NORTON BASIN/LITTLE BAY
STATISTICAL ANALYSIS

PRELIMINARY PROJECT REPORT
AND SUMMARY OF DATA ANALYSES

Submitted by Great Eastern Ecology, Inc.
227 W. 17th Street,
New York, NY 10011
(212) 614-7400
mlaska@geeinc.net

For Barry A. Vittor & Associates, Inc.

Data Structure

Fish, macrocrustacean and benthic macroinvertebrate abundance and biomass and associated environmental variables were collected during a three-year period (2000 – 2002) by Barry A. Vittor & Associates and their contractors for the US Army Corps of Engineers (USACE) and New York State Department of Environmental Conservation (NYSDEC). These data are intended to provide direction to the UCACE and NYSDEC in determining the feasibility of bathymetric recontouring of Norton Basin and Little Bay to restore shallow estuarine habitat. This report provides a summary of multivariate and univariate statistical approaches to explore relationships between biotic resources (fish, macrocrustacean and benthic macroinvertebrates) and environmental variables. Presumably, a statistical evaluation of such relationships could provide guidance to restoration measures and understanding baseline ecological parameters.

In order to draw statistical relationships between the biotic resources of Norton Basin and Little Bay and environmental factors that may influence the distribution and abundance of these resources, information on both biotic and environmental variables must be available for each sampling location and time. Thus, to allow for statistical inference, biotic and environmental data must be sampled at the same sites and at the same time. We used this as a strict criterion (Criterion #1) to identify which datasets could be used in our analyses. Initial screening of the data was conducted to identify datasets that did not meet this criterion. Biotic data that did not have accompanying environmental data were excluded from the analyses. A reason that this criterion was not met for some datasets was that there were different sampling efforts for the biotic and environmental sampling. A second criterion (Criterion #2) specific to multivariate analyses was that datasets must have a greater number of sampling locations (sites) than biotic variables (i.e., species or taxa). This criterion was necessary to insure robust interpretation of the multivariate analyses. Too few sites relative to variables introduce an unacceptable level of uncertainty as to the validity of the results. Datasets that did not meet either of these criteria were also excluded from the analyses.

Biotic and associated environmental datasets that met both Criterion #1 and Criterion #2 and that are included in this report are listed in Table 1.

Table 1. Biotic and associated environmental data meeting criterion #1 and #2 (above) that are included in this report.

	2000	2001		2002	
Description	September	June	October	June	October
Biotic variables					
Fish and Macrocrustaseans* (Gill Net data)	Abundance	-	-	-	-
	BPUE	-	-	-	-
	CPUE	-	-	-	-
Benthic Macroinvertebrates (Benthic Grab data)	-	Abundance[§] by taxonomic group	-	Abundance by taxonomic group	Abundance by taxonomic group
	-	Biomass by taxonomic group	-	Biomass by taxonomic group	Biomass by taxonomic group
Environmental data					
	Depth Temperature Salinity DO[†] pH Turbidity	Depth Temperature Salinity DO Turbidity Ammonium Phosphate Nitrate Total dissolved phosphorus Total dissolved nitrogen Silica Dissolved organic carbon Particulate nitrogen Particulate carbon Particulate phosphorus Total suspended solids Total volatile solids Biogenic silica Total chlorophyll Phaeophytin Active Chlorophyll Percent organic matter Organic matter content Sulfides	-	Depth Temperature Conductivity Salinity DO Turbidity Ammonium Phosphate Nitrate Total dissolved phosphorus Total dissolved nitrogen Silica Dissolved organic carbon Particulate nitrogen Particulate carbon Particulate phosphorus Total suspended solids Total volatile solids Biogenic silica Total chlorophyll Phaeophytin Active Chlorophyll Percent organic matter Organic matter content Sulfides	Depth Temperature Conductivity Salinity DO Turbidity Ammonium Phosphate Nitrate Total dissolved phosphorus Total dissolved nitrogen Silica Dissolved organic carbon Particulate nitrogen Particulate carbon Particulate phosphorus Total suspended solids Total volatile solids Biogenic silica Total chlorophyll Phaeophytin Active Chlorophyll Percent organic matter Organic matter content Sulfides

*BPUE: biomass per unit effort; Abundance; CPUE: catch per unit effort.

[†]Dissolved oxygen concentration. [§] Abundance: individual counts

Data Analysis

The 2000, 2001 and 2002 data were analyzed for relationships between biotic resources and environmental factors in Norton Basin and Little Bay using a combination of multivariate and univariate statistical methods. Ordination is a multivariate method that is useful for reducing multi-species datasets into a smaller and more manageable number of variables that account for the variability in the data (Pielou 1984). If environmental variables are sampled along with the species data, the new variables derived from the ordination (ordination variables) can then be related to underlying environmental variables. A statistical relationship between the ordination variables and an environmental factor suggests that the community as a whole is responding to that factor in some way. We used ordination techniques to explore potential relationships between fish and macrocrustacean species and benthic macroinvertebrate taxa with environmental factors that may influence these biotic resources. We also used traditional univariate approaches to examine specific relationships between individual species (or taxa) and potentially important environmental variables.

As an exploratory method of identifying environmental variables that might influence species composition and abundance, we used principal components analysis (PCA). This method is a commonly used data reduction technique in community ecology (Pielou 1984). We used PCA to reduce our multi-species fish and benthic macroinvertebrate datasets to a small number of variables that summarized the variability in the data. All environmental variables collected at the sampling locations were then regressed against these summary PCA axes to determine whether relationships existed between any environmental variables and species (or taxon) composition and abundance. If significant relationships existed, univariate methods were employed to explore how particular species or taxa were responding to those environmental variables.

When possible, significant environmental variables identified through PCA were entered into a canonical correspondence analysis (CCA) (ter Braak 1986). This method is used when meaningful environmental variables are known to structure the data (Okland 1996). CCA was used to summarize the relationship between meaningful environmental variables (derived from exploratory PCA) and species or taxonomic distributional patterns among sites. CCA allowed us to rank (ordinate) sample locations by how species or taxa responded to particular environmental variables.

Results

2000 Abundance Data

Eleven sampling locations for gill net catch data had accompanying environmental variables: Norton Basin Pit, Little Bay Pit, Grass Hassock 1, 1a, 2, 2a, 3 and 3a, and The Raunt 1, 2 and 3. These data were entered into the PCA.

