Salinity, Nutrients, and Chlorophyll, Vertical and Horizontal Profiles in Oyster Pond

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Abstract

We are attempting to assess the water quality of Oyster Pond by following saltwater incursions, testing nutrient distributions, and finding patterns therein. The average salinity of the Pond is 2.4 ppt, only greatly changing in secluded coves where freshwater inputs are great and within 200 m of the culvert. We found a small increase in nitrate concentrations near TreeTops where there had been a higher population density through the summer. Because there is no relationship between N-load from groundwater and nutrients or chlorophyll in the water, we concluded that horizontal mixing has such a strong enough influence on the water that it masks the sources of the nutrients. When the actual concentrations of nutrients were compared with similar standard ranges (Smith *et al* 1999), Oyster Pond was determined to be mesotrophic. Almost all of the peripheral site N:P ratios were close to 5:1, much less than the Redfield ratio suggesting that these areas are nitrogen limited. Salt water was seen to sink to the southern basin as soon as it entered the Pond, pooling there where the salinity was consistently 14 ppt. Nitrate, ammonium and phosphate profiles all showed high concentrations in the lowest 2 m of the basins where decomposition and absorption would raise levels above the Pond mean. Chlorophyll levels are highest in the basins due to sinking plankton accumulating and slowly decomposing. Because of the effective horizontal mixing, any water sample with a salinity of 2.4 ppt would be representative of the entire Pond.

Introduction

Water quality in estuaries such as the Oyster Pond system depend to a large degree on the nutrients brought in from its watershed by flow from groundwater, and by tidal exchange (Emory 1997). To identify the parts of the watershed that contributed nutrients, we sampled near where water entered the periphery of the pond. To examine the effects of seawater incursions during high tide, we followed the salinity change during high tide and low tide conditions. Studies of nutrient and chlorophyll concentrations in Oyster Pond showed substantial variations over time (Burdick *et al* 2001) to determine the present water quality of the Pond, we measured concentrations of nutrients through the Pond, both horizontally and vertically.

The saltwater entering the system from the Sound is monitored and controlled by a weir system to maintain a constant salinity between 2 ppt and 5 ppt throughout the pond. The incursion of fresh groundwater from aquifers accounts for a net flow of 2200 m^3 day^{-1} out of the pond.

This examination of the Oyster Pond system aims to trace the paths of fresh and salt water entering the pond, determine how and why the nutrients are distributed as they are, and determine the role of nutrients on chlorophyll. Through these analyses we aim to assess the overall quality of water in the Oyster Pond system.

Methods

To define the horizontal distribution of salinity, nutrients, and chlorophyll concentrations, and to identify the probable sources of nutrients, we collected water samples from the periphery of Oyster Pond (Fig. 1) from September 6 to September 17, 2002. Two 500 ml samples were taken from 36 locations around the periphery of the pond, four locations from the lagoon and two locations from Trunk River (Fig. 2). Each sample was filtered through a 150μm mesh to remove large zooplankton. Salinity, dissolved oxygen concentrations, and temperature readings were taken at each collection site using an electronic YSI. In the lab each water sample was filtered using a GF/F ashed filter, the filters were frozen until we could extract chlorophyll, and analyses were performed. 250 ml of the remaining filtrate were reserved for nitrate, ammonium, and phosphate analyses. These 250ml samples were also frozen until nutrient analyses were performed. Nitrate concentrations were determined by using the methods detailed by Jones (1983). Methods described by Strickland et al. (1984) were used to determine concentrations of ammonium and phosphate.

To determine the concentrations of chlorophyll α in the collected samples, each filter was placed in a 50 ml centrifuge tube with 25ml of cold 90% acetone solution. The filters were allowed to extract for 12 hrs at $4^{o}C$. After 12 hrs, each tube was centrifuged for 5 min, and then read in a 10cm cell in a spectrophotometer at absorbancies of 750 nm and 665 nm. Ten drops of a 25% HCl solution were added to the cell and the absorbancies were taken again. A 1cm cell was used for samples with high concentrations of chlorophyll. When the 1cm cell was used, only five drops of 25% HCl were added to the cell. To calculate the concentrations of chlorophyll a from the absorbancy readings, the formula from Lorenzen (1967) was used to determine concentrations.

To determine the vertical profiles of salinity, nutrients, and chlorophyll, in the Pond, we collected water at 1 m depth intervals from 9 locations in Oyster Pond (Fig. 2). At each of these nine locations, 500 ml samples were taken at 1 m depth intervals. These water samples were filtered through a 150 μm sieve to remove large zooplankton. Salinity, dissolved oxygen, and temperature readings were taken at each sampling depth, using the same methods as described above. Concentrations of NH_4, PO_4, and O_2 were measured in those samples. Chlorophyll α was analyzed using methods described by Jeffrey *et al.*

To determine the degree of the incursion of seawater into the Pond during high tides, we measured salinity, dissolved oxygen, and temperature using the YSI device from 18 locations in the south end of the Pond during a spring high tide and low neap tide.

Results and Discussion

Horizontal Distribution

Surface salinity values for Oyster Pond were nearly uniformly 2.4 ppt. Slight variations are found in northern sections of the pond where values range from 0 to 2.5ppt.

In the southern section of the pond values ranged from 2.3 to 24.7 ppt, depending on the tides. Throughout the middle of the pond salinity ranged from 2.3 to 2.5ppt (Fig. 3).

Variations in the pond's salinity can be explained primarily as a result of tidal flow. During high tide conditions, salt water floods the lagoon and flows into Oyster Pond over the weir (Fig. 3). Saline surface waters sink quickly, and their effects extend no farther than 200m from the weir, even during spring high tides.

The consistent salinity concentrations found throughout the surface waters of the pond support that there is effective horizontal mixing, perhaps by wind. Areas of low salinity occur in secluded sections of the pond where wind induced mixing is reduced by physical barriers or areas like the northern end of the pond where freshwater inputs are largest (Fig. 3).

Surface concentrations for nitrate (Fig. 4) vary throughout the pond, and seem to show no particular pattern. Compared to last year's data, many of the concentrations are in the same range of 0 to 5μM, except in a few key places (Burdick *et al.* 2001). For example, in this year's zone 3, there are readings of 1.5 and 1.7μM, where last year the readings were 0.3 and 3.0μM. Another important difference is that last year, the highest value was 5.0μM in zone 2, where this year the highest value is 4.5μM in zone 7.

In figure 4, zone 3, there is a pattern of higher concentrations of nitrates, which coincidentally, is the area of high density housing of TreeTops condos (Fig 4). Zone 3 has an N-load of 340 kg N yr^{-1}(Good 2001), the highest in the system. This suggests that the higher nitrates found in the water may be due to the high density of homes and people in the watershed. There is still a difference between the nitrates in the ground water and in the perimeter water.

The ammonium data show results similar to the nitrate data in that there is no pattern across the pond (Fig. 5). The highest concentration of 1.8μM is found in zone 1, and the lowest is 0.0μM and is found in various areas around the pond in every recharge zone except 2 and 3. The surface phosphate data are all in the range of 0.00 to 2.3μM (Fig. 6). Many of the values are less than 1.0μM, but the few that are greater are found in the northern end of the pond in zones 2, 3 and 4. Both of these data sets show fairly low values throughout the pond, similar to last year's data (Burdick 2001). The concentrations point to effective horizontal mixing throughout the Pond.

