have preferential settling orientations on both slides and vacuum filters, most individuals could be measured in this way. Finally, surface area to volume ratios of individuals were calculated from those live species at Stations 1 and 14 that were also present at the shallow-water Stations DET I-B and ND IV-D. This was done by calculating the ratio of the surface area of the valve face to the total volume based on 20 individuals of each species from both the deepwater and shallow-water localities, collectively. Though these calculations assume a rectilinear shape, any biases will be continuous and proportional throughout the sample set. The results of these quantitative analyses were then correlated with the physical conditions of their respective areas recorded from CTD casts. CTD data logs for each station were imported into Microsoft Excel and SigmaPlot 9, with graphs made to better illustrate the fluxes in temperature and irradiance with depth for the duration of the cast's descent. Basic conclusions regarding relation of species composition and frustal morphology to their respective environmental conditions were then made.

Following the individual station analyses from the deepwater and shallow water sites, comparisons were made between their respective stations to ascertain any differences in diatom species assemblage and morphometrics related to differences between their respective environments. Apical axis length, transapical axis length, ornamentation indices, and surface area to volume ratios from the collective morphometric analyses from each area were analyzed for variance using a one-way ANOVA to determine if differences in these parameters were significant between shallow water and deepwater regimes. ANOVA was used due to the non-normal distribution of most of the morphometric data, even after log transformation. Differences between deepwater and shallow water datasets using ANOVA were accepted as significant when p-values were less than 0.05. Datasets returning p-values greater than 0.05 were considered non-significant, and were rejected.

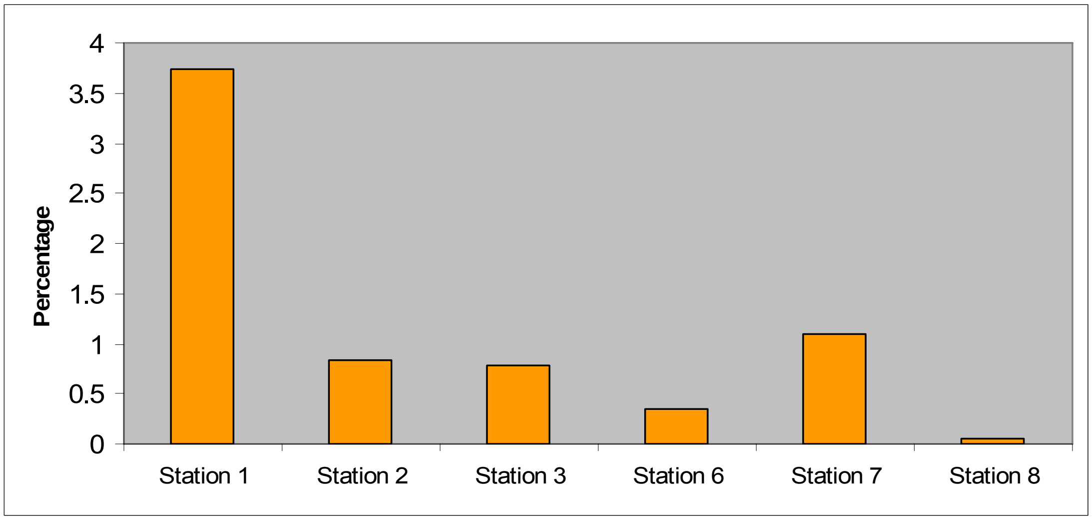
Because any statistical analyses of the deepwater versus shallow water regions required that sample sizes between the two be equal, it was necessary to reduce the overall sample size of the shallow water valves from 400 to 259. To do this, data from 71 from Station DET I-B, and 70 valves from Station ND IV-D were randomly eliminated. This was done using a random number generator in SigmaPlot calibrated to select 71 and 70 non-repeating numbers ranging from 1 to 200. Since each valve measured was numbered consecutively, the random numbers generated by SigmaPlot were used as an extraction list. This caused slight fluctuations in mean apical and transapical axis lengths, and in the percent fractions of valves belonging to each morphometric category. These fluctuations were never more than 2%, however, and therefore deemed fit for further analyses.

RESULTS

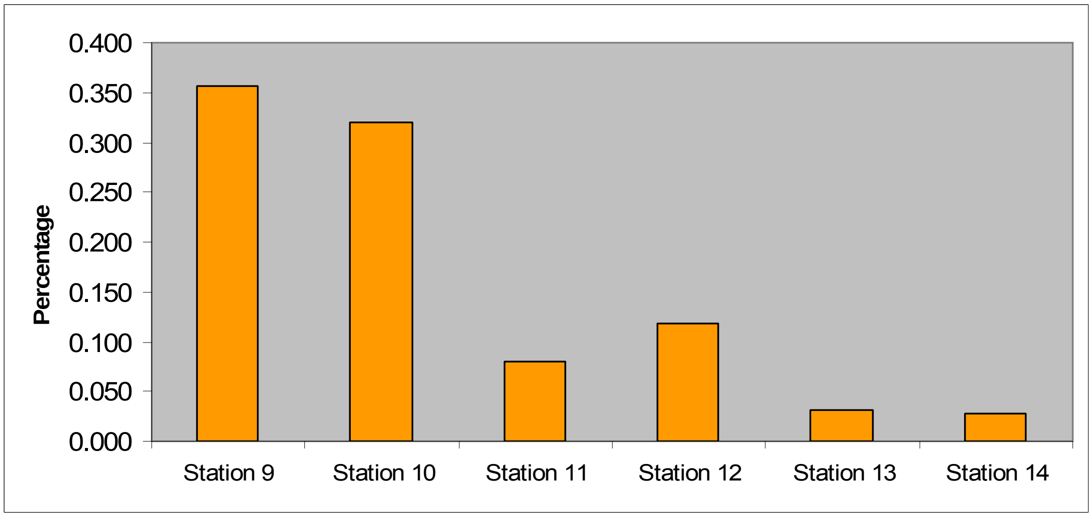
Deepwater Locality: Onslow Bay

The 14 stations sampled in Onslow Bay were located within 60 nautical miles southeast and east southeast of the mouth of the Cape Fear River, and ranged in water depths from 67.2 m to 191.1 m (Figure 2, Appendix A). At shallower stations, ROV footage showed exposed marine hard bottom outcrops, part of the Tertiary sequences of the Onslow Embayment on the Carolina Platform (Riggs and Belknap, 1988). Bottom sediments began as poorly sorted, subangular course sands, and grew finer with depth to very well sorted, rounded very fine to fine sands. Irradiance/PAR values decreased exponentially with depth at all stations except Station 1, for which the decrease appeared more linear (Appendix B-D). This trend was likely the result of ship movement combined with surface layering due to the thermocline. Station 7 featured a sharp decrease in irradiance between 5 and 10 m depth, followed by an equally sharp increase to values greater than the values at the surface (Appendix C). This rebound in irradiance was followed by the expected exponential decrease in irradiance values with depth, indicating a period of time in which the CTD rosette likely passed under the ship's shadow. Percent surface incident irradiation/PAR at the bottom decreased with station depth; however, attenuation coefficients fluctuated between 0.0443 (4.43% per meter) and 0.0842 (8.42% per meter), with water clarity being higher when coefficients are low (Figure 6-7, Appendix B). Surface water temperatures fluctuated very little while bottom water temperatures decreased with deeper station depths (Figure 8, Appendix B-D).

One hundred twenty-six species of diatoms were found in sediments collected in the deepwater stations (Appendix E). Of these, 122 species in 29 genera were identified at least to the genus level, with four valves unidentified at the genus level. Frustal orientation, poor

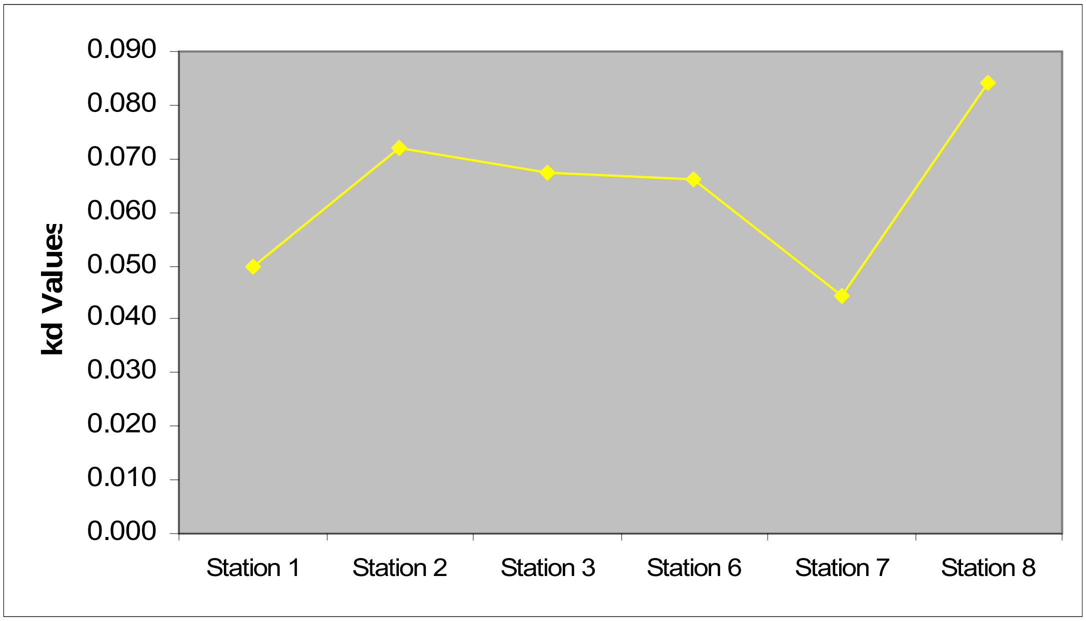


a.

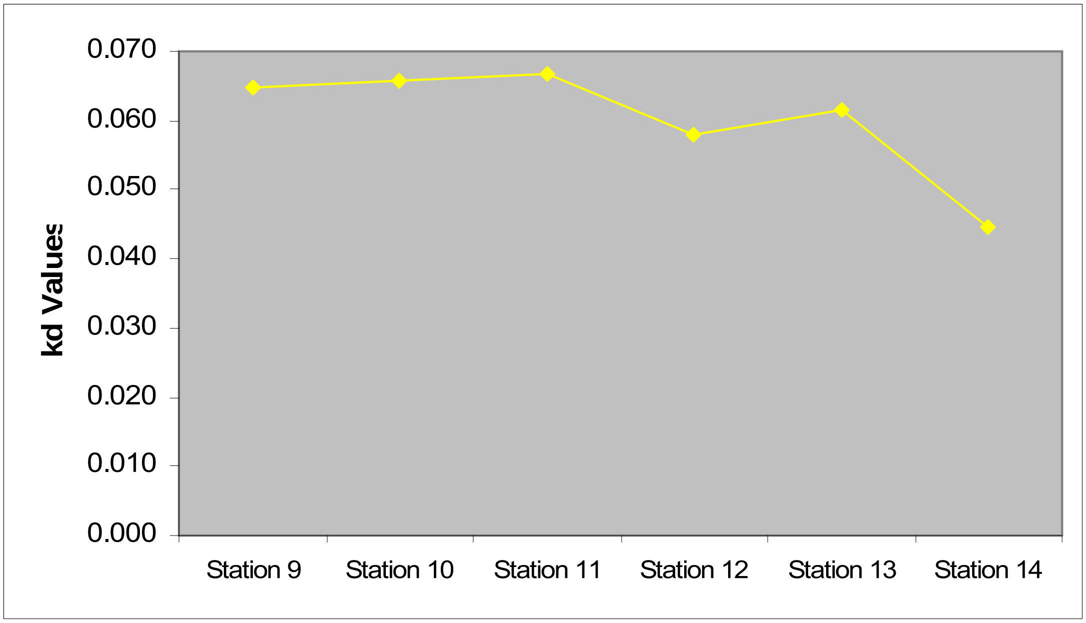


b.

Figure 6. a) Transect 1 percent surface incident irradiation at the bottom of the water column.
b) Transect 2 percent surface incident irradiation at the bottom of the water column.

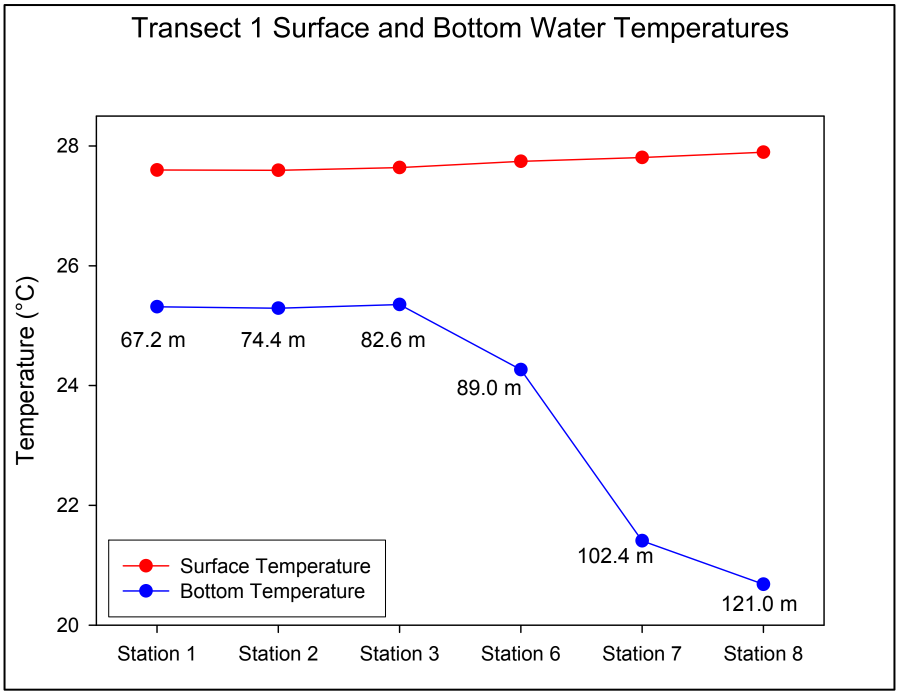


a.

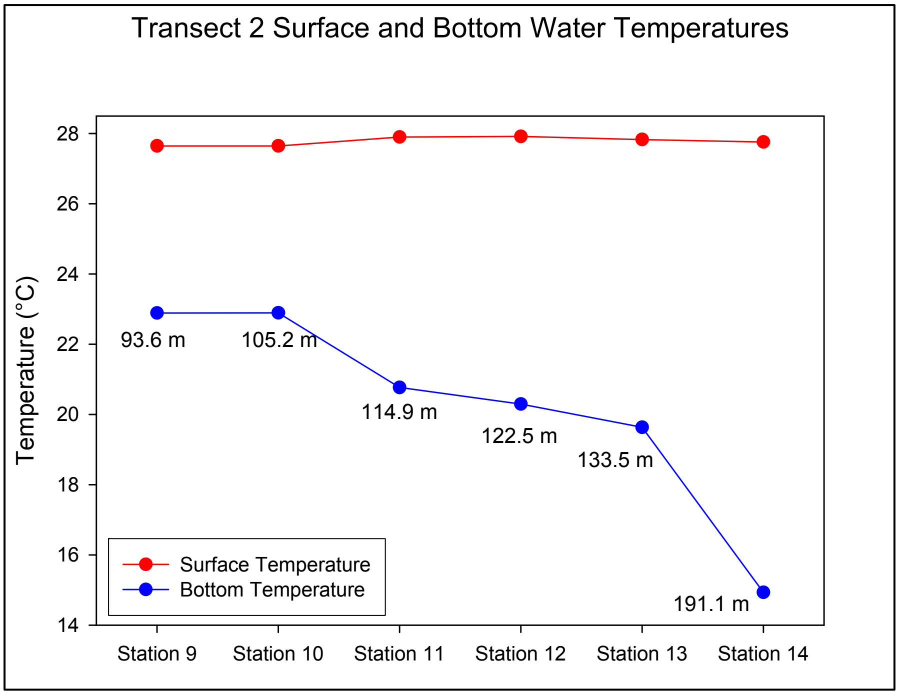


b.

Figure 7. a) Transect 1 attenuation coefficients (% attenuation per meter).
b) Transect 2 attenuation coefficients (% attenuation per meter).



a.



b.

Figure 8. a) Transect 1 surface and bottom temperatures, with bottom depths.
b) Transect 2 surface and bottom temperatures, with bottom depths.

preservation quality, and/or low species abundance contributed to the inability to identify some valves on the genus, and/or species level. Qualitative observations based on LM and SEM analysis estimated *Cocconeis* as the dominant genus for all 14 stations, closely followed by *Navicula*, *Amphora*, *Diploneis*, *Nitschia*, and *Achnanthes*, based on relative abundances of these genera in bulk samples, strewn slides, and SEM stubs.

Transect 1

Stations 1-8 were sampled on October 16, 2003 and are located 51.7 nautical miles southeast of the Cape Fear River at the shelf-break region known as The Steeples, situated on the Cape Fear Terrace (Figure 2). These stations made up a 2.12 nautical mile transect with depths ranging from 67.2 m at Station 1 to 121.0 m at Station 8 (Appendix A). Due to technical issues, CTD casts were not made for Stations 4 and 5; however, two ROV dives took place at Station 3, with the second dive being labeled as Station 4. Percent surface incident irradiation/PAR at the bottom of the water column decreased from 3.740% at Station 1 to 0.0480% at Station 8 (Figure 6, Appendix B). Attenuation coefficients averaged 0.0640 (6.4% per meter) for all eight stations with the lowest value at Station 7 and the highest at Station 8 (Figure 7, Appendix B). Surface water temperatures increased slightly from 27.6 °C at Station 1 to 27.9 °C at Station 8 (Figure 8, Appendix B). Bottom water temperatures decreased from 25.31 °C at Station 1 to 20.68 °C at Station 8.

Microscopy of Transect 1 sediments yielded 123 species (Appendix E). Four species could not be identified to the genus level; however, the remaining 119 species represented 27 genera. At Station 1, fifty-five species of diatoms from 19 genera were recorded with one species unidentified to the genus level (Appendix F). Of these species, 9 species of the genera

Amphora, *Cocconeis*, *Navicula*, and *Nitschia* were found live in the sediments. Taxonomic analysis on 500 valves of these living species showed that *Cocconeis* and *Nitschia* displayed the most species diversity with three species each (Table 1, Appendix G). However, the species *Cocconeis disculus* was by far the most common diatom found, with 359, or 72% of the total number of valves. Morphometric analyses on 200 valves yielded a mean apical axis size of 14.31 μm and mean transapical axis size of 6.91 μm, with 110 valves, or 50%, falling in the 10 μm ≤ n < 20 μm category (Table 1, Appendix H). All valves were pennate in form (thus bilaterally symmetric) and since *Cocconeis* was the dominant genus, the most common valve type was monoraphid, which accounted for 177 valves, or 89%. The mean ornamentation index was 2.43, with 114 valves, or 57%, having hyaline to complex ornamentation. No valves had hyaline ornamentation. Unoccluded areolae was the dominant ornamentation type, with 133 valves, or 67%, though multiple ornamentation was also relatively common, with 42 valves, or 21%.

Transect 2

The upper-slope region of Onslow Bay was sampled on October 17, 2003, and lies approximately 37 nautical miles northeast of the Station 8 on the shelf break (60 nautical miles from the mouth of the Cape Fear River). Stations 9-10 made up the 5.26 nautical mile transect with depths ranging from 93.6 m at Station 9 to 191.1 m at Station 14 (Figure 2). Percent surface incident PAR at the bottom of the water column decreased from 0.356% at Station 9 to 0.028% at Station 14 (Figure 6, Appendix B). Mean attenuation coefficient values measured 0.0602 (6.02% per meter) and decreased with depth (Figure 7, Appendix B). Surface water temperatures increased between Stations 9 and 14, from 27.65 °C to

Table 1. Station 1 taxonomic composition and morphometrics.

Species Counts	No. Valves
Amphora coffeaformis	24
Cocconeis disculus	359
Cocconeis distans	27
Cocconeis placentula	9
Navicula sp. a	15
Navicula digitoconvergens	17
Nitschia frustulum	6
Nitschia pellucida	7
Nitschia panduriformis	36

Apical Axis Size	No. Valves
<10 μm	59
10 μm ≤ n < 20 μm	110
20 μm ≤ n < 30 μm	16
30μm ≤ n < 40 μm	13
>41 μm	2

Form Diversity	No. Valves
Pennate	200
Centric	0

Valve Type	No. Valves
Araphid	0
Monoraphid	177
Biraphid	23

Symmetry Type	No. Valves
Radial Discoid	0
Radial Cylindrical	0
Radial Total	0
Bilateral	200

Ornamentation Index	No. Valves
Hyaline - Index 1	0
Hyaline to complex - Index 2	114
Complex - Index 3	86

Dominant Ornamentation Type	No. Valves
Unoccluded areolae	133
Hymenate	7
Multiple	42
Volae	17
None	1

27.8 °C (Figure 8, Appendix B). Bottom water temperatures decreased between Station 9 and 14, from 22.9 °C to 14.9 °C.

Microscopy of sediments from Transect 2 excluded Stations 11-13 due to time restrictions and the paucity of valves present; however, because Station 14 was the deepest location sampled, it was included. Stations 9-10 and 14 therefore yielded 29 species of diatoms from 13 genera (Appendix E). Nine live species of diatoms from 6 genera were recorded from sediments at Station 14. Of these, four species from the genera *Actinoptychus*, *Amphora*, *Cocconeis*, and *Nitschia* were found live in the sediments (Table 2, Appendix I). A complete taxonomic and morphometric analysis could not be done for this station, once again, due to the paucity of valves present in the sediments. Though sands and silts could be separated from the bulk sample collected from this station, a high concentration of clays, particularly montmorillonite, remained. Due to similarities in size, shape, and density of montmorillonite and the majority of diatom frustules present, the processing and settling techniques used in this study were ineffective in concentrating the number of frustules required for the taxonomic and morphometric analyses. Despite attempting several variations of these techniques, only 59 total frustules were found (Table 2, Appendix J). Taxonomic analyses on this smaller subset yielded one species for each of the four genera, with *Cocconeis disculus* being the most numerous with 36 frustules, or 61% of the total.

Morphometric analyses showed that 45 frustules, or 76%, had apical axes less than 20 μm, with nearly equal numbers of frustules fitting into both the <10 μm and the 10 μm $\leq n <$ 20 μm categories. The mean apical axis length was 16.87 μm and mean transapical axis length was 8.96 μm. Fifty-seven frustules, or 97% were bilaterally symmetric, and 36 individuals, or 61%,

Table 2. Station 14 taxonomic composition and morphometrics.

Species Counts	No. Valves
Actinoptychus splendens	2
Cocconeis disculus	36
Diploneis chersonensis	3
Nitschia panduriformis	18

Apical Axis Size	No. Valves
<10 µm	24
10 µm ≤ n < 20 µm	21
20 µm ≤ n < 30 µm	7
30µm ≤ n < 40 µm	3
>40 µm	4

Symmetry Type	No. Valves
Radial Discoid	2
Radial Cylindrical	0
Radial Total	2
Bilateral	57

Dominant Ornamentation Type	No. Valves
Unoccluded areolae	50
Volae	9

Form Diversity	No. Valves
Pennate	57
Centric	2

Valve Type	No. Valves
Araphid	2
Monoraphid	36
Biraphid	21

Ornamentation Index	No. Valves
Hyaline - Index 1	0
Hyaline to complex - Index 2	36
Complex - Index 3	23

were monoraphid (accounting for the higher volume of *Cocconeis disculus* in the sample). Biraphid frustules were also relatively common, due to the frequency of *Nitschia panduriformis*. Unoccluded areolae was the most common dominant ornamentation type, with 50 individuals, or 85%. The ornamentation index averaged 2.43, with hyaline to complex ornamentation (Index 2) accounting for 36 frustules, or 61%; however, complex ornamentation (Index 3) was also relatively common, with 23 frustules, or 39%.

Surface area to volume ratios were performed on valves of the species previously documented as live, *Cocconeis disculus*, *Fallacia forcipata*, *Navicula* sp. a, *Nitschia frustulum*, and *Nitschia panduriformis*, which were also present in the shallow water sediments (Table 3, Appendix O). The lowest ratios belonged to *Navicula panduriformis*, averaging 0.216, while *Cocconeis disculus* had the highest mean ratio with 0.592.

Shallow water Locality: Masonboro Island

Masonboro Island is an undeveloped 13.3 km long barrier island south of Wrightsville Beach, North Carolina. The island width ranges from 60 m to 1.6 km with a narrow beach on the ocean side and dune ridges extending into a large back-barrier *Spartina alterniflora* marsh on the sound side. The island is a semi-diurnal microtidal system with a mean amplitude of 1.15 m (Panasik, 2003). Marsh deterioration has been problematic on Masonboro Island, resulting in net sediment loss from erosion. Renourishment of both deteriorated and non-deteriorated areas of the island has taken place to mitigate this issue and has consequently changed the sediment composition for these areas. Fractionation estimates prior to renourishment were 50% fine silts and 50% fine grained sands for both deteriorated and non-deteriorated sites (Panasik, 2003).

Table 3. Deepwater mean surface area to volume ratios by species.

Species	Mean S/V Ratio
Cocconeis disculus	0.592
Fallacia forcipata	0.225
Navicula sp. a	0.446
Nitschia frustulum	0.523
Nitschia panduriformis	0.216

Mean grain size rose from 0.10-0.11 mm before renourishment to 0.244-0.321 mm after, with the mean grain size of the dredge spoil fill being 0.56 mm (Panasik, 2003; Croft, 2003).

Samples from Masonboro Island were taken from intertidal sediments in both deteriorated and non-deteriorated sites that were previously renourished by dredge spoils (Figure 4). Non-deteriorated sediment samples were given the prefix "ND" in their station number, while deteriorated sediment samples were given the prefix "DET".

Station DET I-B

Of the 500 valves counted, 107 species of 25 genera were found, with 7 species unidentified to the genus level (Table 4, Appendix K). The genera *Navicula, Nitschia*, and *Amphora* exhibited the highest species diversity with 26, 19, and 13 each, respectively, and accounted for the most number of valves with 138, 62, and 66 each, respectively.

Of the 200 valves quantified using morphometric analyses, 181 (91%) were pennate in form, and 19 (9%) were centric in form (Table 4, Appendix L). Most valves had bilateral symmetry, accounting for 181 valves (91%). Nineteen valves were radially symmetric with 15 valves being radial cylindrical (80%, or 7.5% of the total) and 4 valves being radial discoid (20%, or 2% of the total). Biraphid diatoms made up the majority of valve types with 132 valves (66%). Araphid and monoraphid types included 60 valves (30%) and 8 valves (4%), respectively. Apical axis measurements averaged 25.79 µm, while transapical axis measurements averaged 7.87 µm, with most valves being under 20 µm. Complex ornamentation (Index 3) and hyaline to complex ornamentation (Index 2) dominated the valve ornamentation types with 101 valves (50.5%) and 98 valves (49%), respectively. Unoccluded areolae and multiple ornamentation types were the most common among dominant ornamentation with 98

Table 4. Station DET I-B taxonomic composition and morphometrics.

Individuals Per Genus	No. Valves
Achnanthes	17
Amphora	66
Bacillaria	5
Biddulphia	3
Campylosira	1
Cerataulus	1
Cocconeis	32
Cyclotella	2
Delphenies	27
Dimeregramma	21
Diploneis	8
Entomoneis	4
Eunotogramma	2
Fallacia	15
Fragilaria	16
Gyrosigma	9
Melosira	8
Navicula	138
Nitschia	62
Odontella	2
Opephora	28
Paralia	6
Plagiogramma	1
Rhopalodia	2
Thalassiosira	15
Unknown	9

Apical Axis Size	No. Valves
<10 µm	46
10 µm ≤ n < 20 µm	76
20 µm ≤ n < 30 µm	37
30µm ≤ n < 40 µm	16
>40 µm	25

Symmetry Type	No. Valves
Radial Discoid	4
Radial Cylindrical	15
Radial Total	*19*
Bilateral	181

Form Diversity	No. Valves
Pennate	181
Centric	19

Valve Type	No. Valves
Araphid	60
Monoraphid	8
Biraphid	132

Dominant Ornamentation Type	No. Valves
Unoccluded areolae	98
Hymenate	26
Rotae	15
Cribera	7
Multiple	52
None	2

Ornamentation Index	No. Valves
Hyaline - Index 1	1
Hyaline to complex - Index 2	98
Complex - Index 3	101

valves (49%) and 52 valves (26%), respectively. The ornamentation index for this station averaged 2.5.

