Analyses of 2005 Data on Wetland Biota and Water Quality in Farmington Bay, Great Salt Lake, Utah.

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Introduction

An integral part of the Great Salt Lake ecosystem, the Farmington Bay wetlands are valued as important feeding and nesting areas for migratory birds and for support of aquatic life and various recreational activities. The construction of a causeway in 1969 subsequently reduced natural mixing between Farmington Bay and the Great Salt Lake, often causing nutrients to remain concentrated in Farmington Bay. In recent years, there has also been growing concern among natural resource agencies and local stakeholders about the effects of nutrient loads from publicly-owned treatment works (POTWs) and other natural and anthropogenic sources on the assimilative capacity of the Farmington Bay wetlands. In response to these concerns, the Utah Division of Water Quality began a program in 2004 to characterize the wetland ecosystems of Farmington Bay.

The ongoing program includes intensive sampling of multiple wetlands sites that represent a cross-section of the different wetland ecosystems along Farmington Bay. The first year of sampling to characterize water quality, wetland soils, plants and macroinvertebrates along Farmington Bay was completed in 2004 and included sites that received sheet-flow hydrology and impounded wetlands. The results of the 2004 survey were described in a draft technical memorandum (CH2M HILL 2005, Appendix A) and provided a preliminary evaluation of the ecological relationships and patterns between key biological and water quality parameters. Additionally, the 2004 results also offered useful insights into potential metrics that may be useful in evaluating wetland function in relation to changes in water quality.

All of the sheetflow and impounded wetland sites sampled in 2004 were subsequently sampled multiple times between June and November of 2005 to assess wetland plants and macroinvertebrates in relation to water quality. This technical memorandum describes the analyses and results of the wetland plant and macroinvertebrate data collected from Farmington Bay in 2005, and reflects the second year of a 3-year effort aimed at characterizing the wetlands of Farmington Bay.

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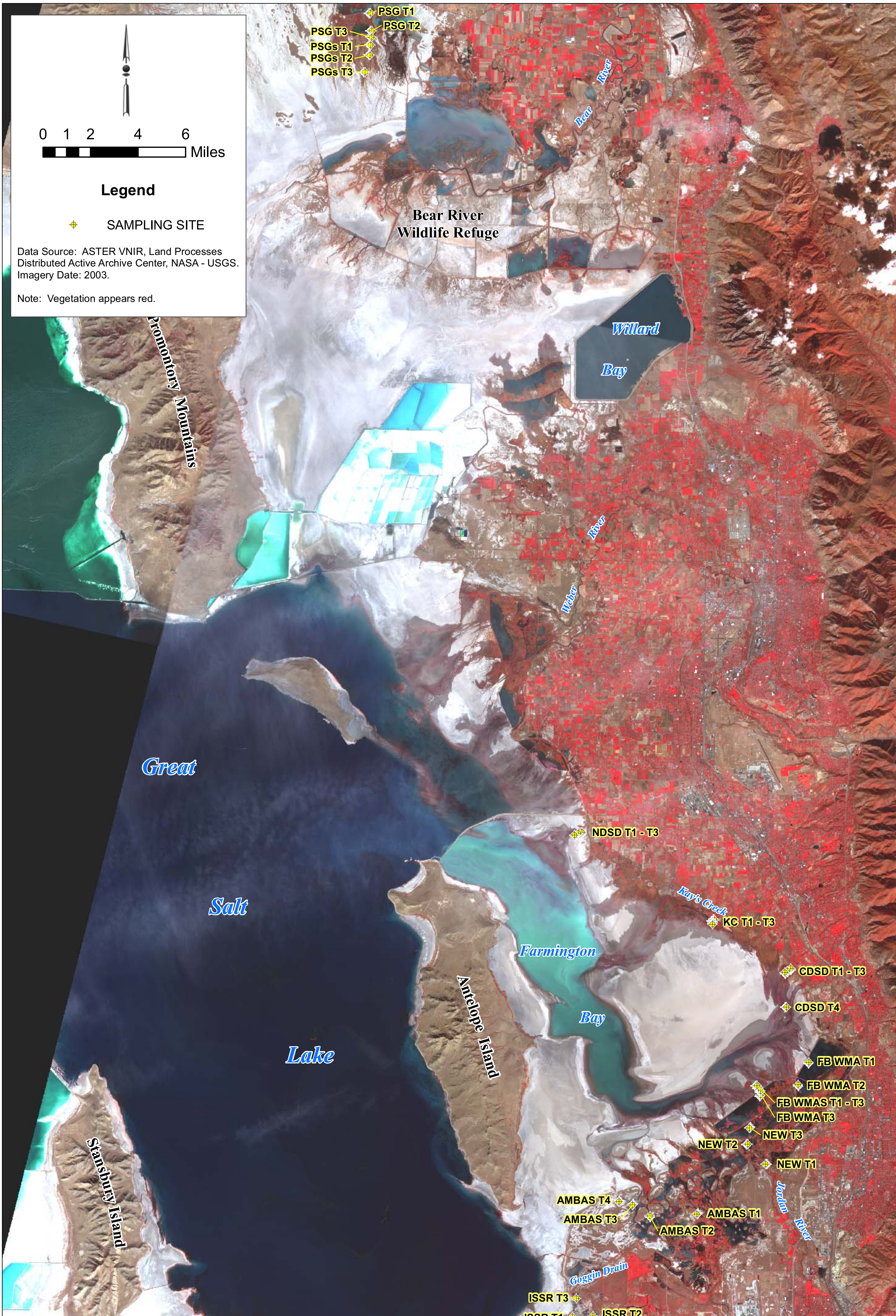

EXHIBIT 1

WETLANDS SAMPLING SITES

STATISTICAL ANALYSES OF 2005 DATA ON WETLAND PLANTS AND INVERTEBRATES IN FARMINTON BAY, GREAT SALT LAKE, UTAH

CH2MHILL

Study Roles

Many personnel were involved in the planning and execution of this study in 2004-2005. The primary roles of key staff involved in this study and their respective affiliations are noted in Table 1.

TABLE 1. SUMMARY OF KEY STAFF INVOLVED WITH THEIR AFFILIATIONS AND THEIR LEAD ROLES IN THE 2004-2005 STUDY

Staff	Affiliation	Roles
Sharook Madon, Ph.D.	CH2M HILL, Inc.	Study planning, experimental design, data organization, data analyses and draft & final reports.
Heidi Hoven, Ph.D.	SWCA	Study planning, experimental design, field sampling and data support.
Theron Miller, Ph.D.	Utah Department of Environmental Quality (UDEQ)	Study planning, experimental design, field sampling and data support.
Samuel Rushforth, Ph.D.	Utah Valley State College (UVSC)	Laboratory analysis and enumeration of phytoplankton samples[1]
Lawrence Gray, Ph.D.	Utah Valley State College (UVSC)	Laboratory analysis and enumeration of macroinvertebrate samples
John Cavitt, Ph.D.	Weber State University (WSU)	Bird data[2]

[1]Phytoplankton analysis is not included in this or the 2004 report by CH2M HILL, but are in separate reports produced by Dr. Rushforth.

[2]Bird data analysis is not specifically included in this report, but forms an important component of the overall study and reference is made to it in this report.

Data Analyses

This technical memorandum focuses on an exploratory analysis of relationships between plant invertebrate and water chemistry variables measured during 2005 at various sites in the wetlands of Farmington Bay.

Wetland Sites

Plant, macroinvertebrate and water quality data from the following wetland sites (Exhibit 1, Table 2) reflecting both impounded and sheetflow hydrology were incorporated into the analyses.

TABLE 2. SUMMARIES OF WETLAND SITES SAMPLED IN 2004 AND 2005.

Site	Hydrology	Abbreviation for Exhibit 1	Abbreviation for Figures	Sampled in 2004 (Y/N)	Sampled in 2005 (Y/N)	Comments
Ambassador Transects 1-4	Impounded	AMBAS T1 - T3	A1-4	Y	Y	
Farmington Bay Waterfowl Management Area Transects 1-3	Impounded	FBWMA T1-T3	F1-4	Y	Y	
Inland Sea Shorebird Refuge Transects 1-3	Impounded	ISSR T1-T3	I1-3	N	Y	
Newstate Transects 1-3	Impounded	NEW T1-T3	N1-3	Y	Y	
Public Shooting Grounds Transects 1-3	Impounded	PSG T1-T3	P1-3	Y	Y	Reference sites for impounded wetlands
Central Davis Sewer District Transects 1-4	Sheetflow	CDSD T1-T4	C1-4	Y	Y	POTW discharge sites
Farmington Bay Waterfowl Management Area Sheetflow Transects 1-3	Sheetflow	FBWMAs T1-T4	Fs1-4	Y	Y	
Kays Creek Transects 1-3	Sheetflow	KC T1-T3	K1-3	Y	Y	
North Davis Sewer District Transects 1-3	Sheetflow	NDSD T1-T3	N1-3	Y	Y	POTW discharge sites
Public Shooting Grounds Sheetflow Transects 1-3	Sheetflow	PSG T1-T3	Ps1-3	Y	Y	Reference sites for sheetflow wetlands

Wetlands Variables Used in Data Analysis

Plant Variables

Percent cover data of all plant species observed in quadrats placed in each transect were recorded. However, only percent cover data of plant species frequently observed at the sites were included in the statistical analysis. Plant species with rare occurrences, for example, found at low percent cover only on one occasion, were eliminated from statistical analysis to conserve the robustness of the analysis. The plant species displayed in Table 3 were all included in the analysis. Additionally, for both 2004 and 2005 data, plant species were also categorized by status (native, introduced or invasive) for analysis.

TABLE 3. SUMMARY OF PLANT SPECIES SAMPLED IN THE WETLANDS OF FARMINGTON BAY IN 2005
Species listed here include those that were used in the statistical data analysis.

Plant Species Name	Common Name	Comments
Alopecurus aequalis	Short awn Foxtail	Native, found at sheetflow sites
Atriplex micrantha	Two scale Saltbush	Introduced, found at sheetflow sites
Bidens cernua	Nodding Beggars-tick	Native, Invasive, found at sheetflow sites
Distichlis spicata	Desert Saltgrass	Native, Invasive, found at sheetflow sites
Horduem jubatum	Foxtail Barley	Native, Invasive, found at sheetflow sites
Phalaris arundinacea	Reed Canary Grass	Native, Invasive, found at sheetflow sites
Phragmites australis	Common Reed	Native, Invasive, found at sheetflow sites
Polygonium lapathifolium	Curlytop Knotweed	Native, Invasive, found at sheetflow sites
Rumex crispus	Curly Dock	Introduced, Invasive, found at sheetflow sites
Salicornia rubra	Red Swampfire	Native, found at sheetflow sites. A type of pickleweed
Schoenoplectus acutus	Hardstem Bulrush	Native, found at sheetflow sites
Schoenoplectus americanus	Olney's Bulrush	Native, found at sheetflow sites
Schoenoplectus maritimus	Cosmopolitan Bulrush or Alkali Bulrush	Native, found at sheetflow sites
Typha dominghensis	Southern Cattail	Native, Invasive, found at sheetflow sites
Typha latifolia	Broadleaf Cattail	Native, Invasive, found at sheetlow sites
Lemna minor	Lesser Duckweed	Floating aquatic vegetation

TABLE 3. SUMMARY OF PLANT SPECIES SAMPLED IN THE WETLANDS OF FARMINGTON BAY IN 2005
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Plant Species Name	Common Name	Comments
Azola mexicanus	Mexican mosquitofern	Floating aquatic vegetation
Ceratophyllum demersum	Coon's Tail	Native, found at impounded sites
Chara species	Muskgrass species	Native, a multicellular macro-alga, not a true plant. Found at impounded sites
Ruppia cirrhosa	Ditch Grass	Native, found at impounded sites
Stuckenia species	Pondweed species	Native, mostly consisted of *Stuckenia filiformis,* fineleaf pondweed. Found at impounded sites

Algae were also recorded and included in the analysis involving sheetflow sites.

Wetland Macroinvertebrate Variables

Macroinvertebrates were collected at each of the wetlands sites and later enumerated to genus, or whenever possible, to species level. The number of individuals per sample for various macroinvertebrate taxa observed in the samples (Table 4) were recorded and included in the analyses. Macroinvertebrates such as *Ephydra, Ylodes, Oecetis, Holorusia,* and Stratiomyidae, were rarely observed in the samples and were included in the category titled "other" for the statistical analyses.

TABLE 4. SUMMARY OF MACROINVERTEBRATE TAXA SAMPLED IN THE WETLANDS OF FARMINGTON BAY IN 2005.

Taxanomical Category	Taxanomical Descriptions	Representative Genus/Species Observed †
Ephemeropterans	Order Ephemeroptera, represented by mayflies	*Callibaetis* sp. (CG), *Caenis* sp. (CG)
Odonates	Order Odonata, represented by damselflies and dragonflies	*Ischnura* sp. (PR), *Erythemis* sp. (PR), *Aeshna* sp. (PR)
Hemipterans	Order Hemiptera, represented by corixids (water boatman) and notonectids (Backswimmers)	Corixids: *Corisella* sp. (PR), *Hesperocorixa* sp. (PR), *Trichocorixa* sp. (PR) Notonectids: *Notonecta* sp. (PR), few *Limnoporus* sp. (PR)
Chironomids	Order Diptera*, represented by the Family Chironomidae	Mainly *Chironomus* sp. (CG) Fewer individuals of Orthocladiinae (CG), Tanytarsini (CG), and Tanypodinae (PR).
Gastropods	Class Gastropoda, represented by various snail species	*Physella* sp. (SH), *Stagnicola* sp. (SH), and *Gyraulus* sp. (SH)

TABLE 4. SUMMARY OF MACROINVERTEBRATE TAXA SAMPLED IN THE WETLANDS OF FARMINGTON BAY IN 2005.

Taxanomical Category	Taxanomical Descriptions	Representative Genus/Species Observed †
Crustaceans	Family Hyalellidae, and a few members belonging to Family Asellidae	Hyalellidae: *Hyallela azeteca* (CG) Asellidae: *Caecidotea occidentalis* (CG)
Platyhelminthes	Phylum Platyhelminthes, represented by planarian flatworms	*Phagocota* sp. (PR), *Dugesia* sp. (PR)
Annelids	Phylum Annelida, represented by leeches	*Erpobdella parva* complex (PR), *Helobdella stagnalis* (PR), and *Glossophonia complanata* (PR)
Coleopterans	Represented by beetles of families Dytiscidae, Hydrophilidae, Haliplidae, Gyrinidae	Dytiscidae: *Agabus* sp. (PR), *Hydroporus* sp. (PR), *Hydaticus* sp. (PR), *Laccophilus* sp. (PR), *Graphoderus* sp. (PR) Hydrophilidae: *Ametor* sp. (CG), *Enochrus* sp. (CG), *Berosus* sp. (CG), *Tropisternis* sp. (Adults CG, larvae PR), *Hydrophilus* sp. (Adults CG, larvae PR) Halipidae: *Haliplus* sp. (SH) Gyrinidae: *Gyrinus* sp. (PR)
Acari	Represented by mites and ticks	Individuals were rare, and were not identified by species, but grouped under the sub-class Acari (PR)
Ostracods	Represented by crustaceans with laterally compressed body and undifferentiated heads	Individuals were rare, and were not identified by species, but grouped under the class Ostracoda (CG)

*Members of the Order Diptera that included Families such as Ephydridae, Tabanidae, Stratiomyidae and Tipulidae were also observed, but were rare and included in the "Others" category.

† Trophic classifications for the various species are provided in parenthesis. CG = collector-gatherers, FC = Filterer-collector, PR = predators, SH = Shredders.

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
- Total suspended solids (TSS), mg/L
- Dissolved oxygen (DO), mg/L
- Phosphorus as total-P (TP), mg/L

- Nitrogen as total-N (TN, nitrite and nitrate), mg/L
- Water temperature (^{0}C)

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

Data Analyses Approach

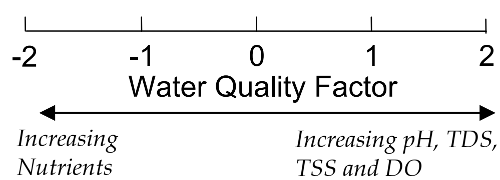
Consistent with analysis conducted on 2004 data, both univariate and multivariate statistical tests were used to explore relationships between water quality and biological variables measured at various wetland sites in Farmington Bay 2005.

In general, multivariate statistical tests such as factor analysis were used to convert multiple water quality variables (pH, TDS, TSS, DO, TP, TN, and water temperature) into a single water quality factor. The water quality factor, as such, conveniently describes the range of water quality variables in a single factor (axis) by scaling these variables across a range of factor scores. Once water quality variables are described by a single water quality factor, biotic variables that describe plants and invertebrate communities can be conveniently scaled against the water quality factor to assess wetland biotic responses to water quality. The overall analytical approach involved:

The Water Quality Factor

A multivariate test known as factor analysis (Systat ver. 11) was used to generate the principal components of the water quality variables including pH, TDS, TSS, DO, nutrients (TP and TN), and water temperature, and also to generate a single factor that described water quality (Exhibit 2). The water quality factor was derived from log-transformed data on individual water quality variables. As such, water quality variables such as pH, TDS, TSS, and water temperature were $\log_{10}$ (X) transformed, whereas TN, TP, and DO were $\log_{10}$ (X+1) transformed to account for data values that included 0. The water quality factor was used in subsequent univariate and multivariate analyses conducted to explore the relationships of biotic variables (plants and invertebrates) to water quality across the various wetland sites.

EXHIBIT 2. Descriptive example of the water quality factor used in the analysis



Univariate Analysis of Biotic Variables and Water Quality

Univariate regression analysis was used to explore the relationships between water quality and plant and macroinvertebrate variables across impounded and sheetflow wetland sites in 2004 and 2005. Specifically, simple regression analysis was conducted to explore the relationships between water quality and functional categories of plants and macroinvertebrates (Table 5) for both 2004 and 2005 data sets.

TABLE 5. SUMMARY OF TYPES OF UNIVARIATE ANALYSIS CONDUCTED TO EXPLORE RELATIONSHIPS BETWEEN WATER QUALITY, PLANT AND MACROINVERTEBRATE DATA.
All relationships of biotic variables (plants and macroinvertebrates) were explored in relation to information on water quality variables (pH, TDS, TSS, nutrients, DO, and water temperature) contained in the Water Quality Factor.

Type of Analysis	Site Hydrology Type	Year of Data Set	Statistical analysis	Comments
Plants				
Number of Native Plant Species vs. Water quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Analysis was conducted on both non-transformed and $\log_{10}$ (X+1) transformed plant data.
Percent of Native Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Number of native plant species as a percent of the total number of species at each wetland site was calculated. Analysis was conducted on both non-transformed and Arcsin-transformed† plant data.
Number of Introduced Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Analysis was conducted on both non-transformed and $\log_{10}$ (X+1) transformed plant data.
Percent of Introduced Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Number of introduced plant species as a percent of the total number of species at each wetland site was calculated. Analysis was conducted on both non-transformed and Arcsin-transformed† plant data.
Number of Invasive Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Analysis was conducted on both non-transformed and $\log_{10}$ (X+1) transformed plant data.

TABLE 5. SUMMARY OF TYPES OF UNIVARIATE ANALYSIS CONDUCTED TO EXPLORE RELATIONSHIPS BETWEEN WATER QUALITY, PLANT AND MACROINVERTEBRATE DATA.
All relationships of biotic variables (plants and macroinvertebrates) were explored in relation to information on water quality variables (pH, TDS, TSS, nutrients, DO, and water temperature) contained in the Water Quality Factor.

Type of Analysis	Site Hydrology Type	Year of Data Set	Statistical analysis	Comments
Percent of Invasive Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	Individual plants species observed at each site were grouped into categories such as natives, introduced and invasive for this analysis. Number of invasive plant species as a percent of the total number of species at each wetland site was calculated. Analysis was conducted on both non-transformed and Arcsin-transformed† plant data.
Total Number of Plant Species vs. Water Quality	Sheetflow Sites Only*	2004 and 2005	Simple Linear Regression or DWLS**	The total number of plant species observed at each wetland site was recorded. Analysis was conducted on both non-transformed and $\log_{10}$ (X+1) transformed plant data.
Macroinvertebrates				
Percent Relative Abundance of Tolerant Species	Impounded and Sheetflow Sites	2004 and 2005	Simple Linear Regressions or DWLS	Macroinvertebrates were grouped into functional categories such as tolerant species, numbers of Ephemeropterans (sensitive species), and trophic categories such as numbers of collector-gatherers, predators, and shredders. Percent relative abundance†† of macroinvertebrate species (arcsin-transformed) belonging to these functional categories was then calculated for each wetland site.
Percent Relative Abundance of Ephemeropterans	Impounded and Sheetflow Sites	2004 and 2005	Simple Linear Regressions or DWLS	Macroinvertebrates were grouped into functional categories such as tolerant species, numbers of Ephemeropterans (sensitive species), and trophic categories such as numbers of collector-gatherers, predators, and shredders. Percent relative abundance†† of macroinvertebrate species (arcsin-transformed) belonging to these functional categories was then calculated for each wetland site.
Percent Relative Abundance of Collector-Gatherer Species	Impounded and Sheetflow Sites	2004 and 2005	Simple Linear Regressions or DWLS	Macroinvertebrates were grouped into functional categories such as tolerant species, numbers of Ephemeropterans (sensitive species), and trophic categories such as numbers of collector-gatherers, predators, and shredders. Percent relative abundance†† of macroinvertebrate species (arcsin-transformed) belonging to these functional categories was then calculated for each wetland site.
Percent Relative Abundance of Predatory Species	Impounded and Sheetflow	2004 and 2005	Simple Linear Regressions	Macroinvertebrates were grouped into functional categories such as tolerant species, numbers of Ephemeropterans (sensitive species), and trophic categories such as

TABLE 5. SUMMARY OF TYPES OF UNIVARIATE ANALYSIS CONDUCTED TO EXPLORE RELATIONSHIPS BETWEEN WATER QUALITY, PLANT AND MACROINVERTEBRATE DATA.
All relationships of biotic variables (plants and macroinvertebrates) were explored in relation to information on water quality variables (pH, TDS, TSS, nutrients, DO, and water temperature) contained in the Water Quality Factor.

Type of Analysis	Site Hydrology Type	Year of Data Set	Statistical analysis	Comments
	Sites		or DWLS	numbers of collector-gatherers, predators, and shredders. Percent relative abundance†† of macroinvertebrate species (arcsin-transformed) belonging to these functional categories was then calculated for each wetland site.
Percent Relative Abundance of Shredder Species	Impounded and Sheetflow Sites	2004 and 2005	Simple Linear Regressions or DWLS	Macroinvertebrates were grouped into functional categories such as tolerant species, numbers of Ephemeropterans (sensitive species), and trophic categories such as numbers of collector-gatherers, predators, and shredders. Percent relative abundance†† of macroinvertebrate species (arcsin-transformed) belonging to these functional categories was then calculated for each wetland site.

* Impounded Sites had only native plant species, so no analysis was conducted on these sites. ** DWLS: Distance Weighted Least Squares.

† Arcsin Transformation = $(2/\prod) * \text{Arcsin}(\sqrt{X_{ij}})$, where X_{ij} = proportion of relative abundance or relative density of species.

†† Percent Relative Abundance = (n/N)*100, where n is the number of invertebrates belonging to each functional category (e.g., predators) and N is the total number of macroinvertebrates, at each wetland site.

A preliminary visual examination of scatterplots of plant and macroinvertebrate variables on the water quality factor often indicated non-linear relationships between these variables. In such cases, a distance-weighted least squares (DWLS) curve fitting method (Systat ver. 11) was used to define these 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. As such, the DWLS method provides a true representation of relationships between sets of observed ecological data.

Summaries of macroinvertebrate tolerances to various environmental variables that were used to derive functional groups in the analyses outlined in Table 5 are also provided in Table 6. Summaries of macroinvertebrate trophic categories used to derive functional groups used in the analyses summarized in Table 5 are provided in Table 4.

TABLE 6. TOLERANCES OF SELECTED MACROINVERTEBRATE TAXA TO ENVIRONMENTAL VARIABLES.
Data on tolerances and preferred habitat of macroinvertebrates are obtained from Gray (2005).
Tolerances to eutrophication, anaerobic conditions, water temperature, pH and conductivity were used in the analysis.

