INTERACTIONS BETWEEN OYSTER REEFS AND ADJACENT SANDFLATS: EFFECTS ON MICROPHYTOBENTHOS AND SEDIMENT CHARACTERISTICS

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ABSTRACT

Oyster reef restoration is currently receiving increased attention as a means of enhancing water quality and fisheries. Oyster reefs not only directly provide habitat for fish and invertebrates, but also may indirectly affect adjacent sandflat areas with broader ecological consequences. Aspects of reef morphology, including vertical and edge complexity, influence the degree of impact oyster reefs have on adjacent communities. This study examines the extent to which created reefs of varying vertical and edge complexity influence sediment nutrient fluxes, microphytobenthos biomass, sediment grain size, and sediment organic content in a southeastern North Carolina intertidal sandflat. An overall significant effect of reef edge complexity on microphytobenthos biomass, pore water nutrients, and sediment grain size was discovered, though some patterns varied seasonally. Reef surface complexity was associated with changes in sediment characteristics, including greater proportions of fine sediments and percent organic matter immediately adjacent to the reef. Seasonal trends were highly significant with strong differences among seasons. This study is significant in demonstrating linkages between intertidal oyster reefs and adjacent sandflat communities including changes in microphytobenthos biomass and sediment characteristics in the sandflat area. Moreover, the nature of these linkages is influenced by both edge and surface attributes of the reef.

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INTRODUCTION

Oyster, *Crassostrea virginica* (Gmelin), reefs are important functional and structural components of shallow intertidal estuaries along the southeastern United States. Oyster reefs influence estuaries physically by removing suspended particles and changing currents, and biologically by removing primary producers and particulates, increasing water clarity (Cloern 1982, Officer et al. 1982, Newell 1988, Gerritsen et al. 1994), creating habitat, and producing biodeposits containing inorganic and organic nutrients (Dame and Patten 1981, Dame et al. 1989, Dame and Libes 1993, Dame 1999, Newell et al. 2002). Other specific effects include increasing sedimentation rates (Haven and Morales-Alamo 1966, Dame et al. 1980, Dame et al. 1991b), retaining essential nutrients (Kuenzler 1961), controlling water column microbial biomass through filtration (Dame et al. 1980, Cloern 1982, Officer et al. 1982), increasing benthic remineralization (Dame et al. 1984), increasing system-wide recycling of nutrients (Dame et al. 1984, Dame et al. 1989, Dame et al. 1991a), and creating habitat for transient and resident species (Dame 1979, Bahr and Lanier 1981, Posey and Ambrose 1994, Breitburg 1999, Coen et al. 1999, Griffitt et al. 1999, Posey et al. 1999, Breitburg et al. 2000).

Oyster reefs are significant generators of benthic-pelagic coupling. They filter seston from the water column, change particulate size and chemical composition, and transfer remineralized particles to the surrounding sediment (Newell 1988, Dame et al. 1989, Lenihan et al. 1996). Oysters convert and release particulate carbon, nitrogen, silicates and phosphorus into dissolved forms and pseudofeces that are assimilated by planktonic and benthic organisms (Dame et al. 1984, Dame et al. 1989, Dame et al. 1991a, Dame et al. 1991b, Dame 1999). The removal of seston from the water increases photosynthetically active radiation (PAR) at the sediment surface, which leads to increased microphytobenthos biomass and increased absorption of inorganic nutrients regenerated from biodeposits (Kaspar et al. 1985, Kautsky and Evans 1987, Dame et al. 1991b, Newell et al. 2002). Because feces and pseudofeces are voided as mucus-bound aggregates, they have a higher sinking velocity, up to 40 times higher, than nonaggregated particles (Kautsky and Evans 1987, Widdows et al. 1998), promoting retention on the bottom and incorporation into the sediments (Haven and Morales-Alamo 1966, 1968; Dame 1987, Jaramillo et al. 1992, Newell 2002).

However, oyster reef ecosystem effects may vary depending on reef landscape. For intertidal reefs, edge and surface complexity may be especially important in modifying adjacent sandflat areas. Edge complexity is the relative amount of convolution along the edge of the oyster reef, with greater convolution providing a greater perimeter of connection between sandflat and reef (Griffitt et al. 1999). A more complex edge may affect taxa foraging between reefs and adjacent sandflats (Griffitt et al. 1999), many fish and decapods orient towards the edges of reefs (Powell 1994, Breitburg 1999, Posey et al. 1999, Breitburg 2000). Edge complexity may influence microphytobenthos and adjacent sediment characteristics via increased fine sediments (Saoud 2000, Danovaro 2002), which can lower the biomass of benthic microalgae (Cahoon et al. 1999). Edge may also have physical effects as the rising tide first encounters the reef and flows around it.

Vertical complexity is defined here as the three-dimensional increase in surface area and surface roughness of the reef. On a macroscopic scale, vertical complexity can affect water flow, modifying tidal creek morphology, structurally altering tidal creeks through erosion in some areas and sedimentation in others (Dame et al. 1984, Dame 1996). Hydrodynamic effects resulting from vertical complexity can also occur on a local scale, changing tidal flow patterns, increasing water residence times (Keck et al. 1973, Frey and Basan 1978, Bahr and Lanier 1981, Lenihan et al. 1996, Dame et al. 2002), controlling the delivery and retention of planktonic oyster larvae (Breitburg et al. 1999), resuspending food materials and increasing sedimentation and erosion, affecting oyster recruitment, growth, and survival (Lenihan 1999). Increasing vertical complexity no intertidal reefs may increase oyster survival by providing shade, producing low and turbulent flow, and increasing assessable substrate (Bushek 1988, Michener and Kenny 1991, Ritchie and Menzel 1969). Increased turbulent flow and mixing can lead to greater delivery of food to the bottom (Butman et al. 1994). Increased three-dimensional structure also increases habitat heterogeneity, supporting diverse assemblages of benthic and nektonic organisms (Powell 1994, Posey et al. 1999, Bartol and Mann 1999, Breitburg 1999, Coen et al. 1999, Meyer and Townsend 2000, Dame et al. 2002), many of which occur at greatly elevated densities compared to surrounding sand or mud habitats (Dame 1979, Bahr and Lanier 1981, Zimmerman et al. 1989, Coen et al. 1999, Posey et al. 1999). Increased vertical relief can change flow patterns, which increases sedimentation downstream of the reef.

There are also more complex biological relationships between oyster reefs and microphytobenthos. Several species of oyster have been tested isotopically to determine their major food sources and have been found to include microphytobenthos as a large part of their diet (Riera and Richard 1996), likely due to resuspension (Baillie and Welsh 1980, Cahoon 1999). Baillie and Welsh (1980) determined that 73-76% of the diatoms present in the water column above an oyster reef during both tides were pennate. Epipelic algae are dominated by pennate forms of diatoms (Round 1971) while phytoplankton communities contain mostly centric forms (Baillie and Welsh 1980). Microphytobenthos are available throughout the year and may constitute an important food source for oysters between phytoplankton blooms (Baillie and Welsh 1980). There is still debate on whether this consumption affects microphytobenthos populations negatively or is just a utilization of resuspended and possibly lost organisms.

This study examines the extent to which the physical presence of intertidal oyster reefs and the different morphologies, varying vertical and edge complexity, influence sediment nutrient levels, benthic microalgae biomass, sediment grain size, and sediment organic content in an adjacent intertidal sandflat.

METHODS

This research was conducted in the UNC Wilmington research lease on a tidal flat at the mouth of Hewletts Creek adjacent to *Spartina alterniflora* salt marshes that separate the site from the Intracoastal Waterway (Fig 1). Hewletts Creek is a moderately-developed (Mallin et al. 1999), incised mainland tidal creek located within the North Carolina coastal plain in New Hanover County. The site is located approximately 3 km south of Wrightsville Beach, North Carolina (33°20' N, 79°10' W) and is closed to shellfish harvesting. The salinity ranged from 25 ppt to 36 ppt and annual temperature ranged from 8°C to 32°C during this investigation.

This project utilized artificial reefs as a model system for examining oyster reef and reef landscape effects on adjacent soft sediment habitat. Artificial reefs allowed us to

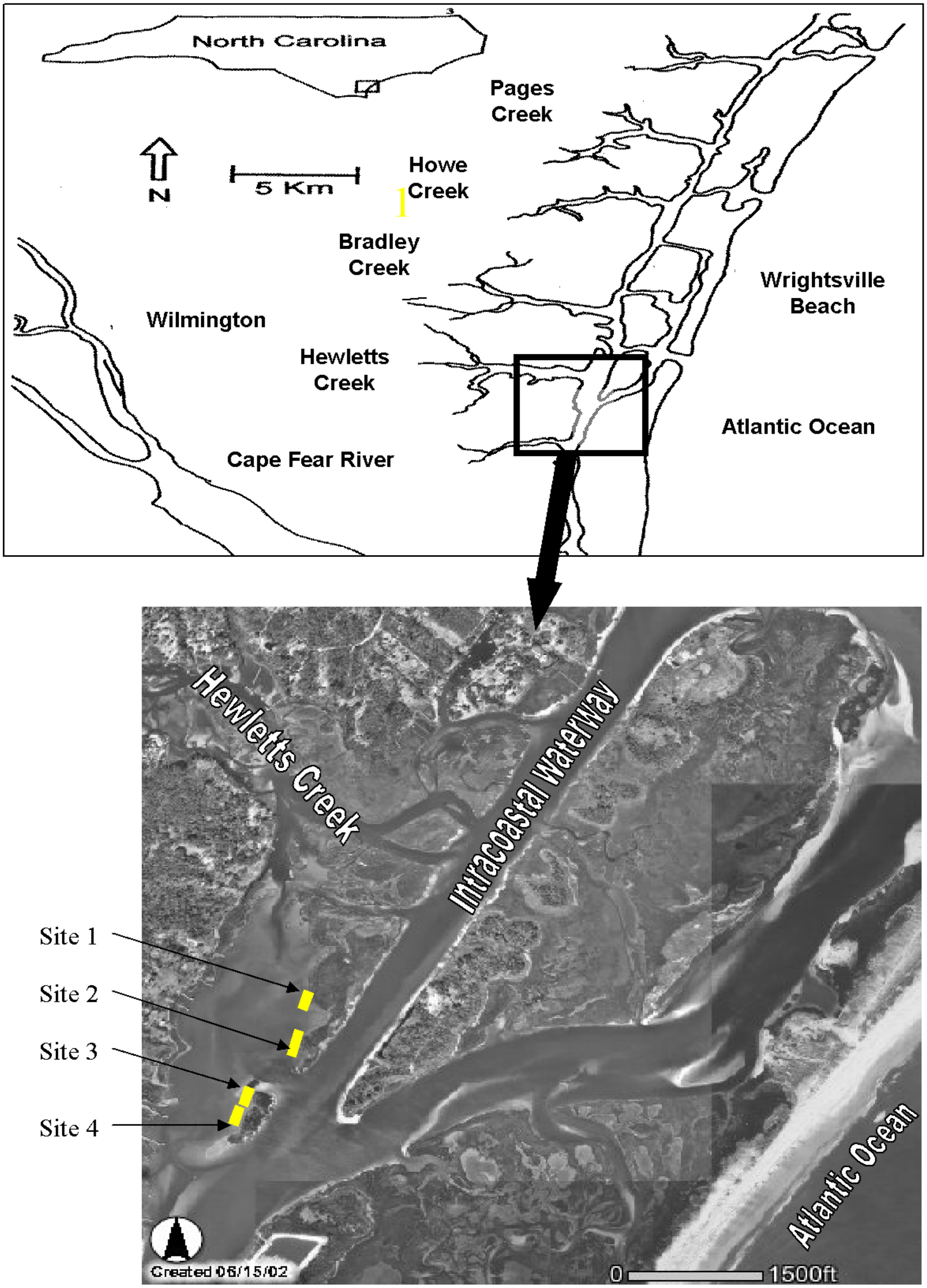

Figure 1: Study site: Southeastern North Carolina watersheds (top) and Hewletts Creek watershed and specific site locations (bottom).

study landscape effects of reefs using controlled, replicate treatments placed in a blocked design. There were four basic reef designs: low vertical complexity/ smooth edge, high vertical complexity/ smooth edge, low vertical complexity/ convoluted edge, high vertical complexity/ convoluted edge, and a sand flat control area (Fig 2). Reefs were established at mid, intertidal locations in May 2002. For smooth edge treatments, clean oyster shell was then placed within a 11.3 m circumference circle, to a depth of 20 cm and evenly distributed. For convoluted-edged reefs, shell was placed within a 12.57 m circumference circle that had three triangles with 1 m^2 area and two triangles of 0.50 m^2 area were removed from the area (basal side on the outer circumference) to form convolutions. Surface area was 10 m^2 for all reefs, a size consistent with many natural patch reefs in the general area. The low relief areas, on both high and low vertical complexity reefs, were covered with a single layer of live oysters (200/m^2). High vertical relief was created by dividing the reef treatments into 12 subsections and then transplanting developed culms from nearby natural reefs into 6 of the 12 sections, alternating between culm and clean shell/single live oyster areas. One replicate of each treatment was placed in each of four separate sites to control for spatial variation in patterns and allows for blocked analysis of treatment effects. The four sites were chosen based on isolation from other oyster reefs, isolation from salt marshes, similarity in elevations, and evidence of historic oyster reefs in the location. A sampling was conducted along two transects placed downstream of each reef.