Station ND IV-D

Ninety species of 26 genera of diatoms comprised the total 500 valves counted (Table 5, Appendix M). *Navicula* and *Nitschia* accounted for the most number of individuals per species, with 143 individuals (29%) and 79 individuals (16%), respectively, and were the most diverse in terms of species per genera, with 25 species and 14 species, respectively. Various species of *Amphora*, *Cocconeis*, and *Melosira*, were also relatively common with between 30 and 37 individuals each, though *Amphora* and *Cocconeis* were more diverse in terms of species per genus.

Of the 200 valves sampled for morphometric analyses, 164 valves (82%) were pennate in form and bilaterally symmetric, and 36 (18%) were centric. Most centric forms were radial-cylindrical in symmetry, accounting for 35 valves (97%, or 18% of the total). One hundred thirty-two valves were biraphid (66%), 57 valves were araphid (29%), and 11 valves were monoraphid (5%). The mean apical and transapical axis sizes were 22.81μm and 7.36 μm, respectively. Over half the valves sampled had apical axes less than 21 μm, accounting for 132 total valves (66%), though the dominant apical axis size range was between 10 μm and 20 μm, with 83 valves (42%). Like Station DET I-B, unoccluded areolae was the most common dominant ornamentation type with 116 valves (58%) though the multiple ornamentation type was also common, accounting for 53 valves (26.5%). All valves were either hyaline to complex (Index 2) or complex (Index 3) in ornamentation, with 105 (52.5%) and 95 (47.5%) respectively. The ornamentation index for this station averaged 2.48.

Table 5. Station ND IV-D taxonomic composition and morphometrics.

Individuals Per Genus	No. Valves
Achnanthes	3
Actinoptychus	2
Amphora	30
Bacillaria	4
Campylosira	1
Cocconeis	34
Coscinodiscus	2
Cyclotella	12
Cymatosira	2
Delphenies	23
Dimeregramma	14
Diploneis	8
Entomoneis	2
Eunotogramma	7
Fallacia	12
Gyrosigma	11
Melosira	37
Navicula	143
Nitschia	79
Odontella	1
Opephora	25
Paralia	18
Plagiogramma	2
Pleurosigma	2
Rhopalodia	1
Thalassiosira	25

Apical Axis Size	No. Valves
<10 µm	49
10 µm ≤ n < 20 µm	83
20 µm ≤ n < 30 µm	30
30µm ≤ n < 40 µm	13
>40 µm	25

Symmetry Type	No. Valves
Radial Discoid	1
Radial Cylindrical	35
Radial Total	*36*
Bilateral	164

Form Diversity	No. Valves
Pennate	164
Centric	36

Valve Type	No. Valves
Araphid	57
Monoraphid	11
Biraphid	132

Dominant Ornamentation Type	No. Valves
Unoccluded areolae	116
Hymenate	12
Rotae	15
Cribera	3
Multiple	53
Volae	1
None	0

Ornamentation Index	No. Valves
Hyaline - Index 1	0
Hyaline to complex - Index 2	105
Complex - Index 3	95

Mean surface area to volume ratios showed that *Nitschia frustulum* had the highest mean ratio at 0.648, while *Fallacia forcipata* had the lowest mean ratio at 0.237 (Table 6, Appendix O).

Deepwater/Shallow water Comparison

Though more valves of benthic diatoms were measured in the shallow water stations than the deepwater stations, two important factors must be noted. First, the volume of deepwater sediment examined greatly exceeds the volume of inshore sediment examined due to the greater number of deepwater stations. Were equal volumes of sediment examined for both regions, it would be expected that the number of taxa and individuals would be higher in the shallow water regions. Second, frustules of species found alive in the deepwater samples were used in the morphometric analyses, and were both less abundant and less diverse in the deepwater region compared to the shallow water region based on microscopy of wet mount slides from deepwater. Though diatoms present in the Masonboro Island samples were dead at the time of this study, it is presumed the taxonomic composition of those samples represents a subset of the live assemblage in that area based on a comparison with previous studies and the wider variety of habitats and substrates on which these species can live (sands, muds, rocks, plants, etc.) versus the deepwater (Hustedt, 1955; Hilterman, 1999). In the end, despite differences in sample sizes, fluctuations less than 2% occurred in the percentages of valves in each morphometric category when 141 valve measurements were extracted from the total sample size of 400 (Table 7).

The mean apical axis length for deepwater valves measured 14.89 µm, while the same for shallow water valves was 51% larger, at 22.54 µm (Table 8). P-values returned in the one-way ANOVA for this parameter equaled 8.6×10^{-6}, indicating a significant increase in apical axes

Table 6. Shallow water mean surface area to volume ratios by species.

Species	Mean S/V Ratio
Cocconeis disculus	0.578
Fallacia forcipata	0.237
Navicula sp. a	0.411
Nitschia frustulum	0.648
Nitschia panduriformis	0.454

Table 7. Morphometric analysis of 400 shallow water valves versus morphometric analysis of a subset of 259 randomly selected valves from the same sample.

	(n = 400)	(n = 259)
Mean Apical Axis Length	23.80 μ	22.54 μ
Mean Transapical Axis Length	7.61	7.43 μ
Mean Ornamentation Index	2.49	2.48

Morphology	Percentage	Percentage
Pennate	86.25%	87%
Centric	13.75%	13%
Bilateral	86.25%	87%
Radial discoid	1.25%	1%
Radial cylindrical	12.50%	12%
Biraphid	66%	65.25%
Monoraphid	4.75%	5.5%
Araphid	29.25%	29.25%
Index 1	0.25%	0%
Index 2	50.75%	52.75%
Index 3	49%	47.25%
Unoccluded areolae	53.50%	54%
Hymenate	9.50%	9.25%
Volae	0.25%	0.375%
Cribera	2.50%	2.75%
Rotae	7.50%	7%
Multiple	26.25%	26.25%
None	0.50%	0.375%

Table 8. Deepwater/shallow water morphometric comparison using same sample sizes (n = 259).

	Deepwater Valves	Shallow water Valves
Mean Apical Axis Length	14.89 µm	22.54 µm
Mean Transapical Axis Length	7.37 µm	7.43 µm
Mean Ornamentation Index	2.42	2.44

	Deepwater (n = 259)		*Shallow water (n = 259)*	
Morphological Parameter	Number of Valves	Percentage	Number of Valves	Percentage
Pennate	257	99%	225	87%
Centric	2	1%	34	13%
Bilateral	257	99%	225	87%
Radial discoid	0	0%	3	1%
Radial cylindrical	2	1%	31	12%
Biraphid	44	17%	169	65.25%
Monoraphid	213	82%	14	5.5%
Araphid	2	0.75%	76	29.25%
Index 1	0	0%	0	0%
Index 2	150	58%	134	52.75%
Index 3	109	42%	125	47.25%
Unoccluded areolae	183	70.75%	140	54%
Hymenate	7	2.75%	24	9.25%
Volae	26	10%	1	0.375%
Cribera	0	0%	7	2.75%
Rotae	0	0%	18	7%
Multiple	42	16%	68	26.25%
None	1	0.50%	1	0.375%

Species	Deepwater S/V Ratio	Shallow water S/V Ratio
Cocconeis disculus	0.592	0.578
Fallacia forcipata	0.225	0.237
Navicula sp. a	0.446	0.411
Nitschia frustulum	0.523	0.648
Nitschia panduriformis	0.216	0.454

lengths in shallow water valves (Table 9). Mean transapical axis length for deepwater valves was 7.37 μm, non-significantly smaller than shallow water valves which averaged 7.43 μm. The mean ornamentation index also varied very little and was considered non-significant between the two localities. The ornamentation index for deepwater valves averaged 2.42, while shallow water valves were 0.83% larger, at 2.44. Hyaline to complex ornamentation was most common in both regimes, accounting for just over half the total valves sampled, though all of the remaining valves had complex ornamentation. In both localities, unoccluded areolae was the most common dominant ornamentation type; however, was 16.75% more common in the deepwater valves than those in the shallow water. Multiple ornamentation types were also common, though were 10.25% more prevalent in the deepwater valves than the shallow water.

Ninety-nine percent of valves sampled in the deepwater stations were both pennate in form and bilaterally symmetrical, as expected in a deepwater benthic assemblage. In contrast, 87% of valves were both pennate and bilateral in shallow water samples, accounting for a few centric forms that can be present in benthic assemblages under shallow-water conditions. Most of these centric forms were radial cylindrical in symmetry, and upon species analysis, are typically chain-forming colonial species that adhere to substrates or are planktonic. Deepwater valves were dominated by monoraphid valve types, due to the vast abundance of *Cocconeis* species in the assemblage. Though monoraphids forms were present in the shallow water morphometric analysis, they accounted for only 5.5% of the total number of valves examined. The biraphid valve type was much more prevalent, accounting for 65.25% of the shallow water total, and is due to the prevalence of *Navicula*, *Nitschia*, and *Amphora* in the taxonomic assemblage. Araphid valves were also relatively numerous in the shallow water analysis,

Table 9. ANOVA results for deepwater versus shallow water morphological and S/V ratio parameters.

Morphological:

Parameter	F-value	df	P-value
Apical Axis	20.2	1, 516	0.0000086
Transapical Axis	2.73	1, 516	0.099
Ornamentation Index	0.193	1, 516	0.66

S/V Ratio:

Species	F-value	df	P-value
Cocconeis disculus	0.0578	1, 38	0.81
Fallacia forcipata	9.17	1, 38	0.0044
Navicula sp. *a*	14.75	1, 38	0.00045
Nitschia frustulum	7.64	1, 38	0.0088
Nitschia panduriformis	14.46	1, 38	0.00050

accounting for 29.25% of the total valves, and all but absent in the deepwater with 0.75% of the total valves.

Significant differences in mean surface area to volume ratios occurred in all species sampled between deepwater and shallow water locations, with the exception of *Cocconeis disculus* (Table 9). *Fallacia forcipata*, *Nitschia frustulum*, and *Nitschia panduriformis* were significantly lower in their S/V ratios in deepwater stations, while *Navicula* sp. a had a significantly larger S/V ratio in the deepwater stations. This shows that for three species, the frustule took on a more cylindrical shape, while one took on a discoid shape in deepwater. S/V ratios for *Cocconeis disculus* were not significantly different between the deep and shallow water regimes.

In summary, the following overall findings were drawn based on the abovementioned results: 1) benthic marine diatoms were located at depths substantially deeper than the previously recorded maximum depth by Plant-Cuny (1978); 2) these diatoms were present in areas where the percent surface incident irradiation flux to the bottom was as low as 0.028%, far lower than the traditionally accepted 1% compensation depth; 3) both the taxonomic diversity and diversity of forms of benthic diatoms were greater in the shallow water region; 4) apical axis lengths were significantly higher in the shallow water region, but no significant difference in transapical axis length and ornamentation existed; and 5) surface area to volume ratios were significantly lower in the deepwater region for three of the five species measured, indicating that frustules may be more cylindrical-shaped than discoid.

DISCUSSION

Benthic diatoms are not typically believed to be found in deepwater areas due to limitations in light availability. Nevertheless, assemblages have been found *in situ* in these areas and are probably not transients swept from the shore by wave energy and ocean currents. The higher fucoxanthin:chlorophyll *a* ratios documented at depths up to 63 m in Onslow Bay indicate an adaptation to low light conditions, as such high ratios in shallow water floras do not exist (Cahoon et al. 1992). Should shallow water floras be swept into deeper water via physical processes, the high fucoxanthin:chlorophyll *a* ratio signal would be dampened. Though fucoxanthin:chlorophyll *a* ratios were not examined from the fourteen Onslow Bay station samples collected in this study, evidence still suggests the species from these samples are likely *in-situ* residents and not transported from the 63 m depth area. Physical forcing by waves and strong currents do not generally penetrate to the depths sampled in this study, except perhaps during storm events. No such event took place prior to the sampling cruise, and though a mild current affected ROV operations, the velocity was not sufficient to move the predominantly sandy sediments, as witnessed by the absence of turbidity and sediment movement on the bottom in the live ROV footage. Furthermore, the vast majority of the live benthic species noted were epipsammic. No tychopelagic species were found, and the one planktonic species documented, *Actinoptychus splendens*, is a larger and more robust species than most planktonic species, which would account for its presence, albeit rare, in these sediments. Finally, if benthic diatoms are transported from the locations sampled by Cahoon et al. (1992), it would be expected that their presence in deeper sediments would be patchy, being dependent on the direction and strength of the current. Nevertheless, they were documented in this study continuously at all fourteen stations.

Taxonomic diversity and composition are the more obvious differences that exist between deepwater benthic diatoms of Onslow Bay, North Carolina and those living in the adjacent shallow water regions. The variation in environmental conditions between these regions is undoubtedly the reason for this difference, with light availability likely being the most important factor. With this in mind, does the exterior morphology of the benthic diatoms in these areas reflect adaptations to their respective shallow water or deepwater location, or does the adaptation exist in their physiology? Is it in both?

Potential habitats for benthic diatoms are much more diverse in marsh and estuarine environments compared to environments in the deepwater. In shallower and/or less turbid waters where ample irradiance reaches the bottom, planktonic diatoms typically found in the water column may occasionally settle to the bottom, live for a time, and become resuspended (tychopelagic) without disrupting their metabolic processes. Likewise, colonial chain-forming diatoms may adhere to benthic substrates, and any mobile benthic species may migrate through the upper few millimeters of the sediment based on irradiance flux. In deepwater environments however, the variety of habitats becomes much lower. On the deepwater sand flats in Onslow Bay, epiphytic diatom habitats are absent, and depending on the distance from shore, epipsammic diatom habitats give way to epipelic habitats. Few live tychopelagic or benthic colonial chain-forming species would be found in the benthic environments. Epilithic diatoms may be found on exposed marine hard bottom reefs, however would likely be less numerous than epipsammic and epipelic diatoms, as sand/mud environments are relatively more common.

It should therefore not be surprising that species diversity and diversity of morphological features is lower in the deepwater stations sampled in this study. Biases in the sample sizes used in this study are no doubt of concern; however, thorough qualitative inspection of samples took place prior to taxonomic and morphometric analyses, and little variation in the results would likely have taken place had the sample size for Station 14 in the deepwater regime been greater. Light and scanning electron microscopy yielded very few valves in general, and very few valves of the live species, in particular. The abundance of montmorillonite in Station 14 sediments made concentrating the number of valves all but impossible. Because the clay size fraction, shape, and density of montmorillonite was nearly identical to that of the diatoms, heavy liquids, settling, and decantation techniques were ineffective. Because centrifugation is simply a form of settling, it was ruled out as a possible separation method. Biomarkers and labeling may be a valid option in future studies, however.

External Morphology

The presence of living diatoms in dark regions is not a newly discovered phenomenon, though it was commonly accepted that they, like some other phytoplankton species, may become inactive by entering into a resting spore stage. Alternatively, Jochem (1999) noted that the diatoms in his phytoplankton assemblage remained in the active state when he exposed them to long periods of darkness, and in fact, began to reproduce immediately upon their return to normal light conditions. These observations were also made by Murphy and Cowles (1997). Though some diatoms have been noted to revert to heterotrophy in low-light conditions, this ability is not likely to be a useful advantage due to the high metabolic cost of producing and maintaining both autotrophic and heterotrophic processes (Peters, 1996; Peters & Thomas, 1996). Less costly adaptations such as increased size or surface area to volume ratios may be an alternative, though only one relevant study, done by Nayer et al. (2005), has been found that explores these parameters. The data presented here do not readily fit with the data of Nayer et al., though the varying methods by which cells were measured may account for this discrepancy.

No studies comparing valve ornamentation and its effects on light collection in diatoms have been published, but no significant difference has been noted in ornamentation indices between the deep and shallow-water floras in this study. The surface area to volume ratios, however, do show some significant differences, at least at the genus level, between the shallow water and deepwater regimes. Rather than frustules growing more discoid in shape with depth, three of the five species used in the S/V ratio analysis were more cylindrical. The two species of *Nitschia* and *Fallacia forcipata* in this study showed significant decreases in S/V ratios in deepwater, indicating that the surface area of the valve face was proportionately smaller in that region. *Navicula* sp. a showed a significantly larger S/V ratio in the deepwater, illustrating that its valve face was proportionately larger in the deepwater. *Cocconeis disculus* showed no significant difference in S/V ratios between deep and shallow water. It appears, for at least some species, an allometric decrease takes place in valve size, with apical and transapical axes becoming smaller with depth relative to the pervalvar axis. This is reflected by the greater fluctuation in maximum and minimum apical and transapical axes lengths as compared to the same fluctuations in pervalvar axis lengths (Appendix O). *Navicula* sp. a does not fall into this category, nor does *Cocconeis disculus*, suggesting that changes in S/V ratio may be linked to taxonomy rather than the assemblage as a whole. The tendency of *Cocconeis disculus* to retain its discoid shape despite depth, coupled with its high percentage in the deepwater stations might suggest that the discoid shape is more advantageous. However, this does not account for the turnover in shape from discoid to cylindrical in three of the remaining four species. A more thorough examination of S/V ratio using larger sample sizes and/or a wider variety of species common to both the deep and shallow water regimes could help flush out whether or not these differences are indeed taxonomic responses. If taxonomy does seem to play a role, more in-depth studies of the characteristics of these species and their responses under varying conditions should follow.

Physiology

Chloroplast size and pigment content are more common parameters of study for assessing phytoplankton growth and production, and much research has been done to assess their relation with external factors, including nutrient and light availability and fluctuations in temperature, salinity, and oxygen. The metabolic cost of variation in pigmentation of phytoplankton is also much lower compared to the ability to convert to heterotrophy, and high fucoxanthin:chlorophyll *a* ratios are commonly associated with light-limited diatoms. This phenomenon has been noted in sediments in the 60 m depth range in Onslow Bay, North Carolina (and extrapolated to depths of 90 m), with ratios being two to over seven times higher than in sediments from shelf sites in Onslow Bay, as well as regions in Stellwagen Bank off the Massachusetts coast and the Florida Keys (Cahoon et al., 1992; Cahoon and Laws, 1993). Mouget et al. (2004) took this one step further by finding increased fucoxanthin concentrations and higher fucoxanthin:chlorophyll *a* ratios in the cultures of the marine diatom *Haslea ostrearia* when incubated with blue and green light under low-light conditions, compared to a white light control at the same intensity as well yellow, red, and far-red light variables.

Other factors may be at work, however, as discussed by Goericke et al. (2000) in their research on the picoplankton *Prochlorococcus*. Though strains of *Prochlorococcus* were thriving at depths of 80 m to 140 m in the Arabian Sea and the tropical Pacific off Mexico, the irradiance levels at these depths was low enough to, at best, greatly retard growth despite abnormally high pigment concentrations present in the genus. Rather than finding higher fucoxanthin:chlorophyll *a* ratios, high concentrations of an unusual carotenoid complement, 7’,8’-dihydro-derivative of zeaxanthin (believed to be the carotenoid parasiloxanthin) were discovered. This was hypothesized to be the key adaptation based on its high concentrations in *Prochlorococcus* grown in low-light, low-temperature cultures.

Chloroplast size and the presence or absence of certain pigments and their concentrations was not a parameter tested in this study Nevertheless, it has been demonstrated that it is certainly an interesting avenue of future research in Onslow Bay in light of the results indicating that only shape differences seem to occur between the deep and shallow-water regimes of this area. Some research has already been done by Cahoon et al. (1992) and Panasik (2003) contrasting the concentrations of chlorophyll *a* between Onslow Bay and Masonboro Island, with deepwater (>100 m) concentrations ranging from over 20 mg m^{-2} to less than 5 mg m^{-2}. Fucoxanthin:chlorophyll *a* ratios were not reported for Masonboro Island; however, based on comparisons by Cahoon et al. (1992), it is expected that ratios would be lower compared to deepwater sites.

Implications

That benthic diatoms can live and photosynthesize in deepwater conditions has interesting biological implications, particularly in terms of nutrient fluctuation. Not only does this add a new variable for which biologists may need to account when estimating rates of, and methods of, nutrient cycling, but also any associated feedback loops could have the potential to greatly affect the food web. Cahoon (1999) establishes this idea and states that as gate-keepers of the sediment/water interface, benthic diatoms are highly likely to impact biochemical movement through the area. Furthermore, Yin et al. (1998) were able to demonstrate a reduction in nitrate uptake inhibition by ammonium in diatoms living in low light conditions. Though Onslow Bay is considered an oligotrophic regime as a whole, phosphorous is abundant due to Neogene phosphorus deposits on the Carolina Platform (Riggs, 1983), and upwelling occurs at the shelf-break region. It is therefore presumed that the only limiting factor for deepwater benthic diatom communities for this area would be light.

The presence of benthic diatoms provides a food source for grazers; therefore diatoms in deepwater regimes may extend the range of grazers typically found in shallower waters, and/or may provide a new source of food for deepwater grazers (Cahoon, 1999). If present in abundance, benthic diatoms therefore may exert a significant impact on local food web dynamics. Because they are actively photosynthesizing and reproducing, their nutritional value is higher as compared to diatoms living in resting spore stages, and would serve as a more valuable food source.

Continental margin environments are dynamic areas where coastal processes meet those of the open ocean. Nutrient levels are typically higher on average due to export from near-shore environments via river and tidal inputs, though seasonal upwelling from the slope may also occur and add nutrients, as well as oxygen, from the deep sea. Combined effects of nutrient levels, and warmer water temperatures associated with the shallower depths, causes most margin environments, as a whole, to be more productive than the adjacent open ocean. Primary productivity in these regions, however, is commonly thought to be limited to the water column, with compensation depths varying based on light availability and mixing dynamics. In addition, in areas with wide continental margins, rates of primary productivity may decrease with distance from the shore as nutrient resources become diffuse and/or depleted. If the results of this study hold for the entire continental margin in this area, estimates of the rate of primary productivity here, and thusly productivity as a whole, have been greatly underestimated. Furthermore, the estimated rates of primary productivity for all continental margins, at least within temperate zones, may be underestimated as well. At the very least, the factors affecting primary productivity in these margin environments have been misunderstood.

CONCLUSIONS

This study supports previous work that has established that benthic microalgae can adapt and survive under conditions traditionally believed to not support photosynthetic growth. Though not as abundant or taxonomically diverse in the deepwater regions, benthic diatoms are actively living and photosynthesizing at depths up to 191 m with surface incident PAR fluxes as low as 0.028%, significantly below the 1% compensation depth. While Nayer et al. (2005) has shown that external morphology may play a role in adapting to such conditions, this study demonstrates that as a whole, surface area to volume ratios exhibited the only major difference. The frustules of the deepwater assemblage, when taken as a whole, were largely discoid in shape, characterized by higher S/V ratios reflected in the abundance of *Cocconeis disculus*. However, when examined taxonomically, S/V ratios fluctuated between the deep and shallow water frustules. Because only apical axes were significantly different between the deep and shallow water assemblages, frustules may be shrinking allometrically with depth. This conclusion does not completely refute the hypothesis that external morphological features are the distinguishing characteristics of benthic diatoms for these two regimes, but certainly size and ornamentation do not appear to be as important as shape. Chloroplast size, pigment concentrations, and pigment ratios are also likely factors based on their documented variations elsewhere; however, other unknown variables may also be at work. More research, such as HPLC analyses, can help to determine some of these variables.

Regardless of their adaptation, the presence of active benthic diatoms in Onslow Bay has the potential to impact nutrient cycling and the food web of the region. Light availability is likely the only factor limiting their abundance; however, they may still provide valuable food sources for local grazers and/or extend the ranges of grazers from surrounding areas. A more widespread assessment of benthic diatom communities, including higher resolution studies of their abundance with depth, impacts on nutrient cycling at the sediment/water interface, and nutrient limitation should be done to estimate their influence in this region.

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APPENDIX

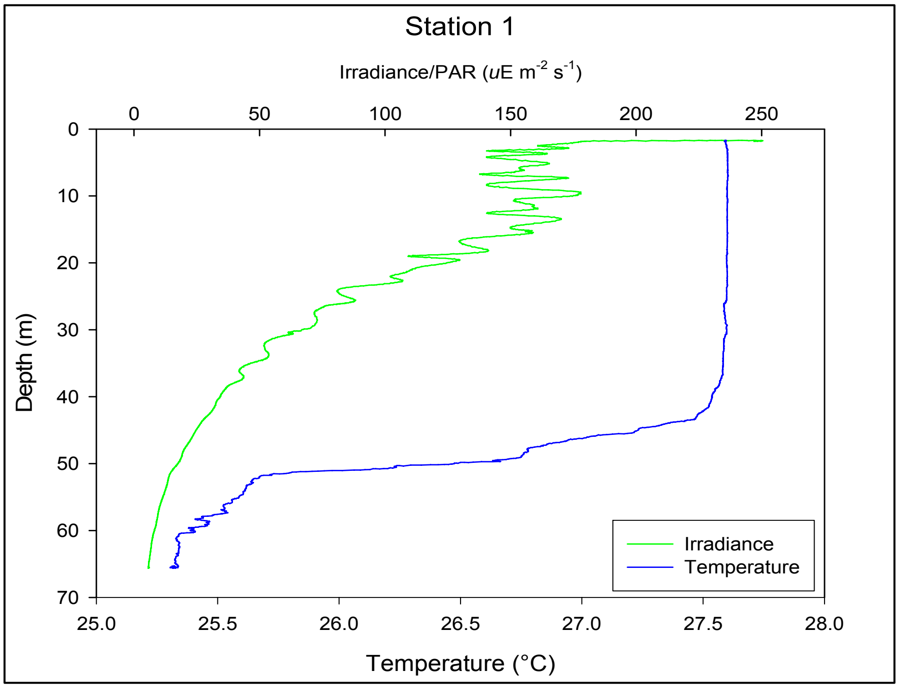
Appendix A. Deep water station sample dates, coordinates, and depths.

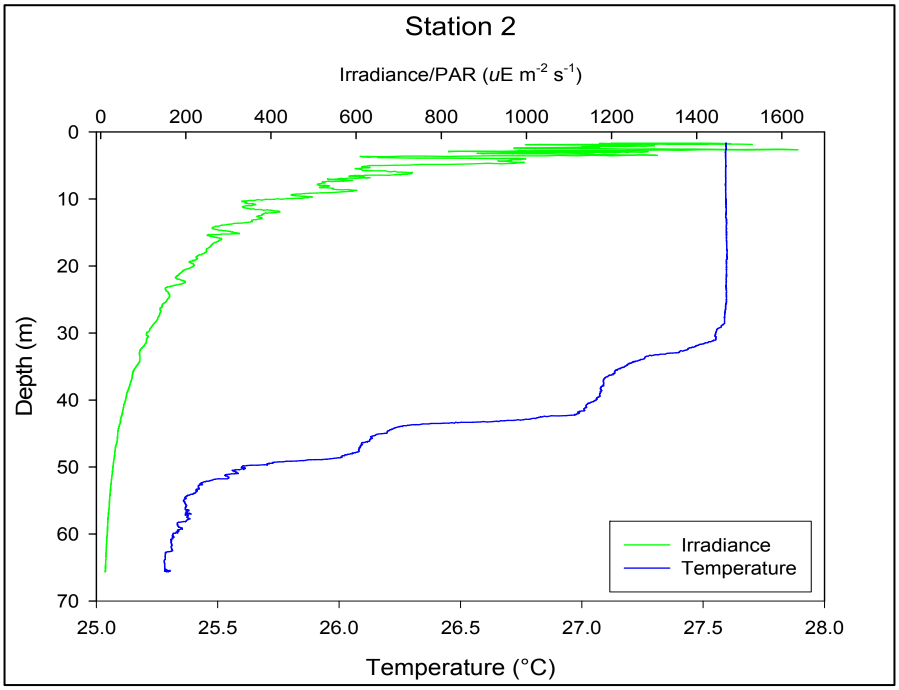
Station	Date	Coordinates		Depth (m)
1	10/16/2003	33'12.0 N	77'22.0 W	67.2
2	10/16/2003	33'11.700 N	77'23.107 W	74.4
3	10/16/2003	33'11.456 N	77'23.540 W	82.6
4	10/16/2003	33'11.456 N	77'23.540 W	82.6
5	10/16/2003	33'11.11 N	77'25.113 W	91.7
6	10/16/2003	33'11.13 N	77'25.25 W	89.0
7	10/16/2003	33'10.91 N	77'24.66 W	102.4
8	10/16/2003	33'10.562 N	77'23.846 W	121.0
9	10/17/2003	33'36.223 N	76'51.823 W	93.6
10	10/17/2003	33'35.794 N	76'51.681 W	105.2
11	10/17/2003	33'35.421 N	76'51.335 W	114.9
12	10/17/2003	33'34.817 N	76'51.167 W	122.5
13	10/17/2003	33'34.087 N	76'50.989 W	133.5
14	10/17/2003	33'32.56 N	76'47.405 W	191.1

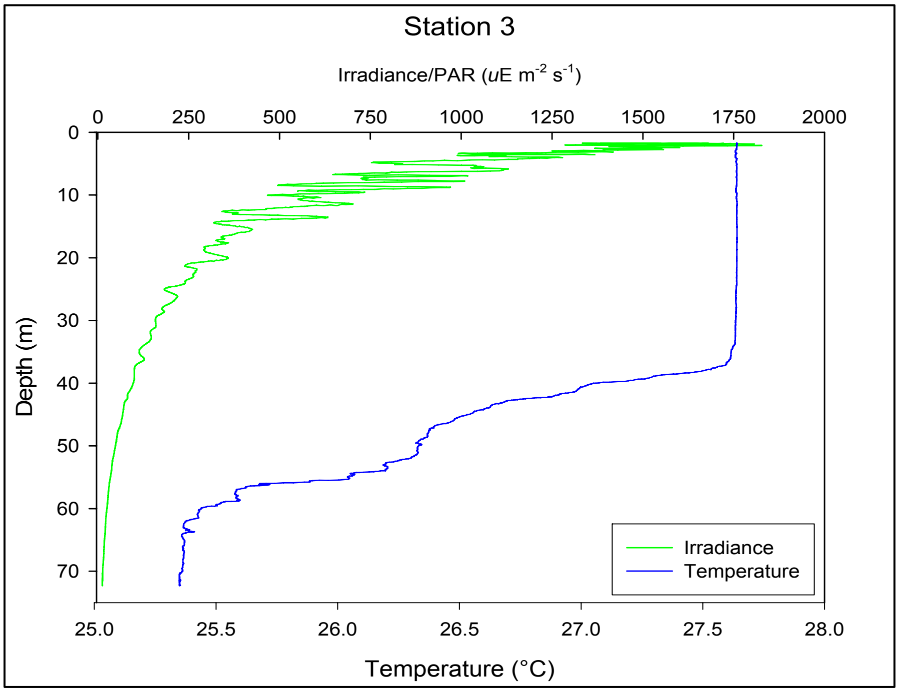
Appendix B. Deep water irradiance/PAR flux to the bottom of the water column, attenuation coefficients, surface temperature and bottom temperature, by station.