A PCA indicated that the first three ordination axes accounted for 91% of the variance in the community, with Axis 1 accounting for over half (52%) of the variation (Table 2).

Table 2. Summary statistics for the first three principal components axes derived from a Principal Components Analysis (PCA) of 2000 gill net catch data.

Axis	Eigenvalue	% Variance	Cum.% Variance
1	70.132	52.321	52.321
2	33.572	25.046	77.368
3	18.527	13.822	91.19

Each environmental variable was regressed against each principal component axis to determine whether any significant relationships existed. We found a significant positive relationship between salinity and Axis 1 (Fig. 1). A significant negative relationship was observed between depth and Axis 1; however, because the relationship was based on a single high value at one end of Axis 1, caution must be exercised in the interpretation of these data.

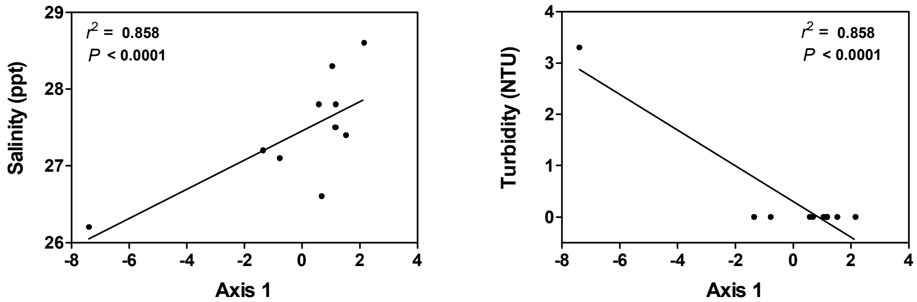

Figure 1. Regression of salinity and turbidity versus the first principal component axis (Axis 1) derived from a PCA of the 2000 gill net catch data.

Biomass per unit effort (BPUE) and catch per unit effort (CPUE) datasets showed a similar relationship to salinity, but in each case the effect was very weak. No relationship between these data and turbidity was observed.

A CCA of the 2000 catch data was conducted using salinity as the environmental factor. Three axes explained 71.5% of the variation in the dataset (Table 3). Axis 1, which explained 26% of the variation, was the only axis that showed a correlation with salinity.

Table 3. Summary statistics for three canonical axes derived from a Canonical Correspondence Analysis (CCA) of 2000 gill net catch (Species) versus salinity (Environment) data.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.554	0.57	0.38
Variance in species data			
% Variance explained	26.3	27.1	18.1
Cumulative % explained	26.3	53.4	71.5
Pearson Correlation (Species x Environment)	0.948	0	0
Kendall (Rank) Correlation (Species x Environment)	0.629	0	0

A graphical relationship (CCA diagram) between sampling sites (ordinated by species) and salinity is shown in Fig. 2.

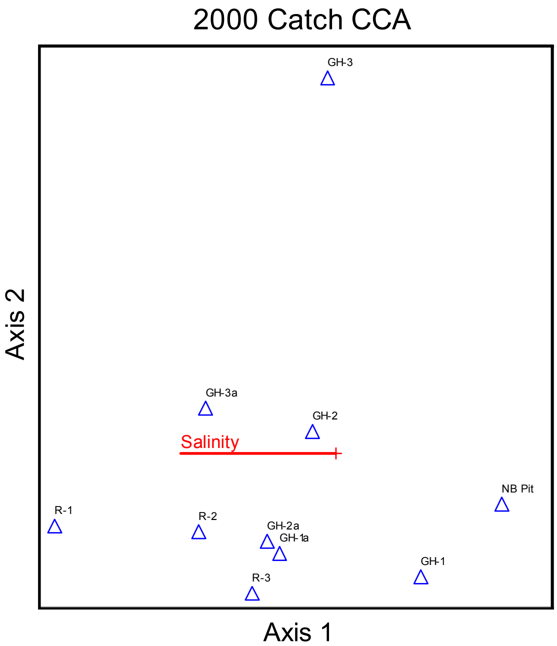

Figure 2. Graphical results of a canonical correspondence analysis (CCA) of 2000 gill net catch data and salinity. The spatial spread of points (triangles) shows the relationship of sampling sites with respect to fish species composition and abundance. The environmental vector indicates the direction and magnitude of the correlation between Axis 1 and salinity.

The CCA indicates that salinity is a strong predictor of fish species composition and abundance across the sampling sites. The Norton Basin Pit (NB pit) site and the Raunt (R) sites separate out along Axis 1 due to differences in fish and macrocrustasean composition and abundance. Correlation coefficients between Axis 1 and fish and macrocrustacean species indicate that fish species (e.g., Blueback Herring) tend to occur in greater numbers in the NB pit and Grass Hassock (GH) sites, whereas macrocrustaceans (e.g., Lady Crab) are distributed primarily in the Raunt sites (Table 4). Furthermore, these distributions can be explained by differences in salinity across these sites, the NB pit site having low salinity levels and the Raunt sites higher salinity. Higher salinity levels in the Raunt are due to the proximity of these sites to greater tidal movement and higher salinity waters. The NB pit site experiences little tidal flushing and is furthest from the high saline waters; Grass Hassock sites are intermediate to these sites.

Table 4. Pearson correlation coefficients (r) and regression coefficients (r^2) between Axis 1 of the PCA and individual fish and macrocrustacean species abundance (i.e., gill net catch).

	CCA Axis 1	
Species	r	r^2
Blueback Herring	0.777	0.604
Striped Searobin	0.644	0.414
Bluefish	0.637	0.406
Spot	0.626	0.392
Northern Searobin	0.626	0.392
Smooth Dogfish	0.626	0.392
Summer Flounder	0.197	0.039
Weakfish	0.132	0.017
Horseshoe Crab	0.119	0.014
Blue Crab	-0.298	0.089
Lady Crab	-0.650	0.423

2001 Benthic Data

The 2001 benthic data was collected in June and October and included both abundance (counts) and biomass data although only the June data qualified for these analyses (discussed below). Benthic macroinvertebrates were classified into four taxonomic groups: Annelids, Arthropods, Molluscs and Other Taxa. A PCA was conducted to explore relationships between environmental variables and benthic macroinvertebrate community structure. It must be noted that there were only seven sampling locations that had associated environmental data. These locations were: Grass Hassock 2 and 3, Little Bay 1 and 2, and Norton Basin 1, 2 and 3. As there were relatively few sites upon which to base conclusions, caution should be taken in interpreting these data.