There were no signs of relationships between concentrations and load for each recharge zone (Fig. 7). Figure 7 plots each nutrient against salinity (ppt) and N- Load (kg N yr^{-1}). It appears that horizontal mixing has such a strong influence that it masks the patterns of sources of the nutrients. We compared concentrations of our nutrients and chlorophyll to the standard concentration ranges for freshwater and saltwater systems (Fig. 8) set in Smith *et al* (1999). Our dissolved inorganic nitrogen and phosphate levels were oligotrophic to mesotrophic in both fresh and salt water systems. Chlorophyll concentrations were generally eutrophic compared to salt systems, but oligotrophic when compared to fresh systems. These conclusions suggest that Oyster Pond falls between the oligotrophic state, found through freshwater ranges, and the eutrophic state, determined through saltwater ranges. Oyster Pond is almost uniformly mesotrophic.

Except for one point, all of the computed N:P ratios are lower than the Redfield Ratio of 16:1 (Fig. 9) (Redfield 1958). This data suggests that through most of Oyster Pond nitrogen may be limiting (Valiela 1995). In zone 1, the ratio is much higher than Redfield, suggesting that phosphorus may be limiting. In this zone there is a fairly high

N-load, perhaps coming from nearby Spohr Gardens. The garden may be an area of high nitrogen input from fertilizers, possibly making phosphorus limiting.

There were no clear horizontal patterns in the chlorophyll α concentrations (Fig. 10, 11), further evidence that the Pond seems well mixed horizontally.

Vertical Profiles

Salinity concentrations increased with depth (Fig. 12). Highest salinity readings in the interior of the pond were in the southern basin. These results agree with earlier data from Oyster Pond (Burdick 2001), and can be predicted through estuary salt water influx models (Libes 1994).

In spite of the well-established horizontal mixing, there is some evidence that the major source of fresh water is from the shore of the north end of Oyster Pond. There was a consistent but small decrease in salinity from 2.4 ppt to 2.3 ppt salinity on the northern end of our vertical profile (Fig. 12). The entire water column in the northern basin is at this slightly lower salinity.

Nitrate concentrations vary along a depth gradient (Fig. 13). Concentrations remain relatively constant in the top four meters of water and the highest nitrate concentration of 20.1μM occurs at six meters depth in the southern basin. The concentration drops back to 2.7μM at a depth of seven meters. Changes in nitrate concentrations in the bottom 3 m of the southern basin may be due to denitrification. According to Christensen *et al.*, denitrification is restricted to a thin layer of water immediately below the oxic zone (1989). The sharp decrease in concentration between 6 m and 7 m is another indication of anoxic bottom water in the southern basin.

Ammonium concentrations varied with depth in the same manner as nitrate concentrations (Fig. 13). Concentrations are several orders of magnitude greater in the basins than they are in upper layers of water. Concentrations in the upper layers of the pond remain relatively constant.

Ammonium is largely generated by decomposition (Valiela 1995). Most of this decomposition occurs on the pond floor, which explains the large increase in ammonium concentrations in the northern and southern basins. An *et al.* (2002) showed that excessive nitrate may directly reduce to ammonium, which could be the cause of the high ammonium concentrations in the south basin.

While there are high concentrations of phosphate in the basins, there is very little through the bulk of the Pond water (Fig. 13). The low levels in the top 4 m of the pond may be because phosphate adsorbs quickly onto pond sediments and is removed for the system. In the anoxic basins, phosphate is released into the water column (Valiela 1995), which is consistent with our readings (Fig. 13).

Chlorophyll α concentrations range from 0.8-5.5mg/L with the exception of the north and south basin deeps, and a point just north of the weir (Fig. 14), where they range to 30 mg/L. Higher concentrations are found in the basins due to the accumulation of particles that have fallen through the water column. The higher concentration near the weir is likely due to particles being stirred by tidal movements.

Because Oyster Pond is well mixed horizontally and uniform through the depths, the best sampling site along the periphery to test water quality is any site where the salinity is 2.4 ppt.

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Table 1. N load, nutrient, chlorophyll and dissolved oxygen for each recharge zone. Included is the standard error for each data set.

Zone	N Load	DO	std. error	NO3	std. error	NH4	std. error	PO4	std. error	Chl.	std. error
	(kg/yr)	ug/L		(uM)		(uM)		(uM)		mg/L	
1	136	8.70	± 0.69	1.19	± 0.29	0.47	± 0.22	0.02	± 0.02	4.02	± 0.48
2	152	7.80	± 0.22	0.30	± 0.19	0.80	± 0.21	0.70	± 0.34	5.00	± 0.56
3	340	7.10	± 0.23	0.76	± 0.26	0.31	± 0.10	0.18	± 0.17	3.92	± 1.43
4	116	7.90	± 0.54	0.91	± 0.23	0.17	± 0.07	0.76	± 0.44	5.75	± 2.37
5	74	8.80	± 0.18	0.76	± 0.48	0.33	± 0.14	0.19	± 0.18	2.59	± 0.59
6	45	7.20	± 0.44	0.78	± 0.21	1.14	± 0.12	0.18	± 0.13	6.03	± 3.06
7	7	10.00	± 0.55	1.09	± 0.88	0.03	± 0.03	0.15	± 0.13	3.21	± 0.46

Figure Legend

Fig. 1. Map of Oyster Pond system and surrounding watershed, with recharge zones, 1-7.

Fig. 2. Map of Oyster Pond system showing perimeter sampling sites (shown by numbers) interior sampling sites (shown by letters), Lagoon and Trunk River sampling sites (shown as L and S). Recharge zones are seperated by tickmarks as layed out in fig. 1.

Fig. 3. Maps of Oyster Pond system showing surface high tide (left), and low tide (right) salinities concentrations (ppt). Extent of salt water intrusion shown by line at south end of pond.

Fig. 4. Map of Oyster Pond system showing surface concentration of nitrate in μM.

Fig. 5. Map of Oyster Pond system showing surface concentration of ammonium in μM.

Fig. 6. Map of Oyster Pond system showing surface concentration of phosphate in μM.

Fig. 7. Relationship between nitrate, ammonium, and phosphate averages per recharge zone versus salinity (ppt) and N load (kg N / yr).

Fig. 8. Chart showing classifications of respective recharges zones as compared to fresh and marine systems in terms of trophic categorization

Fig. 9. Graph of N:P ratio at each recharge zone versus the chlorophyll a levels. Dotted insert is the mean Redfield Ratio of 16:1 N:P. Recharge zone 1 is the outlier.

Fig. 10. Map of Oyster Pond showing surface chlorophyll concentrations in mg/L.

Fig. 11. Chlorophyll concentrations in mg/L versus N load (kg N/yr) and salinity (ppt).

Fig. 12. Salinity concentrations with depth along transect.

Fig. 13. Nitrate, ammonium, and phosphate concentrations in uM with depth along transect.

Fig. 14. Chlorophyll a concentrations with depth along transect. Contour interval is 5 mg/L