Macroinvertebrate Taxa	Preferred Habitat	Eutrophication (Nutrients)	Anaerobic Conditions	Water Temperature > 30^0C	pH > (.0	Conductivity > 5000 mS	Pesticides (e.g., malathion)	Bti (Bacillus thurengiensis)
EPHEMEROPTERA								
Callibaetis sp.	Lentic +/- aquatic vegetation	(S)	S	V	V	V	S	T
ODONATA								
Ischnura barberi/cervula	Climbers on aquatic vegetation	T	T	T	T	V	S	T
Aeshna californica	Climbers on aquatic vegetation	T	S	T	T	T?	S	T
Erythemis collocata	Sprawlers in silt/mud	(S)	S	T	T	S	S	T
Tramea lacerata	Sprawlers in silt, detritus and vegetation	(S)	S	S	S	S	S	T
HEMIPTERA								
Corisella inscripta	Ponds	V	V	T	V	V	S	T
Hesperocorixa laevigata	Ponds with dense submerged vegetation	T	V	T	V	T	S	T
Notonecta undulate	Ponds	T	V	T	V	T	S	T
Trichocorixa verticalis	Highly saline ponds and the Great Salt Lake	V	V	T	V	V	S	T
DIPTERA								
Chironomus sp.	Lentic benthos	V	T	V	T	T	S	S
Orthocladiinae sp.	Lentic/lotic benthos	V	T	T	T	T	S	S
Tanytarsini sp.	Lentic/lotic benthos	V	T	T	T	T	S	S
GASTROPODA (Pulmonate Snails)								
Physella sp.	Lentic/lotic benthos	V	V	V	V	V	T	T
Stagnicola sp.	Lentic/lotic benthos	V	V	V	V	V	T	T
Gyraulus sp.	Lentic/lotic benthos	V	V	V	V	V	T	T
ANNELIDA (Leeches)								
Erpobdella parva (complex)	Lentic/lotic benthos	V	V	S	T	S	T	T
Glossophonia complanata	Lentic/lotic benthos (rocks)	V	V	S	T	S	T	T
Helobdella stagnalis	Lentic/lotic benthos	V	V	S	T	S	T	T

TABLE 6. TOLERANCES OF SELECTED MACROINVERTEBRATE TAXA TO ENVIRONMENTAL VARIABLES.
Data on tolerances and preferred habitat of macroinvertebrates are obtained from Gray (2005).
Tolerances to eutrophication, anaerobic conditions, water temperature, pH and conductivity were used in the analysis.

Macroinvertebrate Taxa	Preferred Habitat	Eutrophication (Nutrients)	Anaerobic Conditions	Water Temperature > 30°C	pH > (.0	Conductivity > 5000 mS	Pesticides (e.g., malathion)	Bti (Bacillus thurengiensis)
OLIGOCHAETA	Lentic/lotic benthos (muds)	V	V	T	S	S	T	T
CRUSTACEA								
Hyallela azteca	Lentic/lotic benthos	T	S	T	T	S	S	T
Caecidotea occidentalis	Lentic/lotic benthos	T	S	S	S	S	S	T
PLATYHELMINTHES (Planarian flatworms)								
Phagocota sp.	Lentic/lotic benthos	V	T	V	V	(S)	V	T
Dugesia sp.	Lentic/lotic benthos	V	T	V	V	(S)	V	T

KEY: S = Sensitive to the noted environmental variable, as determined from literature, (S) = sensitive to the noted environmental variable, as determined from field data, T = tolerant to the noted environmental variable, V = very tolerant to the noted environmental variable

Multivariate Analysis of Biotic Variables and Water Quality

Factor analysis is used to explore relationships between the plant and macroinvertebrate community and water quality across wetland sites in the Farmington Bay. Factor analysis is a useful method for assessing complex ecological community data with multiple dependent and independent variables. 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, macroinvertebrate factor, plant 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, TSS, conductivity 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 (shown earlier in Exhibit 2).

A summary of the types of multivariate analyses (Factor Analysis) that were conducted to explore the relationships between water quality, plants and macroinvertebrates across wetland sites in 2005 is provided (Table 7).

TABLE 7. SUMMARY OF TYPES OF MULTIVARIATE ANALYSIS CONDUCTED TO EXPLORE RELATIONSHIPS BETWEEN WATER QUALITY, PLANT AND MACROINVERTEBRATE DATA.

Type of Analysis	Site Hydrology Type	Year of Data Set	Statistical analysis	Comments
Plants				
Plant species distributions in relation to water quality across wetland sites	Impounded and Sheetflow sites	2005	Factor Analysis	Percent cover data on plant species observed at each wetland site was Arcsin-transformed† for multivariate analysis to generate a plant species factor. The plant species factor was then scaled against the water quality factor to explore how various plants species grouped across water quality at specific wetland sites.
Macroinvertebrates				
Macroinvertebrate taxa distributions in relation to water quality across wetland sites	Impounded and Sheetflow sites	2005	Factor Analysis	Abundances (X) of macroinvertebrate taxa observed at each wetland site was $\log_{10}$ (X+1) transformed for multivariate analysis to generate a macroinvertebrate taxa factor. The macroinvertebrate factor was then scaled against the water quality factor to explore how various invertebrate taxa grouped across water quality at specific wetland sites.
Macroinvertebrate species diversity in relation to water quality across wetland sites	Impounded and Sheetflow sites	2004 and 2005	Factor Analysis	Species diversity indices (Y) of macroinvertebrates observed at each wetland site was calculated and then $\log_{10}$ (Y+1) transformed for multivariate analysis to generate a macroinvertebrate diversity factor. The macroinvertebrate diversity factor was then scaled against the water quality factor to explore how invertebrate diversity grouped across water quality at specific wetland sites.

† Arcsin Transformation = (2/∏) * Arcsin($\sqrt{X_{ij}}$), where X_{ij} = percent cover of plant species.

Data on the types and numbers of macroinvertebrate species observed at each wetland site was used to estimate species diversity, species richness and species evenness indices for 2004 and 2005. These measures of species diversity, richness and evenness were converted to a single integrated species diversity factor using factor analysis and then used in the multivariate analysis to explore the relationships between species diversity and water quality across wetland sites in 2004 and 2005.

Macroinvertebrate species diversity was estimated using the Shannon-Wiener Diversity index, (N') (Shannon and Weaver 1963, Krebs 1989, McCune and Grace 2002).

$$N' = 10^{H'}$$

$$H' = -\sum_{i=1}^{S} Pi \log Pi$$

where P_i = the proportion of the total number of individuals in the i^{th} species; and S = the number of species.

Species richness (d) was also estimated for macroinvertebrates as an additional measure of diversity (Atlas and Bartha 1981, Krebs, 1989).

$$d = \frac{S - 1}{\log_{10} N}$$

where S = the number of species; and N = the number of individuals.

Species evenness (J) was also calculated (Pielou 1966, 1969; McCune and Grace 2002).

$$J = \frac{H'}{\log_{10} S}$$

where S is the number of species in the sample, and H' is as noted above in the formula for the Shannon-Wiener Diversity Index.

Results

The section presents the results of the analyses conducted on 2004 and 2005 Farmington Bay wetlands data. Presentation of the results follows the analytical approach described in the methods section.

Figures referenced in this section are available at the end of this document.

Site Specific Summary of Plant Percent Cover, 2005

Percent covers of plant species were averaged across site transects and multiple sampling dates to generate a mean percent cover value for each species at a particular site.

SHEETFLOW SITES

All of the sheetflow sites had floating aquatic vegetation, often at high percent covers relative to emergent wetland macrophytes. However, floating aquatic vegetation tends to accumulate in certain spots due to wind effects and water flow. Thus, measures of percent cover of floating aquatic vegetation (*Lemna minor*, *Azola mexicanus,* and also algae) observed in transects may not be true representations of its abundance or density in a particular transect. Thus, the following discussion on plant percent covers in sheetflow sites focuses primarily on emergent wetland plants.

Central Davis Sewer District Site (CDSD)

The emergent macrophytes, *Phragmites australis* and *Typha latifolia* dominated the CDSD site, followed by *Schoenoplectus americanus* and *Schoenoplectus maritimus* (Figure 1). Other macrophytes such as *Salicornia rubra* and *Rumex crispus* represented less than 10 percent of the mean plant cover and algae was also present at this site (Figure 1). Floating aquatic vegetation, *Lemna minor*, had the highest percent cover at the CDSD site (Figure 1), but this may be an artifact of wind and/or flow effects.

Farmington Bay Waterfowl Management Area Sheetflow Site (FBWMAs)

The emergent macrophytes, *Phragmites australis* and *Schoenoplectus maritimus* dominated the FBWMAs site, followed by *Typha dominghensis* and *Schoenoplectus americanus* (Figure 2). Other macrophytes such as *Atriplex micrantha, Bidens cernua, Polygonium lapathifolium, Rumex crispus, Salicornia rubra* were also present at this site but represented less than 5 percent of the mean plant cover (Figure 2). Floating aquatic vegetation, *Lemna minor* and *Azola mexicanus,* and algae were also present at the FBWMAs site (Figure 2).

Kays Creek Site (KC)

Typha latifolia, Phragmites australis and *Schoenoplectus americanus* had the highest percent coves at the KC site, followed by *Schoenoplectus maritimus* and *Bidens cernua* (Figure 3). *Schoenoplectus acutus* represented less than 1 percent of mean plant cover at this site (Figure 3). Floating aquatic vegetation, *Lemna minor*, and algae were also present at the KC site (Figure 3).

North Davis Sewer District Site (NDSD)

The NDSD site had, in general, more plant species than other sites. *Alopecurus aequalis, Phalaris arundanecea, Phragmites australis, Salicornia rubra* and *Schoenoplectus maritimus* had the highest mean percent covers (12-35 percent cover range), followed by *Atriplex micrantha, Bidens cernua, Polygonium lapathifolium, Schoenoplectus acutus, Schoenoplectus americanus* and *Typha dominghensis* (5-10 percent cover range) (Figure 4). *Rumex crispus and Typha latifolia* were also present but represented less than 3 percent of mean plant cover collectively (Figure 4). Floating aquatic vegetation, *Lemna minor* was also present at the NDSD site (Figure 4).

Public Shooting Grounds Sheetflow Sites (PSGs)

Desert saltgrass, *Distichlis spicata,* dominated the PSGs site, followed by *Schoenoplectus americanus* and *Schoenoplectus maritimus* (Figure 5). *Hordeum jubatum* was also present but represented less than 4 percent of the mean plant cover at the PSGs site (Figure 5). Floating aquatic vegetation, *Azola mexicanus*, and algae were also present at the PSGs site (Figure 5).

IMPOUNDED SITES

The impounded wetland sites had, in general, far fewer plant species than sheetflow sites. All four plant species observed at the impounded sites were native species.

Ambassador Site (AMBAS)

Stuckenia species (pondweeds) had the highest percent cover at the AMBAS site, followed by *Ruppia cirrhosa* and *Ceratophyllum demersum*, both of which had percent covers below 5 percent (Figure 6). *Chara* species was not observed in the transects at the AMBAS site.

Farmington Bay Waterfowl Management Area Impounded Site (FBWMA)

Stuckenia species was the only dominant plant at the FBWMA site, followed by *Ceratophyllum demersum* at less than 1 percent cover (Figure 7). Both *Chara* and *Ruppia cirrhosa* were absent from the transects sampled at the FBWMA site.

Inland Sea Shorebird Refuge Site (ISSR)

Stuckenia species had the highest percent cover at the ISSR site, followed by *Ruppia cirrhosa* and *Chara* species, both of which had a combined percent cover below 6 percent (Figure 8). *Ceratophyllum demersum* was not observed in the transects at the ISSR site.

New State Site (NEW)

Stuckenia species was the only dominant plant at the NEW site, followed by *Ceratophyllum demersum* at less than 1 percent cover (Figure 9). Both *Chara* and *Ruppia cirrhosa* were absent from the transects sampled at the NEW site.

Public Shooting Grounds Impounded Site (PSG)

Both *Stuckenia* and *Chara* species had relatively high percent covers and were the only two plant species observed at the PSG site (Figure 10). *Ruppia cirrhosa* and *Ceratophyllum demersum* were both absent in the transects at the PSG site.

Site Specific Summary of Macroinvertebrate Numbers, 2005

Numbers of macroinvertebrates were averaged across site transects and multiple sampling dates to generate a mean number (abundance) for each taxa at a particular site.

SHEETFLOW SITES

Central Davis Sewer District Site (CDSD)

Crustaceans (*Hyallela azteca)* and chironomids (midges) were the most abundant macroinvertebrate taxa observed in samples collected at CDSD, followed by annelids (leeches), gastropods (snails) and odonates (damselflies and dragonflies) (Figure 11).

Ephemeropterans (mayflies), hemipterans (corixids and notonectids), Platyhelminthes (flatworms) and coleopterans (beetles) were relatively far less abundant (Figure 11).

Farmington Bay Waterfowl Management Area Sheetflow Site (FBWMAs)

Crustaceans (*Hyallela azteca)* were the most abundant macroinvertebrate taxon observed in samples collected at FBWMAs, followed by gastropods, chironomids, and hemipterans (Figure 12). Ephemeropterans, odonates, annelids and coleopterans were relatively far less abundant (Figure 12).

Kays Creek Site (KC)

The Kays Creek site was dominated by hemipterans, mostly corixids (Figure 13). Ephemeropterans, odonates, chironomids, gastropods, crustaceans, platyhelminthes, annelids and coleopterans were also observed in the samples, their mean numbers were relatively lower (Figure 13).

North Davis Sewer District Site (NDSD)

Compared to other sheetflow sites, relatively fewer macroinvertebrate taxa were observed at the NDSD site. This site was overwhelmingly dominated by chironomids, followed by hemipterans, the next most abundant taxon (Figure 14). Odonates, gastropods, annelids, and coleopterans were also observed in samples collected at this site, but in far fewer numbers (Figure 14).

Public Shooting Grounds Sheetflow Sites (PSGs)

Hemipterans and ephemeropterans were the most abundant taxa at the PSGs site, followed by gastropods and chironomids (Figure 15). Odonates, crustaceans and coleopterans were also observed, but in relatively lower numbers (Figure 15).

IMPOUNDED SITES

Ambassador Site (AMBAS)

The AMBAS site was dominated by crustaceans, chironomids and hemipterans (Figure 16). Ephemeropterans, odonates and gastropods were also observed, but in relatively fewer numbers, whereas annelids and coleopterans were rare in the samples (Figure 16).

Farmington Bay Waterfowl Management Area Impounded Site (FBWMA)

Crustaceans, odonates and hemipterans were abundant at the FBWMA site, followed by relatively fewer numbers of ephemeropterans and gastropods (Figure 17). Chironomids, annelids, and coleopterans were also observed, but were relatively rare in the samples collected at FBWMA(Figure 17).

Inland Sea Shorebird Refuge Site (ISSR)

The ISSR site was dominated by chironomids and hemipterans (Figure 18). Ephemeropterans, odonates, gastropods, crustaceans and coleopterans were also observed but in relatively fewer numbers (Figure 18). In contrast to other impounded sites, large numbers of the dipteran *Ephydra*, were observed in the June 22 sample collected at the ISSR site; this was included in the “other” category (Figure 18).

New State Site (NEW)

Samples of macroinvertebrates collected at the NEW site were mainly represented by hemipterans, odonates, gastropods, crustaceans and chironomids (Figure 19). Ephemeropterans, annelids and coleopterans are also observed, but at relatively lower abundances (Figure 19).

Public Shooting Grounds Impounded Site (PSG)

Crustaceans, chironomids, hemipterans, gastropods and odonates were all abundant at the PSG site, followed by fewer numbers of ephemeropterans, annelids and platyhelminthes (Figure 20). Coleoptera and acari (mites) were also observed in the samples, but were extremely rare (Figure 20).

Univariate Analysis of Biotic Variables and Water Quality

Simple regression analysis or DWLS analysis was conducted to explore the relationships between water quality and functional categories of plants and macroinvertebrates (Table 5) for both 2004 and 2005 data sets. All biotic variables were scaled to the water quality factor (EXHIBIT 2).

Native, Introduced and Invasive Plant Species in Relation to Water Quality: 2004

All impounded sites had only native plant species (of which none were invasive plants), so this analysis focused on sheetflow sites which had a mix of native, introduced and invasive (NII) plant species. No significant linear relationships were observed between the numbers or proportions of native, introduced or invasive plant species and the water quality factor at sheetflow sites. However, distance-weighted least squares (DWLS) revealed a number of non-linear relationships between the numbers or proportions of NII plant species and water quality (Figures 21-32). For each category of plant species, the analysis was conducted on species numbers and proportions, as well as their $\log_{10}$-transformed or arcsin-transformed values (for example, native species – Figures 21-24).

The number of native species observed was lower on both extremes of the water quality factor, where nutrient levels were high on one end and where nutrient levels were low but pH, TDS, and DO were high on the other end (Figures 21-22). However, in relation to the number of native plant species, the proportion of native species showed an inverted curve trend across the water quality factor (Figures 23-24), mostly due to the increase in the numbers and proportions of introduced plant species at sites that fell in the mid-range of the water quality factor (Figures 25-28). The PSGs reference sites had 100 percent native plant species, along with other sites that included some transects of the NDSD and CDSD sites (POTW sites) (Figure 23). However, some transects at the POTW sites (N1, N2, C3, C4) and KC site (K1, K3) had reduced percent native plant species (Figure 23) and an increased proportion of introduced plant species (Figure 27).

Invasive plant species were present at most of the sites sampled, including the reference (Ps1-Ps3) and POTW sites (C1-C3, N1-N3) (Figures 29-30). Some of the POTW site transects (N1, N2, and C3) and the KC site transects (K1-K3) had higher numbers of invasive plants than other sites (Figures 29-30). No strong trends were observed between water quality and the percent of invasive plant species observed at specific sites (Figures 31-32). The slight non-linear trend in percent invasive plant species across water quality is likely an artifact of one POTW transect (C4), which had no invasive plant species (Figures 31-32).

The total number of plant species (a measure of species diversity) was non-linearly correlated with water quality, with plant diversity lower at both extremes of the water quality factor, with nutrient levels on one end and low nutrient levels but higher pH, TDS, and DO on the other end (Figures 33-34), indicating that high nutrients may be limiting species diversity on one end, with high TDS likely limiting plant diversity on the other extreme.

Native, Introduced and Invasive Plant Species in Relation to Water Quality: 2005

As was the case in 2004, all impounded sites in 2005 had only native plant species (of which none were invasive plants). Therefore, the analysis for 2005 data focused on sheetflow sites where a mixture of native, introduced and invasive (NII) plant species were observed. In general, no significant relationships (linear or non-linear) were observed between the numbers or proportions of native, introduced or invasive plant species and the water quality factor at sheetflow sites in 2005. The plant dataset for 2005 generally had a lot of variability as it included data from multiple seasons (the 2004 data, in contrast was mainly from only one season). Seasonal variability in plant species will likely dilute any trends of species across water quality. However, in spite of seasonal variability, this analysis is still useful as it allows insights into how various sites cluster together in relation to water quality. The 2005 analysis will thus focus on site clustering based on NII plant species in relation to water quality. For each category of plant species, the analysis was conducted on species numbers and proportions, as well as their $\log_{10}$-transformed or arcsin-transformed values (Figures 35-48).

Generally, the number of native plant species is higher at some of the nutrient-rich POTW sites (particularly NDSD sites N1 and N2) than at the PSGs reference sites (Ps1-Ps3) (Figures 35-36). The number of native plant species declines in general with decreasing nutrients and increasing pH, TDS, conductivity and DO (Figures 35-36). Native plant species in proportion to the total number of plant species (percent native species) are generally high, with 100 percent native plants observed in most sites through the different seasons sampled (Figures 37-38). Some of the POTW sites (N1-N3 and C3) including two reference site transects (Ps1 and Ps3 sampled in September) had fewer percent native plant species (Figures 37-38), likely due to the presence of introduced species at those sites (Figures 3-42).

Consistent with 2004 data, invasive plant species were present at most of the sites sampled in 2005, including the reference (Ps1-Ps3) and POTW sites (C1-C3, N1-N3) (Figures 43-46). Some of the POTW site transects (N1 and C3), the KC (K1) and the FBWMAs (Fs1) site transects had higher numbers of invasive plants than other sites (Figures 43-44). No strong trends were observed between water quality and the percent of invasive plant species observed at specific sites but notably, the PSGs reference site (Ps1-Ps3) had a high proportion of invasive plant species (30-70 percent), even exceeding the percent of invasive plants found at several of the POTW sites (Figures 45-46). Consistent with 2004 data, the C4 (CDSD) POTW site transect had no invasive species (Figures 45-46).

The total number of plant species (a measure of species diversity) was correlated with water quality, with plant diversity generally higher at several of the high nutrient POTW sites (particularly NDSD site) than at the reference sites (Ps) with lower nutrient levels and high pH, TDS, conductivity and DO (Figures 47-48), indicating that high TDS, among other factors, may be limiting plant species diversity at the reference sites.

Functional Categories of Invertebrates in Relation to Water Quality: 2004

IMPOUNDED SITES - 2004

Relative Abundance of Tolerant Macroinvertebrate Species: The relative abundance of tolerant macroinvertebrate species (percent tolerant species) generally declined with decreasing nutrient levels and increasing pH, TDS, conductivity and DO (Figure 49). However, the relationship between the water quality factor and relative abundance of tolerant macroinvertebrate species was not statistically significant (at $\alpha = 0.05$ level) due to variability in the data (Table 8). The PSG reference sites (P1-P3) generally had relatively fewer tolerant macroinvertebrate species than the nutrient-rich sites (Figure 49).

Relative Abundance of Ephemeroptera (Mayflies): Mayflies are extremely sensitive to various water quality parameters, including eutrophication and anaerobic conditions (Table 5) and are a useful indicator of conditions in aquatic ecosystems. The relative abundance of mayflies (primarily *Callibaetis* sp.) generally increased with decreasing nutrient levels and increasing pH, TDS, conductivity and DO (Figure 50), and the relationship between the water quality factor and relative abundance of mayflies was statistically significant (at $\alpha = 0.05$ level) (Table 7). The PSG reference sites (P1-P3) had the highest numbers of mayflies relative to other sites (Figure 50), indicating generally favorable water quality (low nutrients, high DO) at those sites.

Relative Abundance of Collector-Gatherer Macroinvertebrate Species: A non-linear relationship was observed between the relative abundance of collector-gatherers (functional feeding group) and water quality (Table 8). The relative abundance of collector-gatherers was constant across sites with relatively high nutrient levels, but increased sharply with declining nutrient loads at the PSG reference sites, P1-P3 (Figure 51). Collector-gatherers at the reference sites were primarily represented by mayflies and *Hyallela*, both of which are relatively sensitive invertebrate taxa, and some of the more tolerant chironomids.

TABLE 8. REGRESSION ESTIMATES OF MACROINVERTEBRATE COMMUNITY RESPONSES TO THE WATER QUALITY FACTOR AT IMPOUNDED SITES IN 2004.
Regressions are of the form: Invertebrate Community Factor (Y) = α + β*Water Quality Factor Score (X), where α is the Y intercept and β is the slope of the relationship. For each functional group analysis, arcsin-transformed values of invertebrate functional parameters were regressed on the water quality factor scores.

Invertebrate Community Factor	α	β	N	R^2	F	p
FUNCTIONAL GROUP ANALYSIS						
Independent variable (X):						
Percent Relative Abundance of Tolerant Species	0.49	-0.05	10	0.346	4.23	0.074 (49)
Percent Relative Abundance of Ephemeroptera	0.28	0.13	10	0.562	10.27	0.013** † (50)
Percent Relative Abundance of Collector-Grazers	0.56	0.03	10	0.270	2.96	0.124 † (51)

TABLE 8. REGRESSION ESTIMATES OF MACROINVERTEBRATE COMMUNITY RESPONSES TO THE WATER QUALITY FACTOR AT IMPOUNDED SITES IN 2004.
Regressions are of the form: Invertebrate Community Factor (Y) = α + β*Water Quality Factor Score (X), where α is the Y intercept and β is the slope of the relationship. For each functional group analysis, arcsin-transformed values of invertebrate functional parameters were regressed on the water quality factor scores.