A PCA of the June 2001 abundance data indicated that the first two ordination axes accounted for virtually all of the variance in the community, with Axis 1 accounting for close to two thirds (61%) of the variation and Axis 2 the remaining variation (Table 5). For the biomass data, Axis 1 accounted for virtually all of the variation in the community.

Table 5. Summary statistics for the first two principal components axes derived from a Principal Components Analysis of June 2001 macroinvertebrate abundance and biomass data.

Axis	Eigenvalue	% Variance	Cum.% Variance
Abundance			
1	8215832	61.44	61.44
2	5155935	38.56	100
Biomass			
1	895.8	99.47	99.47

Environmental variables were regressed against each principal component axis for both macroinvertebrate abundance and biomass to determine whether any significant relationships existed. For macroinvertebrate abundance, we found a significant negative relationship between nitrate concentration and the first principal component axis (Axis 1) of the PCA (Fig. 3A). With respect to the second principal component axis (Axis 2) for macroinvertebrate abundance, regression analysis indicated that there was a significant negative relationship with depth and a significant positive relationship with turbidity (Fig. 3B). However, the relationship of these two factors with Axis 2 of the PCA was driven by a single sample. This taken together with the relatively small amount of variation explained by these factors (~39%), caution must be taken in interpreting the importance of these factors in governing the observed distribution and abundance of macroinvertebrate taxa.

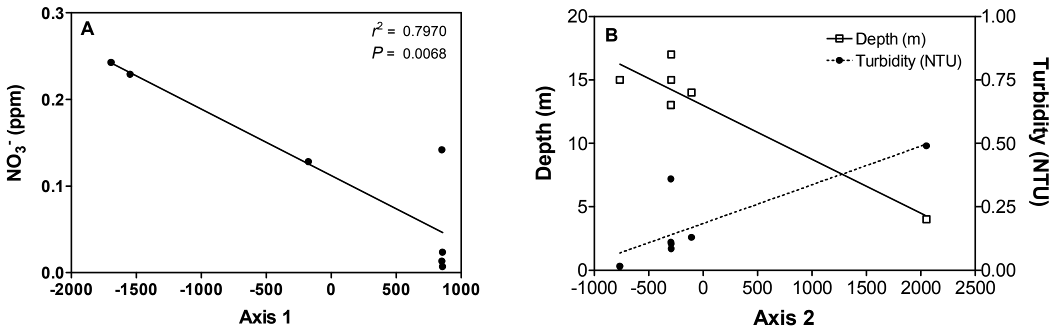

Figure 3. A) Regression of sample nitrate concentration onto the first principal component axis (Axis 1) derived from a PCA of June 2001 macroinvertebrate abundance data. B) Regression of sample depth (r^2 = 0.875; P = 0.002) and turbidity (r^2 = 0.674; P = 0.024) onto the second principal component axis (Axis 2) derived from a PCA of June 2001 macroinvertebrate abundance data.

For macroinvertebrate biomass, we found a significant positive relationship of depth and a significant negative relationship of dissolved oxygen concentration with respect to the first principal component axis (Axis 1) of the PCA (Fig. 4). However, as was observed for macroinvertebrate abundance, the relationship between depth and Axis 1 of the PCA for the June 2001 biomass data was driven by a single sample. Therefore, caution must be taken in interpreting the importance of this factor in governing the observed distribution and biomass abundance of macroinvertebrate taxa.

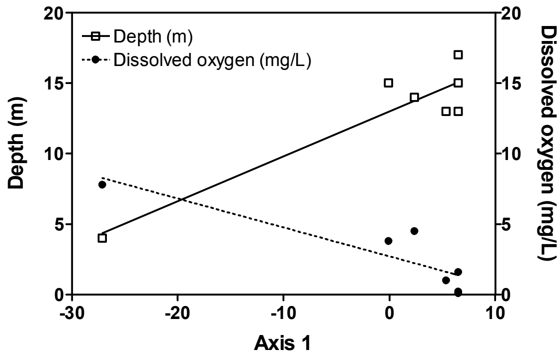

Figure 4. Regression of sample depth and dissolved oxygen concentration onto the first principal component axis (Axis 1) derived from a PCA of June 2001 macroinvertebrate biomass data. For sample depth (r^2 = 0.857; P = 0.003) and dissolved oxygen (r^2 = 0.790; P = 0.008)

Neither a PCA nor a CCA could be conducted on the macroinvertebrate abundance or biomass data for October 2001 because these data sets did not meet the minimum dataset size criterion for conducting multivariate analysis of the data (i.e., Criterion #2 above). Likewise, a CCA could not be conducted on the June 2001 data because of the complete absence of benthic organisms at some sampling locations. Consequently, removal of these sampling locations for multivariate analysis would have resulted in the dataset not meeting the minimum dataset size criterion (i.e., Criterion #2 above).

Because nitrate concentration was identified by Axis 1 in the PCA of June 2001 abundance data as a potentially important factor influencing the distribution and abundance of macroinvertebrate taxa in the benthic zone, a regression analysis was conducted of macroinvertebrate abundance against nitrate concentration (Fig. 5). The regression indicated that the abundance of benthic arthropods increases significantly at higher nitrate concentrations.

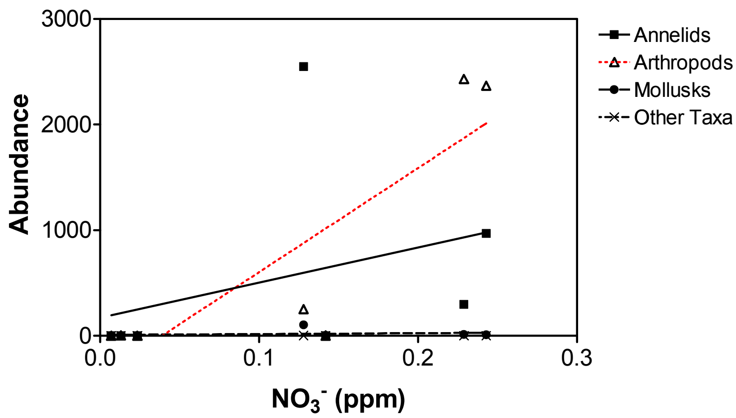

Figure 5. Regression of June 2001 macroinvertebrate abundance against nitrate concentration (NO_3^-). The regression line in red indicates that the relationship is significant at $P < 0.05$.