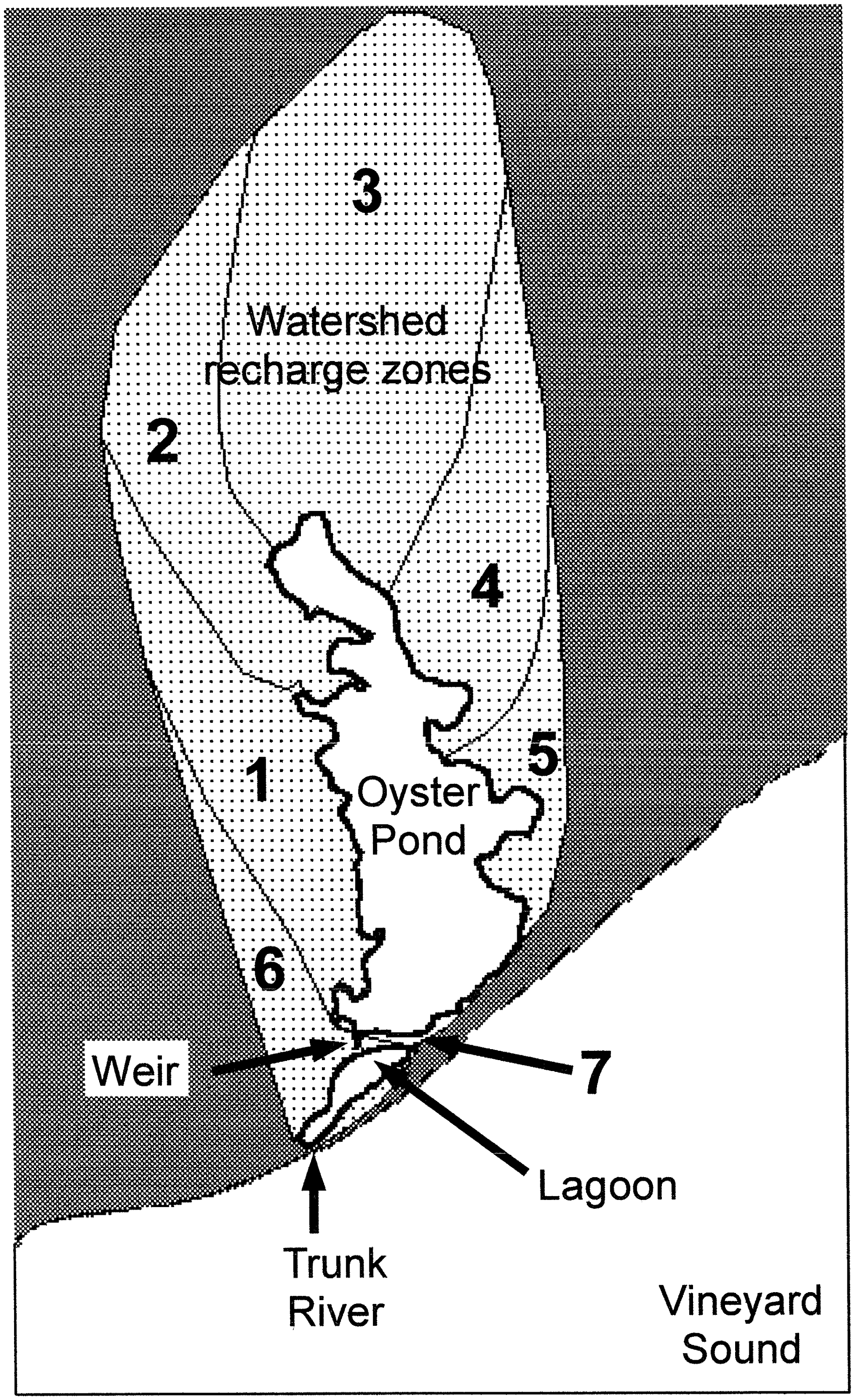

3
Watershed
recharge zones
2
4
5
1
Oyster
Pond
6
Weir
7
Lagoon
Trunk
River
Vineyard
Sound

Figure 1.