Flows over the reefs were examined via dye studies at the sediment surface over a six-day period. Each site was tested immediately after peak high tide through the ebb cycle and immediately after peak low tide through the flood cycle until water reached

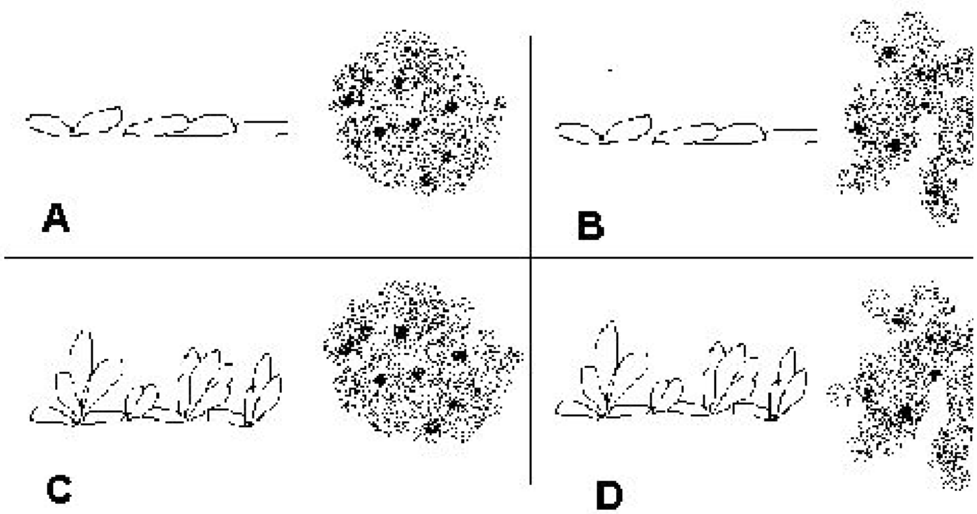

Fig 2: Schematics of artificial reef treatments: A) low vertical complexity/ smooth edge; B) low vertical complexity/ convoluted edge; C) high vertical complexity/ smooth edge; D) high vertical complexity/ convoluted edge.

approximately 1 m depth. Fluorescent Y/G tablets were mixed in salt water to form a fluorescent green dye, which was placed upstream of each reef and control area and then followed downstream, over and around the reef, to determine the adjacent sandflat area downstream of the reef on an ebb tide. The direction of flow for both ebb and flood tides was unidirectional on all four sites.

Cores were taken seasonally, July 2002, October 2002, January 2003, and April 2003. All reefs were constructed with placement of live oysters in May 2002 and a large recruitment of oyster spat (>20/400 cm^2) was observed by early July 2002. Effort was made to keep disturbance to a minimum during construction. Four cores (2.5 cm diameter to a minimum depth of 3 cm) were taken at each of three distances (5 cm, 50 centimeters, and 500 centimeters from the reef edge along each transect) along two transects for each reef type (a total of 960 cores). Two sets of four cores were taken, 1 m apart, in the control area of each site (Fig 3). A set of four cores was also taken within a randomly chosen convolution, 5 cm from all sides, on each of the convoluted-edged reefs. Each sediment core was extruded into a 50 ml polypropylene centrifuge tube, placed on ice in the dark, returned to the lab within two hours of collection, and frozen at –5 °C until analysis could be completed (< 1 month after collection). Two cores were used for chlorophyll *a* measurements, one core was used for total phosphorus and total nitrogen measurements, and the final core was used for sediment composition analysis.

The analysis of total phosphorus and total nitrogen was done on one core from each distance utilizing the persulfate digestion method, as described by Valderrama (1981). After digestion, samples were analyzed, in duplicate, for $P0_4^{3-}$, NO_3^-, and NO_2^- using a Bran and Luebbe Auto Analyzer 3.

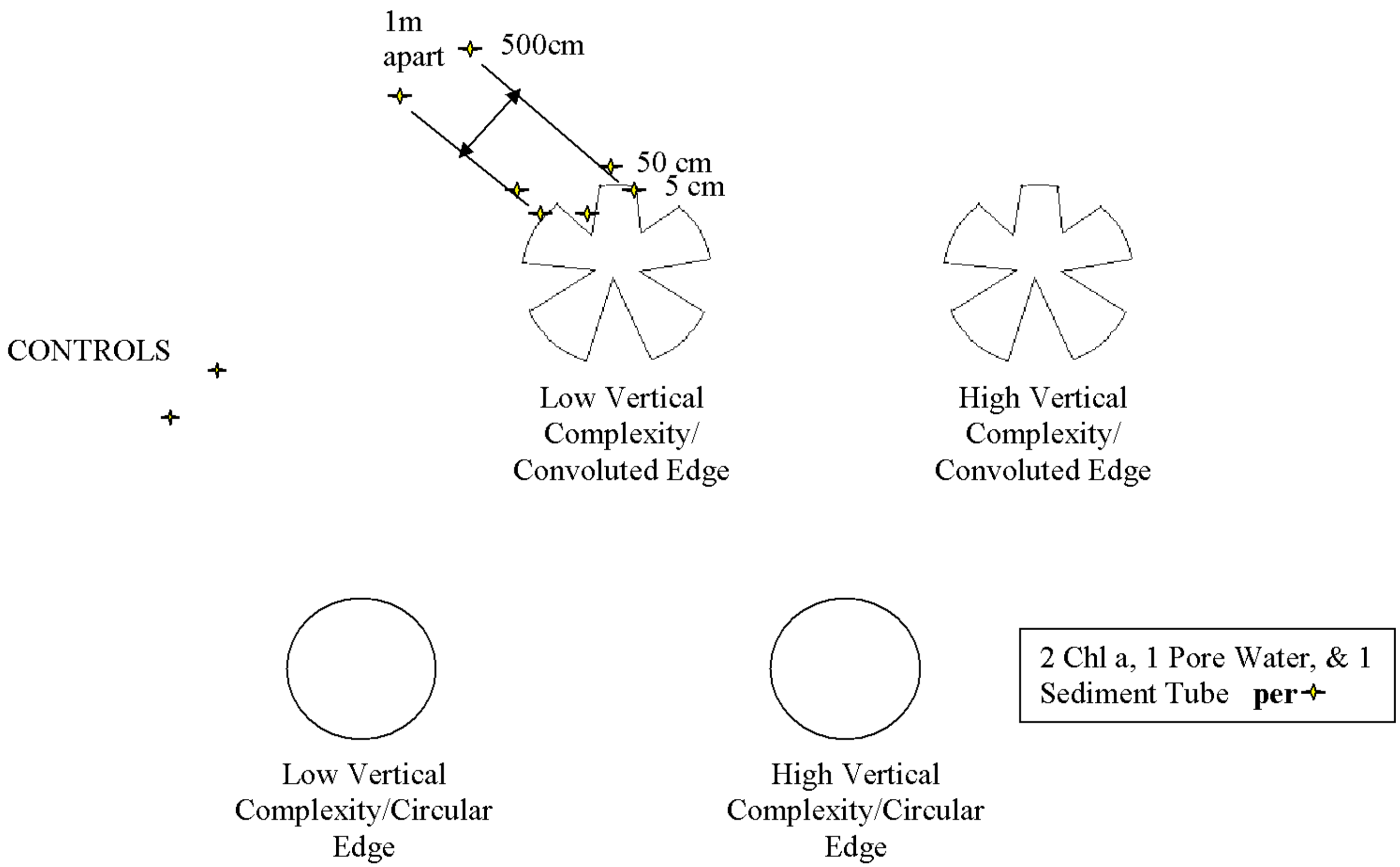

Figure 3: General schematic for treatment types with placement randomized among sites.

Analysis of chlorophyll *a* to determine microphytobenthos biomass was done on two cores from each transect position according to the double extraction and spectrophotometry method of Whitney and Darley (1979), which corrects for degraded pigments commonly found in sediments.

Sediment grain size was determined via use of the LS Particle Size Analyzer. Sediment samples were frozen prior to analysis and later thawed at room temperature in the laboratory. Each sediment sample was then filtered through a 1.7 mm sieve to remove large particles that could damage the analyzer. For all samples, less than 1% of the material was removed, most of it being oyster shell fragments. Samples were added to the chimney until obscuration was between 8-12% and run on the LS control program in optical mode. This was repeated three times for each sample in order to determine the precision of the equipment.

Organic content was measured through ashing. Sediment samples were frozen prior to analysis. In the laboratory, samples were thawed carefully and placed into a drying oven at 60°C for 48 hours in order to remove all water. One gram of each sample was placed in a pre-numbered, pre-ashed, and pre-weighed tray. The samples and trays were then dried at 110°C for 8 hours then weighed for an initial weight. Samples and trays were placed in an ashing oven for 4 hours at 450°C (Lerat 1990). The samples and trays were allowed to cool, weighed again for a final weight, and the difference in weights was considered as the organic content of each sample.

ANOVA was used to compare sediments, nutrients, and chlorophyll *a* factors among the different treatments. An F-max test demonstrated non-heterogeneity of variances for all tests. A 5-way ANOVA was run using SAS under the PROC GLM procedures for season, edge, surface, distance from the reef, and site (block variable) effects, along with interactions. Significant seasonal effects were demonstrated for all variables, so blocked effect of site was determined separately for each season using a 4-way ANOVA with interactions for edge, surface, and distance from the reef. The Student-Newman-Keul (SNK) test was used to conduct pairwise comparisons among treatments where ANOVA indicated a significant overall effect. Correlations of total nitrogen, total phosphorus, chlorophyll *a*, fine sediment, and total organic matter, sorted by season, were run using SAS under the PROC CORR procedures.

RESULTS

Overall, highly significant differences ($P=<0.0001$, Table 1) were observed among seasons for all variables. Significant differences occurred among sites for all variables, except for total phosphorus (Table 1). A significant interaction between season and site was also observed for all variables (Table 1). These strong season and site effects were associated with site*season interactions for many factors (Table 1). Edge convolution significantly affected all variables, except for the total organic matter and the percentage of fine sediment, which was marginally non-significant (Table 1). The smooth edged reefs had higher concentrations of total nitrogen, total phosphorus, and chlorophyll *a* compared to convoluted edged reefs and controls though specific pairwise differences were not detected by the Student-Newman-Keul comparisons (Table 2). Distance from the reef had significant effects for chlorophyll *a,* percentage of fine sediment, and total organic matter. Chlorophyll *a* concentration was significantly greater at 50 cm distance than the control area, while the 5 cm distance had greater percent fine

Table 1. 5-way ANOVA results for all variables and factors. F-values are on the top and P-values are in parentheses on the bottom (bold values are significant, $P<0.05$). There were no significant 3-way, 4-way, or 5-way interactions.

Variable	Season	Site	Edge	Surface	Distance	Season*Site	Season*Edge	Season*Surface
Total Nitrogen	14.26	15.65	5.98	1.15	0.11	12.05	0.6	1.82
	(<0.0001)	**(<0.0001)**	**(0.015)**	(0.283)	(0.896)	**(<0.0001)**	(0.613)	(0.142)
Total Phosphorus	15.95	0.39	5.06	1.26	0.45	4.03	1.89	5.82
	(<0.0001)	(0.763)	**(0.025)**	(0.263)	(0.641)	**(<0.0001)**	(0.130)	**(0.0007)**
Chlorophyll *a*	10.02	16.4	7.86	0.86	4.22	14.91	0.93	0.56
	(<0.0001)	**(<0.0001)**	**(0.005)**	(0.353)	**(0.0154)**	**(<0.0001)**	(0.425)	(0.638)
Fine Sediment	18.59	8.98	3.69	21.84	64.53	7.51	1.1	2.62
	(<0.0001)	**(<0.0001)**	**(0.052)**	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	(0.351)	**(0.050)**
Total Organic	12.92	8.24	1.87	19.32	65.31	6.13	2.93	1.35
Matter	**(<0.0001)**	**(<0.0001)**	(0.173)	**(<0.0001)**	**(<0.0001)**	**(<0.0001)**	**(0.034)**	(0.256)

Table 1 (continued). 5-way ANOVA results for all variables and factors. F-values are on top and P-values are in parentheses on bottom (bold values are significant, P<0.05). There were no significant 3-way, 4-way, or 5-way interactions.