Depth and turbidity were also identified by the PCA (on Axis 2) on June 2001 macroinvertebrate abundance as potentially important factors. A regression of macroinvertebrate abundance against depth indicated that annelids, molluscs and other taxa declined significantly at greater sampling depths (Fig. 6A). However, no significant relationship was observed between macroinvertebrate abundance and turbidity (Fig. 6B).

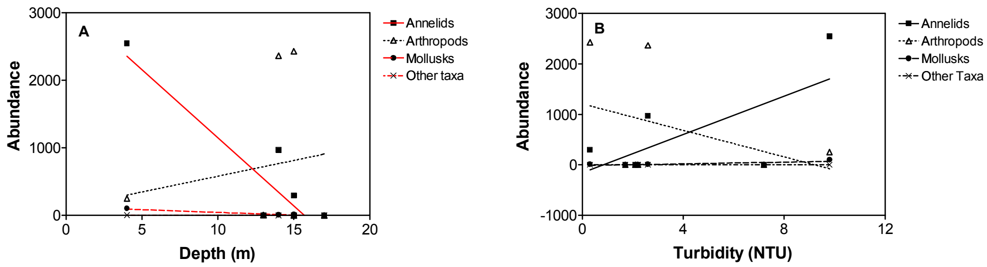

Figure 6. Regression of June 2001 macroinvertebrate abundance against A) depth and B) turbidity. Regression lines in red indicate that the relationship is significant at $P < 0.05$.

In the PCA of macroinvertebrate biomass data, depth and dissolved oxygen were identified as important factors influencing the distribution and biomass abundance of macroinvertebrate taxa in the benthic zone. A regression analysis of macroinvertebrate biomass against depth indicated that molluscs and other taxa declined significantly at greater sampling depths (Fig. 7A). In contrast, arthropods, molluscs and other taxa increased significantly with increasing concentrations of dissolved oxygen (Fig. 7B).

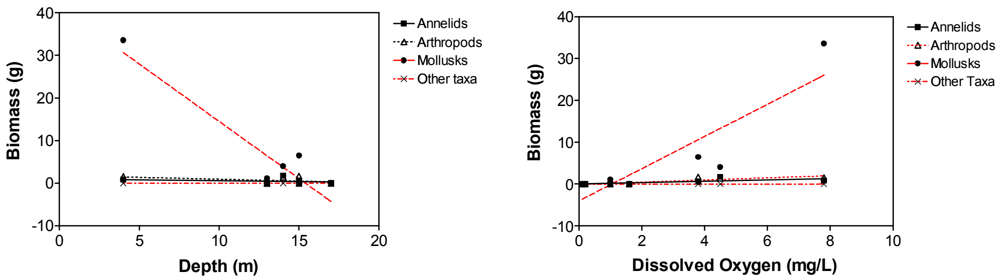

Figure 7. Regression of June 2001 macroinvertebrate biomass against A) depth and B) dissolved oxygen. Regression lines in red indicate that the relationship is significant at $P < 0.05$.

2002 Benthic Data

The 2002 benthic data was collected in June and October and included both abundance and biomass data. Benthic macroinvertebrates were classified into four taxonomic groups: Annelids, Arthropods, Molluscs and Other Taxa. Ten sampling sites were used in these analyses: Grass Hassock 2, Little Bay 3, 5 and 7, and Norton Basin 4, 8, 9, 12, 14 and 15. A PCA was conducted on these datasets to explore relationships between environmental variables and benthic community structure.

A PCA of the June 2002 abundance data indicated that the first two ordination axes accounted for close to 100% of the variance in the benthic community, with Axis 1 accounting for two thirds (66%) of this variation and Axis 2 the remaining variation (Table 6). For the biomass data, the PCA indicated that Axis 1 accounted for almost all of the variation in the benthic community, with Axis 2 adding only a small amount.

Table 6. Summary statistics for the first two principal components axes derived from a Principal Components Analysis of June 2002 macroinvertebrate abundance and biomass data.

Axis	Eigenvalue	% Variance	Cum.% Variance
Abundance			
1	80356840	65.67	65.67
2	41983728	34.31	99.98
Biomass			
1	117219.805	99.83	99.83
2	197.075	0.17	100

Environmental variables were regressed against each principal component axis to determine whether any significant relationships existed. We found a significant positive relationship between depth and Axis 1 and a significant negative relationship between dissolved oxygen concentration and Axis 1 (Fig. 8).

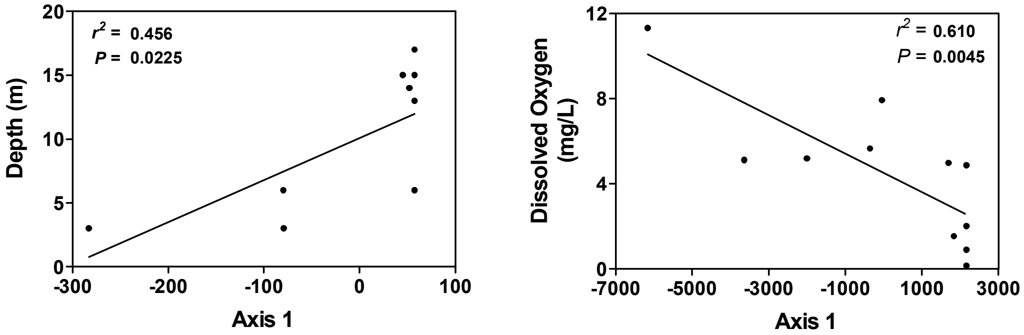

Figure 8. Regression of depth and dissolved oxygen concentration (DO) versus the first principal component axis (Axis 1) derived from a PCA of June 2002 macroinvertebrate data. The relationship for depth is derived from the biomass data, whereas the relationship for DO is from the abundance data.

No relationships were found between any environmental variables and benthic taxa in the October 2002 benthic data for either abundance or biomass.