Figure 2.
Sampling Sites

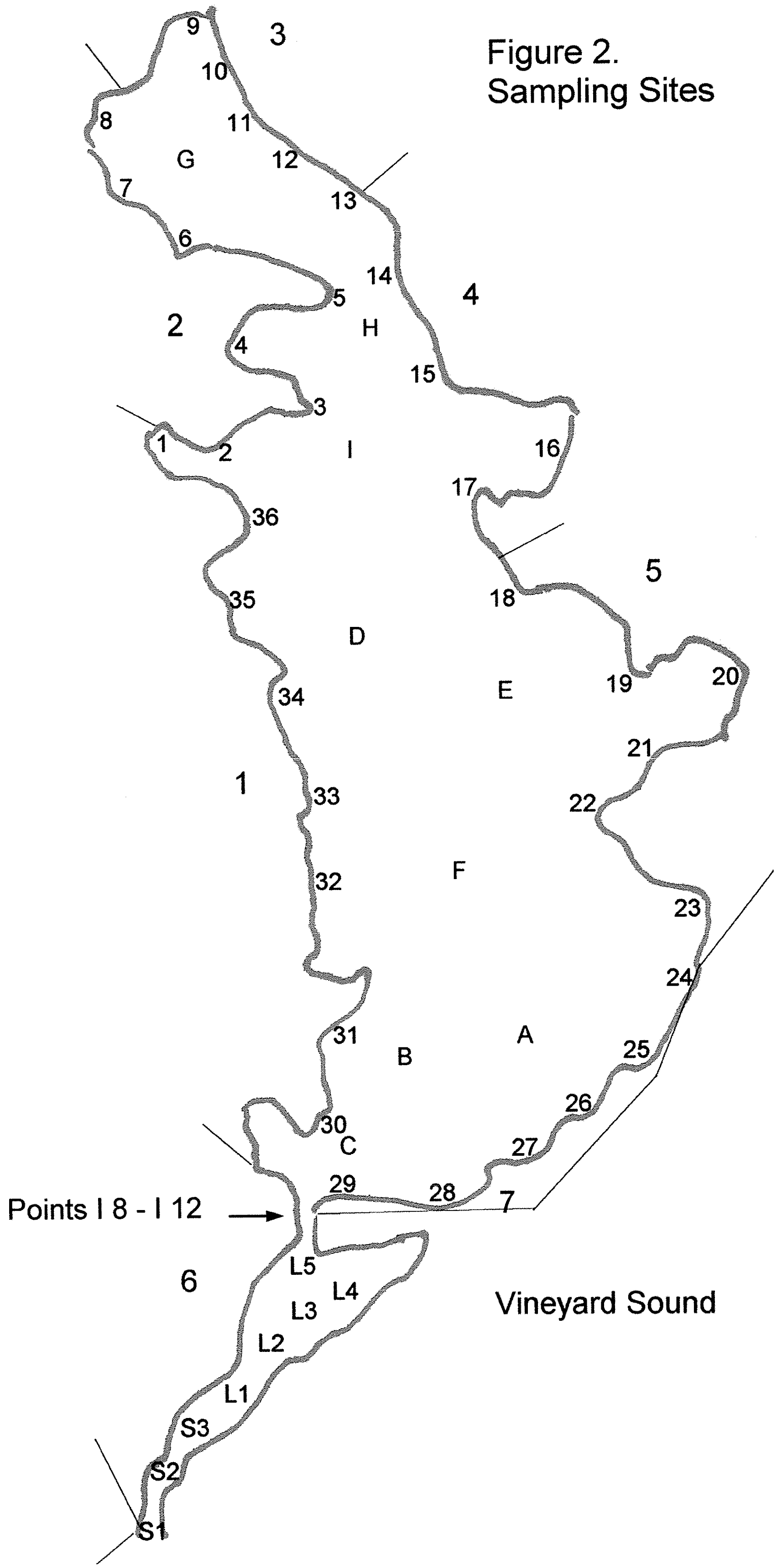


Figure 3. Surface Salinity

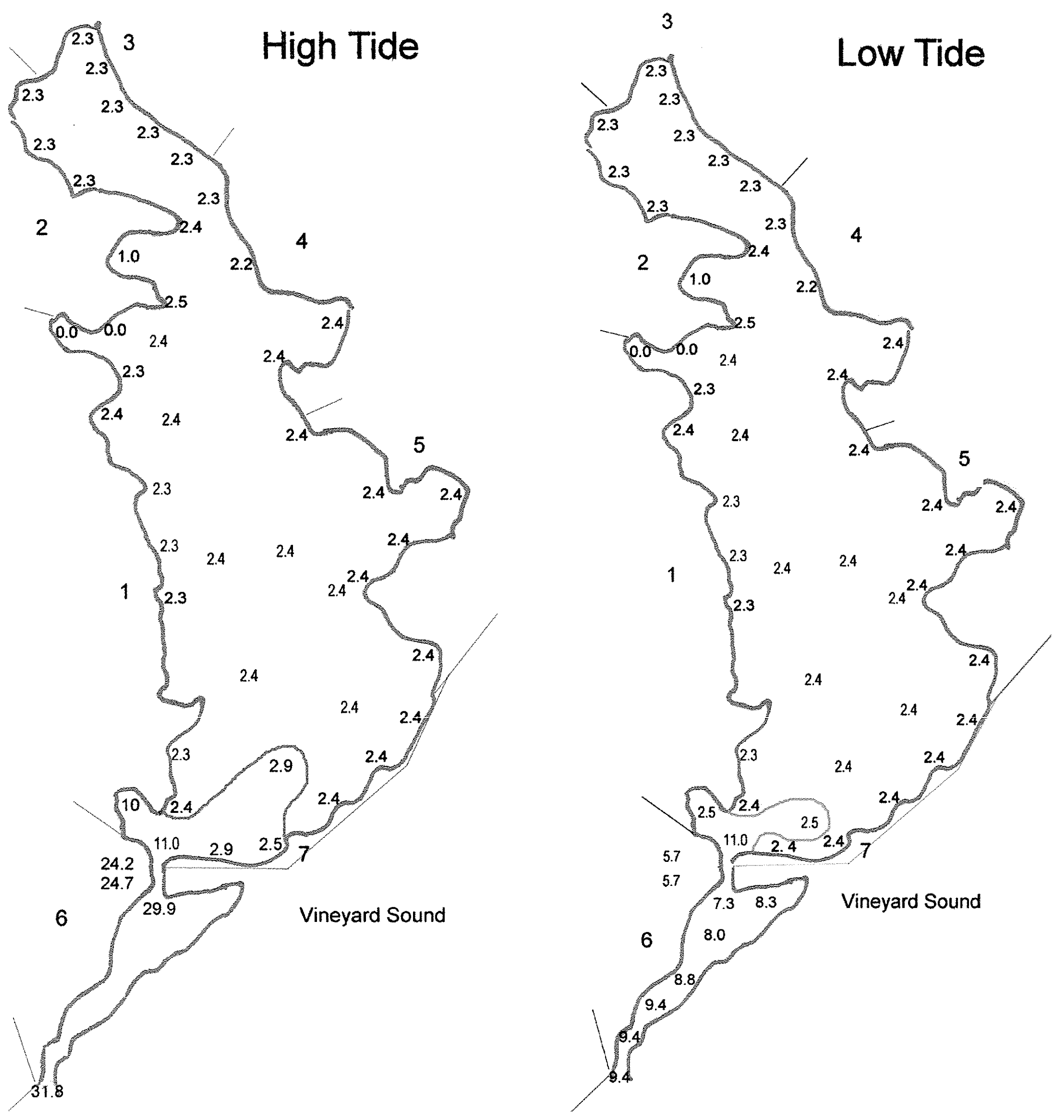
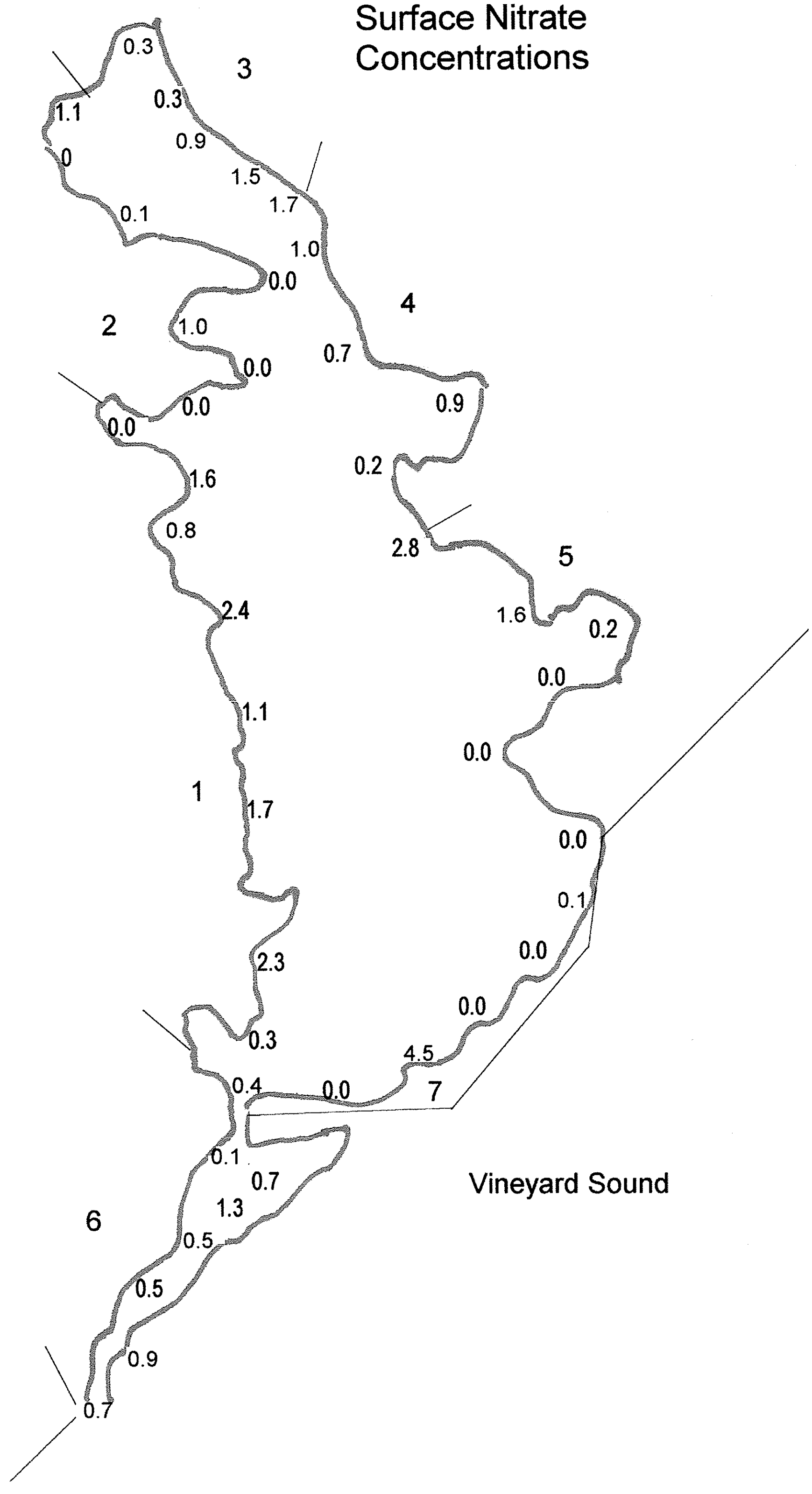


