Statistical Analyses of 2004 Data on Wetland Plants and Invertebrates in Farmington Bay, Great Salt Lake, Utah

PREPARED FOR: Theron Miller/Utah Department of Water Quality

Leland Myers/Central Davis Sewer District, Utah

PREPARED BY: Sharook Madon/CH2M HILL

COPIES: Heidi Hoven/SWCA, Jeff DenBleyker/CH2M HILL

DATE: September 13, 2005

PROJECT NUMBER: 322512

Introduction

In 2004, The Utah Division of Water Quality (UDWQ) began a program to characterize the wetland and open water ecosystems of Farmington Bay in the Great Salt Lake. This characterization will serve as the basis for developing a successful and implementable plan for defining, evaluating, and protecting Farmington Bay's beneficial uses and resources. The ongoing program includes intensive sampling of multiple wetlands sites that represent a cross-section of the different wetland ecosystems along Farmington Bay. These wetland sites will be re-sampled in 2005 and 2006 in addition to the open water sites to provide a comprehensive characterization of the Farmington Bay ecosystem and its beneficial uses.

The first year of intensive sampling of wetland sites along Farmington Bay was recently completed and included sites receiving sheet-flow hydrology and impounded wetlands. Sampling was conducted during 2004 to characterize water quality, wetland soils, plants, and macroinvertebrates at each wetland site. Sample processing and analyses were recently completed. This technical memorandum describes the analyses and results of part of the wetland plant and macroinvertebrate data collected from Farmington Bay in 2004.

Data Analyses

This technical memo focuses on the analyses of relationships between plant, invertebrate, water, and soil chemistry variables measured at various sites in the Farmington Bay wetlands.

Wetland Sites

Data from the following wetland sites (Exhibit 1) exhibiting both impounded and sheetflow hydrology are incorporated into the analysis:

Impounded Sites (13 sites**)**
- Ambassador Transects 1-4 (AMBAS T1-T4 in Exhibit 1; A1-4 in Figures 89-97)
- Farmington Bay Water Management Area Transects 1-3 (FBWMA T1-T3 in Exhibit 1; F1-3 in Figures 89-97)
- Newstate Transects 1-3 (NEW T1-T3 in Exhibit 1; NW1-3 in Figures 89-97)
- Public Shooting Grounds Transects 1-3 (PSG T1-T3 in Exhibit 1; P1-3 in Figures 89-97)

Sheetflow Sites (16 sites)
- Central Davis Sewer District Transects 1-4 (CDSD T1-T4 in Exhibit 1; C1-4 in Figures 89-97)
- Farmington Bay Water Management Area Sheetflow Transects 1-3 (FBWMAs T1-T3 in Exhibit 1; Fs1-3 in Figures 89-97)
- Kays Creek Transects 1-3 (KC T1-T3 in Exhibit 1; K1-3 in Figures 89-97)
- North Davis Sewer District Transects 1-3 (NDSD T1-T3 in Exhibit 1; N1-3 in Figures 89-97)
- Public Shooting Grounds SheetflowTransects 1-3 (PSGs T1-T3 in Exhibit 1; Ps1-3 in Figures 89-97)

Variables Used in Data Analyses

Wetland Plant Variables

Percent cover and height data for six species of wetland plants most frequently observed at the sites are included in the analyses:

- *Distichlis spicata*, Desert saltgrass
- *Phragmites australis*, Common reed
- *Typha latifolia*, Broadleaf cattail
- *Scirpus americanus*, Olney's bulrush
- *Scirpus maritimus*, Cosmopolitan bulrush
- *Stukenia* (Potomageton) species, consisting primarily of *Stukenia filiformis*, Fineleaf pondweed, and *Stukenia pectinatus*, Sego pondweed

Other plant species were rarely encountered in the transects established at the sites to provide sufficient data, and are thus excluded from analyses.

\\Slcdb\gis\PROJECTS\Farmington_Bay\MapDocuments\FARMBAY_GPS.mxd; 8/10/05; cl

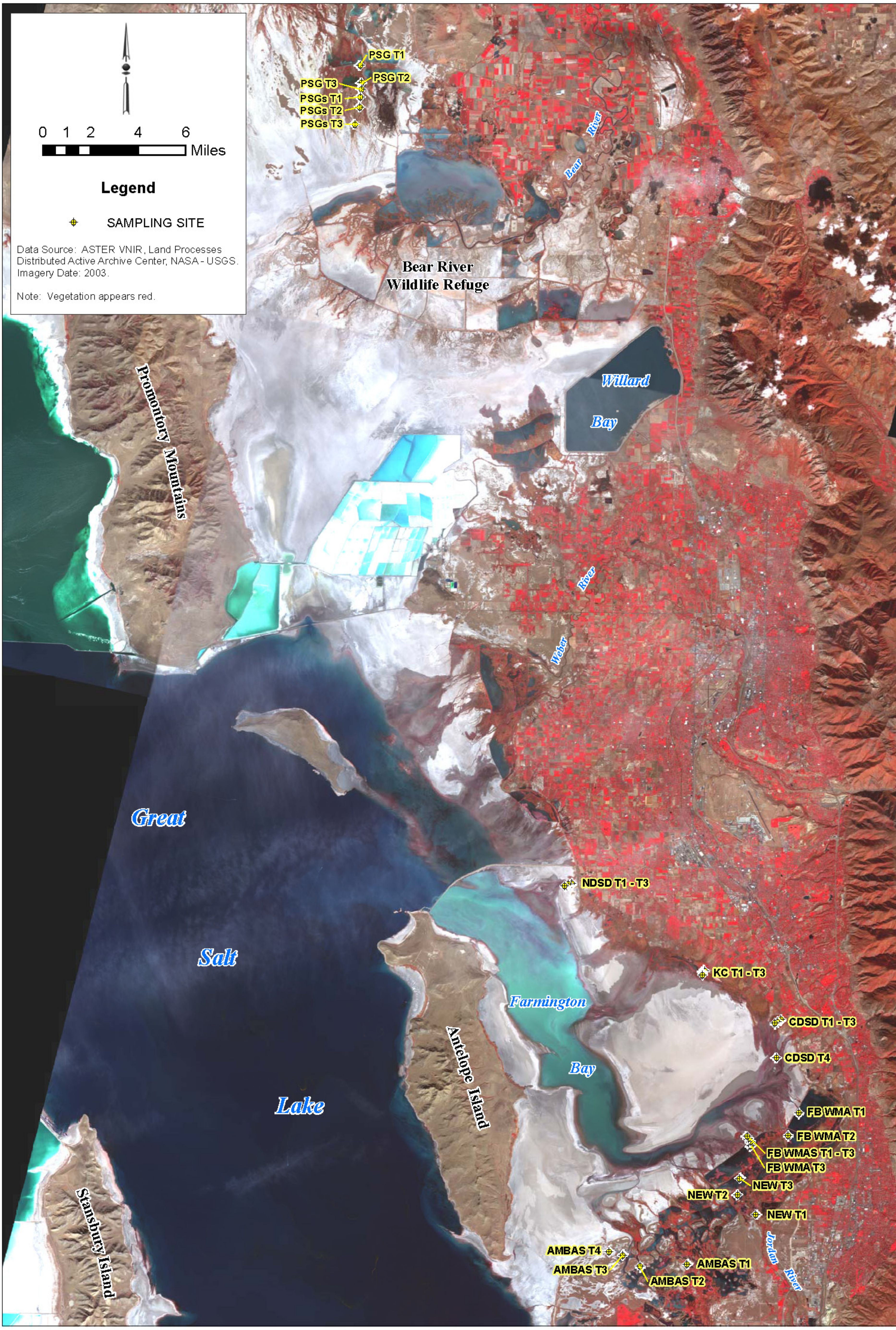

EXHIBIT 1

WETLANDS SAMPLING SITES

STATISTICAL ANALYSES OF 2004 DATA ON WETLAND PLANTS
AND INVERTEBRATES IN FARMINTON BAY, GREAT SALT LAKE, UTAH

CH2MHILL

Wetland Invertebrate Variables

The number of individuals per sample for the following macroinvertebrate taxa are included in the analyses. More detailed information on the various taxa can be found in Gray (2005):

- **Ephemeropterans:** Order Ephemeroptera, primarily mayflies of the genus, *Callibaetis*
- **Odonates:** Order Odonata, includes damselflies and dragonflies, of which the damselfly belonging to the genus, *Ischnura*, was most abundant
- **Hemipterans:** Order Hemiptera, represented primarily by corixids (water boatman) and notonectids (backswimmers)
- **Chironomids:** Order Diptera, primarily represented by the genus *Chironomus* (Family Chironomidae), commonly known as midges
- **Gastropods:** Primarily snails (Class Gastropoda) represented by the genera *Physella, Stagnicola* and *Gyraulus*
- **Crustaceans:** Primarily amphipod (commonly known as scuds) species *Hyallela azteca*
- **Platyhelminthes:** Primarily planarian flatworms of the genera *Phagocata* and *Dugesia*
- **Annelids:** Phylum Annelida, represented by leeches, primarily species *Helobdella stagnalis, Glossophonia complanata* and *Erpobdella parva* complex.

Other invertebrates such as various dipterans, isopods, and aquatic beetles were also present in the samples, but were too rare, and are included in the category titled “other” in the analyses.

Water Quality Variables

Physical/chemical data on water samples were collected to assess the responses of plant and invertebrate variables to a range of environmental conditions across wetland sites. These water quality parameters included:

- pH
- Total dissolved solids (TDS), mg/L
- Dissolved oxygen, mg/L
- Phosphorus as P, mg/L
- Nitrogen as N (nitrite and nitrate), mg/L
- Maximum water temperature (˚C)

All water quality data is $\log_{10}$-transformed for the analyses, except in a few cases, as noted.

Soil Chemistry Variables

Physical/chemical data on soils were collected to assess the responses of plant and invertebrate variables to a range of environmental conditions across wetland sites.

- Soil pH
- Soil Conductivity (dS/m)
- Soil Organic Matter (% loss on ignition)

Data Analyses Approach

Univariate and multivariate statistical tests are used to explore relationships between physical, chemical, and biological variables measured at various wetland sites in Farmington Bay. A three-tiered statistical approach defines the analyses of Farmington Bay data and involves:

- Tier 1: Univariate regressions of plant and invertebrate variables on soil and water quality variables to explore individual relationships between these variables. Example: Simple regression of *Distichlis spicata* percent cover on soil pH.
- Tier 2: Variables from statistically significant univariate regressions are selected to include into multiple regression models. Example: Univariate regressions of *Typha latifolia* percent cover on total dissolved solids, water temperature and soil pH are statistically significant at the $p \leq 0.05$ level. These three environmental variables are chosen to construct a multiple regression model of *Typha latifolia* percent cover on total dissolved solids, water temperature, and soil pH. This type of analysis allows an assessment, for example, of the amount of variation in *Typha latifolia* percent cover that can be explained by total dissolved solids, water temperature, and soil pH.
- Tier 3: A multivariate test such as factor analysis is used to assess patterns between biological factors (plants and invertebrates) and physical/chemical factors (soil chemistry and water quality parameters) across wetland sites in the Farmington Bay. Multivariate tests are useful for exploring relationships in complex data sets involving multiple environmental and biological variables measured at multiple sites. Factor analysis, for example, parsimoniously treats multivariate biological community and environmental data, such that a few resulting factors (e.g., invertebrate factor, vegetation factor, water quality factor) can be used to interpret patterns and relationships across sites.

All statistical analyses are conducted on log-transformed data on biological and environmental variables. Logarithmic transformations ensure that the assumptions of statistical tests including normal distributions of data and homogenous distributions of variances are not violated. Plant percent cover and invertebrate numbers data (X) are $\log_{10}(X+1)$ transformed to account for data values that included 0. All plant height, soil chemistry, and water quality data are $\log_{10}$-transformed.

In the tier 1 analysis, visual examination of scatterplots of certain biological variables on environmental variables indicated non-linear relationships between these variables. In such cases, a distance-weighted least squares (DWLS) curve fitting method (Systat ver. 11) is used to define non-linear relationships. DWLS is a powerful and versatile method that fits a line to a set of points in a scatterplot by least squares methodology, where the line is allowed to flex locally to fit the data. The DWLS method produces a true, locally-weighted curve running through a set of points and does not assume the shape of the curve, as in the case of linear least squares and polynomial regressions.

Data Analyses Methods

Least squares univariate and multiple regressions and multivariate analyses are used to analyze the data, based on the three-tiered approach:

Tier 1: Simple Univariate Regressions

The following univariate regressions were conducted to explore potential relationships between:

Plants and soil chemistry

- Plant species percent cover and soil pH
- Plant species percent cover and soil conductivity
- Plant species percent cover and soil organic matter content
- Plant species height and soil pH
- Plant species height and soil conductivity
- Plant species height and soil organic matter

Plants and water quality

- Plant species percent cover and pH
- Plant species percent cover and total dissolved solids
- Plant species percent cover and dissolved oxygen
- Plant species percent cover and total phosphorus
- Plant species percent cover and total nitrogen
- Plant species percent cover and maximum water temperature
- Plant species height and pH
- Plant species height and total dissolved solids
- Plant species height and dissolved oxygen
- Plant species height and total phosphorus
- Plant species height and total nitrogen
- Plant species height and maximum water temperature

Invertebrates and soil chemistry

- Invertebrate taxa (numbers per sample) and soil pH
- Invertebrate taxa (numbers per sample) and soil conductivity
- Invertebrate taxa (numbers per sample) and soil organic matter content

Invertebrates and water quality

- Invertebrate taxa (numbers per sample) and pH
- Invertebrate taxa (numbers per sample) and total dissolved solids
- Invertebrate taxa (numbers per sample) and dissolved oxygen
- Invertebrate taxa (numbers per sample) and total phosphorus
- Invertebrate taxa (numbers per sample) and total nitrogen
- Invertebrate taxa (numbers per sample) and maximum water temperature

Invertebrates and plants

- Invertebrate taxa (numbers per sample) and *Typha latifolia* percent cover
- Invertebrate taxa (numbers per sample) and *Phragmites australis* percent cover
- Invertebrate taxa (numbers per sample) and *Distichlis spicata* percent cover
- Invertebrate taxa (numbers per sample) and *Scirpus americanus* percent cover
- Invertebrate taxa (numbers per sample) and *Stukenia* species percent cover

Relationships between various invertebrate taxa and *Scirpus maritimus* are not explored due to lack of sufficient data.

Tier 2: Multiple Regression Models

Based on the tier 1 analyses, plant, invertebrate, soil, and water chemistry variables are chosen to include into three categories of multiple regression models:

- Plant species percent cover vs. soil chemistry and water quality parameters
- Plant species height vs. soil chemistry and water quality parameters
- Invertebrate taxa (numbers per sample) vs. soil chemistry, water quality, and plant percent cover

Tier 3: Multivariate Factor Analysis of Biological Community and Environmental Data

Factor analysis is used to explore relationships between biological factors (plants and invertebrates) and physical/chemical factors across wetland sites in the Farmington Bay. The factor model explains variation within and relations among observed variables as partly common variation among factors and partly specific variation among random errors (Systat ver. 11). Factor analysis allows exploration of multivariate biological community and environmental data and has many advantages:

- Correlations of large number of variables can be studied by grouping the variables in factors (i.e., water quality factor, invertebrate factor, vegetation factor), so that variables within each factor are more tightly correlated with other variables in that factor than with variables in other factors.
- Many variables can be parsimoniously summarized by a few factors. For example, pH, DO, TDS, and nutrients, can potentially be summarized into a single water quality factor.
- Each factor can be interpreted according to the meaning of the variables. For example, a water quality factor may scale increasing pH, DO, and TDS on positive factor loadings and increasing nutrients on negative factor loadings.

Factor analysis on the 2004 Farmington Bay dataset is conducted using the following steps:

- A correlation matrix is computed for each biological community and environmental dataset.
    - Variables used to compute the plant percent cover correlation matrix included percent covers of *Distichlis spicata*, *Phragmites australis,Typha latifolia, Scirpus americanus, Scirpus maritimus,* and *Stukenia* (formerly known as *Potomageton*) species across various impounded and sheetflow sites in Farmington Bay (Figure 1).
    - The correlation matrix for water quality included pH, TDS, DO, total N, and total P across various sites.

   - Variables included in the invertebrates correlation matrix included numbers per sample of Ephemeroptera, Odonata, Hemiptera, Chironomidae, Gastropoda, Crustacea, Platyhelminthes, and Annelida across all sites.

- The factor loadings are estimated and the factors are then extracted for the biological community and environmental datasets. A single factor is extracted for each dataset.
   - Vegetation Factor: includes information on percent covers of the *Distichlis spicata*, *Phragmites australis,Typha latifolia, Scirpus americanus, Scirpus maritimus,* and *Stukenia* species
   - Water Quality Factor: includes information on pH, TDS, DO, total N, and total P
   - Invertebrate Factor: includes information on number of individuals per sample of Ephemeroptera, Odonata, Hemiptera, Chironomidae, Gastropoda, Crustacea, Platyhelminthes, and Annelida
- The factors are then rotated by an orthogonal rotation method known as Varimax rotation that minimizes the number of variables that have high loadings on each factor to make the loadings more interpretable
- The factor scores are computed and stored for correlation analysis. The relationships between factors are explored across the wetland sites:
   - Vegetation and water quality factors
   - Invertebrate and water quality factors
   - Invertebrate and vegetation factors
   - Invertebrate, vegetation and water quality factors

Soil chemistry factors are not included in the factor analysis as they do not correlate significantly with many biological variables in the tier 1 analysis.

Results

The section presents the results of the analyses conducted on 2004 Farmington Bay wetlands data. Presentation of the results follows the three-tiered analytical approach described in the methods section.

Tier 1: Results of Simple Univariate Regressions

Simple regressions of biological and environmental parameters are presented in Table 1. These regressions are of the form $Y = \alpha + \beta X$, and Table 1 contain the following regression coefficients and parameters:

- α = Y-intercept
- β = slope, where the sign (negative or positive) indicates whether the relationship between the dependent (Y) and independent (X) variables is negative or positive
- N = number of data pairs in the regression

- R^2 = proportion of variation in the dependent variable (Y) that can be accounted for by the independent variable (X)
- *F-ratio* is as the ratio between the mean square of the regression (MSR) and the mean square of the error (MSE) and is used to test whether the regression is significant. A large *F*-ratio indicates that the regression is significant
- *p-values* indicate the probabilistic level of significance

Plants and Soil Chemistry

Soil parameters such as soil pH, soil conductivity, and soil organic matter content, generally do not explain the variations observed in plant percent cover, except in the case of *Typha latifolia* percent cover which is significantly correlated with soil pH (Table 1, Figure 1).

TABLE 1. REGRESSIONS ESTIMATES OF WETLAND PLANT % COVER BY SPECIES ON SOIL PARAMETERS
Regressions are of the form: Plant % Cover (Y) = $\alpha + \beta$*Soil Parameter (X), where α is the Y intercept and β is the slope.
Regression analyses is conducted on (log_{10} + 1) transformed values of plant %Cover and log_{10} transformed values of soil parameters.
Stukenia species mainly consists of Stukenia filiformis and S. pectinatus.

PLANT % COVER (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
SOIL pH vs:						
Distichlis spicata	2.79	-2.82	29	0.006	0.16	0.695
Phragmites australis	5.57	-5.93	29	0.033	0.92	0.346
Scirpus americanus	-1.35	2.17	29	0.003	0.08	0.779
Scirpus maritimus	8.54	-9.31	29	0.068	1.98	0.171
Stukenia species	1.08	-0.40	29	0.001	0.002	0.966
Typha latifolia	14.76	-16.35	29	0.225	7.84	0.009 ** (1)
Independent Variable (X):						
SOIL CONDUCTIVITY vs:						
Distichlis spicata	0.22	0.09	29	0.002	0.04	0.841
Phragmites australis	0.18	0.18	29	0.007	0.20	0.662
Scirpus americanus	0.92	-0.40	29	0.025	0.70	0.410
Scirpus maritimus	0.07	0.29	29	0.016	0.45	0.508
Stukenia species	0.89	-0.19	29	0.004	0.11	0.748
Typha latifolia	0.78	-0.52	29	0.056	1.61	0.215
Independent Variable (X):						
SOIL ORGANIC MATTER vs:						
Distichlis spicata	0.04	0.40	29	0.015	0.41	0.529
Phragmites australis	0.04	0.43	29	0.022	0.62	0.439

TABLE 1. REGRESSIONS ESTIMATES OF WETLAND PLANT % COVER BY SPECIES ON SOIL PARAMETERS
Regressions are of the form: Plant % Cover (Y) = $\alpha + \beta$*Soil Parameter (X), where α is the Y intercept and β is the slope.
Regression analyses is conducted on (log_{10} + 1) transformed values of plant %Cover and log_{10} transformed values of soil parameters. Stukenia species mainly consists of Stukenia filiformis and S. pectinatus.

PLANT % COVER (by species)	α	β	N	R^2	F	p
Scirpus americanus	0.69	-0.17	29	0.002	0.06	0.810
Scirpus maritimus	-0.19	0.76	29	0.058	1.67	0.207
Stukenia species	1.36	-0.95	29	0.048	1.38	0.251
Typha latifolia	-0.26	0.88	29	0.084	2.46	0.128

NOTES: p values > 0.05 indicate that the relationship between variables is not significant . ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships.

In contrast, heights of various plant species are significantly related to soil parameters (Table 2).

TABLE 2. REGRESSIONS ESTIMATES OF WETLAND PLANT HEIGHTS (CM) BY SPECIES ON SOIL PARAMETERS
Regressions are of the form: Plant Height (Y) = $\alpha + \beta$*Soil Parameter (X), where α is the Y intercept and β is the slope.
Plant height and soil parameters were Log_{10} transformed and regressions analyses conducted on log-transformed values. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT HEIGHT (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
SOIL pH vs:						
Distichlis spicata	10.67	-10.38	6	0.379	2.44	0.193 † (2)
Phragmites australis	2.94	-0.85	8	0.008	0.05	0.835
Scirpus americanus	7.56	-6.48	12	0.455	8.35	0.016 ** (3)
Scirpus maritimus	8.34	-7.13	6	0.284	1.59	0.276
Stukenia species	5.89	-5.81	14	0.129	1.78	0.207
Typha latifolia	9.76	-8.59	8	0.389	3.82	0.099
Independent Variable (X):						
SOIL CONDUCTIVITY vs:						
Distichlis spicata	1.07	0.59	6	0.346	2.12	0.219 † (4)
Phragmites australis	2.17	0.04	8	0.009	0.05	0.826 † (5)
Scirpus americanus	2.07	-0.31	12	0.251	3.36	0.097
Scirpus maritimus	2.34	-0.29	6	0.386	2.52	0.188
Stukenia species	1.89	-0.49	14	0.134	1.85	0.199
Typha latifolia	2.56	-0.35	8	0.530	6.76	0.041 ** (6)

TABLE 2. REGRESSIONS ESTIMATES OF WETLAND PLANT HEIGHTS (CM) BY SPECIES ON SOIL PARAMETERS
Regressions are of the form: Plant Height (Y) = α + β*Soil Parameter (X), where α is the Y intercept and β is the slope.
Plant height and soil parameters were Log_{10} transformed and regressions analyses conducted on log-transformed values. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT HEIGHT (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
SOIL ORGANIC MATTER vs:						
Distichlis spicata	0.80	0.99	6	0.524	4.40	0.104 † (7)
Phragmites australis	2.05	0.20	8	0.158	1.13	0.329
Scirpus americanus	2.10	-0.40	12	0.219	2.81	0.125
Scirpus maritimus	1.89	0.26	6	0.168	0.81	0.419
Stukenia species	0.93	-0.27	14	0.010	0.13	0.729
Typha latifolia	2.13	0.20	8	0.081	0.53	0.494

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. † indicates that a significant non-linear relationship exist between the variables. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships.

Patterns in heights of *Distichlis spicata* are significantly explained by soil pH, conductivity, and organic matter content (Table 2, Figures 2, 4, and 7, respectively). Variations in heights of *Scirpus americanus, Phragmites australis,* and *Typha latifolia* are also significantly explained by soil parameters (Table 2, Figures 3, 5, and 6).