Variable	Season*Position	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Total Nitrogen	1.02	2.82	4.63	1.49	2.5	0.55
	(0.414)	**(0.039)**	**(0.003)**	(0.227)	(0.084)	(0.459)
Total Phosphorus	1.08	0.61	3.39	1.55	0.56	2.24
	(0.374)	(0.608)	**(0.018)**	(0.213)	(0.570)	(0.135)
Chlorophyll *a*	0.56	3.91	0.1	0.16	0.09	2.58
	(0.766)	**(0.009)**	(0.959)	(0.855)	(0.915)	(0.109)
Fine Sediment	3.39	0.6	1.37	3.9	6.82	6.35
	(0.003)	(0.617)	(0.253)	**(0.021)**	**(0.001)**	**(0.012)**
Total Organic Matter	2.05	2.03	1.94	2.75	8.74	4.46
	(0.058)	(0.110)	(0.123)	(0.065)	**(0.0002)**	**(0.035)**

Table 2. Total nitrogen (µmol/L), total phosphorus (µmol/L), chlorophyll *a* (mg/m^2), percentage fine sediment, and percentage total organic matter mean values with standard error in parentheses for edge and surface treatments. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, $P<0.05$, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Variable	Convo	Smooth	Control	High	Low	Control
Total Nitrogen	178.69(6.19)^{A}	195.28(6.51)^{A}	173.72(14.98)^{A}	183.12(5.85)	189.58(6.85)	173.72(14.98)
Total Phosphorus	4.39(0.22)^{A}	5.09(0.31)^{A}	3.89(0.57)^{A}	4.54(0.23)	4.89(0.29)	3.89(0.57)
Chlorophyll *a*	59.97(1.69)^{AB}	66.44(2.30)^{A}	57.74(4.80)^{B}	63.79(1.98)	62.11(1.99)	57.74(4.80)
Fine Sediment	22.86(0.90)^{A}	20.21(0.78)^{A}	16.14(0.96)^{B}	23.61(0.91)^{A}	19.66(0.79)^{B}	16.14(0.96)^{C}
Total Organic Matter	1.56(0.06)	1.41(0.05)	1.11(0.04)	1.62(0.06)^{A}	1.37(0.05)^{B}	1.11(0.04)^{C}

sediment and total organic matter than other distances (Table 3). The 5 cm and 50 cm distances had intermediate chlorophyll *a* concentrations (Table 3). Distance was not significant for all other variables (Table 1). High vertical complexity was associated with greater percent fine sediment and organic matter than low vertical complexity, which was significantly greater than the controls for both (Table 2). Interactive effects varied. A significant interaction was observed between site and edge effect for chlorophyll *a* and total nitrogen, while a site and vertical complexity interaction was significant for total nitrogen and total phosphorus (Table 1). Percent fine sediment was the only one to demonstrate significant interactions between edge effect and distance from the reef (Table 1). Percent fine sediment and total organic matter had significant vertical complexity and distance from the reef interactions along with significant edge and vertical complexity interactions (Table 1). No 3- or 4-way interactions were significant. Due to the significant seasonal effects for all variables, site, edge, vertical complexity (surface), distance from reef, and blocked effects of site were analyzed separately for each season by a 4-way ANOVA.

Total Nitrogen

Total nitrogen was significantly higher in July than in any other season (Fig 4). Significant edge effects on total nitrogen occurred in January and April 2003 (Table 4), with higher concentrations in smooth edged treatments than control areas (Table 5). All other main effects were non-significant for all seasons. Total nitrogen had site*surface interactions in October 2002 and January 2002 (Table 4). The site*surface interaction was due to site 3 having higher concentrations in high vertical complexity compared to

Table 3. Total nitrogen (µmol/L), total phosphorus (µmol/L), chlorophyll *a* (mg/m^2), percentage fine sediment, and percentage total organic matter mean values with standard error in parentheses for distance treatments. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, $P<0.05$, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Variable	5cm	50cm	500cm	Control
Total Nitrogen	187.08(6.57)	184.42(7.44)	187.36(9.60)	173.72(14.98)
Total Phosphorus	4.77(0.27)	4.82(0.40)	4.54(0.30)	3.89(0.57)
Chlorophyll *a*	60.87(2.31)^{AB}	67.93(2.63)^{A}	60.57(2.32)^{AB}	57.74(4.80)^{B}
Fine Sediment	148.49(9.55)^{A}	142.78(14.02)^{B}	145.89(10.00)^{C}	16.14(0.96)^{C}
Total Organic Matter	1.90(0.08)^{A}	1.30(0.06)^{B}	1.17(0.03)^{B}	1.11(0.04)^{B}

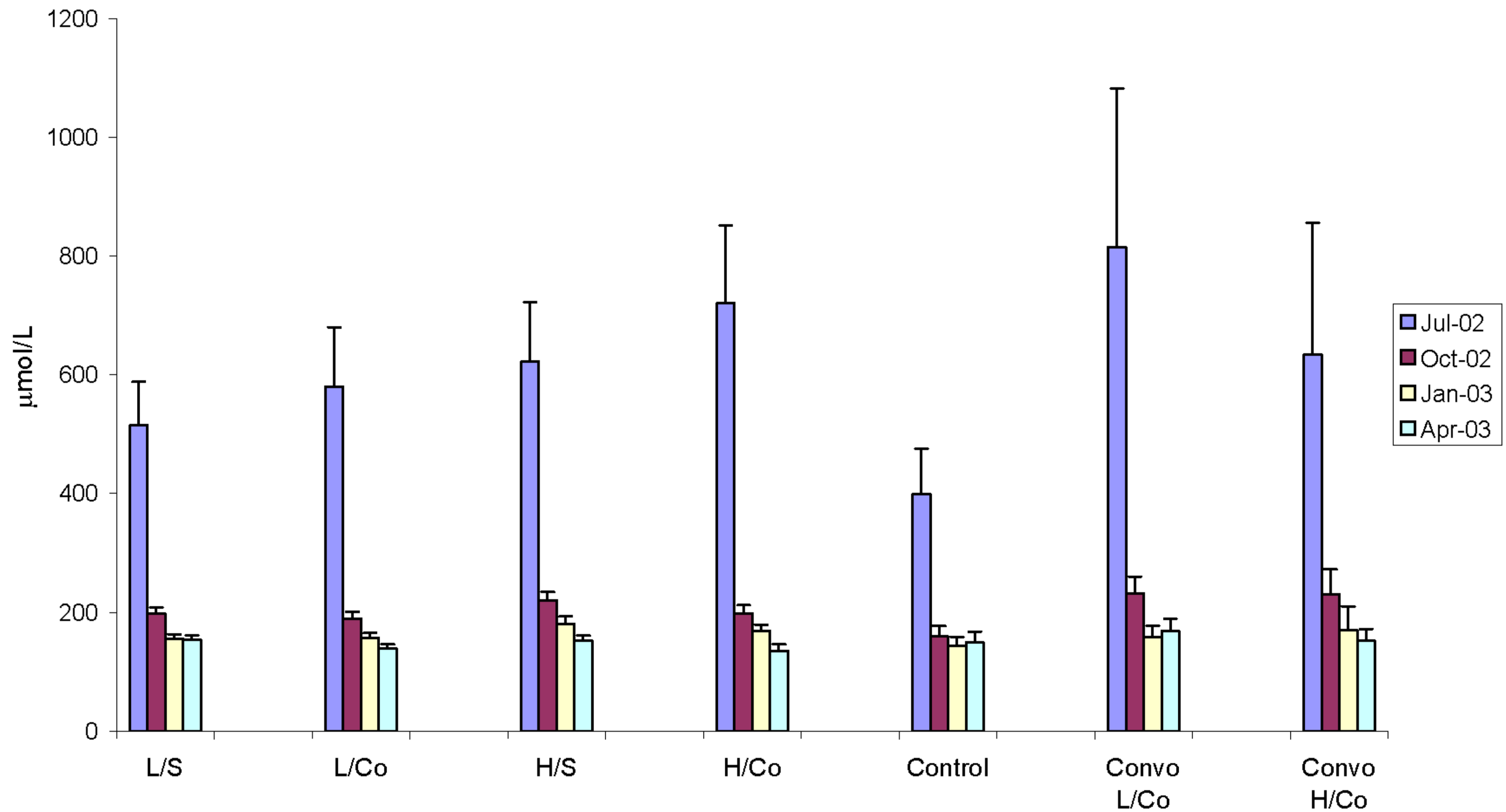

Figure 4: Mean total nitrogen concentrations, in pore water, for all treatments and all seasons. Error bars indicate standard error (L=Low vertical complexity, H=High vertical complexity, S=Smooth edge, Co=Convoluted edge, Convo=samples taken within convolution).

Table 4. 4-way ANOVA testing effects of edge, surface complexity, distance and site (block) on total nitrogen for each season. F-values are on top and P-values are in parentheses on bottom (bold values are significant, P<0.05). There were no significant 3 or 4-way interactions.

Date	Site	Edge	Surface	Distance	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Jul-02	5.39	0.00	2.14	0.36	1.20	2.04	0.15	0.61	1.92
	(0.002)	(0.995)	(0.147)	(0.701)	(0.316)	(0.115)	(0.857)	(0.543)	(0.169)
Oct-02	7.78	2.77	1.23	1.18	1.78	2.89	0.01	0.66	0.21
	(0.0001)	(0.100)	(0.270)	(0.313)	(0.157)	**(0.040)**	(0.992)	(0.518)	(0.645)
Jan-03	14.31	5.93	0.00	2.79	1.91	3.59	5.43	2.33	0.32
	(<0.0001)	**(0.017)**	(0.973)	(0.067)	(0.134)	**(0.017)**	**(0.006)**	(0.103)	(0.575)
Apr-03	7.02	3.95	1.63	0.12	1.07	0.83	0.59	0.92	0.39
	(0.0003)	**(0.050)**	(0.205)	(0.885)	(0.364)	(0.483)	(0.555)	(0.404)	(0.533)

Table 5. Total nitrogen (μmol/L), total phosphorus (μmol/L), and chlorophyll *a* (mg/m^2)mean values with standard error in parentheses for edge and surface treatments and for all variables. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, P<0.05, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Date	Variable	Convo	Smooth	Control	High	Low	Control
Jul-02	Total Nitrogen	228.65(16.35)	229.62(14.94)	199.05(37.95)	214.95(10.49)	243.25(19.56)	199.05(37.95)
Jul-02	Total Phosphorus	7.46(0.55)	7.78(0.54)	4.45(1.21)	7.81(0.56)	7.40(0.53)	4.45(1.21)
Jul-02	Chlorophyll *a*	69.55(3.15)^{A}	78.68(4.10)^{A}	72.39(8.23)^{A}	74.34(3.67)	73.18(3.64)	72.39(8.23)
Oct-02	Total Nitrogen	190.26(11.18)	210.03(12.38)	209.30(32.93)	207.02(13.18)	191.745(10.17)	209.30(32.93)
Oct-02	Total Phosphorus	3.60(0.34)^{A}	5.41(0.87)^{A}	4.91(1.72)^{A}	3.15(0.23)^{A}	5.72(0.83)^{A}	4.91(1.72)^{A}
Oct-02	Chlorophyll *a*	48.76(4.11)	59.96(6.28)	47.12(8.64)	52.68(5.42)	55.19(4.99)	47.12(8.64)
Jan-03	Total Nitrogen	159.97(9.07)^{AB}	183.81(11.92)^{A}	143.50(17.96)^{B}	171.43(11.16)	170.52(9.87)	143.50(17.96)
Jan-03	Total Phosphorus	3.03(0.25)	2.84(0.19)	3.24(0.75)	3.21(0.26)^{A}	2.67(0.19)^{A}	3.24(0.75)^{A}
Jan-03	Chlorophyll *a*	62.90(2.70)	65.04(3.43)	60.20(12.05)	65.26(2.73)	62.52(3.31)	60.20(12.05)
Apr-03	Total Nitrogen	135.89(7.67)^{A}	157.65(10.40)^{A}	143.02(24.34)^{A}	139.06(8.69)	152.80(9.35)	143.02(24.34)
Apr-03	Total Phosphorus	3.49(0.26)^{A}	4.35(0.46)^{A}	2.96(0.55)^{A}	3.99(0.41)	3.78(0.31)	2.96(0.55)
Apr-03	Chlorophyll *a*	58.64(2.81)	62.08(3.62)	51.25(8.12)	62.90(2.96)	57.56(3.38)	51.25(8.12)

low vertical complexity and control treatments, and also due to the control concentrations being significantly higher at sites 1 and 4 yet significantly lower at sites 2 and 3 in October 2002. The site*surface interaction in January 2003 was due to site 3 low vertical complexity having greater concentrations than at any of the other three sites. There was an edge*distance interaction effect in January 2002 (Table 4) due to high total nitrogen 50 cm away from smooth edged reefs as compared to all other distances and the controls. There were no other interactive effects for total nitrogen. There were significant correlations between total nitrogen and chlorophyll *a* for all seasons (Tables 5-8). The correlations were positive for all seasons except for October 2002 (Table 8). A significant positive correlation appears between total nitrogen and total phosphorus in January 2003 (Table 9) and continues in April 2003 (Table 10).