Invertebrate Community Factor	α	β	N	R^2	F	p
FUNCTIONAL GROUP ANALYSIS						
Independent variable (X):						
Percent Relative Abundance of Tolerant Species	0.49	-0.05	10	0.346	4.23	0.074 (49)
Percent Relative Abundance of Ephemeroptera	0.28	0.13	10	0.562	10.27	0.013** † (50)
Percent Relative Abundance of Predators	0.36	-0.03	10	0.233	2.43	0.157 (52)
Percent Relative Abundance of Shredders	0.21	0.003	10	0.002	0.01	0.910 † (53)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. ** denotes a significant linear relationship between the variables. † indicates that a non-linear relationship may also exists between the variables. Corresponding Figure numbers (in parentheses) are also referenced.

Relative Abundance of Predator Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of macroinvertebrate predators and water quality (Figure 52, Table 8).

Relative Abundance of Shredder Macroinvertebrate Species: A significant non-linear relationship was observed between shredder macroinvertebrates and water quality (Figure 53, Table 8). The highest numbers of shredders were observed at intermediate levels of the water quality factor, primarily in transects at the AMBAS (A2) and NEW (NW2) sites (Figure 53).

SHEETFLOW SITES - 2004

Relative Abundance of Tolerant Macroinvertebrate Species: A significant non-linear relationship was observed between tolerant species and water quality (Figure 54, Table 9). The relative abundance of tolerant macroinvertebrate species was constant across sites with high nutrient loads and then rapidly declined with decreasing nutrient levels and increasing pH, TDS, conductivity and DO (Figure 54). The PSGs reference sites (Ps1-Ps3) had the lowest abundance of tolerant species (Figure 54).

Relative Abundance of Ephemeroptera (Mayflies): A significant non-linear relationship was observed between the relative abundance of mayflies and water quality (Figure 55, Table 8). Mayflies were relatively rare at sites with high nutrient loads (primarily POTW sites C1-C4 and N1-N3), bur rapidly increased at the PSGs reference sites where nutrient levels were low and pH, TDS, conductivity and DO were all relatively higher (Figure 55).

TABLE 9. REGRESSION ESTIMATES OF MACROINVERTEBRATE COMMUNITY RESPONSES TO THE WATER QUALITY FACTOR AT SHEET FLOW SITES IN 2004.
Regressions are of the form: Invertebrate Community Factor (Y) = α + β*Water Quality Factor Score (X), where α is the Y intercept and β is the slope of the relationship. For each functional group analysis, arcsin-transformed values of invertebrate functional parameters were regressed on the water quality factor scores.

Invertebrate Community Factor	α	β	N	R^2	F	p
FUNCTIONAL GROUP ANALYSIS						
Independent variable (X):						
Percent Relative Abundance of Tolerant Species	0.84	-0.114	10	0.275	3.04	0.120 † (54)
Percent Relative Abundance of Ephemeroptera	0.09	0.09	10	0.187	1.84	0.213 † (55)
Percent Relative Abundance of Collector-Grazers	0.50	0.17	10	0.361	4.53	0.066 (56)
Percent Relative Abundance of Predators	0.45	-0.18	10	0.421	5.81	0.042 ** (57)
Percent Relative Abundance of Shredders	0.13	0.013	10	0.035	0.30	0.602 (58)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. ** denotes a significant linear relationship between the variables. † indicates that a non-linear relationship may exist between the variables. Corresponding Figure numbers (in parentheses) are also referenced.

Relative Abundance of Collector-Gatherer Macroinvertebrate Species: The relative abundance of collector-grazer macroinvertebrate species generally increased with decreasing nutrient levels and increasing pH, TDS, conductivity and DO (Figure 56). However, the relationship between the water quality factor and relative abundance of collector-grazer macroinvertebrate species was not statistically significant (at α = 0.05 level) due to variability in the data (Table 9). The PSG reference sites (P1-P3) generally had relatively more collector-grazer macroinvertebrate species than some of the nutrient-rich sites, with the exception of the NDSD sites (N1 and N2) (Figure 56).

Relative Abundance of Predator Macroinvertebrate Species: A significant linear relationship was observed between the relative abundance of macroinvertebrate predators and water quality (Figure 57, Table 9). The relative abundance of macroinvertebrate predators was typically higher at some of the nutrient-rich POTW sites than at the PSGs reference sites. Most of the macroinvertebrates at those POTW sites were flatworms, leeches and odonates, all of which are functionally classified as predators. In addition, the KC sites were dominated by predatory macroinvertebrates (Figure 57).

Relative Abundance of Shredder Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of shredder macroinvertebrates and water quality (Figure 58, Table 9).

Functional Categories of Invertebrates in Relation to Water Quality: 2005

IMPOUNDED SITES - 2005

Typically, no significant relationships were observed between functional categories of macroinvertebrates and water quality in 2005, likely due to variation caused by the inclusion of macroinvertebrate data from multiple seasons for each site (Figures 59-62, Table 9).

Relative Abundance of Tolerant Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of tolerant macroinvertebrate species and water quality (Figure 59, Table 10).

TABLE 10. REGRESSION ESTIMATES OF MACROINVERTEBRATE COMMUNITY RESPONSES TO THE WATER QUALITY FACTOR AT IMPOUNDED SITES IN 2005.
Regressions are of the form: Invertebrate Community Factor (Y) = $\alpha + \beta$*Water Quality Factor Score (X), where α is the Y intercept and β is the slope of the relationship. For each functional group analysis, arcsin-transformed values of invertebrate functional parameters were regressed on the water quality factor scores.

Invertebrate Community Factor	α	β	N	R^2	F	p
FUNCTIONAL GROUP ANALYSIS						
Independent variable (X):						
Percent Relative Abundance of Tolerant Species	0.62	0.01	45	0.001	0.05	0.821 (59)
Percent Relative Abundance of Ephemeroptera	0.09	0.002	45	0.001	0.03	0.856 (60)
Percent Relative Abundance of Collector-Grazers	0.45	0.03	45	0.038	1.71	0.198 (61)
Percent Relative Abundance of Predators	0.50	0.01	45	0.001	0.04	0.837 (62)
Percent Relative Abundance of Shredders	0.13	-0.05	45	0.165	8.47	0.006 ** (63)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. ** denotes a significant linear relationship between the variables. † indicates that a non-linear relationship may also exists between the variables. Corresponding Figure numbers (in parentheses) are also referenced.

Relative Abundance of Ephemeroptera (Mayflies): No significant linear or non-linear relationships were observed between the relative abundance of mayflies and water quality (Figure 60, Table 10).

Relative Abundance of Collector-Gatherer Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of collector-gatherer macroinvertebrate species and water quality (Figure 61, Table 10).

Relative Abundance of Predator Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of macroinvertebrate predators and water quality (Figure 62, Table 10).

Relative Abundance of Shredder Macroinvertebrate Species: A significant linear relationship was observed between shredder macroinvertebrates and water quality

(Figure 63, Table 10). High numbers of shredders were generally observed at more nutrient-rich (Figure 63).

SHEETFLOW SITES - 2005

Relative Abundance of Tolerant Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of tolerant macroinvertebrate species and water quality (Figure 64, Table 11).

Relative Abundance of Ephemeroptera (Mayflies): Consistent with observations at sheetflow sites in 2004, a significant non-linear relationship was also observed between the relative abundance of mayflies and water quality in 2005 (Figure 65, Table 11). Mayflies were relatively rare at sites with high nutrient loads (primarily POTW sites C1-C4 and N1-N3), bur rapidly increased at the PSGs reference sites where nutrient levels were low and pH, TDS, conductivity and DO were all relatively higher (Figure 65). Some mayflies were also found at the KC (K3) site (Figure 65).

TABLE 11. REGRESSION ESTIMATES OF MACROINVERTEBRATE COMMUNITY RESPONSES TO THE WATER QUALITY FACTOR AT SHEET FLOW SITES IN 2005.
Regressions are of the form: Invertebrate Community Factor (Y) = α + β*Water Quality Factor Score (X), where α is the Y intercept and β is the slope of the relationship. For each functional group analysis, arcsin-transformed values of invertebrate functional parameters were regressed on the water quality factor scores.

Invertebrate Community Factor	α	β	N	R^2	F	p
FUNCTIONAL GROUP ANALYSIS						
Independent variable (X):						
Percent Relative Abundance of Tolerant Species	0.66	-0.004	30	0.001	0.01	0.942 (64)
Percent Relative Abundance of Ephemeroptera	0.07	0.08	30	0.312	12.70	0.001 ** (65)
Percent Relative Abundance of Collector-Grazers	0.49	-0.114	30	0.246	9.13	0.005 ** (66)
Percent Relative Abundance of Predators	0.42	0.11	30	0.220	7.91	0.009 ** (67)
Percent Relative Abundance of Shredders	0.19	0.03	30	0.039	1.14	0.294 (68)

NOTES: p values > 0.05 indicate that a linear relationship between variables is not significant. ** denotes a significant linear relationship between the variables. † indicates that a non-linear relationship may exist between the variables. Corresponding Figure numbers (in parentheses) are also referenced.

Relative Abundance of Collector-Gatherer Macroinvertebrate Species: A significant linear relationship was observed between the relative abundance of collector-gatherers and water quality. The relative abundance of collector-grazer macroinvertebrate species declined with decreasing nutrient levels and increasing pH, TDS, conductivity and DO (Figure 66, Table 11). The PSG reference sites (P1-P3) generally had relatively lower abundances of collector-grazer macroinvertebrate species than several of the nutrient-rich POTW sites (Figure 66).

Relative Abundance of Predator Macroinvertebrate Species: A significant linear relationship was observed between the relative abundance of macroinvertebrate predators and water quality (Figure 67, Table 11). The relative abundance of macroinvertebrate predators was typically lower at most of the nutrient-rich POTW sites than at the PSGs reference sites (Figure 67).

Relative Abundance of Shredder Macroinvertebrate Species: No significant linear or non-linear relationships were observed between the relative abundance of shredder macroinvertebrates and water quality (Figure 68, Table 11).

Multivariate Analysis of Biotic Variables and Water Quality

Factor analysis was used to explore relationships between water quality and species distributions of plants and macroinvertebrates across sheetflow and impounded wetland sites (Table 6). Factor analysis involved the computation of biotic factor variables such as the plant factor which parsimoniously summarized the percent covers of various species and the macroinvertebrate diversity and macroinvertebrate species factors which contained information on species diversity indices and macroinvertebrate abundances, respectively, across wetland sites.

Plant Species Distributions in Relation to Water Quality – 2005

SHEETFLOW SITES - 2005

The plant factor included arcsin-transformed percent covers of the various plant species observed across the sheetflow sites. The water quality factor included pH, dissolved oxygen, total dissolved solids, conductivity, total N and total P (nutrients) concentrations. Plots of wetland sampling sites that are based on the plant and water quality factor scores for each site is shown in Figures 69 and 70 (without and with DWLS line). Low values on the water quality factor axis reflect freshwater habitats (low TDS, low conductivity, low pH, low dissolved oxygen) with high nutrient (N+P) loads. High values represent more saline habitats that are relatively low in nutrients. Sites in-between represent more moderate water chemistry.

On the plant factor axis, three distinct groupings of plant species were observed. Overall, the factor plots (Figures 69 and 70) indicated a trend of plant groupings changing from more freshwater, eutrophic sites to more oligotrophic, saline sites. In general, freshwater, eutrophic sites (including the POTW sites, NDSD, and CDSD) were dominated by plant species such *Alopecurus aqualis, Atriplex micrantha, Bidens cernua, Phalaris arundinacea, Polygonium lapathifolium, Salicornia rubra and Schoenoplectus acutus* and another plant group characterized by species such as *Phragmites australis, Rumex crispus, Typha dominghensis and Lemna minor*. Conversely, more oligotrophic and saline sites (including the reference sites at PSGs) were dominated by plant species such as *Distichlis spicata, Hordeum jubatum, Schoenoplectus americanus, Schoenoplectus maritimus, Typha latifolia.* The floating plants *Azola mexicanus* and algae were also more dominant at these sites.

IMPOUNDED SITES – 2005

No distinct trends in plant species groupings were observed in relation to the water quality factor at impounded wetland sites in 2005. However, two plant groupings were observed across sites, one with *Ruppia cirrhosa* which was present at some of the AMBAS (A3 and A4) and ISSR (I1 and I3) sites, and the other plant group consisting of *Stuckenia* species, *Chara* sp. and *Ceratophyllum demersum* which were found at the remainder of the sites, including the PSG reference sites (Figure 71).

Macroinvertebrate Taxa Distributions in Relation to Water Quality – 2005

IMPOUNDED SITES - 2005

No distinct trends in invertebrate taxa groupings were observed in relation to the water quality factor at impounded wetland sites in 2005. However, two macroinvertebrate taxa groupings were observed across sites, mainly due to the presence of relatively large numbers of annelids (leeches), platyhelminthes (flatworms) and gastropods (snails) at a transect in the reference PSG (P3) site, which were not as abundant at other sites (Figure 72). While crustaceans were also present at most of the other impounded wetland sites, these were mostly characterized by Ephemeropterans (mostly at the reference PSG (P1-3) sites), hemipterans, odonates, coleopterans and chironomids (Figure 72).

SHEETFLOW SITES – 2005

Macroinvertebrate species distributions across sheetflow sites were distinctly related to the water quality factor. Low values on the invertebrate factor axis (Figure 73) represent sites dominated crustaceans (mainly *Hyallela azteca*), flatworms (Platyhelminthes) and leeches (Annelida) whereas high values reflect sites dominated by mayflies (Ephemeroptera), water boatman and backswimmers (Hemiptera), beetles (Coleoptera), snails (Gastropoda), damselflies and dragonflies (odonates) and midges (chironomids). Overall, a general trend was observed, where more eutrophic, freshwater sheetflow sites (including some of the POTW sites, especially some CDSD sites) were dominated by crustaceans, flatworms and leeches, while more saline, oligotrophic sites were characterized by mayflies, water boatman, backswimmers, beetles, snails damselflies/dragonflies and chironomids. (Figure 73). Chironomids were especially abundant at the NDSD (N1-N3) site.

Macroinvertebrate Species Diversity in Relation to Water Quality

The macroinvertebrate species diversity factor included information on species diversity (Shannon-Wiener diversity index), species richness (d) and species evenness (J) in a single factor. High values on the species diversity factor indicate relatively high species diversity, richness and evenness, low values indicate relatively low species diversity, richness and evenness across wetland sites (Figures 74-77).

IMPOUNDED SITES – 2004

No distinct trend in invertebrate species diversity groupings was observed in relation to the water quality factor at impounded wetland sites in 2004. Species diversity factor values were lower at some of the PSG reference wetland transects (P1 and P2) (Figure 74).

SHEETFLOW SITES – 2004

No trend in invertebrate species diversity groupings was observed in relation to the water quality factor at sheetflow wetland sites in 2004. Species diversity factor values for the POTW sites (NDSD and CDSD) were approximately equal to or lower than those for the

PSGs reference sites (Figure 75). For example, certain POTW site transects (C2, C3 and N3) had species diversity factor values that were approximately equal to or higher than the reference sites (Ps1-Ps3), while other POTW transects (C1, C4, N1, N2) had lower diversity factor values than the reference sites (Figure 75).

IMPOUNDED SITES – 2005

A slight trend in invertebrate species diversity groupings was observed in relation to the water quality factor at impounded wetland sites in 2005, but this was likely influenced by two Newstate site transects (NW1 and NW2) with high species diversity factor values (Figure 76).

SHEETFLOW SITES – 2005

Invertebrate species diversity was linearly related the water quality factor at sheetflow wetland sites in 2005. Species diversity factor values for some the POTW sites (mostly all of the NDSD sites, N1-N3) were lower than those for the PSGs reference sites (Figure 77). However, certain POTW site transects (e.g., C1 and C3) had species diversity factor values that were approximately equal to or higher than the reference sites (Ps1-Ps3) (Figure 77).

Conclusions

This technical memorandum mainly represents the second year of an ongoing effort to characterize the wetland systems of Farmington Bay. The purpose of this analysis was to provide an in-depth evaluation of key biological and water quality parameters components in the Farmington Bay wetlands that – as part of an ongoing effort – would assist in characterizing the wetlands and defining its beneficial uses. Together, with the first year of analysis conducted on 2004 data (CH2M HILL 2005), this analysis offers useful insights into potential biological and environmental metrics that may be useful in evaluating wetland function in relation to water quality at POTW, other test sites and reference sites.

Conclusions based on the analysis conducted in this study are:

- While impounded wetland sites provided valuable information on variances in water quality conditions and the general response of plants and macroinvertebrate communities to those conditions, the sheetflow sites which included both the POTW effluent discharge sites (CDSD and NDSD), overall provided a better range of conditions to facilitate the comparison of wetland plant and invertebrate responses to water quality.

- At both impounded and sheetflow wetland sites, water quality conditions differed among the wetland sites and ranged from mostly freshwater, nutrient-rich (eutrophic) conditions to more saline, nutrient-poor (oligotrophic) conditions. This range of water quality conditions allowed an assessment of how plant and invertebrate communities responded to water quality in Farmington Bay wetlands. Sheetflow sites included the POTW sites (CDSD and NDSD) with freshwater and high nutrient (total N and P) loads, sites with more intermediate water quality (KC and FBWMAs) and the PSGs reference sites which were more saline and oligotrophic. These sites provided a wide range of water quality conditions under which one could assess the responses of the plant and macroinvertebrate communities. In general, compared to impounded sites, a stronger set of biotic metrics and responses emerged from the evaluation of sheetflow sites.

- Impounded sites were characterized by four plant species, *Stuckenia* sp., *Chara* sp., *Ruppia cirrhosa*, and *Ceratophyllum demersum*. Of these, the pondweed *Stuckenia* sp. dominated all of the impounded wetland sites in terms of percent cover. In contrast, plant species diversity was higher at the sheetflow wetland sites, which collectively contained in excess of fifteen emergent macrophyte species.

- Among the sheetflow sites, plant species diversity in both years (2004 and 2005) was higher at some transects in the freshwater, nutrient-rich POTW sites than at any of the more saline, oligotrophic reference sites. High nutrient levels and freshwater conditions at these sites may be promoting plant species diversity. It is likely that higher salinity at the reference sites, among other factors, may be limiting plant species diversity.

- For both 2004 and 2005, the number of invasive plant species was higher at some transects in the freshwater, nutrient-rich POTW sites than at some of the more saline, oligotrophic reference sites. High nutrient levels and freshwater conditions at these sites may overall be promoting plant species diversity, but at the same time may be contributing to the establishment of more aggressive invasive plant species.

- In terms of some of the beneficial uses of Farmington Bay wetlands, the wetland macrophytes serve an important function by providing structural habitat for nesting bird species. Ongoing field studies have indicated that bird species such as American Avocets and Black-neck Stilts will often nest among stands of *Typha* and *Schonoeplectus*. Both these plant species are thrive at the POTW sites and could potentially be used by birds for refuge and nesting. Data on the nesting success of birds at the POTW sites in relation to the reference sites at the PSGs is needed to more directly assess beneficial uses.

- There are several unknowns that may be affecting plant community dynamics at the impounded sites. These are the presence of herbivorous carp in the impounded sites and the periodic draining and hydrological management of impounded reference sites at the PSG. More information on these factors is needed to evaluate how these may be affecting plant community dynamics at those sites.

- Some of the macroinvertebrate invertebrate taxa observed at the wetland sites served as extremely sensitive indicators of water quality. A consistently sensitive indicator of water quality (both in 2004 and 2005) was the number of Ephemeropterans (mayflies). In both impounded and sheetflow sites, mayflies were typically far more abundant at the relatively saline, oligotrophic reference sites, than at the freshwater, more eutrophic, POTW sites.

- Generally, tolerant macroinvertebrate species were more abundant at the freshwater nutrient-rich sites (including POTW sites), than at the more saline, oligotrophic reference sites. Tolerant macroinvertebrates such as flatworms, leeches, gastropods and chironomids were usually abundant at POTW sites. These sites also contained some hemipterans and crustaceans. While the reference sites also contained some of the macroinvertebrate taxa observed at the POTW sites, they were dominated by pollution sensitive species such as Ephemeropterans (mayflies) and odonates (damselflies and dragonflies.

- Invertebrate species diversity was generally higher at the more saline, oligotrophic reference sites than at some of the POTW site transects (2005 data). Some of the NDSD POTW site transects had the lowest macroinvertebrate species diversity, and were overwhelmingly dominated by chironomids, a tolerant species.
- In terms of the beneficial uses of Farmington Bay wetlands, wetland macroinvertebrates serve an important function by providing forage for bird species. Ongoing field studies have indicated that chironomids and corixids (hemiptera) are important prey items in the diets of bird species such as American Avocets and Black-neck Stilts, with chironomids contributing in excess of 95 percent of the diet of the American avocets sampled (data provided by John Cavitt, Weber State University). Chironomids and corixids thrive at the POTW sites and could potentially be used by birds for forage. Additional data on the feeding habits of birds at the POTW sites in relation to the reference sites at the PSGs is needed to more directly assess these beneficial uses.
- There are some unknowns that may be affecting macroinvertebrate community dynamics at the wetland sites. Many of these sites are treated for vector control which includes treatment with the biotic agent *Bacillus thurengiensis (Bti)*, as well as chemical pesticides. Depending on the vector control agent used, these can eliminate or reduce the abundance of certain types of macroinvertebrates (chironomids, mayflies, odonates, hemipterans and crustaceans) that are sensitive to these vector control agents. More information on these vector control schedules, locations and agents used is needed to evaluate how these may be affecting invertebrate community dynamics at those sites.

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Figures

Figure 1. Mean percent cover (± SE) of plant species at the Central Davis Sewer District sheetflow wetlands site in 2005, averaged across transects and sampling dates.

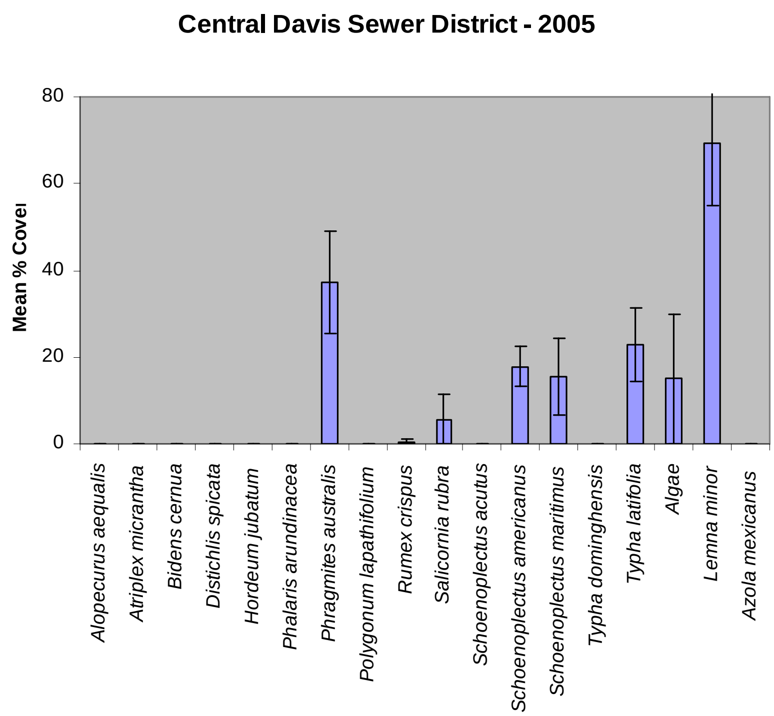


Figure 2. Mean percent cover (± SE) of plant species at the Farmington Bay Waterfowl Management Area sheetflow wetlands site in 2005, averaged across transects and sampling dates.

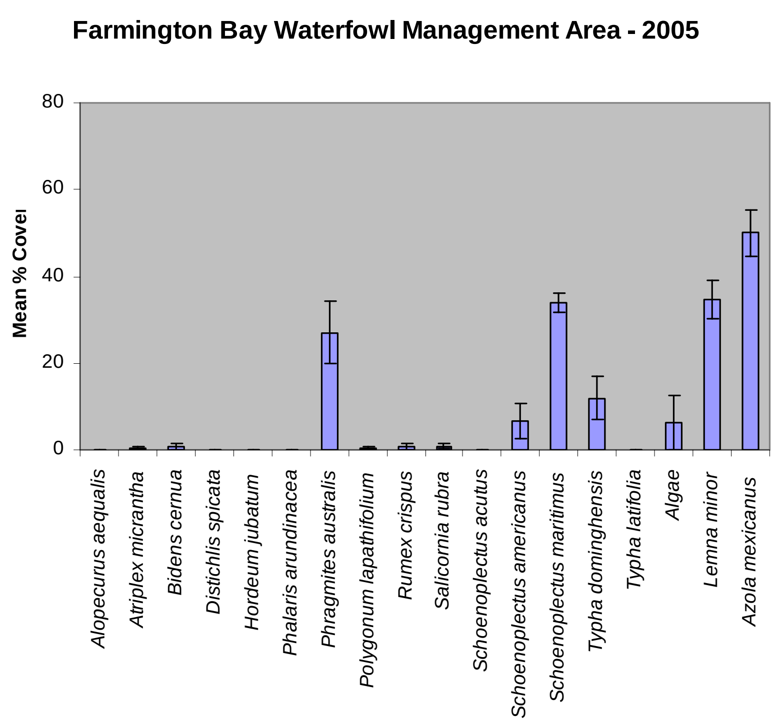


Figure 3. Percent cover (± SE) of plant species at the Kays Creek sheetflow wetlands site in 2005, averaged across transects and sampling dates.