Plants and Water Quality

Each water quality parameter correlates significantly with percent cover of at least two or more plant species, except total N, which fails to explain patterns in plant percent cover (Table 3, Figures 8–25).

TABLE 3. REGRESSIONS ESTIMATES OF WETLAND PLANT PERCENT COVER BY SPECIES ON WATER QUALITY PARAMETERS
Regressions are of the form: Plant Percent Cover (Y) = α + β*Water Quality Parameter (X), where α is the Y intercept and β is the slope.
Plant percent cover values were (log_{10} + 1) transformed and water quality parameters were log_{10} transformed. Regression analyses were conducted on log-transformed values. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT % COVER (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
pH vs:						
Distichlis spicata	7.12	-7.34	28	0.115	3.38	0.077
Phragmites australis	7.82	-8.14	28	0.202	6.60	0.016 ** (8)
Scirpus americanus	11.22	-11.57	28	0.257	9.01	0.006 ** (9)
Scirpus maritimus	6.79	-7.00	28	0.110	3.21	0.085
Stukenia species	-20.24	22.72	28	0.632	4.60	<0.001 ** (10)
Typha latifolia	7.32	-7.55	28	0.137	4.14	0.052

TABLE 3. REGRESSIONS ESTIMATES OF WETLAND PLANT PERCENT COVER BY SPECIES ON WATER QUALITY PARAMETERS
Regressions are of the form: Plant Percent Cover (Y) = $\alpha + \beta$*Water Quality Parameter (X), where α is the Y intercept and β is the slope.
Plant percent cover values were (log_{10} + 1) transformed and water quality parameters were log_{10} transformed. Regression analyses were conducted on log-transformed values. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT % COVER (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
TOTAL DISSOLVED SOLIDS (TDS) vs:						
Distichlis spicata	-0.54	0.27	28	0.011	0.28	0.601
Phragmites australis	3.63	-1.08	28	0.253	8.79	0.006 ** (11)
Scirpus americanus	3.74	-1.03	28	0.147	4.47	0.044 ** (12)
Scirpus maritimus	3.48	-1.02	28	0.166	5.17	0.032 ** (13)
Stukenia species	-2.88	1.17	28	0.120	3.53	0.072
Typha latifolia	4.98	-1.49	28	0.384	16.21	<0 .001 ** † (14 & 15)
Independent Variable (X):						
DISSOLVED OXYGEN (DO) vs:						
Distichlis spicata	0.66	-0.43	28	0.017	0.44	0.511
Phragmites australis	1.31	-1.18	28	0.183	5.81	0.023 ** (16)
Scirpus americanus	1.30	-0.89	28	0.066	1.83	0.188
Scirpus maritimus	1.00	-0.78	28	0.059	1.62	0.214
Stukenia species	-1.21	2.26	28	0.271	9.65	0.005 ** (17)
Typha latifolia	1.12	-0.89	28	0.083	2.36	0.137
Independent Variable (X):						
TOTAL PHOSPHORUS (P) vs:						
Distichlis spicata	0.12	-0.37	28	0.179	5.68	0.025 ** (18)
Phragmites australis	0.07	0.24	28	0.219	7.29	0.012 ** ! (19)
Scirpus americanus	0.52	-0.04	28	0.002	0.04	0.837
Scirpus maritimus	0.42	0.21	28	0.059	1.62	0.214
Stukenia species	1.04	-0.32	28	0.148	4.53	0.043 ** ! (20)
Typha latifolia	0.40	0.12	28	0.021	0.56	0.463

TABLE 3. REGRESSIONS ESTIMATES OF WETLAND PLANT PERCENT COVER BY SPECIES ON WATER QUALITY PARAMETERS
Regressions are of the form: Plant Percent Cover (Y) = $\alpha + \beta$*Water Quality Parameter (X), where α is the Y intercept and β is the slope.
Plant percent cover values were (log_{10} + 1) transformed and water quality parameters were log_{10} transformed. Regression analyses were conducted on log-transformed values. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT % COVER (by species)	α	β	N	R^2	F	p
Independent Variable (X):						
TOTAL NITROGEN (N) vs:						
Distichlis spicata	0.18	-0.21	28	0.071	1.98	0.172
Phragmites australis	0.37	0.16	28	0.061	1.70	0.203
Scirpus americanus	0.56	0.06	28	0.006	0.15	0.702
Scirpus maritimus	0.37	0.08	28	0.010	0.26	0.615
Stukenia species	0.68	-0.16	28	0.023	0.62	0.437
Typha latifolia	0.44	0.19	28	0.067	1.87	0.183
Independent Variable (X):						
MAX. WATER TEMPERATURE vs:						
Distichlis spicata	5.41	-3.69	16	0.219	3.93	0.068
Phragmites australis	8.57	-5.83	16	0.341	7.24	0.018 ** (21)
Scirpus americanus	8.80	-5.97	16	0.302	6.04	0.028 ** (22)
Scirpus maritimus	7.97	-5.39	16	0.257	4.85	0.045 ** (23)
Stukenia species	-10.47	8.05	16	0.267	5.09	0.041 ** (24)
Typha latifolia	9.61	-6.47	16	0.287	5.64	0.032 ** (25)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. † indicates that a significant non-linear relationship exist between the variables. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships. ! indicates that the regression was conducted with untransformed water quality parameter.

The pH of water explains variations in percent cover of *Phragmites australi*s, *Scirpus americanus,* and *Stukenia* species (Table 3, Figures 8–10). Significant relationships also exist between total dissolved solids and *Phragmites australi*s, *Scirpus americanus, Scirpus maritimus,* and *Typha latifolia* (Table 3, Figures 11–15). Percent covers of *Phragmites australi*s and *Stukenia* species are significantly correlated to dissolved oxygen (Table 3, Figures 16–17), whereas total P concentration explains variations in percent covers of *Distichlis spicata, Phragmites australi*s, and *Stukenia* species (Table 3, Figures 18–20). Maximum water temperature is significantly correlated with percent covers of all plant species tested, except *Distichlis spicata* (Table 3, Figures 21–25).

Relatively fewer correlations exist between plant species heights and water quality variables (Table 4). Dissolved oxygen and total P concentrations do not correlate with heights of any of the plant species tested (Table 4).

TABLE 4. REGRESSIONS ESTIMATES OF WETLAND PLANT HEIGHT BY SPECIES ON WATER QUALITY PARAMETERS
Regressions are of the form: Plant Height (Y) = $\alpha + \beta$*Water Quality Parameter (X), where α is the Y intercept and β is the slope.
Regression analyses were conducted on log_{10} transformed values of plant height and water quality parameters. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.

PLANT HEIGHT (by species)	**α**	**β**	**N**	**R^2**	**F**	**P**
Independent Variable (X):						
pH vs:						
Distichlis spicata	0.36	1.28	6	0.003	0.01	0.919
Phragmites australis	6.10	-4.31	8	0.493	5.83	0.050 ** (26)
Scirpus americanus	-2.16	4.41	12	0.128	1.47	0.253
Scirpus maritimus	7.46	-5.94	6	0.455	3.34	0.142
Stukenia species	7.34	-6.95	14	0.304	5.25	0.041 ** (27)
Typha latifolia	5.87	-3.96	8	0.228	1.78	0.231
Independent Variable (X):						
TOTAL DISSOLVED SOLIDS (TDS) vs:						
Distichlis spicata	1.02	0.16	6	0.022	0.09	0.779
Phragmites australis	2.44	-0.08	8	0.012	0.07	0.795
Scirpus americanus	3.07	-0.41	12	0.300	4.29	0.065
Scirpus maritimus	3.73	-0.57	6	0.416	2.85	0.167
Stukenia species	2.02	-0.39	14	0.117	1.59	0.232
Typha latifolia	4.22	-0.68	8	0.525	6.62	0.042 ** (28)
Independent Variable (X):						
DISSOLVED OXYGEN (DO) vs:						
Distichlis spicata	1.26	0.04	6	0.079	0.34	0.591
Phragmites australis	2.43	-0.30	8	0.338	3.06	0.131
Scirpus americanus	1.59	0.30	12	0.075	0.81	0.389
Scirpus maritimus	2.30	-0.29	6	0.155	0.73	0.440
Stukenia species	1.91	-1.18	14	0.199	2.98	0.110
Typha latifolia	2.47	-0.24	8	0.121	0.83	0.398
Independent Variable (X):						
TOTAL PHOSPHORUS (P) vs:						
Distichlis spicata	1.43	-0.11	6	0.132	0.61	0.480
Phragmites australis	2.21	0.09	8	0.189	1.40	0.282

TABLE 4. REGRESSIONS ESTIMATES OF WETLAND PLANT HEIGHT BY SPECIES ON WATER QUALITY PARAMETERS
Regressions are of the form: Plant Height (Y) = α + β*Water Quality Parameter (X), where α is the Y intercept and β is the slope. *Regression analyses were conducted on log_{10} transformed values of plant height and water quality parameters. Stukenia species mainly consist of Stukenia filiformis and S. pectinatus.*

PLANT HEIGHT (by species)	α	β	N	R^2	F	P
Scirpus americanus	1.81	-0.04	12	0.028	0.29	0.603
Scirpus maritimus	2.10	0.02	6	0.004	0.02	0.902
Stukenia species	0.70	-0.13	14	0.075	0.97	0.344
Typha latifolia	2.26	-0.04	8	0.019	0.12	0.743
Independent Variable (X):						
TOTAL NITROGEN (N) vs:						
Distichlis spicata	1.36	-0.23	6	0.542	4.73	0.095
Phragmites australis	2.21	0.04	8	0.099	0.66	0.449
Scirpus americanus	1.86	0.06	12	0.103	1.14	0.310
Scirpus maritimus	2.13	0.13	6	0.497	3.96	0.118
Stukenia species	0.84	0.14	14	0.125	1.72	0.215
Typha latifolia	2.32	0.18	8	0.769	20.0	0.004 ** (29)
Independent Variable (X):						
MAX. WATER TEMPERATURE vs:						
Distichlis spicata	*na*	*na*	*na*	*na*	*na*	*na*
Phragmites australis	6.05	-2.77	4	0.617	3.22	0.214
Scirpus americanus	-2.25	2.96	4	0.239	0.63	0.511
Scirpus maritimus	2.72	-0.41	4	0.091	0.20	0.699
Stukenia species	3.51	-1.91	10	0.067	0.58	0.469
Typha latifolia	-1.51	2.81	5	0.724	7.86	0.068 † (30)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. † indicates that a significant non-linear relationship exist between the variables. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships. ! indicates regression on non-transformed water quality parameter. *na* = not applicable; insufficient data to perform regression analyses.

Heights of *Phragmites australi*s and *Stukenia* species are significantly correlated with pH (Table 4, Figures 26–27), whereas the height of *Typha latifolia* is significantly correlated with TDS, total N concentration, and maximum water temperature (Table 4, Figures 28–30)

Invertebrates and Soil Chemistry

Variations in numbers of invertebrates belonging to a few taxa can be explained by soil chemistry parameters (Table 5). Linear relationships exist between flatworms and soil pH, ephemeropterans and soil conductivity, and annelids and soil organic matter (Table 5, Figures 32, 33, and 36). A few responses of invertebrates to soil parameters are non-linear, including gastropods and soil pH, gastropods and soil conductivity, and crustaceans and soil conductivity (Table 5, Figures 31, 34, and 35).

TABLE 5. REGRESSIONS ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON SOIL CHEMISTRY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Soil Chemistry Parameter (X), where α is the Y intercept and β is the slope. Regression analyses were conducted on ($\log_{10}$+1) transformed values of invertebrate numbers and $\log_{10}$ transformed values of soil chemistry parameters.

INVERTEBRATE NUMBERS (by taxa)	**α**	**β**	**N**	**R^2**	**F**	**P**
Independent Variable (X):						
SOIL pH vs:						
Ephemeropterans (Mayflies)	6.02	-5.71	22	0.013	0.26	0.613
Odonates (Damselflies)	3.59	-2.81	22	0.007	0.15	0.710
Hemipterans (Water boatman, backswimmers)	9.09	-8.88	22	0.082	1.78	0.197
Chironomids (Midges)	-15.07	18.50	22	0.157	3.73	0.068
Gastropods (Snails)	1.95	-0.93	22	0.001	0.03	0.875 † (31)
Crustaceans (Scuds)	9.24	-9.53	22	0.033	0.68	0.420
Platyhelminthes (Flatworms)	16.59	-18.40	22	0.220	5.66	0.027 ** (32)
Annelids (Leeches)	6.48	-7.09	22	0.072	1.55	0.227
Other	1.19	-0.86	22	0.001	0.03	0.874
Independent Variable (X):						
SOIL CONDUCTIVITY vs:						
Ephemeropterans (Mayflies)	-0.47	1.80	22	0.252	6.73	0.017 ** (33)
Odonates (Damselflies)	1.84	-0.90	22	0.144	3.36	0.082
Hemipterans (Water boatman, backswimmers)	1.19	0.11	22	0.002	0.05	0.833
Chironomids (Midges)	1.06	0.21	22	0.004	0.08	0.786
Gastropods (Snails)	0.54	0.73	22	0.148	3.49	0.077 † (34)
Crustaceans (Scuds)	0.40	0.56	22	0.022	0.45	0.510 † (35)
Platyhelminthes (Flatworms)	1.25	-1.07	22	0.145	3.39	0.081
Annelids (Leeches)	0.44	-0.25	22	0.018	0.36	0.557
Other	0.10	0.42	22	0.067	1.28	0.271

TABLE 5. REGRESSIONS ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON SOIL CHEMISTRY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Soil Chemistry Parameter (X), where α is the Y intercept and β is the slope. Regression analyses were conducted on (log_{10}+1) transformed values of invertebrate numbers and log_{10} transformed values of soil chemistry parameters.

INVERTEBRATE NUMBERS (by taxa)	**α**	**β**	**N**	**R^2**	**F**	**P**
Independent Variable (X):						
SOIL ORGANIC MATTER vs:						
Ephemeropterans (Mayflies)	1.79	-1.14	22	0.067	1.43	0.245
Odonates (Damselflies)	1.26	-0.21	22	0.005	0.10	0.753
Hemipterans (Water boatman, backswimmers)	1.72	-0.64	22	0.055	1.16	0.294
Chironomids (Midges)	0.77	0.65	22	0.025	0.51	0.482
Gastropods (Snails)	0.79	0.48	22	0.042	0.89	0.358
Crustaceans (Scuds)	1.22	-0.52	22	0.013	0.26	0.616
Platyhelminthes (Flatworms)	-0.26	0.93	22	0.072	1.55	0.227
Annelids (Leeches)	-0.79	1.45	22	0.392	12.87	0.002 ** (36)
Other	0.40	0.06	22	0.001	0.02	0.903

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. † indicates that a significant non-linear relationship also exists between the variables. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships.

Invertebrates and Water Quality

Responses of invertebrates to various water quality parameters are varied. Variations in pH, to various degrees, explain variations in invertebrate numbers (Table 5), including ephemeropterans (Figures 37–38), hemipterans (Figures 39–40), chironomids, gastropods, crustaceans (Figures 41–43, respectively), and annelids (Figures 44–45). In many cases, non-linear responses provide better fits to the invertebrate data.

TABLE 6. REGRESSION ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WATER QUALITY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Water Quality parameter (X), where α is the Y intercept and β is the slope of the relationship. Regression analyses were conducted on (log_{10} + 1) transformed values of invertebrate numbers and log_{10} transformed values of water quality parameters.

INVERTEBRATE NUMBERS (by taxa)	**α**	**β**	**N**	**R^2**	**F**	**P**
Independent Variable (X):						
pH vs:						
Ephemeropterans (Mayflies)	-13.00	15.21	22	0.272	7.48	0.013 ** † (37 & 38)
Odonates (Damselflies)	-5.37	7.05	22	0.135	3.12	0.093
Hemipterans (Water boatman, backswimmers)	-8.93	11.1	22	0.377	12.10	0.002 ** † (39 & 40)
Chironomids (Midges)	13.35	-13.19	22	0.236	6.17	0.022 ** (41)
Gastropods (Snails)	-7.72	9.62	22	0.394	13.01	0.002 ** (42)

TABLE 6. REGRESSION ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WATER QUALITY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Water Quality parameter (X), where α is the Y intercept and β is the slope of the relationship. Regression analyses were conducted on ($\log_{10}$ + 1) transformed values of invertebrate numbers and $\log_{10}$ transformed values of water quality parameters.

INVERTEBRATE NUMBERS (by taxa)	α	β	N	R^2	F	P
Crustaceans (Scuds)	-20.37	23.08	22	0.568	26.32	< 0.001 ** (43)
Platyhelminthes (Flatworms)	7.03	-7.22	22	0.100	2.23	0.151
Annelids (Leeches)	6.37	-6.67	22	0.188	4.63	0.044 ** † (44 & 45)
Other	4.72	-4.66	22	0.112	2.52	0.128
Independent variable (X):						
TOTAL DISSOLVED SOLIDS (TDS) vs:						
Ephemeropterans (Mayflies)	-7.51	2.73	22	0.667	40.07	< 0.001 ** † (46 & 47)
Odonates (Damselflies)	4.15	-0.97	22	0.196	4.88	0.039 ** (48)
Hemipterans (Water boatman, backswimmers)	-0.50	0.57	22	0.075	1.63	0.217
Chironomids (Midges)	0.56	0.213	22	0.005	0.094	0.762
Gastropods (Snails)	-0.96	0.67	22	0.145	3.39	0.081
Crustaceans (Scuds)	-2.42	1.05	22	0.090	1.97	0.175
Platyhelminthes (Flatworms)	6.04	-1.81	22	0.482	18.63	< 0.001 ** † (49 & 50)
Annelids (Leeches)	2.67	-0.78	22	0.197	4.91	0.038 ** † (51 & 52)
Other	0.35	0.03	22	< 0.001	0.01	0.936
Independent variable (X):						
DISSOLVED OXYGEN (DO) vs:						
Ephemeropterans (Mayflies)	-1.28	2.69	22	0.373	11.89	0.003 ** (53)
Odonates (Damselflies)	1.22	-0.12	22	0.002	0.036	0.852
Hemipterans (Water boatman, backswimmers)	-0.46	2.06	22	0.568	26.25	< 0.001 ** (54)
Chironomids (Midges)	2.98	-2.089	22	0.259	6.87	0.016 ** (55)
Gastropods (Snails)	0.45	0.80	22	0.118	2.69	0.117
Crustaceans (Scuds)	-1.34	2.60	22	0.315	9.19	0.007 ** (56)
Platyhelminthes (Flatworms)	1.63	-1.47	22	0.181	4.43	0.048 ** (57)
Annelids (Leeches)	1.37	-1.35	22	0.339	10.25	0.004 ** (58)
Other	1.34	-1.04	22	0.245	6.48	0.019 **

TABLE 6. REGRESSION ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WATER QUALITY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = α + β*Water Quality parameter (X), where α is the Y intercept and β is the slope of the relationship. Regression analyses were conducted on (log_{10} + 1) transformed values of invertebrate numbers and log_{10} transformed values of water quality parameters.

INVERTEBRATE NUMBERS (by taxa)	α	β	N	R^2	F	P
Independent variable (X):						
TOTAL PHOSPHORUS (P) vs:						
Ephemeropterans (Mayflies)	0.60	-0.83	22	0.575	27.02	< 0.001 ** (59)
Odonates (Damselflies)	1.24	0.26	22	0.132	3.03	0.097
Hemipterans (Water boatman, backswimmers)	1.54	-0.27	22	0.314	9.15	0.007 ** ! (60)
Chironomids (Midges)	0.88	0.34	22	0.221	5.69	0.027 ** ! (61)
Gastropods (Snails)	1.08	-0.09	22	0.027	0.55	0.466
Crustaceans (Scuds)	0.82	-0.07	22	0.004	0.08	0.786 † (62)
Platyhelminthes (Flatworms)	0.47	0.17	22	0.041	0.84	0.369
Annelids (Leeches)	0.35	0.25	22	0.194	4.80	0.040 ** † (63 & 64)
Other	0.46	0.05	22	0.010	0.20	0.662
Independent variable (X):						
TOTAL NITROGEN (N) vs:						
Ephemeropterans (Mayflies)	0.63	-0.81	22	0.627	33.64	< 0.001 ** (65)
Odonates (Damselflies)	1.19	0.16	22	0.059	1.26	0.276
Hemipterans (Water boatman, backswimmers)	1.20	-0.17	22	0.073	1.59	0.223
Chironomids (Midges)	1.24	0.05	22	0.002	0.05	0.826
Gastropods (Snails)	0.98	-0.32	22	0.363	11.37	0.003 ** (66)
Crustaceans (Scuds)	1.18	-0.21	22	0.272	7.47	0.013 ** ! (67)
Platyhelminthes (Flatworms)	0.54	0.33	22	0.172	4.16	0.055
Annelids (Leeches)	0.29	0.14	22	0.064	1.37	0.256
Other	0.44	-0.004	22	< 0.001	0.001	0.970
Independent variable (X):						
MAX. WATER TEMPERATURE vs:						
Ephemeropterans (Mayflies)	-15.56	11.65	16	0.569	18.45	0.001 ** † (68 & 69)
Odonates (Damselflies)	1.15	0.13	16	<0.001	0.004	0.948
Hemipterans (Water boatman, backswimmers)	-7.68	6.39	16	0.485	13.18	0.003 ** † (70 & 71)

TABLE 6. REGRESSION ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WATER QUALITY PARAMETERS
Regressions are of the form: Invertebrate Numbers (Y) = α + β*Water Quality parameter (X), where α is the Y intercept and β is the slope of the relationship. Regression analyses were conducted on (log_{10} + 1) transformed values of invertebrate numbers and log_{10} transformed values of water quality parameters.

INVERTEBRATE NUMBERS (by taxa)	α	β	N	R^2	F	P
Chironomids (Midges)	7.92	-4.87	16	0.110	1.73	0.210
Gastropods (Snails)	-2.90	2.92	16	0.132	2.13	0.167
Crustaceans (Scuds)	-9.80	7.71	16	0.228	4.14	0.061
Platyhelminthes (Flatworms)	11.44	-7.67	16	0.304	6.13	0.027 ** (72)
Annelids (Leeches)	7.71	-5.19	16	0.298	5.94	0.029 ** (73)
Other	4.24	-2.67	16	0.107	1.69	0.215

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. † indicates that a significant non-linear relationship also exists between the variables. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships. ! indicates that regression was conducted on non-transformed water quality parameter.

Numbers of ephemeropterans, odonates, crustaceans, and annelids are also related to TDS (Table 6, Figures 46–52). Total dissolved oxygen explains variations in each of the invertebrate taxa included in the analysis, except odonates, gastropods, and the "other" category (Table 6, Figures 53–58). Invertebrates show responses to both total N and total P concentrations. Numbers of ephemeropterans, hemipterans, chironomids, crustaceans and annelids are significantly related to total P (Table 6, Figures 59–64), whereas total N concentrations help explain various degrees of variation in ephemeropterans, gastropods and crustaceans (Table 6, Figures 65–67). Maximum water temperature helps explain variations in numbers of ephemeropterans, hemipterans, flatworms, and annelids (Table 6, Figures 68–73).

Invertebrates and Plants

Statistically significant relationships are found between percent covers of various wetland plants and invertebrate taxa (Table 7). Significant relationships are found between percent cover of:

- *Typha latifolia* and ephemeropterans, flatworms, and annelids (Table 7, Figures 74–76)
- *Phragmites australis* and ephemeropterans, hemipterans, flatworms and annelids (Table 7, Figures 77–80)
- *Distichlis spicata* and odonates (Table 7, Figure 81)
- *Scirpus americanus* and gastropods, crustaceans (Table 7, Figures 82–83)
- *Stukenia* species and ephemeropterans, hemipterans, chironomids, gastropods, and crustaceans (Table 7, Figures 84–88)

TABLE 7. REGRESSIONS ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WETLAND PLANT PERCENT COVER
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Plant Percent Cover (X), where α is the Y intercept and β is the slope. Regression analyses were conducted on ($\log_{10}$+1) transformed values of invertebrate numbers and plant percent cover.
Stukenia species consists mainly of Stukenia filiformis and S. pectinatus.