Total Phosphorus

Total phosphorus (Fig 5) was significantly higher in July than in any other season. Edge complexity had a significant effect on total phosphorus in October 2002 and April 2003 (Table 11) with smooth edge reefs having higher concentrations than convoluted edges and controls for both months (Table 5). The vertical complexity of the reefs had a significant effect on total phosphorus in October 2002 and January 2003 (Table 11). The low vertical complexity reefs had higher levels than both high vertical complexity reefs and controls in October 2002 and lower means than both in January 2003 (Table 5). Distance had a significant effect on total phosphorus in April 2003 (Table 11). Phosphorus concentrations at 5 cm from the reef were higher than all other distances (Table 6). Only one interaction, site*surface in January 2003, was significant for total

Table 6. Total nitrogen (μmol/L), total phosphorus (μmol/L), and chlorophyll *a* (mg/m^2) mean values with standard error in parentheses for distance treatments and for all variables. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, $P<0.05$, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Date	Variable	5cm	50cm	500cm	Control
Jul-02	Total Nitrogen	226.59(12.24)	220.45(15.83)	240.88(29.06)	199.05(37.95)
Jul-02	Total Phosphorus	7.17(0.63)	8.05(0.66)	7.72(0.72)	4.45(1.21)
Jul-02	Chlorophyll *a*	73.01(4.16)	78.08(4.19)	70.40(5.07)	72.39(8.23)
Oct-02	Total Nitrogen	207.60(15.13)	186.07(11.52)	202.42(15.68)	209.30(32.93)
Oct-02	Total Phosphorus	4.18(0.44)	5.07(1.24)	4.11(0.55)	4.91(1.72)
Oct-02	Chlorophyll *a*	49.33(5.92)	61.86(7.70)	51.75(5.29)	47.12(8.64)
Jan-03	Total Nitrogen	165.63(11.57)	188.37(15.10)	160.25(11.84)	143.50(17.96)
Jan-03	Total Phosphorus	3.19(0.32)	2.93(0.23)	2.65(0.24)	3.24(0.75)
Jan-03	Chlorophyll *a*	64.32(3.67)	68.51(4.23)	58.73(2.99)	60.20(12.05)
Apr-03	Total Nitrogen	148.49(9.55)	142.78(14.02)	145.89(10.00)	143.02(24.34)
Apr-03	Total Phosphorus	4.56(0.56)^{A}	3.26(0.23)^{A}	3.67(0.36)^{A}	2.96(0.55)^{A}
Apr-03	Chlorophyll *a*	56.83(3.61)	63.29(3.66)	61.43(4.46)	51.25(8.12)

Table 7. Pearson's correlation test results for all variables in July 2002. Correlations (r) are on the top and P-values are on the bottom (significant correlations, P<0.05, are in bold). CHL= chlorophyll *a*, TN= total nitrogen, TP= total phosphorus, SEDFINE=fine sediment, and TOM= total organic matter.

	CHL	TN	TP	SEDFINE	TOM
CHL	1	0.294	0.050	0.193	0.088
		0.002	0.603	**0.041**	0.358
TN		1	0.151	-0.126	-0.137
			0.112	0.184	0.151
TP			1	-0.280	-0.259
				0.003	**0.006**
SEDFINE				1	0.809
					<0.0001
TOM					1

Table 8. Pearson's correlation test results for all variables in October 2002. Correlations (r) are on the top and P-values are on the bottom (significant correlations, $P<0.05$, are in bold). CHL= chlorophyll *a*, TN= total nitrogen, TP= total phosphorus, SEDFINE=fine sediment, and TOM= total organic matter.

	CHL	TN	TP	SEDFINE	TOM
CHL	1	-0.320	-0.203	-0.019	-0.079
		0.0006	**0.032**	0.844	0.409
TN		1	0.145	-0.114	-0.123
			0.127	0.231	0.198
TP			1	-0.116	-0.097
				0.221	0.310
SEDFINE				1	0.963
					<0.0001
TOM					1

Table 9. Pearson's correlation test results for all variables in January 2003. Correlations (r) are on the top and P-values are on the bottom (significant correlations, $P<0.05$, are in bold). CHL= chlorophyll *a*, TN= total nitrogen, TP= total phosphorus, SEDFINE=fine sediment, and TOM= total organic matter.

	CHL	TN	TP	SEDFINE	TOM
CHL	1	0.392	-0.079	0.158	0.233
		<0.0001	0.410	0.096	**0.013**
TN		1	0.420	0.010	0.083
			<0.0001	0.916	0.386
TP			1	0.038	0.084
				0.690	0.378
SEDFINE				1	0.892
					<0.0001
TOM					1

Table 10. Pearson's correlation test results for all variables in April 2003. Correlations (r) are on the top and P-values are on the bottom (significant correlations, P<0.05, are in bold). CHL= chlorophyll *a*, TN= total nitrogen, TP= total phosphorus, SEDFINE=fine sediment, and TOM= total organic matter.

	CHL	TN	TP	SEDFINE	TOM
CHL	1	0.222	0.098	-0.255	-0.204
		0.018	0.303	**0.007**	**0.030**
TN		1	0.381	-0.015	0.052
			<0.0001	0.877	0.587
TP			1	-0.118	-0.044
				0.214	0.642
SEDFINE				1	0.880
					<0.0001
TOM					1

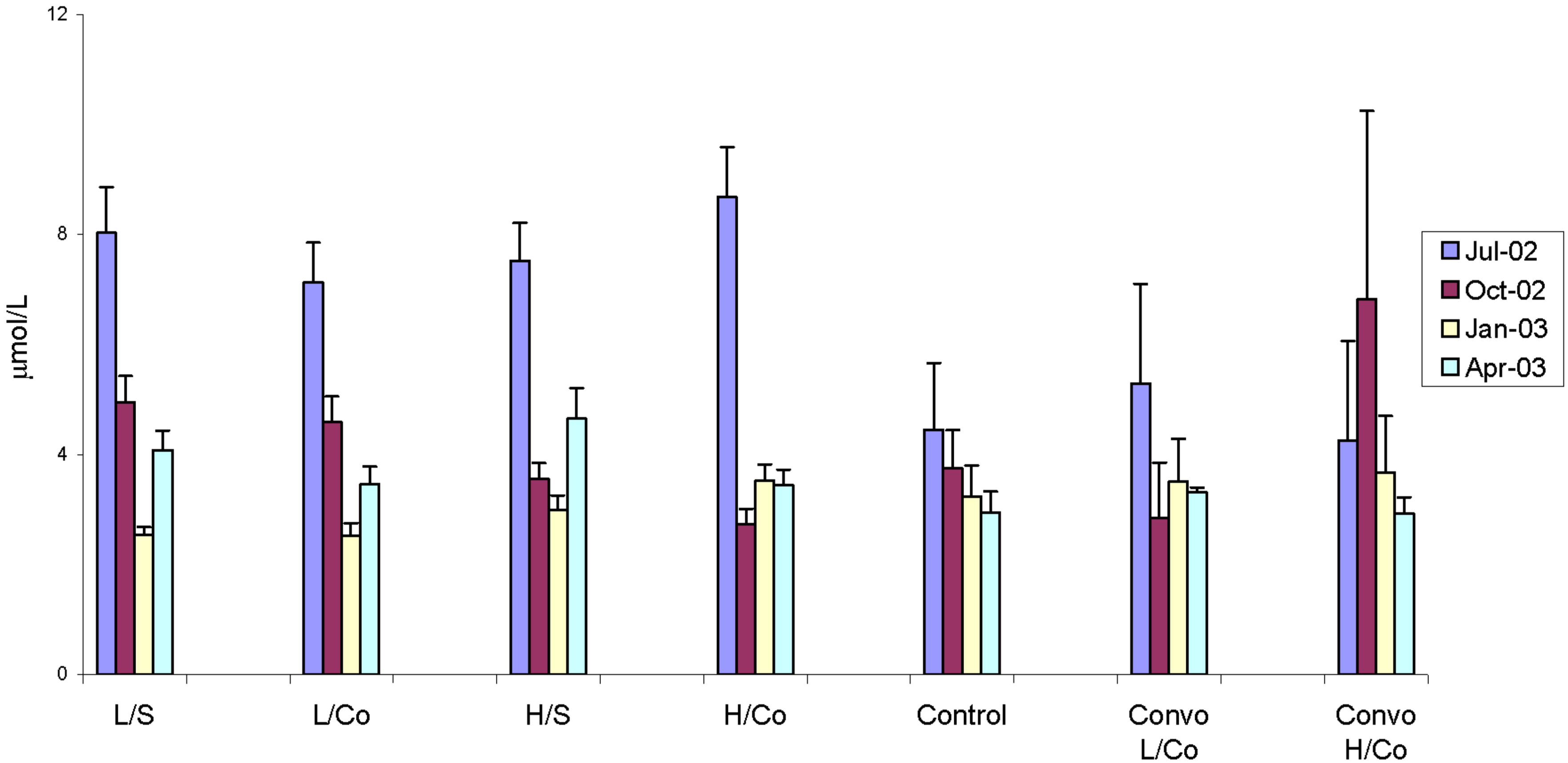

Figure 5: Mean total phosphorus concentrations, in pore water, for all treatments and all seasons. Error bars indicate standard error (L=Low vertical complexity, H=High vertical complexity, S=Smooth edge, Co=Convoluted edge, Convo=samples taken within convolution).

Table 11. 4-way ANOVA testing effects of edge, surface complexity, distance and site (block) on total phosphorus for each season. F-values are on top and P-values are in parentheses on bottom (bold values are significant, $P<0.05$). There were no significant 3 or 4-way interactions.

Date	Site	Edge	Surface	Distance	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Jul-02	0.70	0.07	0.36	0.37	1.28	2.22	0.99	1.04	1.68
	(0.556)	(0.797)	(0.551)	(0.690)	(0.285)	(0.091)	(0.375)	(0.358)	(0.198)
Oct-02	0.47	4.34	10.18	0.42	0.42	1.64	1.57	1.18	1.25
	(0.706)	**(0.040)**	**(0.002)**	(0.656)	(0.737)	(0.186)	(0.214)	(0.313)	(0.267)
Jan-03	11.48	0.30	4.11	1.29	1.68	4.07	0.46	0.03	0.56
	(<0.0001)	(0.588)	**(0.046)**	(0.281)	(0.177)	**(0.009)**	(0.634)	(0.966)	(0.458)
Apr-03	4.68	4.35	0.25	3.52	0.35	1.88	0.35	0.10	0.63
	(0.004)	**(0.040)**	(0.617)	**(0.034)**	(0.786)	(0.139)	(0.707)	(0.901)	(0.429)

phosphorus (Table 11). This interaction was significant due to high levels in the control at site 2 and extremely low levels for all edge treatments at site 4 compared to the other three sites. Significant correlations varied seasonally for total phosphorus. In July 2002, total phosphorus was negatively correlated with percentage fine sediment and total organic matter (Table 7). In October 2002, total phosphorus was negatively correlated with chlorophyll *a* (Table 8). There were significant positive correlations between total phosphorus and total nitrogen in January 2003 (Table 9) and April 2003 (Table 10).

Chlorophyll *a*

Chlorophyll *a* was higher in July 2002 than in any other season for all treatments except the high vertical complexity/convoluted edged reefs (Fig 6). There was a significant effect due to edge on chlorophyll *a* in July 2002 and a marginally non-significant concordant pattern in October 2002 (Table 12). This effect was due to increased chlorophyll *a* numbers on smooth edged reefs as compared to convoluted edges and controls (Table 5). Site 1 also demonstrated increased chlorophyll *a* adjacent to smooth edged reefs as compared to convoluted edges and controls for all seasons. The only interaction effects were edge*surface in July 2002 and site*edge in January 2003 on chlorophyll *a*. The edge*surface interaction was due to high vertical complexity/convoluted edge reefs having a lower chlorophyll *a* value than low vertical complexity/convoluted reefs and controls while high vertical complexity/smooth edged reefs had higher values than all other treatments. The site*edge interaction was due to the low chlorophyll *a* concentrations for the control at site 2 compared to controls at all other sites. There were significant correlations between chlorophyll *a* and total nitrogen