A CCA of the June 2002 benthic data was conducted on both the biomass and abundance data, using either depth (biomass dataset) or dissolved oxygen concentration (abundance dataset) as the constraining environmental factor. Three axes derived from the biomass x depth CCA explained 100% of the variation in the dataset (Table 7). Axis 1, which explained 33% of the variation, was the only axis that showed a correlation with depth.

Table 7. Summary statistics for three canonical axes derived from a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate biomass (Species) versus depth (Environment) data.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.089	0.107	0.071
Variance in species data			
% Variance explained	33.2	40.2	26.6
Cumulative % explained	33.2	73.4	100
Pearson Correlation (Species x Environment)	0.743	0	0
Kendall (Rank) Correlation (Species x Environment)	0.189	0	0

The graphical relationship (CCA diagram) between sampling sites (ordinated by species) and the relationship to depth is shown in Fig. 9.

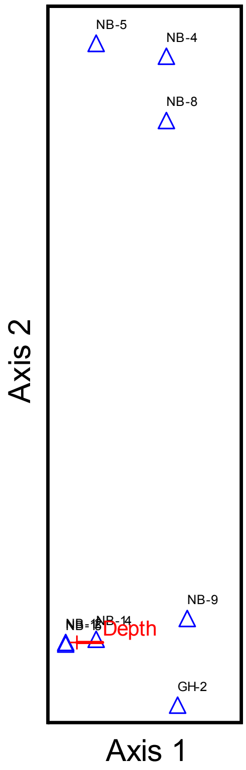

Figure 9. Graphical results of a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate biomass data constrained by depth. The spatial spread of points (triangles) shows the relationship of sampling sites with respect to benthic macroinvertebrate composition and abundance. The environmental vector indicates the direction and magnitude of the correlation between Axis 1 and depth.

The macroinvertebrate biomass CCA indicates that depth is a weak but significant predictor of benthic taxa composition and abundance across the sampling sites. Because the June 2002 benthic dataset was primarily limited to Norton Basin sites, it is difficult to make predictions about the importance of depth in structuring the benthic communities across sites. However, because depth is positively correlated with Axis 1, negative correlation coefficients for the benthic taxa (particularly molluscs) in relation to Axis 1 of the CCA (Table 8) indicate that benthic community abundance decreases with increasing depth. Thus, fewer benthic species are present at greater depths in Norton Basin.

Table 8. Pearson correlation coefficients (r) and regression coefficients (r^2) between Axis 1 of the CCA and biomass of individual benthic taxa.

	CCA Axis 1	
Species	r	r^2
Annelids	-0.448	0.201
Arthropods	-0.328	0.107
Molluscs	-0.747	0.558
Other Taxa	-0.003	0

Consistent with its strongly negative correlation coefficient in the CCA, a regression of benthic taxa biomass against depth shows that biomass of molluscs decreases significantly with increasing depth (Fig. 10).

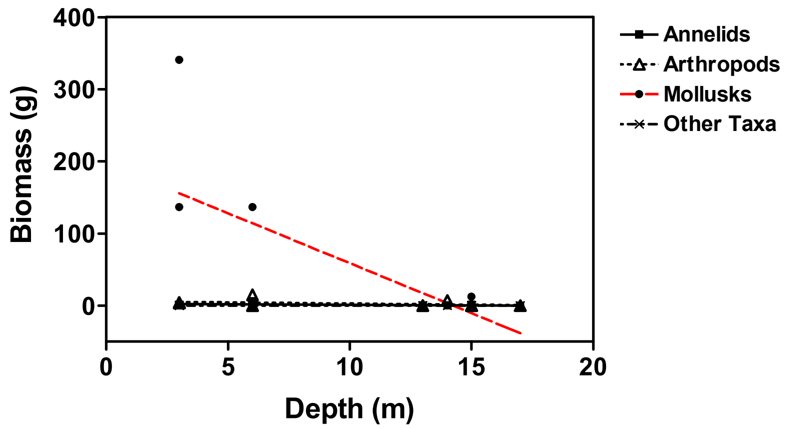

Figure 10. Regression of June 2002 benthic macroinvertebrate taxa against depth. The regression line in red indicates that the relationship is significant at $P < 0.05$.

Three axes derived from the abundance x dissolved oxygen (DO) CCA explained 100% of the variation in the dataset (Table 9). Axis 1, which explained 17.6% of the variation, was the only axis that showed a correlation with DO.

Table 9. Summary statistics for three canonical axes derived from a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate abundance (Species) data. Dissolved oxygen (Environment) is the environmental variable.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.065	0.305	0.001
Variance in species data			
% Variance explained	17.6	82.1	0.3
Cumulative % explained	17.6	99.7	100
Pearson Correlation (Species x Environment)	0.440	0	0
Kendall (Rank) Correlation (Species x Environment)	-0.473	0	0

The graphical relationship (CCA diagram) between sampling sites (ordinated by species) and the relationship to DO is shown in Fig. 11.

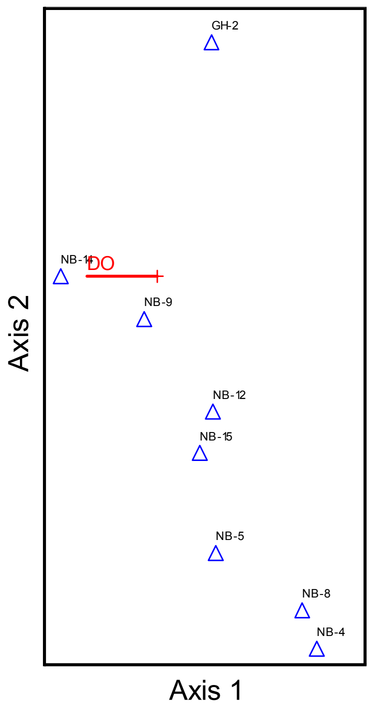

Figure 11. Graphical results of a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate abundance data constrained by dissolved oxygen concentration (DO). The spatial spread of points (triangles) shows the relationship of sampling sites with respect to benthic taxa composition and abundance. The environmental vector indicates the direction and magnitude of the correlation between Axis 1 and DO.