INVERTEBRATE NUMBERS (by taxa)	α	β	N	R^2	F	P
Independent Variable (X): ***Typha latifolia* % COVER** vs:						
Ephemeropterans (Mayflies)	1.22	-0.79	22	0.279	7.73	0.012 ** (74)
Odonates (Damselflies)	1.03	0.31	22	0.100	2.23	0.151
Hemipterans (Water boatman, backswimmers)	1.35	-0.25	22	0.073	1.59	0.222
Chironomids (Midges)	1.28	-0.18	22	0.016	0.33	0.574
Gastropods (Snails)	1.19	-0.23	22	0.087	1.91	0.182
Crustaceans (Scuds)	1.02	-0.56	22	0.127	2.90	0.104
Platyhelminthes (Flatworms)	0.07	1.06	22	0.818	89.96	< 0.001 ** (75)
Annelids (Leeches)	0.06	0.59	22	0.561	25.60	< 0.001 ** (76)
Other	0.40	0.12	22	0.029	0.60	0.446
Independent Variable (X): ***Phragmites australis* % COVER** vs:						
Ephemeropterans (Mayflies)	1.23	-0.99	22	0.310	9.00	0.007 ** (77)
Odonates (Damselflies)	1.04	0.32	22	0.074	1.59	0.221
Hemipterans (Water boatman, backswimmers)	1.42	-0.61	22	0.310	9.00	0.007 ** (78)
Chironomids (Midges)	1.16	0.27	22	0.027	0.55	0.468
Gastropods (Snails)	1.15	-0.09	22	0.010	0.20	0.660
Crustaceans (Scuds)	0.98	-0.54	22	0.083	1.82	0.193
Platyhelminthes (Flatworms)	0.19	0.83	22	0.355	11.01	0.003 ** (79)
Annelids (Leeches)	0.04	0.80	22	0.721	51.70	< 0.001 ** (80)
Other	0.40	0.18	22	0.042	0.88	0.359
Independent Variable (X): ***Distichlis spicata* % COVER** vs:						
Ephemeropterans (Mayflies)	0.87	0.33	22	0.067	1.44	0.245
Odonates (Damselflies)	1.31	-0.52	22	0.401	13.41	0.002 ** (81)
Hemipterans (Water boatman, backswimmers)	1.36	-0.24	22	0.092	2.03	0.169
Chironomids (Midges)	1.20	0.05	22	0.002	0.04	0.851
Gastropods (Snails)	1.19	-0.17	22	0.065	1.38	0.254

TABLE 7. REGRESSIONS ESTIMATES OF INVERTEBRATE NUMBERS BY TAXA ON WETLAND PLANT PERCENT COVER
Regressions are of the form: Invertebrate Numbers (Y) = $\alpha + \beta$*Plant Percent Cover (X), where α is the Y intercept and β is the slope. Regression analyses were conducted on (log_{10}+1) transformed values of invertebrate numbers and plant percent cover.
Stukenia species consists mainly of Stukenia filiformis and S. pectinatus.

INVERTEBRATE NUMBERS (by taxa)	α	β	N	R^2	F	P
Crustaceans (Scuds)	1.05	-0.54	22	0.170	4.08	0.057
Platyhelminthes (Flatworms)	0.36	0.09	22	0.008	0.16	0.693
Annelids (Leeches)	0.26	-0.08	22	0.014	0.29	0.594
Other	0.40	0.10	22	0.027	0.56	0.463
Independent Variable (X): **_Scirpus americanus_ % COVER** vs:						
Ephemeropterans (Mayflies)	1.25	-0.48	22	0.125	2.85	0.107
Odonates (Damselflies)	1.28	-0.30	22	0.110	2.48	0.131
Hemipterans (Water boatman, backswimmers)	1.45	-0.32	22	0.147	3.45	0.078
Chironomids Midges)	0.99	0.43	22	0.114	2.58	0.124
Gastropods (Snails)	1.35	-0.41	22	0.330	9.87	0.005 ** (82)
Crustaceans (Scuds)	1.36	-0.91	22	0.412	14.02	0.001 ** (83)
Platyhelminthes (Flatworms)	0.29	0.18	22	0.028	0.57	0.459
Annelids (Leeches)	0.26	-0.05	22	0.005	0.11	0.746
Other	0.38	0.11	22	0.028	0.58	0.456
Independent Variable (X): **_Stukenia_ species % COVER** vs:						
Ephemeropterans (Mayflies)	0.61	0.50	22	0.228	5.90	0.025 ** (84)
Odonates (Damselflies)	0.91	0.28	22	0.168	4.03	0.058
Hemipterans (Water boatman, backswimmers)	0.98	0.39	22	0.352	10.88	0.004 ** (85)
Chironomids (Midges)	1.58	-0.47	22	0.234	6.12	0.022 ** (86)
Gastropods (Snails)	0.94	0.25	22	0.201	5.02	0.037 ** (87)
Crustaceans (Scuds)	0.34	0.68	22	0.383	12.42	0.002 ** (88)
Platyhelminthes (Flatworms)	0.47	-0.13	22	0.025	0.51	0.481
Annelids (Leeches)	0.40	-0.22	22	0.162	3.86	0.064
Other	0.50	-0.08	22	0.026	0.53	0.477

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. ** denotes a significant linear relationship between the log_{10}-transformed variables. Figure numbers (in parentheses) are referenced for significant relationships.

Tier 2: Results of Multiple Regression Models

Based on simple regression analyses, biological, physical, and chemical variables that are significantly correlated in the Tier 1 analyses are included into multiple regression models. These models offer useful insights into potential biological metrics that may eventually be useful in evaluating wetland function due to their strong responses to specific environmental variables.

Multiple regressions of percent covers of *Phragmites australis, Stukenia* species, and *Typha latifolia* on environmental variables (soil chemistry and water quality variables) are highly significant (Table 8). Conversely, multiple regression models of both *Scirpus* species are not statistically significant.

TABLE 8. MULTIPLE REGRESSIONS OF PLANT PERCENT COVER, PLANT HEIGHT, AND INVERTEBRATE NUMBERS ON ENVIRONMENTAL PARAMETERS MEASURED IN THE FARMINGTON BAY WETLANDS

Environmental parameters are independent variables in the multiple regressions and include water quality and soil chemistry parameters for regressions on plant percent cover and plant height. Multiple regressions on invertebrate numbers include water quality, soil chemistry and plant species percent covers as independent environmental parameters.

DEPENDENT VARIABLE	REGRESSION	N	ADJUSTED R^2	F	p
VEGETATION PERCENT COVER					
Phragmites australis	$\log_{10}$ (PHASpc +1) = -4.927 + 2.242($\log_{10}$ pH) – 0.558($\log_{10}$ TDS) – 1.599($\log_{10}$ DO) + 0.284(P) + 4.208($\log_{10}$ MaxT)	16	0.701	8.027	0.003 **
Stukenia species	$\log_{10}$ (STspc +1) = -13.731 + 19.939($\log_{10}$ pH) + 0.438($\log_{10}$ DO) - 0.144(P) – 2.828($\log_{10}$ MaxT)	16	0.659	8.259	0.002 **
Typha latifolia	$\log_{10}$ (TYLApc +1) = 13.767 – 1.265($\log_{10}$ TDS) – 2.246($\log_{10}$ MaxT) – 7.116($\log_{10}$ SpH)	16	0.464	5.336	0.014 **
Scirpus americanus	$\log_{10}$ (SCAMpc +1) = 7.592 – 0.114($\log_{10}$ pH) – 0.870($\log_{10}$ TDS) – 3.141($\log_{10}$ MaxT)	16	0.268	2.832	0.083
Scirpus maritimus	$\log_{10}$ (SCMApc +1) = 7.144 – 0.573*($\log_{10}$ TDS) – 3.557*($\log_{10}$ MaxT)	16	0.202	2.895	0.091
VEGETATION HEIGHT					
Typha latifolia	$\log_{10}$ (TYLAht) = 2.334 – 0.039($\log_{10}$ TDS) + 0.139($\log_{10}$ N) – 0.164($\log_{10}$ SEC)	8	0.701	6.464	0.050 **
INVERTEBRATE NUMBERS					
Ephemeropterans (Mayflies)	$\log_{10}$ (CALLI +1) = -5.753 – 0.843($\log_{10}$ pH) + 2.043($\log_{10}$ TDS) – 2.106($\log_{10}$ DO) - 0.280($\log_{10}$ P) – 0.158($\log_{10}$ N) + 2.670($\log_{10}$ MaxT) – 1.376($\log_{10}$ SEC) – 0.307($\log_{10}$TYLApc) -0.185($\log_{10}$ PHASpc) + 0.348($\log_{10}$ STspc)	16	0.913	16.812	0.003 **

TABLE 8. MULTIPLE REGRESSIONS OF PLANT PERCENT COVER, PLANT HEIGHT, AND INVERTEBRATE NUMBERS ON ENVIRONMENTAL PARAMETERS MEASURED IN THE FARMINGTON BAY WETLANDS

Environmental parameters are independent variables in the multiple regressions and include water quality and soil chemistry parameters for regressions on plant percent cover and plant height. Multiple regressions on invertebrate numbers include water quality, soil chemistry and plant species percent covers as independent environmental parameters.

DEPENDENT VARIABLE	REGRESSION	N	ADJUSTED R^2	F	p
Hemipterans (water boatman, backswimmers)	$\log_{10}$ (HEMIP +1) = 1.027 – 2.921($\log_{10}$ pH) + 0.608($\log_{10}$ DO) - 0.030(P) + 2.002($\log_{10}$ MaxT) – 0.657($\log_{10}$ PHASpc) - 0.074($\log_{10}$ STspc)	16	0.821	12.476	0.001 **
Platyhelminthes (flatworms)	$\log_{10}$ (PLATY +1) = 1.459 – 0.454($\log_{10}$ TDS) – 1.868($\log_{10}$ DO) + 2.069($\log_{10}$ MaxT) – 1.209($\log_{10}$ SpH) + 0.976($\log_{10}$TYLApc) – 0.593($\log_{10}$ PHASpc)	16	0.796	10.734	0.001 **
Annelids (leeches)	$\log_{10}$ (ANNE +1) = -2.767 – 0.744($\log_{10}$ pH) – 0.053($\log_{10}$ TDS) – 0.06($\log_{10}$ DO) + 0.182($\log_{10}$ P) + 2.550($\log_{10}$ MaxT) + 0.269($\log_{10}$ SOM) – 0.193($\log_{10}$TYLApc) + 0.592($\log_{10}$ PHASpc)	16	0.736	6.218	0.013 **
Gastropods (snails)	$\log_{10}$ (GASTR +1) = -5.751 – 7.654($\log_{10}$ pH) – 0.238($\log_{10}$ N) – 0.278($\log_{10}$SCAMpc) – 0.156($\log_{10}$ STspc)	22	0.602	8.949	< 0.001 **
Crustaceans (scuds)	$\log_{10}$ (HYALL +1) = -15.489 + 18.781($\log_{10}$ pH) – 0.569($\log_{10}$ DO) – 0.085(N) - 0.481($\log_{10}$SCAMpc) - 0.072($\log_{10}$ STspc)	22	0.582	6.848	0.001 **
Odonates (Damselflies)	$\log_{10}$ (ODON +1) = 3.993 – 0.864($\log_{10}$ TDS) – 0.497($\log_{10}$ DISPpc)	22	0.508	11.838	< 0.001 **
Chironomids (midges)	$\log_{10}$ (CHIRO +1) = 1.943 – 0.254($\log_{10}$ pH) – 0.538($\log_{10}$ DO) + 0.164(P) - 0.264($\log_{10}$ STspc)	22	0.145	1.889	0.159

** Indicates a significant relationship between the variables in the regression and the $p \leq 0.05$ level.

Abbreviations:

Water Quality Parameters: TDS = Total dissolved solids; DO = Dissolved oxygen; P = Total phosphorus; N = Total nitrogen; MaxT = Maximum water temperature

Soil Chemistry Parameters: SpH = Soil pH; SEC = Soil Electrical Conductivity; SOM = Soil organic matter

Plant Species Parameters: PHASpc = *Phragmites australis* % cover; TYLApc = *Typha latifolia* % cover; SCAMpc = *Scirpus americanus* % cover; SCMApc = *Scirpus maritimus* % cover; STspc = *Stukenia species* percent cover; DISPpc = *Distichlis spicata* % cover; TYLAht = *Typha latifolia* height

Invertebrate Parameters: CALLI = Ephemeropterans (Mayflies); ODON = Odonates (Damselflies); HEMIP = Hemipterans (Water boatman, backswimmers); CHIRO = Chironomids (Midges); GASTR = Gastropods (snails); HYALL = Crustaceans (scuds); PLATY = Platyhelminthes (flatworms); ANNE = Annelids (leeches)

Plant percent cover in relation to environmental variables:

- pH, total dissolved solids, dissolved oxygen, total P, and maximum water temperature helps explain 70.1 percent of the variation observed in percent cover of *Phragmites australis* (Table 8)
- pH, dissolved oxygen, total P, and maximum water temperature helps explain 65.9 percent of the variation observed in percent cover of *Stukenia* species (Table 8)
- total dissolved solids and maximum water temperature explains 46.4 percent of the variation observed in percent cover of *Typha latifolia* (Table 8)

Plant height in relation to environmental variables:

- total dissolved solids, total N, and soil electrical conductivity helps explain 70.1 percent of the variation observed in percent cover of Typha latifolia (Table 8)

All invertebrate taxa included in the multiple regression analyses, except chironomids, show statistically significant relationships with environmental variables (Table 8).

- 91.3 percent of the variation observed in numbers of Ephemeroptera (Mayflies) is explained by pH, total dissolved solids, dissolved oxygen, total P, total N, maximum water temperature, soil electrical conductivity and percent covers of Typha latifolia, Phragmites australis and Stukenia species (Table 8)
- 82.1 percent of the variation observed in numbers of Hemiptera (water boatman, backswimmers) is explained by pH, dissolved oxygen, total P, maximum water temperature, and percent covers of Phragmites australis and Stukenia species (Table 8)
- 79.6 percent of the variation observed in numbers of Platyhelminthes (flatworms) is explained by total dissolved solids, dissolved oxygen, maximum water temperature, soil pH and percent covers of Typha latifolia and Phragmites australis (Table 8)
- 73.6 percent of the variation observed in numbers of Annelida (leeches) is explained by pH, total dissolved solids, dissolved oxygen, total P, maximum water temperature, soil organic matter and percent covers of Typha latifolia and Phragmites australis (Table 8)
- 60.2 percent of the variation observed in numbers of Gastropoda (snails) is explained by pH, total N, and percent covers of Scirpus americanus and Stukenia species (Table 8)
- 58.2 percent of the variation observed in numbers of Crustacea (scuds) is explained by pH, dissolved oxygen, total N, and percent covers of Scirpus americanus and Stukenia species (Table 8)
- 50.8 percent of the variation in numbers of Odonata (Damselflies) is explained by just two variables, total dissolved solids and percent cover of Distichlis spicata (Table 8)

Tier 3: Results of Multivariate Factor Analyses

Factor analysis provides useful insights into patterns observed between the biological communities and environmental variables across the wetland sites in Farmington Bay. Factor analysis is also used to explore patterns in biological and environmental components separately in sites with sheetflow hydrology and impounded sites.

Vegetation and Water Quality Across All Sites

The vegetation factor included percent covers of *Phragmites australis, Typha latifolia, Scirpus americanus, Scirpus maritimus, Distichlis spicata,* and *Stukenia* species. The water quality factor included pH, dissolved oxygen, total dissolved solids, total N and total P concentrations. A plot of wetland sampling sites based on the vegetation and water quality factor scores for each site is shown in Figure 89. Low values on the water quality factor axis reflect freshwater habitats (low TDS, low pH, low dissolved oxygen) with high nutrient (N+P) loads. High values represent more saline habitats relatively low in nutrients. Sites in-between represent a more moderate water chemistry. On the vegetation factor axis, low values represent a plant community dominated by *Stukenia* species, whereas high values represent communities dominated by *Phragmites australis, Typha latifolia,* and both *Scirpus* species. Sites in-between tend to have *Distichlis spicata*. Overall, the plot indicates a trend from more freshwater, eutrophic sites dominated by *Phragmites australis, Typha latifolia,* and both *Scirpus* species to more oligotrophic and saline sites dominated by *Stukenia* species. Sites with moderate water chemistry had *Distichlis spicata*.

Invertebrates and Water Quality Across All Sites

The invertebrate factor included information on numbers per sample of all invertebrate taxa, except the “other” category of invertebrates. Low values on the invertebrate factor axis (Figure 90) represent sites dominated chironomids, flatworms and leeches, whereas high values reflect sites dominated by mayflies (Ephemeroptera), damselflies (Odonates), water boatman and backswimmers (Hemiptera), Hyallela (Crustacea), and snails (Gastropoda). Overall, the graph (Figure 90) indicates the general trend of more eutrophic, freshwater sites dominated by chironomids, flatworms and leeches to more saline, oligotrophic site dominated by mayflies, damselflies, water boatman, backswimmers, Hyallela, and snails.

Invertebrates and Plants Across All Sites

Figure 91 indicates the relationship between the invertebrate and vegetation factors. A general trend reflects invertebrate communities dominated by mayflies, damselflies, water boatman, backswimmers, Hyallela, and snails at sites where *Stukenia* is the dominant plant species. Conversely, sites dominated by *Phragmites australis, Typha latifolia,* and both *Scirpus* species contain an invertebrate community consisting mainly of chironomids, flatworms and leeches.

Invertebrates, Plants, and Water Quality Across All Sites

A three-way representation of the relationship between the invertebrate, plant and water quality factors is shown in Figure 92. This graph reveals an overall trend of more freshwater, eutrophic sites dominated by *Phragmites australis, Typha latifolia,* and both *Scirpus* species and an invertebrate assemblage composed mainly of chironomids, flatworms and leeches. Conversely, relatively saline, oligotrophic sites consist of a plant assemblage represented by *Stukenia* species with an invertebrate community composed of mayflies, damselflies, water boatman, backswimmers, Hyallela, and snails.

Vegetation and Water Quality: Comparing Sheet-Flow and Impounded Sites

A plot of wetland sites with sheetflow hydrology based on the vegetation and water quality factor scores for each site is shown in Figure 93. Low values on the water quality factor axis reflect freshwater habitats (low TDS, low pH, low dissolved oxygen) with high nutrient (N+P) loads. High values represent more saline habitats relatively low in nutrients. On the vegetation factor axis, low values represent a plant community dominated by *Distichlis spicata* and *Scirpus americanus*, whereas high values represent communities dominated by *Phragmites australis, Typha latifolia,* and *Scirpus maritimus*. Overall, the plot indicates a trend from more freshwater, eutrophic sites dominated by *Phragmites australis, Typha latifolia,* and *Scirpus maritimus* to more oligotrophic and saline sites dominated by *Distichlis spicata* and *Scirpus americanus*.

In impounded sites, the vegetation is dominated with *Stukenia* species, and other species observed in sheetflow sites are notably absent. Because of the dominance of a single plant species, factor analysis, which is designed for analysis of multivariate datasets, could not be conducted.

Invertebrates and Water Quality: Comparing Sheet-Flow and Impounded Sites

For sheetflow sites, low values on the invertebrate factor axis (Figure 94) represent sites dominated flatworms (Platyhelminthes), leeches (Annelida) and damselflies (Odonata), whereas high values reflect sites dominated by mayflies (Ephemeroptera), water boatman and backswimmers (Hemiptera), snails (Gastropoda) and chironomids. *Hyallela* (Crustacea) are represented by values inbetween. Overall, the graph (Figure 94) reveals a general trend where more eutrophic, freshwater sheetflow sites are dominated by flatworms, leeches, and damselflies, in contrast to more saline, oligotrophic sites which tend to be dominated by mayflies, water boatman, backswimmers, snails, and chironomids.

Impounded sites reveal a general trend with more saline, oligotrophic sites being dominated by mayflies, water boatman, backswimmers and chironomids, and more freshwater eutrophic sites represented by damselflies, snails, and *Hyallela* (Figure 95).

Invertebrates and Plants: Comparing Sheet-Flow and Impounded Sites

Figure 96 shows the relationship between the invertebrate and vegetation factors at sheetflow sites. The invertebrate community is dominated by mayflies, water boatman, backswimmers, snails, and chironomids at sites where *Distichlis spicata* and *Scirpus americanus* are the dominant plant species. Conversely, sites dominated by *Phragmites australis* and *Typha latifolia* contain an invertebrate community consisting mainly of flatworms, leeches, and damselflies.

The only dominant plant species in impounded sites is *Stukenia*; therefore multivariate analysis on the plant component could not be conducted and the relationship between invertebrates and plants for impounded sites is not explored.

Invertebrates, Plants and Water Quality: Comparing Sheet-Flow and Impounded Sites

The relationships between invertebrates, plants and water quality is shown for sheetflow sites in Figure 97. This graph shows an overall trend of more freshwater, eutrophic sites being dominated by *Phragmites australis* and *Typha latifolia,* and an invertebrate assemblage composed mainly of flatworms, leeches and damselflies. Conversely, relatively saline, oligotrophic sites consist of a plant assemblage represented by *Distichlis spicata* and *Scirpus americanus* and an invertebrate community composed of mayflies, water boatman, backswimmers, snails, and chironomids. Sites with moderate water quality are represented occasionally by *Hyallela* (Crustacea).

The only dominant plant species in impounded sites is *Stukenia*; therefore a three-way multivariate relationship between water quality, plants, and invertebrates could not be explored.

Conclusions

The data presented in this technical memorandum represents the first year of an ongoing effort to characterize the wetland systems of Farmington Bay. The purpose of this analysis is to provide a preliminary evaluation of some biological and environmental components of the Farmington Bay wetlands that, as part of an ongoing effort, serves as a first step towards characterizing the wetlands and defining its beneficial uses. This analysis also offers some insights into potential biological and environmental metrics that may be useful in evaluating wetland function. As such, results from this analysis could be used not only as part of a larger data set being collected in ongoing studies, but also to guide future sampling efforts and analysis on subsequent data sets (i.e., choice of data analysis methods, choice of biological and environmental metrics that show strong functional responses, focus sampling efforts on collecting data on metrics that work).

Some key conclusions based on the analysis conducted in this study are presented:

- Although the soil parameters (soil pH, soil conductivity, and soil organic matter) correlated with biological metrics on only a few occasions, it is suggested that sampling of these parameters continue in subsequent efforts. Certain metrics such as plant height and a few invertebrate taxa showed significant linear and non-linear responses to these soil parameters. Subsequent sampling should also focus on adding soil nutrients and soil texture to the suite of measurements.
- Continue with the sampling of all water quality parameters included in this analysis. The biological metrics (plants and invertebrates) measured in this study exhibit strong responses to the water quality parameters.
- The choice of sites that include sites with impounded and sheetflow hydrology over a large geographical area around Farmington Bay appears to be well-suited for this study. These sites reflect a wide range of environmental conditions based on soil and water chemistry parameters and exhibit a range of responses in the biological metrics that were measured.
- Plant percent cover and plant height were both useful metrics of wetland function as both showed significant responses to soil chemistry and water quality in certain plant species.
- Six species of plants were included in this analysis. Multiple regression models indicate that of these, three species, *Phragmites australis, Stukenia* species and *Typha latifolia* appear to show significant responses in percent cover to a range of soil chemistry and water quality parameters. Approximately 70 percent and 66 percent of the variation in percent cover of *Phragmites australis* and *Stukenia* species, respectively, could be explained by a

few water quality parameters. To a lesser extent, approximately 46 percent of the variation in percent cover of *Typha latifolia* was explained by select soil chemistry and water quality parameters. *Typha latifolia* also shows responses in height and approximately 70 percent of the variation in height of this species was explained by a few soil and water parameters. Based on this analysis, *Phragmites australis, Stukenia* species, and *Typha latifolia* are potential candidate species for establishing key biological metrics to assess wetlands function in Farmington Bay. These species also represent both types of hydrology at the sites, with *Phragmites australis* and *Typha latifolia* dominant at sheetflow sites and *Stukenia* species at impounded sites. Future sampling efforts should however focus on sampling all plant species within each transect, as temporal shifts in species responses are likely.

- Invertebrate taxa in this analysis served as sensitive indicators of environmental condition and displayed a range of responses to soil chemistry and particularly to water quality. Numbers of individuals per sample appeared to be an appropriate metric for invertebrates in this analysis.