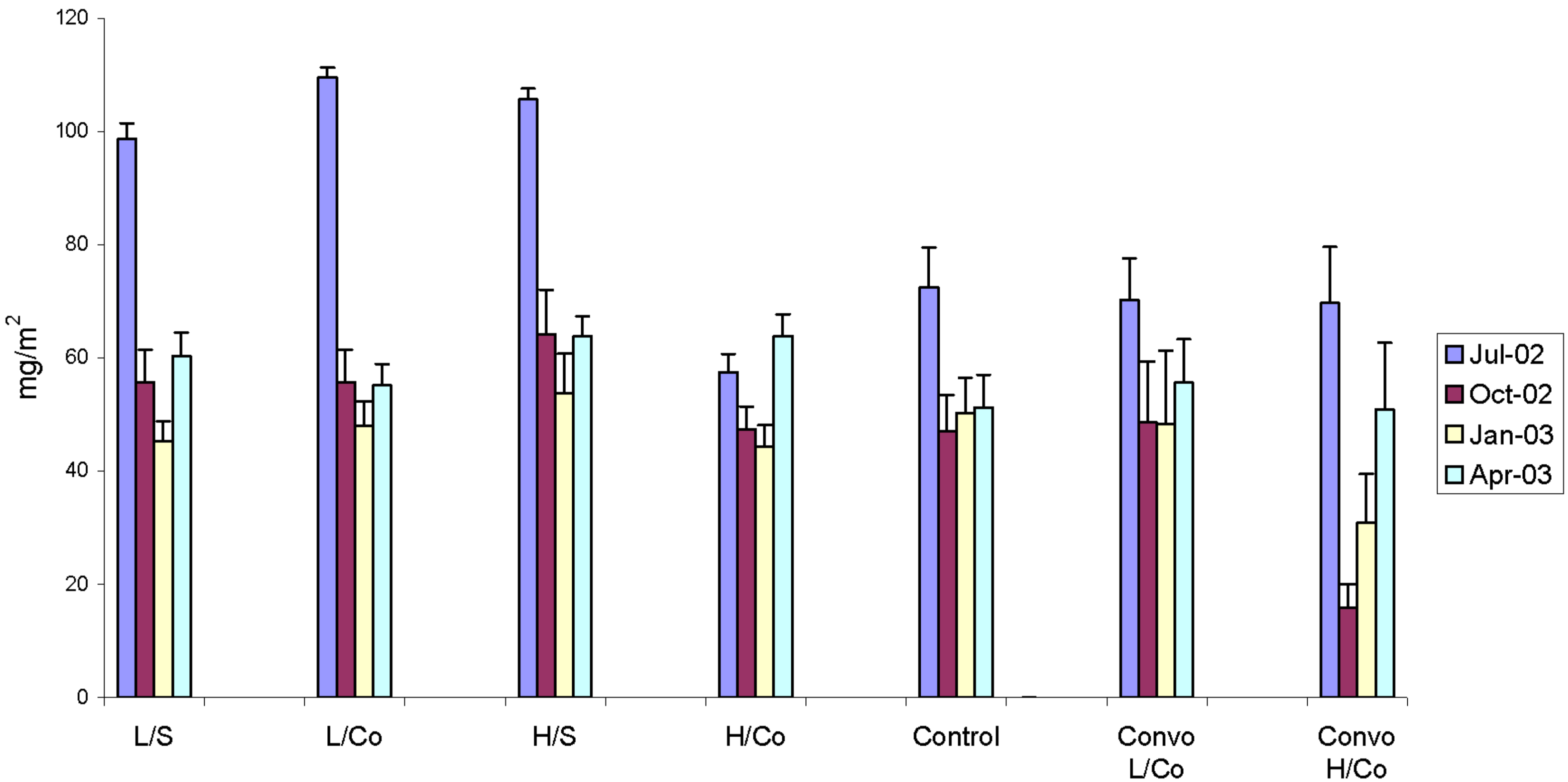

Figure 6: Mean chlorophyll *a* concentrations for all treatments and all seasons. Error bars indicate standard error (L=Low vertical complexity, H=High vertical complexity, S=Smooth edge, Co=Convoluted edge, Convo=samples taken within convolution).

Table 12. 4-way ANOVA testing effects of edge, surface complexity, distance and site (block) on chlorophyll *a* for each season. F-values are on top and P-values are in parentheses on bottom (bold values are significant, P<0.05). There were no significant 3 or 4-way interactions.

Date	Site	Edge	Surface	Distance	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Jul-02	15.84	6.27	0.19	1.38	2.52	2.23	0.74	0.50	6.14
	(<0.0001)	**(0.014)***	(0.660)	(0.257)	(0.063)	(0.094)	(0.481)	(0.609)	**(0.015)**
Oct-02	11.57	3.35	0.04	1.58	1.68	0.56	1.66	1.09	3.16
	(<0.0001)	(0.071)**	(0.847)	(0.212)	(0.176)	(0.642)	(0.196)	(0.340)	(0.079)
Jan-03	12.44	0.41	0.48	2.25	6.40	1.25	2.75	0.00	0.61
	(<0.0001)	(0.524)‡	(0.490)	(0.111)	**(0.0006)**	(0.297)	(0.069)	(0.996)	(0.437)
Apr-03	5.78	0.68	1.50	1.04	2.63	0.81	1.10	0.07	0.13
	(0.001)	(0.410)‡‡	(0.224)	(0.357)	(0.055)	(0.494)	(0.337)	(0.930)	(0.724)

July 2002

* Site 1 P= .0254 Site 3 P= NS
Site 2 P= NS Site 4 P= NS

October 2002

** Site 1 P= 0.021 Site 3 P= NS
Site 2 P= NS Site 4 P= NS

January 2003

‡ Site 1 P= <0.0001 Site 3 P= NS
Site 2 P= NS Site 4 P= NS

April 2003

‡‡ Site 1 P= .039 Site 3 P= NS
Site 2 P= NS Site 4 P= NS

for all seasons (Tables 5-8). The correlations were positive for all seasons except for October 2002 (Table 8). There was a significant positive correlation between chlorophyll *a* and the percentage fine sediment in July 2002 (Table 7) and a significant negative correlation in April 2003 (Table 10). There was a significant correlation, positive, with total organic matter in January 2003 (Table 9), andin April 2003, a negative correlation occurred (Table 10). There was also a significant negative correlation between chlorophyll *a* and total phosphorus in October 2002 (Table 8).

Fine Sediment

January 2003 had the highest overall percentage of fine sediment per season (Fig 7). Within convolutions had significantly higher percentages of fine sediment in all seasons (Fig 7). Fine sediments were proportionately greater immediately adjacent to the reef (5cm) than all other distances for all seasons (Table13 & 14). There were no significant edge effects on the percentage of fine sediment for any season (Table 13). There were significant surface complexity effects on percent fine sediment for October 2002 and January 2003 (Table 13). This effect was due to high surface complexity treatments having significantly greater percent fine sediment than control areas for October 2002 and January 2003 (Table 15). The percent fine sediment on high surface complexity reefs was also significantly greater than on low surface complexity reefs in October as well (Table 15). Convoluted and smooth edged reefs both had significantly greater percentages of fine sediment than control areas in January 2003 but not in any other season (Table 15). There were three significant interactive effects on the percentage of fine sediment, site*edge in July 2002, surface*distance in October 2002

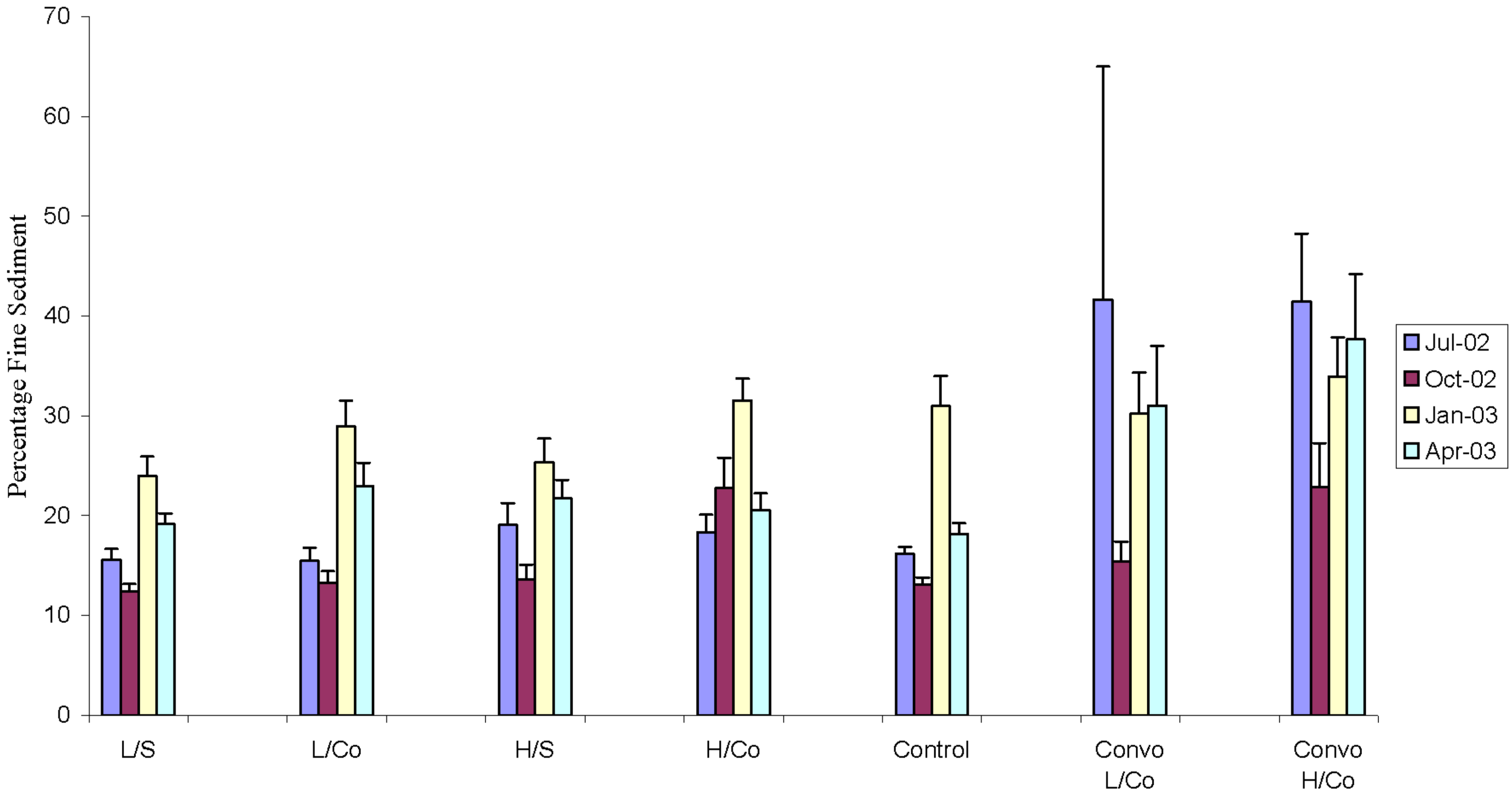

Figure 7: Percentage fine sediment (0.375µm - 63.41µm) for all treatments and seasons. Error bars indicate standard error (L=Low vertical complexity, H=High vertical complexity, S=Smooth edge, Co=Convoluted edge, Convo=samples taken within convolution).

Table 13. 4-way ANOVA testing effects of edge, surface complexity, distance and site (block) on percent fine sediment for each season. F-values are on top and P-values are in parentheses on bottom (bold values are significant, $P<0.05$). There were no significant 3 or 4-way interactions.

Date	Site	Edge	Surface	Distance	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Jul-02	3.16	0.85	3.27	12.01	3.10	0.27	2.99	0.65	0.00
	(0.029)	(0.358)	(0.074)	**(<0.0001)**	**(0.031)**	(0.847)	(0.055)	(0.523)	(0.978)
Oct-02	5.13	0.28	20.05	16.21	0.85	1.64	0.23	9.15	3.34
	(0.003)	(0.595)	**(<0.0001)**	**(<0.0001)**	(0.471)	(0.187)	(0.796)	**(0.0002)**	(0.071)
Jan-03	6.69	3.13	7.01	33.55	2.15	0.34	1.77	1.42	4.98
	(0.0004)	(0.080)	**(0.010)**	**(<0.0001)**	(0.100)	(0.799)	(0.177)	(0.247)	**(0.028)**
Apr-03	5.42	2.57	0.21	11.27	2.04	0.46	0.92	0.62	1.92
	(0.002)	(0.112)	(0.650)	**(<0.0001)**	(0.114)	(0.709)	(0.402)	(0.540)	(0.169)

Table 14. Percentage fine sediment and percentage total organic matter mean values with standard error in parentheses for distance treatments and for all variables. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, $P<0.05$, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Date	Variable	5cm	50cm	500cm	Control
Jul-02	Fine Sediment	25.41(2.42)^{A}	15.31(1.48)^{B}	14.61(1.04)^{B}	14.99(1.33)^{B}
Jul-02	Total Oranic Matter	1.54(0.10)^{B}	0.96(0.04)^{B}	1.02(0.05)^{B}	0.98(0.08)^{B}
Oct-02	Fine Sediment	21.50(2.27)^{A}	12.78(1.07)^{B}	13.28(0.92)^{B}	12.39(1.34)^{B}
Oct-02	Total Oranic Matter	1.63(0.16)^{A}	1.03(0.06)^{B}	1.02(0.05)^{B}	1.01(0.08)^{B}
Jan-03	Fine Sediment	37.10(1.84)^{A}	28.95(2.33)^{B}	19.42(1.25)^{C}	18.99(2.33)^{C}
Jan-03	Total Oranic Matter	2.48(0.21)^{A}	1.51(0.16)^{B}	1.24(0.07)^{BC}	1.13(0.12)^{C}
Apr-03	Fine Sediment	26.51(1.60)^{A}	20.49(1.59)^{B}	18.27(1.29)^{B}	18.17(1.84)^{B}
Apr-03	Total Oranic Matter	2.00(0.14)^{A}	1.39(0.07)^{B}	1.32(0.07)^{B}	1.23(0.06)^{B}

Table 15. Percentage fine sediment and total organic matter mean values with standard error in parentheses for edge and surface treatments and for all variables. Comparisons of treatment totals, by the Student-Newman-Keul (SNK) test, are indicated by superscript letters (statistically different, $P<0.05$, treatments have different letters). The SNK test is only shown where the ANOVA was significant.