The macroinvertebrate abundance CCA indicates that dissolved oxygen concentration (DO) is a significant predictor of benthic taxa composition and abundance across the sampling sites. Because the June 2002 benthic dataset was primarily limited to Norton Basin sites, it is difficult to make predictions about the importance of dissolved oxygen concentration in structuring the benthic communities across sites. However, because DO is negatively correlated with Axis 1, negative correlation coefficients for the benthic taxa in relation to Axis 1 of the CCA (Table 10) indicate that benthic community abundance decreases with decreasing oxygen concentration. Thus, fewer benthic taxa are present in Norton Basin where oxygen concentrations are low.

Table 10. Pearson correlation coefficients (r) and regression coefficients (r^2) between Axis 1 of the CCA and abundance of individual benthic taxa.

	CCA Axis 1	
Species	r	r^2
Annelids	-0.774	0.598
Arthropods	-0.26	0.067
Molluscs	-0.791	0.625
Other Taxa	-0.756	0.572

Consistent with the strongly negative correlation coefficients in the CCA, a regression of benthic taxa abundance against DO shows that abundance of Annelids, Molluscs and other benthic macroinvertebrate taxa increases significantly with increasing DO (Fig. 12).

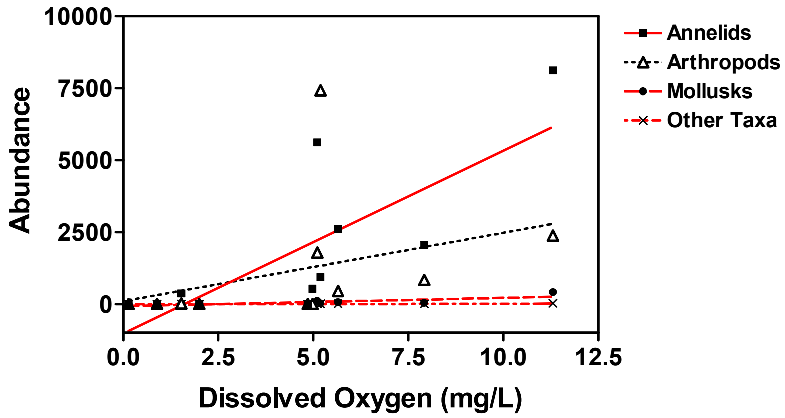

Figure 12. Regression of June 2002 benthic macroinvertebrate taxa against dissolved oxygen concentration (DO). Regression lines in red indicate that the relationship is significant at $P < 0.05$.

We found a significant negative relationship between both nitrate concentration and three chlorophyll indicators and Axis 1 of a PCA of June 2002 macroinvertebrate data (Fig. 13).

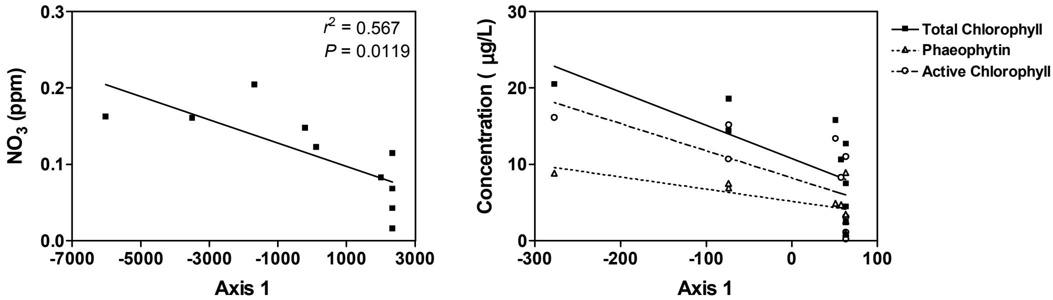

Figure 13. Regression of NO_3 concentration and three chlorophyll indicators versus the first principal component axis (Axis 1) derived from a PCA of June 2002 macroinvertebrate data. The relationship for NO_3 is derived from the abundance data, whereas the relationship for chlorophyll indicators is from biomass data. Total chlorophyll (r^2 = 0.511; P = 0.020); Pheaophytin (r^2 = 0.418; P = 0.044); Active chlorophyll (r^2 = 0.451; P = 0.033).

A second CCA of the June 2002 macroinvertebrate data was conducted on both the biomass and abundance data, using either nitrate concentration (abundance dataset) or two chlorophyll indicators (biomass dataset) as the constraining environmental factors.

Three axes derived from the abundance x nitrate CCA explained 100% of the variation in the dataset (Table 11). Axis 1, which explained 71% of the variation, was the only axis that showed a correlation with nitrate concentration.

Table 11. Summary statistics for three canonical axes derived from a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate abundance (Species) versus nitrate concentration (Environment) data.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.258	0.102	0.004
Variance in species data			
% Variance explained	70.8	28	1.2
Cumulative % explained	70.8	98.8	100
Pearson Correlation (Species x Environment)	0.85	0	0
Kendall (Rank) Correlation (Species x Environment)	0.619	0	0

The graphical relationship (CCA diagram) between sampling sites (ordinated by species) and the relationship to nitrate concentration is shown in Fig. 14.

