Stormwater Impact on the Savannas State Reserve

St. Lucie and Martin Counties, Florida

Florida Department of Environmental Prtotection
Southeast District Ambient Monitoring Program
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Abstract

The Florida Department of Environmental Protection Southeast District Ambient Monitoring Program evaluated the water quality effects of both state-of-the-art treated and untreated stormwater on an oligotrophic, freshwater marsh macroinvertebrate community during 1995-96. Twenty sampling sites were distributed throughout the length of the Savannas State Reserve freshwater marsh. Sites received runoff from natural upland areas or one of two major subdivisions that utilize the Reserve for stormwater disposal. One of these developments has no stormwater treatment, while the other uses an advanced system; thus, the study constituted a natural experiment to examine differences among treatment levels. Multivariate and other statistical tests were used to elucidate ecological effects. Areas of the Reserve receiving untreated stormwater had a significantly greater abundance of tolerant aquatic macroinvertebrates relative to sites receiving runoff from predominantly natural areas. Higher levels of phosphorus, pH, and hardness and lower levels of oxygen were identified as causes of community differences. On the basis of these results, an inter-agency task force has been convened to remediate the stormwater pollution. Two taxa are proposed for use as water quality indicator organisms.

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Executive Summary

The Savannas State Reserve is dominated by an oligotrophic, freshwater marsh in eastern St. Lucie and Martin counties, Florida. Background water quality within the Reserve is characteristically low in nutrients, chloride and hardness, and has an acidic pH. This physico-chemical regime supports an assemblage of aquatic plants and animals adapted to these conditions.

Macroinvertebrate and water quality samples were collected during 1995-96 to evaluate the ecological consequences of stormwater discharge into the Reserve. Two residential subdivisions in St. Lucie county use the Reserve for stormwater disposal: East Port St. Lucie (which has an advanced stormwater treatment system) and Indian River Estates (an older subdivision with no treatment). Sample collection locations were distributed the length of the Reserve, coinciding with areas near and removed from stormwater inflows.

The introduction of stormwater was found to alter the composition and character of the Reserve's water quality and macroinvertebrate community. Key causative water quality factors were identified as increased total phosphorus, hardness, and pH, and decreased dissolved oxygen. In response, the macroinvertebrate community exhibited increased numbers of tolerant or opportunistic organisms. Stormwater was also found to transport heavy metals and pesticides into the Reserve.

Advanced treatment reduced the extent and nature of stormwater effects on water quality and macroinvertebrate communities. Effects in the area of the Savannas adjacent to Indian River Estates were more severe than those near East Port St. Lucie. The marsh water in this area possessed significantly higher pH, hardness and total phosphorus, and lower dissolved oxygen than all other locations sampled. Species diversity and number of taxa were highest in this area of the Reserve most severely impacted by stormwater; thus, the prevailing assumption that increased pollution will always result in a corresponding reduction in these biotic metrices was found to be unsound.

Violations of Florida Administrative Codes (FAC) 62-302.530(31), 62-302.530(47), 62-302.530(48), 62-302.560(19) and 62-302.700(1) were documented. Recommendations of this study include no new stormwater discharges, retrofitting of the Indian River Estates subdivision, and periodic maintenance of the existing East Port St. Lucie stormwater treatment system. A multi-agency task force was formed to resolve water quality and quantity issues.

Introduction

The Savannas Reserve is a 4,600-acre, ten mile long managed environmental area extending from Fort Pierce to Jensen Beach in St. Lucie and Martin counties. During the last 15 years, land has been purchased to protect the Reserve through the Environmentally Endangered Lands, Conservation and Recreation Lands, South Florida Water Management District's (SFWMD) "Save Our Rivers" program and local governmental preservation plans. These purchases will eventually total 6,000 acres (Florida Department of Natural Resources [FDNR], 1993) at a cost in excess of $20 million.