- Eight invertebrate taxa and a category, "other," that included those taxa rarely found in the samples were included in this analysis. Multiple regression models indicate that of these, four taxa, Ephemeroptera (Mayflies), Hemiptera (water boatman, backswimmers), Platyhelminthes (flatworms) and Annelids (leeches) appeared to show the strongest responses to a range of soil chemistry, water quality, and plant parameters. From 74 percent to 91 percent of the variation in invertebrate numbers belonging to these four taxa was explained by soil, water and plant parameters. To a lesser extent, approximately 51 percent to 60 percent of the variation in numbers of Gastropoda (snails), Crustacea (scuds, mainly *Hyallela*) and Odonata (damselflies) was explained by soil, water and plant parameters. These invertebrate taxa could supplement the plant taxa noted as valuable biological metrics in assessing wetland function. It is recommended that future sampling efforts particularly focus on collecting invertebrates as part of the sampling at all sites.

- While univariate and multiple regression analyses offer useful insights into the potential relationships between biological and environmental variables, multivariate analysis helps to provide an overall assessment of the general trends and patterns of biological and environmental variable across sites. Multivariate analysis across all sites (sheetflow and impounded) shows that in general, freshwater sites that are more eutrophic tend to be dominated by a plant assemblage consisting of *Phragmites australis, Typha latifolia,* and both *Scirpus* species, and an invertebrate community composed of chironomids flatworms and leeches. Relatively saline, oligotrophic sites are dominated by *Stukenia* species and invertebrates such as mayflies, damselflies, water boatman, backswimmers, *Hyallela*, and snails.

- Multivariate analysis in sheetflow sites shows that more freshwater, eutrophic sites are dominated by *Phragmites australis* and *Typha latifolia,* and an invertebrate assemblage composed mainly of flatworms, leeches and damselflies. Conversely, relatively saline, oligotrophic sheetflow sites consist of a plant assemblage represented by *Distichlis spicata* and *Scirpus americanus* and an invertebrate community composed of mayflies, water boatman, backswimmers, snails, and chironomids. Sites with moderate water quality are represented occasionally by *Hyallela* (Crustacea). Data from the first year data (2004) should be compared to data from subsequent analyses (2005 and 2006) to detect any potential temporal and spatial changes in these patterns.

References

Gray, L. J. 2005. Composition of macroinvertebrate communities of the Great Salt Lake wetlands and relationships to water chemistry. Report prepared for the Utah Department of Environmental Quality, Water Quality Management Section. March 2005.

Systat. Version 11. 2004. Statistical Analysis Software. WWW.SYSTAT.COM

Figures

Figure 1. T. latifolia % Cover and Soil pH

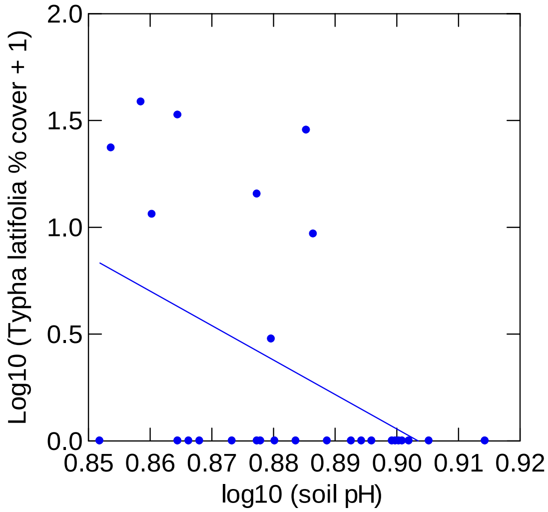

Figure 2. D. spicata height and Soil pH

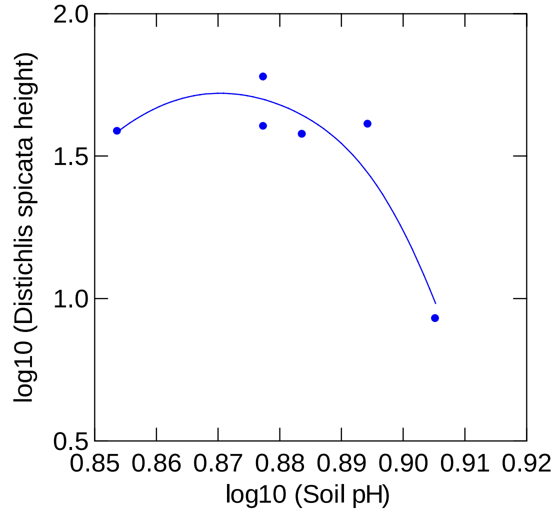

Figure 3. S. americanus height and Soil pH

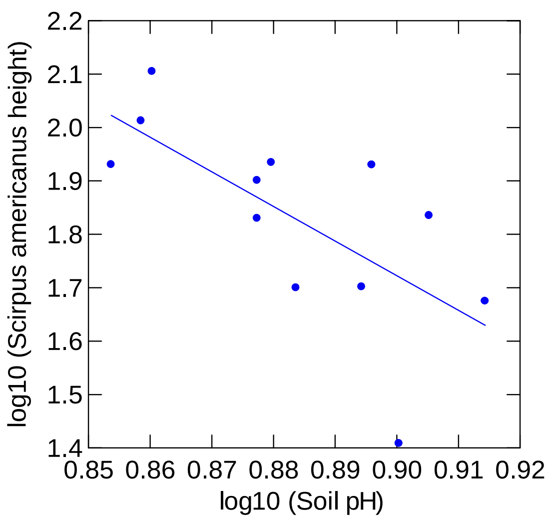

Figure 4. D. spicata height and Soil Conductivity - DWLS

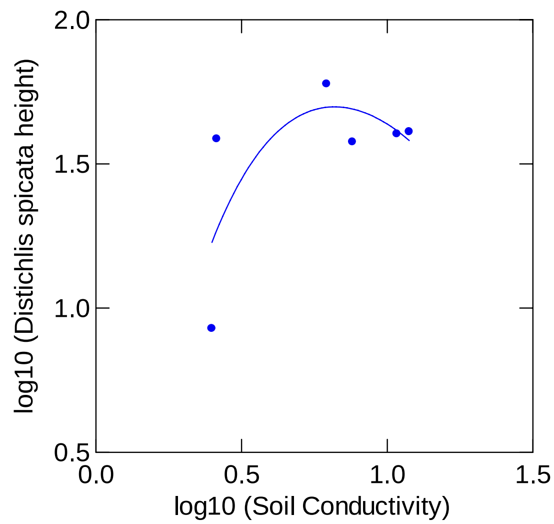

Figure 5. P. australis height and Soil Conductivity – DWLS

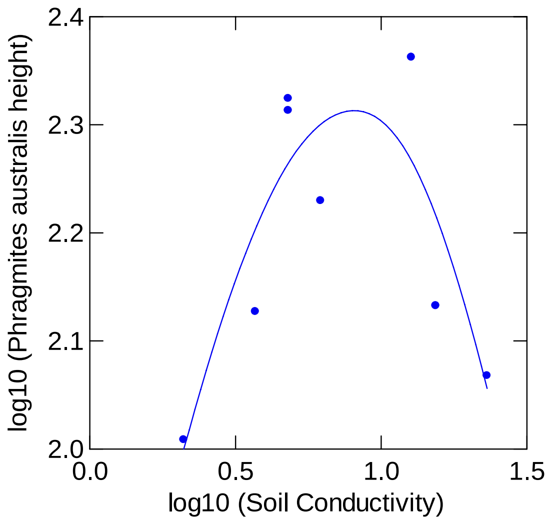

Figure 6. T. latifolia height and Soil Conductivity

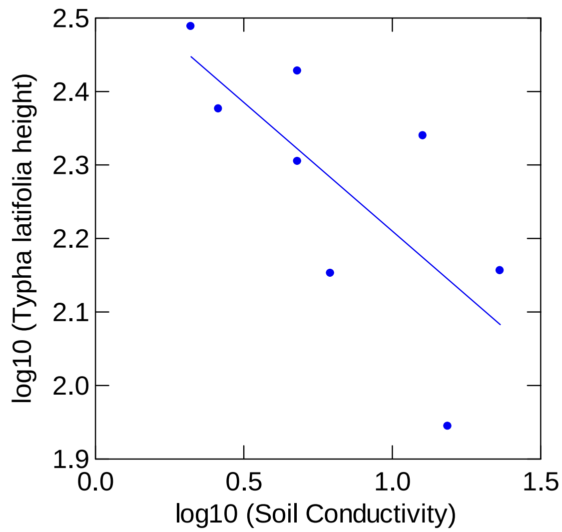

Figure 7. D. spicata Height and Soil Organic Matter

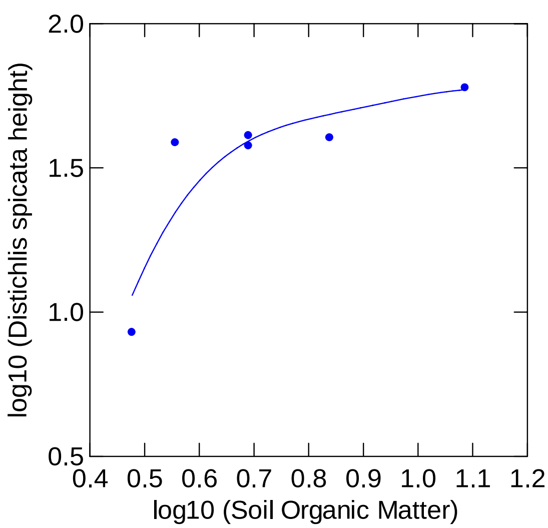

Figure 8. P. australis % Cover and pH

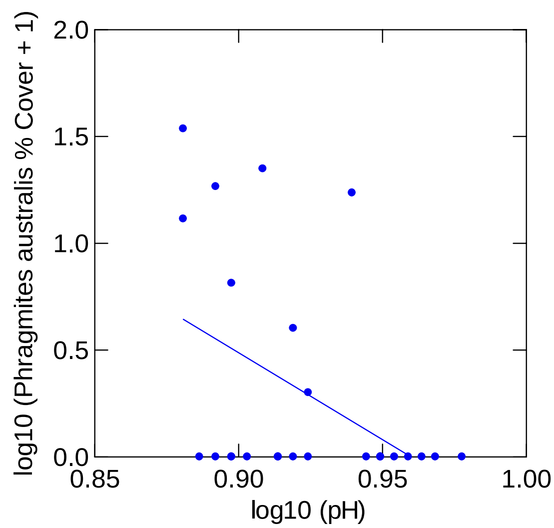

Figure 9. S. americanus % Cover and pH

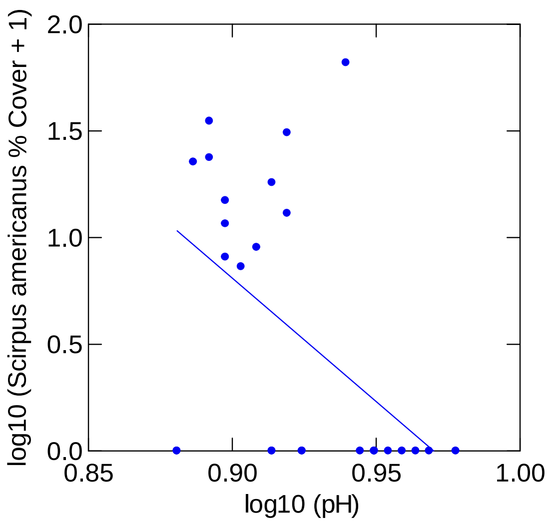

Figure 10. Stukenia spp. % Cover and pH

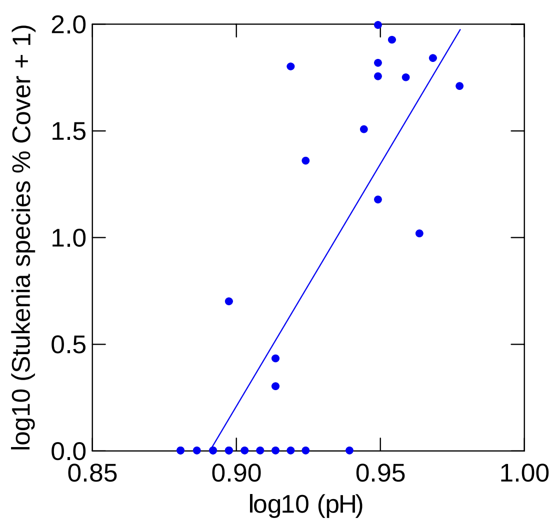

Figure 11. P. australis % Cover and TDS

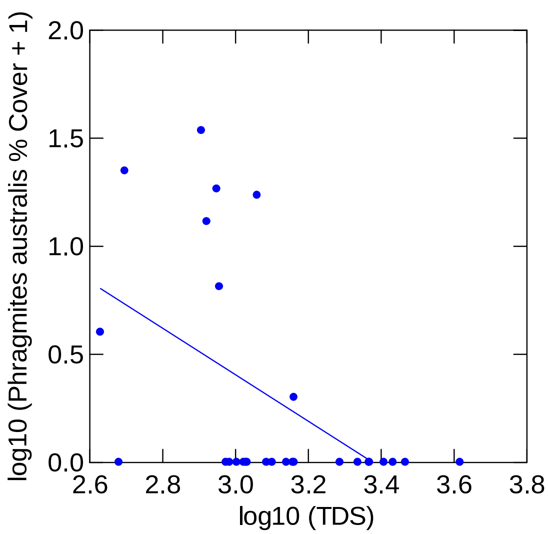

Figure 12. S. americanus % Cover and TDS

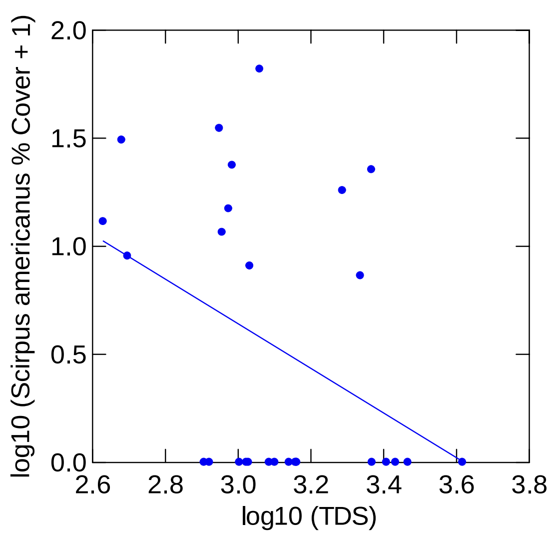

Figure 13. S. maritimus % Cover and TDS

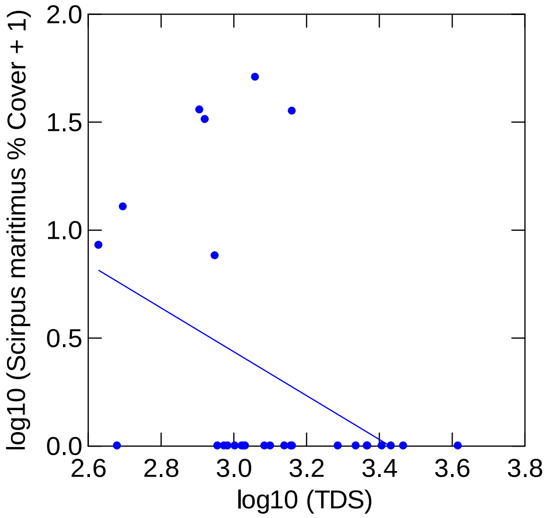

Figure 14. T. latifolia % Cover and TDS

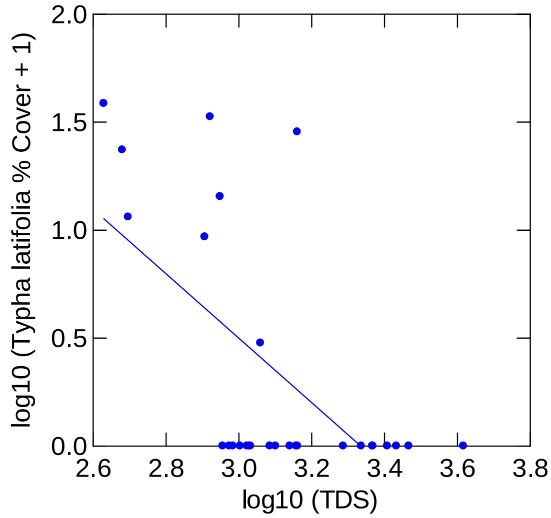

Figure 15. T. latifolia % Cover and TDS

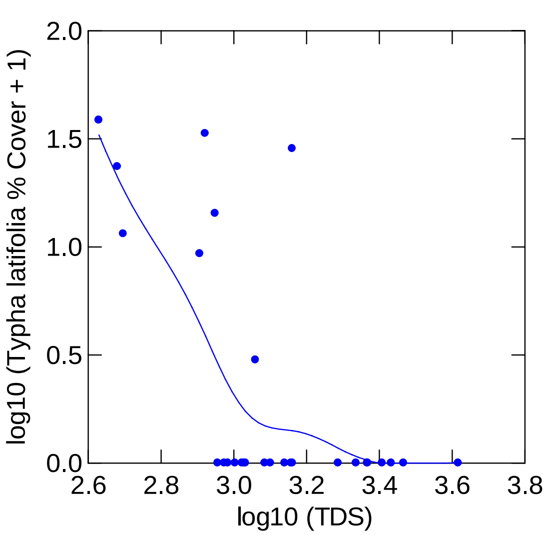

Figure 16. P. australis % Cover and D.O.

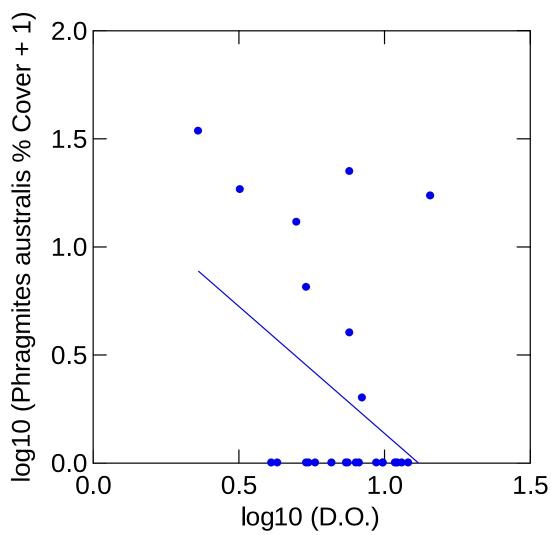

Figure 17. Stukenia spp. % Cover and D.O.

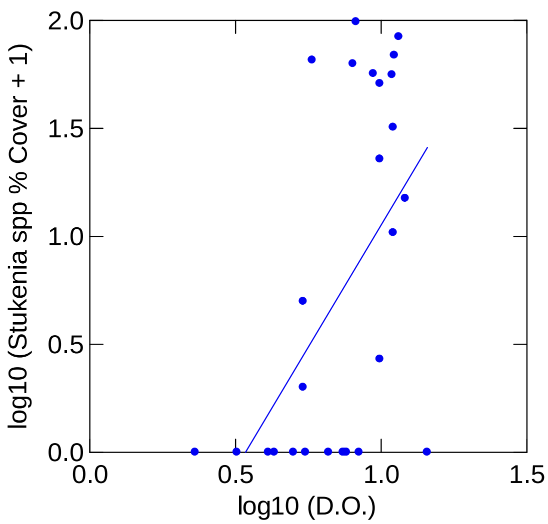

Figure 18. D. spicata % Cover and Total P

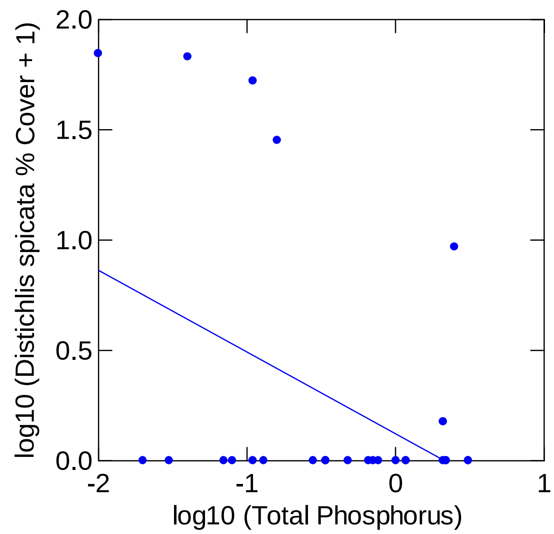

Figure 19. P. australis % Cover and Total P

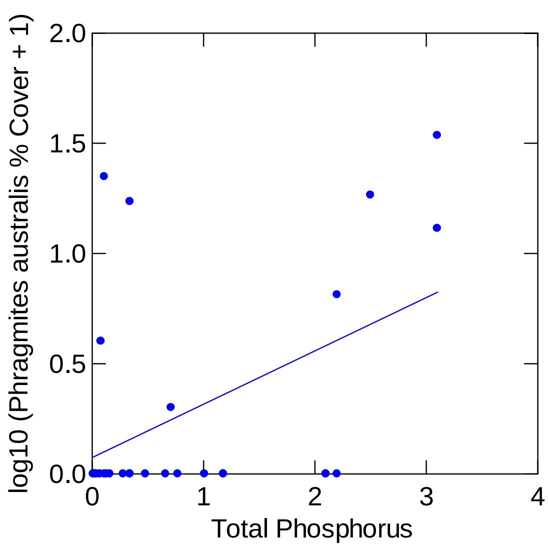

Figure 20. Stukenia spp. % Cover and Total P

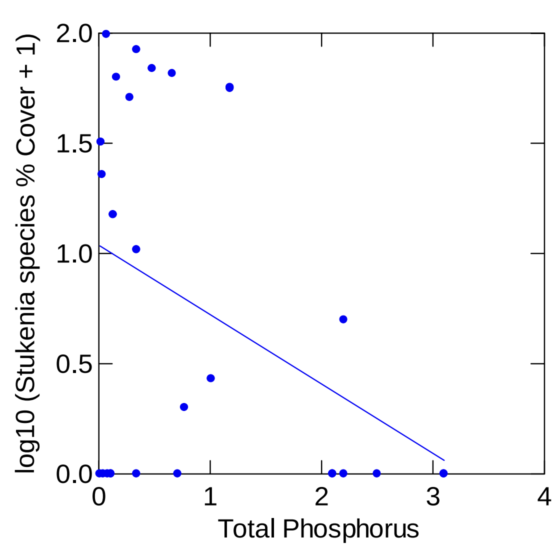

Figure 21. P. australis % Cover and Max. Water Temp.

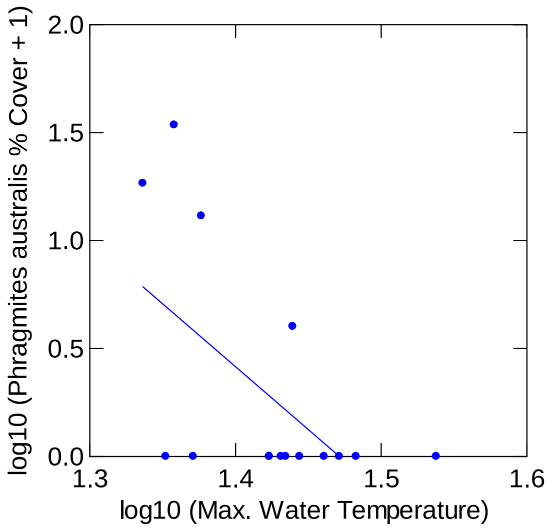

Figure 22. S. americanus % Cover and Max. Water Temp.

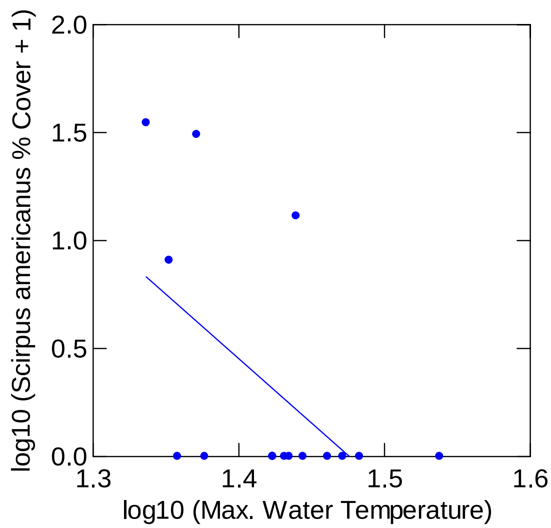

Figure 23. S. maritimus % Cover and Max. Water Temp.