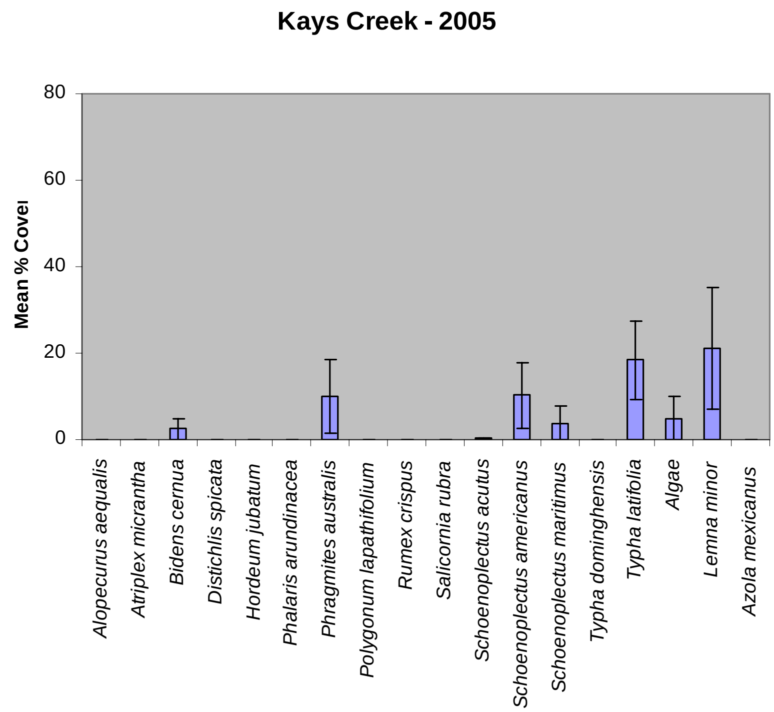


Figure 4. Percent cover (± SE) of plant species at the North Davis Sewer District sheetflow wetlands site in 2005, averaged across transects and sampling dates.

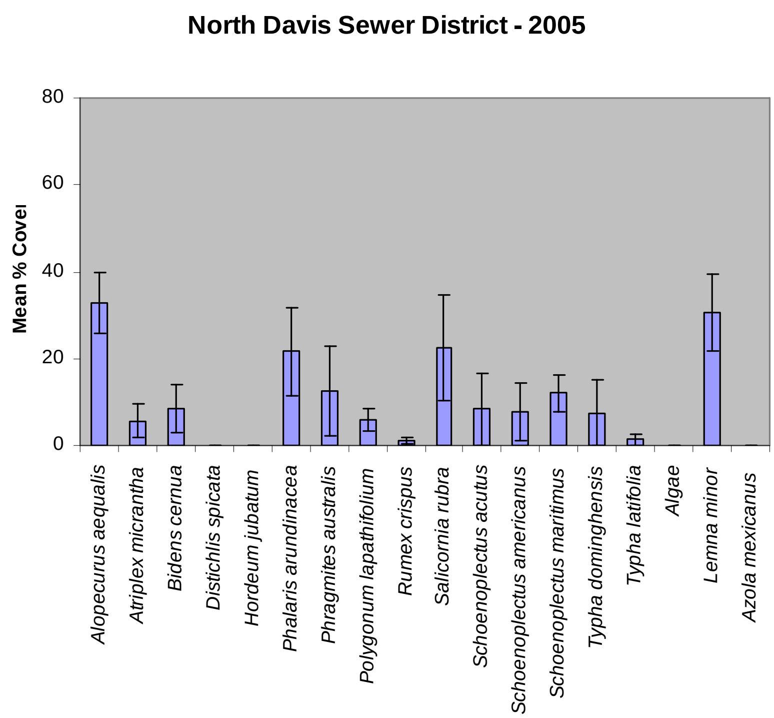


Figure 5. Percent cover (± SE) of plant species at the Public Shooting Grounds sheetflow wetlands site in 2005, averaged across transects and sampling dates.

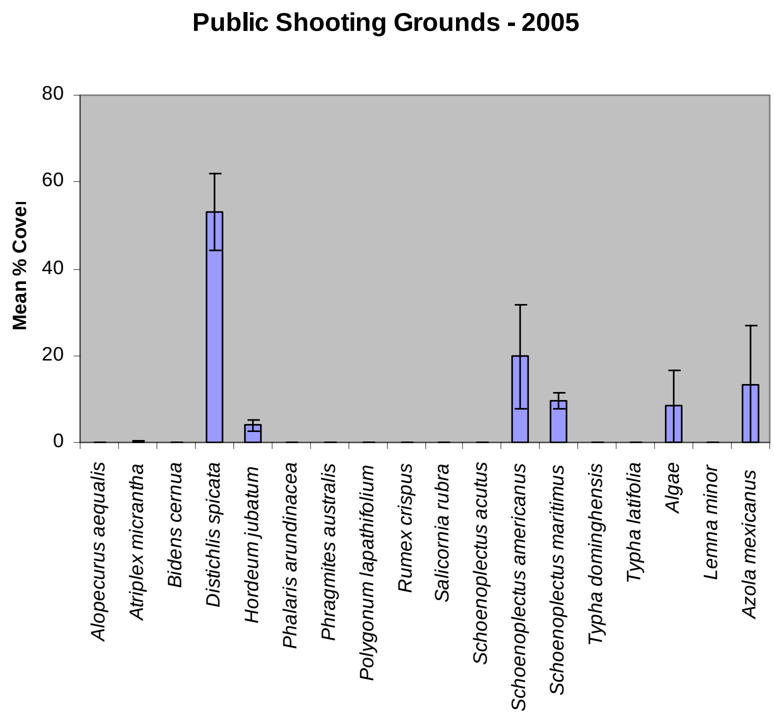


Figure 6. Percent cover (± SE) of plant species at the Ambassador Ponds impounded wetlands site in 2005, averaged across transects and sampling dates.

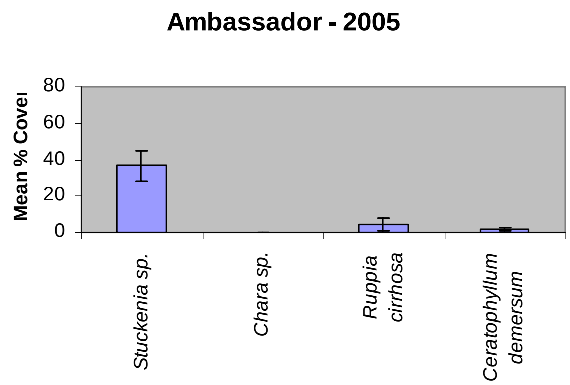


Figure 7. Percent cover (± SE) of plant species at the Farmington Bay Waterfowl Management Area impounded wetlands site in 2005, averaged across transects and sampling dates.

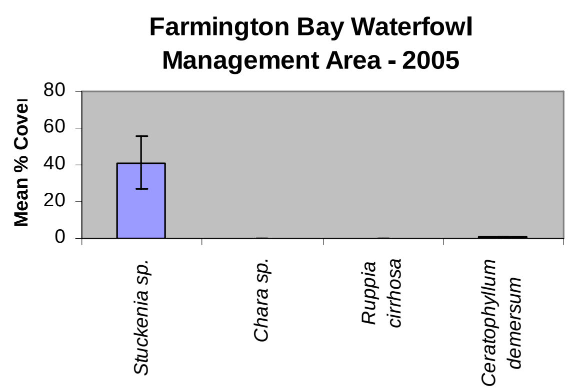


Figure 8. Percent cover (± SE) of plant species at the Inland Sea Shorebird Reserve impounded wetlands site in 2005, averaged across transects and sampling dates.

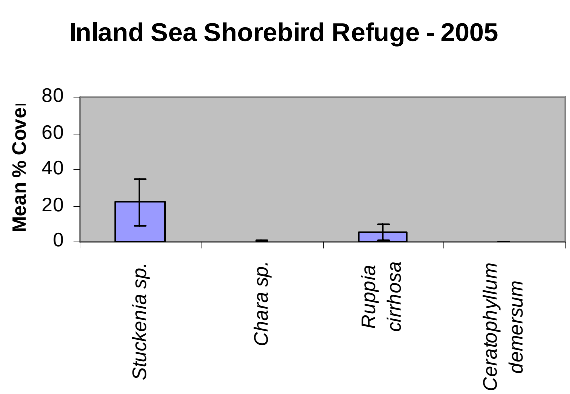


Figure 9. Percent cover (± SE) of plant species at the New State impounded wetlands site in 2005, averaged across transects and sampling dates.

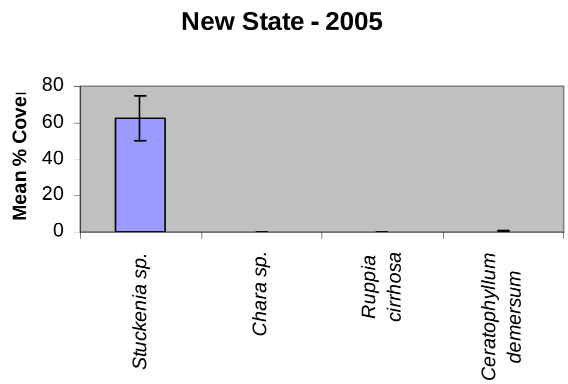


Figure 10. Percent cover (± SE) of plant species at the Public Shooting Grounds impounded wetlands site in 2005, averaged across transects and sampling dates.

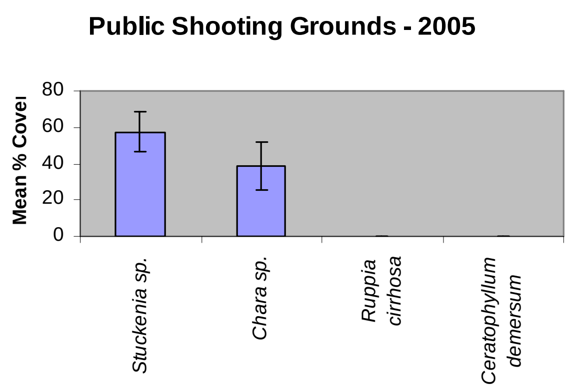


Figure 11. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Central Davis Sewer District sheetflow wetlands site in 2005, averaged across transects and sampling dates.

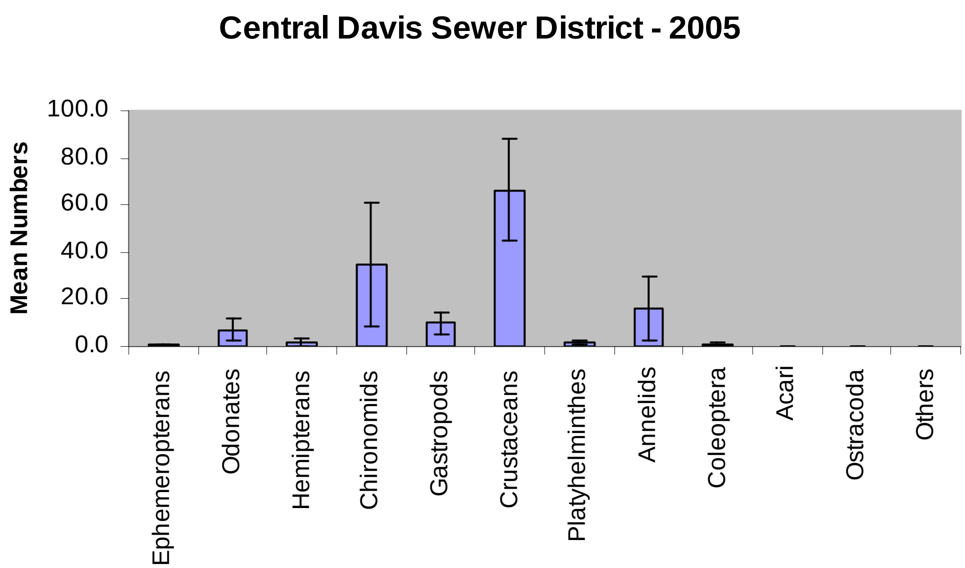


Figure 12. Mean number of individuals (± SE) of macroinvertebrate taxa at the Farmington Bay Waterfowl Management Area sheetflow wetlands site in 2005, averaged across transects and sampling dates.

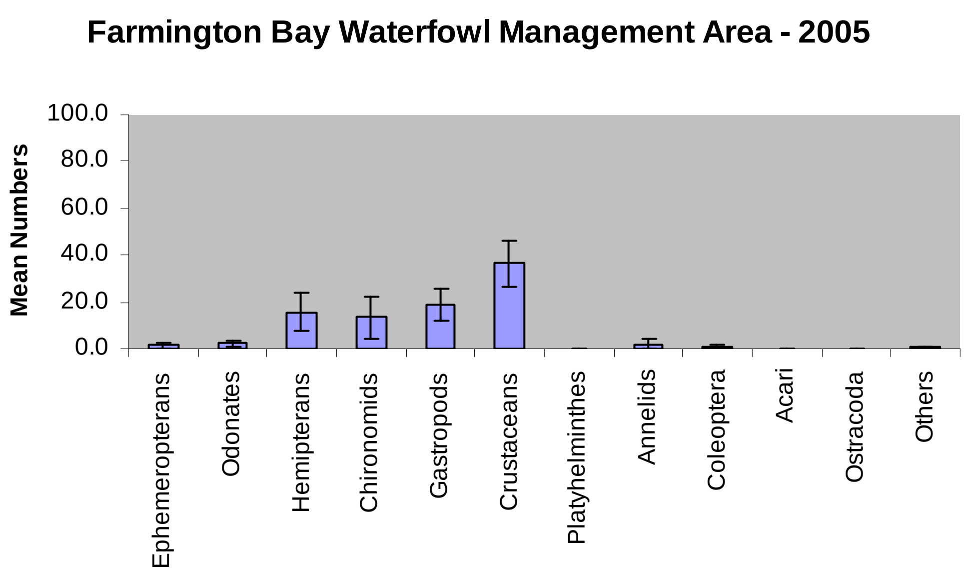


Figure 13. Mean number of individuals (± SE) of macroinvertebrate taxa at the Kays Creek sheetflow wetlands site in 2005, averaged across transects and sampling dates.

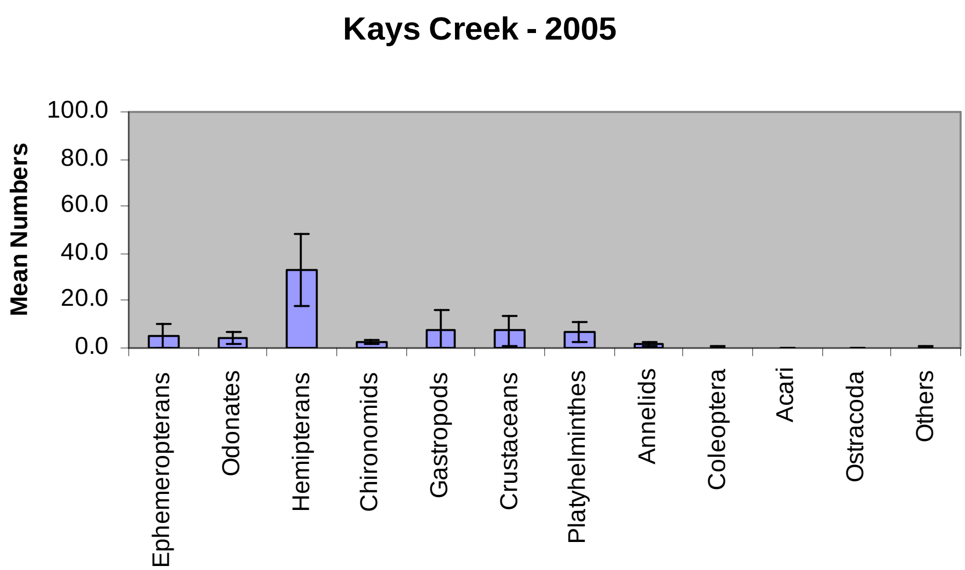


Figure 14. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the North Davis Sewer District sheetflow wetlands site in 2005, averaged across transects and sampling dates.

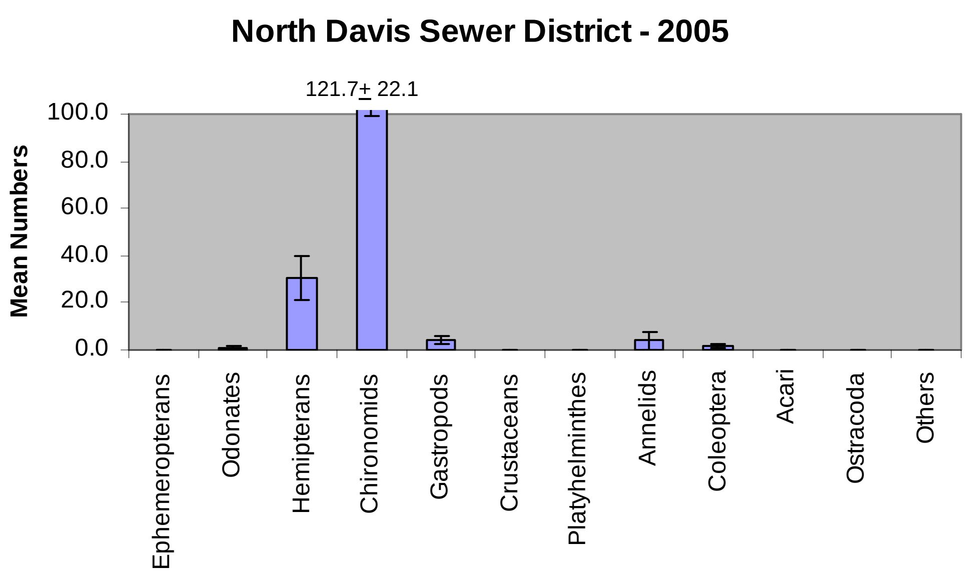


Figure 15. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Public Shooting Grounds sheetflow wetlands site in 2005, averaged across transects and sampling dates.

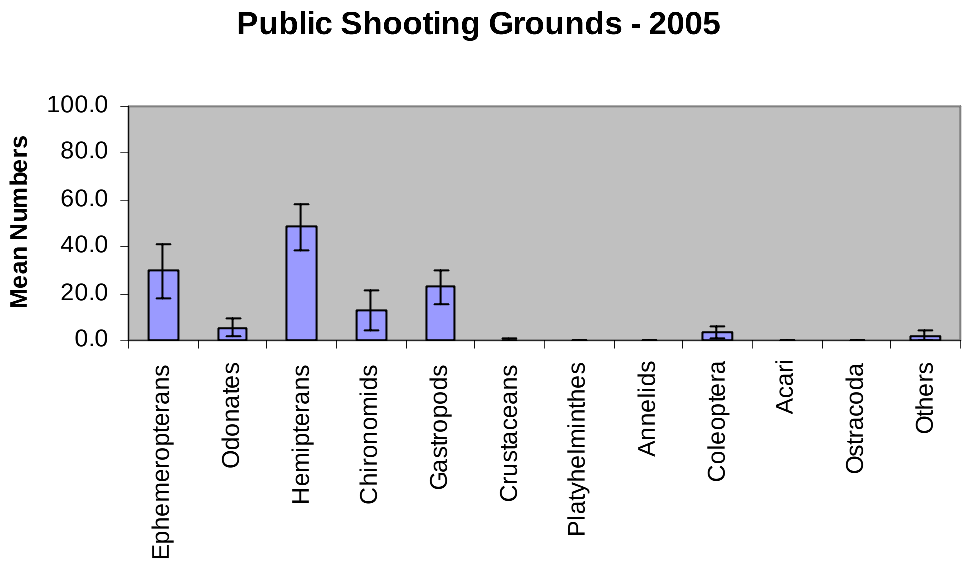


Figure 16. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Ambassador Ponds impounded wetlands site in 2005, averaged across transects and sampling dates.

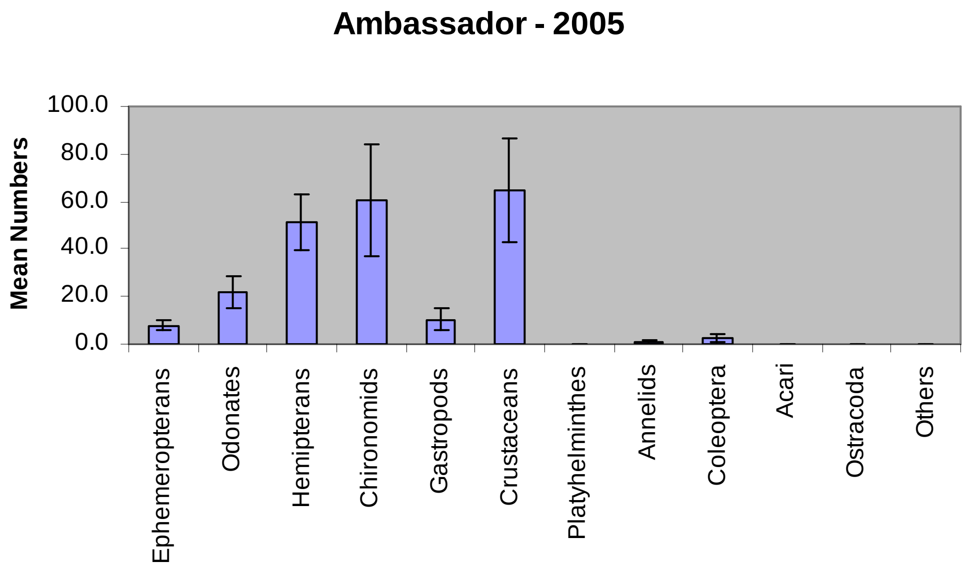


Figure 17. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Farmington Bay Waterfowl Management Area impounded wetlands site in 2005, averaged across transects and sampling dates.

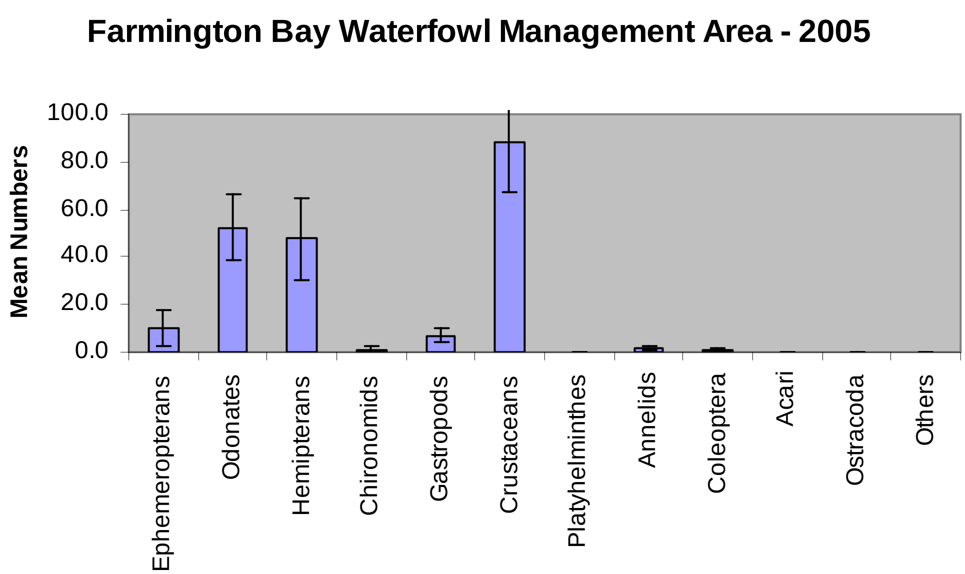


Figure 18. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Inland Sea Shorebird Refuge impounded wetlands site in 2005, averaged across transects and sampling dates.