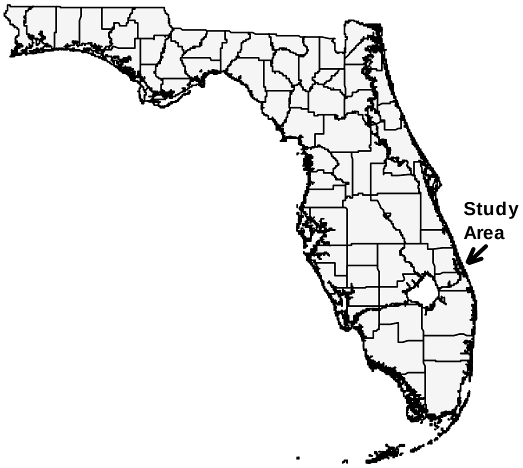

Figure 1. Study Area

The Reserve "includes the best remaining segment of Florida's east coast savannas" (FDNR,1993). Habitats include extensive freshwater marshes and wet prairies extending from the eastern coastal ridge to the pine flatwoods to the west. Soils of the coastal ridge are well drained, and support the endangered scrub community. Soils of the western part of the Reserve are poorly drained and retain surface water in a complex system of lakes, marshes, pine flatwoods and wet prairies. The diverse Savannas ecosystem includes eight natural community types: scrub, scrubby flatwoods, mesic flatwoods, basin marsh, marsh lake, wet prairie, wet flatwoods and depression marsh. More than 1,000 species of plants and animals have been identified in the Reserve.

Stormwater is known to be a source of nutrients, heavy metals, pesticides and other contaminants (Livingston et al., 1988). Oligotrophic ecosystems such as the Savannas are particularly vulnerable to such pollutants (David, 1996; Davis, 1994; McCormick et al., 1996; SFWMD, 1990). A previous study (Graves and Strom, 1995) documented biological and water quality impairment caused by stormwater inflows from the Indian River Estates subdivision into the Reserve. This earlier study was undertaken because replacement of native plant communities by invasive nuisance plant species was observed in these stormwater affected areas. The current study was undertaken to comprehensively document the effects of stormwater discharge into the Savannas State Reserve. This study was in essence a natural experiment addressing three treatments: areas receiving natural runoff, areas receiving treated stormwater and areas receiving untreated stormwater.

Methods

Study Area

The eastern side of the Savannas marsh is largely undeveloped. West of the marsh, uplands harbor natural areas and residential developments. Indian River Estates and East Port St. Lucie residential subdivisions use the marsh for stormwater disposal. Twenty sample collection areas were distributed north to south along the western side of the Savannas (Figure 2, Table 1). Each sampling area was roughly a circle of fifty foot radius. The exact shape of each area was dictated by local morphology and aquatic vegetative distribution characteristics.