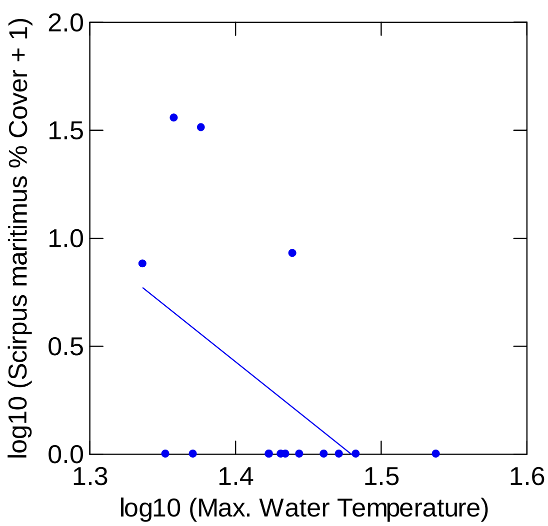

Figure 24. Stukenia spp. % Cover and Max. Water Temp.

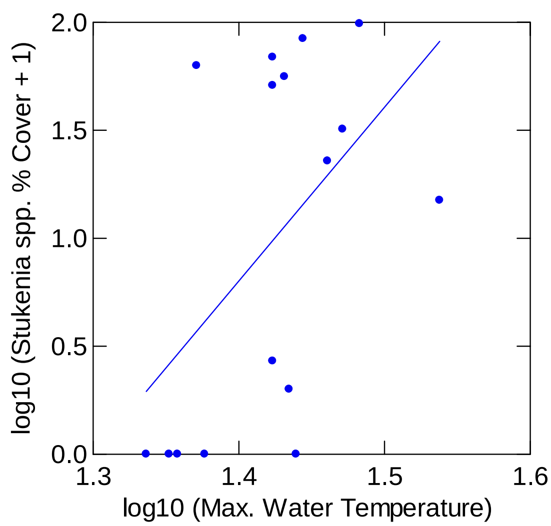

Figure 25. T. latifolia % Cover andMax. Water Temp.

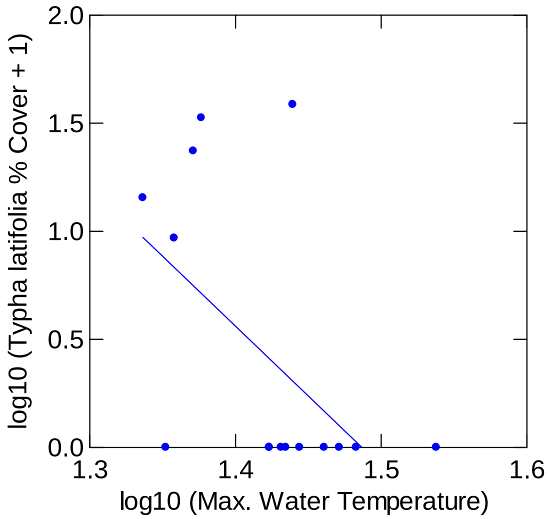

Figure 26. P. australis Height and pH

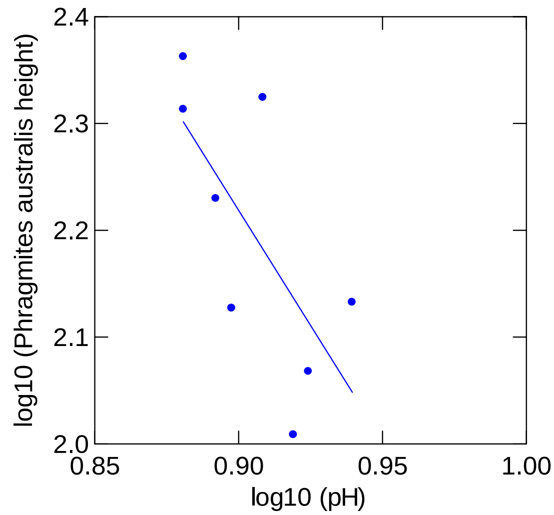

Figure 27. Stukenia spp. Height and pH

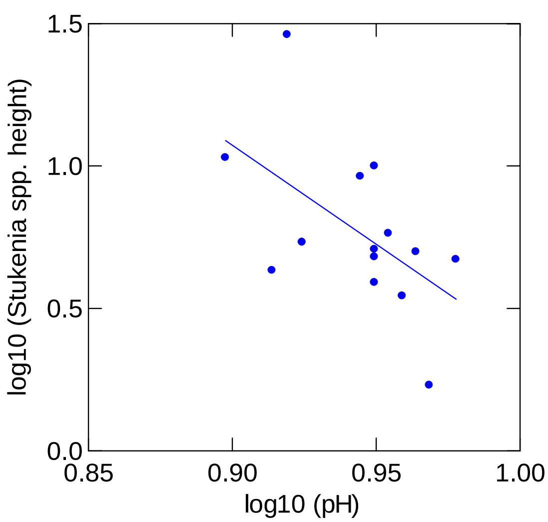

Figure 28. T. latifolia Height and TDS

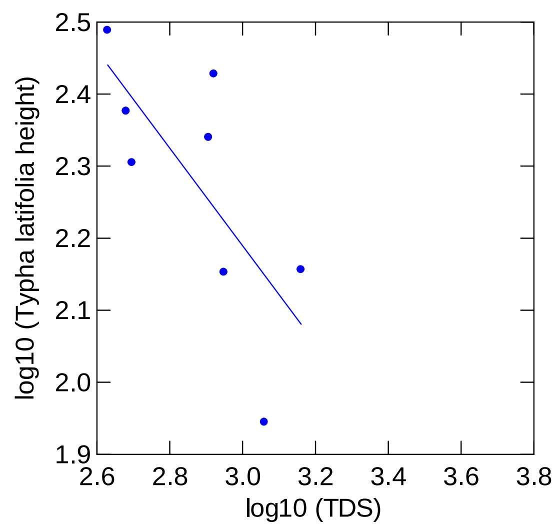

Figure 29. T. latifolia Height and Total N

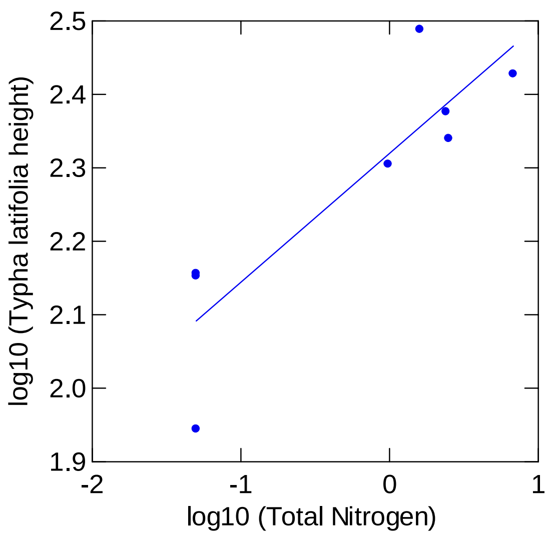

Figure 30. T. latifolia Height and Max. Water Temp.