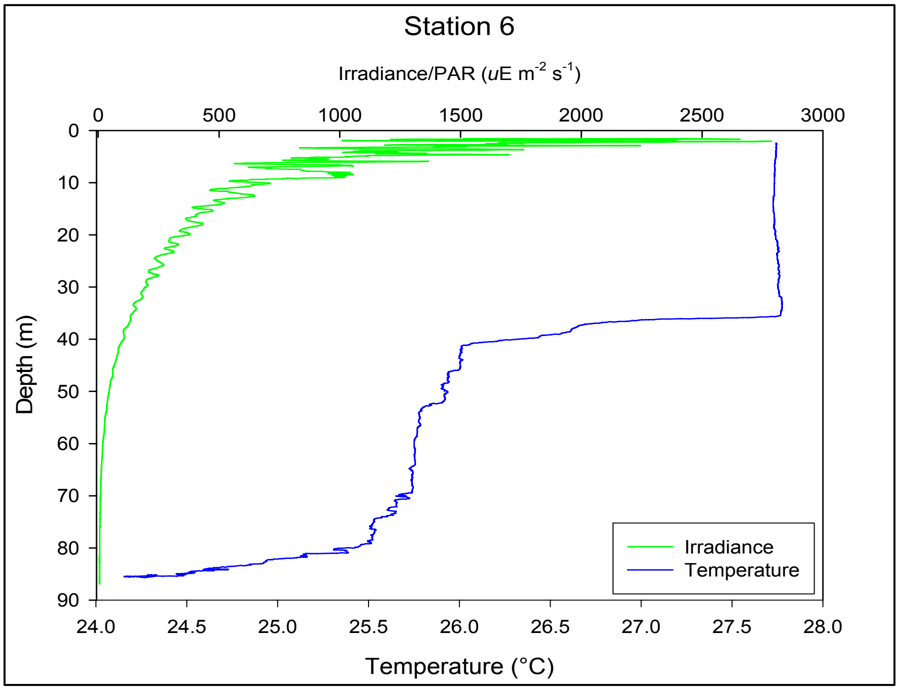
	PAR Flux (%)	kD (% m^{-2})	Mean Surface Temp (°C)	Mean Bottom Temp (°C)
Station 1	3.740	0.0497	27.599	25.316
Station 2	0.830	0.0721	27.594	25.291
Station 3	0.776	0.0674	27.64	25.352
Station 6	0.355	0.0661	27.744	24.266
Station 7	1.089	0.0443	27.806	21.407
Station 8	0.048	0.0842	27.897	20.682
Station 9	0.356	0.0647	27.648	22.887
Station 10	0.320	0.0658	27.649	22.893
Station 11	0.079	0.0666	27.901	20.767
Station 12	0.119	0.0581	27.919	20.295
Station 13	0.031	0.0616	27.831	19.634
Station 14	0.028	0.0446	27.759	14.931

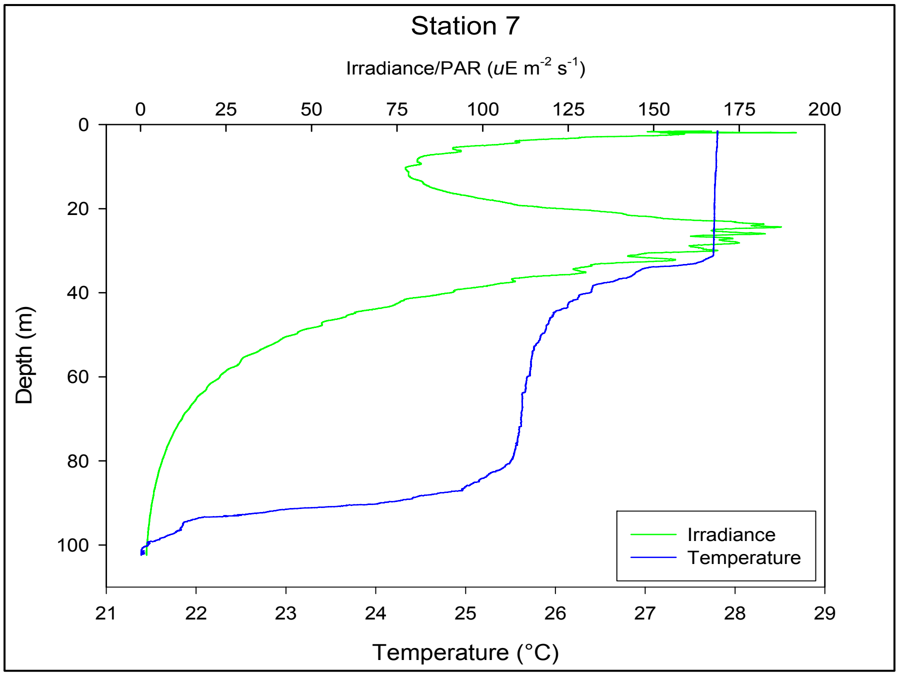
Appendix C. Deep water irradiance/PAR profiles by station.

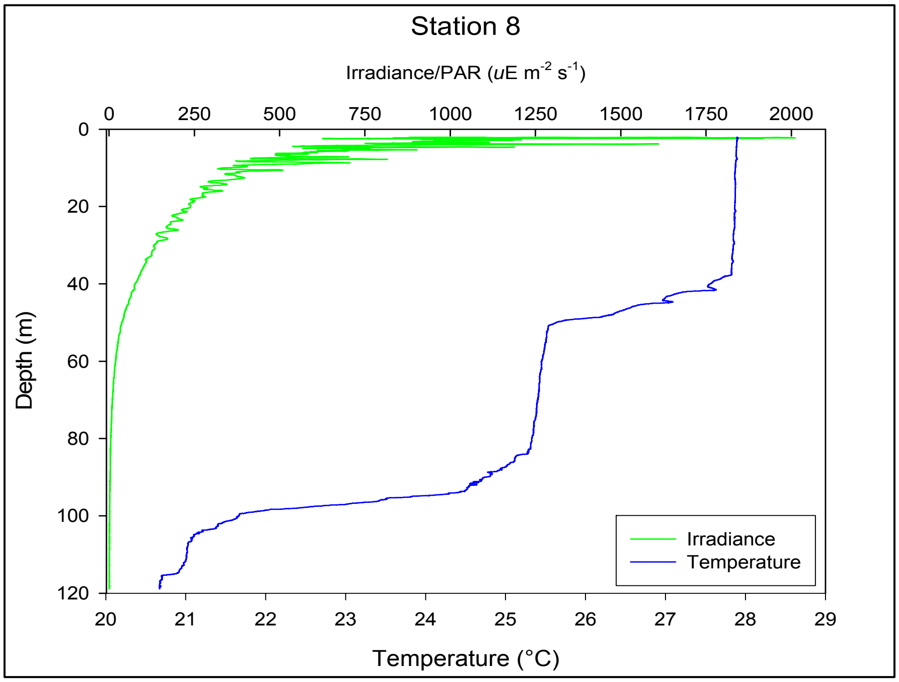


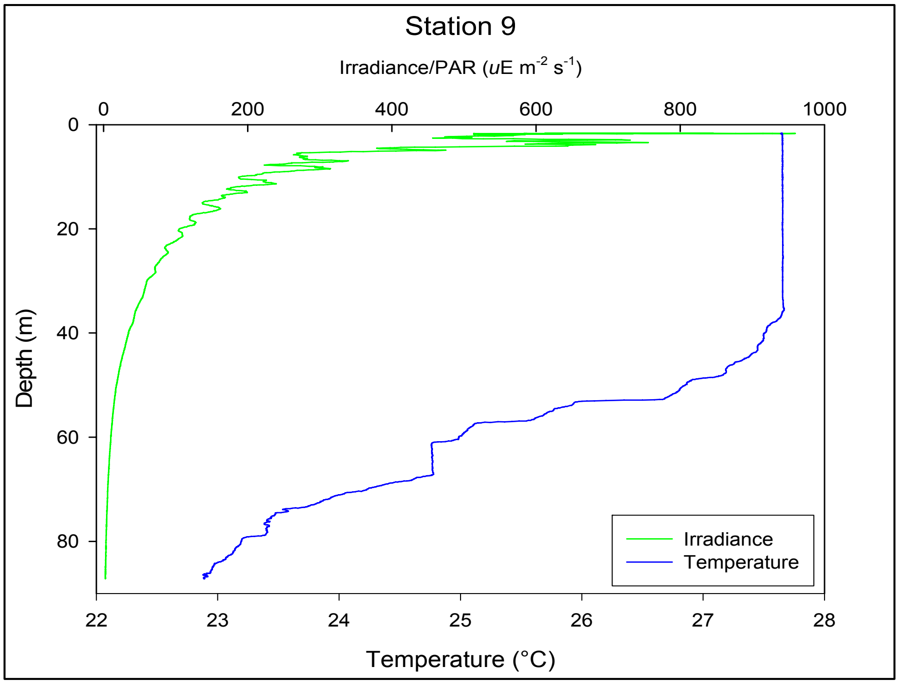


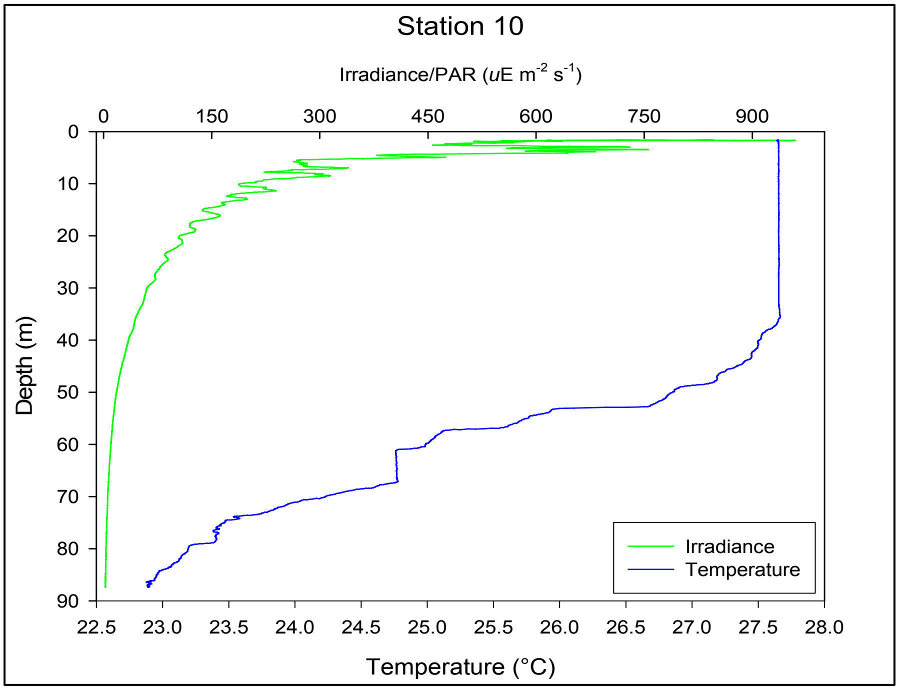

Station 3
Irradiance/PAR (uE m^{-2} s^{-1})
0
250
500
750
1000
1250
1500
1750
2000
Depth (m)
0
10
20
30
40
50
60
70
Irradiance
Temperature
25.0
25.5
26.0
26.5
27.0
27.5
28.0
Temperature (°C)

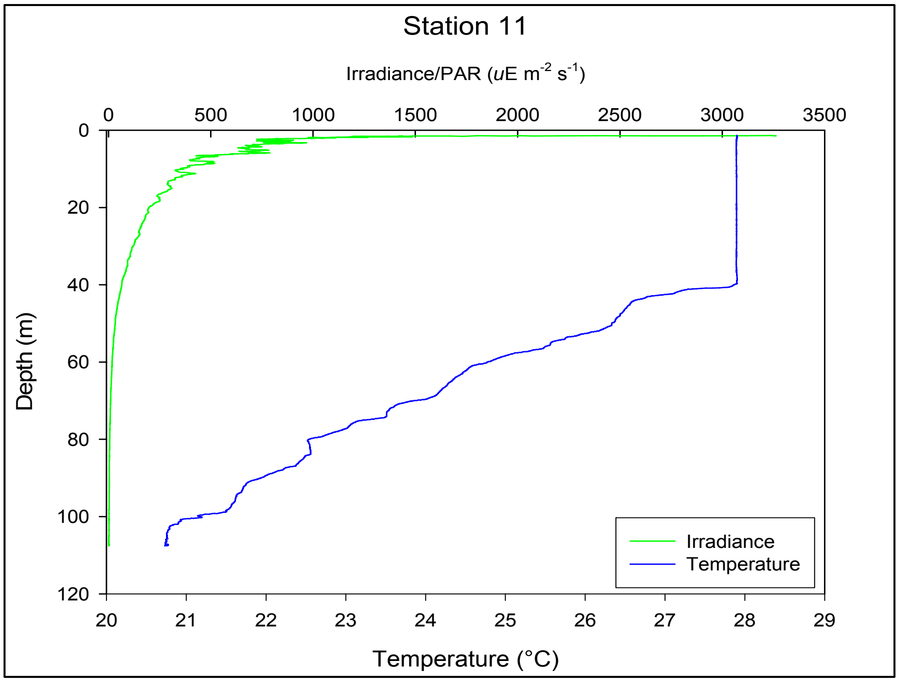

Station 6
Irradiance/PAR (uE m^{-2} s^{-1})
0
500
1000
1500
2000
2500
3000
Depth (m)
0
10
20
30
40
50
60
70
80
90
Irradiance
Temperature
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
Temperature (°C)

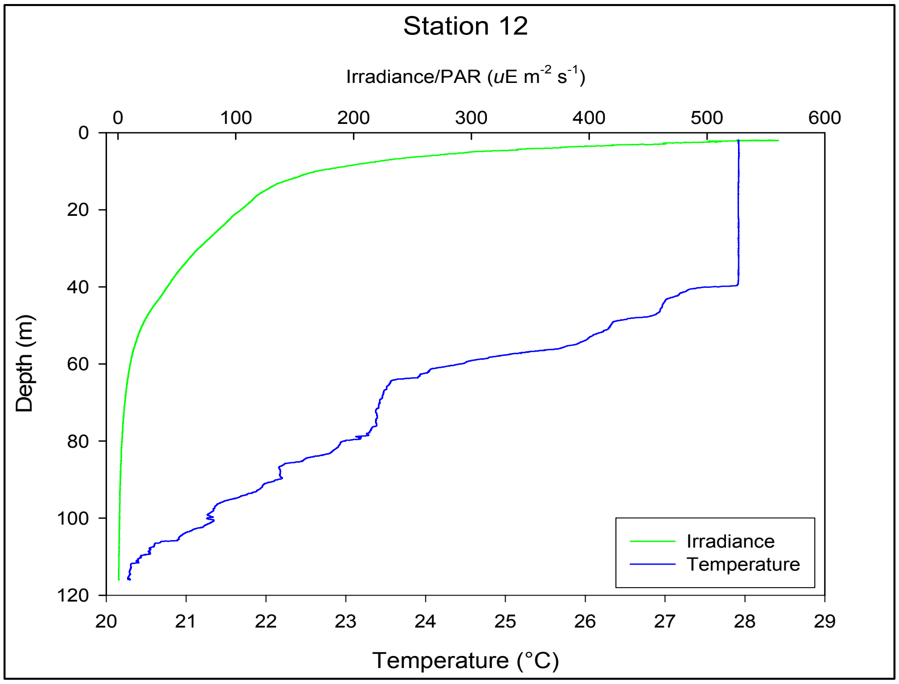

Station 7
Irradiance/PAR (uE m^{-2} s^{-1})
0
25
50
75
100
125
150
175
200
Depth (m)
0
20
40
60
80
100
21
22
23
24
25
26
27
28
29
Temperature (°C)
Irradiance
Temperature

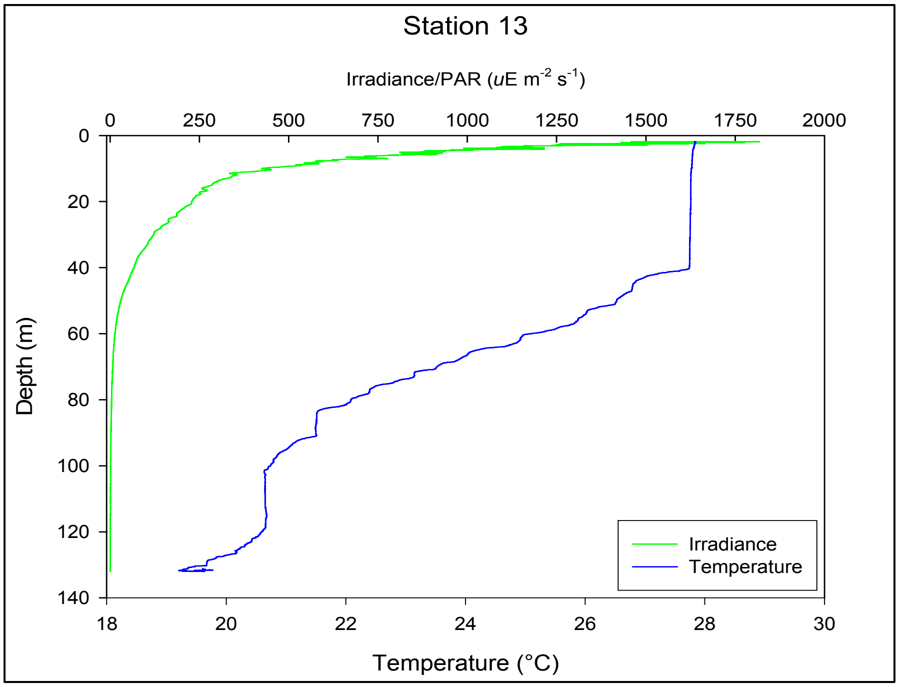

Station 8
Irradiance/PAR (uE m^{-2} s^{-1})
0
250
500
750
1000
1250
1500
1750
2000
Depth (m)
0
20
40
60
80
100
120
20
21
22
23
24
25
26
27
28
29
Temperature (°C)
Irradiance
Temperature

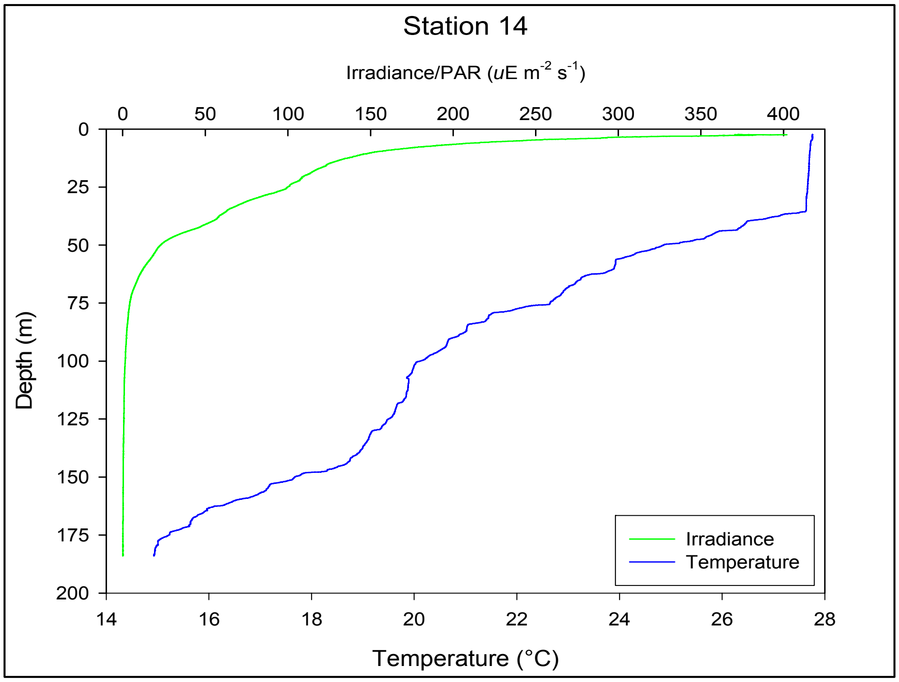

Station 9
Irradiance/PAR (uE m-2 s-1)
0
200
400
600
800
1000
0
20
40
60
80
Depth (m)
22
23
24
25
26
27
28
Temperature (°C)
Irradiance
Temperature


Station 10
Irradiance/PAR (uE m-2 s-1)
0
150
300
450
600
750
900
0
10
20
30
40
50
60
70
80
90
Depth (m)
22.5
23.0
23.5
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
Temperature (°C)
Irradiance
Temperature


Station 11
Irradiance/PAR (uE m-2 s-1)
0
500
1000
1500
2000
2500
3000
3500
Depth (m)
0
20
40
60
80
100
120
Irradiance
Temperature
20
21
22
23
24
25
26
27
28
29
Temperature (°C)


Station 12
Irradiance/PAR (uE m-2 s-1)
0
100
200
300
400
500
600
Depth (m)
0
20
40
60
80
100
120
Irradiance
Temperature
20
21
22
23
24
25
26
27
28
29
Temperature (°C)


Station 13
Irradiance/PAR (uE m^{-2} s^{-1})
0
250
500
750
1000
1250
1500
1750
2000
Depth (m)
0
20
40
60
80
100
120
140
18
20
22
24
26
28
30
Temperature (°C)
Irradiance
Temperature


Station 14
Irradiance/PAR (uE m^{-2} s^{-1})
0
50
100
150
200
250
300
350
400
Depth (m)
0
25
50
75
100
125
150
175
200
14
16
18
20
22
24
26
28
Temperature (°C)
Irradiance
Temperature

Appendix D. Deep water CTD profiles by station: mean irradiance/PAR and temperature per 10 m water depth.

	Depth	Irradiance (μE m^{-2} s^{-1})	Temperature (°C)
Station 1	20 m	122.828	27.598
	30 m	61.692	27.594
	40 m	32.393	27.526
	50 m	16.314	26.227
	60 m	8.203	25.396
Station 2	0 m	1311.032	27.594
	10 m	357.480	27.594
	20 m	203.011	27.596
	30 m	109.333	27.551
	40 m	56.112	27.033
	50 m	28.289	25.586
	60 m	14.815	25.314
Station 3	0 m	1526.462	27.640
	10 m	560.767	27.639
	20 m	308.498	27.640
	30 m	159.020	27.635
	40 m	93.747	27.014
	50 m	46.529	26.328
	60 m	23.839	25.429
	70 m	13.123	25.352
Station 6	0 m	1673.697	27.744
	10 m	641.157	27.732
	20 m	356.190	27.741
	30 m	206.255	27.756
	40 m	118.052	26.161
	50 m	59.713	25.924
	60 m	29.372	25.752
	70 m	15.126	25.689
	80 m	8.163	25.357
Station 7	0 m	162.132	27.806
	10 m	77.646	27.790
	20 m	131.848	27.771
	30 m	153.535	27.761
	40 m	86.554	26.291
	50 m	42.740	25.835
	60 m	22.583	25.682
	70 m	11.702	25.620
	80 m	6.171	25.487
	90 m	3.261	23.777
	100 m	1.877	21.427
Station 8	0 m	1314.132	27.897
	10 m	401.543	27.872
	20 m	225.651	27.868
	30 m	132.390	27.847

	40 m	74.336	27.539
	50 m	35.794	25.577
	60 m	18.349	25.450
	70 m	9.390	25.397
	80 m	4.985	25.327
	90 m	2.697	24.707
	100 m	1.504	21.635
	110 m	0.890	21.010
Station 9	0 m	678.473	27.648
	10 m	206.176	27.654
	20 m	106.181	27.655
	30 m	59.193	27.655
	40 m	33.673	27.499
	50 m	17.264	26.821
	60 m	9.882	24.935
	70 m	5.713	24.130
	80 m	3.410	23.184
Station 10	0 m	740.088	27.649
	10 m	206.176	27.654
	20 m	106.181	27.655
	30 m	59.193	27.655
	40 m	33.673	27.499
	50 m	17.264	26.821
	60 m	9.882	24.935
	70 m	5.713	24.130
	80 m	3.410	23.184
Station 11	0 m	2106.523	27.901
	10 m	341.605	27.895
	20 m	193.891	27.896
	30 m	115.193	27.896
	40 m	63.472	27.761
	50 m	31.847	26.316
	60 m	17.171	24.693
	70 m	9.769	23.742
	80 m	5.913	22.528
	90 m	3.750	21.857
	100 m	2.333	21.057
Station 12	0 m	539.060	27.919
	10 m	162.170	27.922
	20 m	102.080	27.915
	30 m	66.796	27.920
	40 m	40.651	27.357
	50 m	19.851	26.302
	60 m	10.075	24.290
	70 m	5.628	23.416
	80 m	3.226	22.935
	90 m	1.933	22.075
	100 m	1.217	21.317

	110 m	0.819	20.412
Station 13	0 m	1663.774	27.831
	10 m	430.288	27.774
	20 m	227.135	27.764
	30 m	118.479	27.754
	40 m	64.590	27.689
	50 m	28.665	26.515
	60 m	13.144	13.144
	70 m	7.023	23.493
	80 m	3.943	22.072
	90 m	4.825	42.998
	100 m	1.532	20.708
	110 m	1.038	20.651
	120 m	0.689	20.571
	130 m	0.564	19.505
Station 14	0 m	380.107	27.759
	10 m	148.440	27.705
	20 m	109.306	27.680
	30 m	77.803	27.641
	40 m	51.881	26.460
	50 m	22.165	24.808
	60 m	12.113	23.865
	70 m	5.725	22.889
	80 m	3.299	21.456
	90 m	2.176	20.694
	100 m	1.431	20.053
	110 m	0.938	19.883
	120 m	0.757	19.641
	130 m	0.555	19.172
	140 m	0.358	18.859
	150 m	0.291	17.653
	160 m	0.225	16.468
	170 m	0.167	15.626
	180 m	0.113	14.961

Appendix E. Diatom taxa present from Stations 1-14, Onslow Bay, NC.