Figure 4.
Surface Nitrate
Concentrations



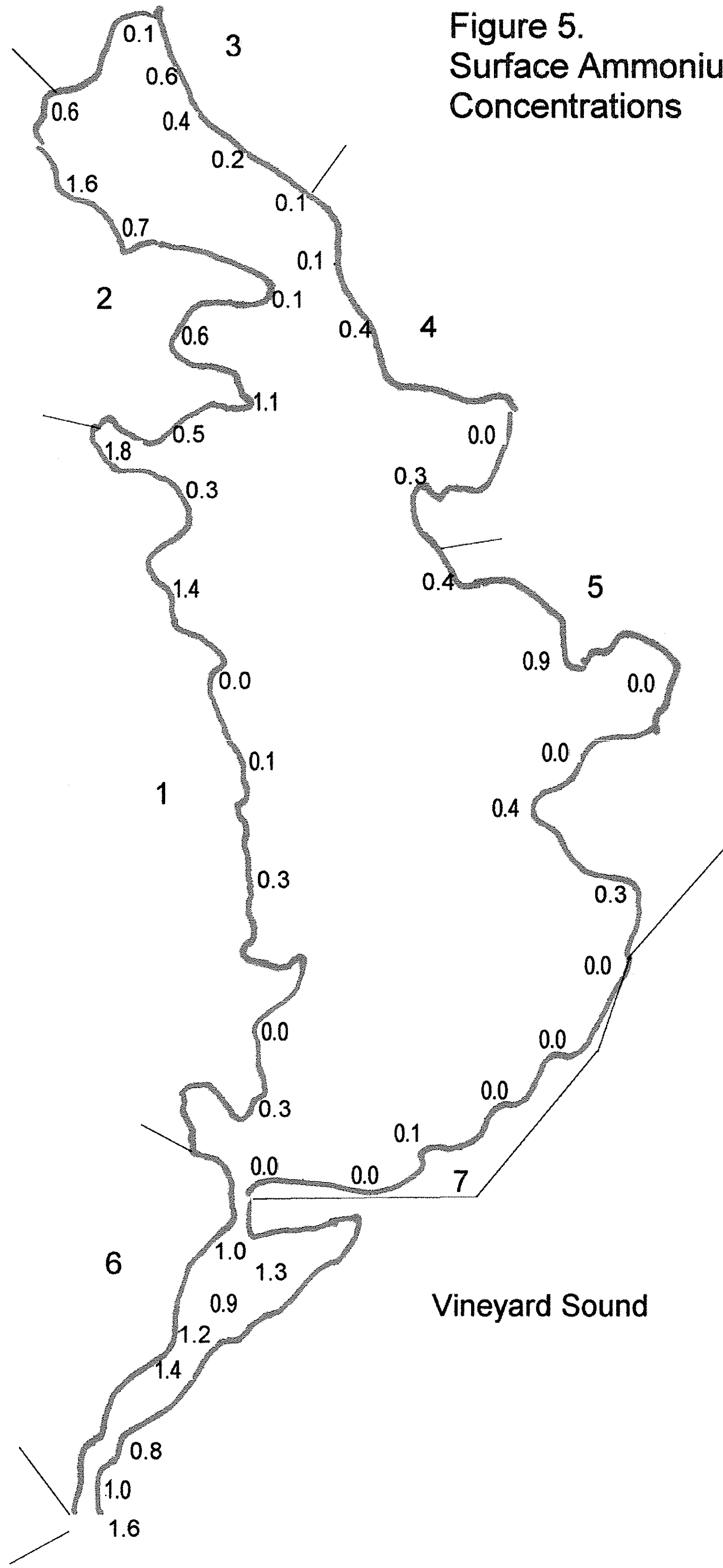
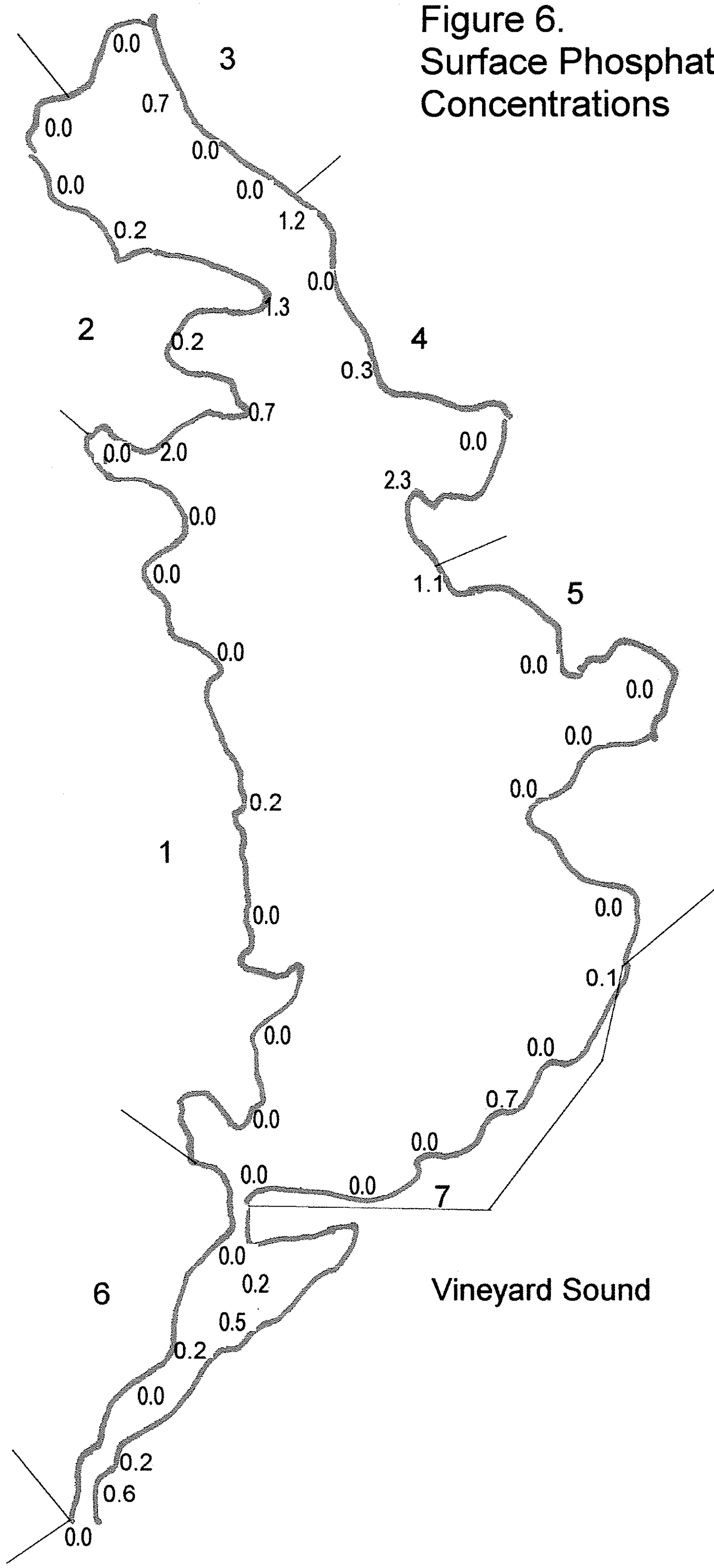