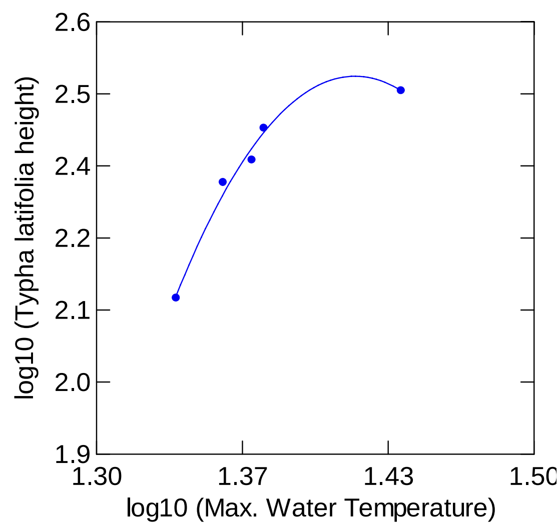

Figure 31. Gastropod Numbers and Soil pH

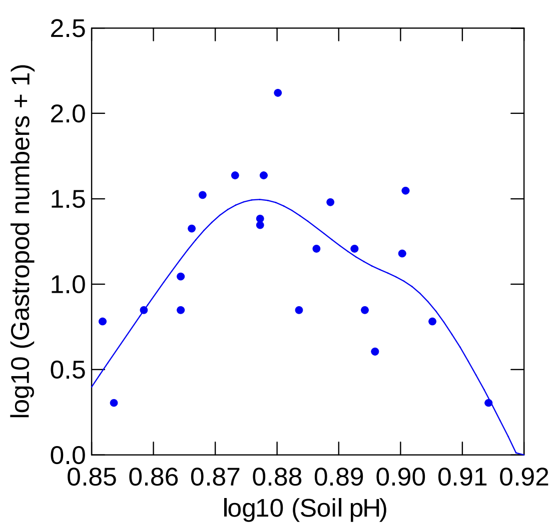

Figure 32. Platyhelminthes Numbers and Soil pH

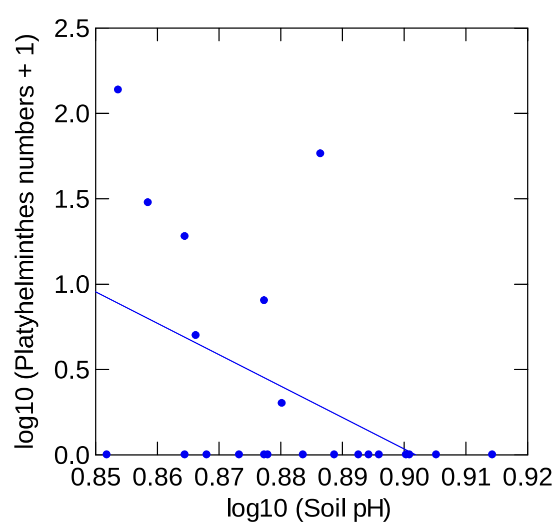

Figure 33. Ephemeropteran Numbers and Soil Conductivity

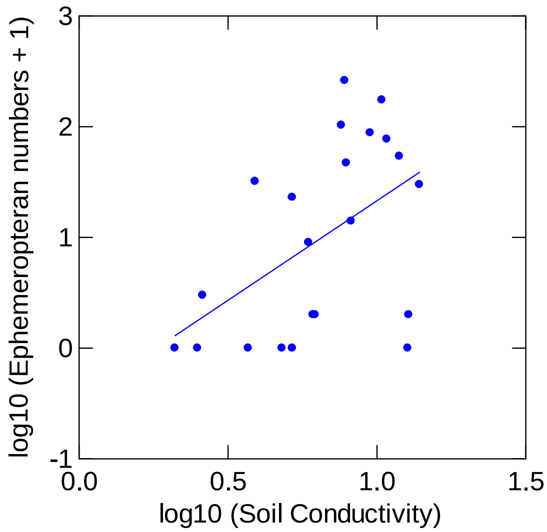

Figure 34. Gastropod Numbers and Soil Conductivity

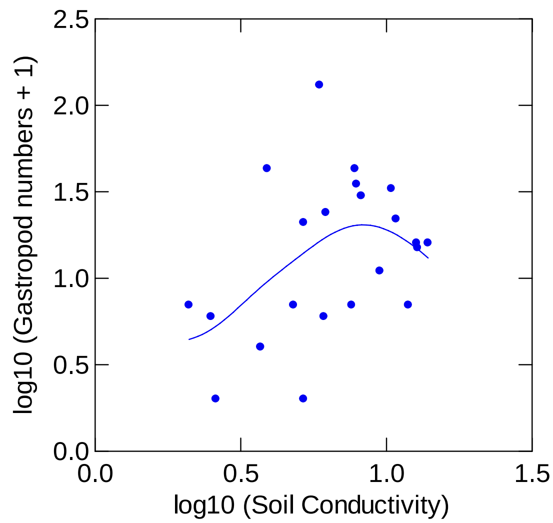

Figure 35. Crustacean Numbers and Soil Conductivity

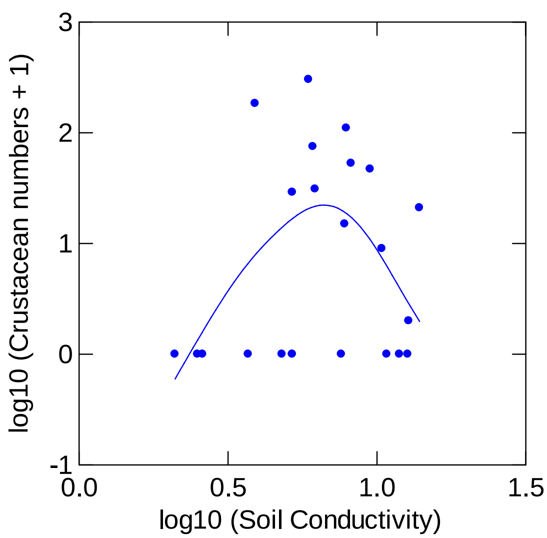

Figure 36. Annelid Numbers and Soil Conductivity

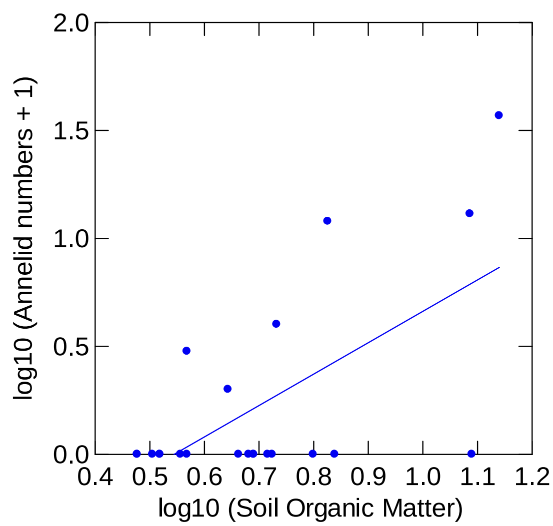

Figure 37. Ephemeropteran Numbers and pH

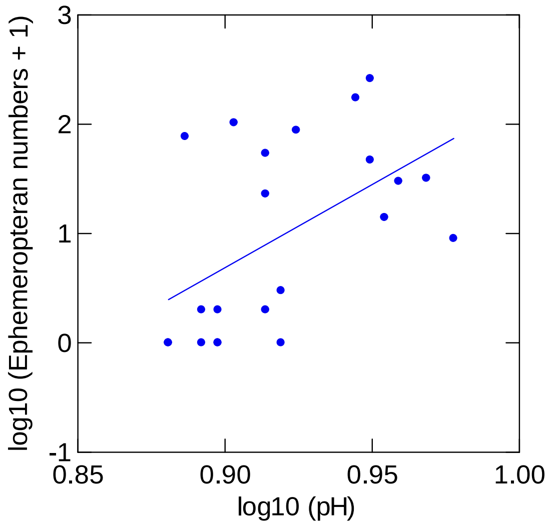

Figure 38. Ephemeropteran Numbers and pH – DWLS

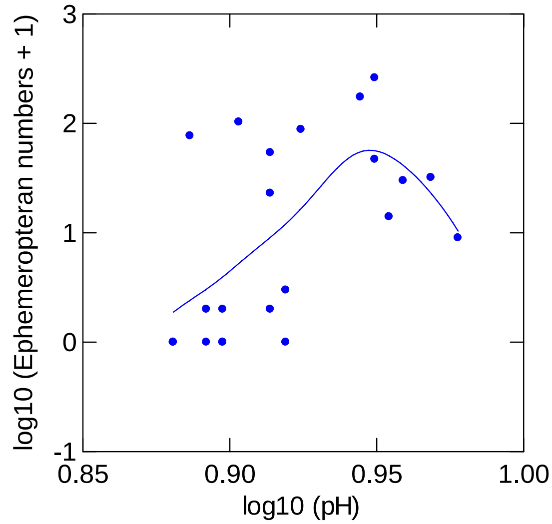

Figure 39. Hemipteran Numbers and pH

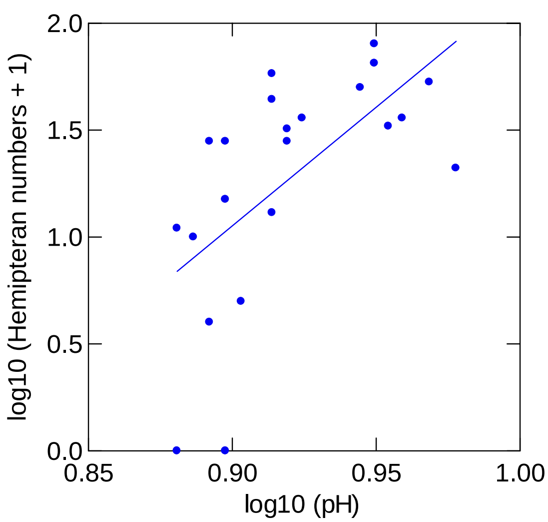

Figure 40. Hemipteran Numbers and pH – DWLS

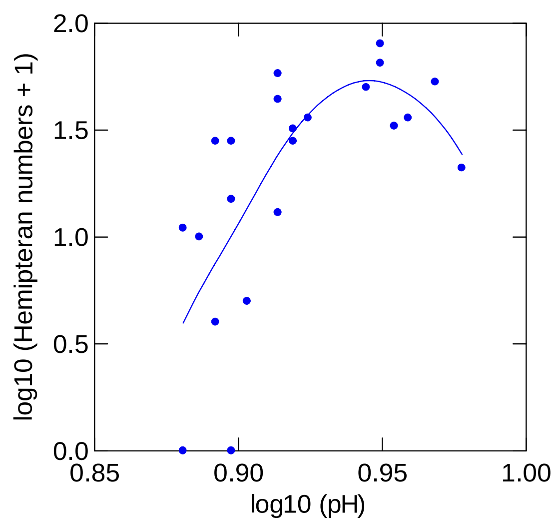

Figure 41. Chironomid Numbers and pH

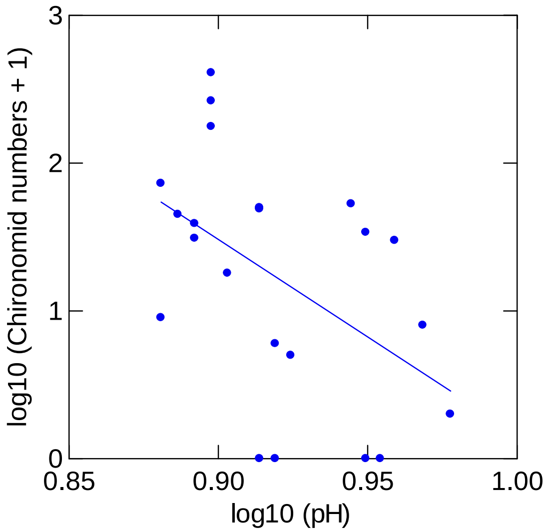

Figure 42. Gastropod Numbers and pH

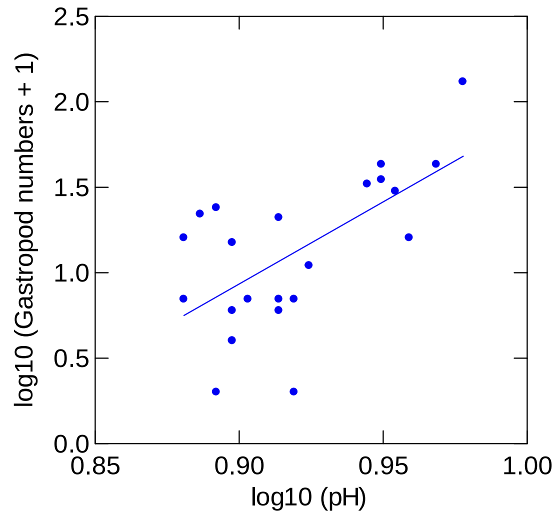

Figure 43. Crustacean Numbers and pH

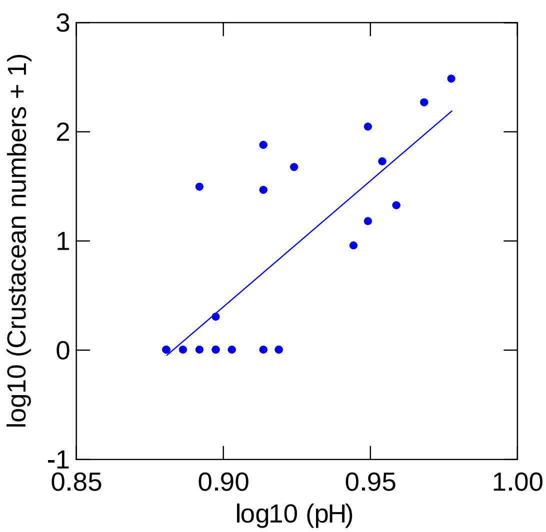

Figure 44. Annelid Numbers and pH

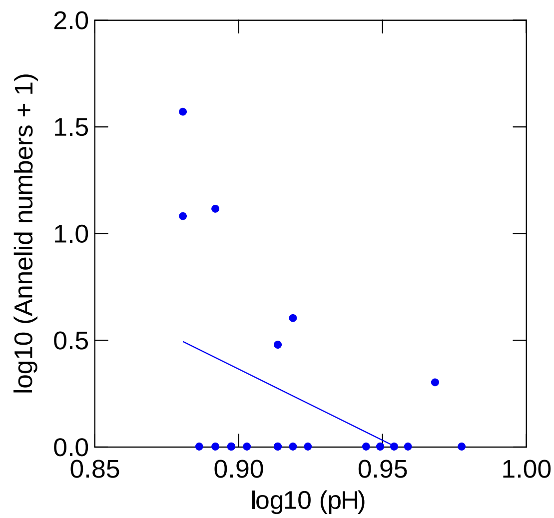

Figure 45. Annelid Numbers and pH - DWLS

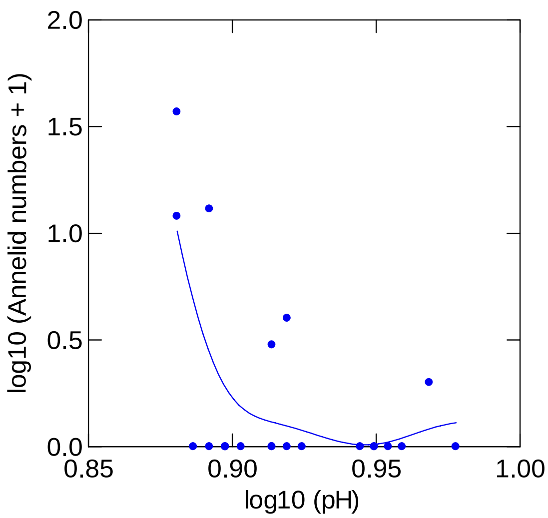

Figure 46. Ephemeropteran Numbers and TDS

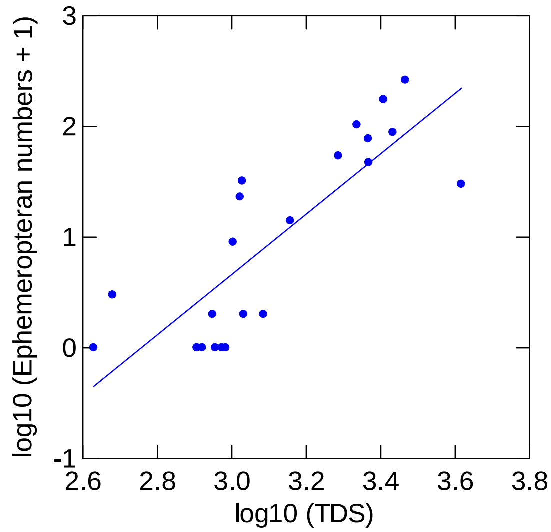

Figure 47. Ephemeropteran Numbers and TDS – DWLS

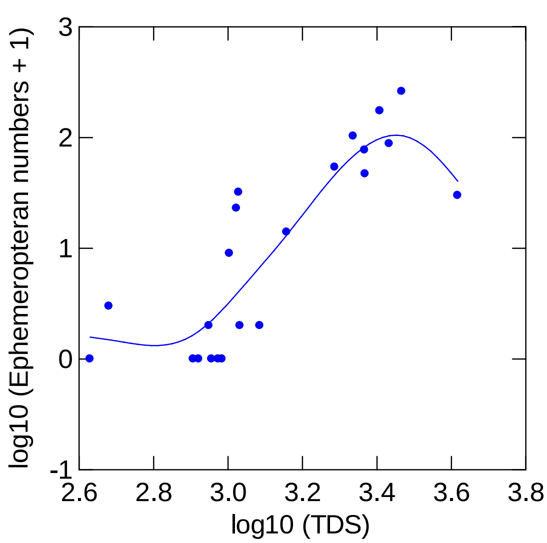

Figure 48. Odonate Numbers and TDS

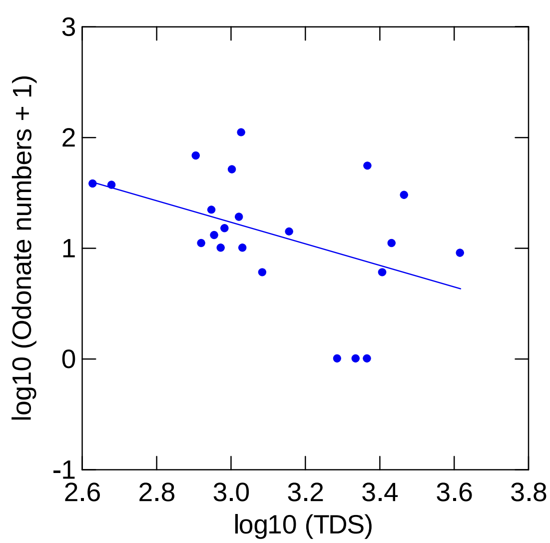

Figure 49. Platyhelminthes Numbers and TDS

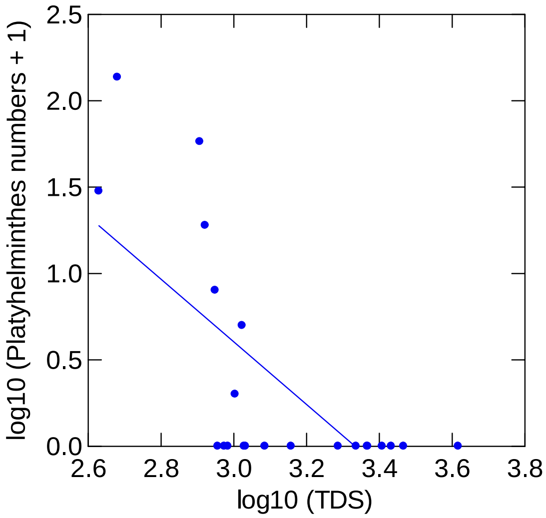

Figure 50. Platyhelminthes Numbers and TDS - DWLS

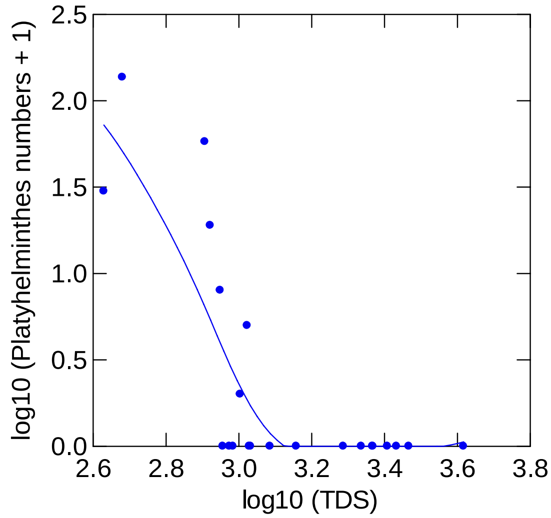

Figure 51. Annelid Numbers and TDS

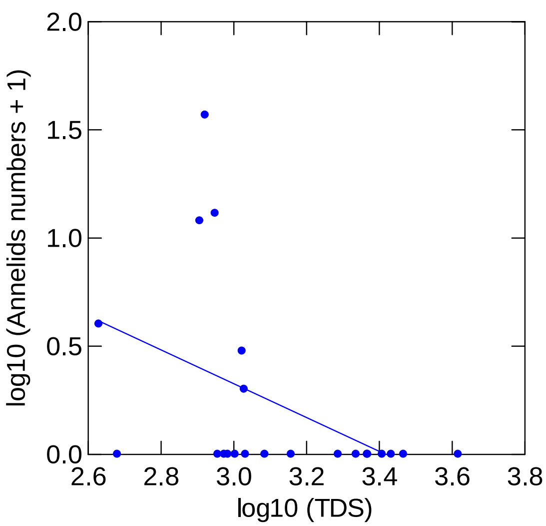

Figure 52. Annelid Numbers and TDS - DWLS

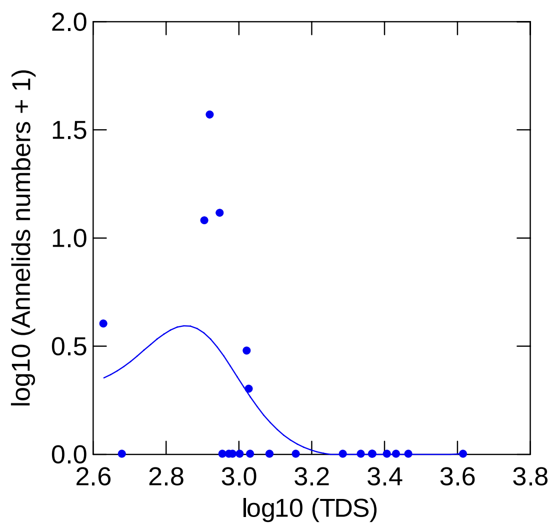

Figure 53. Ephemeropteran Numbers and D. O.

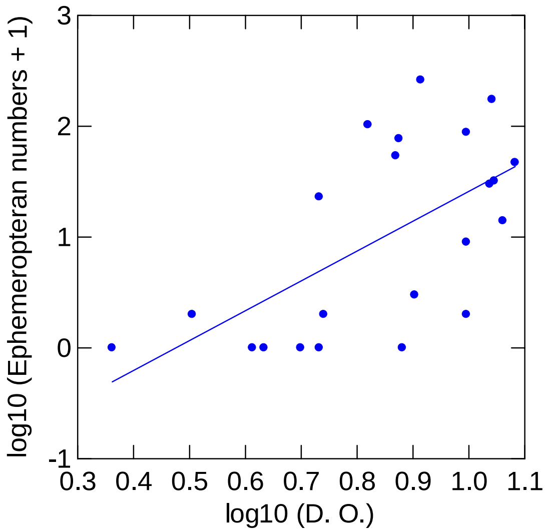

Figure 54. Hemipteran Numbers and D. O.

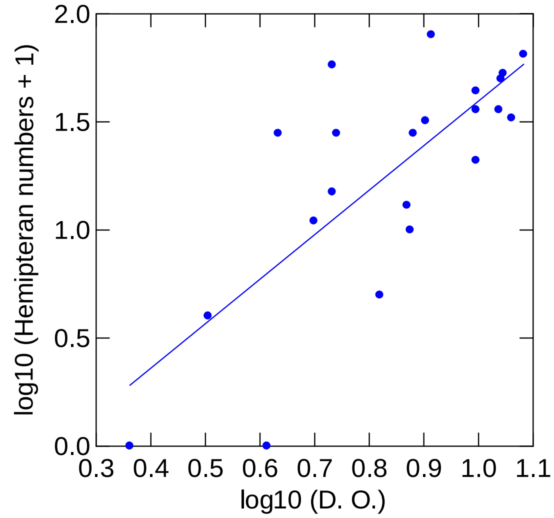

Figure 55. Chironomid Numbers and D.O.

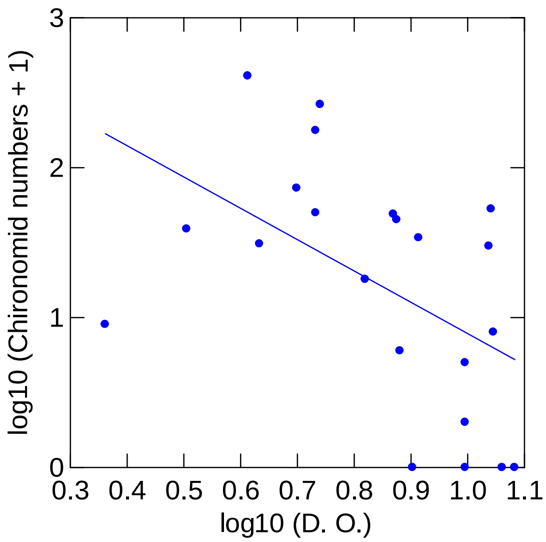

Figure 56. Crustacean Numbers and D.O.

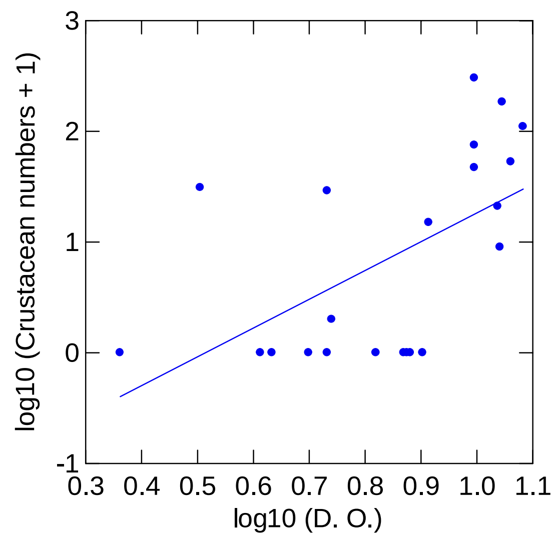

Figure 57. Platyhelminthes Numbers and D.O.

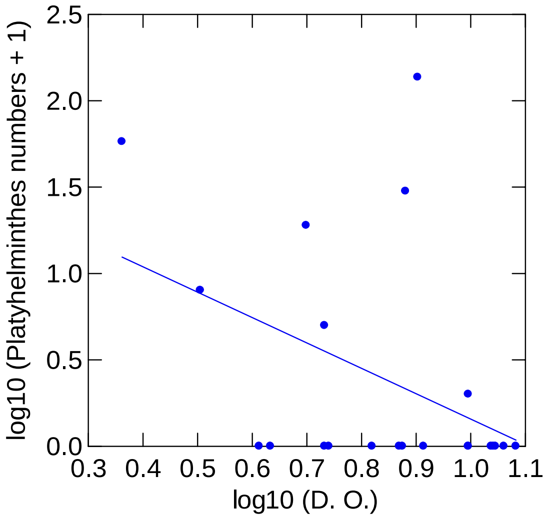

Figure 58. Annelid Numbers and D.O.

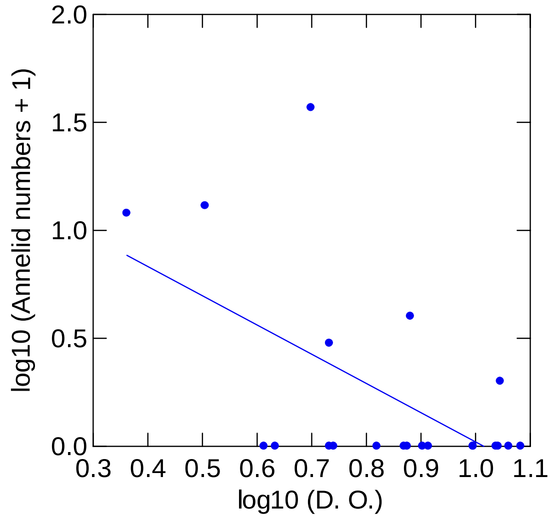

Figure 59. Ephemeropteran Numbers and Total P

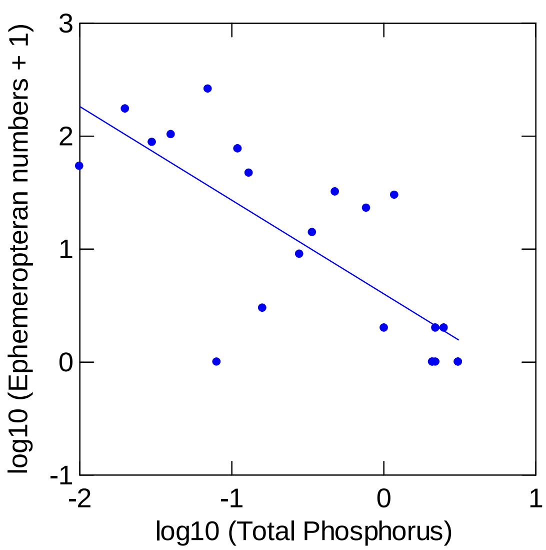

Figure 60. Hemipteran Numbers and Total P

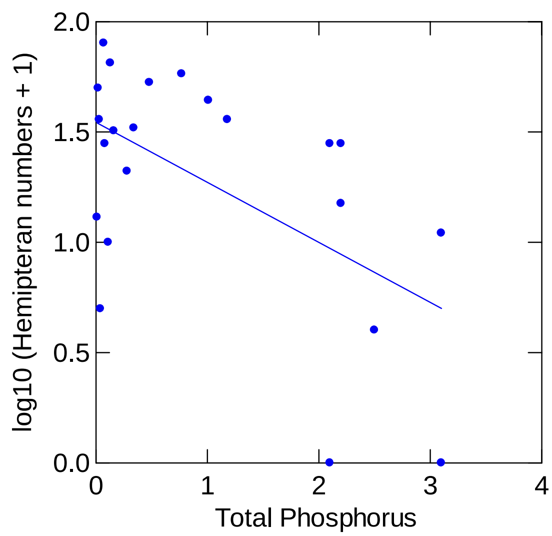

Figure 61. Chironomid Numbers and Total P

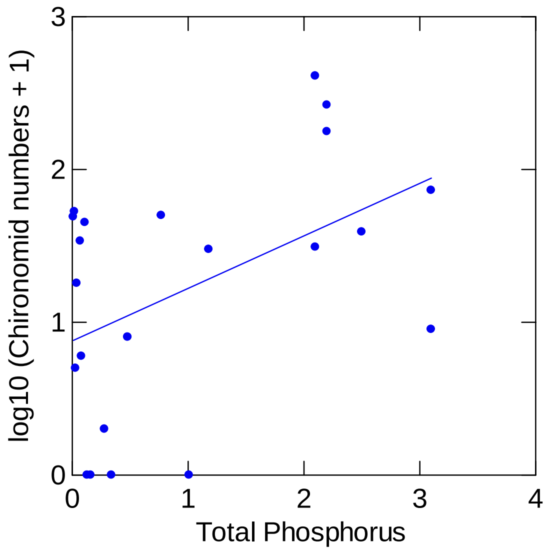

Figure 62. Crustacean Numbers and Total P

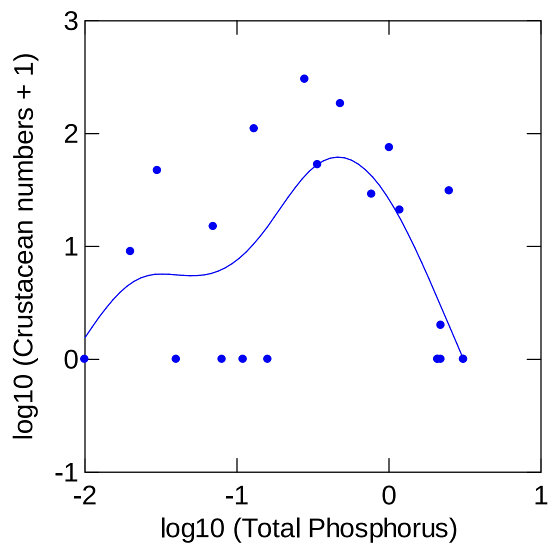

Figure 63. Annelid Numbers and Total P

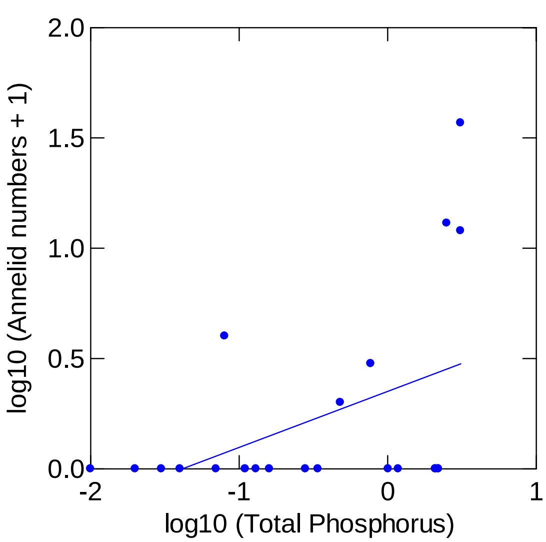

Figure 64. Annelid Numbers and Total P - DWLS

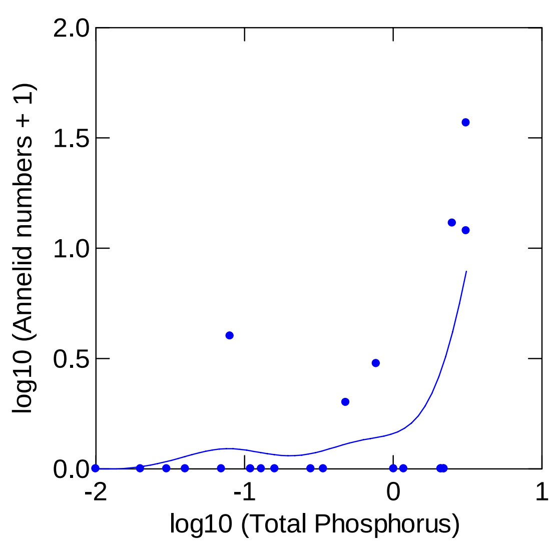

Figure 65. Ephemeropteran Numbers and Total N

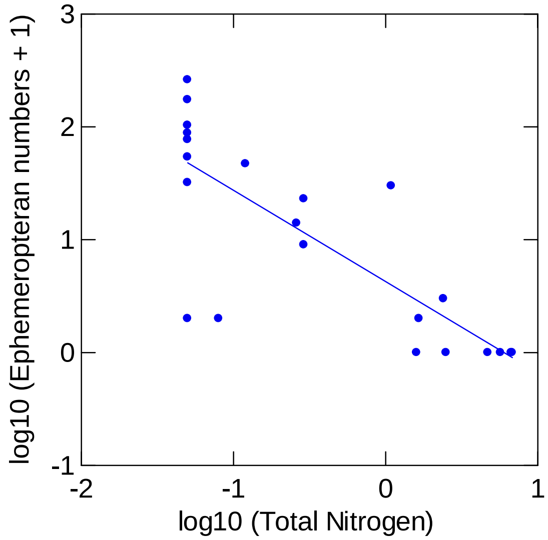

Figure 66. Gastropod Numbers and Total N

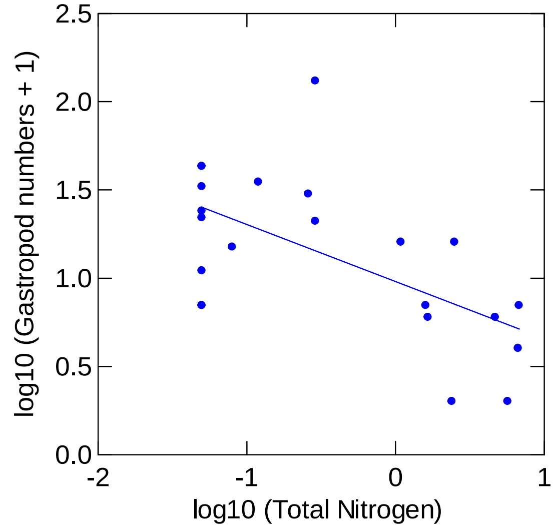

Figure 67. Crustacean Numbers and Total N

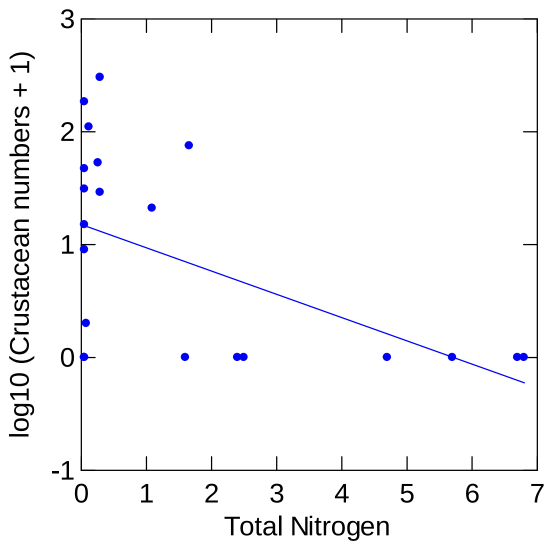

Figure 68. Ephemeropteran Numbers and Max. Temp.

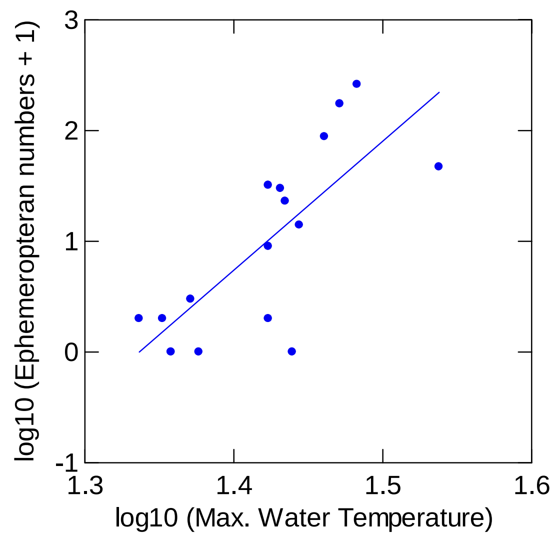

Figure 69. Ephemeropteran Numbers and Max. Temp. – DWLS

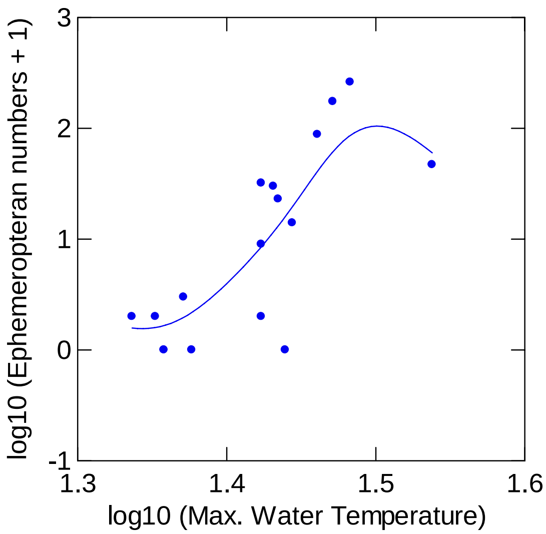

Figure 70. Hemipteran Numbers and Max. Temp.

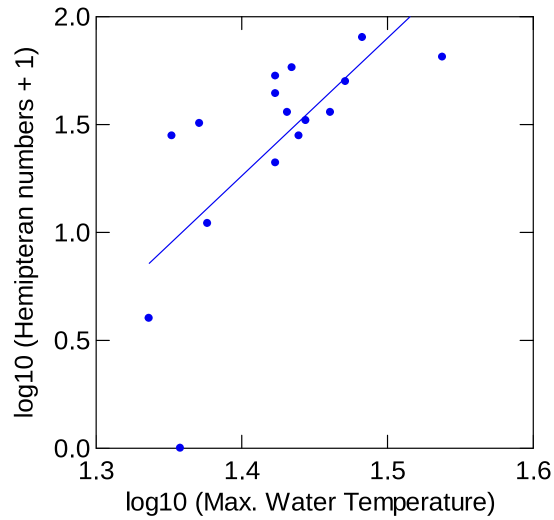

Figure 71. Hemipteran Numbers and Max. Temp. – DWLS

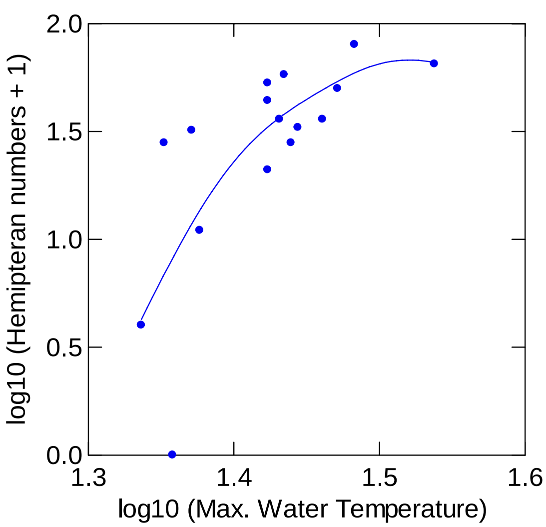

Figure 72. Platyhelminthes Numbers and Max. Temp.