Species	Stations Present	Species	Stations Present
Achnanthes brevipes	4	*Fallacia* Sp. V	3
Achnanthes delicatula	2,5,8	*Fallacia* Sp. a	2,5
Achnanthes danica	1,5	*Fragilaria brevistriata*	2-4,6
Achnanthes hauckiana	1,4,7,10	*Fragilaria hyalina*	2
Achnanthes Kolbei	1,6	*Fragilaria tabulata*	3-4,9
Achnanthes manifera	6	*Fragilaria* Sp. I	1-2
Achnanthes pseudobliqua	3,8	*Fragilaria* Sp. II	1
Achnanthes reidensis	1-2	*Fragilaria* Sp. III	1
Achnanthes taeniata	3	*Fragilaria* Sp. a	1,4-5,7
Achnanthes tenera	1	*Grammatophora marina*	2-7
Actinoptychus splendens	14	*Lyrella* Sp. I	3
Amphora beaufortiana	1-2	*Mastogloia angusta*	1
Amphora coffeaeformis	2-3,7,14	*Mastogloia lanceolata*	8
Amphora costata	3	*Mastogloia pseudoelegans*	1
Amphora delicatissima	6	*Melosira moniliformis*	1-4
Amphora exigua	4-5,9	*Navicula abunda*	1
Amphora granulata	1-3	*Navicula cancellata*	2,6
Amphora helenensis	5,7	*Navicula digitoconvergens*	1
Amphora ovalis	1-4	*Navicula diplonoides*	1,6
Amphora pannucea	5	*Navicula diversestriata*	1
Amphora pseudoholsatica	3	*Navicula ergadensis*	5
Amphora subcuneata	1-2	*Navicula Humii*	1,7
Amphora tenerrima	2	*Navicula menisculus*	3,4
Amphora Sp. I	4	*Navicula muraliformis*	5
Amphora Sp. II	3,6	*Navicula nummularia*	1,4-6
Amphora Sp. III	2,4	*Navicula palpebralis*	6,10
Amphora Sp. IV	9	*Navicula paul-schulzii*	1,4-5
Biddulphia regina	5-6	*Navicula reinhardtii*	5
Biremis lucens	1-2	*Navicula riparia*	2,5
Cocconeis californica	1,3,5,6-7,9	*Navicula subhamulata*	1
Cocconeis convexa	1,6	*Navicula* Sp. I	1,8,14
Cocconeis dirupta	1-4	*Navicula* Sp. II	7
Cocconeis disculus	1-10,14	*Navicula* Sp. III	1,5
Cocconeis distans	1,5-7,14	*Nitschia amphibia*	3
Cocconeis distantula	1,3,5,8	*Nitschia angularis*	3,5,8,10
Cocconeis granulifera	2,4	*Nitschia brevirostris*	2
Cocconeis hoffmanni	1-2,4	*Nitschia constricta*	4
Cocconeis peltoides	1,5	*Nitschia frustulum*	1,2,14
Cocconeis pinnata	2,6	*Nitschia hybridaeformis*	1,3,5,10
Cocconeis placentula	2,10	*Nitschia incurva*	3,4
Cocconeis scutellum	1-2,4-6	*Nitschia marginata*	1
Cocconeis Sp. I	1,2,6,10	*Nitschia panduriformis*	1-10,14
Cocconeis Sp. II	1,2,7	*Nitschia* Sp. I	1
Cocconeis Sp. III	3-4,6-7,9	*Nitschia* Sp. II	3-4,7
Cymatosira lorenziana	1,-5,7-8,10	*Nitschia* Sp. III	7

Delphenies karstenii	1,5,10	*Odontella aurita*	6
Delphenies surirella	1,4,6,10	*Opephora pacifica*	1-2
Diploneis aestuarii	1-10,14	*Parlibellus adnatus*	4
Diploneis bombus	5,8,10	*Petronies latissima*	3
Diploneis chersonensis	4,8,10,14	*Pinnularia lanceolata*	5
Diploneis decipiens	6,10	*Pinnularia* Sp. I	4
Diploneis Smithii	7,9	*Plagiogramma pygmaeum*	1
Entomoneis kjellmanii	1	*Pleurosigma distinguendum*	5-8,10,14
Eunotogramma marinum	2-7	*Pleurosigma marinum*	1,6
Eunotogramma rostratum	2-7	*Pleurosigma rostratum*	3
Fallacia forcipata	7,14	*Thallassiosira decipiens*	9
Fallacia litoricola	1,4,8	*Thallassiosira* Sp. I	6
Fallacia plathii	3	*Trachysphinia acuminata*	1
Fallacia vittata	5	*Trachyneis* Sp. I	1.5
Fallacia Sp. I	2	Unknown Sp. I	1,3
Fallacia Sp. II	5	Unknown Sp. II	2
Fallacia Sp. III	3	Unknown Sp. III	3
Fallacia Sp. IV	2-3	Unknown Sp. IV	2

Appendix F. Diatom taxa present from Station 1, Onslow Bay, NC.

Achnanthes danica	*Cocconeis scutellum*	*Navicula diplonoides*
Achnanthes hauckiana	*Cocconeis* Sp. I	*Navicula diversestriata*
Achnanthes Kolbei	*Cocconeis* Sp. II	*Navicula Humii*
Achnanthes reidensis	*Cymatosira lorenziana*	*Navicula nummularia*
Achnanthes tenera	*Delphenies karstenii*	*Navicula paul-schulzii*
Amphora beaufortiana	*Delphenies surirella*	*Navicula subhamulata*
Amphora granulata	*Diploneis aestuarii*	*Navicula* Sp. I
Amphora ovalis	*Entomoneis kjellmanii*	*Navicula* Sp. III
Amphora subcuneata	*Fallacia litoricola*	*Nitschia frustulum*
Biremis lucens	*Fragilaria* Sp. I	*Nitschia hybridaeformis*
Cocconeis californica	*Fragilaria* Sp. II	*Nitschia marginata*
Cocconeis convexa	*Fragilaria* Sp. III	*Nitschia panduriformis*
Cocconeis dirupta	*Fragilaria* Sp. a	*Nitschia* Sp. I
Cocconeis disculus	*Mastogloia angusta*	*Opephora pacifica*
Cocconeis distans	*Mastogloia pseudoelegans*	*Plagiogramma pygmaeum*
Cocconeis distantula	*Melosira moniliformis*	*Pleurosigma marinum*
Cocconeis hoffmanni	*Navicula abunda*	*Trachysphinia acuminata*
Cocconeis peltoides	*Navicula digitoconvergens*	*Trachyneis* Sp. I

Appendix G. Diatom taxa present from Station 14, Onslow Bay, NC.

Amphora coffeaformis
Cocconeis disculus
Cocconeis distans
Cocconeis placentula
Navicula Sp. a
Navicula digitoconvergens
Nitschia frustulum
Nitschia hybridiformis
Nitschia panduriformis

Appendix H. Deep water Station 1 morphometric measurements.

	Species	Apical Axis (µm)	Transapical Axis (µm)	Symmetry	Raphe Type	Ornamentation	Index	Dominant Ornamentation Type
1	*Amphora coffeaformis*	9	4.25	bilateral	biraphid	hyaline to complex	2	multiple
2	*Amphora coffeaformis*	8.75	4	bilateral	biraphid	hyaline to complex	2	multiple
3	*Amphora coffeaformis*	9.25	4.5	bilateral	biraphid	hyaline to complex	2	multiple
4	*Cocconeis disculus*	17.5	12.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
5	*Cocconeis disculus*	8.5	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
6	*Cocconeis disculus*	8.25	5	bilateral	monoraphid	hyaline to complex	2	unoccluded
7	*Cocconeis disculus*	13	7	bilateral	monoraphid	hyaline to complex	2	unoccluded
8	*Cocconeis disculus*	7.75	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
9	*Cocconeis disculus*	8	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
10	*Cocconeis disculus*	8	5	bilateral	monoraphid	hyaline to complex	2	unoccluded
11	*Cocconeis disculus*	6.75	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
12	*Cocconeis disculus*	11.25	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
13	*Cocconeis disculus*	7.25	3.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
14	*Cocconeis disculus*	9.5	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
15	*Cocconeis disculus*	12	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
16	*Cocconeis disculus*	6.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
17	*Cocconeis disculus*	6.25	3.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
18	*Cocconeis disculus*	10	5.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
19	*Cocconeis disculus*	11	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
20	*Cocconeis disculus*	11.75	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
21	*Cocconeis disculus*	11.5	5.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
22	*Cocconeis disculus*	11.5	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
23	*Cocconeis disculus*	11	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
24	*Cocconeis disculus*	21.25	13	bilateral	monoraphid	hyaline to complex	2	unoccluded
25	*Cocconeis disculus*	10.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
26	*Cocconeis disculus*	6.75	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
27	*Cocconeis disculus*	12.5	6	bilateral	monoraphid	hyaline to complex	2	volae
28	*Cocconeis disculus*	17	9.25	bilateral	monoraphid	hyaline to complex	2	volae

29	*Cocconeis disculus*	16.5	9	bilateral	monoraphid	hyaline to complex	2	volae
30	*Cocconeis disculus*	18.5	9.5	bilateral	monoraphid	hyaline to complex	2	volae
31	*Cocconeis disculus*	17.5	8	bilateral	monoraphid	hyaline to complex	2	volae
32	*Cocconeis disculus*	17.5	8.25	bilateral	monoraphid	hyaline to complex	2	volae
33	*Cocconeis disculus*	17.25	8	bilateral	monoraphid	hyaline to complex	2	volae
34	*Cocconeis disculus*	17.5	8.25	bilateral	monoraphid	hyaline to complex	2	volae
35	*Cocconeis disculus*	9	4	bilateral	monoraphid	hyaline to complex	2	volae
36	*Cocconeis disculus*	18	9.25	bilateral	monoraphid	hyaline to complex	2	volae
37	*Cocconeis disculus*	13.75	6.5	bilateral	monoraphid	hyaline to complex	2	volae
38	*Cocconeis disculus*	21.75	9.5	bilateral	monoraphid	hyaline to complex	2	volae
39	*Cocconeis disculus*	15	10	bilateral	monoraphid	hyaline to complex	2	volae
40	*Cocconeis disculus*	17	9.25	bilateral	monoraphid	hyaline to complex	2	volae
41	*Cocconeis disculus*	12	5.5	bilateral	monoraphid	hyaline to complex	2	volae
42	*Cocconeis disculus*	8.5	4.25	bilateral	monoraphid	hyaline to complex	2	volae
43	*Cocconeis disculus*	11.5	4.25	bilateral	monoraphid	hyaline to complex	2	volae
44	*Cocconeis disculus*	10.25	4	bilateral	monoraphid	complex	3	hymenate
45	*Cocconeis disculus*	8.25	4	bilateral	monoraphid	complex	3	hymenate
46	*Cocconeis disculus*	9.25	4	bilateral	monoraphid	complex	3	hymenate
47	*Cocconeis disculus*	12.75	5.25	bilateral	monoraphid	complex	3	hymenate
48	*Cocconeis disculus*	7.75	3.5	bilateral	monoraphid	complex	3	unoccluded
49	*Cocconeis disculus*	10	4.5	bilateral	monoraphid	complex	3	unoccluded
50	*Cocconeis disculus*	10.75	5	bilateral	monoraphid	complex	3	unoccluded
51	*Cocconeis disculus*	11.5	5	bilateral	monoraphid	complex	3	unoccluded
52	*Cocconeis disculus*	12.25	5.25	bilateral	monoraphid	complex	3	unoccluded
53	*Cocconeis disculus*	8.75	3.75	bilateral	monoraphid	complex	3	unoccluded
54	*Cocconeis disculus*	9.75	4	bilateral	monoraphid	complex	3	unoccluded
55	*Cocconeis disculus*	10	4.25	bilateral	monoraphid	complex	3	unoccluded
56	*Cocconeis disculus*	9	4.5	bilateral	monoraphid	complex	3	unoccluded
57	*Cocconeis disculus*	11.5	4.25	bilateral	monoraphid	complex	3	unoccluded
58	*Cocconeis disculus*	11	5	bilateral	monoraphid	complex	3	unoccluded
59	*Cocconeis disculus*	11.25	5.25	bilateral	monoraphid	complex	3	unoccluded
60	*Cocconeis disculus*	10.25	4.75	bilateral	monoraphid	complex	3	unoccluded

61	*Cocconeis disculus*	8.5	2	bilateral	monoraphid	complex	3	unoccluded
62	*Cocconeis disculus*	8	4.25	bilateral	monoraphid	complex	3	unoccluded
63	*Cocconeis disculus*	22.5	10	bilateral	monoraphid	complex	3	unoccluded
64	*Cocconeis disculus*	9	4.25	bilateral	monoraphid	complex	3	unoccluded
65	*Cocconeis disculus*	14.5	7.5	bilateral	monoraphid	complex	3	unoccluded
66	*Cocconeis disculus*	10	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
67	*Cocconeis disculus*	8.75	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
68	*Cocconeis disculus*	12	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
69	*Cocconeis disculus*	11	5.25	bilateral	monoraphid	complex	3	unoccluded
70	*Cocconeis disculus*	11	5.5	bilateral	monoraphid	complex	3	unoccluded
71	*Cocconeis disculus*	11	5.25	bilateral	monoraphid	complex	3	unoccluded
72	*Cocconeis disculus*	11	5.25	bilateral	monoraphid	complex	3	unoccluded
73	*Cocconeis disculus*	8.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
74	*Cocconeis disculus*	12	5	bilateral	monoraphid	complex	3	unoccluded
75	*Cocconeis disculus*	13	3.75	bilateral	monoraphid	complex	3	unoccluded
76	*Cocconeis disculus*	12	4	bilateral	monoraphid	complex	3	unoccluded
77	*Cocconeis disculus*	10.5	5.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
78	*Cocconeis disculus*	13.75	9.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
79	*Cocconeis disculus*	6.5	3.75	bilateral	monoraphid	complex	3	unoccluded
80	*Cocconeis disculus*	10.5	4.25	bilateral	monoraphid	complex	3	unoccluded
81	*Cocconeis disculus*	10.5	4	bilateral	monoraphid	complex	3	unoccluded
82	*Cocconeis disculus*	13.5	5.75	bilateral	monoraphid	complex	3	unoccluded
83	*Cocconeis disculus*	8.5	5	bilateral	monoraphid	complex	3	multiple
84	*Cocconeis disculus*	10.25	4	bilateral	monoraphid	complex	3	multiple
85	*Cocconeis disculus*	9.5	4.25	bilateral	monoraphid	complex	3	multiple
86	*Cocconeis disculus*	9	4	bilateral	monoraphid	complex	3	multiple
87	*Cocconeis disculus*	12	5.75	bilateral	monoraphid	hyaline to complex	2	multiple
88	*Cocconeis disculus*	8.5	4.5	bilateral	monoraphid	complex	3	multiple
89	*Cocconeis disculus*	14.75	13.5	bilateral	monoraphid	complex	3	multiple
90	*Cocconeis disculus*	8.5	4	bilateral	monoraphid	complex	3	multiple
91	*Cocconeis disculus*	13	4.5	bilateral	monoraphid	complex	3	multiple
92	*Cocconeis disculus*	9.75	5	bilateral	monoraphid	complex	3	multiple

93	*Cocconeis disculus*	15.5	9.75	bilateral	monoraphid	complex	3	multiple
94	*Cocconeis disculus*	12.5	5.75	bilateral	monoraphid	complex	3	multiple
95	*Cocconeis disculus*	12.5	5.5	bilateral	monoraphid	complex	3	multiple
96	*Cocconeis disculus*	12.5	5.5	bilateral	monoraphid	complex	3	multiple
97	*Cocconeis disculus*	12.5	5	bilateral	monoraphid	complex	3	multiple
98	*Cocconeis disculus*	12.5	5	bilateral	monoraphid	complex	3	multiple
99	*Cocconeis disculus*	10.5	4.25	bilateral	monoraphid	complex	3	multiple
100	*Cocconeis disculus*	11.5	4.5	bilateral	monoraphid	complex	3	multiple
101	*Cocconeis disculus*	9.75	4.5	bilateral	monoraphid	complex	3	multiple
102	*Cocconeis disculus*	9.5	4	bilateral	monoraphid	complex	3	multiple
103	*Cocconeis disculus*	12	4.75	bilateral	monoraphid	complex	3	multiple
104	*Cocconeis disculus*	8.25	4	bilateral	monoraphid	complex	3	multiple
105	*Cocconeis disculus*	8.5	4.75	bilateral	monoraphid	complex	3	multiple
106	*Cocconeis disculus*	9.25	4.5	bilateral	monoraphid	complex	3	multiple
107	*Cocconeis disculus*	8.75	4.25	bilateral	monoraphid	complex	3	multiple
108	*Cocconeis disculus*	8.5	5	bilateral	monoraphid	complex	3	multiple
109	*Cocconeis disculus*	9.25	4	bilateral	monoraphid	complex	3	multiple
110	*Cocconeis disculus*	16.5	12.75	bilateral	monoraphid	complex	3	unoccluded
111	*Cocconeis disculus*	11	4	bilateral	monoraphid	complex	3	multiple
112	*Cocconeis disculus*	11	4.25	bilateral	monoraphid	complex	3	multiple
113	*Cocconeis disculus*	12.5	4.75	bilateral	monoraphid	complex	3	multiple
114	*Cocconeis disculus*	14.25	6.5	bilateral	monoraphid	complex	3	multiple
115	*Cocconeis disculus*	10.5	5	bilateral	monoraphid	complex	3	multiple
116	*Cocconeis disculus*	10	4.25	bilateral	monoraphid	complex	3	multiple
117	*Cocconeis disculus*	7	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
118	*Cocconeis disculus*	8	3.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
119	*Cocconeis disculus*	7.25	3.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
120	*Cocconeis disculus*	7	3.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
121	*Cocconeis disculus*	7.25	3.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
122	*Cocconeis disculus*	10.25	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
123	*Cocconeis disculus*	21	13	bilateral	monoraphid	hyaline to complex	2	unoccluded
124	*Cocconeis disculus*	9.25	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded

125	*Cocconeis disculus*	9.25	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
126	*Cocconeis disculus*	7.75	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
127	*Cocconeis disculus*	8.75	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
128	*Cocconeis disculus*	7.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
129	*Cocconeis disculus*	10.5	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
130	*Cocconeis disculus*	14.25	8.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
131	*Cocconeis disculus*	13	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
132	*Cocconeis disculus*	11.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
133	*Cocconeis disculus*	11.75	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
134	*Cocconeis disculus*	12.75	5.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
135	*Cocconeis disculus*	11.75	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
136	*Cocconeis disculus*	12.25	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
137	*Cocconeis disculus*	14	12	bilateral	monoraphid	hyaline to complex	2	unoccluded
138	*Cocconeis disculus*	12	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
139	*Cocconeis disculus*	12	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
140	*Cocconeis disculus*	13.25	5	bilateral	monoraphid	hyaline to complex	2	unoccluded
141	*Cocconeis disculus*	10.25	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
142	*Cocconeis disculus*	13	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
143	*Cocconeis disculus*	7.75	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
144	*Cocconeis disculus*	14.5	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
145	*Cocconeis disculus*	19.25	13.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
146	*Cocconeis disculus*	19	13.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
147	*Cocconeis disculus*	17	12.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
148	*Cocconeis disculus*	16	13	bilateral	monoraphid	hyaline to complex	2	unoccluded
149	*Cocconeis disculus*	13.5	6.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
150	*Cocconeis disculus*	29.25	11.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
151	*Cocconeis disculus*	28.5	11.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
152	*Cocconeis disculus*	16.25	9.5	bilateral	monoraphid	hyaline to complex	2	multiple
153	*Cocconeis disculus*	13.5	9	bilateral	monoraphid	hyaline to complex	2	multiple
154	*Cocconeis disculus*	30	9.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
155	*Cocconeis disculus*	28	8.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
156	*Cocconeis disculus*	31	21.25	bilateral	monoraphid	complex	3	multiple

157	*Cocconeis disculus*	29.5	8.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
158	*Cocconeis disculus*	12	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
159	*Cocconeis disculus*	18.75	13	bilateral	monoraphid	hyaline to complex	2	unoccluded
160	*Cocconeis disculus*	18	12.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
161	*Cocconeis disculus*	21.5	10.5	bilateral	monoraphid	complex	3	multiple
162	*Cocconeis disculus*	14.25	8.75	bilateral	monoraphid	complex	3	unoccluded
163	*Cocconeis disculus*	42.75	19.5	bilateral	monoraphid	complex	3	unoccluded
164	*Cocconeis disculus*	37.75	21	bilateral	monoraphid	hyaline to complex	2	unoccluded
165	*Cocconeis disculus*	7	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
166	*Cocconeis disculus*	7	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
167	*Cocconeis disculus*	7	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
168	*Cocconeis disculus*	7.5	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
169	*Cocconeis disculus*	12.25	7.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
170	*Cocconeis disculus*	8.5	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
171	*Cocconeis distans*	39.75	24.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
172	*Cocconeis distans*	33.5	19.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
173	*Cocconeis distans*	28.25	20	bilateral	monoraphid	hyaline to complex	2	unoccluded
174	*Cocconeis distans*	28.75	20.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
175	*Cocconeis distans*	40	24.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
176	*Cocconeis distans*	37.75	22.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
177	*Cocconeis distans*	28.25	20	bilateral	monoraphid	hyaline to complex	2	unoccluded
178	*Cocconeis distans*	38	20.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
179	*Cocconeis placentula*	10	5.5	bilateral	monoraphid	complex	3	multiple
180	*Cocconeis placentula*	10.5	5.5	bilateral	monoraphid	complex	3	multiple
181	*Navicula Sp. I*	20	4	bilateral	biraphid	hyaline to complex	2	hymenate
182	*Navicula Sp. I*	19.5	4.75	bilateral	biraphid	hyaline to complex	2	hymenate
183	*Navicula Sp. I*	18.25	4.5	bilateral	biraphid	hyaline to complex	2	hymenate
184	*Navicula Sp. I*	18	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
185	*Navicula Sp. I*	26.5	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
186	*Nitschia frustulum*	6	2.25	bilateral	biraphid	hyaline to complex	2	unoccluded
187	*Nitschia hybridiformis*	16.75	2	bilateral	biraphid	complex	3	none
188	*Nitschia panduriformis*	18.25	13	bilateral	biraphid	complex	3	unoccluded

189	*Nitschia panduriformis*	13.5	4.25	bilateral	biraphid	complex	3	unoccluded
190	*Nitschia panduriformis*	11.75	4	bilateral	biraphid	complex	3	unoccluded
191	*Nitschia panduriformis*	28.75	12.5	bilateral	biraphid	complex	3	unoccluded
192	*Nitschia panduriformis*	30	13.75	bilateral	biraphid	complex	3	unoccluded
193	*Nitschia panduriformis*	11.5	4.25	bilateral	biraphid	complex	3	unoccluded
194	*Nitschia panduriformis*	30	10.25	bilateral	biraphid	complex	3	unoccluded
195	*Nitschia panduriformis*	11.75	4.25	bilateral	biraphid	complex	3	unoccluded
196	*Nitschia panduriformis*	35	12.5	bilateral	biraphid	complex	3	unoccluded
197	*Nitschia panduriformis*	32.25	11.5	bilateral	biraphid	complex	3	unoccluded
198	*Nitschia panduriformis*	31.75	12.5	bilateral	biraphid	complex	3	unoccluded
199	*Nitschia panduriformis*	26.75	9.75	bilateral	biraphid	complex	3	unoccluded
200	*Nitschia panduriformis*	33.5	12	bilateral	biraphid	complex	3	unoccluded
Mean:		**14.31**	**6.91**				**2.43**	
Standard Deviation:		**7.77**	**4.49**				**0.50**	

Appendix I. Diatom taxa present from Station 14, Onslow Bay, NC.

Amphora coffeaeformis
Cocconeis disculus
Cocconeis distans
Diploneis aestuarii
Diploneis chersonensis
Navicula Sp. al
Nitschia frustulum
Nitschia panduriformis
Pleurosigma distinguendum

Appendix J. Deep water Station 14 morphometric measurements.

	Species	Apical Axis (μm)	Transapical Axis (μm)	Symmetry	Raphe Type	Ornamentation	Index	Dominant Ornamentation Type
1	Actinoptychus splendens	72	72	radial discoid	araphid	complex	3	unoccluded
2	Actinoptychus splendens	58.75	58.75	radial discoid	araphid	complex	3	unoccluded
3	Cocconeis disculus	11	6	bilateral	monoraphid	hyaline to complex	2	unoccluded
4	Cocconeis disculus	14.75	9.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
5	Cocconeis disculus	16.25	8.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
6	Cocconeis disculus	7.25	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
7	Cocconeis disculus	9.5	5.5	bilateral	monoraphid	complex	3	unoccluded
8	Cocconeis disculus	9.75	6.5	bilateral	monoraphid	complex	3	unoccluded
9	Cocconeis disculus	7.25	5	bilateral	monoraphid	hyaline to complex	2	unoccluded
10	Cocconeis disculus	8	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
11	Cocconeis disculus	8	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
12	Cocconeis disculus	9.75	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
13	Cocconeis disculus	15.25	11.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
14	Cocconeis disculus	20	9	bilateral	monoraphid	hyaline to complex	2	unoccluded
15	Cocconeis disculus	20.25	9.25	bilateral	monoraphid	complex	3	unoccluded
16	Cocconeis disculus	8	4.25	bilateral	monoraphid	complex	3	unoccluded
17	Cocconeis disculus	18	12.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
18	Cocconeis disculus	6.5	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
19	Cocconeis disculus	7.75	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
20	Cocconeis disculus	8.25	5.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
21	Cocconeis disculus	8.5	6.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
22	Cocconeis disculus	15.25	7.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
23	Cocconeis disculus	8.75	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
24	Cocconeis disculus	11.25	7	bilateral	monoraphid	hyaline to complex	2	unoccluded
25	Cocconeis disculus	15	10.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
26	Cocconeis disculus	9.25	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
27	Cocconeis disculus	9	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded

28	Cocconeis disculus	7.25	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
29	Cocconeis disculus	8.25	4	bilateral	monoraphid	hyaline to complex	2	unoccluded
30	Cocconeis disculus	11.75	7.25	bilateral	monoraphid	hyaline to complex	2	volae
31	Cocconeis disculus	11.5	5.75	bilateral	monoraphid	hyaline to complex	2	volae
32	Cocconeis disculus	10	6.75	bilateral	monoraphid	hyaline to complex	2	volae
33	Cocconeis disculus	11.25	5.5	bilateral	monoraphid	hyaline to complex	2	volae
34	Cocconeis disculus	13.75	6	bilateral	monoraphid	hyaline to complex	2	volae
35	Cocconeis disculus	8.75	5.25	bilateral	monoraphid	hyaline to complex	2	volae
36	Cocconeis disculus	9.5	5.5	bilateral	monoraphid	hyaline to complex	2	volae
37	Cocconeis disculus	10.75	6.75	bilateral	monoraphid	hyaline to complex	2	volae
38	Cocconeis disculus	11.25	7	bilateral	monoraphid	hyaline to complex	2	volae
39	Diploneis chersonensis	33	13.5	bilateral	biraphid	hyaline to complex	2	unoccluded
40	Diploneis chersonensis	67.25	23.5	bilateral	biraphid	hyaline to complex	2	unoccluded
41	Diploneis chersonensis	54.5	16.75	bilateral	biraphid	hyaline to complex	2	unoccluded
42	Nitschia panduriformis	10	3.75	bilateral	biraphid	complex	3	unoccluded
43	Nitschia panduriformis	10	4	bilateral	biraphid	complex	3	unoccluded
44	Nitschia panduriformis	10	4.25	bilateral	biraphid	hyaline to complex	2	unoccluded
45	Nitschia panduriformis	20.25	11.75	bilateral	biraphid	complex	3	unoccluded
46	Nitschia panduriformis	34.25	18	bilateral	biraphid	complex	3	unoccluded
47	Nitschia panduriformis	7.75	2.5	bilateral	biraphid	complex	3	unoccluded
48	Nitschia panduriformis	9.25	2.5	bilateral	biraphid	complex	3	unoccluded
49	Nitschia panduriformis	19.5	7.75	bilateral	biraphid	complex	3	unoccluded
50	Nitschia panduriformis	19.75	2.75	bilateral	biraphid	complex	3	unoccluded
51	Nitschia panduriformis	20	7.75	bilateral	biraphid	complex	3	unoccluded
52	Nitschia panduriformis	22.5	10	bilateral	biraphid	complex	3	unoccluded
53	Nitschia panduriformis	25	9.5	bilateral	biraphid	complex	3	unoccluded
54	Nitschia panduriformis	38	9.5	bilateral	biraphid	complex	3	unoccluded
55	Nitschia panduriformis	7.5	2.75	bilateral	biraphid	complex	3	unoccluded
56	Nitschia panduriformis	8	2.25	bilateral	biraphid	complex	3	unoccluded
57	Nitschia panduriformis	9.5	2.25	bilateral	biraphid	complex	3	unoccluded

58	Nitschia panduriformis	19.5	8.75	bilateral	biraphid	complex	3	unoccluded
59	Nitschia panduriformis	22.5	7	bilateral	biraphid	complex	3	unoccluded
Mean:		**16.87**	**8.96**				**2.39**	
Standard Deviation:		**14.46**	**11.44**				**0.49**	

Appendix K. Shallow water Station DET-IB taxonomic composition.