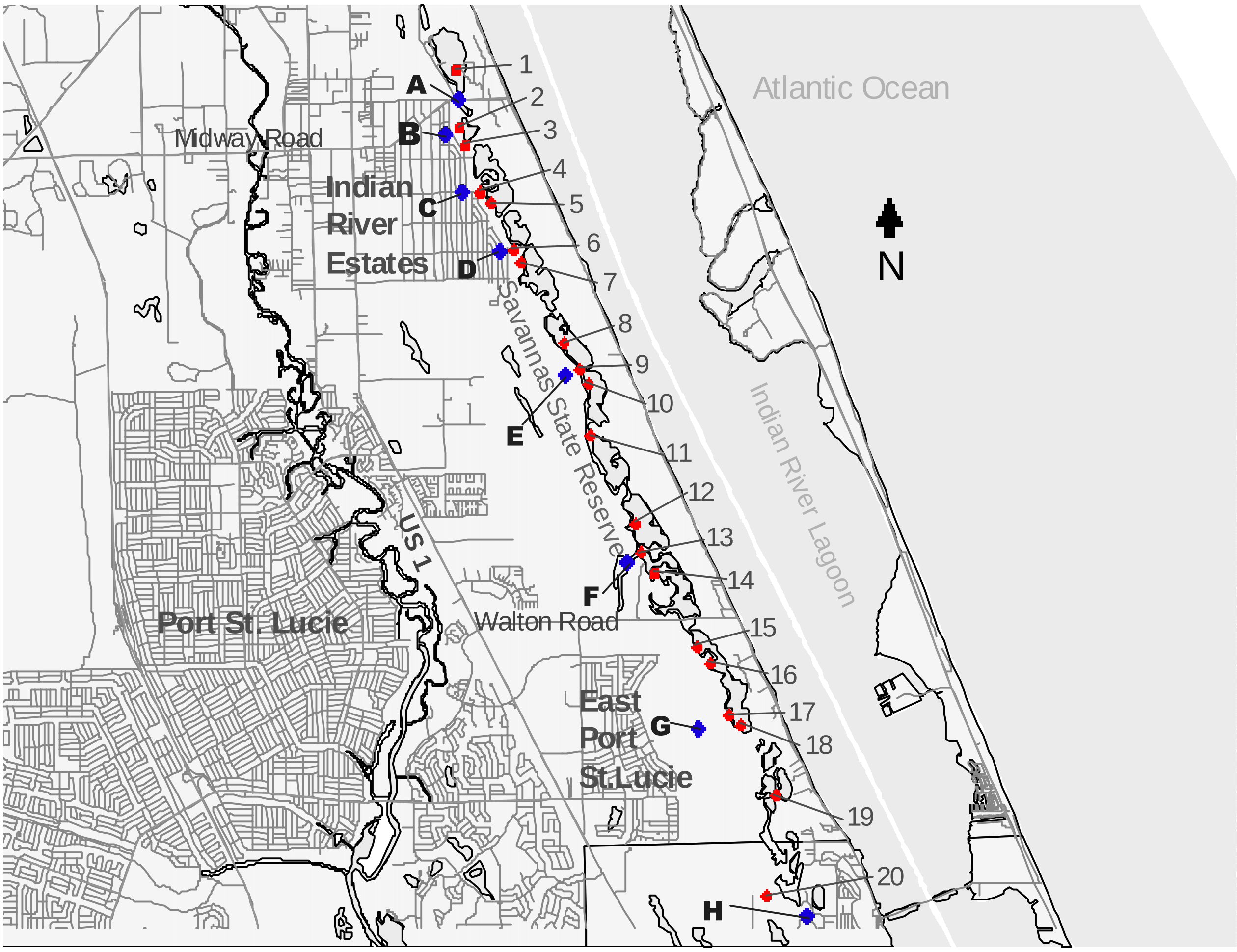

Figure 2. Study site locations.

Table 1. Key to Savannas State Reserve sampling sites.

Site	Type	USEPA Storet No.	Latitude 27°+	Longitude 080° +	Location Description
1	Marsh	28010107	23.228	18.447	St. Lucie Rec. Area/Palm Is.
2	Marsh	28010290	22.669	18.296	Scott St. ditch E end.
3	Marsh	28010289	22.598	18.267	100 yards S of Station 2.
4	Marsh	28010260	21.962	18.177	Howard St. ditch E. end.
5	Marsh	28010291	21.950	18.042	100 yards S of Station 4.
6	Marsh	28010293	21.406	17.628	Bartow St. ditch E end.
7	Marsh	28010292	21.293	17.558	100 yards S of Station 6.
8	Marsh	28010111	20.551	17.180	1.5 mi. SE Balsam Road end.
9	Marsh	28010294	20.465	17.078	Hog Pen Ditch E end.
10	Marsh	28010295	20.233	16.894	End of road S of 9.
11	Marsh	28010296	19.688	16.822	End of road SE of 10.
12	Marsh	28010297	18.806	16.416	Cove N of end of Walton trail.
13	Marsh	28010298	18.532	16.400	E end Savanna drainage ditch.
14	Marsh	28010299	18.433	16.264	Peninsula N of Walton Road.
15	Marsh	28010301	17.820	15.877	North end EPSL disch. ditch.
16	Marsh	28010300	17.710	15.783	100 yards S 15.
17	Marsh	28010302	17.062	15.415	100 yards E of 18.
18	Marsh	28010303	17.083	15.475	100 yards NE of G.
19	Marsh	28010304	16.321	15.054	W side W of Lake Eden.
20	Marsh	28010305	15.315	15.216	SW corner Reserve marsh.
A	STM	28010258	22.890	18.296	Culvert under Midway Road.
B	STM	28010284	22.692	18.425	Ditch at E end Scott Street.
C	STM	28010259	21.999	18.191	Ditch at E end of Howard St.
D	STM	28010285	21.449	17.767	Ditch at E end of Bartow St.
E	STM	28010286	20.275	17.067	Hogpen Ditch E weir.
F	STM	28010287	18.516	16.416	Road at Sav. drainage ditch.
G	STM	28010263	17.030	15.490	Spillway SE Melaleuca Street.
H	STM	28010288	14.686	14.721	Warner Cr. S Jensen Blvd.