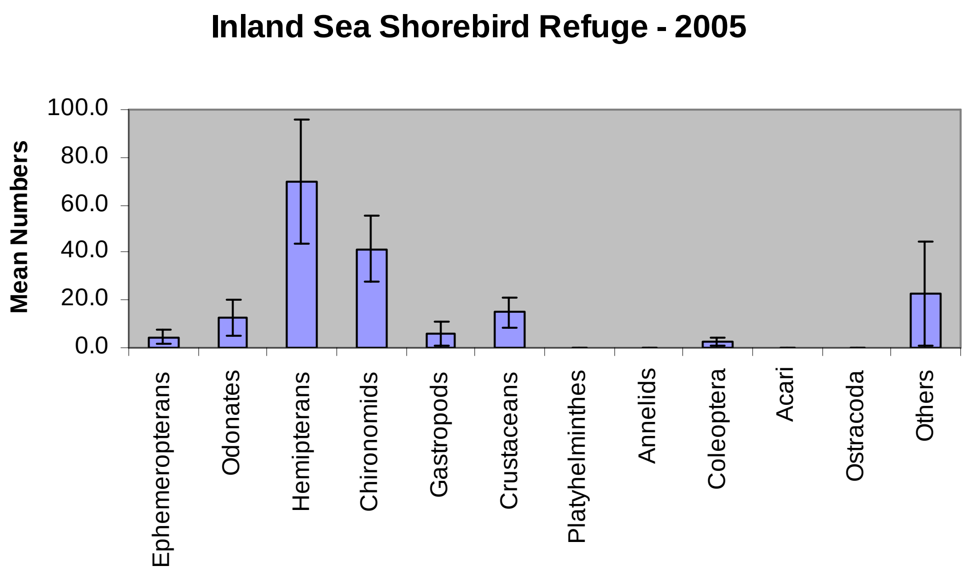


Figure 19. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the New State impounded wetlands site in 2005, averaged across transects and sampling dates.

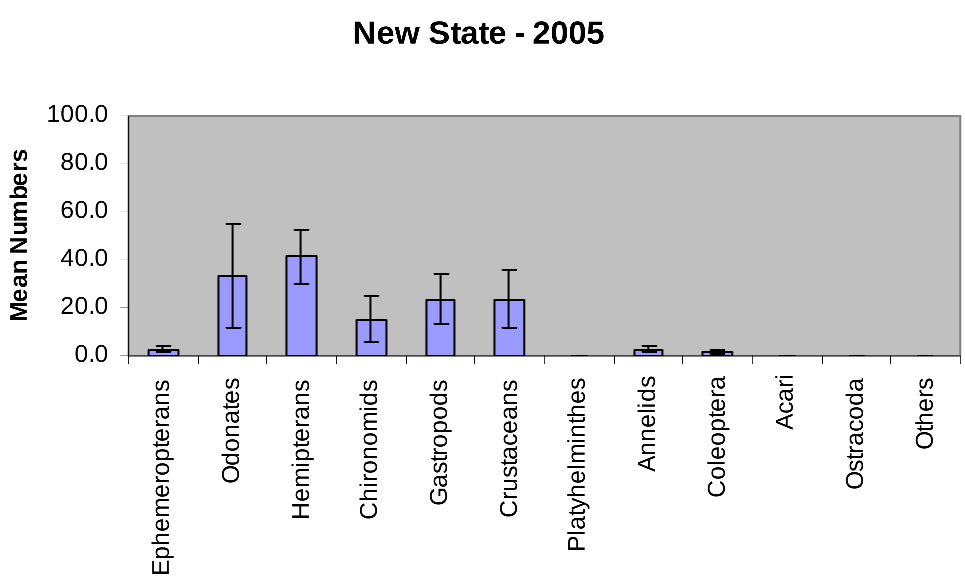


Figure 20. Mean numbers of individuals (± SE) of macroinvertebrate taxa at the Public Shooting Grounds impounded wetlands site in 2005, averaged across transects and sampling dates.

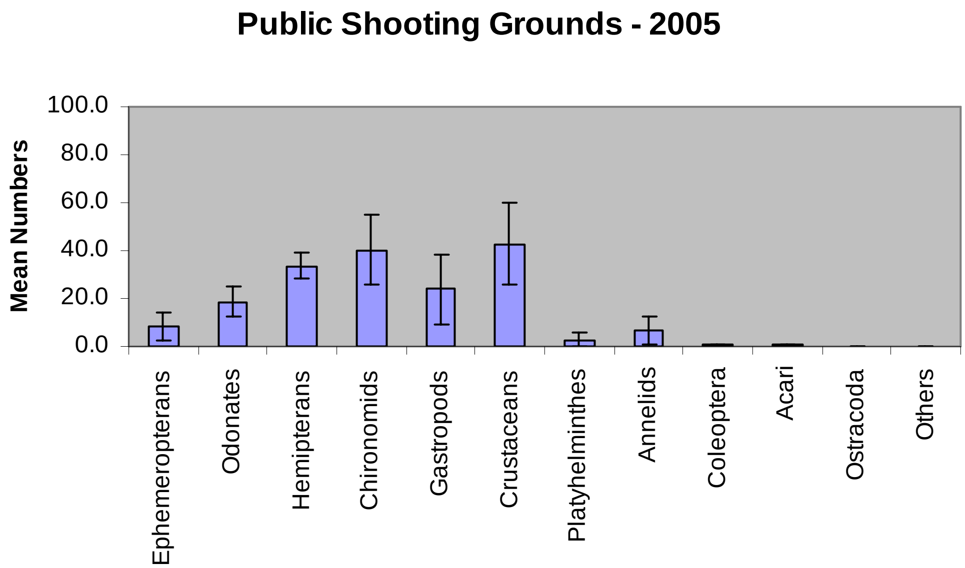


Figure 21. Native Plants & Water Quality(WQ)

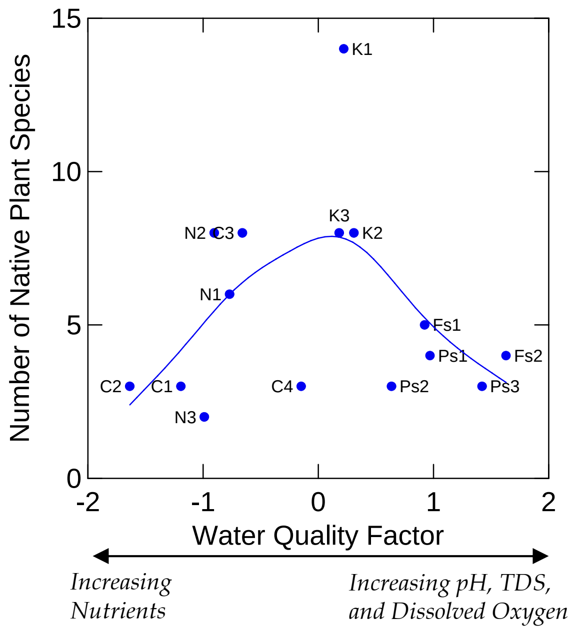


Figure 22. Log_{10} Native Plants & WQ

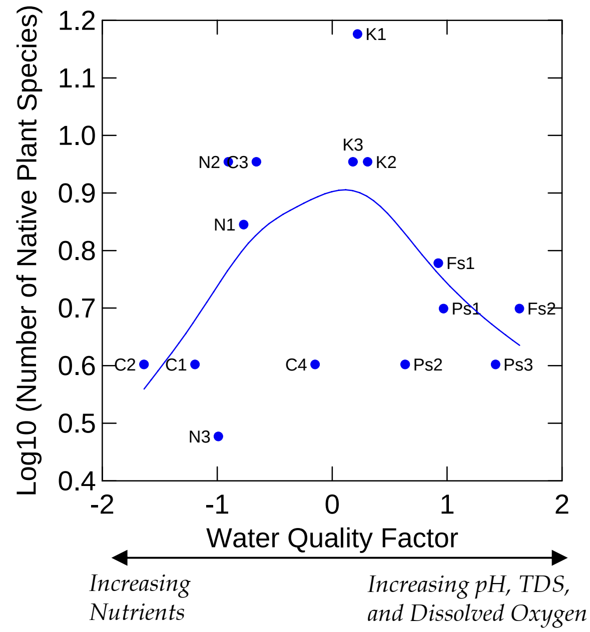


Figure 23. % Native Plants & WQ

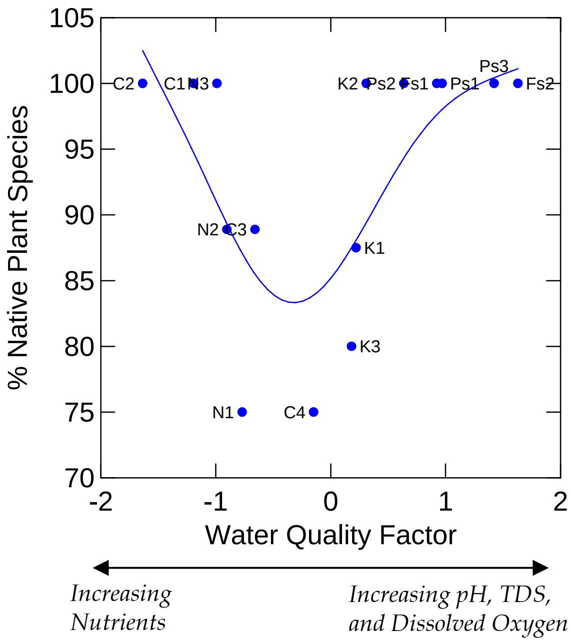


Figure 24. Arcsin % Native Plants & WQ

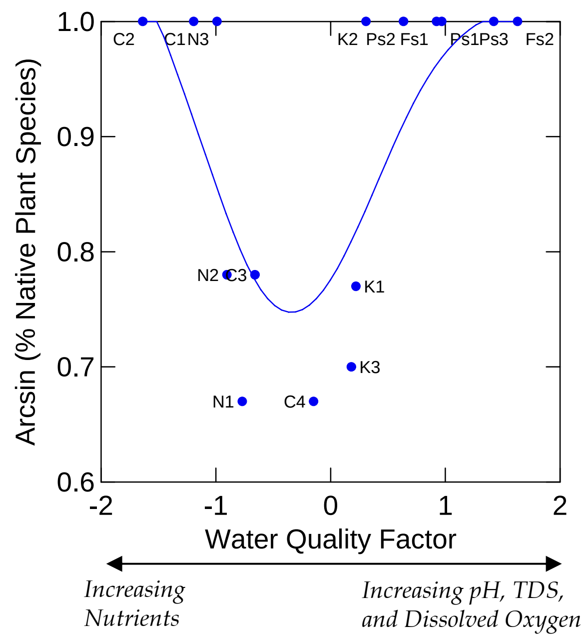


Figure 25. Introduced Plants and WQ

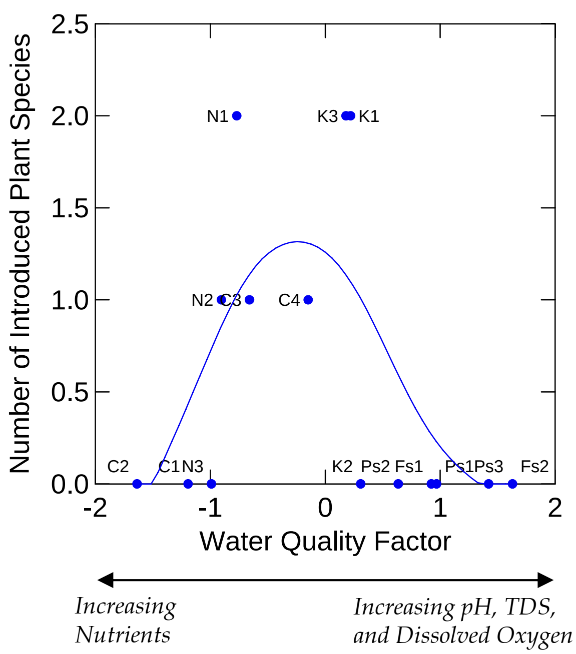


Figure 26. Log_{10} Introduced Plants & WQ

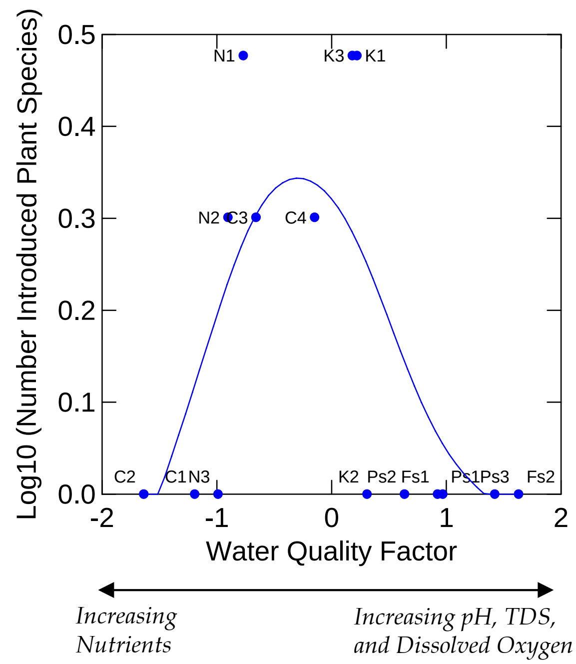


Figure 27. % Introduced Plants & WQ

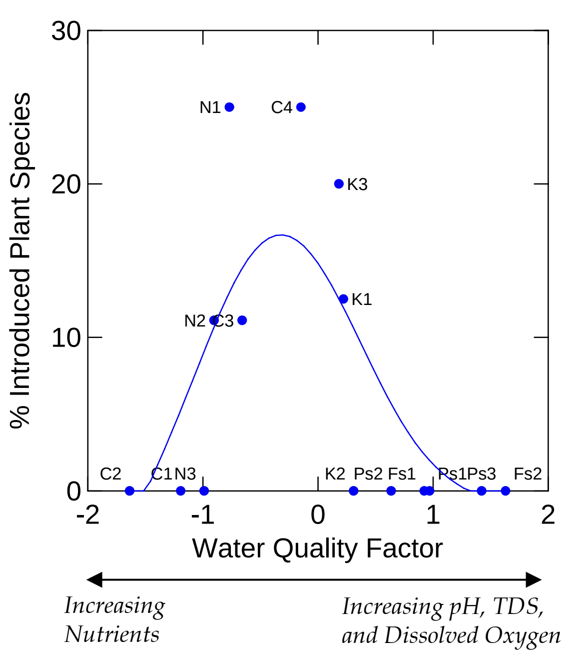


Figure 28. Arcsin % Introduced Plants & WQ

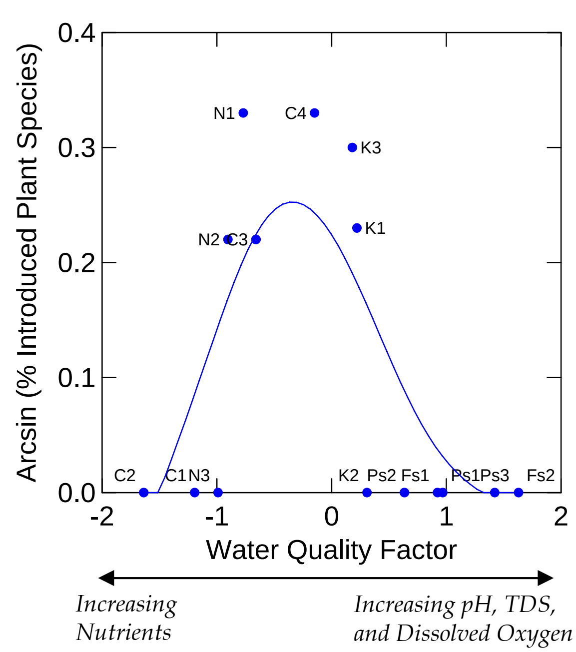


Figure 29. Invasive Plants and WQ

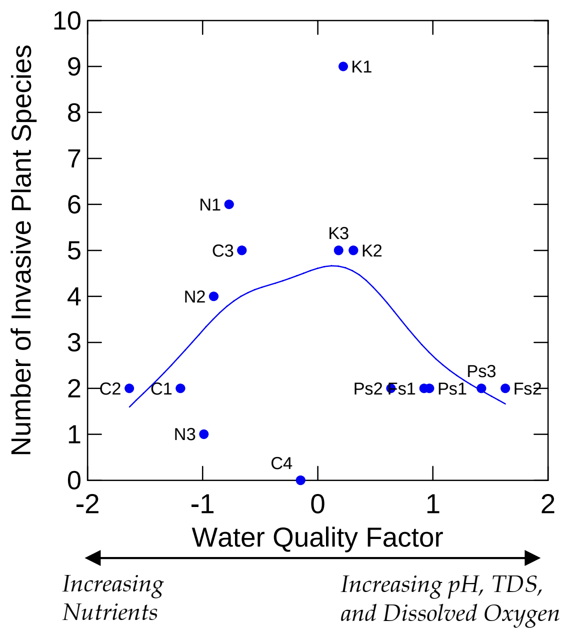


Figure 30. Log$_{10}$ Invasive Plants & WQ

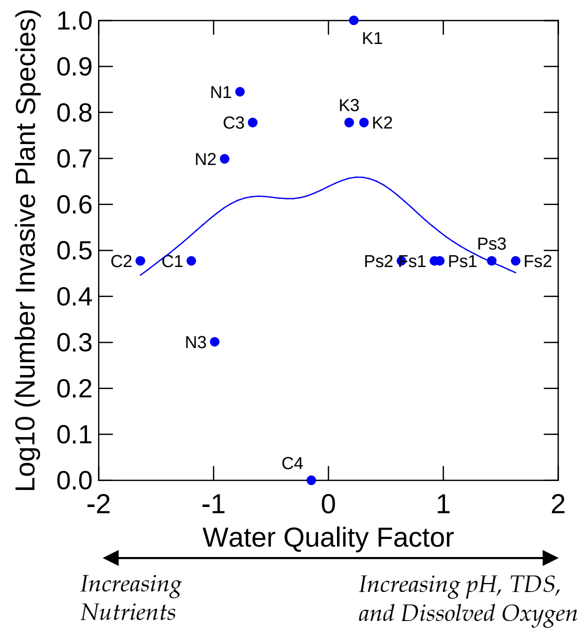


Figure 31. % Invasive Plants & WQ

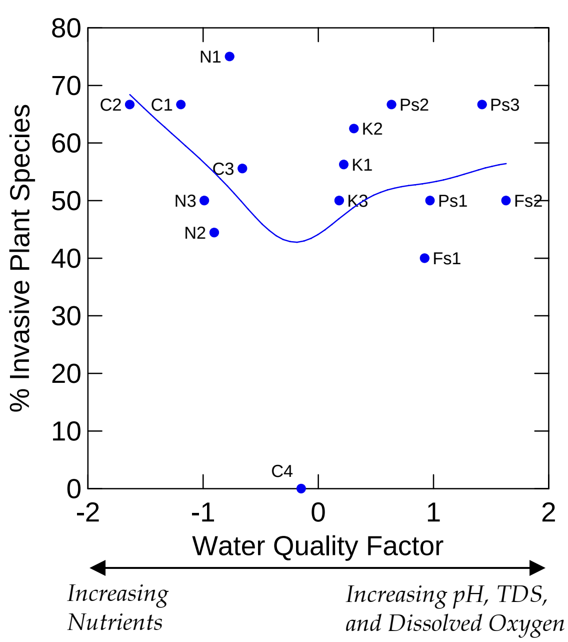


Figure 32. Arcsin % Invasive Plants & WQ

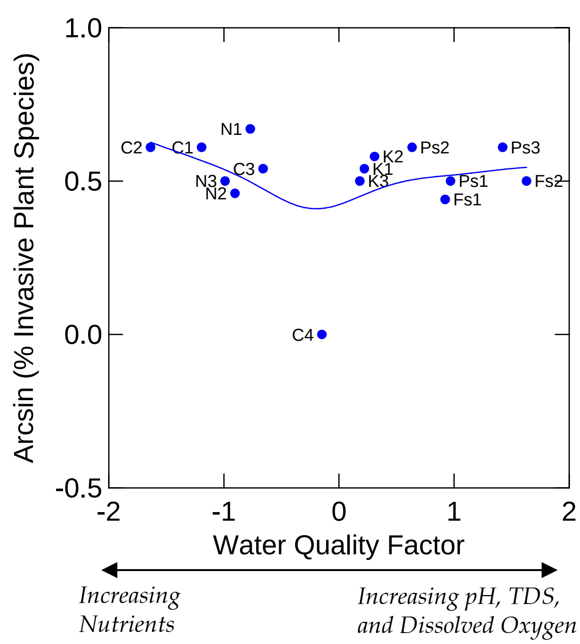


Figure 33. Total Plant Species and WQ

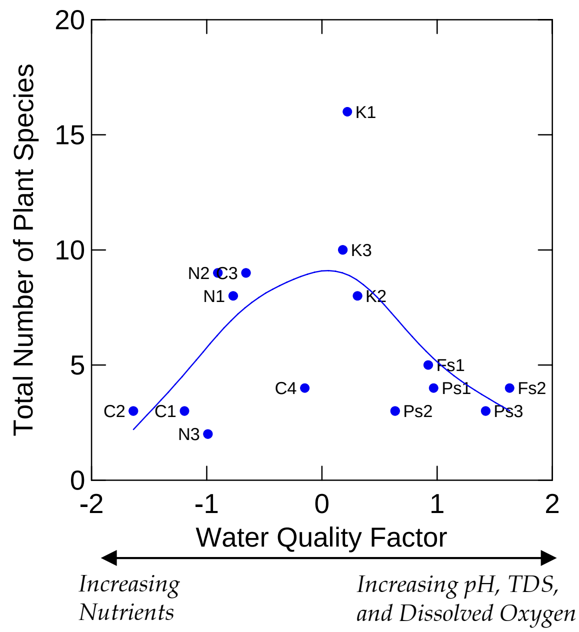


Figure 34. Log_{10} Total Plant Species & WQ

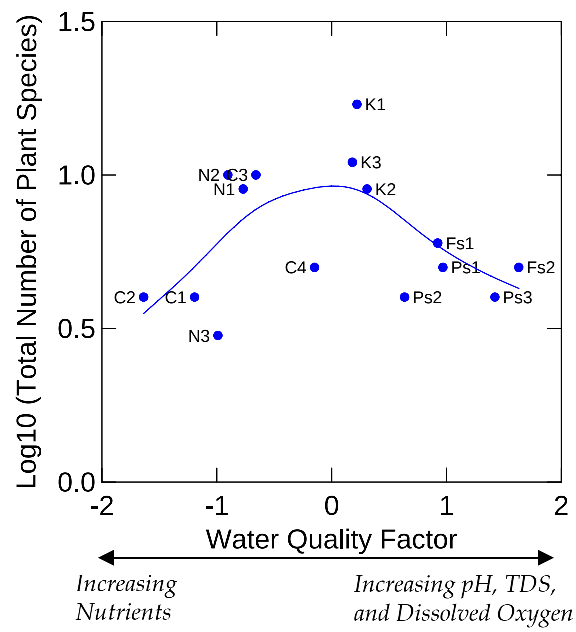


Figure 35. Native Plants & Water Quality(WQ)