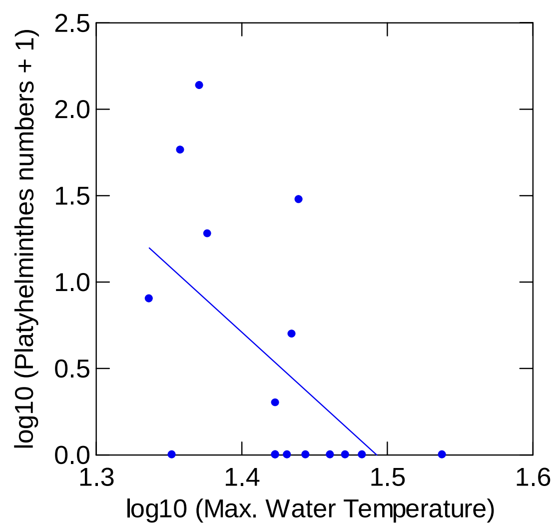

Figure 73. Annelid Numbers and Max. Temp.

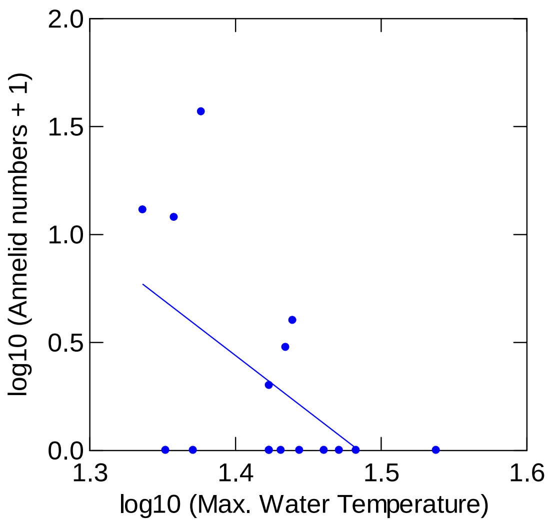

Figure 74. Ephemeropterans and T. latifolia % Cover

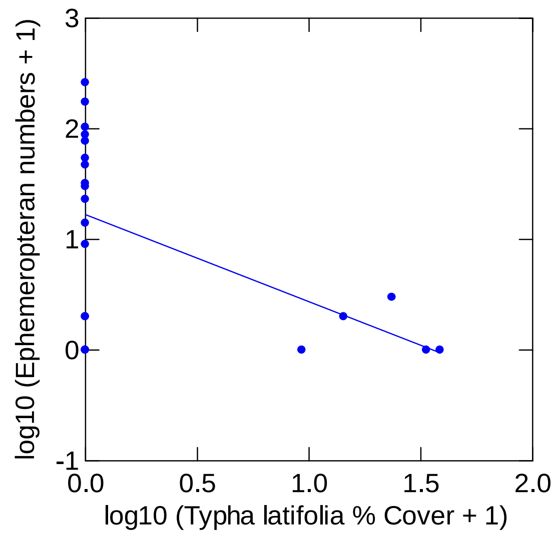

Figure 75. Platyhelminthes and T.latifolia % Cover

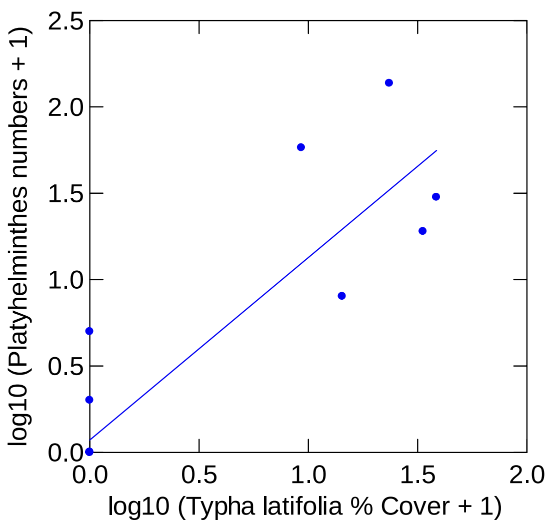

Figure 76. Annelids and T. latifolia % Cover

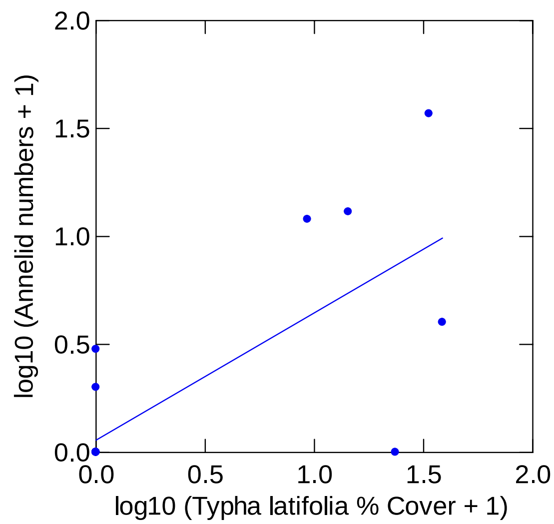

Figure 77. Ephemeropterans and P. australis % Cover

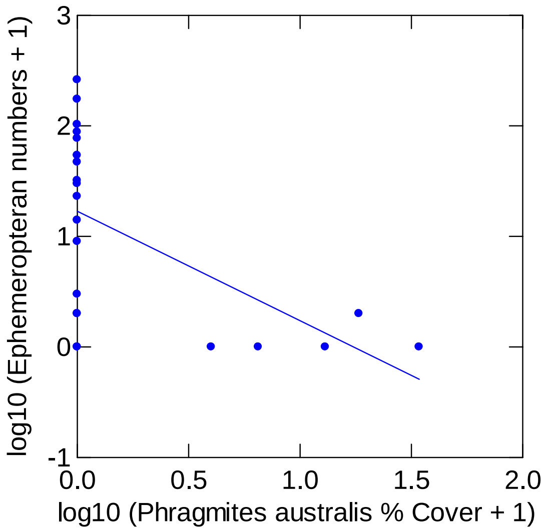

Figure 78. Hemipterans and P. australis % Cover

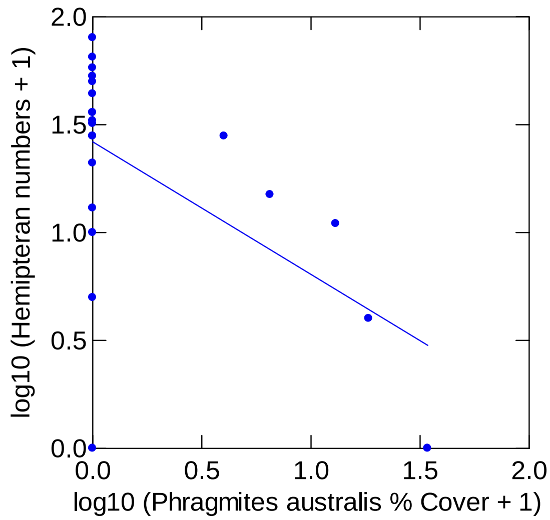

Figure 79. Platyhelminthes and P. australis % Cover

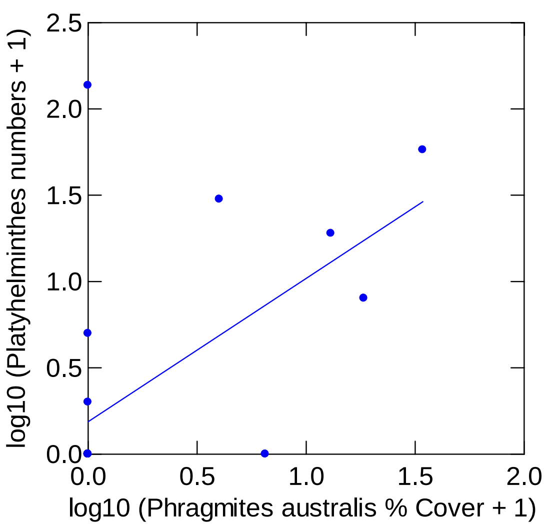

Figure 80. Annelids and P. australis % Cover

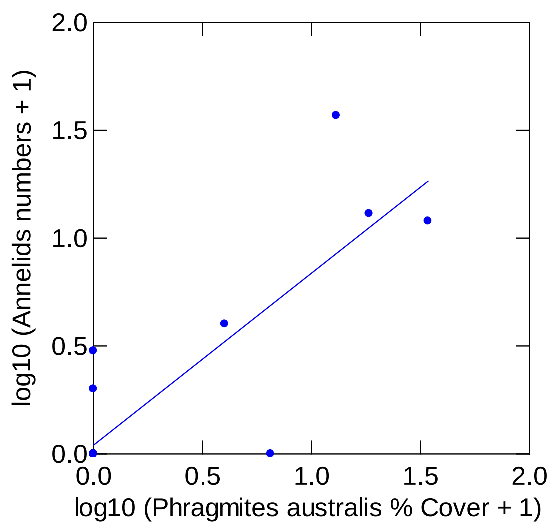

Figure 81. Odonates and D. spicata % Cover

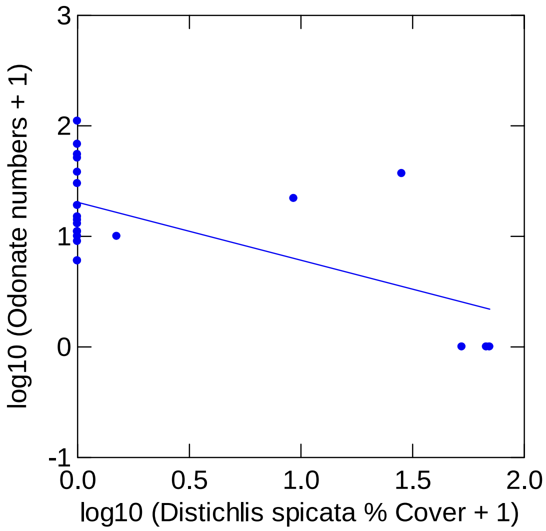

Figure 82. Gastropods and S. americanus % Cover

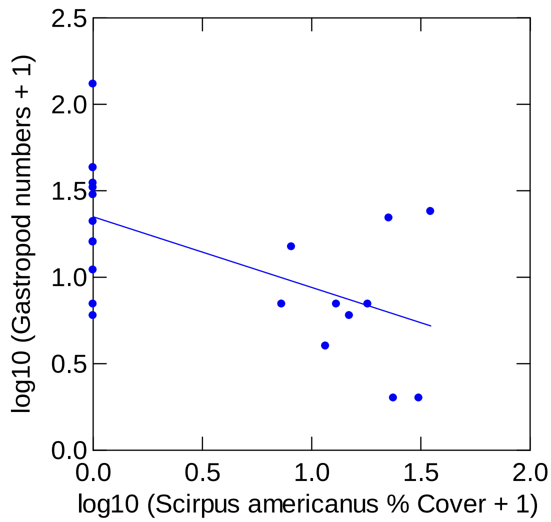

Figure 83. Crustaceans and S. americanus % Cover

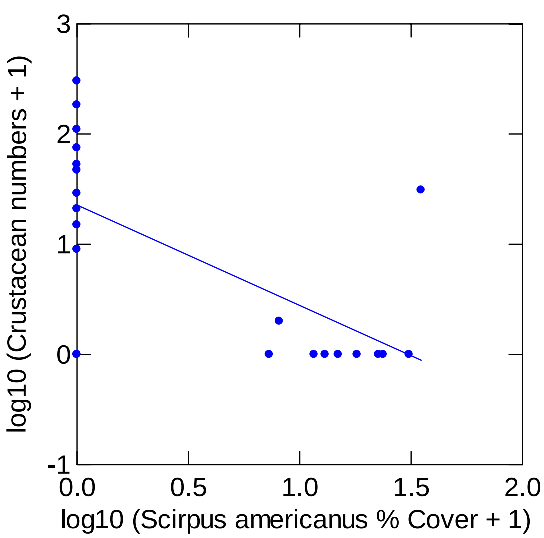

Figure 84. Ephemeropterans and Stukenia spp. % Cover

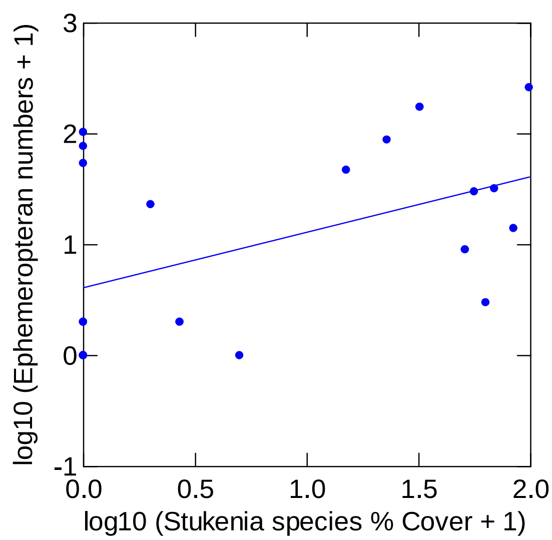

Figure 85. Hemipterans and Stukenia spp. % Cover

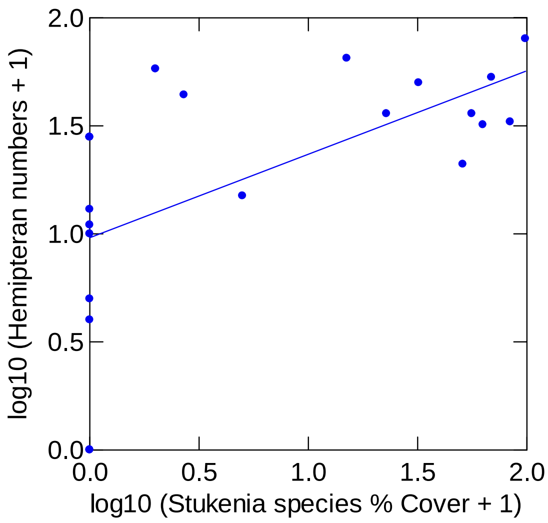