Species	No.	Species	No.	Species	No.
Achnanthes conspicua	2	*Fragilaria pinnata*	14	*Nitschia Brittoni*	3
Achnanthes hauckiana	5	*Fragillaria* Sp. a	2	*Nitschia calciola*	1
Achnanthes longipes	9	*Gyrosigma acuminatum*	1	*Nitschia coarctata*	1
Achnanthes tenuis	1	*Gyrosigma balticum*	3	*Nitschia constricta*	3
Amphora arenaria	2	*Gyrosigma beaufortianum*	2	*Nitschia frustulum*	1
Amphora coffeaeformis	1	*Gyrosigma fasciola*	2	*Nitschia granulata*	1
Amphora ovalis	24	*Gyrosigma simile*	1	*Nitschia grossestriata*	4
Amphora pseudoholsatica	1	*Melosira nummuloides*	8	*Nitschia järnefeltii*	1
Amphora subturgida	12	*Navicula agnita*	1	*Nitschia longa*	3
Amphora tenerrima	2	*Navicula ammophila*	2	*Nitschia navicularis*	1
Amphora ventricosa	16	*Navicula Bastowii*	16	*Nitschia panduriformis*	10
Amphora wisei	1	*Navicula cincta*	5	*Nitschia proxima*	1
Amphora Sp. A	1	*Navicula directa*	4	*Nitschia sigma*	6
Amphora Sp. B	2	*Navicula diversistriata*	2	*Nitschia valdestriata*	1
Amphora Sp. C	2	*Navicula eidrigiana*	3	*Nitschia* Sp. A	3
Amphora Sp. D	1	*Navicula elginesis*	7	*Nitschia* Sp. C	1
Amphora Sp. E	1	*Navicula fenestrella*	7	*Nitschia* Sp. D	1
Bacillaria paxillifer	5	*Navicula formenterae*	1	*Odontella aurita*	1
Biddulphia alternans	1	*Navicula Hummii*	1	*Odontella rhombus form trigona*	1
Biddulphia pulchella	2	*Navicula jeffreyi*	1	*Opephora marina*	7
Campylosira cymbelliformis	1	*Navicula menisculus*	21	*Opephora martyi*	20
Cerataulus radiatus	1	*Navicula oculiformis*	2	*Opephora schwartzii*	1
Cocconeis disculus	11	*Navicula pseudolanceolata*	9	*Paralia sulcata*	6
Cocconeis distans	4	*Navicula pullis*	4	*Plagiogramma Wallichianum*	1
Cocconeis pinnata	12	*Navicula rupicola*	12	*Rhopalodia musculus*	2
Cocconeis scutellum	5	*Navicula salinarum*	17	*Thallassiosira decipiens*	2
Cyclotella striata	2	*Navicula Sovereignae*	1	*Thallassiosira eccentrica*	8
Delphenies surirella	27	*Navicula submitis*	2	*Thallassiosira* Sp. A	5
Dimeregramma minor	21	*Navicula tripunctata*	8	Unknown Sp. A	1
Diploneis bombus	4	*Navicula* Sp. A	3	Unknown Sp. B	2
Diploneis Smithii	1	*Navicula* Sp. B	1	Unknown Sp. C	1
Diploneis vetula	3	*Navicula* Sp. C	1	Unknown Sp. D	1
Entomoneis alata	4	*Navicula* Sp. D	6	Unknown Sp. E	1
Eunotogramma marinum	2	*Navicula* Sp. E	1	Unknown Sp. F	1
Fallacia forcipata	8	*Nitschia amphibia*	15	Unknown Sp. G	2
Fallacia litoricola	7	*Nitschia angularis*	5		

Appendix L. Shallow water Station DET I-B morphometric measurements.

	Species	Apical Axis (µm)	Transapical Axis (µm)	Symmetry	Raphe Type	Ornamentation	Index	Dominant Ornamentation Type
1	*Amphora arenaria*	7	16	bilateral	biraphid	complex	3	unoccluded
2	*Amphora coffeaeformis*	42.5	6.75	bilateral	biraphid	hyaline to complex	2	unoccluded
3	*Amphora ovalis*	28.5	10.25	bilateral	biraphid	hyaline to complex	2	unoccluded
4	*Amphora ovalis*	28.25	14.5	bilateral	biraphid	hyaline to complex	2	unoccluded
5	*Amphora ovalis*	24	24.5	bilateral	biraphid	hyaline to complex	2	unoccluded
6	*Amphora similis*	12.75	8.25	bilateral	biraphid	hyaline to complex	2	hymenate
7	*Amphora tenerrima*	12.25	8	bilateral	biraphid	hyaline to complex	2	unoccluded
8	*Amphora tenerrima*	16.25	3.75	bilateral	biraphid	hyaline to complex	2	multiple
9	*Amphora ventricosa*	15.25	7.5	bilateral	biraphid	complex	3	unoccluded
10	*Amphora ventricosa*	20.75	4	bilateral	biraphid	complex	3	unoccluded
11	*Amphora ventricosa*	17.75	3.75	bilateral	biraphid	complex	3	unoccluded
12	*Amphora wisei*	14	3.5	bilateral	biraphid	hyaline to complex	2	unoccluded
13	*Amphora* Sp. B	30.25	20.25	bilateral	biraphid	complex	3	unoccluded
14	*Amphora* Sp. C	19.75	6.25	bilateral	biraphid	hyaline to complex	2	unoccluded
15	*Amphora* Sp. D	8	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
16	*Amphora* Sp. E	32.75	6.5	bilateral	biraphid	hyaline to complex	2	unoccluded
17	*Bacillaria paxillifer*	66.75	5.75	bilateral	biraphid	complex	3	hymenate
18	*Bacillaria paxillifer*	51.25	4.75	bilateral	biraphid	complex	3	hymenate
19	*Bacillaria paxillifer*	67.5	4.75	bilateral	biraphid	complex	3	hymenate
20	*Bacillaria paxillifer*	64.75	4.75	bilateral	biraphid	complex	3	hymenate
21	*Biddulphia pulchella*	46.75	21.75	bilateral	araphid	complex	3	multiple
22	*Campylosira cymbelliformis*	19	4.75	radial-cylind	araphid	complex	3	rotae
23	*Cerataulus radiatus*	29	29	radial-disc	araphid	complex	3	unoccluded
24	*Cocconeis disculus*	23.75	10	bilateral	monoraphid	hyaline to complex	2	unoccluded
25	*Cocconeis disculus*	11.75	4.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
26	*Cocconeis disculus*	8.5	5.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
27	*Cocconeis disculus*	10.25	9.75	bilateral	monoraphid	hyaline to complex	2	unoccluded

28	*Cocconeis disculus*	10.25	5.5	bilateral	monoraphid	hyaline to complex	2	hymenate
29	*Cocconeis disculus*	11.5	5.25	bilateral	monoraphid	complex	3	hymenate
30	*Cocconeis disculus*	23	15	bilateral	monoraphid	complex	3	hymenate
31	*Cocconeis pinnata*	8.25	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
32	*Cyclotella striata*	8.75	8.75	radial-cylind	araphid	hyaline to complex	2	unoccluded
33	*Cyclotella striata*	13.25	13.25	radial-cylind	araphid	complex	3	unoccluded
34	*Delphenies surirella*	13.25	8.5	bilateral	araphid	hyaline to complex	2	rotae
35	*Delphenies surirella*	13.75	8.25	bilateral	araphid	hyaline to complex	2	rotae
36	*Delphenies surirella*	10.25	8.25	bilateral	araphid	hyaline to complex	2	rotae
37	*Delphenies surirella*	8.75	6.25	bilateral	araphid	hyaline to complex	2	rotae
38	*Delphenies surirella*	8.25	6.25	bilateral	araphid	hyaline to complex	2	rotae
39	*Delphenies surirella*	14.5	8.75	bilateral	araphid	hyaline to complex	2	rotae
40	*Delphenies surirella*	21.5	12	bilateral	araphid	hyaline to complex	2	rotae
41	*Delphenies surirella*	11.75	8.75	bilateral	araphid	hyaline to complex	2	rotae
42	*Delphenies surirella*	9.75	6.25	bilateral	araphid	hyaline to complex	2	rotae
43	*Delphenies surirella*	19.75	11.5	bilateral	araphid	hyaline to complex	2	rotae
44	*Delphenies surirella*	11.5	8	bilateral	araphid	hyaline to complex	2	rotae
45	*Delphenies surirella*	8.75	6	bilateral	araphid	hyaline to complex	2	rotae
46	*Delphenies surirella*	5.75	3.25	bilateral	araphid	hyaline to complex	2	rotae
47	*Delphenies surirella*	17.5	10	bilateral	araphid	complex	3	rotae
48	*Dimeregramma minor*	10.75	8	bilateral	araphid	hyaline to complex	2	multiple
49	*Dimeregramma minor*	16.25	6.75	bilateral	araphid	hyaline to complex	2	multiple
50	*Dimeregramma minor*	14.25	6.75	bilateral	araphid	hyaline to complex	2	multiple
51	*Dimeregramma minor*	15.25	6.25	bilateral	araphid	hyaline to complex	2	multiple
52	*Dimeregramma minor*	10.25	6.75	bilateral	araphid	hyaline to complex	2	multiple
53	*Dimeregramma minor*	20.5	6.5	bilateral	araphid	hyaline to complex	2	multiple
54	*Dimeregramma minor*	10.25	5.75	bilateral	araphid	hyaline to complex	2	multiple
55	*Dimeregramma minor*	20.25	9	bilateral	araphid	hyaline to complex	2	multiple
56	*Dimeregramma minor*	13.75	7.5	bilateral	araphid	hyaline to complex	2	multiple
57	*Entomoneis alata*	16	14.5	bilateral	biraphid	complex	3	multiple
58	*Entomoneis alata*	12.75	14.75	bilateral	biraphid	complex	3	multiple
59	*Entomoneis alata*	28	17.5	bilateral	biraphid	complex	3	multiple

60	*Entomoneis alata*	12.25	14.5	bilateral	biraphid	hyaline to complex	2	hymenate
61	*Fallacia forcipata*	16	8.25	bilateral	biraphid	complex	3	unoccluded
62	*Fallacia forcipata*	16.25	5.75	bilateral	biraphid	complex	3	unoccluded
63	*Fallacia forcipata*	32.75	13	bilateral	biraphid	complex	3	unoccluded
64	*Fallacia forcipata*	18.75	7.5	bilateral	biraphid	complex	3	unoccluded
65	*Fallacia forcipata*	24	8.25	bilateral	biraphid	complex	3	unoccluded
66	*Fallacia forcipata*	17.75	7.25	bilateral	biraphid	complex	3	unoccluded
67	*Fallacia forcipata*	16.5	8.75	bilateral	biraphid	complex	3	unoccluded
68	*Fallacia litoricola*	30	14.5	bilateral	biraphid	complex	3	unoccluded
69	*Fallacia litoricola*	17.75	7.5	bilateral	biraphid	complex	3	unoccluded
70	*Fallacia litoricola*	16.25	7.75	bilateral	biraphid	complex	3	unoccluded
71	*Fallacia litoricola*	16.5	9.25	bilateral	biraphid	complex	3	unoccluded
72	*Fallacia litoricola*	17.5	7.75	bilateral	biraphid	complex	3	unoccluded
73	*Fragillaria* Sp. a	6.25	6.25	bilateral	araphid	hyaline to complex	2	unoccluded
74	*Fragillaria* Sp. a	9.5	3.75	bilateral	araphid	hyaline to complex	2	unoccluded
75	*Gyrosigma acuminatum*	126.5	17.5	bilateral	biraphid	complex	3	unoccluded
76	*Gyrosigma balticum*	86.25	12.5	bilateral	biraphid	complex	3	unoccluded
77	*Gyrosigma balticum*	70.25	10	bilateral	biraphid	complex	3	unoccluded
78	*Gyrosigma balticum*	500	45	bilateral	biraphid	complex	3	unoccluded
79	*Gyrosigma beaufortianum*	67.5	8	bilateral	biraphid	complex	3	unoccluded
80	*Gyrosigma beaufortianum*	70	7.5	bilateral	biraphid	complex	3	unoccluded
81	*Gyrosigma fasciola*	93.75	13	bilateral	biraphid	complex	3	unoccluded
82	*Gyrosigma fasciola*	83.25	12	bilateral	biraphid	complex	3	unoccluded
83	*Gyrosigma simile*	87.5	14.25	bilateral	biraphid	complex	3	unoccluded
84	*Melosira nummuloides*	4.25	4.25	radial-cylind	araphid	complex	3	multiple
85	*Melosira nummuloides*	4.5	4.5	radial-cylind	araphid	complex	3	multiple
86	*Melosira nummuloides*	6.75	6.75	radial-cylind	araphid	complex	3	multiple
87	*Melosira nummuloides*	13	13	radial-cylind	araphid	complex	3	multiple
88	*Melosira nummuloides*	6	6	radial-cylind	araphid	complex	3	multiple
89	*Melosira nummuloides*	8.25	8.25	radial-cylind	araphid	complex	3	multiple
90	*Melosira nummuloides*	7	7	radial-cylind	araphid	complex	3	multiple
91	*Melosira nummuloides*	7.25	7.25	radial-cylind	araphid	complex	3	multiple

92	*Navicula agnita*	59.75	11.75	bilateral	biraphid	hyaline to complex	2	unoccluded
93	*Navicula Bastowii*	22.75	7.25	bilateral	biraphid	hyaline to complex	2	unoccluded
94	*Navicula Bastowii*	21.25	9.75	bilateral	biraphid	hyaline to complex	2	unoccluded
95	*Navicula Bastowii*	21.25	9.5	bilateral	biraphid	hyaline to complex	2	unoccluded
96	*Navicula cincta*	20.25	3.5	bilateral	biraphid	complex	3	unoccluded
97	*Navicula cincta*	12.75	2.25	bilateral	biraphid	hyaline to complex	2	unoccluded
98	*Navicula cincta*	17.5	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
99	*Navicula cincta*	20.25	4.25	bilateral	biraphid	hyaline to complex	2	unoccluded
100	*Navicula directa*	64.5	9.75	bilateral	biraphid	complex	3	multiple
101	*Navicula directa*	54.25	13.25	bilateral	biraphid	complex	3	multiple
102	*Navicula directa*	34.5	7.75	bilateral	biraphid	complex	3	multiple
103	*Navicula diversistriata*	17.25	10.25	bilateral	biraphid	complex	3	multiple
104	*Navicula eidrigiana*	16.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
105	*Navicula eidrigiana*	18.75	2.75	bilateral	biraphid	complex	3	unoccluded
106	*Navicula fenestrella*	8.25	4.75	bilateral	biraphid	hyaline to complex	2	hymenate
107	*Navicula fenestrella*	5.5	3	bilateral	biraphid	hyaline to complex	2	hymenate
108	*Navicula fenestrella*	8.75	3.75	bilateral	biraphid	hyaline to complex	2	hymenate
109	*Navicula fenestrella*	8.5	5	bilateral	biraphid	hyaline to complex	2	hymenate
110	*Navicula fenestrella*	7.75	3.75	bilateral	biraphid	hyaline to complex	2	hymenate
111	*Navicula formenterae*	14.25	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
112	*Navicula jeffreyi*	8.25	2.75	bilateral	biraphid	hyaline to complex	2	hymenate
113	*Navicula menisculus*	22.5	6.25	bilateral	biraphid	hyaline to complex	2	unoccluded
114	*Navicula menisculus*	11.5	5.25	bilateral	biraphid	hyaline to complex	2	unoccluded
115	*Navicula menisculus*	20.5	5.5	bilateral	biraphid	complex	3	unoccluded
116	*Navicula menisculus*	25	5.5	bilateral	biraphid	complex	3	unoccluded
117	*Navicula menisculus*	21	5.25	bilateral	biraphid	complex	3	unoccluded
118	*Navicula menisculus*	29.75	7	bilateral	biraphid	complex	3	unoccluded
119	*Navicula oculiformis*	15.75	8.25	bilateral	biraphid	hyaline to complex	2	multiple
120	*Navicula oculiformis*	18.25	12	bilateral	biraphid	hyaline to complex	2	multiple
121	*Navicula pullus*	9	6.75	bilateral	biraphid	hyaline to complex	2	hymenate
122	*Navicula pullus*	8.75	4.25	bilateral	biraphid	hyaline to complex	2	hymenate
123	*Navicula pullus*	7.5	4.25	bilateral	biraphid	hyaline to complex	2	hymenate

124	*Navicula pullus*	9	4	bilateral	biraphid	hyaline to complex	2	multiple
125	*Navicula salinarum*	27.25	5.75	bilateral	biraphid	hyaline to complex	2	unoccluded
126	*Navicula salinarum*	17.5	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
127	*Navicula salinarum*	21.75	5.25	bilateral	biraphid	hyaline to complex	2	unoccluded
128	*Navicula salinarum*	12.5	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
129	*Navicula salinarum*	20.75	5	bilateral	biraphid	hyaline to complex	2	unoccluded
130	*Navicula salinarum*	17.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
131	*Navicula salinarum*	17.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
132	*Navicula salinarum*	25.75	5	bilateral	biraphid	hyaline to complex	2	unoccluded
133	*Navicula salinarum*	17.75	5	bilateral	biraphid	hyaline to complex	2	unoccluded
134	*Navicula salinarum*	14.75	5.5	bilateral	biraphid	hyaline to complex	2	unoccluded
135	*Navicula salinarum*	24.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
136	*Navicula salinarum*	12.25	4	bilateral	biraphid	hyaline to complex	2	unoccluded
137	*Navicula salinarum*	13.75	5	bilateral	biraphid	hyaline to complex	2	unoccluded
138	*Navicula salinarum*	18.75	5	bilateral	biraphid	hyaline to complex	2	unoccluded
139	*Navicula salinarum*	15.5	6.25	bilateral	biraphid	hyaline to complex	2	unoccluded
140	*Navicula* Sp. A	19.5	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
141	*Navicula* Sp. B	15.5	4.5	bilateral	biraphid	hyaline to complex	2	multiple
142	*Navicula* Sp. C	6.75	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
143	*Navicula* Sp. a	9	4.25	bilateral	biraphid	hyaline to complex	2	multiple
144	*Navicula* Sp. a	8.75	4.25	bilateral	biraphid	hyaline to complex	2	multiple
145	*Navicula* Sp. a	5.5	4	bilateral	biraphid	hyaline to complex	2	multiple
146	*Navicula* Sp. a	9	4.25	bilateral	biraphid	hyaline to complex	2	multiple
147	*Nitschia amphibia*	19.25	2.5	bilateral	biraphid	complex	3	multiple
148	*Nitschia amphibia*	21.75	2.75	bilateral	biraphid	complex	3	multiple
149	*Nitschia amphibia*	9.5	2.25	bilateral	biraphid	complex	3	multiple
150	*Nitschia amphibia*	30.75	4.25	bilateral	biraphid	complex	3	multiple
151	*Nitschia amphibia*	12.25	2	bilateral	biraphid	complex	3	multiple
152	*Nitschia amphibia*	6.5	2.25	bilateral	biraphid	hyaline to complex	2	hymenate
153	*Nitschia amphibia*	6.25	2	bilateral	biraphid	hyaline to complex	2	hymenate
154	*Nitschia Brittoni*	25.5	5	bilateral	biraphid	complex	3	multiple
155	*Nitschia Brittoni*	41.15	10.5	bilateral	biraphid	complex	3	multiple

156	*Nitschia Brittoni*	33.25	10	bilateral	biraphid	complex	3	multiple
157	*Nitschia calciola*	25	5	bilateral	biraphid	complex	3	multiple
158	*Nitschia coarctata*	22.75	9	bilateral	biraphid	complex	3	multiple
159	*Nitschia constricta*	32.75	10.25	bilateral	biraphid	complex	3	multiple
160	*Nitschia constricta*	36.75	5.5	bilateral	biraphid	complex	3	multiple
161	*Nitschia frustulum*	21.25	4.25	bilateral	biraphid	complex	3	hymenate
162	*Nitschia grossestriata*	51.75	8.5	bilateral	biraphid	complex	3	unoccluded
163	*Nitschia grossestriata*	50.25	8.5	bilateral	biraphid	complex	3	unoccluded
164	*Nitschia grossestriata*	38.25	9.5	bilateral	biraphid	complex	3	unoccluded
165	*Nitschia longa*	61.25	5	bilateral	biraphid	complex	3	hymenate
166	*Nitschia navicularis*	32.75	7.5	bilateral	biraphid	complex	3	unoccluded
167	*Nitschia panduriformis*	24.25	8.5	bilateral	biraphid	complex	3	unoccluded
168	*Nitschia panduriformis*	22.25	7.5	bilateral	biraphid	complex	3	unoccluded
169	*Nitschia panduriformis*	27.5	10.5	bilateral	biraphid	complex	3	unoccluded
170	*Nitschia panduriformis*	33.25	15	bilateral	biraphid	complex	3	unoccluded
171	*Nitschia panduriformis*	7.25	3.75	bilateral	biraphid	complex	3	unoccluded
172	*Nitschia panduriformis*	9.75	4.25	bilateral	biraphid	complex	3	unoccluded
173	*Nitschia proxima*	40.25	3.5	bilateral	biraphid	complex	3	hymenate
174	*Nitschia sigma*	38.75	3	bilateral	biraphid	complex	3	hymenate
175	*Nitschia sigma*	65	7.5	bilateral	biraphid	complex	3	unoccluded
176	*Nitschia valdestriata*	12.75	4.75	bilateral	biraphid	complex	3	hymenate
177	*Nitschia* Sp. A	62.25	8.5	bilateral	biraphid	hyaline to complex	2	unoccluded
178	*Nitschia* Sp. B	33.25	10.25	bilateral	biraphid	hyaline to complex	2	unoccluded
179	*Odontella aurita*	17.5	25	bilateral	araphid	complex	3	multiple
180	*Odontella rhombus*	38	38	bilateral	araphid	complex	3	unoccluded
181	*Opephora marina*	13.5	2.5	bilateral	araphid	hyaline to complex	2	multiple
182	*Opephora marina*	11.75	2.5	bilateral	araphid	hyaline to complex	2	multiple
183	*Opephora marina*	12.25	2.5	bilateral	araphid	hyaline to complex	2	multiple
184	*Opephora martyii*	13.25	4.25	bilateral	araphid	complex	3	cribera
185	*Opephora martyii*	7.75	4	bilateral	araphid	complex	3	cribera
186	*Opephora martyii*	6.75	4	bilateral	araphid	complex	3	cribera
187	*Opephora martyii*	9.25	4.5	bilateral	araphid	complex	3	cribera

188	*Opephora martyii*	17.25	5.25	bilateral	araphid	complex	3	cribera
189	*Opephora martyii*	5.75	2.25	bilateral	araphid	hyaline to complex	2	cribera
190	*Opephora martyii*	8.75	3.75	bilateral	araphid	complex	3	cribera
191	*Paralia sulcata*	22.5	22.5	radial-cylind	araphid	hyaline	1	none
192	*Plagiogramma Wallichianum*	33.25	7	bilateral	araphid	complex	3	multiple
193	*Thallassiosira deipiens*	11.75	11.75	radial-disc	araphid	complex	3	unoccluded
194	*Thallassiosira* Sp. A	14.75	14.75	radial-disc	araphid	complex	3	unoccluded
195	*Thallassiosira* Sp. A	4	4	radial-disc	araphid	complex	3	unoccluded
196	*Unknown* Sp. C	21.25	21.25	bilateral	araphid	complex	3	unoccluded
197	*Unknown* Sp. D	12.75	4.25	radial cylind	araphid	hyaline to complex	2	none
198	*Unknown* Sp. E	7	7	radial cylind	araphid	complex	3	hymenate
199	*Unknown* Sp. F	11.75	11.75	radial cylind	araphid	complex	3	multiple
200	*Unknown* Sp. G	11.25	11.25	bilateral	araphid	hyaline to complex	2	unoccluded
Mean:		**24.79**	**7.87**				**2.50**	
Standard Deviation:		**38.71**	**5.70**				**0.51**	

Appendix M. Shallow water Station ND IV-D taxonomic composition.

Species	No.	Species	No.	Species	No.
Achnanthes conspicua	1	*Eunotogramma laea*	1	*Navicula tripunctata*	3
Achnanthes hauckiana	1	*Eunotogramma marinum*	3	*Navicula* Sp. E	1
Achnanthes longipes	1	*Eunotogramma rostratum*	3	*Navicula* Sp. G	4
Actinoptychus splendens	2	*Fallacia forcipata*	3	*Navicula* Sp. a	6
Amphora arenaria	1	*Fallacia litoricola*	9	*Nitschia amphibia*	23
Amphora grannulata	4	*Gyrosigma balticum*	2	*Nitschia angularis*	2
Amphora ovalis	8	*Gyrosigma beaufortianum*	4	*Nitschia Brittoni*	3
Amphora subturgida	3	*Gyrosigma fasciola*	2	*Nitschia coarctata*	7
Amphora tenerrima	3	*Gyrosigma simile*	3	*Nitschia frustulum*	1
Amphora ventricosa	4	*Melosira nummuloides*	37	*Nitschia grossestriata*	3
Amphora Sp. A	3	*Navicula agnita*	1	*Nitschia longa*	5
Amphora Sp. B	1	*Navicula ammophila*	6	*Nitschia navicularis*	3
Amphora Sp. D	3	*Navicula Bastowii*	10	*Nitschia panduriformis*	22
Bacillaria paxillifer	4	*Navicula cincta*	3	*Nitschia proxima*	1
Campylosira cymbelliformis	1	*Navicula directa*	9	*Nitschia sigma*	6
Cocconeis disculoides	1	*Navicula diversistriata*	2	*Nitschia sigmaformis*	1
Cocconeis disculus	16	*Navicula elginensis*	4	*Nitschia valdestriata*	1
Cocconeis distans	3	*Navicula fenestrella*	14	*Nitschia* Sp. A	1
Cocconeis guttata	1	*Navicula formenterae*	2	*Odontella aurita*	1
Cocconeis pinnata	7	*Navicula Hummii*	9	*Opephora marina*	10
Cocconeis placentula	1	*Navicula jeffreyi*	2	*Opephora martyi*	15
Cocconeis scutellum	5	*Navicula menisculus*	5	*Paralia sulcata*	18
Coscinodiscus devius	2	*Navicula misella*	1	*Plagiogramma pygmaeum*	2
Cyclotella striata	12	*Navicula pennata*	1	*Pleurosigma distinguendum*	2
Cymatosira lorenziana	2	*Navicula pseudolanceolata*	8	*Rhopalodia musculus*	1
Delphenies surirella	23	*Navicula pullus*	1	*Thalassiosira decipiens*	13
Dimeregramma minor	14	*Navicula restituta*	3	*Thalassiosira eccentrica*	2
Diploneis bombus	5	*Navicula rupicola*	1	*Thalassiosira* Sp. A	9
Diploneis Smithii	3	*Navicula salinarum*	46	*Thalassiosira weissflogii*	1
Entomoneis alata	2	*Navicula Sovereignae*	1		

Appendix N. Shallow water Station ND IV-D morphometric measurements.