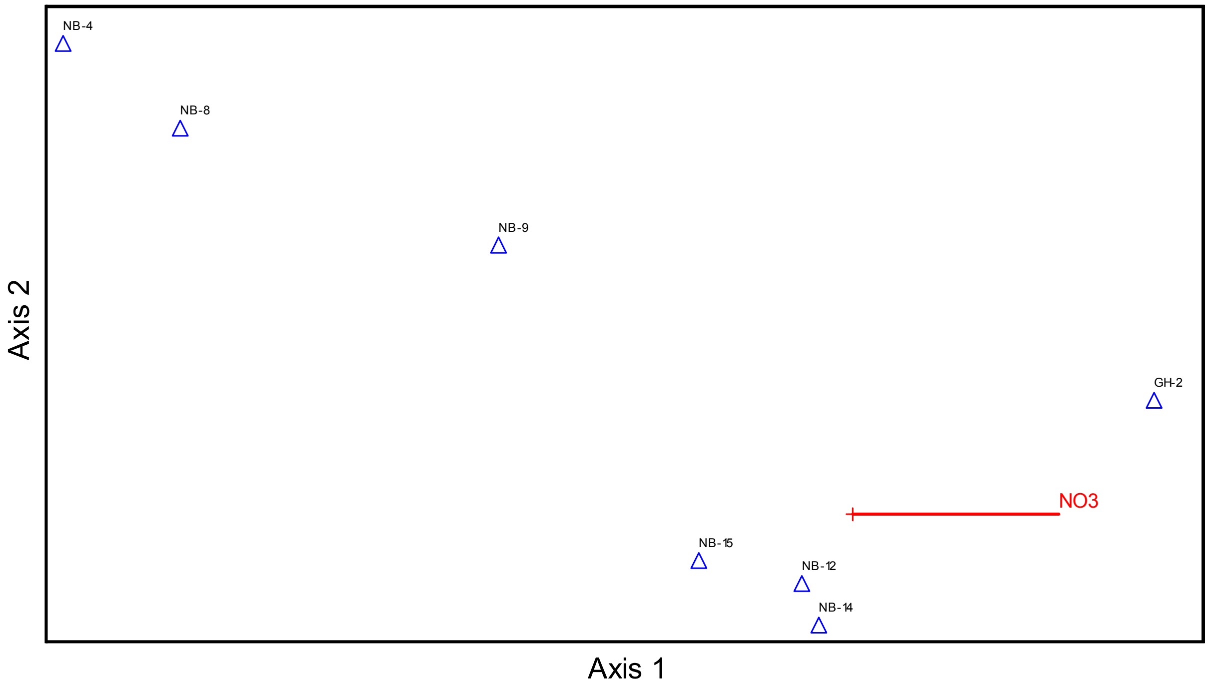

Figure 14. Graphical results of a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate abundance data constrained by nitrate concentration (NO3). The spatial spread of points (triangles) shows the relationship of sampling sites with respect to benthic taxa composition and abundance. The environmental vector indicates the direction and magnitude of the correlation between Axis 1 and NO3.

The macroinvertebrate abundance CCA indicates that nitrate is a significant predictor of benthic taxa composition and abundance across the sampling sites. However, because the June 2002 benthic dataset was primarily limited to Norton Basin sites, it is difficult to make predictions about the importance of nitrate in structuring the benthic communities across sites. Because nitrate is positively correlated with Axis 1, positive correlation coefficients for the benthic taxa (particularly arthropods) in relation to Axis 1 of the CCA (Table 12) indicate that benthic community abundance increases with increasing nitrate concentration. Based on these correlations, arthropods show the greatest positive response to nitrate concentration.

Table 12. Pearson correlation coefficients (r) and regression coefficients (r^2) between Axis 1 of the CCA and abundance of individual benthic taxa.

	CCA Axis 1	
Species	r	r^2
Annelids	0.475	0.226
Arthropods	0.817	0.668
Molluscs	0.377	0.142
Other Taxa	0.416	0.173

A regression of benthic taxa abundance against nitrate concentration shows that abundance of arthropods increases significantly with increasing nitrate concentration (Fig. 15).

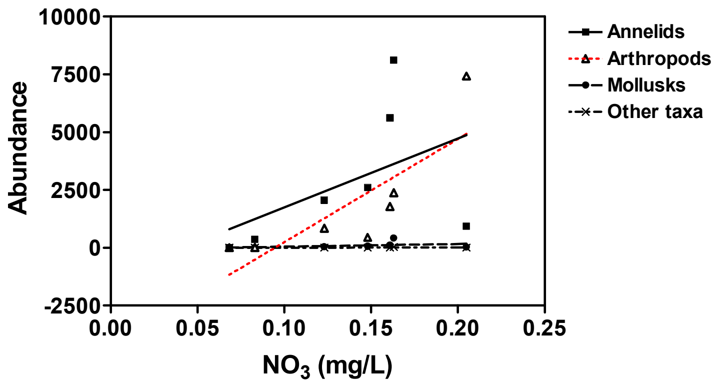

Figure 15. Regression of June 2002 macroinvertebrate abundance against nitrate concentration. The regression line in red indicates that the relationship is significant at $P < 0.05$.

A similar relationship between nitrate and benthic community composition was detected in a PCA of October 2002 macroinvertebrate data. However, the relationship was weak and did not result in any significant relationships between specific benthic taxa and nitrate concentration.

A CCA of the June 2002 macroinvertebrate data was conducted on biomass using two chlorophyll indicators as the constraining environmental factors. Three axes derived from the biomass x chlorophyll CCA explained 90% of the variation in the dataset (Table 13). Axis 1, which explained 53% of the variation, was the only axis that showed a correlation with either chlorophyll indicator.

Table 13. Summary statistics for three canonical axes derived from a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate biomass (Species) constrained by total chlorophyll and phaeophytin concentration (Environment) data.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.098	0	0.067
Variance in species data			
% Variance explained	53.1	0.1	36.5
Cumulative % explained	53.1	53.2	89.7
Pearson Correlation (Species x Environment)	0.817	0.082	0
Kendall (Rank) Correlation (Species x Environment)	1	-0.048	0

The graphical relationship (CCA diagram) between sampling sites (ordinated by species) and the relationship to chlorophyll and pheaophytin concentration is shown in Fig. 16.

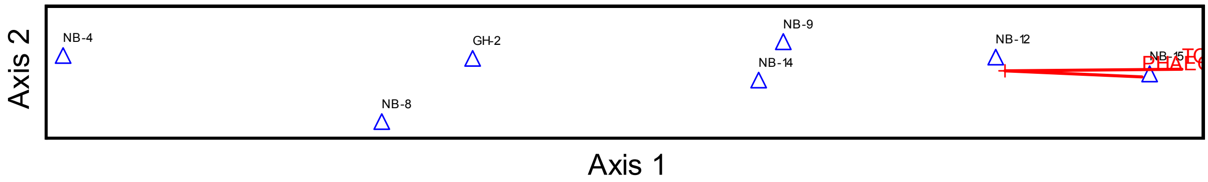

Figure 16. Graphical results of a canonical correspondence analysis (CCA) of June 2002 macroinvertebrate biomass data constrained by total chlorophyll (TOTAL) and phaeophytin concentration (PHAEO). The spatial spread of points (triangles) shows the relationship of sampling sites with respect to benthic taxa composition and abundance. The environmental vectors indicate the direction and magnitude of the correlation between Axis 1 and the environmental variables.