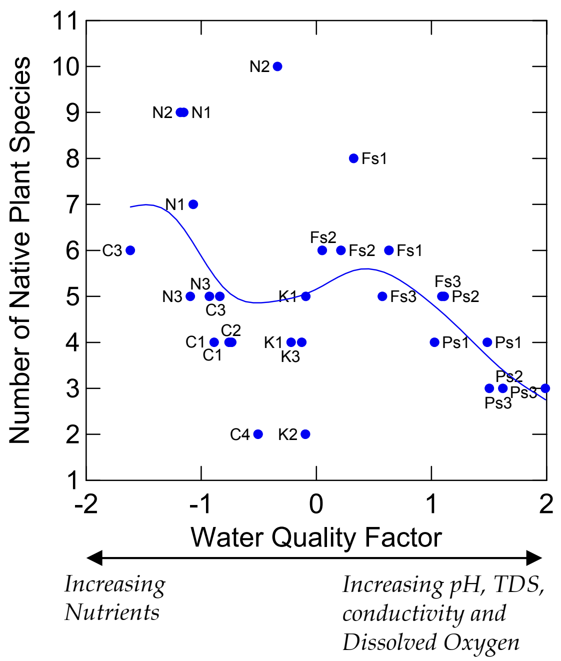


Figure 36. Log_{10} Native Plants & WQ

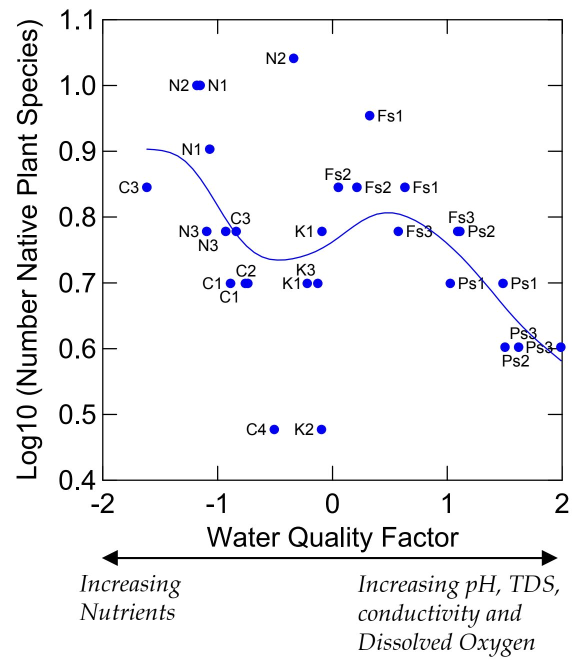


Figure 37. % Native Plants & WQ

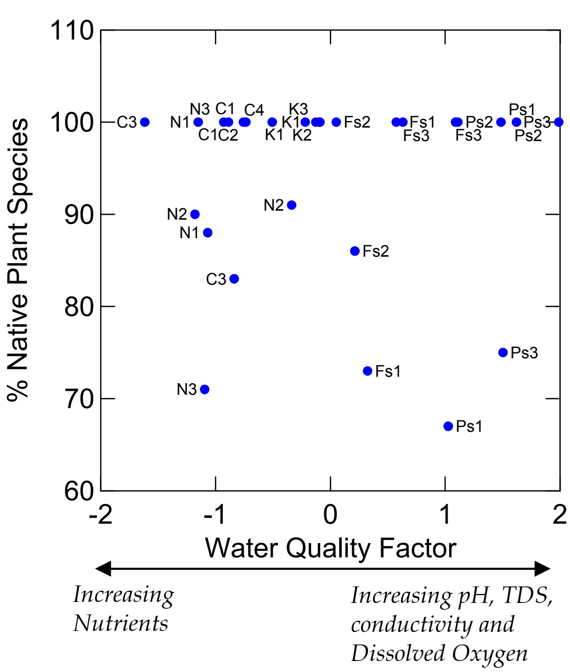


Figure 38. Arcsin % Native Plants & WQ

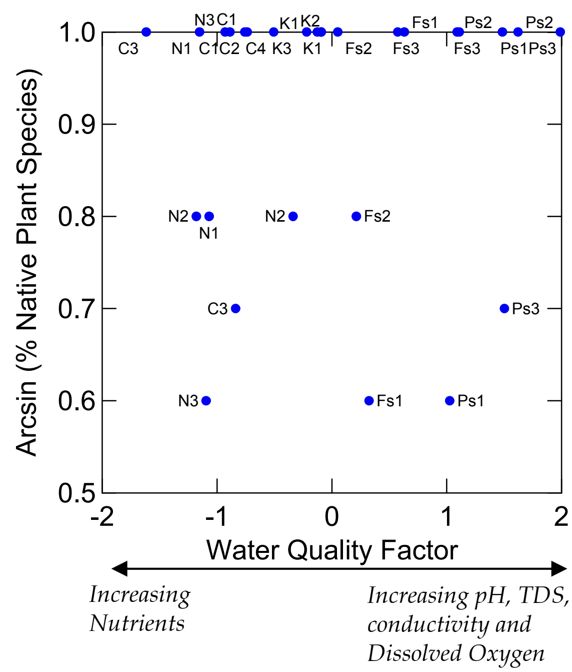


Figure 39. Introduced Plants and WQ

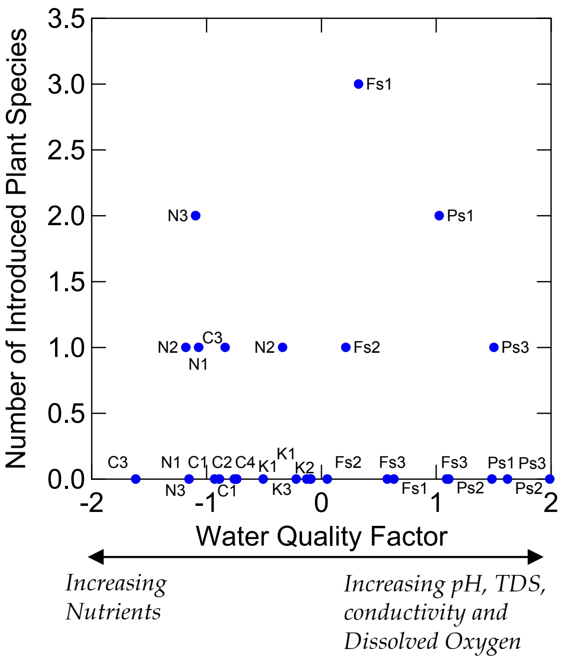


Figure 40. Log_{10} Introduced Plants & WQ

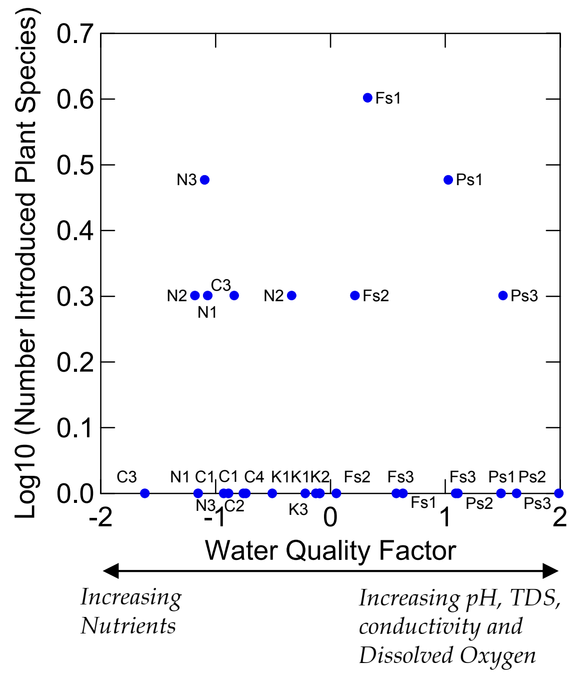


Figure 41. % Introduced Plants & WQ

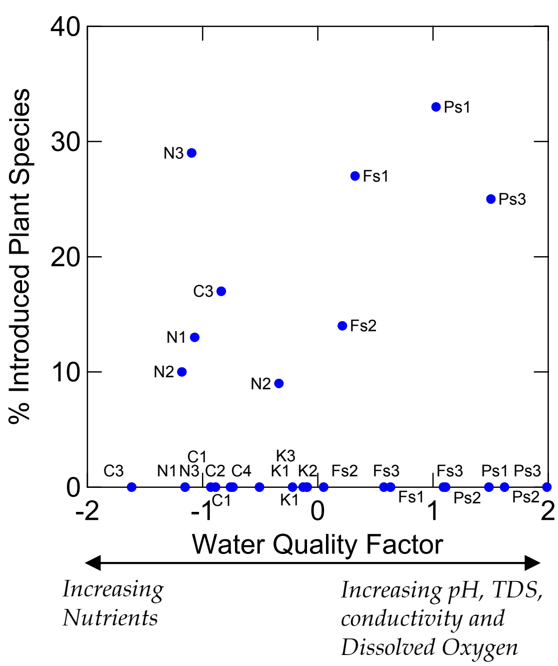


Figure 42. Arcsin % Introduced Plants & WQ

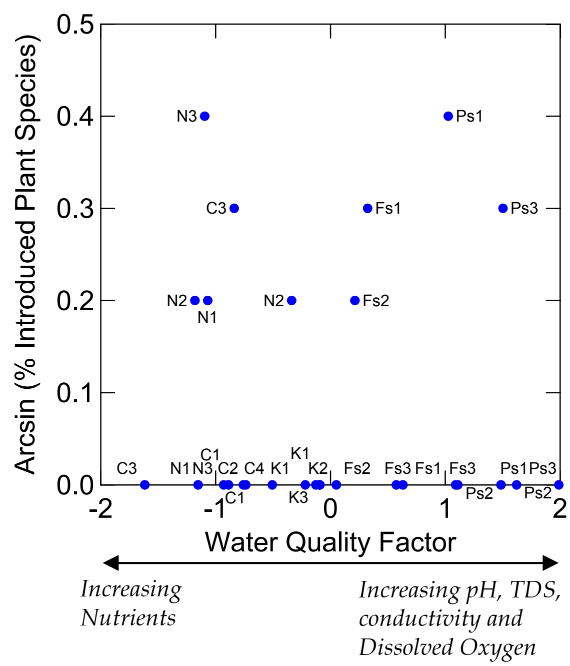
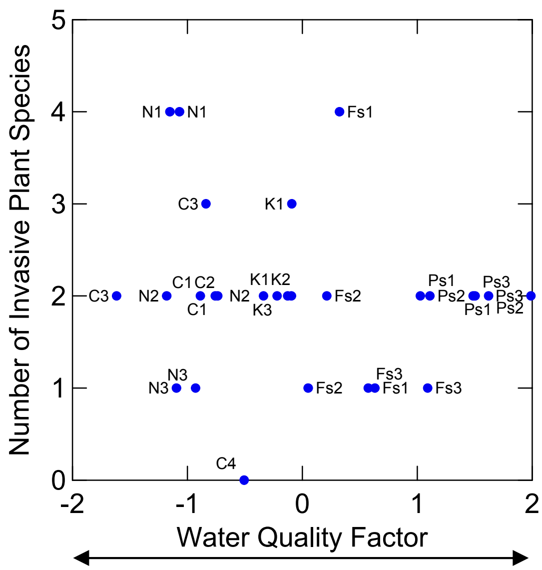


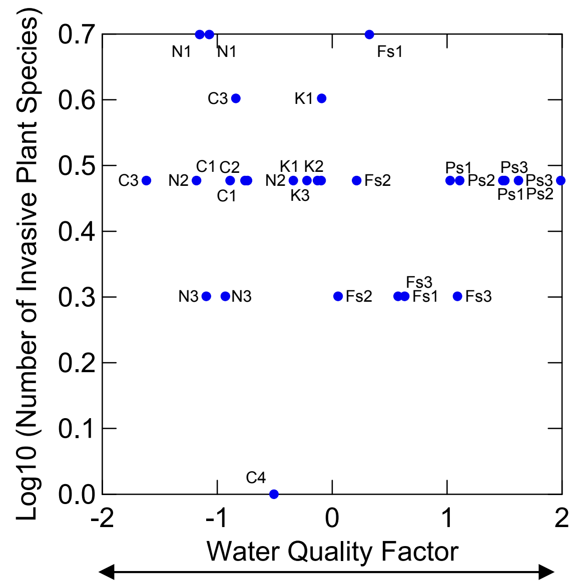
Figure 43. Invasive Plants and WQ



Increasing Nutrients

Increasing pH, TDS, conductivity and Dissolved Oxygen

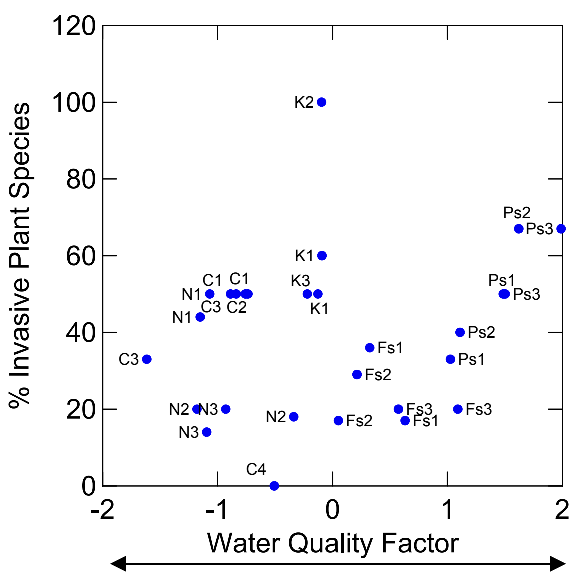
Figure 44. Log_{10} Invasive Plants & WQ



Increasing Nutrients

Increasing pH, TDS, conductivity and Dissolved Oxygen

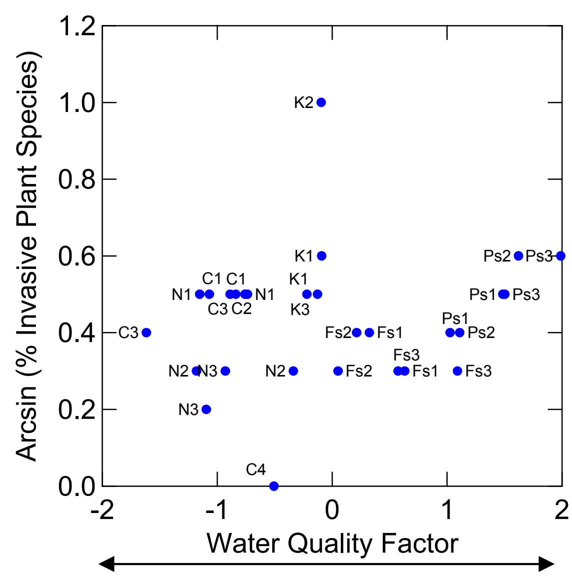
Figure 45. % Invasive Plants & WQ



Increasing Nutrients

Increasing pH, TDS, conductivity and Dissolved Oxygen

Figure 46. Arcsin % Invasive Plants & WQ



Increasing Nutrients

Increasing pH, TDS, conductivity and Dissolved Oxygen

Figure 47. Total Plant Species and WQ

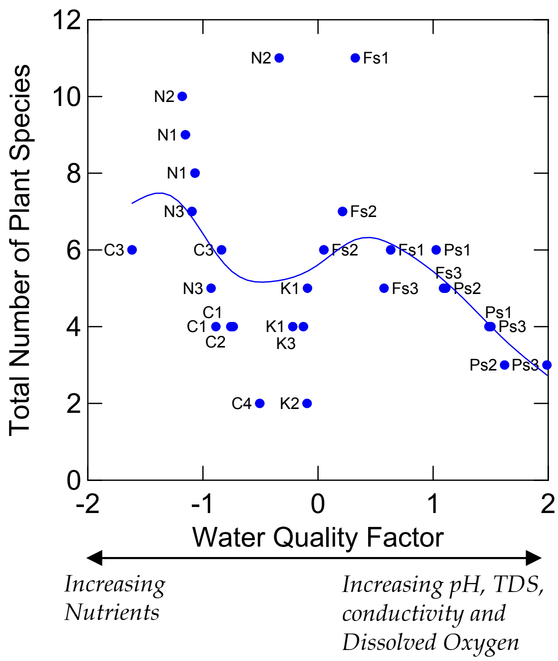
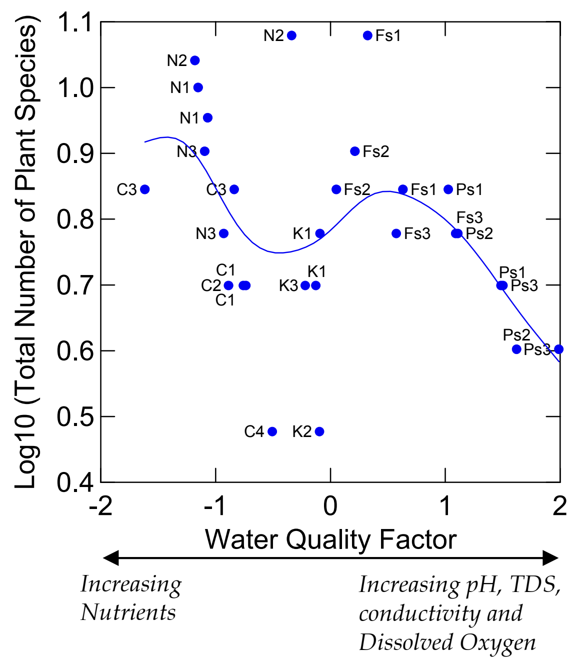


Figure 48. Log_{10} Total Plant Species & WQ



Impounded Sites – 2004

Figure 49. Tolerant Species: Impounded Sites, 2004.

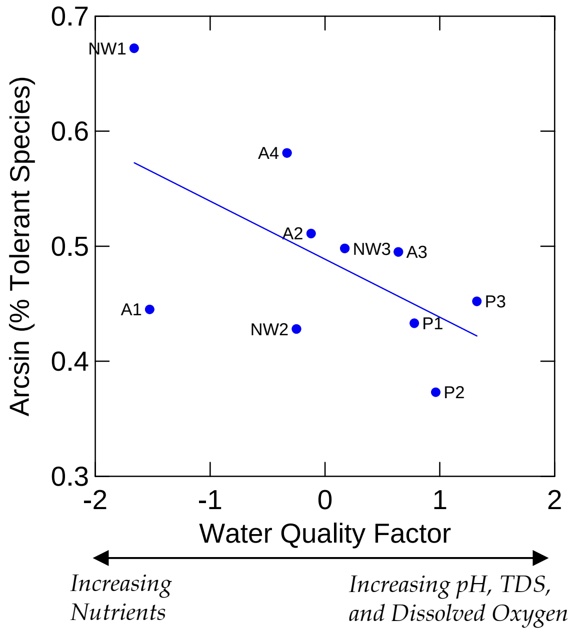


Figure 50. Ephemeroptera: Impounded Sites, 2004

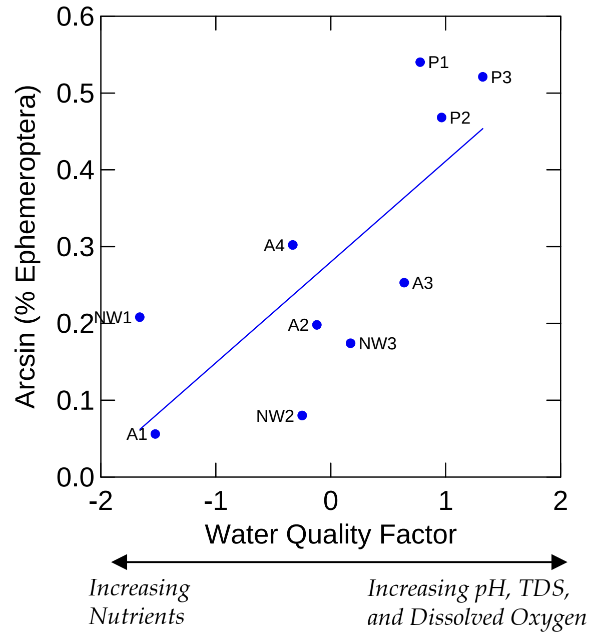


Figure 51. Collector-Gatherers: Impounded Sites, 2004

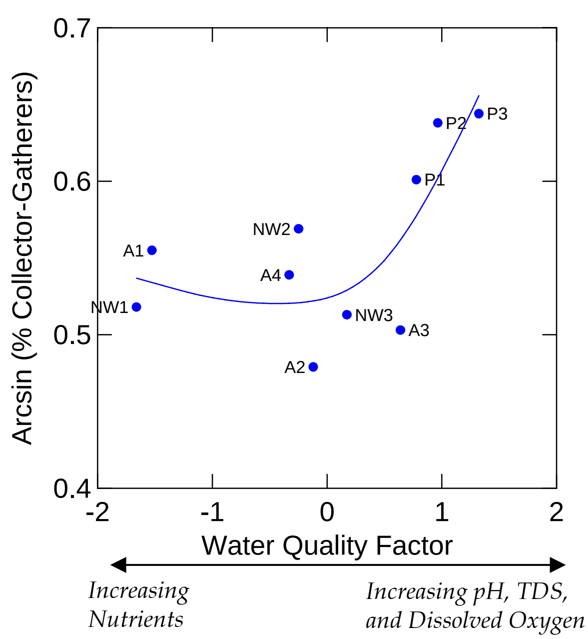


Figure 52. Predators: Impounded Sites, 2004

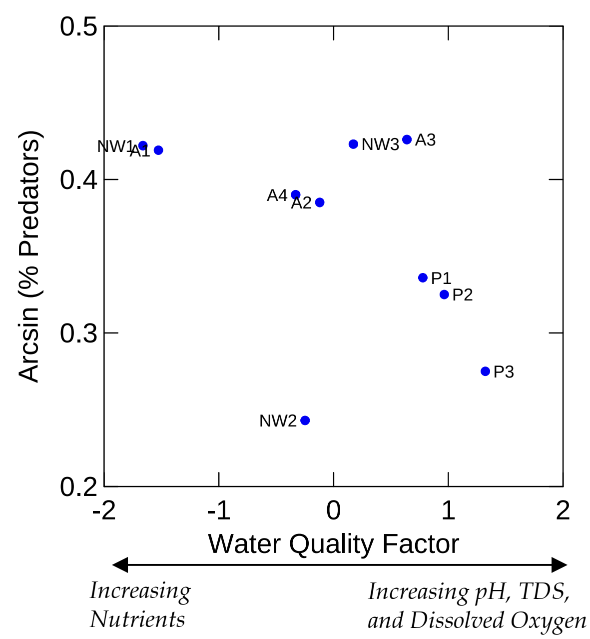
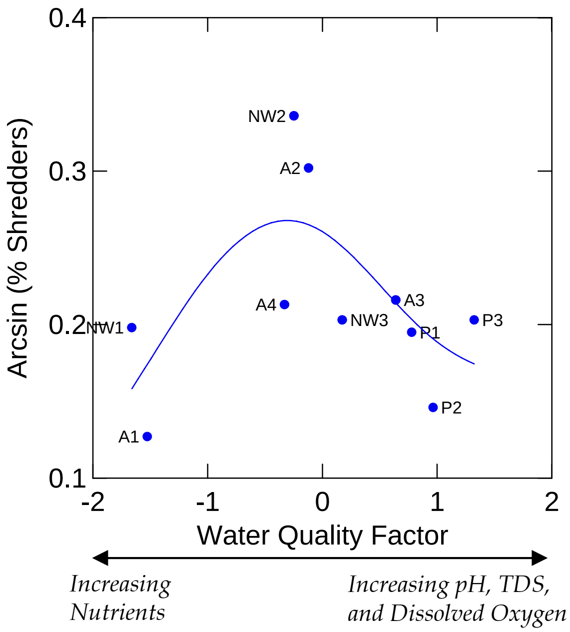