	Species	Apical Axis (µm)	Transapical Axis (µm)	Symmetry	Raphe Type	Ornamentation	Index	Dominant Ornamentation Type
1	*Amphiprora similis*	72.75	23	bilateral	biraphid	complex	3	multiple
2	*Amphora grannulata*	35.5	14	bilateral	biraphid	hyaline to complex	2	unoccluded
3	*Amphora grannulata*	21	7.5	bilateral	biraphid	hyaline to complex	2	unoccluded
4	*Amphora grannulata*	30	14.5	bilateral	biraphid	hyaline to complex	2	unoccluded
5	*Amphora grannulata*	20	6.75	bilateral	biraphid	hyaline to complex	2	unoccluded
6	*Amphora ovalis*	23.25	12.5	bilateral	biraphid	hyaline to complex	2	unoccluded
7	*Amphora ovalis*	10.75	12	bilateral	biraphid	hyaline to complex	2	unoccluded
8	*Amphora ovalis*	11.25	4.25	bilateral	biraphid	hyaline to complex	2	unoccluded
9	*Amphora ovalis*	30.5	12.75	bilateral	biraphid	hyaline to complex	2	unoccluded
10	*Amphora tenerrima*	9.75	3.75	bilateral	biraphid	hyaline to complex	2	multiple
11	*Amphora tenerrima*	18.25	13	bilateral	biraphid	hyaline to complex	2	multiple
12	*Amphora* Sp. D	11.25	4.5	bilateral	biraphid	hyaline to complex	2	unoccluded
13	*Amphora* Sp. D	11.25	4.5	bilateral	biraphid	hyaline to complex	2	unoccluded
14	*Cocconeis disculoides*	36.25	17	bilateral	monoraphid	complex	3	unoccluded
15	*Cocconeis disculus*	12.5	5.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
16	*Cocconeis disculus*	11	5.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
17	*Cocconeis disculus*	12.5	6.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
18	*Cocconeis distans*	25	14.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
19	*Cocconeis guttata*	7.75	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
20	*Cocconeis pinnata*	10.5	4.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
21	*Cocconeis pinnata*	9.75	4.25	bilateral	monoraphid	hyaline to complex	2	unoccluded
22	*Cocconeis pinnata*	11.5	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
23	*Cocconeis pinnata*	7.25	3.5	bilateral	monoraphid	hyaline to complex	2	unoccluded
24	*Cococneis pinnata*	9.75	3.75	bilateral	monoraphid	hyaline to complex	2	unoccluded
25	*Coscinodiscus devius*	19.25	19.25	radial/disc	araphid	complex	3	unoccluded
26	*Cyclotella meneghiniana*	17.75	17.75	radial/cylind	araphid	hyaline to complex	2	multiple
27	*Cyclotella meneghiniana*	20.5	20.5	radial/cylind	araphid	hyaline to complex	2	multiple
28	*Cyclotella meneghiniana*	28.25	28.25	radial/cylind	araphid	hyaline to complex	2	multiple

29	*Cyclotella striata*	28.75	28.75	radial/cylind	araphid	hyaline to complex	2	unoccluded
30	*Cyclotella striata*	12.5	12.5	radial/cylind	araphid	hyaline to complex	2	unoccluded
31	*Delphenies surirella*	12.25	6	bilateral	araphid	hyaline to complex	2	rotae
32	*Delphenies surirella*	13.75	7	bilateral	araphid	hyaline to complex	2	rotae
33	*Delphenies surirella*	3.25	9	bilateral	araphid	hyaline to complex	2	rotae
34	*Delphenies surirella*	9.25	5	bilateral	araphid	hyaline to complex	2	rotae
35	*Delphenies surirella*	11.5	6.25	bilateral	araphid	hyaline to complex	2	rotae
36	*Delphenies surirella*	11.75	4.25	bilateral	araphid	hyaline to complex	2	rotae
37	*Delphenies surirella*	6.75	6.25	bilateral	araphid	hyaline to complex	2	rotae
38	*Delphenies surirella*	7.75	5	bilateral	araphid	hyaline to complex	2	rotae
39	*Delphenies surirella*	11.75	5.75	bilateral	araphid	hyaline to complex	2	rotae
40	*Delphenies surirella*	12.25	6	bilateral	araphid	hyaline to complex	2	rotae
41	*Delphenies surirella*	13.5	4.75	bilateral	araphid	hyaline to complex	2	rotae
42	*Delphenies surirella*	7.5	3.75	bilateral	araphid	hyaline to complex	2	rotae
43	*Delphenies surirella*	12	9.5	bilateral	araphid	hyaline to complex	2	rotae
44	*Delphenies surirella*	17	6	bilateral	araphid	hyaline to complex	2	rotae
45	*Delphenies surirella*	12.5	8.5	bilateral	araphid	hyaline to complex	2	rotae
46	*Dimeregramma minor*	18.25	3.5	bilateral	araphid	hyaline to complex	2	multiple
47	*Diploneis bombus*	54.5	13.75	bilateral	biraphid	hyaline to complex	2	multiple
48	*Diploneis smithii*	18.25	5.75	bilateral	biraphid	hyaline to complex	2	volae
49	*Gyrosigma balticum*	155	23.25	bilateral	biraphid	complex	3	unoccluded
50	*Gyrosigma beafortianum*	60.25	6.5	bilateral	biraphid	complex	3	unoccluded
51	*Gyrosigma beaufortianum*	97	10.25	bilateral	biraphid	complex	3	unoccluded
52	*Gyrosigma beaufortianum*	67	7.25	bilateral	biraphid	complex	3	unoccluded
53	*Gyrosigma beaufortianum*	57	6	bilateral	biraphid	complex	3	unoccluded
54	*Gyrosigma fasciola*	75.5	8.75	bilateral	biraphid	complex	3	unoccluded
55	*Gyrosigma fasciola*	93.75	9.75	bilateral	biraphid	complex	3	unoccluded
56	*Gyrosigma simile*	86.75	12.5	bilateral	biraphid	complex	3	unoccluded
57	*Gyrosigma simile*	95.5	11	bilateral	biraphid	complex	3	unoccluded
58	*Melosira nummuloides*	20	20	radial/cylind	araphid	complex	3	multiple
59	*Melosira nummuloides*	9.25	9.25	radial/cylind	araphid	complex	3	multiple
60	*Melosira nummuloides*	11	11	radial/cylind	araphid	complex	3	multiple

61	*Melosira nummuloides*	8.75	8.75	radial/cylind	araphid	complex	3	multiple
62	*Melosira nummuloides*	11.25	11.25	radial/cylind	araphid	complex	3	multiple
63	*Melosira nummuloides*	13	13	radial/cylind	araphid	complex	3	multiple
64	*Melosira nummuloides*	9.75	9.75	radial/cylind	araphid	complex	3	multiple
65	*Melosira nummuloides*	8.75	8.75	radial/cylind	araphid	complex	3	multiple
66	*Melosira nummuloides*	9.5	9.5	radial/cylind	araphid	complex	3	multiple
67	*Melosira nummuloides*	8.75	8.75	radial/cylind	araphid	complex	3	multiple
68	*Melosira nummuloides*	8	8	radial/cylind	araphid	complex	3	multiple
69	*Melosira nummuloides*	6.75	6.75	radial/cylind	araphid	complex	3	multiple
70	*Melosira nummuloides*	9	9	radial/cylind	araphid	complex	3	multiple
71	*Melosira nummuloides*	11.75	11.75	radial/cylind	araphid	complex	3	multiple
72	*Melosira nummuloides*	8.75	8.75	radial/cylind	araphid	complex	3	multiple
73	*Melosira nummuloides*	10.25	10.25	radial/cylind	araphid	complex	3	multiple
74	*Melosira nummuloides*	10.5	10.5	radial/cylind	araphid	complex	3	multiple
75	*Melosira nummuloides*	11.5	11.5	radial/cylind	araphid	complex	3	multiple
76	*Melosira nummuloides*	11.25	11.25	radial/cylind	araphid	complex	3	multiple
77	*Melosira nummuloides*	13.5	13.5	radial/cylind	araphid	complex	3	multiple
78	*Melosira nummuloides*	8.75	8.75	radial/cylind	araphid	complex	3	multiple
79	*Navicula directa*	62.5	10.5	bilateral	biraphid	complex	3	multiple
80	*Navicula fenestrella*	10.75	4.75	bilateral	biraphid	hyaline to complex	2	hymenate
81	*Navicula fenestrella*	15.5	3	bilateral	biraphid	hyaline to complex	2	hymenate
82	*Navicula fenestrella*	10.25	4.25	bilateral	biraphid	hyaline to complex	2	hymenate
83	*Navicula fenestrella*	7.75	4.25	bilateral	biraphid	hyaline to complex	2	hymenate
84	*Navicula fenestrella*	9.5	4.5	bilateral	biraphid	hyaline to complex	2	hymenate
85	*Navicula forcipata*	29.25	10.25	bilateral	biraphid	complex	3	unoccluded
86	*Navicula forcipata*	15.25	7.5	bilateral	biraphid	complex	3	unoccluded
87	*Navicula Humii*	16.75	10.25	bilateral	biraphid	hyaline to complex	2	unoccluded
88	*Navicula jeffreyi*	9.25	2	bilateral	biraphid	hyaline to complex	2	hymenate
89	*Navicula jeffreyi*	9.25	2.5	bilateral	biraphid	hyaline to complex	2	hymenate
90	*Navicula litoricola*	23	9	bilateral	biraphid	complex	3	unoccluded
91	*Navicula litoricola*	20.5	8.5	bilateral	biraphid	complex	3	unoccluded
92	*Navicula litoricola*	19.5	7.75	bilateral	biraphid	complex	3	unoccluded

93	*Navicula litoricola*	21.25	9.75	bilateral	biraphid	complex	3	unoccluded
94	*Navicula litoricola*	17	8.25	bilateral	biraphid	complex	3	unoccluded
95	*Navicula litoricola*	25.25	9.25	bilateral	biraphid	complex	3	unoccluded
96	*Navicula menisculus*	12.25	4.5	bilateral	biraphid	hyaline to complex	2	unoccluded
97	*Navicula misella*	18.25	5.5	bilateral	biraphid	hyaline to complex	2	unoccluded
98	*Navicula pennata*	29	13.5	bilateral	biraphid	complex	3	multiple
99	*Navicula pseudolanceolata*	28.5	10.5	bilateral	biraphid	hyaline to complex	2	unoccluded
100	*Navicula pseudolanceolata*	18.5	6	bilateral	biraphid	hyaline to complex	2	unoccluded
101	*Navicula restituta*	36	7.5	bilateral	biraphid	complex	3	unoccluded
102	*Navicula restituta*	24	8.5	bilateral	biraphid	complex	3	unoccluded
103	*Navicula restituta*	27	10	bilateral	biraphid	complex	3	unoccluded
104	*Navicula salinarum*	16.5	5.25	bilateral	biraphid	hyaline to complex	2	unoccluded
105	*Navicula salinarum*	19.5	4	bilateral	biraphid	hyaline to complex	2	unoccluded
106	*Navicula salinarum*	12	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
107	*Navicula salinarum*	16	3.5	bilateral	biraphid	hyaline to complex	2	unoccluded
108	*Navicula salinarum*	15.5	3	bilateral	biraphid	hyaline to complex	2	unoccluded
109	*Navicula salinarum*	13.25	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
110	*Navicula salinarum*	15.5	4	bilateral	biraphid	hyaline to complex	2	unoccluded
111	*Navicula salinarum*	16.5	3	bilateral	biraphid	hyaline to complex	2	unoccluded
112	*Navicula salinarum*	19.5	3.5	bilateral	biraphid	hyaline to complex	2	unoccluded
113	*Navicula salinarum*	19.25	4	bilateral	biraphid	hyaline to complex	2	unoccluded
114	*Navicula salinarum*	18.25	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
115	*Navicula salinarum*	17	5	bilateral	biraphid	hyaline to complex	2	unoccluded
116	*Navicula salinarum*	21.75	4.25	bilateral	biraphid	hyaline to complex	2	unoccluded
117	*Navicula salinarum*	18	4.25	bilateral	biraphid	hyaline to complex	2	unoccluded
118	*Navicula salinarum*	19	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
119	*Navicula salinarum*	19.5	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
120	*Navicula salinarum*	19	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
121	*Navicula salinarum*	16.75	4	bilateral	biraphid	hyaline to complex	2	unoccluded
122	*Navicula salinarum*	17.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
123	*Navicula salinarum*	21	5	bilateral	biraphid	hyaline to complex	2	unoccluded
124	*Navicula salinarum*	9.75	2.25	bilateral	biraphid	hyaline to complex	2	unoccluded

125	*Navicula salinarum*	13	4	bilateral	biraphid	hyaline to complex	2	unoccluded
126	*Navicula salinarum*	15.75	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
127	*Navicula salinarum*	16	4	bilateral	biraphid	hyaline to complex	2	unoccluded
128	*Navicula salinarum*	12.5	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
129	*Navicula salinarum*	14.5	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
130	*Navicula salinarum*	18.5	5	bilateral	biraphid	hyaline to complex	2	unoccluded
131	*Navicula salinarum*	15.75	5.25	bilateral	biraphid	hyaline to complex	2	unoccluded
132	*Navicula salinarum*	23.75	5.25	bilateral	biraphid	hyaline to complex	2	unoccluded
133	*Navicula salinarum*	19.5	4.75	bilateral	biraphid	hyaline to complex	2	unoccluded
134	*Navicula salinarum*	21	5.5	bilateral	biraphid	hyaline to complex	2	unoccluded
135	*Navicula salinarum*	12.5	2.25	bilateral	biraphid	hyaline to complex	2	unoccluded
136	*Navicula salinarum*	12.5	2.25	bilateral	biraphid	hyaline to complex	2	unoccluded
137	*Navicula salinarum*	12.75	2.5	bilateral	biraphid	hyaline to complex	2	unoccluded
138	*Navicula tripunctata*	59.75	7.5	bilateral	biraphid	hyaline to complex	2	unoccluded
139	*Navicula tripunctata*	36.75	7	bilateral	biraphid	hyaline to complex	2	unoccluded
140	*Navicula Sp. A*	36	7.5	bilateral	biraphid	hyaline to complex	2	unoccluded
141	*Navicula* Sp. E	9.75	3.75	bilateral	biraphid	hyaline to complex	2	unoccluded
142	*Navicula* Sp. F	33.75	7.25	bilateral	biraphid	complex	3	unoccluded
143	*Navicula* Sp. F	36.25	6.5	bilateral	biraphid	complex	3	unoccluded
144	*Navicula* Sp. F	26.25	5.5	bilateral	biraphid	complex	3	unoccluded
145	*Navicula* Sp. G	60	13.5	bilateral	biraphid	complex	3	unoccluded
146	*Navicula* Sp. G	75.5	7.5	bilateral	biraphid	complex	3	unoccluded
147	*Navicula* Sp. G	65.75	13.5	bilateral	biraphid	complex	3	unoccluded
148	*Navicula* Sp. G	30.25	5.25	bilateral	biraphid	complex	3	unoccluded
149	*Navicula* Sp. a	7.25	3.75	bilateral	biraphid	hyaline to complex	2	multiple
150	*Navicula* Sp. a	7.5	4.25	bilateral	biraphid	hyaline to complex	2	multiple
151	*Navicula* Sp. a	5.5	3.75	bilateral	biraphid	hyaline to complex	2	multiple
152	*Navicula* Sp. a	6.75	4	bilateral	biraphid	hyaline to complex	2	multiple
153	*Navicula* Sp. a	9.75	5	bilateral	biraphid	hyaline to complex	2	multiple
154	*Nitschia amphibia*	27.75	3.5	bilateral	biraphid	complex	3	multiple
155	*Nitschia amphibia*	9.25	2.5	bilateral	biraphid	complex	3	multiple
156	*Nitschia amphibia*	8.25	2.25	bilateral	biraphid	complex	3	multiple

157	*Nitschia amphibia*	9.75	4	bilateral	biraphid	complex	3	multiple
158	*Nitschia amphibia*	21.75	3	bilateral	biraphid	complex	3	multiple
159	*Nitschia amphibia*	7.75	1.75	bilateral	biraphid	hyaline to complex	2	unoccluded
160	*Nitschia Brittoni*	14.5	4.25	bilateral	biraphid	complex	3	multiple
161	*Nitschia Brittoni*	52	9.75	bilateral	biraphid	complex	3	multiple
162	*Nitschia coarctata*	21.25	9.5	bilateral	biraphid	complex	3	multiple
163	*Nitschia coarctata*	19.75	7.5	bilateral	biraphid	complex	3	multiple
164	*Nitschia coarctata*	27.5	9	bilateral	biraphid	complex	3	multiple
165	*Nitschia coarctata*	21.75	9.75	bilateral	biraphid	complex	3	multiple
166	*Nitschia coarctata*	19.75	5.25	bilateral	biraphid	complex	3	multiple
167	*Nitschia coarctata*	39.75	10	bilateral	biraphid	complex	3	multiple
168	*Nitschia coarctata*	19.75	9.5	bilateral	biraphid	complex	3	multiple
169	*Nitschia frustulum*	23.5	2.75	bilateral	biraphid	hyaline to complex	2	hymenate
170	*Nitschia grossestriata*	21	4.5	bilateral	biraphid	complex	3	unoccluded
171	*Nitschia navicularis*	36	6.5	bilateral	biraphid	complex	3	unoccluded
172	*Nitschia navicularis*	38	7.25	bilateral	biraphid	complex	3	unoccluded
173	*Nitschia navicularis*	46	4	bilateral	biraphid	complex	3	unoccluded
174	*Nitschia panduriformis*	21	4.75	bilateral	biraphid	complex	3	unoccluded
175	*Nitschia panduriformis*	8.5	4.75	bilateral	biraphid	hyaline to complex	2	hymenate
176	*Nitschia panduriformis*	7.25	5.25	bilateral	biraphid	hyaline to complex	2	hymenate
177	*Nitschia panduriformis*	4.75	3	bilateral	biraphid	hyaline to complex	2	hymenate
178	*Nitschia sigmaformis*	104	8	bilateral	biraphid	complex	3	unoccluded
179	*Nitschia valdestriata*	7.25	3.75	bilateral	biraphid	complex	3	hymenate
180	*Nitschia* Sp. a	15	5.25	bilateral	biraphid	complex	3	unoccluded
181	*Nitschia* Sp. E	46.5	8.75	bilateral	biraphid	complex	3	unoccluded
182	*Nitschia* Sp. E	45.25	2.25	bilateral	biraphid	complex	3	unoccluded
183	*Nitschia* Sp. E	92.25	2	bilateral	biraphid	complex	3	unoccluded
184	*Odontella aurita*	43.25	17.75	bilateral	araphid	complex	3	multiple
185	*Opephora marina*	10.25	2.25	bilateral	araphid	hyaline to complex	2	multiple
186	*Opephora martyii*	6	2.25	bilateral	araphid	complex	3	cribera
187	*Opephora martyii*	8.75	3.25	bilateral	araphid	complex	3	cribera
188	*Opephora martyii*	7.25	3	bilateral	araphid	complex	3	cribera

189	*Pleurosigma distinguendum*	65.25	10.5	bilateral	biraphid	complex	3	unoccluded
190	*Pleurosigma distinguendum*	64.5	5.75	bilateral	biraphid	complex	3	unoccluded
191	*Rhopalodia musculus*	10	6.5	bilateral	biraphid	complex	3	multiple
192	*Thalassiosira decipiens*	10	10	radial/cylind	araphid	complex	3	unoccluded
193	*Thalassiosira decipiens*	10	10	radial/cylind	araphid	complex	3	unoccluded
194	*Thalassiosira decipiens*	7.25	7.25	radial/cylind	araphid	complex	3	unoccluded
195	*Thalassiosira decipiens*	4.25	4.25	radial/cylind	araphid	complex	3	unoccluded
196	*Thalassiosira decipiens*	5	5	radial/cylind	araphid	complex	3	unoccluded
197	*Thalassiosira weissflogii*	19.75	19.75	radial/cylind	araphid	complex	3	unoccluded
198	*Thalassiosira* Sp. A	3.75	3.75	radial/cylind	araphid	complex	3	unoccluded
199	*Thalassiosira* Sp. A	4.5	4.5	radial/cylind	araphid	complex	3	unoccluded
200	*Thalassiosira* Sp. A	4.75	4.75	radial/cylind	araphid	complex	3	unoccluded
Mean:		**22.81**	**7.36**				**2.47**	
Standard Deviation:		**21.85**	**4.69**				**0.50**	

Appendix O. Deep water and shallow water diatom surface area to volume ratios, by species.

Cocconeis disculus				
Deep water Stations	Apical Axis (µm)	Transapical Axis (µm)	Pervalvar axis (µm)	S/V Ratio
1	5.25	4.25	1	1.000
1	6.75	2.25	1	1.000
1	7.25	5	1.5	0.667
1	8	4	1.75	0.571
1	8	4.25	1.5	0.667
1	9.75	5	1.5	0.667
1	11.5	5.5	2.5	0.400
1	15.25	11	2.5	0.400
1	20	9	3	0.333
1	20.5	9.25	3.25	0.308
9	8	4.25	1.5	0.667
9	18	12.5	3.5	0.286
14	6.5	4.75	1.5	0.667
14	7.75	4.25	1.25	0.800
14	8.25	5.25	1.25	0.800
14	8.25	6.25	1.75	0.571
14	10	6.75	1.75	0.571
14	15	7.75	2.25	0.444
14	15.25	9.75	1.75	0.571
14	19.25	8.25	2.25	0.444
			Mean:	*0.592*
Shallow water Stations				
IB	7.5	4.25	1.25	0.800
IB	8	5.75	1.5	0.667
IB	8	4.5	1.25	0.800
IB	9.5	5.5	1.5	0.667
IB	9.5	6	1.5	0.667
IB	9.75	6.75	1.75	0.571
IB	12.5	5.5	2	0.500
IB	12.75	6.75	2.25	0.444
IB	15.5	2.5	2	0.500
IB	20.25	15.25	3	0.333
IV	7.5	4	1.5	0.667
IV	9.25	6.25	1.75	0.571
IV	10.25	8	2	0.500
IV	10.5	5.5	1.75	0.571
IV	10.75	5.25	1.25	0.800
IV	11.75	6.5	1.5	0.667
IV	12.5	5.25	2	0.500
IV	16.5	2.25	2	0.500
IV	23	11.25	2.25	0.444
IV	23.5	10.75	2.5	0.400
			Mean:	*0.578*

Fallacia forcipata				
Deep water Stations	Apical Axis (µm)	Transapical Axis (µm)	Pervalvar axis (µm)	S/V Ratio
1	15.5	6.25	4	0.250
1	16.5	9.5	4.25	0.235
1	18.25	10.25	4	0.250
1	25.75	9.5	4.5	0.222
1	29	12.5	4.5	0.222
1	30	12.5	4.5	0.222
1	32.25	12.75	4.75	0.211
1	33.25	13.5	4.5	0.222
1	33.5	13.75	4.75	0.211
1	35.75	15	4.75	0.211
5	16.75	6.5	4.25	0.235
5	31.5	12.25	4.5	0.222
5	33.25	13.75	4.5	0.222
7	37.75	15.25	4.75	0.211
7	38.5	16.5	4.75	0.211
8	15.75	6.5	4	0.250
8	31.25	12.5	4.5	0.222
8	35	14.5	4.75	0.211
9	17	9.75	4.25	0.235
14	24.5	9.25	4.5	0.222
			Mean:	*0.225*
Shallow water Stations				
IB	16.25	5.75	4.25	0.235
IB	16.75	6.5	4	0.250
IB	17.5	7.5	4	0.250
IB	18.25	6.75	4.25	0.235
IB	18.5	7.25	4	0.250
IB	18.75	7.5	4	0.250
IB	22.5	7.5	4.25	0.235
IB	24	8.25	4.25	0.235
IB	32.75	13	4.5	0.222
IB	33.5	13.25	4.5	0.222
IV	16	6.25	4	0.250
IV	16.5	8.75	4	0.250
IV	17.75	7.25	4	0.250
IV	18	7.25	4	0.250
IV	21	7.75	4.25	0.235
IV	21.25	7.75	4.25	0.235
IV	22.75	7.5	4.25	0.235
IV	25.5	8.5	4.5	0.222
IV	26	8.25	4.5	0.222
IV	34.5	13.25	4.75	0.211
			Mean:	*0.237*

***Navicula* Sp. a**

Deep water Stations	Apical Axis (µm)	Transapical Axis (µm)	Pervalvar axis (µm)	S/V Ratio
1	16.75	3.5	1.75	0.571
1	17.5	3.75	2.25	0.444
1	18.75	4.25	2.25	0.444
1	19	2.25	2	0.500
1	20.5	4.5	2.5	0.400
1	22	4.25	2	0.500
1	23.25	4.5	2.25	0.444
2	17.25	3.75	2.5	0.400
3	18.75	2	1.75	0.571
3	20.25	4.25	2.25	0.444
3	23.25	4.5	2.5	0.400
3	24.25	4.5	2.5	0.400
4	18.75	4	2	0.500
4	19	4.25	2	0.500
5	17.5	4	2	0.500
5	21	4.25	2	0.500
5	24.5	5	2.75	0.364
6	18.5	2	2	0.500
6	21.5	4.25	2.25	0.444
9	18.5	2	2	0.500
			Mean:	*0.466*
Shallow water Stations				
IB	15.75	4.5	2.75	0.364
IB	17.75	5	2.5	0.400
IB	15.75	5.25	2.5	0.400
IB	15.5	3.25	2.5	0.400
IB	15.25	4.75	2.5	0.400
IB	14.75	5	2.25	0.444
IB	15.5	5	2.25	0.444
IB	18	5.5	2.25	0.444
IB	15.75	4.5	2.25	0.444
IB	20	3.5	2.25	0.444
IV	15.25	5	2.25	0.444
IV	15.5	4	2.25	0.444
IV	17.5	5.25	2.25	0.444
IV	18	6	2.5	0.400
IV	18.75	5.25	2.75	0.364
IV	19.5	4.5	2.5	0.400
IV	19.5	5	2.5	0.400
IV	20	6.75	2.75	0.364
IV	20	5	2.5	0.400
IV	23	6	2.75	0.364
			Mean:	*0.411*

Nitschia frustulum				
Deep water Stations	Apical Axis (µm)	Transapical Axis (µm)	Pervalvar axis (µm)	S/V Ratio
1	6.25	2.5	1.25	0.800
1	7.25	2.25	2	0.500
1	7.5	2.25	1.5	0.667
1	7.5	2.5	2.25	0.444
1	8	2.5	2.5	0.400
1	8.5	2.5	2.5	0.400
1	8.75	2.75	2.5	0.400
2	6.25	2	1.25	0.800
2	8.75	2.75	2.75	0.364
3	6.25	2	1.25	0.800
3	6.75	2.5	1.25	0.800
3	7.75	2.25	2.25	0.444
3	9.5	2.75	2.75	0.364
3	9.5	2.75	2.75	0.364
4	7.5	2.25	2.25	0.444
4	9.25	2.75	2.75	0.364
5	7.25	2.5	2.25	0.444
8	6.5	2	2	0.500
9	9.25	2.75	2.75	0.364
14	7	2	1.25	0.800
			Mean:	*0.523*
Shallow water Stations				
IB	6	2	1.25	0.800
IB	6.25	2	1.25	0.800
IB	6.5	2	1.25	0.800
IB	7.5	2.25	1.5	0.667
IB	7.5	2.25	1.75	0.571
IB	7.5	2.25	1.75	0.571
IB	7.75	2.25	1.75	0.571
IB	8.25	2.5	1.5	0.667
IB	9	2.5	1.5	0.667
IB	9.5	2.75	2	0.500
IV	6.25	2.5	1.5	0.667
IV	6.25	2	1.25	0.800
IV	6.25	2.25	1.75	0.571
IV	6.75	2.5	1.5	0.667
IV	7.5	2.25	1.75	0.571
IV	7.5	2.25	1.75	0.571
IV	7.75	2.25	1.5	0.667
IV	8.25	2.5	1.5	0.667
IV	8.5	2.5	1.5	0.667
IV	9.25	2.75	2	0.500
			Mean:	*0.648*

Nitschia panduriformis				
Deep water Stations	Apical Axis (µm)	Transapical Axis (µm)	Pervalvar axis (µm)	S/V Ratio
1	17.75	7	2.75	0.364
1	30.25	14.25	5.25	0.190
1	31.25	15.25	6.25	0.160
1	31.25	14.75	5	0.200
1	32.75	15.5	5.75	0.174
1	34	17.5	7	0.143
1	34.5	17.25	7	0.143
1	35.5	16.25	6	0.167
3	28	12.75	3.25	0.308
3	30.5	14	4.5	0.222
6	30	14.25	5.75	0.174
7	10.25	4.25	2	0.500
7	29.25	13.75	5.75	0.174
7	32.5	12	5.25	0.190
8	30	16.25	5.5	0.182
8	34.5	13.5	7.25	0.138
14	27.5	13.25	3.5	0.286
14	30.5	16.5	6	0.167
14	33.5	16.5	5.5	0.182
14	34.25	14.75	4	0.250
			Mean:	*0.216*
Shallow water Stations				
IB	6.25	1.75	1.5	0.667
IB	7.75	2.5	1.25	0.800
IB	9.25	2.5	1	1.000
IB	19.5	7.75	2.75	0.364
IB	19.75	2.75	3.25	0.308
IB	20	7.75	3.75	0.267
IB	22.5	10	3	0.333
IB	25	9.5	3.75	0.267
IB	35	15	4.75	0.211
IB	38	9.5	6.25	0.160
IV	7.5	2.75	1.5	0.667
IV	8	2.25	1.25	0.800
IV	9.5	2.25	1	1.000
IV	19.5	9	2.75	0.364
IV	19.5	8.75	2.75	0.364
IV	21	11.25	2.5	0.400
IV	22.5	7	3	0.333
IV	23.5	10.75	3	0.333
IV	30.25	14.5	4.5	0.222
IV	35.5	15	4.5	0.222
			Mean	*0.454*

Appendix P. Taxonomic references.