Figure 86. Chironomids and Stukenia spp. % Cover

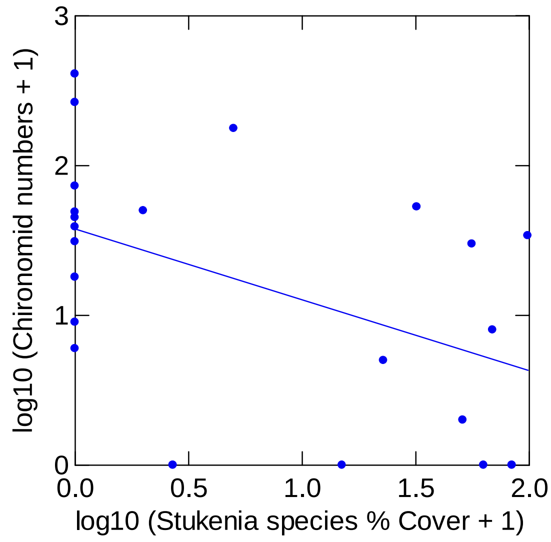

Figure 87. Gastropods and Stukenia spp. % Cover

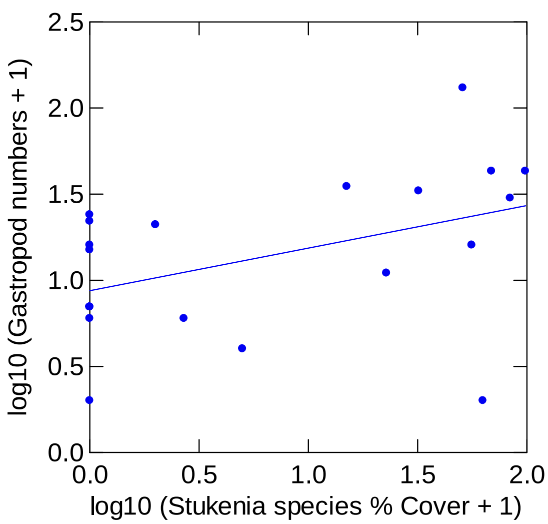

Figure 88. Crustaceans and Stukenia spp. % Cover

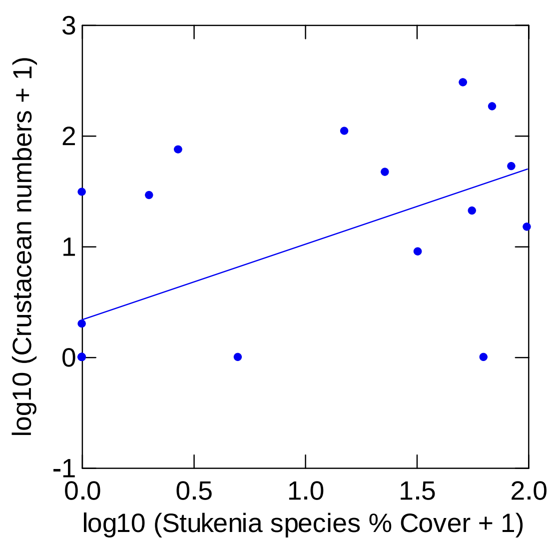

Figure 89. FACTOR ANALYSES: Vegetation and Water Quality

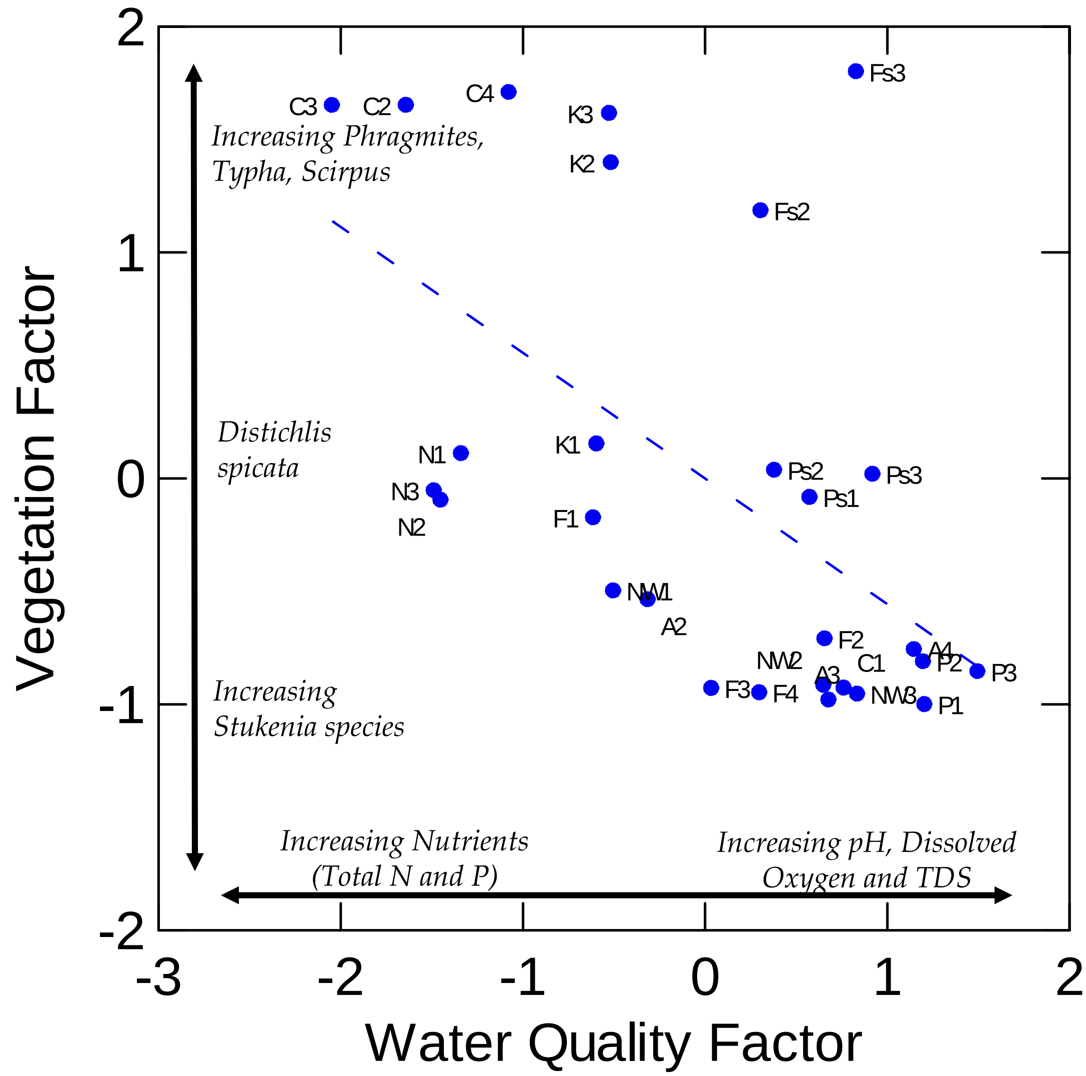

Figure 90. FACTOR ANALYSES: Invertebrates and Water Quality

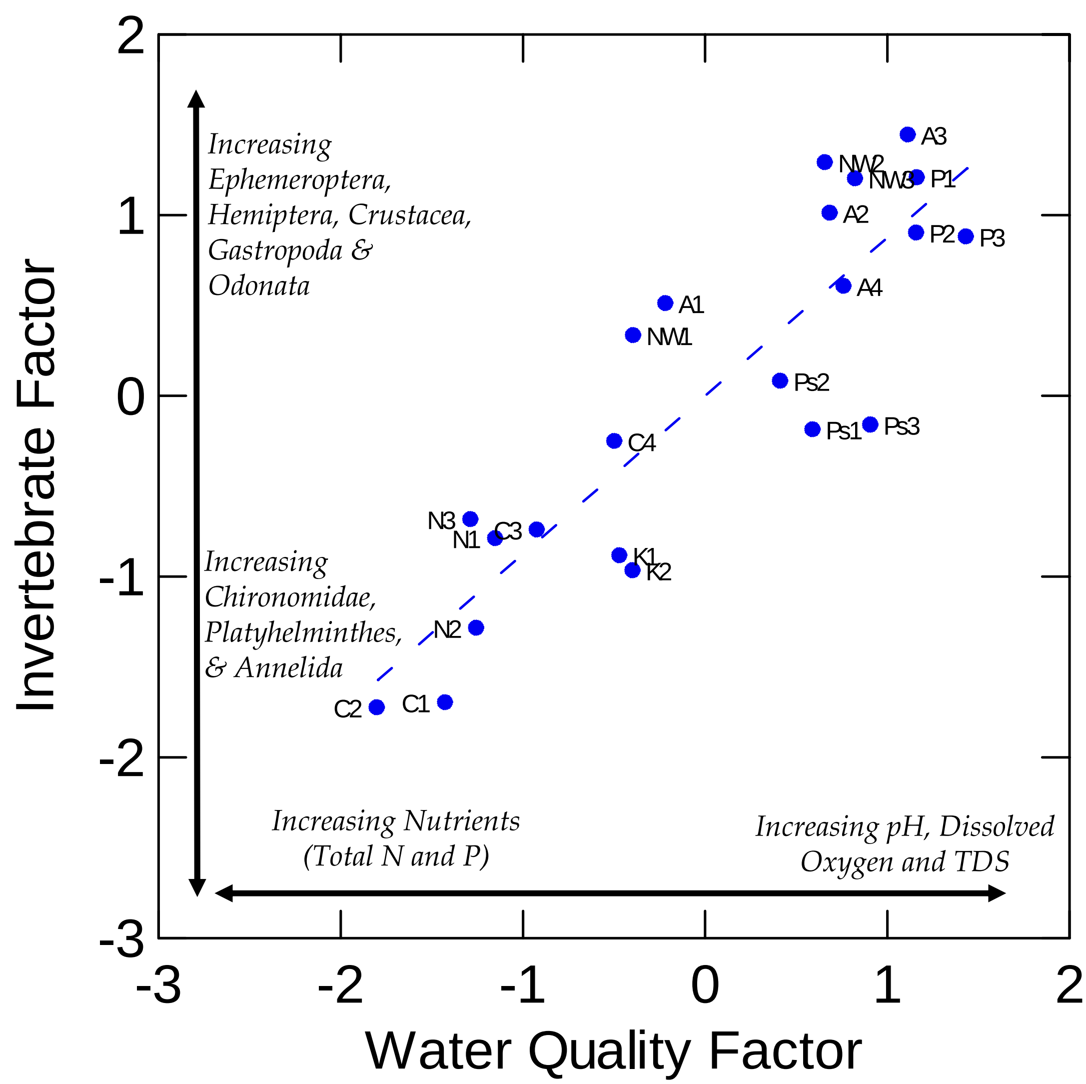

Figure 91. FACTOR ANALYSES: Invertebrates and Vegetation

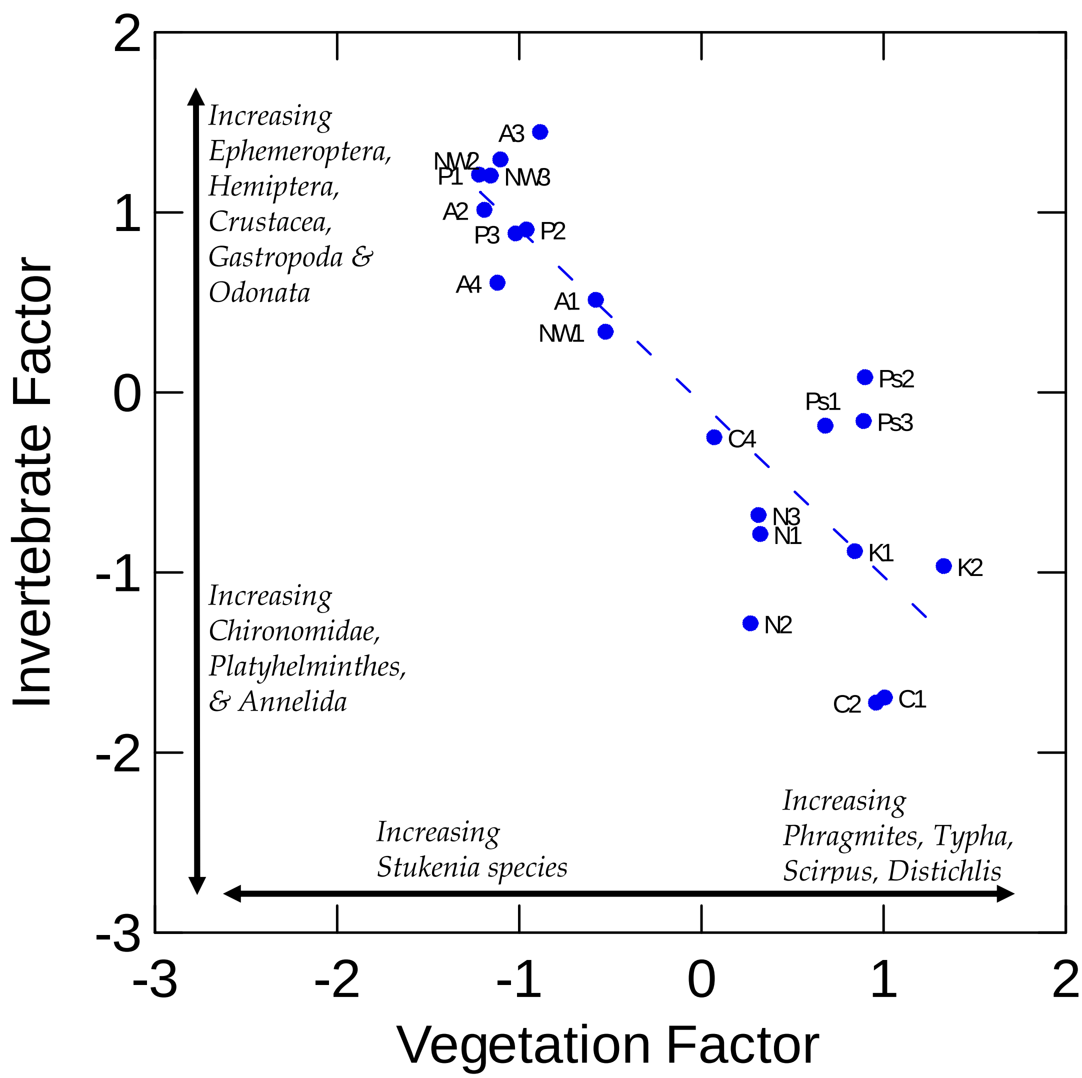

Figure 92. FACTOR ANALYSES: Invertebrates, Vegetation and Water Quality

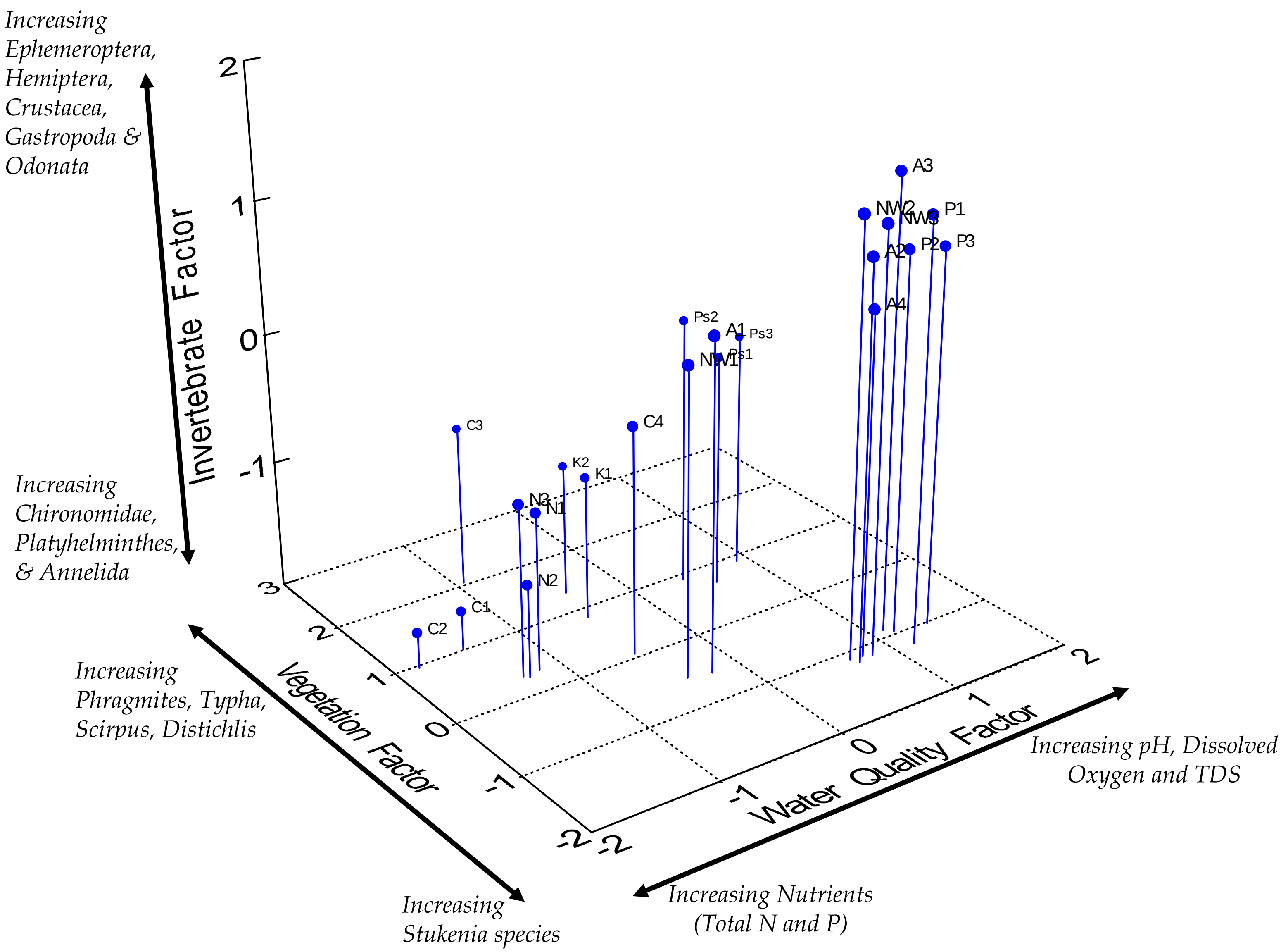

Figure 93. FACTOR ANALYSIS: Water Quality and Vegetation – Sheet-flow Sites

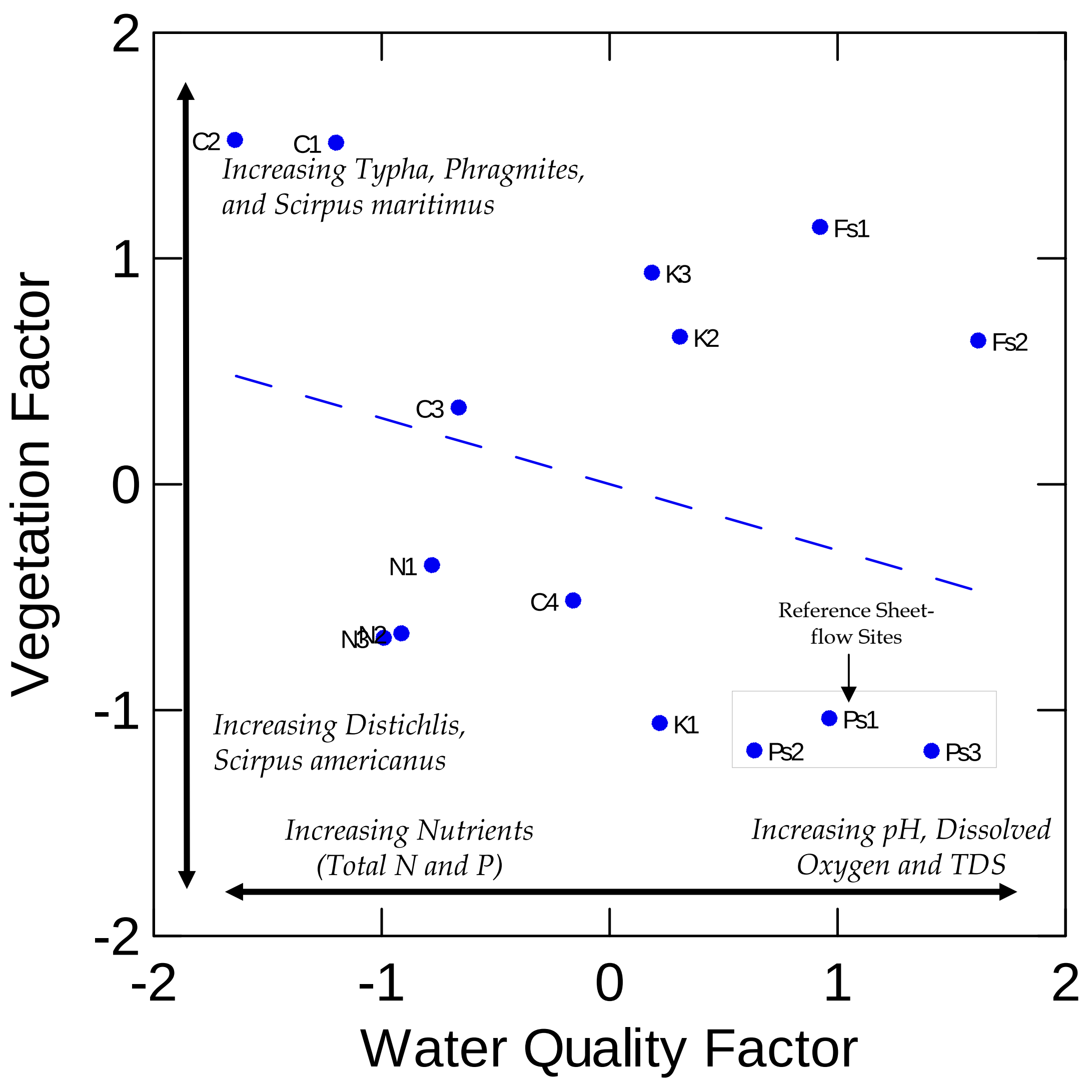

Figure 94. FACTOR ANALYSIS - Invertebrates and Water Quality - Sheet-Flow Sites

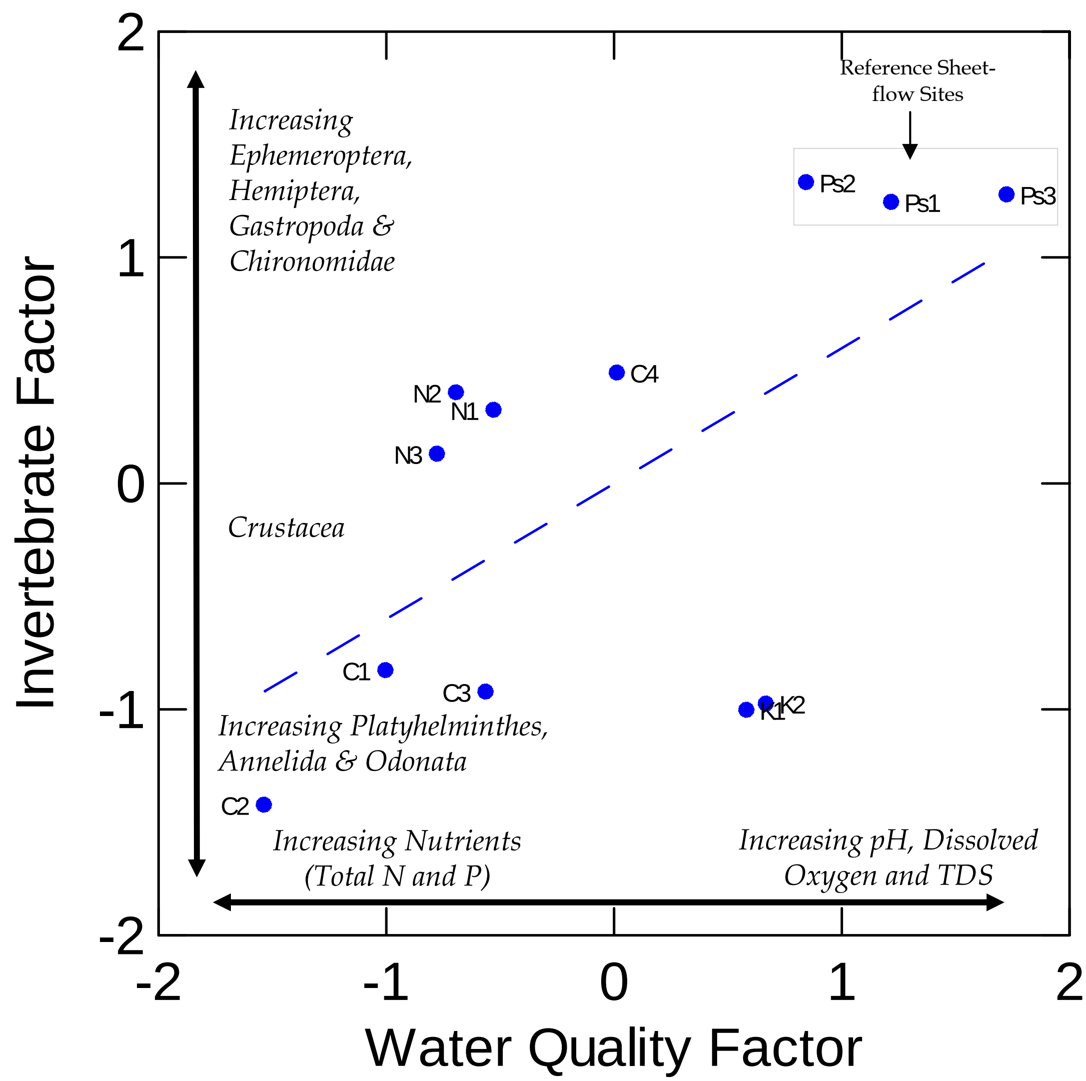

Figure 95. FACTOR ANALYSIS - Invertebrates and Water Quality - Impounded Sites

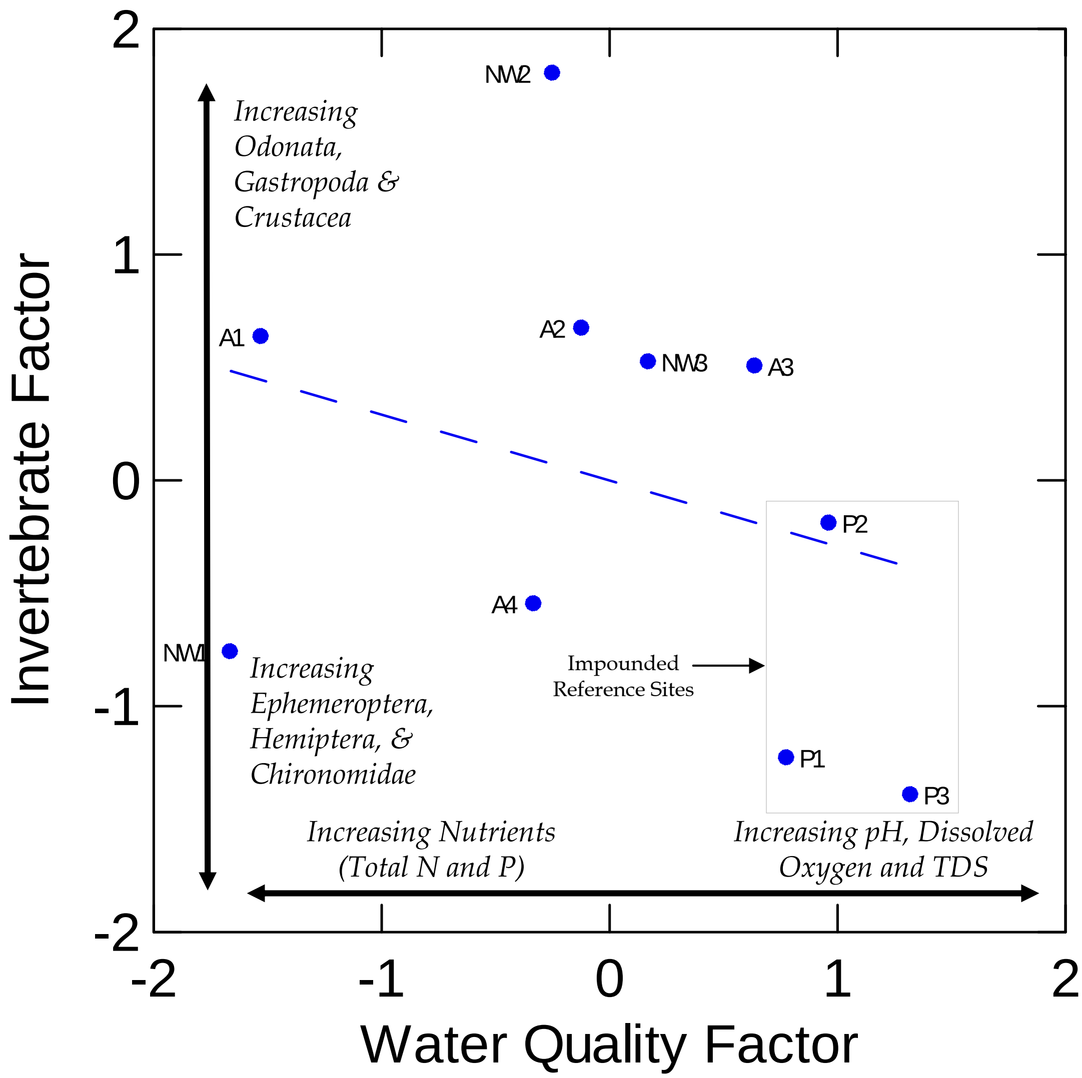

Figure 96. FACTOR ANALYSIS. Invertebrates and Vegetation - Sheet-Flow Sites

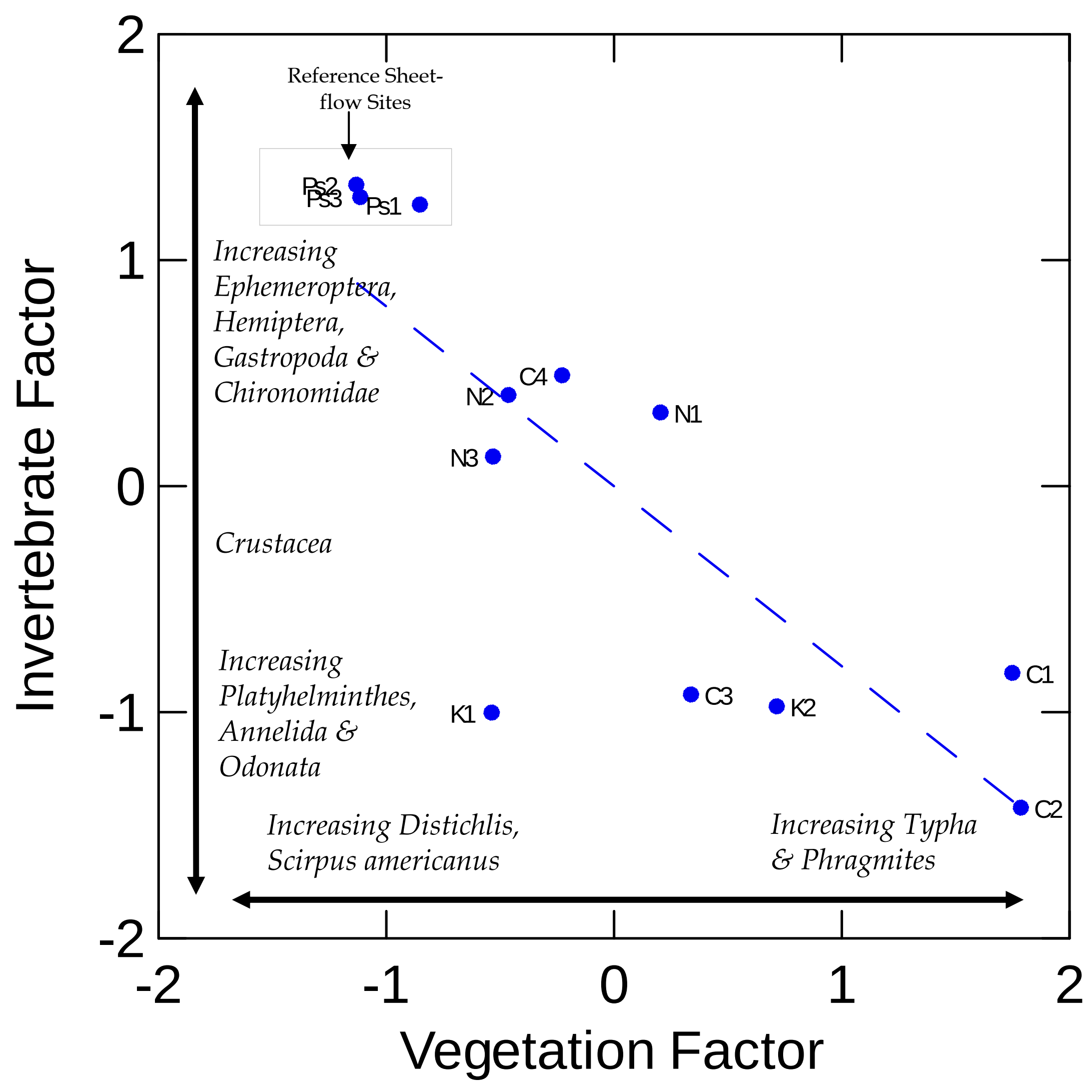

Figure 97. FACTOR ANALYSIS - Invertebrates, Vegetation & Water Quality - Sheet-Flow Sites