Figure 53. Shredders: Impounded Sites, 2004



Sheetflow Sites – 2004

Figure 54. Tolerant Species: Sheetflow Sites, 2004

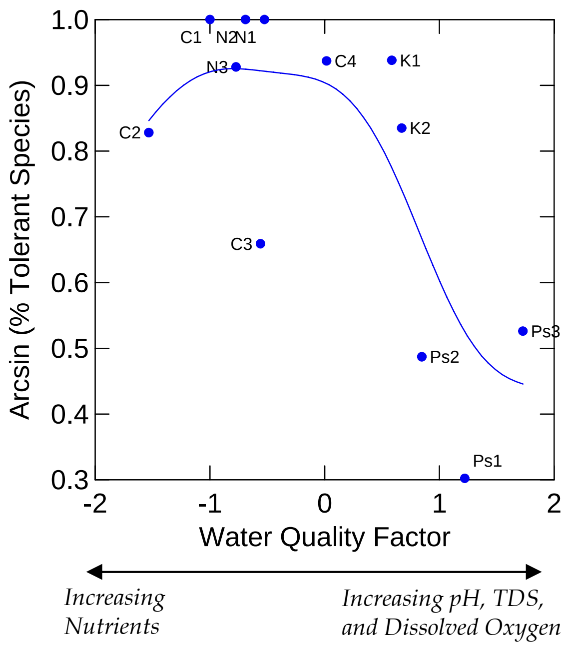


Figure 55. Ephemeroptera: Sheetflow Sites, 2004

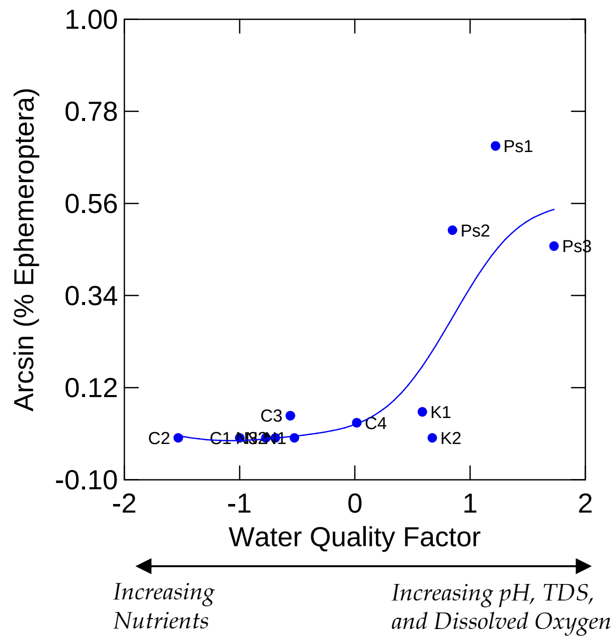


Figure 56. Collector-Gatherers: Sheetflow Sites, 2004

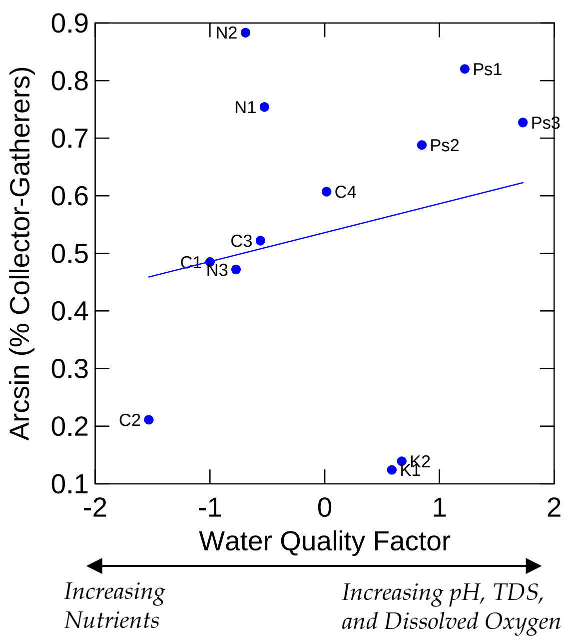


Figure 57. Predators: Sheetflow Sites, 2004

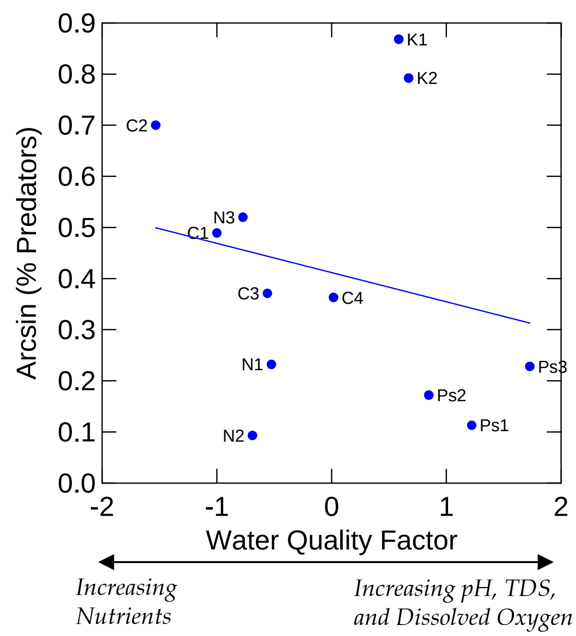
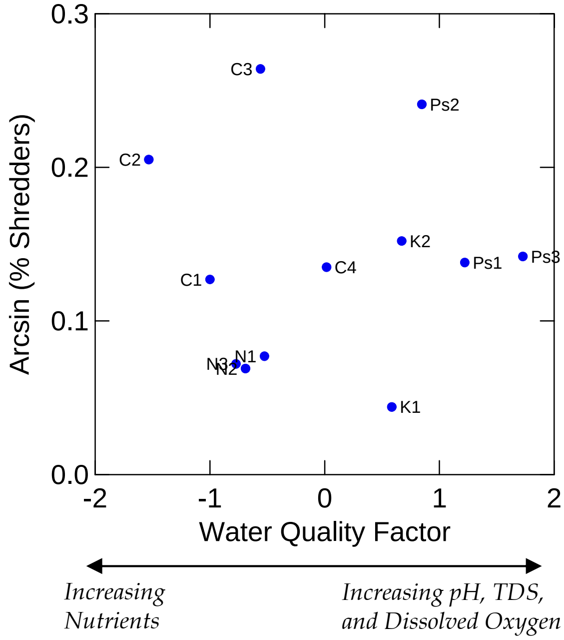


Figure 58. Shredders: Sheetflow sites, 2004



Impounded Sites – 2005

Figure 59. Tolerant Species: Impounded Sites, 2005

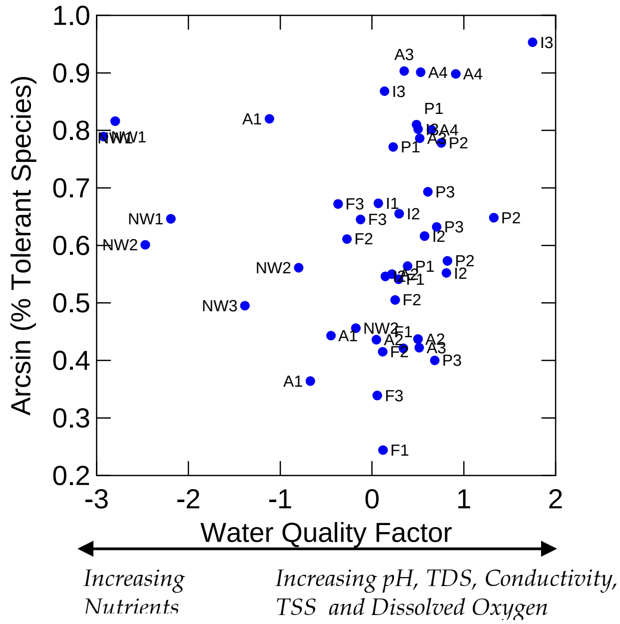


Figure 60. Ephemeroptera: Impounded Sites, 2005

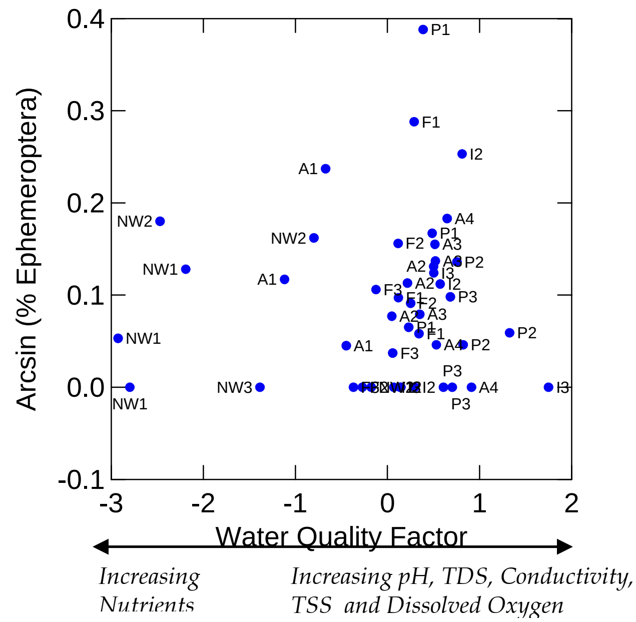


Figure 61. Collector-Gatherers: Impounded Sites, 2005

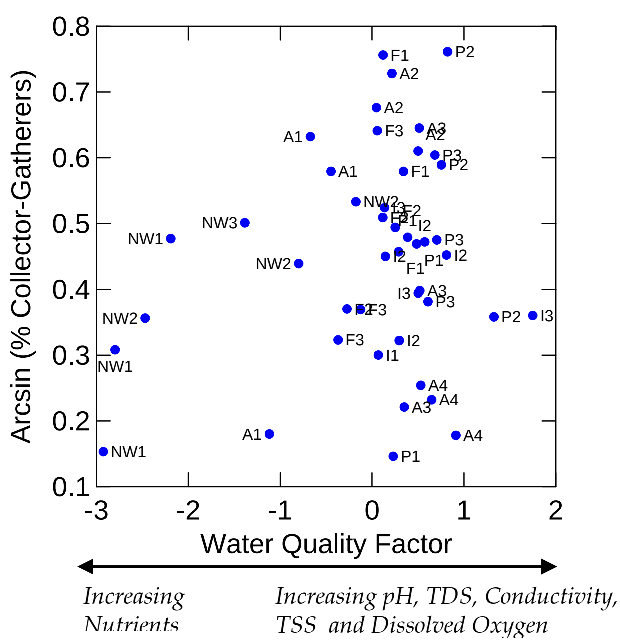


Figure 62. Predators: Impounded Sites, 2005

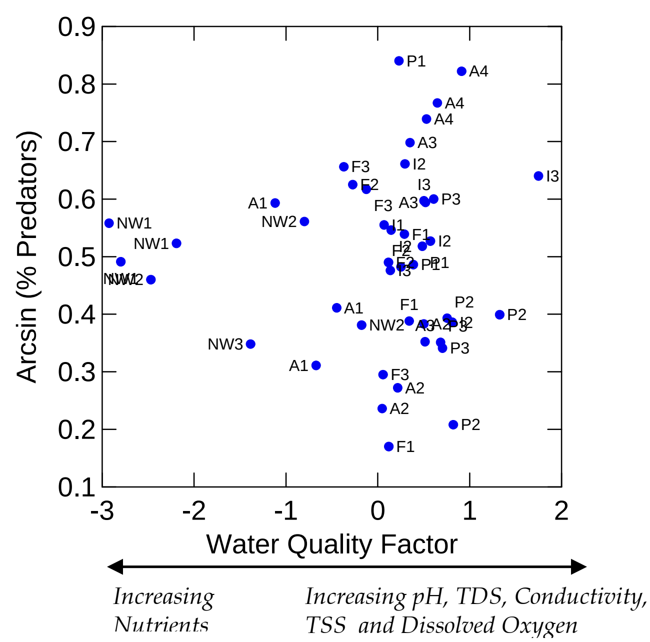
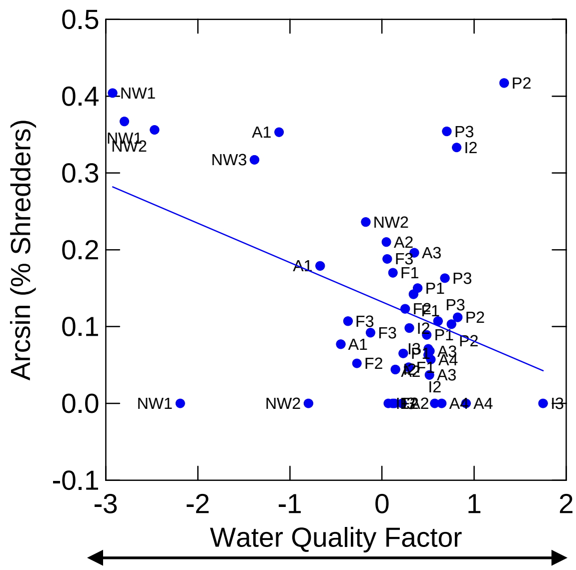


Figure 63. Shredders: Impounded Sites, 2005



Increasing Nutrients

Increasing pH, TDS, Conductivity, TSS and Dissolved Oxygen

Sheetflow Sites – 2005

Figure 64. Tolerant Species: Sheetflow Sites, 2005

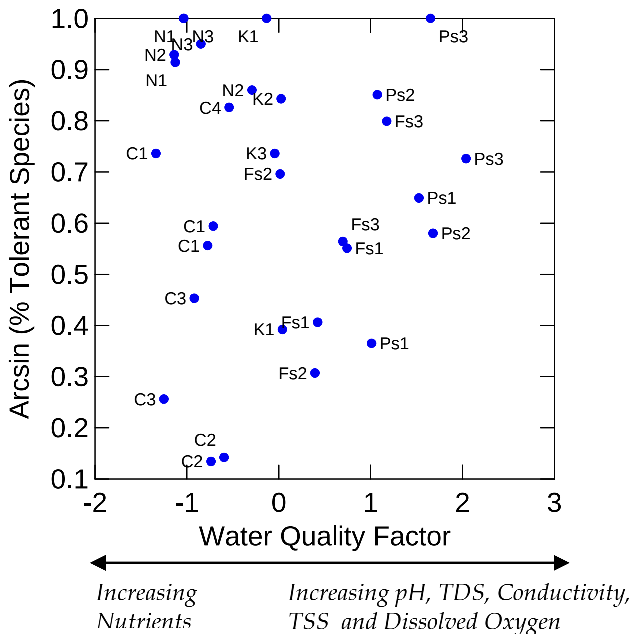


Figure 65. Ephemeroptera: Sheetflow Sites, 2005

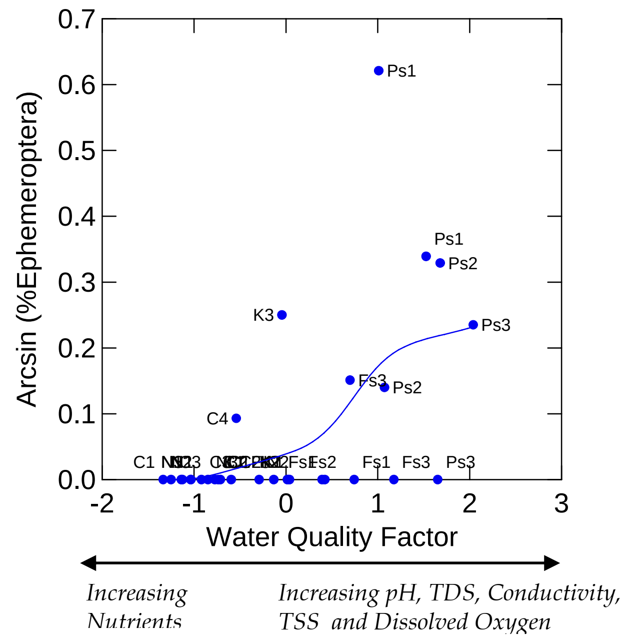


Figure 66. Collector-Gatherers: Sheetflow Sites, 2005

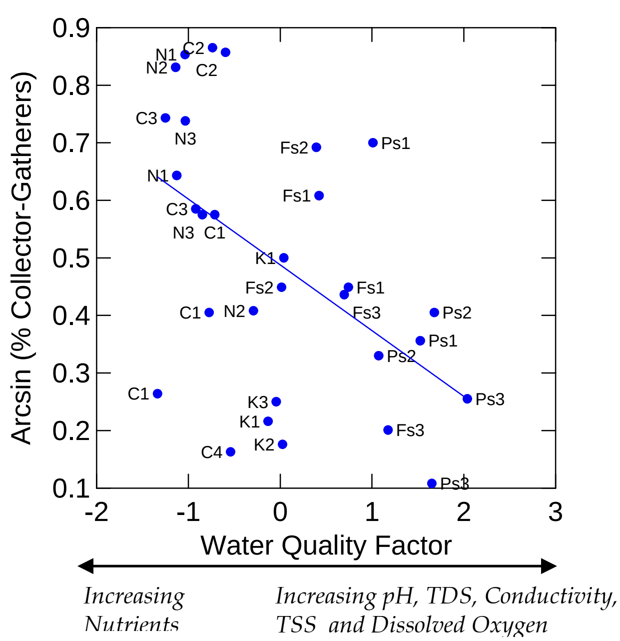


Figure 67. Predators: Sheetflow Sites, 2005

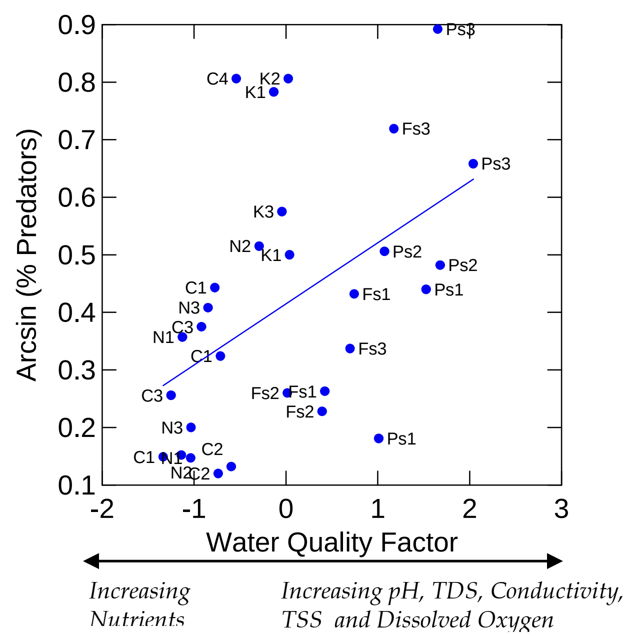


Figure 68. Shredders: Sheetflow Sites, 2005

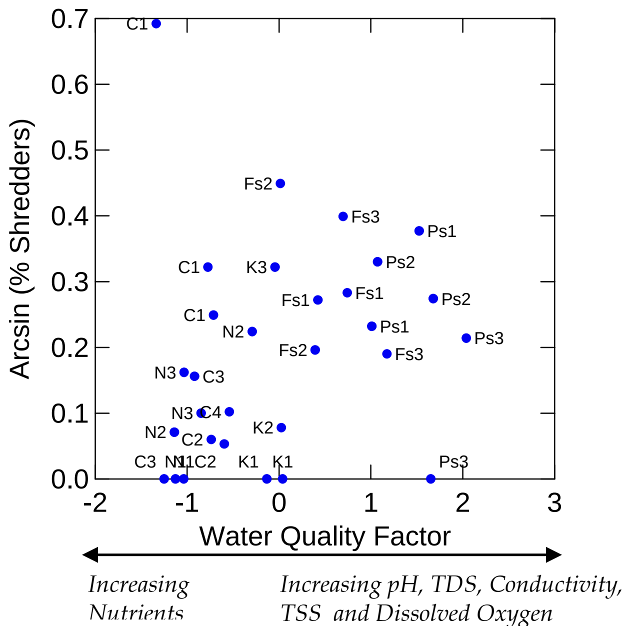


Figure 69. FACTOR ANALYSIS: Plants and Water Quality – Sheetflow Sites, 2005.

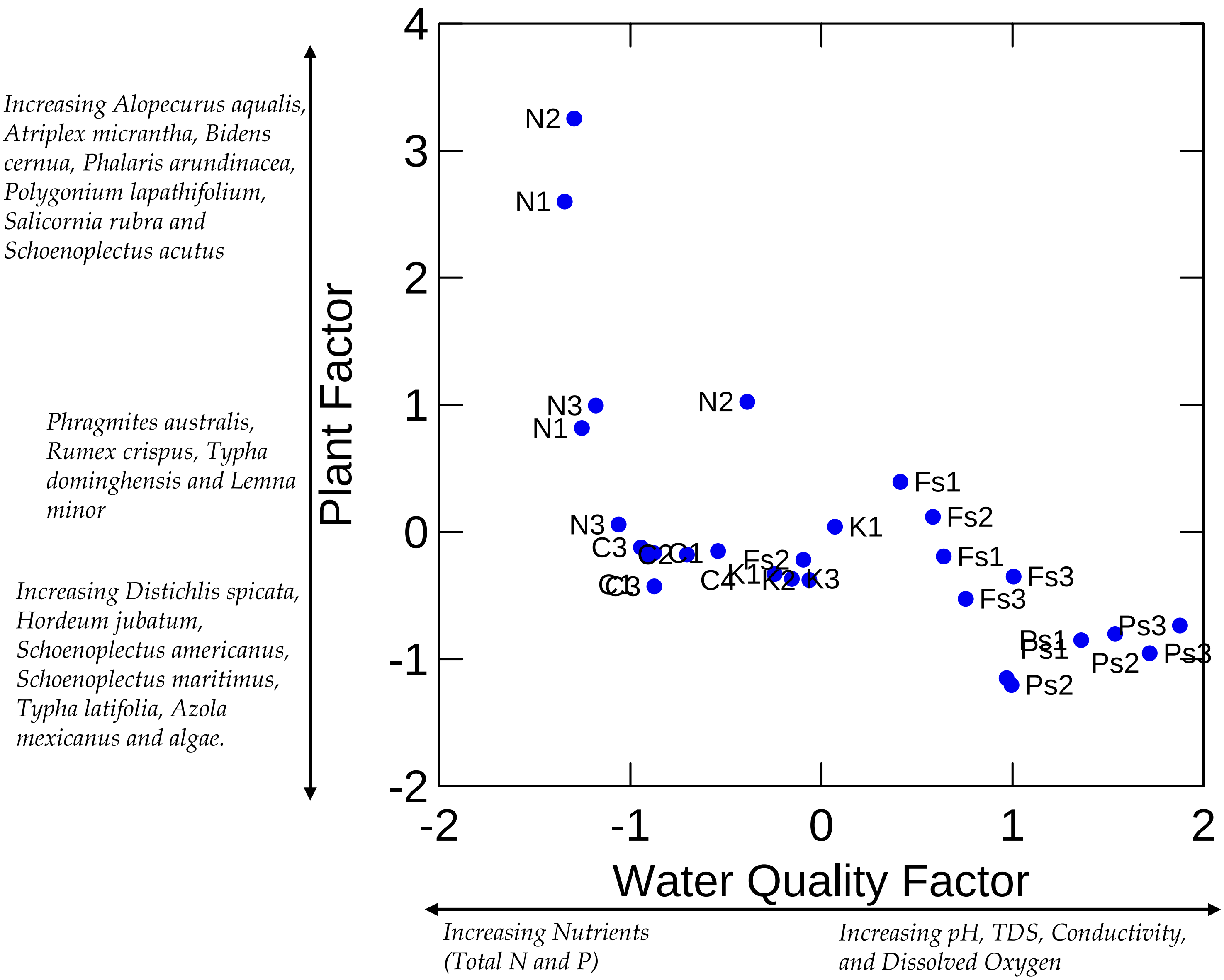


Figure 70. FACTOR ANALYSIS: Plants and Water Quality – Sheetflow 2005, with DWLS line fitted.

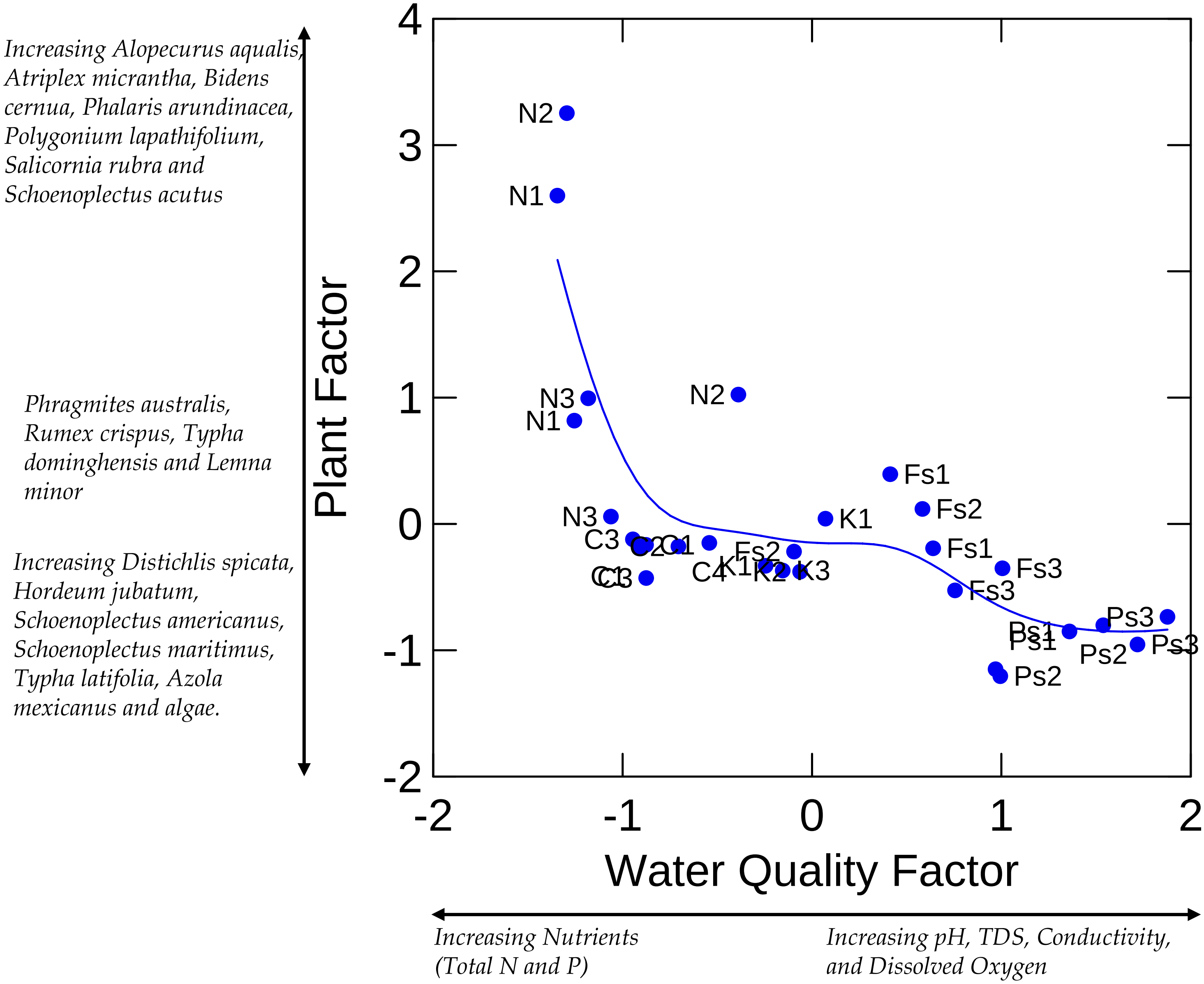


Figure 71. FACTOR ANALYSIS: Plants and Water Quality – Impounded Sites, 2005.