Achnanthes brevipes Agardhl
Lit.: Lange-Bertalot & Krammer 1989, p. 34, Pl. 9 fig. 1-6, Pl. 10 fig. 1-2
Lange-Bertalot 2000, p. 86, Pl. 45 fig. 1-2

Achnanthes conspicua Mayer
Lit.: Cleve-Euler 1953, p. 28, fig. 833

Achnanthes danica (Flögel) Grunow
Lit.: Lange-Bertalot 2000, p. 274, Pl. 114 fig. 7-14

Achnanthes delicatula (Kützing) Grunow
Lit.: John 1983, p. 70, Pl. XXX fig. 3-4

Achnanthes hauckiana Grunow
Lit.: Hustedt 1955, p. 17
Hustedt 1959, p. 388, fig. 834

Achnanthes Kolbei Hustedt
Lit.: Hustedt 1959, p. 397, fig. 846

Achnanthes longipes Agardh
Lit.: Hustedt 1955, p. 18
Lange-Bertalot 2000, p. 92, Pl. 45 fig. 1-12

Achnanthes manifera Brun
Lit.: Hustedt 1955, p. 18, Pl. 6 fig. 1-8

Achnanthes pseudobliqua Simonsen
Lit.: Lange-Bertalot 2000, p. 94, Pl. 48 fig. 32, Pl. 49 fig. 3

Achnanthes reidensis Foged
Lit.: John 1983, p. 75, Pl. XXXII fig. 9-11

Achnanthes taeniata Grunow
Lit.: Hendey 1964, p. 176

Achnanthes tenera Hustedt
Lit.: Hustedt 1955, p. 17, Pl. 5 fig. 22-25

Achnanthes tenuis Hustedt
Lit.: Hustedt 1955, p. 17, Pl. 5 fig. 29-31

Amphora arenaria Donkin
Lit.: Hustedt 1955, p. 42
Hendey 1964, p. 268, Pl. XXXVIII fig. 1-4

Amphora beaufortiana Hustedt
Lit.: Hustedt 1955, p. 38, Pl. 14 fig. 1-5
Lange-Bertalot 2000, p. 131, Pl. 168 fig. 10-11

Amphora coffeaeformis Agardh
Lit.: Hustedt 1955, p. 39
Lange-Bertalot 2000, p.133, Pl. 161 fig. 21-25

Amphora costata W. Smith
Lit.: Hendey 1964, p. 264
Lange-Bertalot 2000, p. 134, Pl. 169 fig. 5-7

Amphora delicatissima Krasske
Lit.: Lange-Bertalot 2000, p. 137, Pl. 163 fig. 11-12, Pl. 168 fig. 8

Amphora exigua Gregory
Lit.: Hendey 1964, p. 266
Lange-Bertalot 2000, p. 137, Pl. 161 fig. 15-17

Amphora granulata Gregory
Lit.: Hustedt 1955, p. 40, Pl. 14 fig. 8-10, 26-27
Lange-Bertalot 2000, p. 139, Pl. 161 fig. 26-27, Pl. 166 fig. 22

Amphora helenensis Giffen
Lit.: Lange-Bertalot 2000, p. 139, Pl. 163 fig. 131-33

Amphora ovalis Kützing
Lit.: John 1983, p. 152, Pl. LXII fig. 11-12

Amphora pannucea Giffen
Lit.: Lange-Bertalot 2000, p. 146, Pl. 162 fig. 23-25

Amphora pseudoholsatica Nagumo & Kobaysi
Lit.: Lange-Bertalot 2000, p. 148, Pl. 161 fig. 5-6

Amphora subcuneata Hustedt
Lit.: Hustedt 1955, p. 39, Pl. 14 fig. 17-18

Amphora subturgida Hustedt
Lit.: John 1983, p. 158, Pl. LXVI fig. 9-11

Amphora tenerrima Aleem & Hustedt
Lit.: Hustedt 1955, p. 39, Pl. 14 fig. 15
Lange-Bertalot 2000, p. 152, Pl. 164 fig. 20

Amphora ventricosa Gregory
Lit.: Hendey 1964, p. 269, Pl. XXXVIII fig. 12
John 1983, p. 156, Pl. LXIV fig. 7-8, LXV fig. 1-10, LXVI fig. 1-2

Amphora wisei Salah
Lit.: Lange-Bertalot 2000, p. 154, Pl. 162 fig. 18-19

Anorthoneis tenuis Hustedt
Lit.: Hustedt 1955, p. 15, Pl. 5 fig. 14-15

Bacillaria paxillifer (Müller) Hendey var. *paxillifer*
Lit.: Hendey 1964, p. 274, Pl. XXI fig. 5
Lange-Bertalot 2000, p. 357, Pl. 212 fig. 9-12

Biddulphia alternans (Bailey) Van Heurck
Lit.: Hendey 1964, p. 102, Pl. XXV fig. 5
Lange-Bertalot 2000, p. 25, Pl. 7 fig. 6, Pl. 8 fig. 1

Biddulphia regina W. Smith
Lit.: Hustedt 1930, p. 836, fig. 492

Biddulphia pulchella Gray
Lit.: Hendey 1964, p. 101, Pl. XXV fig. 1
John 1983, p. 36, Pl. XIII fig. 1-3
Lange-Bertalot 2000, p. 25, Pl. 8 fig. 8-9

Biremis lucens (Hustedt) Sabbe, Witkowski, & Vyverman
Lit.: Lange-Bertalot 2000, p. 159 Pl. 155 fig. 9-15

Campylosira cymbelliformis (Schmidt) Grunow ex Van Heurck
Lit.: Hustedt 1955, p. 13
Hendey 1964, p. 157
Lange-Bertalot 2000, p. 26, Pl. 10 fig. 23-25

Cerataulus radiatus **(**Roper) R. Ross
Lit.: Hartley 1996, p. 116, Pl. 50 fig. 10
Round et al. 1990, p. 234

Cocconeis californica Grunow
Lit.: Lange-Bertalot 2000, p. 102, Pl. 36 fig. 29-30, Pl. 42 fig. 8-15

Cocconeis convexa Giffen
Lit.: John 1983, p. 76, Pl. XXXIII fig. 1-3

Cocconeis dirupta Gregory
Lit.: Hendey 1964, p. 177
Lange-Bertalot 2000, p. 105, Pl. 39 fig. 1-5, Pl. 51 fig. 5,8

Cocconeis disculus Cleve
Lit.: Hendey 1964, p. 178, Pl. XXVIII fig. 19
Patrick & Reimer 1966, p. 239, Pl. 15 fig. 1-2
John 1983, p. 77, Pl. XXXIII fig. 10-11

Cocconeis distans Gregory
Lit.: Hustedt 1955, p. 17, Pl. 6 fig. 4-5
John 1983, p. 78, Pl. XXXIII fig. 12-14
Lange-Bertalot 2000, p. 106, Pl. 38 fig. 12-13

Cocconeis distantula Giffen
Lit.: Lange-Bertalot 2000, p. 107, Pl. 53 fig. 1-2

Cocconeis granulifera Greville
Lit.: Greville 1857

Cocconeis hoffmanni Simonsen
Lit.: Lange-Bertalot 2000, p. 109, Pl. 33 fig. 13, Pl. 14 fig. 13-19

Cocconeis peltoides Hustedt
Lit.: Hustedt 1955, p. 16
Hendey 1964, p. 181

Cocconeis pinnata Gregory ex Greville
Lit.: Lange-Bertalot 2000, p. 112, Pl. 37 fig. 14, Pl. 39 fig. 10

Cocconeis placentula Ehrenberg
Lit.: Patrick & Reimer 1966, p. 240, Pl. 15 fig. 7
John 1983, p. 79, Pl. XXXIV fig 11-12, Pl. XXXV fig. 1

Cocconeis scutellum Ehrenberg
Lit.: Hendey 1964, p. 180, Pl. XXVII fig. 8
Lange-Bertalot 2000, p. 114, Pl. 36 fig. 1-7, Pl. 38 fig. 8

Cyclotella striata (Kützing) Grunow in Cleve & Grunow
Lit.: Hendey 1964, p. 74
John 1983, p. 21, Pl. V fig. 10-12

Cymatosira lorenziana Grunow
Lit.: Hustedt 1955, p. 13
Lange-Bertalot 2000, p. 27, Pl. 11 fig. 12-15

Delphenies karstenii Andrews
Lit.: Lange-Bertalot 2000, p. 45, Pl. 22 fig. 9

Delphenies surirella (Ehrenberg) Andrews
Lit.: Lange-Bertalot 2000, p. 46, Pl. 22 fig. 7-8

Dimeregramma minor (Gregory) Ralfs
Lit.: Hendey 1964, p. 156, Pl. XXVII fig. 12
John 1983, p. 46, Pl. XVII fig. 4-5
Lange-Bertalot 2000, p. 29, Pl. 3 fig. 9

Diploneis aestuarii Hustedt
Lit.: Lange-Bertalot 2000, p. 182, Pl. 33 fig. 11-13

Diploneis bombus Ehrenberg
Lit.: Patrick & Reimer 1966, p. 416, Pl. 38 fig. 13
Lange-Bertalot 2000, p. 183, Pl. 86 fig. 1-2, Pl. 92 fig. 1-3

Diploneis chersonensis (Grunow) Cleve
Lit.: Hendey 1964, p. 227, Pl. XXXII fig. 7-8
Lange-Bertalot 2000, p. 184, Pl. 86 fig. 10

Diploneis decipiens Cleve
Lit.: Lange-Bertalot 2000, p. 185, Pl. 33 fig. 9-10, Pl. 94 fig. 8

Diploneis smithii (Brébisson) Cleve
Lit.: Hustedt 1955, p. 21
Patrick & Reimer 1966, p. 410, Pl. 28 fig. 2
Lange-Bertalot 2000, p. 193, Pl. 33 fig. 2-5, Pl. 89 fig. 1

Diploneis vetula Cleve
Lit.: Hustedt 1955, p. 21, Pl. 6 fig. 17-18
Hendey 1964, p. 224, Pl. XXXII, fig. 6
Lange-Bertalot 2000, p. 196, Pl. 86 fig. 9

Entomoneis alata (Ehrenberg) Ehrenberg
Lit.: Lange-Bertalot 2000, p. 197, Pl. 109 fig. 21-22

Entomoneis kjellmanii (Cleve) Poulin & Cardinal
Lit.: Lange-Bertalot 2000, p. 198, Pl. 173 fig. 12

Eunotogramma marinum W. Smith
Lit.: Hustedt 1955, p. 10, Pl. 4 fig. 10-17
Lange-Bertalot 2000, p. 32, Pl. 10 fig. 1-3

Eunotogramma rostratum Hustedt
Lit.: Hustedt 1955, p. 10, Pl. 4 fig. 18-22

Fallacia forcipata (Greville) Stickle & Mann
Lit.: Round et al. 1990, p. 554, 668
Lange-Bertalot 2000, p. 205, Pl. 72 fig. 2-9

Fallacia litoricola (Hustedt) Mann
Lit.: Round et al. 1990, p. 554, 668
Lange-Bertalot 2000, p. 206, Pl. 71 fig. 7-8, Pl. 72 fig. 31-34

Fallacia plathii (Brockmann) Snoeijs
Lit.: Lange-Bertalot 2000, p. 210, Pl. 70 fig. 30

Fallacia vittata (Cleve) Mann
Lit.: Lange-Bertalot 2000, p. 215, Pl. 70 fig. 21, Pl. 71 fig. 15-16

Fragilaria brevistriata Grunow
Lit.: Patrick & Reimer 1966, p. 128, Pl. 4 fig. 14
John 1983, p. 42, Pl. XVI fig. 1-3

Fragilaria hyalina (Kützing) Grunow
Lit.: Hendey 1964, p. 154
John 1983, p. 43, Pl. XVI fig. 7-10

Fragilaria pinnata Ehrenberg
Lit.: Hendey 1964, p. 153
Patrick & Reimer 1966, p. 127, Pl. 4 fig. 10

Fragilaria tabulata (Hustedt) Lange-Bertalot
Lit.: Navarro 1982, p. 20, Pl. XIV fig. 11

Grammatophora marina (Ralfs) Ehrenberg
Lit.: Hendey 1964, p. 170
Lange-Bertalot, p. 58, Pl. 14 fig. 9-12

Gyrosigma acuminatum Kützing
Lit.: Patrick & Reimer 1966, p. 314, Pl. 23 fig. 1-3

Gyrosigma balticum (Ehrenberg) Cleve
Lit.: Patrick & Reimer 1966, p. 324, Pl. 25 fig. 1
Hendey 1964, p. 248, Pl. XXXV fig. 9
John 1983, p. 113, Pl. XLVII fig. 1-3

Gyrosigma beaufortianum Hustedt
Lit.: Hustedt 1955, p. 34, Pl. 10 fig. 7-8

Gyrosigma fasciola (Ehrenberg) Cleve
Lit.: Hustedt 1955, p. 33, Pl. 10 fig. 9
Hendey 1964, p. 248

Gyrosigma simile (Grunow) Boyer
Lit.: Hustedt 1955, p. 34, Pl. 10 fig. 3

Lyrella atlantica (A. Schmidt) Mann
Lit.: Round et al. 1990, p. 460, 671
Lange-Bertalot 2000, p. 231, Pl. 96 fig. 6, Pl. 98 fig. 5

Mastogloia angusta Hustedt
Lit.: Hustedt 1955, p. 20, Pl. 6 fig. 9
Hustedt 1959, p. 512, fig. 940

Mastogloia lanceolata Thwaites
Lit.: Hustedt 1959, pg. 497, fig. 922
Lange-Bertalot 2000, p. 251, Pl. 73 fig. 6-9

Mastogloia pseudoelegans Hustedt
Lit.: Hustedt 1955, p. 19, Pl. 6 fig. 10

Melosira moniliformis (Müller) Agardh
Lit.: Hustedt 1930, p. 236, fig. 98
Lange-Bertalot 2000, p. 35, Pl. 1 fig. 7-9

Melosira nummuloides Agardh
Lit.: Hendey 1964, p. 72, Pl. 1 fig. 1
Lange-Bertalot 2000, p. 35, Pl. 1 fig. 3-5, 11, 12

Navicula abunda Hustedt
Lit.: Hustedt 1955, p. 27, Pl. 9 fig. 10-12
Lange-Bertalot 2000, p. 265, Pl. 140 fig. 12

Navicula agnita Hustedt
Lit.: Hustedt 1955, p. 27, Pl. 9 fig. 13-16
Lange-Bertalot, p. 266, Pl. 136 fig. 21, Pl. 142 fig. 10
Navicula ammophila Grunow
Lit.: Hendey 1964, p. 199
Lange-Bertalot, p. 266, Pl. 147 fig. 5-6

Navicula Bastowii Hustedt
Lit.: Hustedt 1955, p. 26, Pl. 7 fig. 22-23

Navicula cancellata Donkin
Lit.: Hendey 1964, p. 203, Pl. XXX fig. 18-20
Lange-Bertalot 2000, p. 271, Pl. 132 fig. 1, Pl. 138 fig. 1-3, Pl. 144 fig. 1-7
Navicula cincta Ehrenberg
Lit.: Lange-Bertalot 2000, p. 272, Pl. 110 fig. 1-29

Navicula digitoconvergens Lange-Bertalot
Lit.: Lange-Bertalot 2000, p. 274, Pl. 114 fig. 7-14

Navicula diplonoides Hustedt
Lit.: Hustedt 1955, p. 22, Pl. 8 fig. 21

Navicula directa Cleve
Lit.: Hendey 1964, p. 202
John 1983, p. 88, Pl. XXXVIII fig. 6
Lange-Bertalot 2000, p. 275, Pl. 129 fig. 1, Pl. 133 fig. 10-12

Navicula diversistriata Hustedt
Lit.: Hustedt 1955, p. 28, Pl. 9 fig. 6-9
Lange-Bertalot 2000, p. 275, Pl. 136 fig. 1-2

Navicula eidrigiana Carter
Lit.: Lange-Bertalot 2000, p. 276, Pl. 121 fig. 1-6, Pl. 133 fig. 3-4

Navicula eleginesis Gregory
Lit.: Patrick & Reimer 1966, p. 524, Pl. 50 fig. 3

Navicula ergadensis (Gregory) Ralfs
Lit. Hendey 1964, p. 216, Pl. XXIX fig. 14-15
John 1983, p. 90, Pl. XXXVIII fig. 8-9

Navicula fenestrella Hustedt
Lit.: Hustedt 1955, p. 30, Pl. 5 fig. 32

Navicula formenterae Cleve
Lit.: Hustedt 1955, p. 29, Pl. 7 fig. 28-29
Lange-Bertalot 2000, p. 702, Pl. 130 fig. 32

Navicula Humii Hustedt
Lit.: Hustedt 1955, p. 23, Pl. 8 fig. 8-10, 24

Navicula järnfeltii Hustedt
Lit.: Patrick & Reimer 1966, p. 486, Pl. 46 fig. 9

Navicula jeffreyi Hallegraff & Burford
Lit.: Lange-Bertalot 2000, p. 284, Pl. 142 fig. 37

Navicula menisculus Grunow
Lit.: Patrick & Reimer 1966, p. 519, Pl. 49 fig. 17-18

Navicula nummularia Greville
Lit.: Hustedt 1955, p. 22, Pl. 7 fig. 15-16

Navicula oculiformis Hustedt
Lit.: Hustedt 1955, p. 22, Pl. 8 fig. 6-7

Navicula palpebralis Brébisson
Lit.: Hendey 1964, p. 216, Pl. XXXIV fig. 13-19
Patrick & Reimer 1966, p. 540, Pl. 52 fig. 10
Lange-Bertalot 2000, p. 294, Pl. 139 fig. 9, Pl. 140 fig. 1-3

Navicula paul-schulzii Witkowski & Lange-Bertalot
Lit.: Lange-Bertalot 2000, p. 295, Pl. 141 fig. 19-20, Pl. 145 fig. 16-19

Navicula pseudolanceolata Lange-Bertalot
Lit.: Lange-Bertalot 1980, p. 32, Pl. 2 fig. 1,3

Navicula pullus Hustedt
Lit.: Hustedt 1955, p. 30, Pl. 7 fig. 18

Navicula reinhardtii Grunow
Lit.: Patrick & Reimer 1966, p. 517, Pl. 49 fig. 12

Navicula riparia Hustedt
Lit.: Krammer & Lange-Bertalot 1985, p. 92

Navicula rupicola Hustedt
Lit.: Hustedt 1961-1966, p. 218, fig. 1335

Navicula salinarum Grunow
Lit.: Hustedt 1955, p. 27, Pl. 7 fig. 25
Hendey 1964, p. 199
Lange-Bertalot 2000, p. 304, Pl. 123 fig. 1-8
Navicula Sovereignae Hustedt
Lit.: Hustedt 1955, p. 25, Pl. 8 fig. 18-19

Navicula subhamulata Grunow
Lit.: Patrick & Reimer 1966, p. 495, Pl. 47 fig. 6

Navicula submitis Hustedt
Lit.: Hustedt 1961-1966, p. 128, fig. 1261

Navicula tripunctata Bory
Lit.: Patrick & Reimer 1966, p. 513, Pl. 49 fig. 3

Nitschia amphibia Grunow
Lit.: John 1983, p. 165, Pl. LXXII fig. 14

Nitschia angularis W. Smith
Lit.: Hendey 1964, p. 281, Pl. XXXIX fig. 6
Lange-Bertalot 2000, p. 368, Pl. 199 fig. 5-6

Nitschia brevirostris Hustedt
Lit.: Hustedt 1955, p. 48, Pl. 16 fig. 21-22
John 1983, p. 166, Pl. LXIX fig. 5

Nitschia Brittoni Hagelstein
Lit.: Hustedt 1955, p. 46, Pl. 15 fig. 7-8

Nitschia calciola Aleem & Hustedt
Lit.: Lange-Bertalot 2000, p. 372, Pl. 209 fig. 8-10

Nitschia coarctata Grunow
Lit.: Hendey 1964, p. 278
Lange-Bertalot 2000, p. 374, Pl. 183 fig. 13, Pl. 186 fig. 4-13

Nitschia constricta Kützing
Lit.: Hustedt 1955, p. 45
Lange-Bertalot 2000, p. 377, Pl. 187 fig. 8-12

Nitschia frustulum (Kützing) Grunow
Lit.: Hendey 1964, p. 283
Lange-Bertalot 2000, p. 382, Pl. 209 fig. 13-17

Nitschia granulata Grunow
Lit.: Hustedt 1955, p. 44
Hendey 1964, p. 278
John 1983, p. 168, Pl. LXIX fig. 9-10

Nitschia grossestriata Hustedt
Lit.: Hustedt 1955, p. 46, Pl. 16 fig. 8-10
Lange-Bertalot 2000, p. 384, Pl. 201 fig. 14-16

Nitschia hybridaeformis Hustedt
Lit.: Hustedt 1955, p. 44, Pl. 15 fig. 9-11

Nitschia incurva Grunow
Lit.: John 1983, p. 169, Pl. LXX fig. 1

Nitschia longa Grunow
Lit.: Hustedt 1955, p. 46, Pl. 16 fig. 1

Nitschia marginata Hustedt
Lit.: Hustedt 1955, p. 46, Pl. 16 fig. 11-12

Nitschia navicularis Grunow
Lit.: Hendey 1964, p. 276, Pl. XXXIX fig. 3-5
Lange-Bertalot 2000, p. 394, Pl. 184 fig. 15-18

Nitschia panduriformis Gregory
Lit.: Hendey 1964, p. 279
John 1983, p. 172, Pl. LXXII fig. 1-3
Lange-Bertalot 2000, p. 397, Pl. 184 fig. 13-14, Pl. 186 fig. 1-3

Nitschia proxima Hustedt
Lit.: Hustedt 1955, p. 46, Pl. 16 fig. 13

Nitschia sigma (Kützing) W. Smith
Lit.: Hendey 1964, p. 281, Pl. XLII fig. 1
John 1983, p. 173, Pl. LXXII fig. 10-11
Lange-Bertalot 2000, p. 404, Pl. 206 fig. 1-10

Nitschia valdestriata Aleem & Hustedt
Lit.: Lange-Bertalot 2000, p. 407, Pl. 203 fig. 19-21, Pl. 207 fig. 14-16

Odontella aurita (Lyngbye) Agardh
Lit.: John 1983, p. 32, Pl. XI fig. 10-11
Lange-Bertalot 2000, p. 36, Pl. 8 fig. 12-13, Pl. 9 fig. 1-3

Odontella rhombus (Ehrenberg) Cleve
Syn. Biddulphia rhombus
Lit.: Hendey 1964, p. 103, Pl. XXV fig. 8
Round et al. 1990 p. 220
Hartley 1996, p. 406, Pl. 195 fig. 7-8

Opephora marina Gregory
Lit.: Hustedt 1955, p. 13
Hustedt 1959, p. 136, fig. 656
Hendey 1964, p. 160
Lange-Bertalot, p. 71, Pl. 2-9, fig. 43

Opephora martyi Héribaud
Lit.: Hustedt 1959, p. 135, fig. 654
Patrick & Reimer 1966, p. 115, Pl. 3 fig. 3
John 1983, p. 50, Pl. XX fig. 3-5

Opephora pacifica (Grunow) Petit
Lit.: Hustedt 1955, p. 13, Pl. 4 fig. 47-49
Hendey 1964, p. 159
Lange-Bertalot 2000, p. 72, Pl. 25 fig. 18-26

Opephora schwarzii Grunow
Lit.: Hustedt 1955, p. 13, Pl. 4 fig. 46
John 1983, p. 50, Pl. XX fig. 6-7
Lange-Bertalot 2000, p. 73, Pl. 25 fig. 1

Paralia sulcata (Ehrenberg) Cleve
Lit.: Hendey 1964, p. 73, Pl. XXIII fig. 5
Lange-Bertalot 2000, p. 37, Pl. 8 fig. 10-11

Paribellus adnatus Cox
Lit.: Lange-Bertalot 2000, p. 319, Pl. 104 fig. 16-17

Petroneis latissima (Gregory) Stickle & Mann
Lit.: Lange-Bertalot 2000, p. 328, Pl. 100 fig. 4-5

Pinnularia lanceolata Cleve
Lit.: Cleve-Euler 1955, p. 21

Plagiogramma pygmaeum Greville
Lit.: Hustedt 1955, p. 11, Pl. 4 fig. 30-34

Plagiogramma Wallichianum Greville
Lit.: Hustedt 1955, p. 11, Pl. 4 fig. 29

Pleurosigma distinguendum Hustedt
Lit.: Hustedt 1955, p. 36, Pl. 11 fig. 3-5

Pleurosigma marinum Donkin
Lit.: Hustedt 1955, Pl. 11 fig. 2
Hendey 1964, p. 247, Pl. XXXV fig. 8

Pleurosigma rostratum Hustedt
Lit.: Hustedt 1955, p. 35, Pl. 12 fig. 4

Rhopalodia musculus Kützing
Lit.: Lange-Bertalot 2000, p. 411, Pl. 214 fig. 5-8

Thalassiosira decipiens (Grunow) Jörgensen
Lit.: Hustedt 1930, p. 322, fig. 158
Hendey 1964, p. 87, Pl. 1 fig. 5

Thalassiosira eccentrica (Ehrenberg) Cleve
Lit.: John 1983, p. 18, Pl. IV fig. 1-4

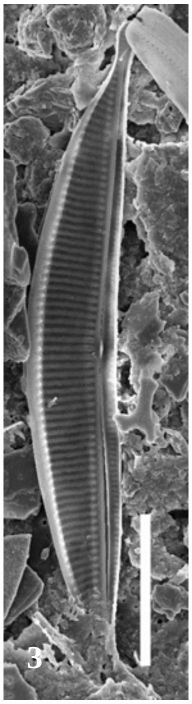
Trachysphinia acuminata Peragallo
Lit.: Hustedt 1955, p. 14, Pl. 4 fig. 50-54
Lange-Bertalot 2000, p. 84, Pl. 24 fig. 17-19

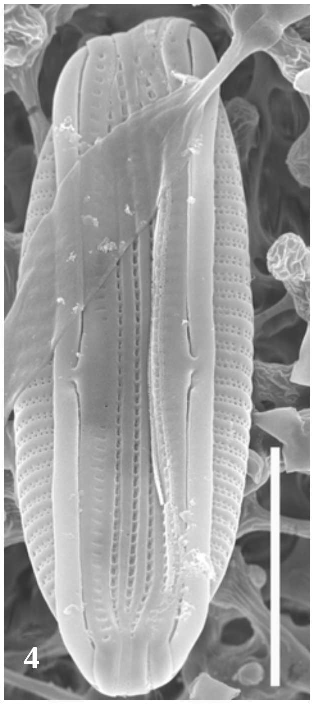
Appendix Q. Deep water diatoms documented as live, and other commonly found species.

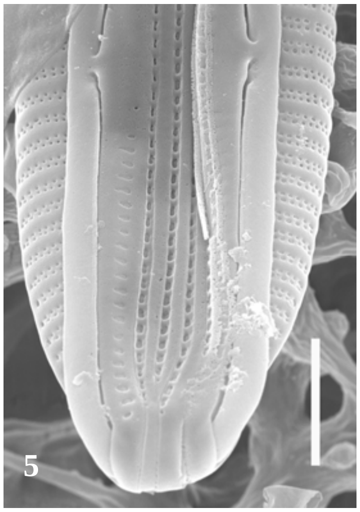
PLATE I.

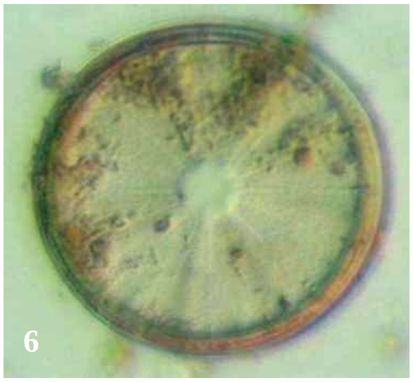
1. *Amphora coffeaformis*, plain polarized light (l = 23.5 µm)
2. *Amphora coffeaformis*, plain polarized light (l = 14 µm)
3. *Amphora coffeaformis*, SEM (scale = 10 µm)
4. *Amphora coffeaformis*, SEM (scale = 5 µm)
5. *Amphora coffeaformis*, fig. 4 close-up, SEM (scale = 2 µm)
6. *Actinoptychus splenden*s, plain polarized light (l = 70.75 µm)
7. *Actinoptychus splendens*, SEM (scale = 20 µm)
8. *Actinoptychus splendens*, plain polarized light (l = 41.25 µm)

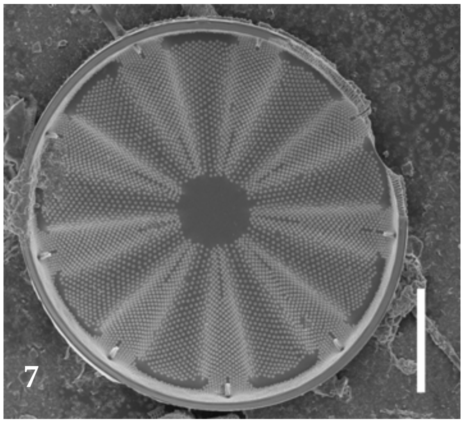
PLATE I.