Notes: Site types: Marsh=macroinvertebrate and water quality sampling site located in the Savannas marsh; STM=stormwater monitoring site. The FDEP USEPA Storet Agency code is 21FLA.

Biological sampling sites were designated by numbers 1 through 20. Site 1 was in the St. Lucie County Recreation Area park north of Midway Road, and north of the Indian River Estates subdivision. Surficial drainage in the northern end of the Savannas, where Indian River Estates lies, was predominantly northward under Midway Road toward site 1. Sites 2 through 7 were adjacent to Indian River Estates residential subdivision in areas receiving untreated stormwater. Sites 2, 4 and 6 were within the Savannas Reserve near mouths of drainage ditches along Bartow, Scott and Howard streets in the subdivision, respectively; sites 3, 5 and 7 were approximately 100 yards distant from the above respective sites.

Sites 8, 10, 11, 12 and 14 were within areas adjoined by natural undeveloped woodlands and were spatially removed from canal mouths or other sources of residential surficial runoff. Sites 15 through 18 were adjacent to East Port St. Lucie within an area that received treated stormwater runoff. Sites 15 and 18 were adjacent to stormwater overflows; sites 16 and 17 were removed from these by about 100 yards, respectively. Sites 19 and 20 were in the southernmost part of the Reserve. Sites 9 and 13 were near mouths of canals that were assumed to provide drainage out of the Savannas.

Stormwater monitoring sites (STM) were designated by letters A through H. Site A was north of the Midway Road culvert, at the north end of the Savannas, north of Indian River Estates subdivision and south of the St. Lucie county recreation area. Sites B, C and D were in the Indian River Estates subdivision at the eastern ends of the Scott, Howard and Bartow streets drainage ditches, respectively, prior to discharge to the Reserve. Sites E and F were in the Hogpen and “Savannas Drainage” ditches, respectively, near their confluence with the Savannas marsh. Site G was at the East Port St. Lucie stormwater treatment overflow point into the Reserve near Melaleuca Street, Port St. Lucie. Site H was south of the Reserve in Warner Creek, at Jensen Beach Boulevard.

Macroinvertebrate Sampling

Benthic macroinvertebrates are commonly used to evaluate water quality; the diversity and ubiquity of species offer a spectrum of responses to environmental stress (Rosenberg and Resh, 1993). Utilization of macroinvertebrate community data in environmental investigations relies on the premise that similar ecological conditions give rise to similar species assemblages. Sites which share common macroinvertebrate abundance characteristics are assumed to share similar water quality and ecological conditions (Clarke and Ainsworth, 1993). Examples of such ecological conditions include but are not limited to factors such as shared basin morphology, meteorological conditions, substrates, recruitment availability and water quality, depth and velocity.

Dip-nets were used to collect macroinvertebrate samples quarterly, in October 1995 and January, April and July 1996. Several days were required within each quarter to collect samples from all twenty sites; however, sample collection was expedited to minimize temporal variation. Sampling was conducted between 10:00 AM and 3:00 PM. Samples were collected from a depth of approximately one meter. Each dipnet sample was a composite of twenty one-half meter sweeps collected from among the natural substrates present within a given sample area. The composite from each area contained two sweeps of bottom sediments with the remaining eighteen sweeps distributed among the dominant aquatic vegetation. Aquatic plants observed at each site during each sampling event were recorded and are listed in Appendix A.

All biological samples were taken and analyzed using standard FDEP protocols (Barbour et al., 1996a; FDEP, 1996; Ross, 1990). Aquatic macroinvertebrates were identified to the lowest practicable taxon. Raw macroinvertebrate data are available from the authors.