Date	Variable	Convo	Smooth	Control	High	Low	Control
Jul-02	Fine Sediment	20.42(1.90)	17.29(1.25)	14.99(1.33)	20.81(1.73)	17.15(1.61)	14.99(1.33)
Jul-02	Total Oranic Matter	1.21(0.07)	1.19(0.06)	0.98(0.08)	1.29(0.08)^{A}	1.11(0.06)^{AB}	0.98(0.08)^{B}
Oct-02	Fine Sediment	16.31(1.32)	16.26(1.69)	12.39(1.34)	19.77(1.86)^{A}	12.81(0.73)^{B}	12.39(1.34)^{B}
Oct-02	Total Oranic Matter	1.25(0.09)	1.26(0.12)	1.01(0.08)	1.46(0.13)^{A}	1.05(0.04)^{B}	1.01(0.08)^{B}
Jan-03	Fine Sediment	31.16(1.87)	26.81(1.70)	18.99(2.33)	31.46(1.83)^{A}	26.84(1.77)^{A}	18.99(2.33)^{B}
Jan-03	Total Oranic Matter	2.01(0.18)^{A}	1.55(0.12)^{AB}	1.13(0.12)^{B}	2.01(0.17)	1.59(0.14)	1.13(0.12)
Apr-03	Fine Sediment	23.54(1.48)	20.47(1.05)	18.17(1.84)	22.41(1.36)	21.84(1.31)	18.17(1.84)
Apr-03	Total Oranic Matter	1.68(0.11)	1.52(0.07)	1.23(0.06)	1.66(0.11)	1.54(0.09)	1.23(0.06)

and edge*surface in January 2003 (Table 13). The site*edge interaction was due to smooth edged reefs on site 2 having greater means than all other smooth edged reefs. The surface*distance interaction in October 2002 was due to the 5 cm/high surface complexity means being significantly greater than the any other distance/surface combination. The edge*surface interaction in January 2003 was due to the low vertical complexity/smooth edged reefs being significantly less than the other treatment combinations. The major significant correlation for the percentage fine sediment was with total organic matter (<0.0001) for all seasons. There were also significant correlations with chlorophyll *a*, positive, and total phosphorus, negative, in July 2002 (Table 7) and chlorophyll *a*, negative, in April 2003 (Table 10).

Total Organic Matter

Patterns for total organic matter are similar to the percent fine sediment with January 2003 showing the highest overall percentage of total organic matter per season and total organic matter percentages in convolutions significantly higher than at other locations for all seasons (Fig 8). The effects of distance are significant for all seasons on total organic matter (Table 16), with percent organic matter adjacent to the reefs (5 cm) being significantly greater than all other distances and for all seasons (Table 14). Edge was only significant for total organic matter during January 2003 (Table 16). The convoluted edged reefs had significantly greater percentages of total organic matter than the controls in January and April 2003 (Table 15). Surface effects on total organic matter were significant in July 2002 and October 2002 (Table 14). High surface complexity reefs had significantly higher percentages of total organic matter than controls (Table 15).

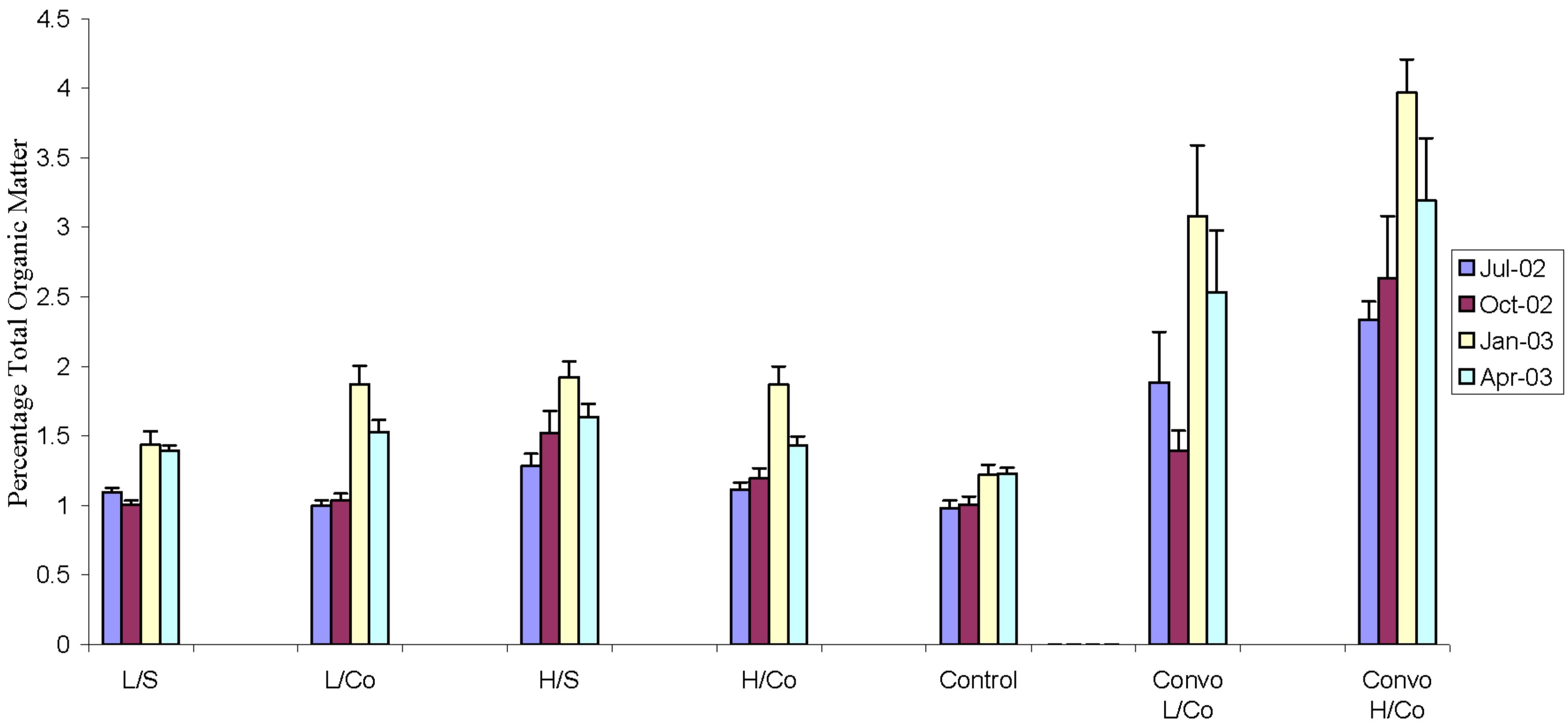

Figure 8: Total Organic Matter for all treatments and seasons. Error bars indicate standard error (L=Low vertical complexity, H=High vertical complexity, S=Smooth edge, Co=Convoluted edge, Convo=samples taken within convolution).

Table 16. 4-way ANOVA testing effects of edge, surface complexity, distance and site (block) on total organic matter for each season. F-values are on top and P-values are in parentheses on bottom (bold values are significant, P<0.05). There were no significant 3 or 4-way interactions.

Date	Site	Edge	Surface	Distance	Site*Edge	Site*Surface	Edge*Distance	Surface*Distance	Edge*Surface
Jul-02	2.89	0.19	5.03	24.33	2.23	1.56	0.67	1.62	0.12
	(0.040)	(0.661)	**(0.028)**	**(<0.0001)**	(0.091)	(0.204)	(0.514)	(0.203)	(0.731)
Oct-02	4.67	0.51	13.31	16.82	1.02	1.79	0.11	8.35	1.92
	(0.004)	(0.477)	**(0.0004)**	**(<0.0001)**	(0.389)	(0.154)	(0.896)	**(0.0005)**	(0.170)
Jan-03	3.60	4.98	3.54	17.38	1.48	0.82	1.17	1.76	1.97
	(0.016)	**(0.028)**	(0.063)	**(<0.0001)**	(0.227)	(0.486)	(0.314)	(0.178)	(0.164)
Apr-03	3.63	0.56	1.37	15.92	3.51	1.45	3.30	0.24	1.38
	(0.016)	(0.458)	(0.246)	**(<0.0001)**	**(0.019)**	(0.235)	**(0.041)**	(0.786)	(0.244)

Interactions were varied with site*edge and edge*distance having a significant influence in April 2003 and surface*distance having a significant effect in October 2002 (Table 16). The significant site*edge interaction was due to the increases in total organic matter around convoluted edged reefs at sites 2 and 3 as compared to sites 4 and 5, also because of the sharp increase in total organic matter at smooth edged reefs at site 2. The significant surface*distance interaction was due to the high percentage of total organic matter at the 5 cm distance around the convoluted edged reefs compared to all other distances and edge types. The significant surface*distance interaction was due to the higher percentage of total organic matter on the high vertical complexity reefs at the 5 cm distance as compared to all other distances and surface types. The major significant correlation for the total organic matter was with the percentage of fine sediment (<0.0001) for all seasons. There were also significant correlations with total phosphorus, negative, in July 2002 (Table 7) and chlorophyll *a*, positive, in January 2003 (Table 9) and negative in April 2003 (Table 10).

DISCUSSION

This study demonstrated that oyster reefs impact microphytobenthos biomass, total nitrogen, total phosphorus, total organic matter, and fine sediment content in adjacent sandflat habitats. Aside from simple presence of reef effects, reef morphology influences the type and degree of these impacts for certain variables. The most significant effect observed for any variable was distance from the reef on the percentage of fine sediment and total organic matter in adjacent sandflat areas. Immediately adjacent to the reefs had greater percent fine sediments and total organic matter than all other distances and control areas for all seasons. This pattern represents a physical impact of the reefs on the adjacent sediments, despite the relatively small size of the reefs (10 m^2). Edge complexity effects on chlorophyll *a*, though small, were consistent and may have important cumulative impacts. Benthic chlorophyll *a* is spatially variable, making spatial patterns difficult to detect without high replication (Cahoon 1999). Even with the limited replication in this study (4 replicate reefs of each type) and the smaller size reef a significant edge effect was observed in July 2002, a marginally non-significant effect occurred in October 2002, and site 1 had an edge effect on chlorophyll *a* throughout all seasons (Table 12). In all cases, smooth edged reefs had higher levels and controls lower levels of chlorophyll *a*.

The simple presence of oyster reefs had major impacts on percent fine sediment and total organic matter in the adjacent sandflat. Both high and low vertical complexity reefs had greater percent fine sediment compared to non-reef areas in January 2003. This effect on the fine sediment is expected due to physical increases in sedimentation that reefs create (Haven & Morales-Alamo 1968, Lenihan 1999, Mugg 2001). There was also a strong distance from the reef effect on percent fine sediment and total organic matter. The percentages immediately adjacent to the reef were greater than at any other distance and control treatments for all seasons (Table 14), which suggests an overall physical reef impact on the adjacent sandflat that is localized for smaller reef patches. Consistent with these spatial patterns, a strong positive correlation between percentage fine sediment and total organic matter also existed for all seasons ($P=<0.0001$). The strong distance effect on both the percent fine sediment and total organic matter, along with the significant positive correlation of the two variables is most likely due to oyster biodeposition of fine sediments and particulate organic matter (POM) combined with the physical presence of the oyster reefs. The link between the percent fine sediment and total organic matter adjacent to oyster reefs has been previously indicated (Saoud & Rouse 2000), but not specific to distance from the reef. The close proximity effect of the reefs on fine sediments and organic matter are presumably due to the small size of the reefs ($10m^2$).

There was also a strong reef impact on chlorophyll *a* concentrations in the adjacent sandflats. Benthic chlorophyll *a* had higher concentrations adjacent to smooth and convoluted edged reefs compared to controls. There was also a significant distance effect on chlorophyll *a,* which was significantly higher at 50 cm than the control areas. This is most likely due to the increases in nutrients and organic matter adjacent to the reefs, out to 50 cm, while microphytobenthos growth immediately adjacent to the reefs could be inhibited by increased fine sediments (Cahoon et al. 1999) and densities of grazers in close proximity to the reefs utilizing the reefs as a refuge (Powell 1994, Breitburg 1999, Breitburg 2000). Total nitrogen also demonstrated a reef effect in January 2003 when the smooth and convoluted edged reefs had higher mean values than the control areas which is most likely due to biodepositional increases (Haven & Morales-Alamo 1966, Newell et al. 2002).

Out of the three treatments (edge, surface, and distance), edge effect had the greatest overall impact on the biologically important variables, chlorophyll *a*, total nitrogen, and total phosphorus. The smooth edged reefs had an overall higher concentration than convoluted edged reefs and controls for total nitrogen, total phosphorus, and chlorophyll *a*. Edge also had a significant effect on total nitrogen in colder sampling periods with smooth edged reefs having higher concentrations than controls and convoluted edged reefs. This may relate to trapping of sediments near convolutions, with possible indirect effects on macrofauna sediment oxygenation and nitrification (Lerat et al. 1990). The smooth edged reefs may have higher total nitrogen than control areas due to biodepositional effects near the reefs. Total phosphorus was also affected by edge in October 2002 and April 2003, with smooth edged reefs again having higher mean values than convoluted reefs and controls. The cause of this edge effect on total phosphorus is very difficult to determine due to the complexities of phosphorus in soil. Phosphorus adsorbs strongly to sediments, but it also can be released via ground disturbances and eutrophic, anaerobic conditions (Correll 1998). So it is unclear if these results are linked solely to edge effects, to environmental changes/disturbances, or to the combination of both.

There was an overall lack of surface complexity effects. Total nitrogen and chlorophyll *a* demonstrated no significant effects due to surface complexity. The percent fine sediment and total organic matter were the variables most significantly affected by vertical surface complexity. The percent fine sediment and total organic matter were both significantly greater on high vertical complexity reefs than low vertical complexity reefs and control areas. Control areas were significantly lower in fine sediment and organic matter than both high and low vertical complexity reefs. Increased organic matter and fine sediment concentrations around high surface complexity reefs may relate to a combination of physical structure slowing down currents locally and oyster biodeposition that aggregates finer particles. Increased total nitrogen and total phosphorus were also expected to increase with high surface complexity due to the slowing of currents and increases in biodeposition, but these increases were not observed.