Figure 5.
Surface Ammonium
Concentrations

Figure 6.
Surface Phosphate
Concentrations



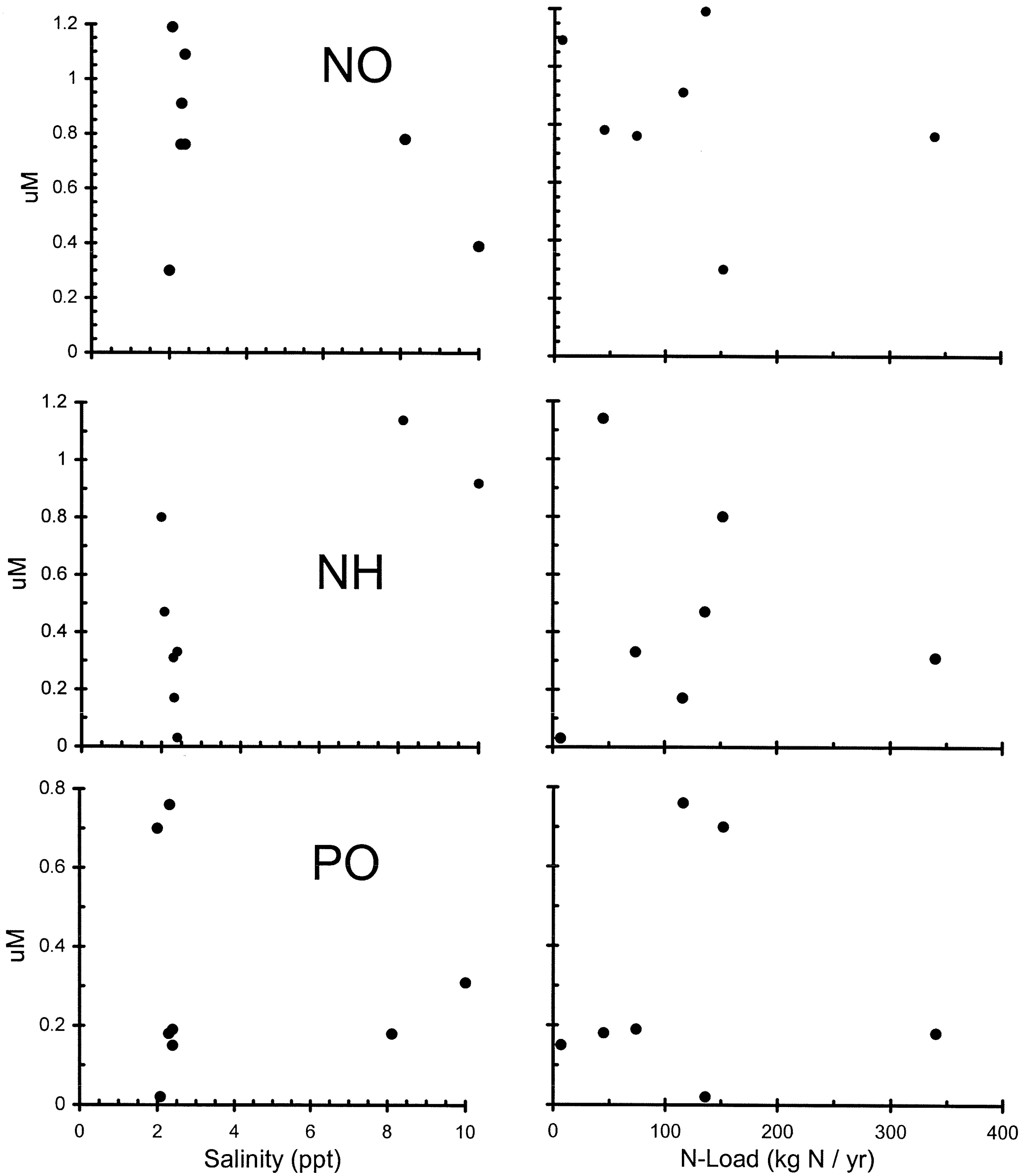

NO
NH
PO
uM
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
100
200
300
400
Salinity (ppt)
N-Load (kg N / yr)

Figure 7.

Freshwater	Oligo	Meso	Eutro	Hyper
DIN	1,2,3,4,5,6,7			
PO4	1,3,5,6,7	2,4		
Chl.	2,3,4,5,6	1,7		

Saltwater	Oligo	Meso	Eutro	Hyper
DIN	1,2,3,4,5,6,7			
PO4	1,3,5,6,7	2,4		
Chl.		5	1,2,3,7	4,6

Figure 8.

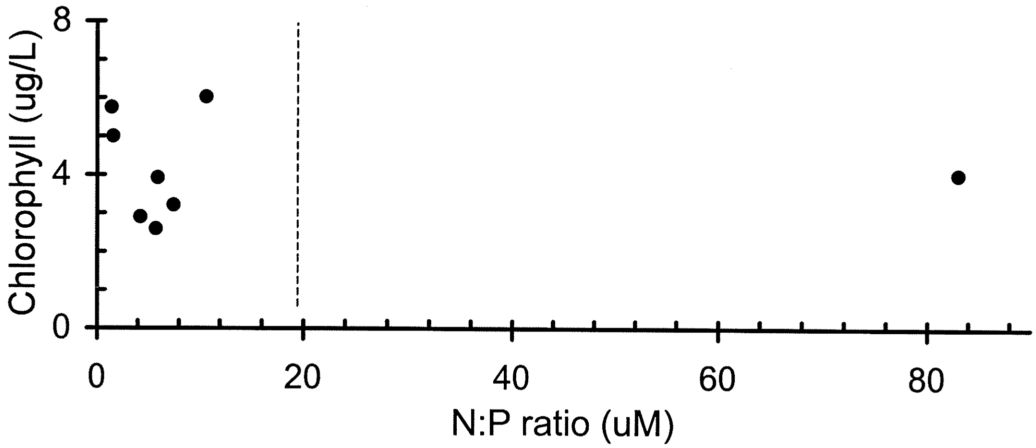
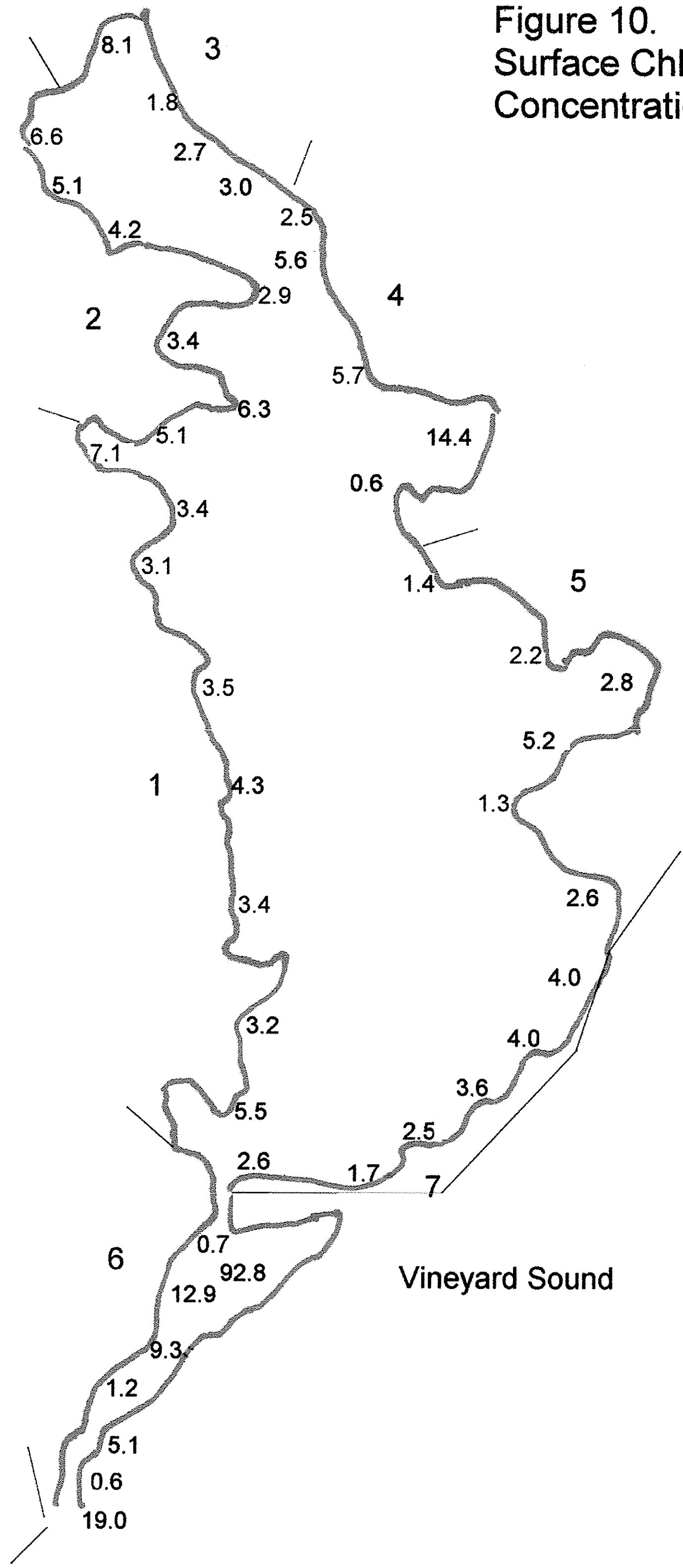


Figure 9.