The macroinvertebrate biomass CCA indicates that both total chlorophyll and pheaophytin concentration are significant predictors of benthic taxa composition and abundance across the sampling sites. Because the June 2002 benthic dataset was primarily limited to Norton Basin sites, it is difficult to make predictions about the importance of these indicators in structuring the benthic communities across sites. However, the positive correlation between these indicators and Axis 1 of the CCA (Table 14) indicates that macroinvertebrate community abundance increases with increasing chlorophyll and pheaophytin concentration. In particular, molluscs show the greatest positive response.

Table 14. Pearson correlation coefficients (r) and regression coefficients (r^2) between Axis 1 of the CCA and biomass of individual benthic taxa.

Species	CCA Axis 1	
	r	r^2
Annelids	0.389	0.151
Arthropods	0.297	0.088
Molluscs	0.797	0.636
Other Taxa	0.149	0.022

A regression of benthic taxa biomass against total chlorophyll shows that, indeed, biomass of molluscs increases significantly with increasing chlorophyll concentration (Fig. 17).

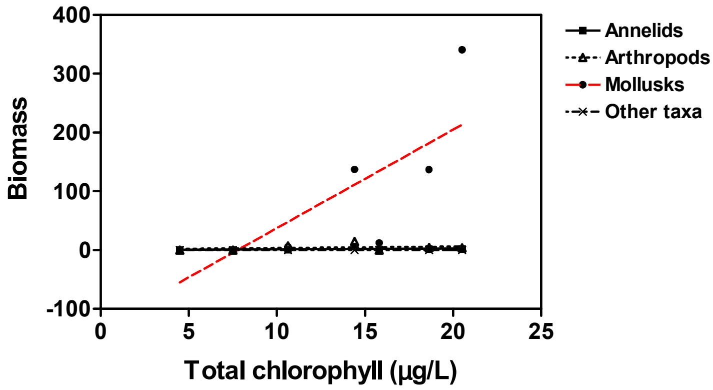

Figure 17. Regression of June 2002 macroinvertebrate biomass against total chlorophyll concentration. The regression line in red indicates that the relationship is significant at $P < 0.05$.

However, no statistical relationship was found when biomass of benthic taxa was regressed against pheaophytin concentration (Fig. 18).

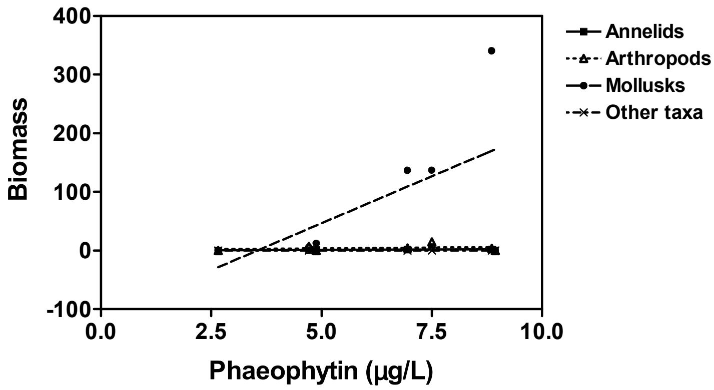

Figure 18. Regression of June 2002 macroinvertebrate biomass against pheaophytin concentration. For molluscs (r^2 = 0.353; P = 0.160).

Summary

The 2000, 2001 and 2002 above were analyzed for relationships between the biotic resources and environmental factors in Norton Basin and Little Bay using multivariate and univariate statistical methods. The following trends were observed:

- Salinity is a strong predictor of fish species composition and abundance across the sampling sites. Specifically, fish species such as Blueback Herring tend to occur in greater numbers in the low salinity Norton Basin Pit (NB pit) site. This location experiences little tidal flushing and is furthest from higher saline waters. Higher salinity levels in the Raunt (R) are due to the proximity of the site to greater tidal movement and higher salinity waters. The Raunt sites differ in fish and macrocrustasean composition and abundance from the NB pit and Grass Hassock (GH) sites with macrocrustaceans such as Lady Crab found in the Raunt sites. Grass Hassock sites are intermediate to these sites in salinity and abundance.

- There are several relationships between environmental variables and benthic macroinvertebrate community structure. For macroinvertebrate abundance, we found a significant negative relationship between nitrate concentration and depth and a significant positive relationship with turbidity. As nitrate concentration and depth increases and turbidity decreases more macroinvertebrates are expected to occur. A regression of macroinvertebrate abundance against depth indicated that annelids, molluscs and other taxa declined significantly at greater sampling depths. We found a positive relationship of depth on macroinvertebrate biomass and a significant negative relationship of dissolved oxygen concentration on macroinvertebrate biomass. This indicates that the abundance of benthic arthropods increases significantly at higher nitrate concentrations.

- In the PCA of macroinvertebrate biomass data, depth and dissolved oxygen were identified as important factors influencing the distribution and biomass abundance of macroinvertebrate taxa in the benthic zone. A regression analysis of macroinvertebrate biomass against depth indicated that molluscs and other taxa declined significantly at greater sampling depths. In contrast, arthropods, molluscs and other taxa increased significantly with increasing concentrations of dissolved oxygen.

- There is variability across different sampling years and location. Depth is a weak but significant predictor of benthic taxa composition and abundance across the sampling sites. Because the June 2002 benthic dataset was primarily limited to Norton Basin sites, it is difficult to make predictions about the importance of depth in structuring the benthic communities across sites. However, the data indicate that benthic community abundance decreases with increasing depth. Thus, fewer benthic species are present at greater depths in Norton Basin.

- Benthic community abundance decreases with decreasing oxygen concentration. Thus, fewer benthic taxa are present in Norton Basin where oxygen concentrations are low. Nitrate is a significant predictor of benthic taxa composition and abundance across the sampling sites. Based on these correlations, arthropods show the greatest positive response to nitrate concentration. Macroinvertebrate community abundance increases with increasing chlorophyll and pheaophytin concentration. In particular, molluscs show the greatest positive response.

These data confirm what biologists intuitively know – that as environmental conditions change, different species respond positively or negatively. The challenge of the Norton Basin and Little Bay bathymetric recontouring project is to determine which target species should benefit from the restoration of shallow estuarine habitat. Depending on the diversity of targeted fish species, ecologists should design habitat features in locations with higher or lower salinity, turbidity, nitrate concentration and depth, and other abiotic factors.

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