Season and site were both highly significant for all variables. Strong site and site interaction effects were expected due to the variation in site locations. Microphytobenthos and nutrients are patchy on horizontal scales of centimeters to meters and kilometers (Cahoon 1999) and nutrients and organic matter undergo numerous transformations in the sediment (Dame 1999) making both difficult to compare spatially, site to site, which was the reason for the blocked spatial design for treatment placement. Seasonal variation was expected due to biological and physical changes each season, biological activity being higher in the summer and spring while slower in the fall and winter. Summer is a time of high biomass numbers for the microphytobenthos community due to increased light intensity (Cahoon 1999), which is consistent with high July levels observed here, and may also relate to high nutrient concentrations at the time (Haven and Morales-Alamo 1966).

Oyster reefs had both reef and morphology effects on adjacent sandflats. Edge and surface complexity, along with distance from the reef, are important components of reef structure that affect microphytobenthos biomass, nutrients, and sediment characteristics. The lack of surface complexity effect overall does not necessarily mean that surface complexity had no effect on these sediment linkages. This could be due to the small size of the reefs, still within natural parameters, but limited in complexity. Larger reefs with more surface complexity could demonstrate significant effects. The result of this study has implications for design of oyster reef restoration projects, ecological consequences of fragmentation of natural reefs, and the importance of oyster reef interactions with adjacent sandflats. The presence of several smaller patch reefs (with smooth edges) may have an overall enhancement effect on adjacent microphytobenthos communities compared to one large artificial oyster reef of similar overall area. Most current restoration efforts consist of the latter. Fragmentation of natural oyster reefs by destructive harvesting practices can change edge and surface complexities, which can affect adjacent microphytobenthos communities and sediment characteristics. Oyster reefs have a strong physical effect on adjacent sediment characteristics, particularly fine sediment and organic matter content. Their presence and their spatial arrangement can change the community composition of the adjacent sandflat area, for better and for worse, and must be considered when creating oyster reefs.

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Appendix A. July 2002 data for all variables and treatments (CHL= Chlorophyll a, TN= Total Nitrogen, TP= Total Phosphorus, Fine Sed= Percentage Fine Sediment, TOM= Total Organic Matter, * indicates samples taken within convolutions).

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
1	SMOOTH	LOW	5cm	98.982	294.050	12.825	16.30	1.20
1	SMOOTH	LOW	50cm	109.512	332.300	15.075	9.91	0.77
1	SMOOTH	LOW	500cm	87.399	466.150	8.075	11.41	0.82
1	CONVO	LOW	5cm	108.810	252.925	8.775	20.67	1.19
1	CONVO	LOW	50cm	105.300	431.800	5.400	11.11	0.80
1	CONVO	LOW	500cm	99.684	530.875	8.300	13.10	0.75
1	SMOOTH	HIGH	5cm	114.426	229.625	8.850	26.54	1.70
1	SMOOTH	HIGH	50cm	101.088	199.650	10.875	6.41	0.58
1	SMOOTH	HIGH	500cm	101.439	355.250	7.725	9.95	0.90
1	CONVO	HIGH	5cm	103.896	258.675	10.525	36.26	1.57
1	CONVO	HIGH	50cm	90.558	213.225	11.250	15.33	0.75
1	CONVO	HIGH	500cm	80.379	340.050	14.300	12.48	0.88
1	CONTROL	CONTROL	100cm	102.843	227.550	0.350	16.58	0.81
1	CONVO*	LOW	5cm	108.810	288.400	0.200	88.29	3.52
1	CONVO*	HIGH	5cm	83.538	294.300	0.500	51.15	2.22
2	SMOOTH	LOW	5cm	53.001	218.127	6.750	25.48	1.35
2	SMOOTH	LOW	50cm	92.664	115.753	5.050	20.82	1.11
2	SMOOTH	LOW	500cm	96.174	119.534	5.435	23.99	1.27
2	CONVO	LOW	5cm	50.193	174.219	3.240	31.68	1.33
2	CONVO	LOW	50cm	90.909	173.961	2.125	21.20	0.94
2	CONVO	LOW	500cm	60.021	183.597	3.455	15.91	0.91
2	SMOOTH	HIGH	5cm	94.770	221.146	6.155	29.10	2.08

Appendix A continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
2	SMOOTH	HIGH	50cm	96.174	289.948	7.360	30.25	1.28
2	SMOOTH	HIGH	500cm	119.340	128.139	6.625	30.42	1.52
2	CONVO	HIGH	5cm	50.193	160.152	7.285	26.54	1.58
2	CONVO	HIGH	50cm	74.412	125.549	10.180	28.32	1.03
2	CONVO	HIGH	500cm	53.352	108.143	9.075	18.45	1.50
2	CONTROL	CONTROL	100cm	65.637	87.950	5.740	19.55	1.32
2	CONVO*	LOW	5cm	68.094	218.004	6.330	20.22	1.57
2	CONVO*	HIGH	5cm	98.982	165.099	7.700	44.91	2.91
3	SMOOTH	LOW	5cm	52.650	209.825	4.650	13.85	1.33
3	SMOOTH	LOW	50cm	60.021	189.438	5.950	14.15	1.19
3	SMOOTH	LOW	500cm	35.451	174.931	7.913	14.66	1.17
3	CONVO	LOW	5cm	65.637	199.731	9.025	14.29	1.04
3	CONVO	LOW	50cm	44.226	280.300	10.638	11.21	1.05
3	CONVO	LOW	500cm	60.372	242.606	7.200	10.60	0.91
3	SMOOTH	HIGH	5cm	74.763	285.706	6.175	25.28	2.10
3	SMOOTH	HIGH	50cm	67.392	193.975	4.963	16.65	1.21
3	SMOOTH	HIGH	500cm	64.584	201.331	4.925	15.29	1.20
3	CONVO	HIGH	5cm	60.021	246.881	6.075	16.48	1.26
3	CONVO	HIGH	50cm	69.498	170.594	6.888	13.96	1.05
3	CONVO	HIGH	500cm	63.531	311.538	9.213	11.87	0.95
3	CONTROL	CONTROL	100cm	71.604	245.213	4.775	12.43	0.89
3	CONVO*	LOW	5cm	62.478	396.950	5.900	16.46	1.22
3	CONVO*	HIGH	5cm	44.928	295.650	1.850	28.22	2.11

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Appendix A continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
4	SMOOTH	LOW	5cm	69.147	175.150	8.763	14.30	1.17
4	SMOOTH	LOW	50cm	62.127	235.563	8.688	9.88	0.81
4	SMOOTH	LOW	500cm	62.829	233.800	7.213	11.69	0.88
4	CONVO	LOW	5cm	75.465	242.388	10.563	12.88	1.04
4	CONVO	LOW	50cm	74.061	197.250	9.025	11.38	0.90
4	CONVO	LOW	500cm	46.683	125.763	7.763	11.58	0.90
4	SMOOTH	HIGH	5cm	62.127	233.563	9.250	14.49	0.99
4	SMOOTH	HIGH	50cm	54.405	218.213	8.313	12.24	0.98
4	SMOOTH	HIGH	500cm	57.915	189.775	9.088	11.93	0.86
4	CONVO	HIGH	5cm	45.279	148.138	5.300	17.39	1.04
4	CONVO	HIGH	50cm	56.862	159.700	6.963	12.14	0.92
4	CONVO	HIGH	500cm	37.206	142.600	7.150	10.37	0.85
4	CONTROL	CONTROL	100cm	49.491	235.475	6.950	11.39	0.90
4	CONVO*	LOW	5cm	43.524	145.450	8.750	22.46	1.77
4	CONVO*	HIGH	5cm	51.246	159.100	6.975	61.44	2.34

Appendix B. October 2002 data for all variables and treatments (CHL= Chlorophyll a, TN= Total Nitrogen, TP= Total Phosphorus, Fine Sed= Percentage Fine Sediment, TOM= Total Organic Matter, * indicates samples taken within convolutions).

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
1	SMOOTH	LOW	5cm	156.897	152.635	3.793	13.12	1.04
1	SMOOTH	LOW	50cm	64.584	241.188	4.263	9.13	0.76
1	SMOOTH	LOW	500cm	85.995	178.040	3.768	10.33	0.81
1	CONVO	LOW	5cm	62.127	190.688	4.450	9.34	0.84
1	CONVO	LOW	50cm	112.671	115.805	2.820	8.90	0.82
1	CONVO	LOW	500cm	76.869	166.900	2.733	8.48	0.85
1	SMOOTH	HIGH	5cm	116.883	156.853	2.945	11.50	0.94
1	SMOOTH	HIGH	50cm	109.512	164.125	3.445	5.74	0.61
1	SMOOTH	HIGH	500cm	92.664	150.195	3.888	14.43	0.80
1	CONVO	HIGH	5cm	75.114	249.673	2.855	17.41	1.29
1	CONVO	HIGH	50cm	73.008	139.040	2.590	12.44	0.99
1	CONVO	HIGH	500cm	60.372	136.050	2.453	9.91	0.82
1	CONTROL	CONTROL	100cm	54.756	323.330	3.653	11.21	0.80
1	CONVO*	LOW	5cm	70.902	166.420	6.125	12.64	1.09
1	CONVO*	HIGH	5cm	26.676	223.735	6.715	30.75	1.82
2	SMOOTH	LOW	5cm	46.332	192.085	9.878	11.88	1.27
2	SMOOTH	LOW	50cm	51.948	125.568	5.133	11.88	1.04
2	SMOOTH	LOW	500cm	54.405	95.343	3.585	17.36	1.34
2	CONVO	LOW	5cm	57.213	76.725	1.723	26.84	1.82
2	CONVO	LOW	50cm	95.121	180.680	3.380	22.62	1.52
2	CONVO	LOW	500cm	75.465	176.238	3.755	19.81	1.31
2	SMOOTH	HIGH	5cm	51.246	184.475	4.663	53.78	4.08

Appendix B continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (µmol/L)	TP (µmol/L)	Fine Sed (%)	TOM (%)
2	SMOOTH	HIGH	50cm	127.413	118.758	1.778	29.95	1.98
2	SMOOTH	HIGH	500cm	91.962	174.585	2.558	23.01	1.50
2	CONVO	HIGH	5cm	45.630	116.928	1.826	28.41	1.95
2	CONVO	HIGH	50cm	62.829	132.368	2.483	17.43	1.30
2	CONVO	HIGH	500cm	76.518	118.515	1.258	21.03	1.38
2	CONTROL	CONTROL	100cm	68.445	114.270	8.270	15.64	1.21
2	CONVO*	LOW	5cm	71.604	96.640	0.750	29.43	2.02
2	CONVO*	HIGH	5cm	25.974	116.585	1.375	40.47	2.84
3	SMOOTH	LOW	5cm	60.021	317.920	9.093	14.46	1.10
3	SMOOTH	LOW	50cm	39.312	206.030	17.973	10.62	0.88
3	SMOOTH	LOW	500cm	30.537	159.063	1.965	11.76	0.86
3	CONVO	LOW	5cm	27.027	227.930	5.148	10.98	0.86
3	CONVO	LOW	50cm	45.981	205.778	4.120	12.35	0.85
3	CONVO	LOW	500cm	40.014	329.663	13.778	10.11	0.81
3	SMOOTH	HIGH	5cm	22.113	346.715	4.310	32.91	2.06
3	SMOOTH	HIGH	50cm	39.312	280.403	1.505	11.55	0.89
3	SMOOTH	HIGH	500cm	24.219	331.630	3.088	15.07	1.13
3	CONVO	HIGH	5cm	21.411	431.828	3.638	16.83	1.26
3	CONVO	HIGH	50cm	45.279	297.628	1.538	11.26	0.92
3	CONVO	HIGH	500cm	31.239	240.575	1.408	8.75	0.69
3	CONTROL	CONTROL	100cm	38.610	152.855	2.720	12.85	0.98
3	CONVO*	LOW	5cm	18.252	224.435	0.985	14.58	1.32
3	CONVO*	HIGH	5cm	21.762	287.470	1.010	18.87	1.39

Appendix B continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
4	SMOOTH	LOW	5cm	25.623	229.528	3.520	10.04	0.96
4	SMOOTH	LOW	50cm	28.080	227.545	17.143	9.45	1.06
4	SMOOTH	LOW	500cm	25.272	274.575	6.808	10.15	0.96
4	CONVO	LOW	5cm	24.570	214.275	4.815	11.15	0.99
4	CONVO	LOW	50cm	25.623	183.078	4.023	9.41	0.91
4	CONVO	LOW	500cm	25.974	207.798	4.300	8.00	0.89
4	SMOOTH	HIGH	5cm	25.623	172.730	3.683	27.38	2.14
4	SMOOTH	HIGH	50cm	39.663	212.073	4.138	12.34	1.06
4	SMOOTH	HIGH	500cm	29.484	348.598	6.805	12.50	1.09
4	CONVO	HIGH	5cm	29.133	214.595	4.460	23.37	1.87
4	CONVO	HIGH	50cm	29.484	147.143	4.725	9.35	0.91
4	CONVO	HIGH	500cm	7.020	151.018	3.653	11.82	1.02
4	CONTROL	CONTROL	100cm	26.676	246.730	4.985	9.89	1.04
4	CONVO*	LOW	5cm	33.696	133.100	5.465	13.14	1.15
4	CONVO*	HIGH	5cm	10.530	104.405	3.320	61.44	4.48

Appendix C. January 2003 data for all variables and treatments (CHL= Chlorophyll a, TN= Total Nitrogen, TP= Total Phosphorus, Fine Sed= Percentage Fine Sediment, TOM= Total Organic Matter, * indicates samples taken within convolutions).