Figure 10.
Surface Chlorophyll
Concentrations



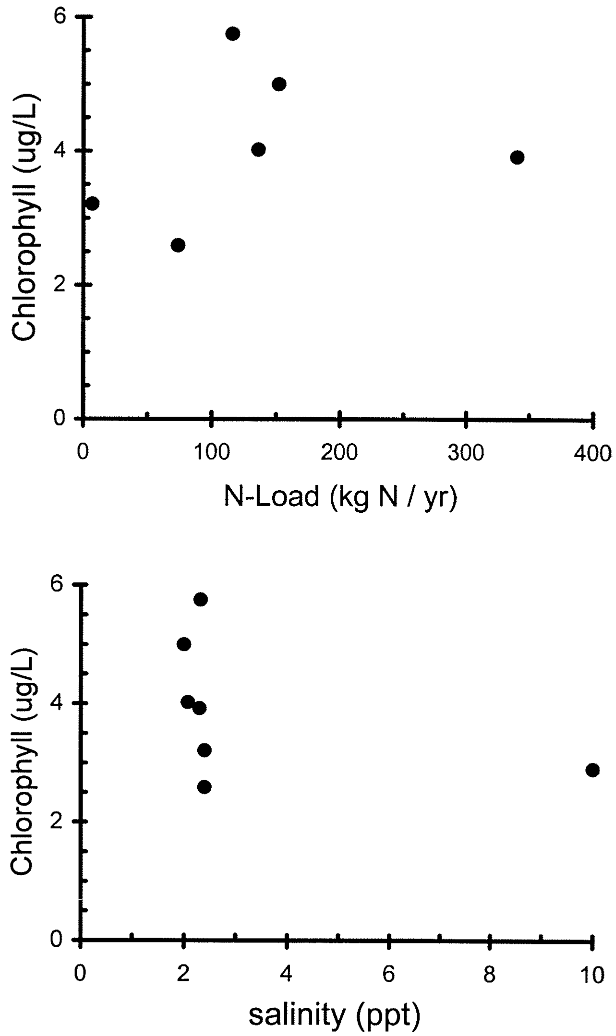

Chlorophyll (ug/L)
6
4
2
0
0
100
200
300
400
N-Load (kg N / yr)
Chlorophyll (ug/L)
6
4
2
0
0
2
4
6
8
10
salinity (ppt)

Figure 11.

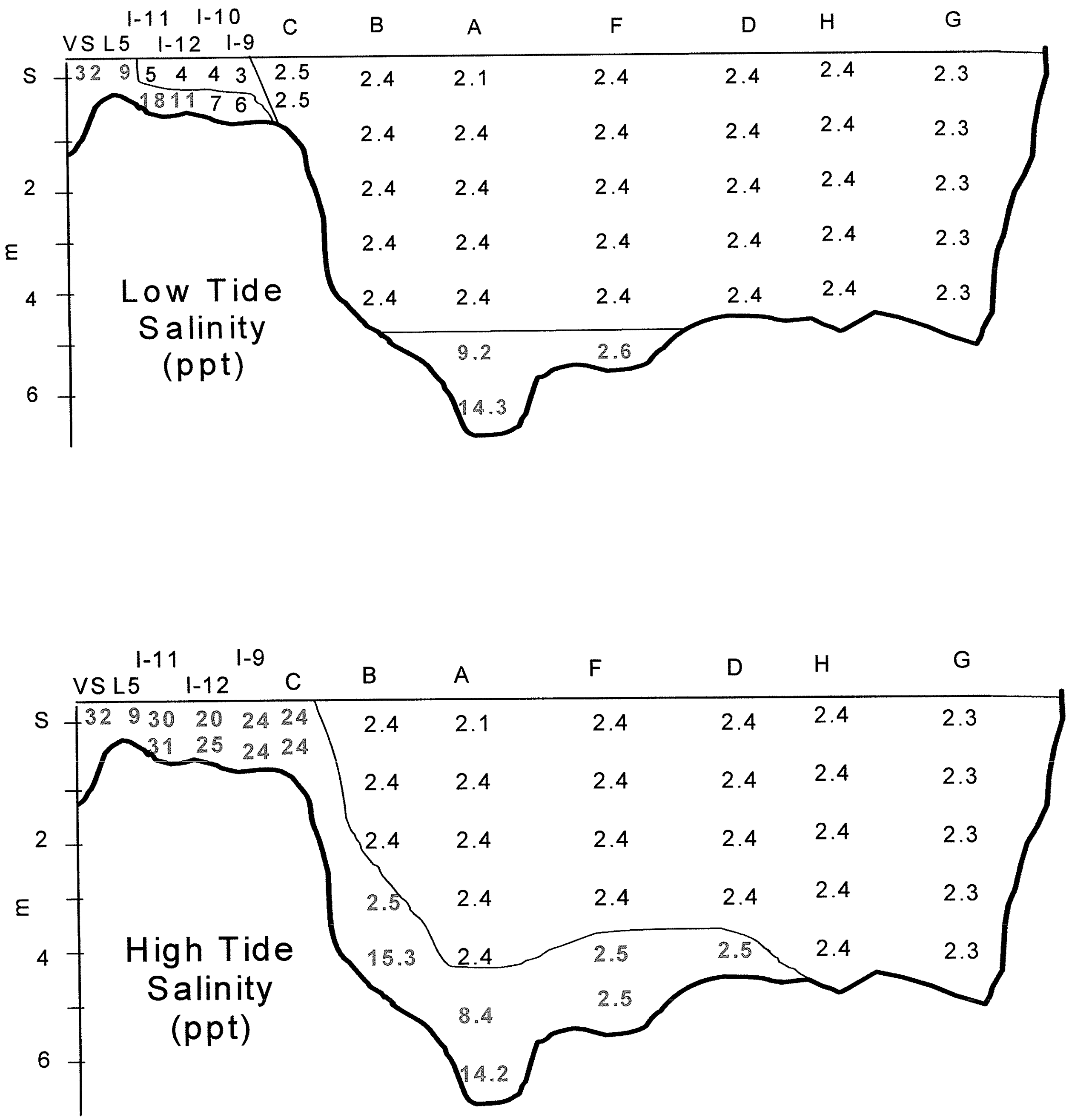

I-11 I-10
VS L5 I-12 I-9
C B A F D H G
S
2
4
6
m
Low Tide
Salinity
(ppt)
32 9 5 4 4 3 2.5
18 11 7 6 2.5
2.4 2.1 2.4 2.4 2.4 2.3
9.2 2.6
14.3
I-11 I-9
VS L5 I-12 C B A F D H G
High Tide
Salinity
(ppt)
32 9 30 20 24 24
31 25 24 24
15.3
8.4 2.5
14.2

Figure 12.