Water Quality Sampling

Samples were collected eight times per year, with four of these sampling events coincident with biological collections. Dissolved oxygen, oxidation reduction potential, pH, conductivity, and temperature were measured with Yellow Springs Instruments YSI® UPG6000 and/or Hydrolab® multi-probe meters during each sampling event. Water samples for total phosphorus, total ortho-phosphorus, ammonia nitrogen, Kjeldahl nitrogen, nitrate plus nitrite nitrogen, color, turbidity, hardness, and chloride were collected at each site. Water samples for the same analyses were taken at a series of stormwater inflow monitoring sites during or following periods of heavy rain. A single set of water and sediment samples from selected sites were analyzed for heavy metals, pesticides and petroleum hydrocarbons.

Chemical analyses were performed using FDEP approved methodologies (Florida Department of Environmental Regulation, 1992). Pesticide and heavy metal analyses were performed by the FDEP Central Laboratory in Tallahassee; all other analyses were performed at the FDEP Port St. Lucie laboratory. Both laboratories have established FDEP QA/QC plans. All water quality data were stored in the USEPA "Storet" database. A complete set of raw data can be obtained directly from Storet or by request from the authors. Station numbers where this data resides in Storet are presented in Table 1.

Data Analysis

The objective of this study was to determine if the macroinvertebrate communities and water quality of an oligotrophic marsh differed between areas receiving treated and untreated stormwater or runoff from natural areas. Statistical analysis was performed using Minitab® (Minitab, Inc.) and Primer® (Plymouth Marine Laboratory) software.

Agglomerative hierarchical cluster analysis was used to determine site groups for subsequent analysis (Dillon and Goldstein, 1984). The biotic relationship among samples was distilled into a matrix of Bray-Curtis (Bray and Curtis, 1957) similarity coefficients representing the similarities between macroinvertebrate communities from separate samples. Similarity coefficients were calculated from the log-transformed mean abundance data of the 243 macroinvertebrate species identified (Appendix B). Several methods of linkage provided the same general result; however, the McQuitty linkage (Minitab, 1996) resulted in the most cogent clustering.

Two ordination methods, principal component analysis (PCA) and multidimensional scaling (MDS) were employed to verify the validity of cluster-identified site groupings, and to elucidate important factors among sample site species community assemblages. PCA and MDS were performed on log-transformed mean species abundances. Low abundance species were removed prior to PCA and MDS analyses to improve discriminatory power. For PCA, species lying beyond the inflection point of a species abundance curve were removed; for MDS, rare taxa ($N<4$) were removed. A rank-similarity matrix was computed from a Bray-Curtis similarity matrix and used to produce the MDS plot. The nonparametric Spearman rank correlation procedure was used to identify highly significant ($P \leq 0.001$) correlations among PCA scores and species abundances to water quality data. Environmental variables best explaining macroinvertebrate community patterns were identified by maximizing a rank correlation between biotic and abiotic similarity matrices (Clarke and Ainsworth, 1993). Species were identified which were important indicators of differences between groups of sites (Clarke and Warwick, 1994).

The Kruskal-Wallis nonparametric test was employed to identify water quality or biotic metrices that were significantly different ($P \leq 0.05$) among groups. Analysis of Means (Ott, 1967; Schilling, 1973), a type of graphical ANOVA for examining the equality of population means, was used to elucidate differences ($P \leq 0.05$) among groups.

Results and Discussion

To successfully implement Ecosystem Management, information must be gathered that accurately identifies aquatic systems worthy of protection and enhancement, especially where ecological integrity has been least damaged by prior management. Managers and scientists must be able to confidently rely upon this information to jointly develop means to ensure protection. This requires a robust study design and data analysis to address the inherent limitations of scientific understanding of ecological systems (Frissell and Bayles, 1996). To maximize the acceptance of conclusions and the likelihood of implementation of recommended solutions, it is critical that the methods used to elucidate processes affecting these ecosystems conform to the standards of the greater scientific community. Objective methods allow probability-based hypothesis testing with a known margin of error (Green, 1979; Zar, 1984; Pielou, 1977; Norris and Georges, 1993).

Hierarchical Agglomerative Cluster Analysis

Cluster analysis can be used to classify samples into groups (Clarke, 1993). Cluster analysis (Figure 3) suggests that sites within the Savannas generally fall into five groups with similar macroinvertebrate species assemblages. These groups were related to proximity to stormwater inflows or related impacts (Table 2).