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (µmol/L)	TP (µmol/L)	Fine Sed (%)	TOM (%)
1	SMOOTH	LOW	5cm	52.299	147.938	1.985	22.31	1.16
1	SMOOTH	LOW	50cm	70.200	248.948	3.605	13.58	0.85
1	SMOOTH	LOW	500cm	62.829	122.348	2.413	12.96	0.68
1	CONVO	LOW	5cm	50.193	170.580	3.708	25.99	1.61
1	CONVO	LOW	50cm	49.140	153.755	2.863	13.59	0.88
1	CONVO	LOW	500cm	58.968	136.073	2.970	11.10	0.89
1	SMOOTH	HIGH	5cm	81.081	146.295	3.290	38.54	1.97
1	SMOOTH	HIGH	50cm	68.445	134.593	2.838	16.54	1.16
1	SMOOTH	HIGH	500cm	44.928	113.855	1.880	12.42	1.01
1	CONVO	HIGH	5cm	42.471	137.353	2.510	25.89	1.87
1	CONVO	HIGH	50cm	70.551	176.265	3.560	10.75	0.84
1	CONVO	HIGH	500cm	70.551	166.528	3.063	11.66	1.06
1	CONTROL	CONTROL	100cm	67.041	138.125	1.900	11.40	0.95
1	CONVO*	LOW	5cm	69.498	135.040	1.980	32.26	1.74
1	CONVO*	HIGH	5cm	65.286	113.220	2.110	53.34	4.46
2	SMOOTH	LOW	5cm	54.054	128.535	2.595	28.49	1.75
2	SMOOTH	LOW	50cm	98.631	299.233	2.828	17.59	1.14
2	SMOOTH	LOW	500cm	47.385	144.923	2.028	17.25	1.78
2	CONVO	LOW	5cm	44.226	99.970	0.873	40.53	1.71
2	CONVO	LOW	50cm	46.332	59.120	1.270	43.90	1.97
2	CONVO	LOW	500cm	53.352	114.830	1.153	15.57	1.60
2	SMOOTH	HIGH	5cm	70.551	182.030	3.663	43.96	2.64

Appendix C continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
2	SMOOTH	HIGH	50cm	55.107	158.533	2.453	32.34	1.81
2	SMOOTH	HIGH	500cm	47.034	98.798	1.873	26.40	1.48
2	CONVO	HIGH	5cm	36.855	114.530	4.605	42.83	2.39
2	CONVO	HIGH	50cm	36.504	90.988	4.810	27.58	1.49
2	CONVO	HIGH	500cm	32.994	133.103	5.413	25.01	1.45
2	CONTROL	CONTROL	100cm	9.828	105.313	6.413	15.15	0.95
2	CONVO*	LOW	5cm	40.014	170.730	6.835	31.96	1.82
2	CONVO*	HIGH	5cm	49.140	116.380	8.310	52.05	3.46
3	SMOOTH	LOW	5cm	54.405	196.378	3.645	28.49	1.83
3	SMOOTH	LOW	50cm	45.279	254.540	3.375	17.59	1.11
3	SMOOTH	LOW	500cm	57.564	223.985	3.288	17.25	1.10
3	CONVO	LOW	5cm	90.909	249.093	6.443	40.53	3.28
3	CONVO	LOW	50cm	54.756	233.273	2.568	43.90	2.81
3	CONVO	LOW	500cm	77.922	208.748	3.635	15.57	1.00
3	SMOOTH	HIGH	5cm	60.723	310.573	5.903	48.14	3.61
3	SMOOTH	HIGH	50cm	69.498	288.325	4.233	23.20	1.43
3	SMOOTH	HIGH	500cm	60.021	283.915	5.103	21.75	1.38
3	CONVO	HIGH	5cm	80.028	250.858	4.378	41.43	3.16
3	CONVO	HIGH	50cm	81.081	266.878	4.393	37.13	2.69
3	CONVO	HIGH	500cm	86.697	276.690	3.260	24.24	1.47
3	CONTROL	CONTROL	100cm	75.114	202.970	3.188	25.09	1.50
3	CONVO*	LOW	5cm	108.108	230.770	3.520	52.20	4.16
3	CONVO*	HIGH	5cm	91.260	351.295	2.885	55.99	4.68

Appendix C continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (µmol/L)	TP (µmol/L)	Fine Sed (%)	TOM (%)
4	SMOOTH	LOW	5cm	81.783	126.630	1.363	32.15	1.67
4	SMOOTH	LOW	50cm	107.055	227.283	3.290	37.87	2.67
4	SMOOTH	LOW	500cm	50.895	120.813	1.650	25.23	1.49
4	CONVO	LOW	5cm	59.319	162.175	1.500	30.86	2.19
4	CONVO	LOW	50cm	64.584	155.433	1.810	36.61	2.58
4	CONVO	LOW	500cm	51.948	131.300	1.555	26.04	1.93
4	SMOOTH	HIGH	5cm	61.074	112.473	1.420	36.23	2.22
4	SMOOTH	HIGH	50cm	90.207	182.573	1.660	45.67	2.69
4	SMOOTH	HIGH	500cm	69.849	158.005	1.743	27.59	1.68
4	CONVO	HIGH	5cm	81.432	118.833	1.448	29.53	1.72
4	CONVO	HIGH	50cm	88.803	84.253	1.298	45.36	2.89
4	CONVO	HIGH	500cm	66.690	130.093	1.335	20.71	1.40
4	CONTROL	CONTROL	100cm	88.803	127.585	1.460	24.33	1.48
4	CONVO*	LOW	5cm	65.286	98.605	1.740	49.59	4.59
4	CONVO*	HIGH	5cm	81.432	100.795	1.385	44.64	3.27

Appendix D. April 2003 data for all variables and treatments (CHL= Chlorophyll a, TN= Total Nitrogen, TP= Total Phosphorus, Fine Sed= Percentage Fine Sediment, TOM= Total Organic Matter, * indicates samples taken within convolutions).

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (µmol/L)	TP (µmol/L)	Fine Sed (%)	TOM (%)
1	SMOOTH	LOW	5cm	44.577	212.565	9.515	19.29	1.52
1	SMOOTH	LOW	50cm	66.690	247.948	4.530	12.88	1.17
1	SMOOTH	LOW	500cm	57.213	237.020	7.133	13.69	1.08
1	CONVO	LOW	5cm	87.048	210.593	4.810	16.73	1.39
1	CONVO	LOW	50cm	71.253	164.713	4.390	12.44	1.01
1	CONVO	LOW	500cm	78.273	155.510	6.453	11.11	0.97
1	SMOOTH	HIGH	5cm	90.909	114.425	4.560	15.06	1.11
1	SMOOTH	HIGH	50cm	74.061	103.675	4.435	9.38	0.82
1	SMOOTH	HIGH	500cm	67.743	197.833	4.368	10.20	0.90
1	CONVO	HIGH	5cm	93.015	159.155	5.628	16.14	1.24
1	CONVO	HIGH	50cm	75.114	146.200	4.338	8.41	0.84
1	CONVO	HIGH	500cm	81.783	223.823	4.568	11.38	0.93
1	CONTROL	CONTROL	100cm	77.922	242.983	4.575	15.75	1.05
1	CONVO*	LOW	5cm	48.438	143.450	5.105	20.61	1.67
1	CONVO*	HIGH	5cm	101.790	220.515	4.535	37.17	2.72
2	SMOOTH	LOW	5cm	58.266	190.415	3.288	26.63	1.79
2	SMOOTH	LOW	50cm	88.803	246.205	2.985	18.02	1.38
2	SMOOTH	LOW	500cm	105.300	135.978	3.028	22.23	1.52
2	CONVO	LOW	5cm	37.908	88.983	1.923	24.60	1.83
2	CONVO	LOW	50cm	27.027	142.578	1.663	40.83	1.63
2	CONVO	LOW	500cm	29.835	166.583	2.108	26.42	1.59
2	SMOOTH	HIGH	5cm	36.504	135.845	4.008	33.33	2.94

Appendix D continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
2	SMOOTH	HIGH	50cm	58.617	229.975	3.733	29.69	2.27
2	SMOOTH	HIGH	500cm	53.352	190.570	4.135	22.47	1.70
2	CONVO	HIGH	5cm	56.160	159.648	4.940	30.71	2.03
2	CONVO	HIGH	50cm	74.763	141.383	3.683	30.43	1.91
2	CONVO	HIGH	500cm	63.882	158.748	1.795	26.78	1.78
2	CONTROL	CONTROL	100cm	31.239	111.078	1.645	14.60	1.35
2	CONVO*	LOW	5cm	46.332	107.610	1.950	32.98	2.19
2	CONVO*	HIGH	5cm	43.524	94.610	1.875	29.07	2.38
3	SMOOTH	LOW	5cm	51.597	140.675	2.880	20.72	1.26
3	SMOOTH	LOW	50cm	64.935	211.660	2.693	24.48	1.60
3	SMOOTH	LOW	500cm	57.213	128.153	2.278	17.39	1.17
3	CONVO	LOW	5cm	59.319	153.375	3.058	46.01	3.10
3	CONVO	LOW	50cm	64.233	115.128	2.405	20.27	1.34
3	CONVO	LOW	500cm	54.405	122.120	2.138	20.56	1.37
3	SMOOTH	HIGH	5cm	65.988	193.195	3.070	21.58	1.63
3	SMOOTH	HIGH	50cm	87.750	113.543	2.613	22.98	1.43
3	SMOOTH	HIGH	500cm	60.723	148.385	3.718	24.93	1.81
3	CONVO	HIGH	5cm	59.319	135.700	3.100	24.95	1.77
3	CONVO	HIGH	50cm	60.372	93.703	1.845	15.71	1.16
3	CONVO	HIGH	500cm	62.478	68.605	1.535	28.27	1.79
3	CONTROL	CONTROL	100cm	58.968	116.685	1.445	22.63	1.27
3	CONVO*	LOW	5cm	77.220	233.315	5.750	47.12	4.53
3	CONVO*	HIGH	5cm	21.762	148.825	3.325	56.26	5.22

Appendix D continued.

SITE	EDGE	SURFACE	POS	CHL (mg/m^2)	TN (μmol/L)	TP (μmol/L)	Fine Sed (%)	TOM (%)
4	SMOOTH	LOW	5cm	41.418	94.530	3.053	18.41	1.34
4	SMOOTH	LOW	50cm	57.915	77.250	3.383	18.70	1.45
4	SMOOTH	LOW	500cm	29.484	101.475	3.895	17.64	1.45
4	CONVO	LOW	5cm	40.014	83.890	7.573	23.98	1.80
4	CONVO	LOW	50cm	46.332	84.015	2.403	22.73	1.44
4	CONVO	LOW	500cm	66.339	115.480	2.655	9.92	0.86
4	SMOOTH	HIGH	5cm	43.875	163.520	11.935	33.78	2.26
4	SMOOTH	HIGH	50cm	48.087	75.390	3.333	22.28	1.56
4	SMOOTH	HIGH	500cm	78.975	93.465	5.913	15.43	1.20
4	CONVO	HIGH	5cm	57.564	87.185	3.148	20.78	1.51
4	CONVO	HIGH	50cm	46.683	91.125	3.690	18.60	1.26
4	CONVO	HIGH	500cm	35.802	90.510	3.078	13.97	0.95
4	CONTROL	CONTROL	100cm	36.855	101.345	4.160	19.68	1.25
4	CONVO*	LOW	5cm	50.544	207.750	3.315	23.40	1.75
4	CONVO*	HIGH	5cm	36.504	136.070	3.590	28.28	2.44

BIOGRAPHICAL SKETCH

Mr. Thomas Joseph Molesky was born in Oberlin, Ohio on March 3, 1973 to Joseph and Joanne Molesky. In 1995, Tom received his bachelor's degree in Biology from the University of Toledo, Ohio. In 1998, Tom received a certification in Secondary Education Science from West Virginia University. In August 1998, Tom began teaching science at New Hanover High School in Wilmington, North Carolina. It was this position that introduced him to the University of North Carolina at Wilmington and the Glaxo-Wellcome Fellowship that lead to this master's degree. In November of 2001, Tom began working on his master's degree under the direction of Dr. Martin Posey with funding from Glaxo-Wellcome and a North Carolina Sea Grant Project. Tom was able to complete his thesis in the summer of 2003. He plans to continue teaching high school science at New Hanover High School and complete his master's degree in science education at the University of North Carolina at Wilmington by the fall of 2004.