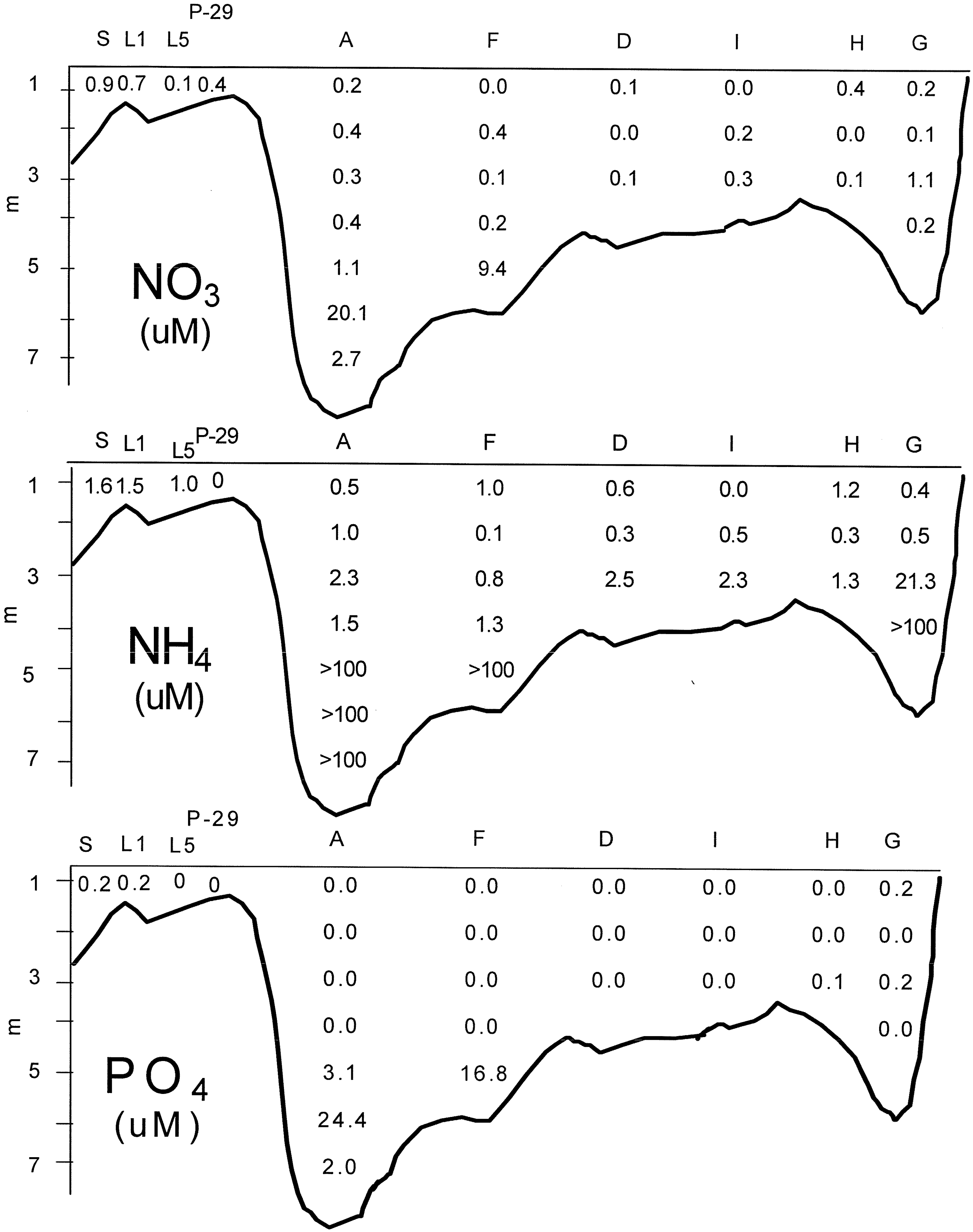
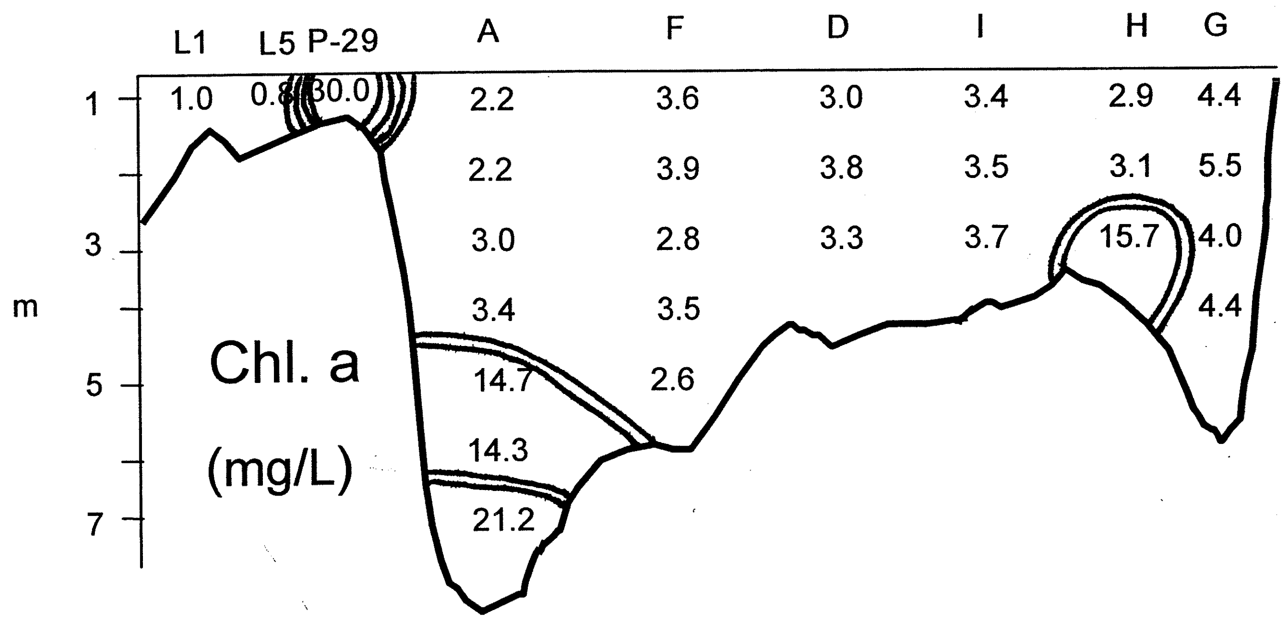

P-29
S L1 L5
A F D I H G
1
3
m
5
7
0.9 0.7 0.1 0.4
0.2 0.4 0.3 0.4 1.1 20.1 2.7
0.0 0.4 0.1 0.2 9.4
0.1 0.0 0.1
0.0 0.2 0.3
0.4 0.0 0.1
0.2 0.1 1.1 0.2
NO3 (uM)
S L1 L5 P-29
A F D I H G
1.6 1.5 1.0 0
0.5 1.0 2.3 1.5 >100 >100 >100
1.0 0.1 0.8 1.3 >100
0.6 0.3 2.5
0.0 0.5 2.3
1.2 0.3 1.3
0.4 0.5 21.3 >100
NH4 (uM)
P-29
S L1 L5
A F D I H G
0.2 0.2 0 0
0.0 0.0 0.0 0.0 3.1 24.4 2.0
0.0 0.0 0.0 0.0 16.8
0.0 0.0 0.0
0.0 0.0 0.0
0.0 0.0 0.1
0.2 0.0 0.2 0.0
PO4 (uM)

Figure 13.



L1
L5
P-29
A
F
D
I
H
G
1
3
m
5
7
1.0
0.8
30.0
2.2
2.2
3.0
3.4
14.7
14.3
21.2
3.6
3.9
2.8
3.5
2.6
3.0
3.8
3.3
3.4
3.5
3.7
2.9
3.1
15.7
4.4
5.5
4.0
4.4
Chl. a
(mg/L)

Figure 14.