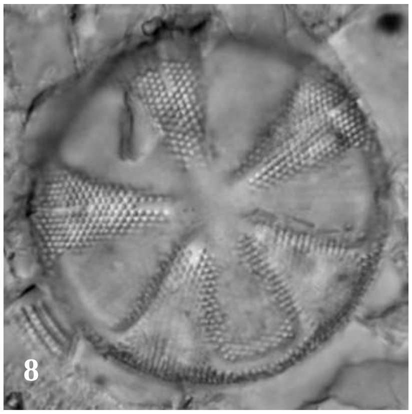
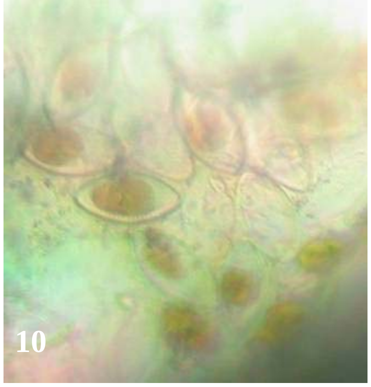
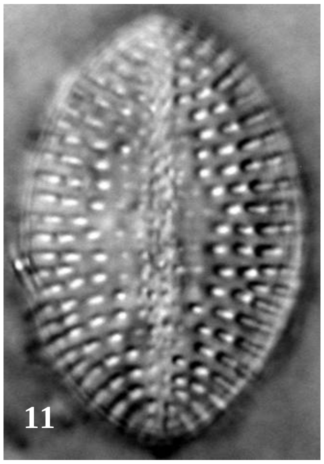


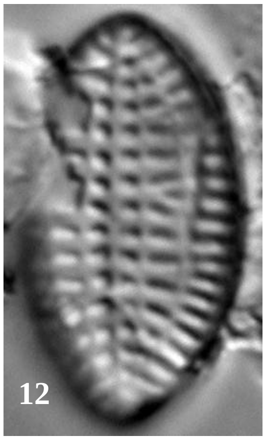
PLATE II.

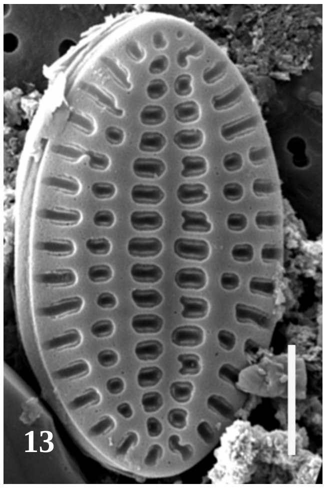
9. *Cocconeis disculus*, plain polarized light (l = ~16 µm)
10. *Cocconeis disculus*, plain polarized light (l = 12 µm)
11. *Cocconeis disculus*, plain polarized light (l = 17.5 µm)
12. *Cocconeis disculus*, plain polarized light (l = 15.25 µm)
13. *Cocconeis disculus*, SEM (scale = 2 µm)
14. *Cocconeis disculus*, SEM (scale = 5 µm)
15. *Cocconeis disculus*, SEM (scale = 2 µm)
16. *Cocconeis disculus*, SEM (scale = 2 µm)
17. *Cocconeis disculus*, SEM (scale = 2 µm)

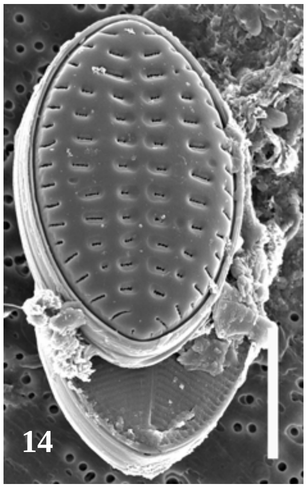
PLATE II.

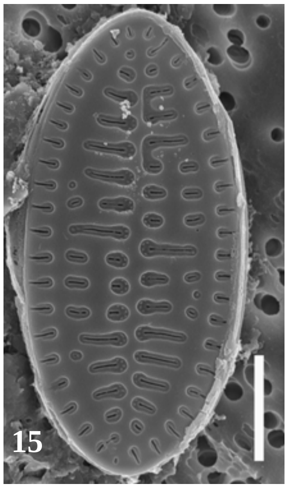


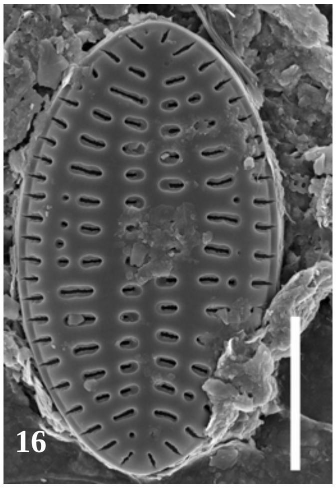












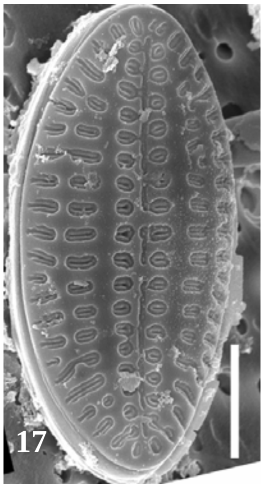
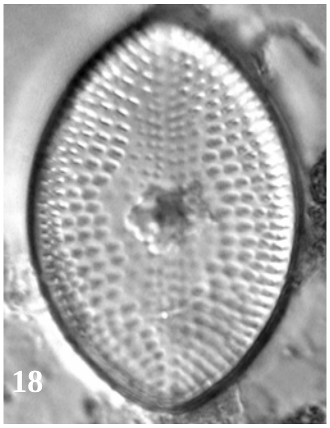


PLATE III.

18. *Cocconeis distans*, plain polarized light (l = 37.25 μm)
19. *Cocconeis distans*, plain polarized light (l = 35.5 μm)
20. *Cocconeis distans*, SEM (scale = 10 μm)
21. *Cocconeis distans*, SEM (scale = 10 μm)
22. *Cocconeis placentula*, plain polarized light (l = 12.5 μm)
23. *Cocconeis placentula*, SEM (scale = 2 μm)
24. *Cocconeis placentula*, SEM (scale = 2 μm)
25. *Cymatosira lorenziana*, plain polarized light (~12 μm)
26. *Cymatosira lorenziana*, plain polarized light (11.5 μm)
27. *Cymatosira lorenziana*, inner valve, SEM (scale = 5 μm)

PLATE III.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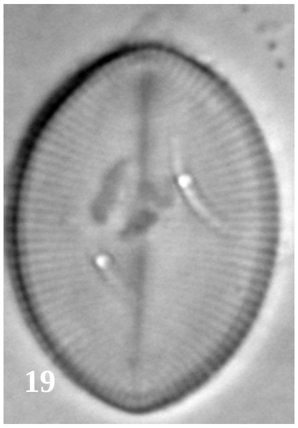
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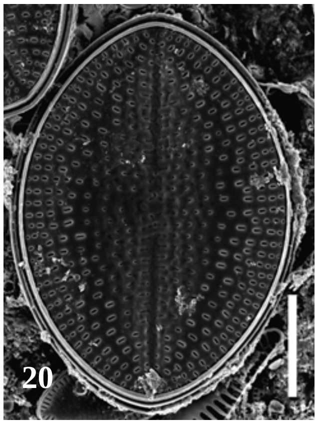
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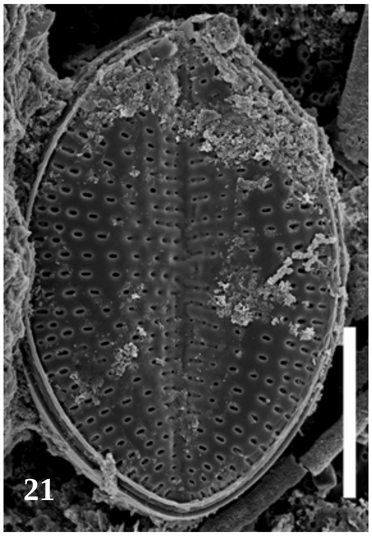
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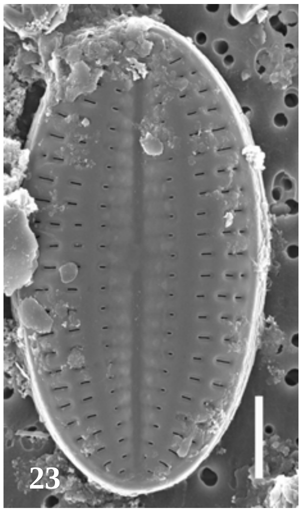
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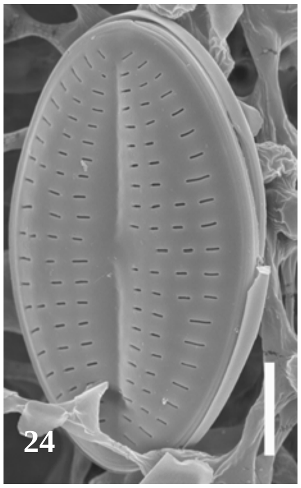
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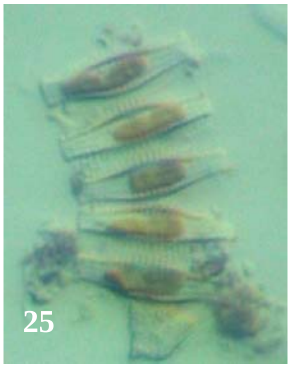
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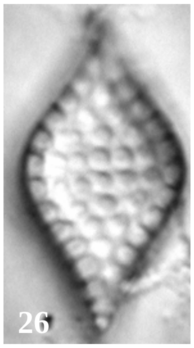
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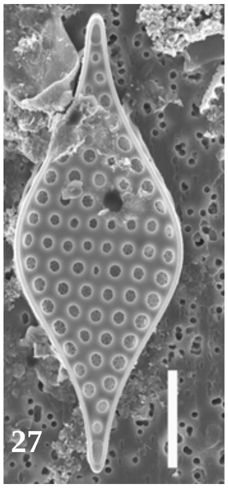
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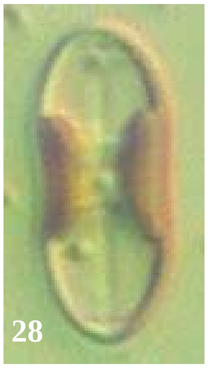
PLATE IV.

28. *Diploneis aestuarii*, plain polarized light (l = 13 µm)
29. *Diploneis aestuarii*, plain polarized light (l = 14.25 µm)
30. *Diploneis aestuarii*, SEM (scale = 5 µm)
31. *Diploneis aestuarii*, SEM (scale = 2 µm)
32. *Diploneis aestuarii*, inner valve, SEM (scale = 2 µm)
33. *Diploneis chersonensis*, plain polarized light (l = 42 µm)
34. *Diploneis chersonensis*, SEM (scale = 10 µm)

PLATE IV.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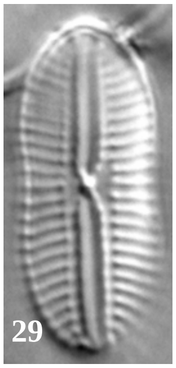
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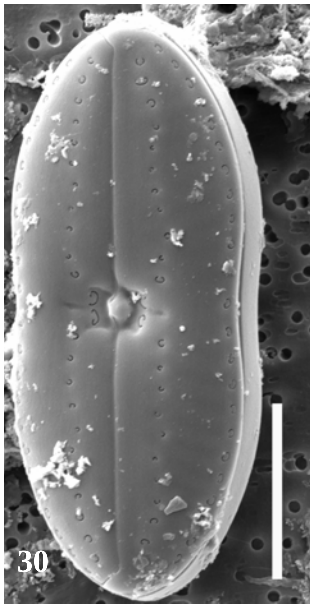
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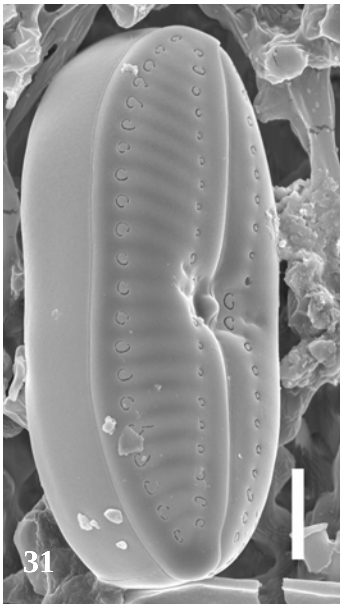
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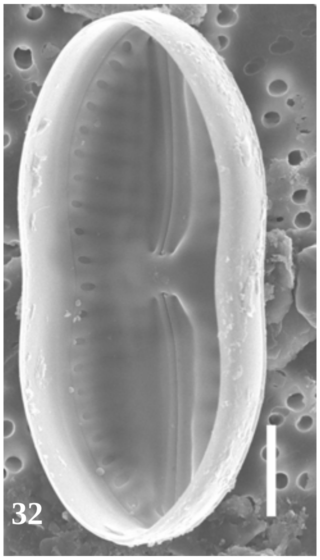
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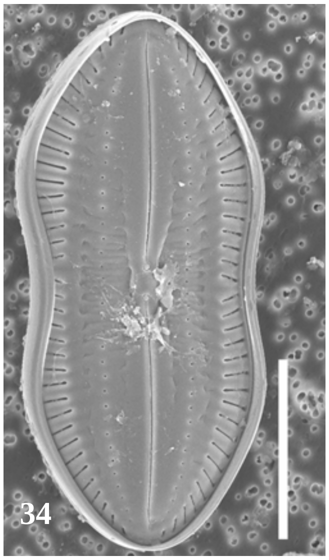
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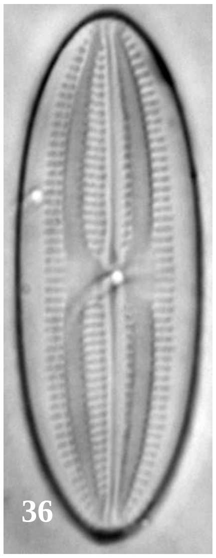
PLATE V.

35. *Fallacia forcipata*, plain polarized light (l = 24.5 μm)
36. *Fallacia forcipata*, plain polarized light (l = 32 μm)
37. *Fallacia forcipata*, plain polarized light (l = 25.75 μm)
38. *Fallacia forcipata*, SEM (scale = 2 μm)
39. *Fallacia forcipata*, SEM (scale = 10 μm)
40. *Fallacia forcipata*, SEM (scale = 5 μm)
41. *Fallacia forcipata*, inner valve, SEM (scale = 10 μm)

PLATE V.


35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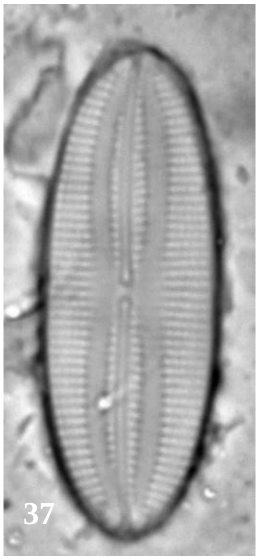
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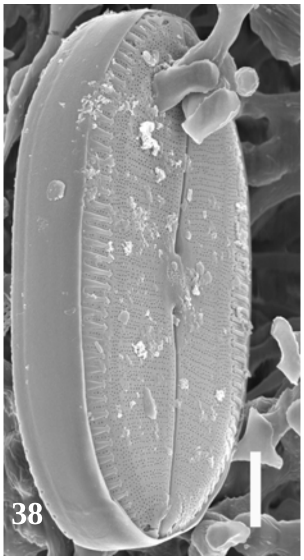
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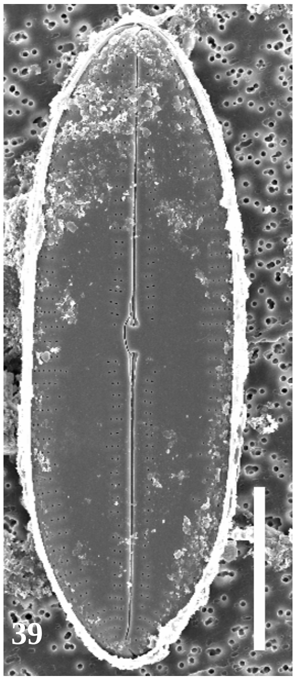
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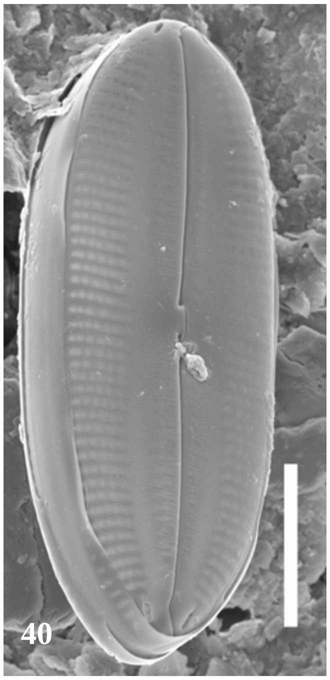
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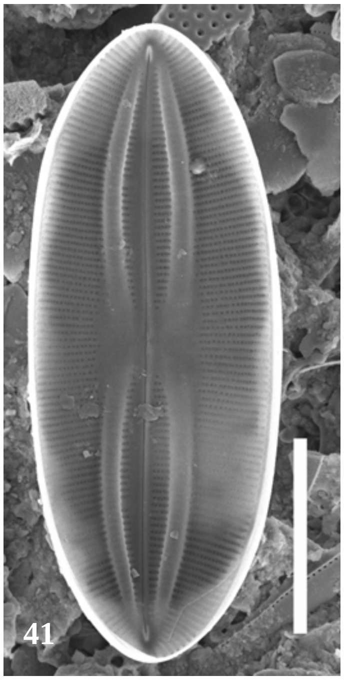
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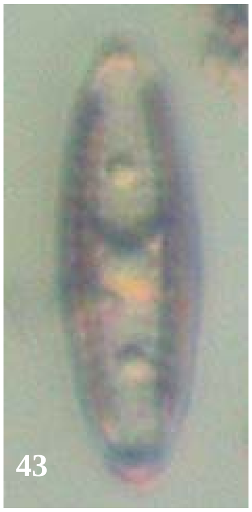
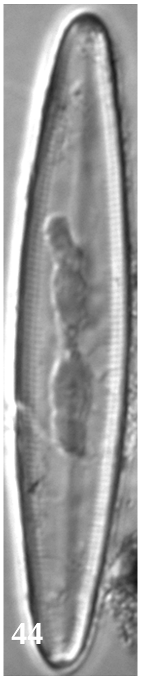
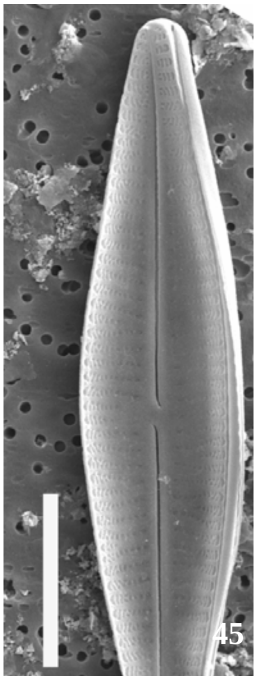
PLATE VI.

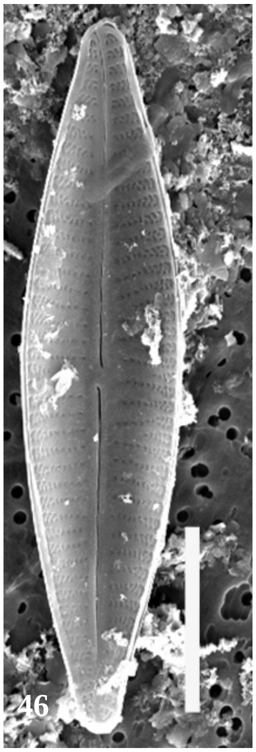
42. *Navicula* Sp. a, plain polarized light (l = 16.5 μm)
43. *Navicula* Sp. a, plain polarized light (l = 17.75 μm)
44. *Navicula* Sp. a, plain polarized light (l = 22 μm)
45. *Navicula* Sp. a, SEM (scale = 5 μm)
46. *Navicula* Sp. a, SEM (scale = 5 μm)
47. *Navicula digitoconvergens*, plain polarized light (l = 18 μm)
48. *Navicula digitoconvergens*, plain polarized light (l = 26.75 μm)
49. *Navicula digitoconvergens*, SEM (scale = 5 μm)

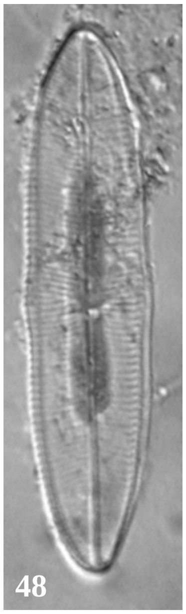
PLATE VI.











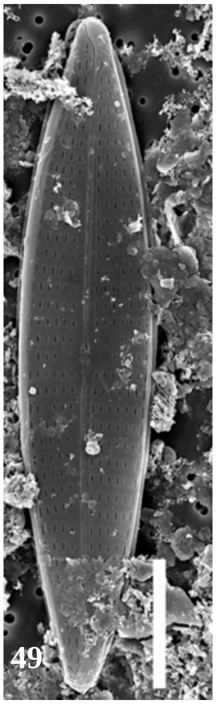
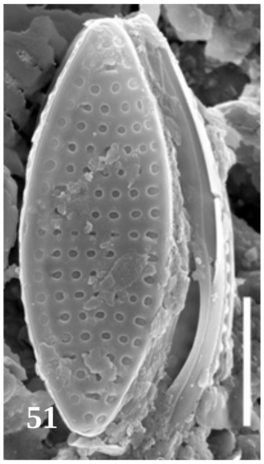


PLATE VII.

50. *Nitschia frustulum*, plain polarized light (l = 8.75 µm)
51. *Nitschia frustulum*, SEM (scale = 2 µm)
52. *Nitschia frustulum*, SEM (scale = 2 µm)
53. *Nitschia panduriformis*, plain polarized light (l = 15 µm)
54. *Nitschia panduriformis*, plain polarized light (l = 26.5)
55. *Nitschia panduriformis*, plain polarized light (l = 34.25 µm)
56. *Nitschia panduriformis*, SEM (scale = 2 µm)
57. *Nitschia panduriformis*, SEM (scale = 10 µm)
58. *Nitschia panduriformis*, SEM (scale = 2 µm)

PLATE VII.


50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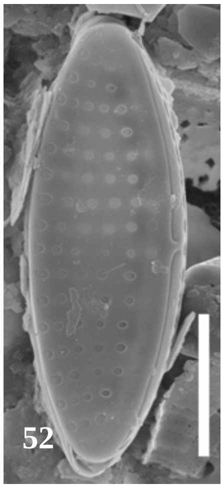
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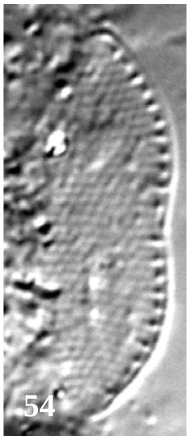
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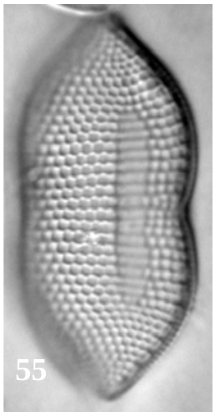
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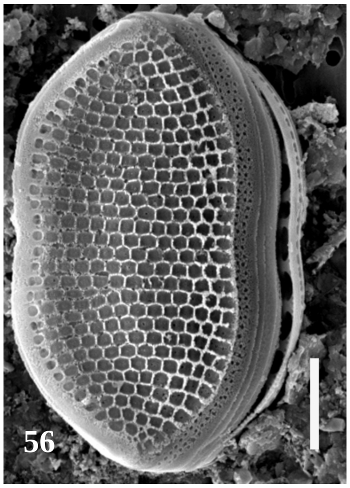
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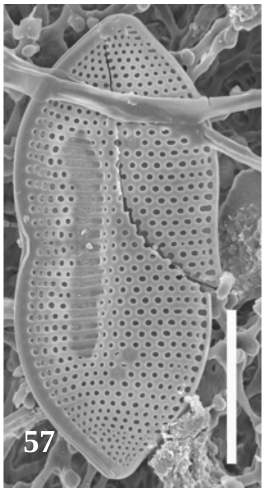
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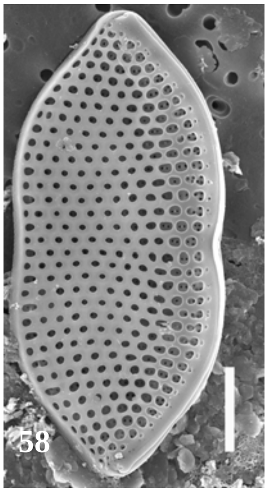
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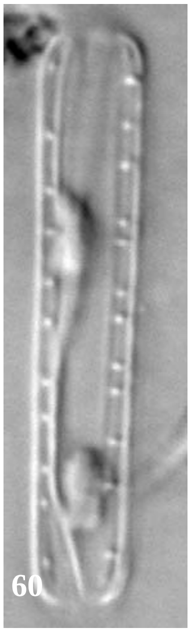
PLATE VIII.

59. *Nitschia pellucida*, plain polarized light (l = 18 µm)
60. *Nitschia pellucida*, plain polarized light (l = 17.75 µm)
61. *Nitschia pellucida*, SEM (scale = 5 µm)
62. *Nitschia pellucida*, SEM (scale = 5 µm)

PLATE VIII.


59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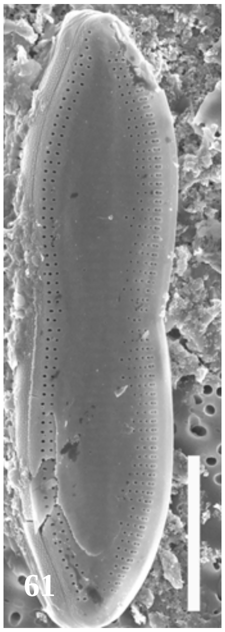
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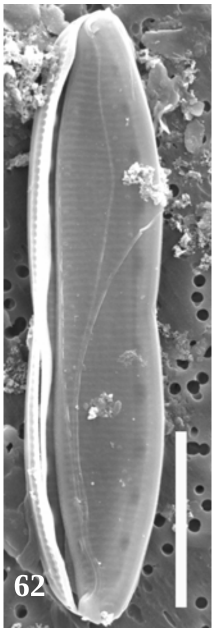
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BIOGRAPHICAL SKETCH

Dorien K. McGee was grew up a coastal girl, living in Savannah, Georgia and Charleston, South Carolina for the majority of her life. She moved inland to Atlanta and graduated with an A.A. from Oxford College of Emory University in 2001 and a B.S. in Environmental Studies from Emory College of Emory University in 2003. There, she supplemented her general environmental background with as much marine science as possible, and spent the summer of 2002 working as a vessel assistant on the NOAA ship FERREL. In the fall of 2003, she began the Masters in Geology program at the University of North Carolina at Wilmington, focusing on marine science and becoming involved with the Coastal Ocean Research and Monitoring Program. She also obtained open water and nitrox SCUBA certifications and quickly became addicted to life underwater.

Dorien's research interests include all things salt water, though coral reef paleontology and biological oceanography have become her passions. She completed a two-year independent study on Pleistocene fossil coral reefs of San Salvador Island, The Bahamas in 2004, presenting her results at the Southeastern Geological Society of America meeting in Memphis, Tennessee in 2003, the annual Geological Soceity of America meeting in Seattle, Washington in 2003, and the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions on San Salvador Island, The Bahamas in 2004. Her research on deepwater benthic diatoms in Onslow Bay has been presented at the annual Aquatic Sciences meeting of the American Society for Limnology and Oceanography in Salt Lake City, Utah in 2004 and at the UNCW Interdisciplinary Graduate Student Symposium in 2005. She is a member of the Geological Soceity of America, the American Institute of Professional Geologists, the American Society for Limnology and Oceanography, the Association for Women Geoscientists, and the Sigma Xi and Lambda Alpha honor societies.

After completing her thesis, Dorien moved to Tampa, Florida to begin a doctoral degree in the Department of Geology at the University of South Florida. Her ultimate goal is to follow her uncle's footsteps and teach geology on the college level.