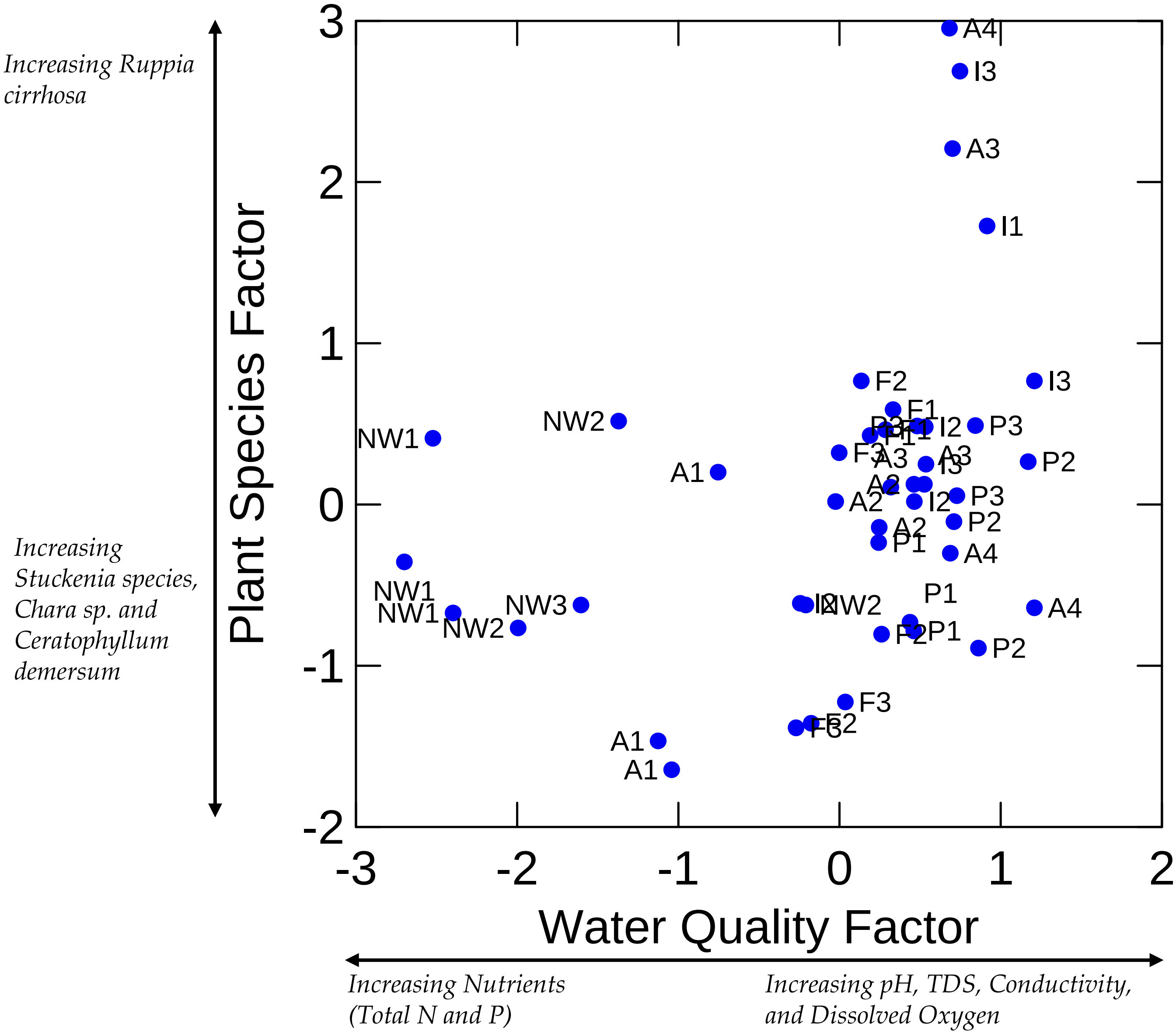


Figure 72. FACTOR ANALYSIS: Invertebrates and Water Quality, Impounded Sites, 2005

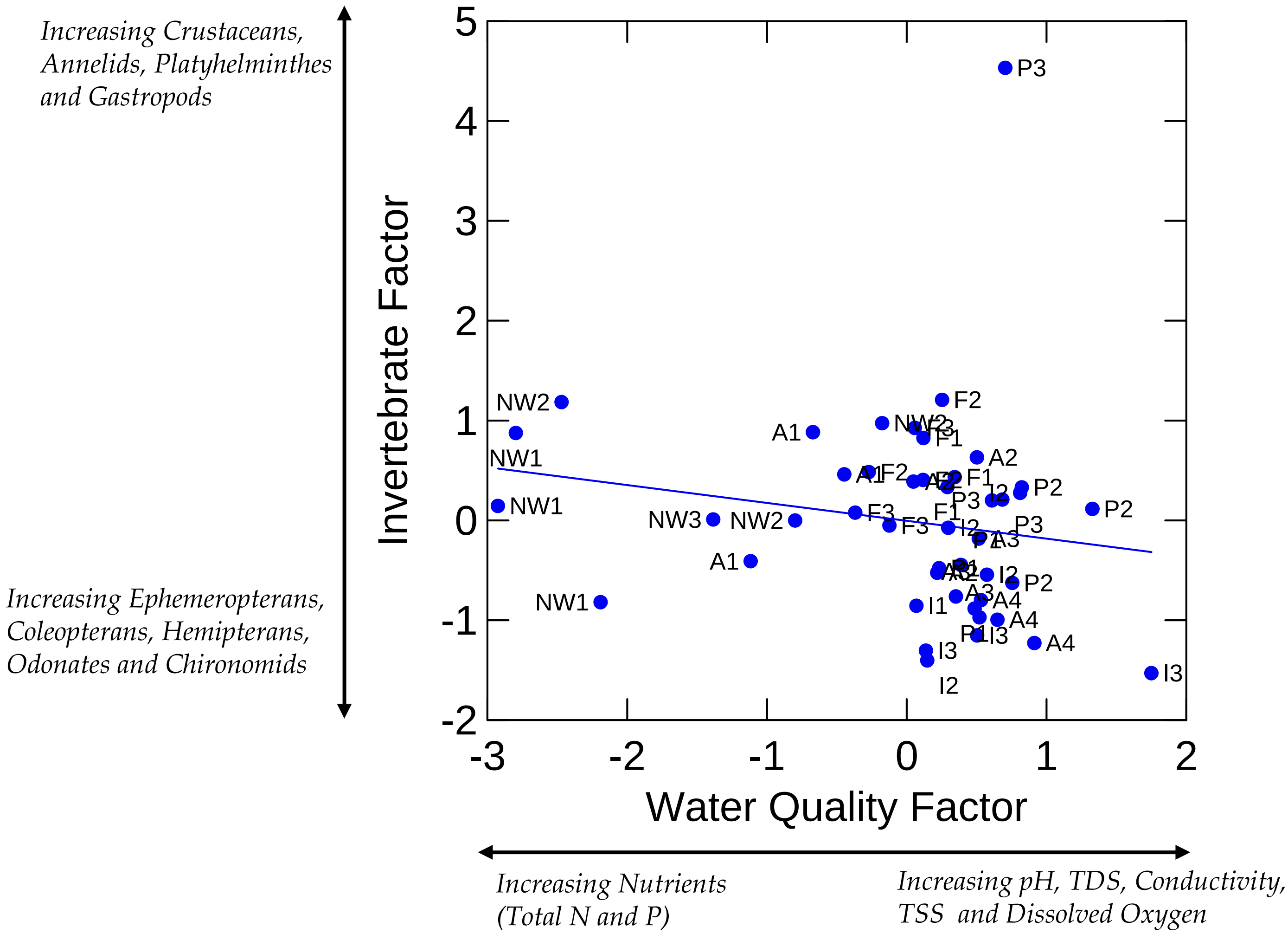


Figure 73. FACTOR ANALYSIS: Invertebrates and Water Quality, Sheetflow Sites, 2005

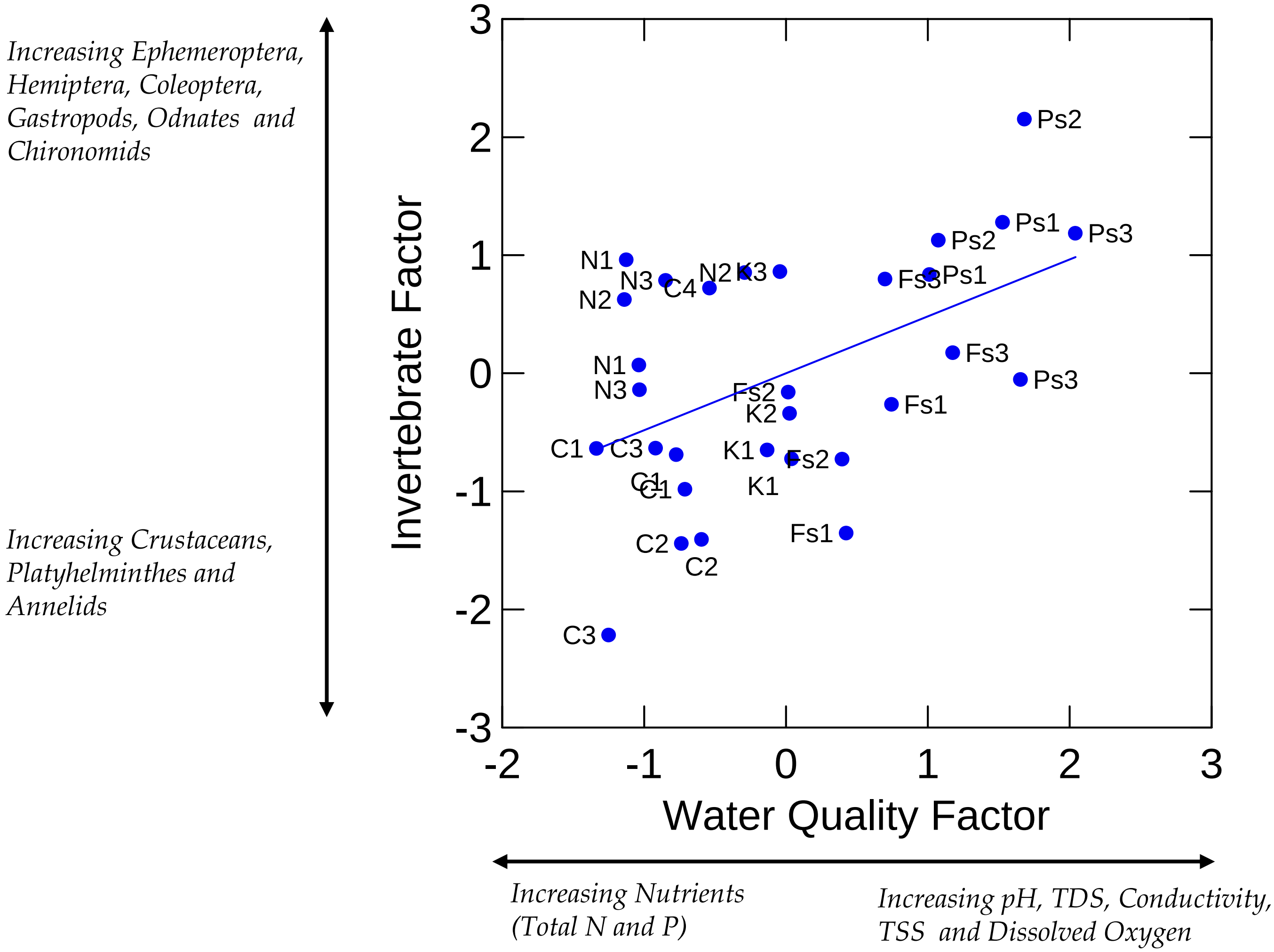


Figure 74. Macroinvertebrate Species Diversity Analysis – Impounded Sites, 2004.

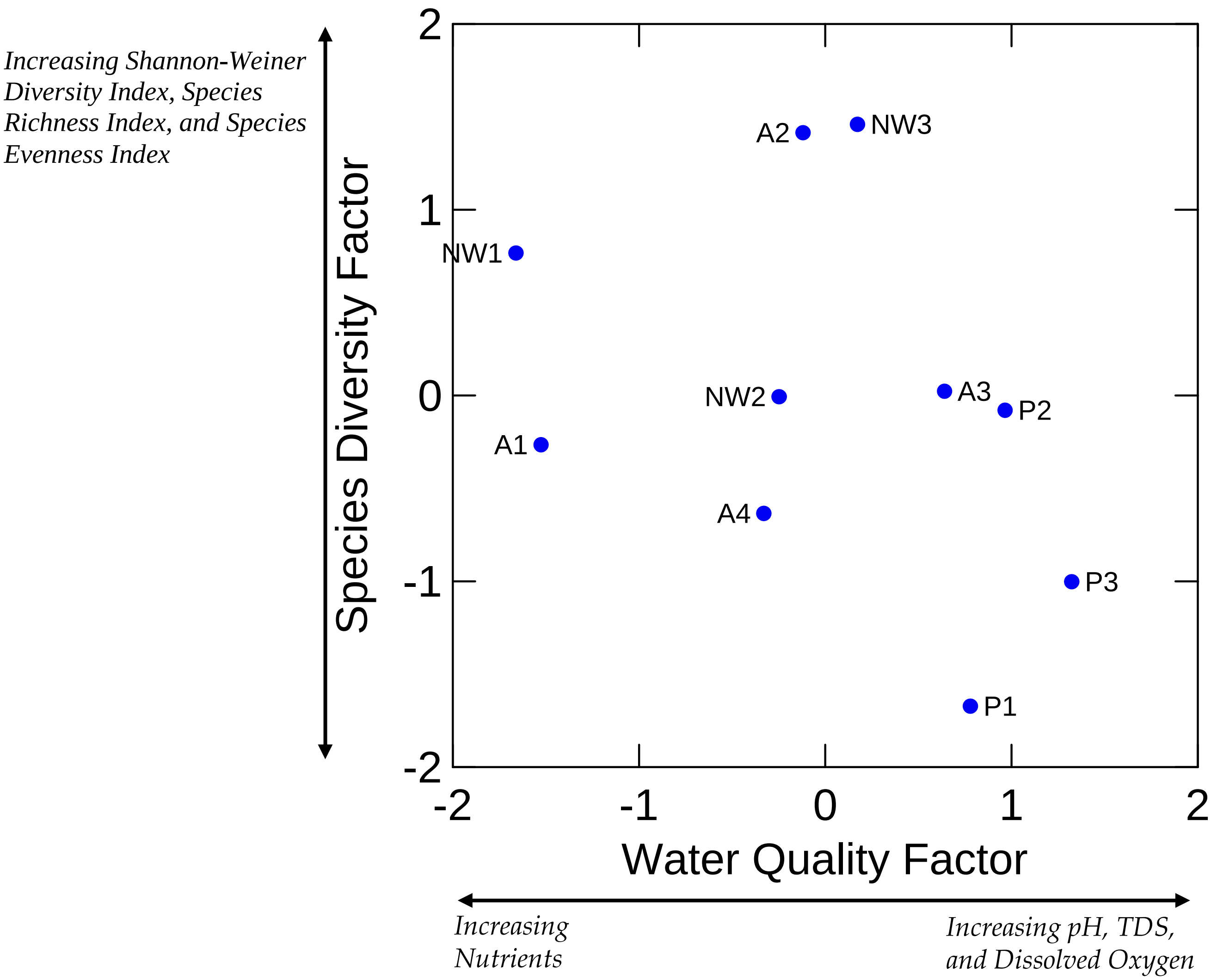


Figure 75. Macroinvertebrate Species Diversity Analysis – Sheetflow Sites, 2004.

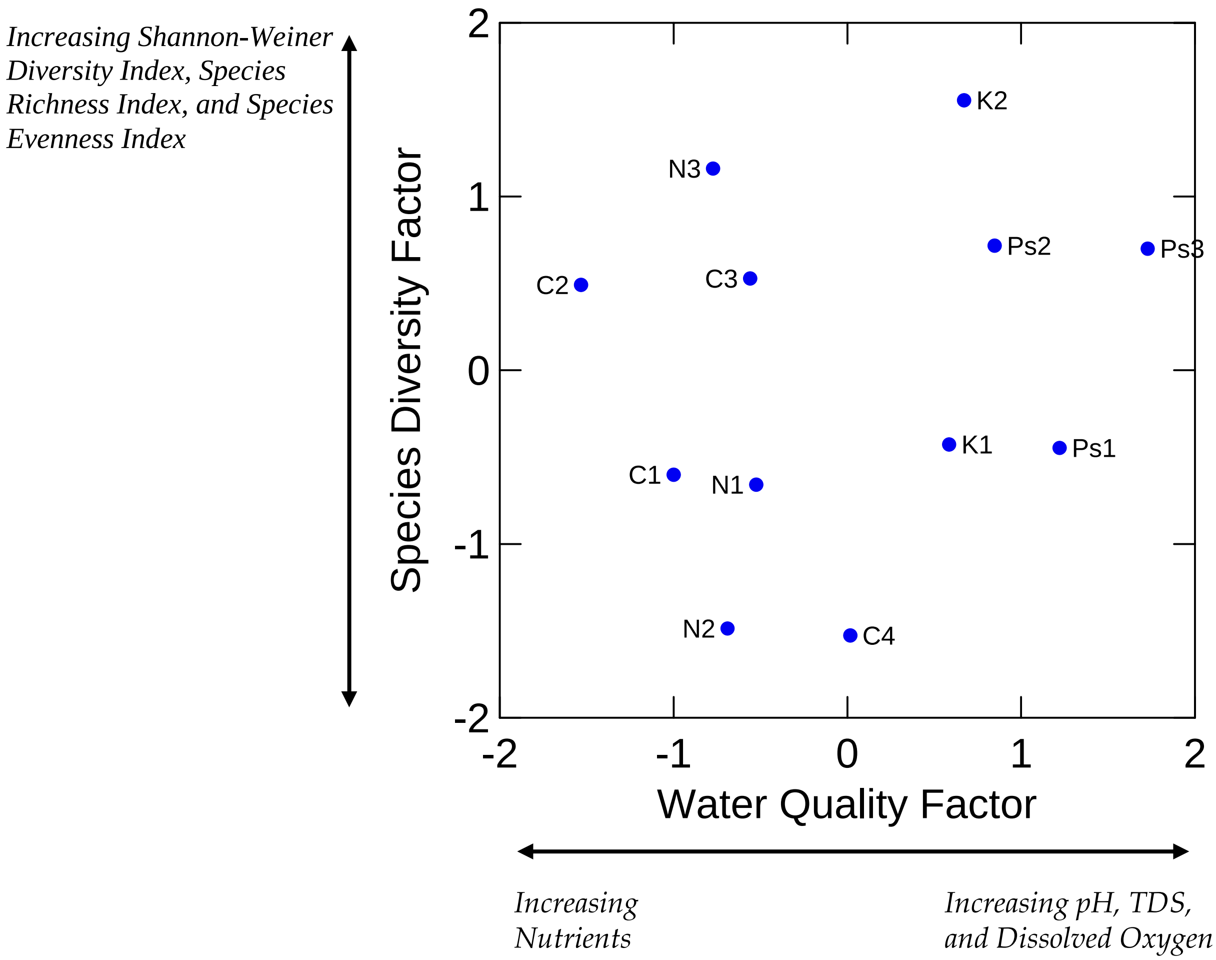


Figure 76. Macroinvertebrate Species Diversity Analysis: Impounded Sites, 2005

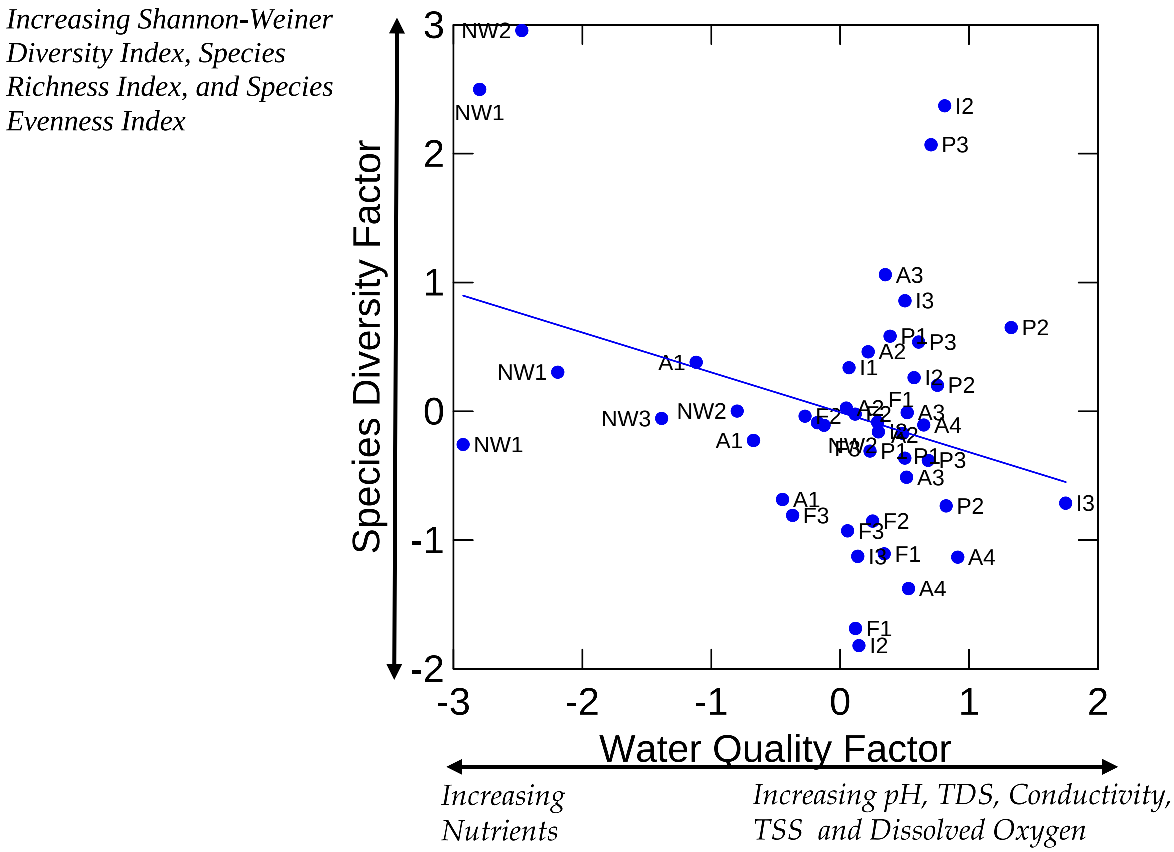


Figure 77. Macroinvertebrate Species Diversity Analysis: Sheetflow Sites, 2005