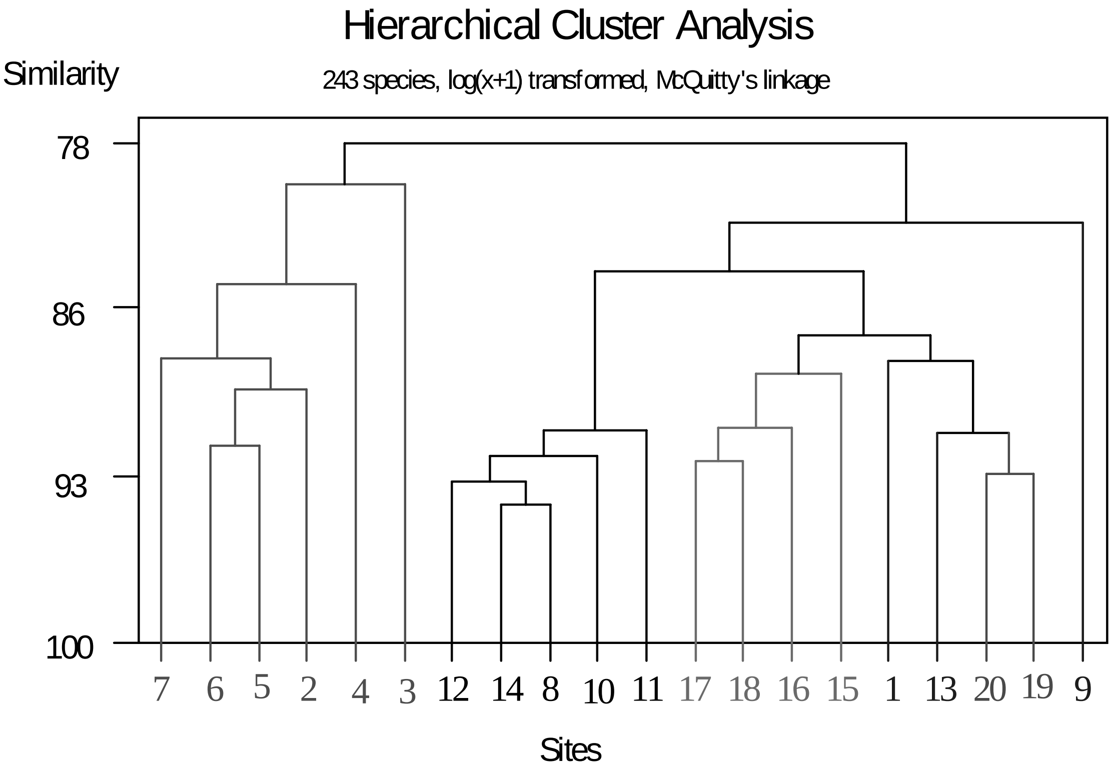

Figure 3. Hierarchical cluster analysis.

These five groups of sites fall into two larger categories: those near Indian River Estates (in red) and all other sites sampled. This implies that the macroinvertebrate community in the group of sites adjacent to Indian River Estates was different than elsewhere in the Savannas. Since cluster analysis involves a number of choices among coefficients and linkage methods that are not strictly equivalent (Hruby, 1985), the significance of these groupings was explored using principal component and multidimensional scaling analyses.

Table 2. Key to groups of sites sharing similar macroinvertebrate communities.

Group	**Color**	**Sites**	**Characteristics**
“Reference”	black	8, 10, 11, 12, 14	Spatially removed from areas of known stormwater inflows.
“IRE”	red	2, 3, 4, 5, 6, 7	Adjacent to Indian River Estates stormwater discharges.
“EPSL”	green	15, 16, 17, 18	Adjacent to East Port St. Lucie stormwater discharges.
“South”	magenta	19, 20	Possible indirect recipients of some form of stormwater borne impact.
“Other”	blue		Known or believed to receive intermittent stormwater:
		9, 13	• near canal mouths known to flow backwards.
		1	• north of Indian River Estates.

Principal Component Analysis

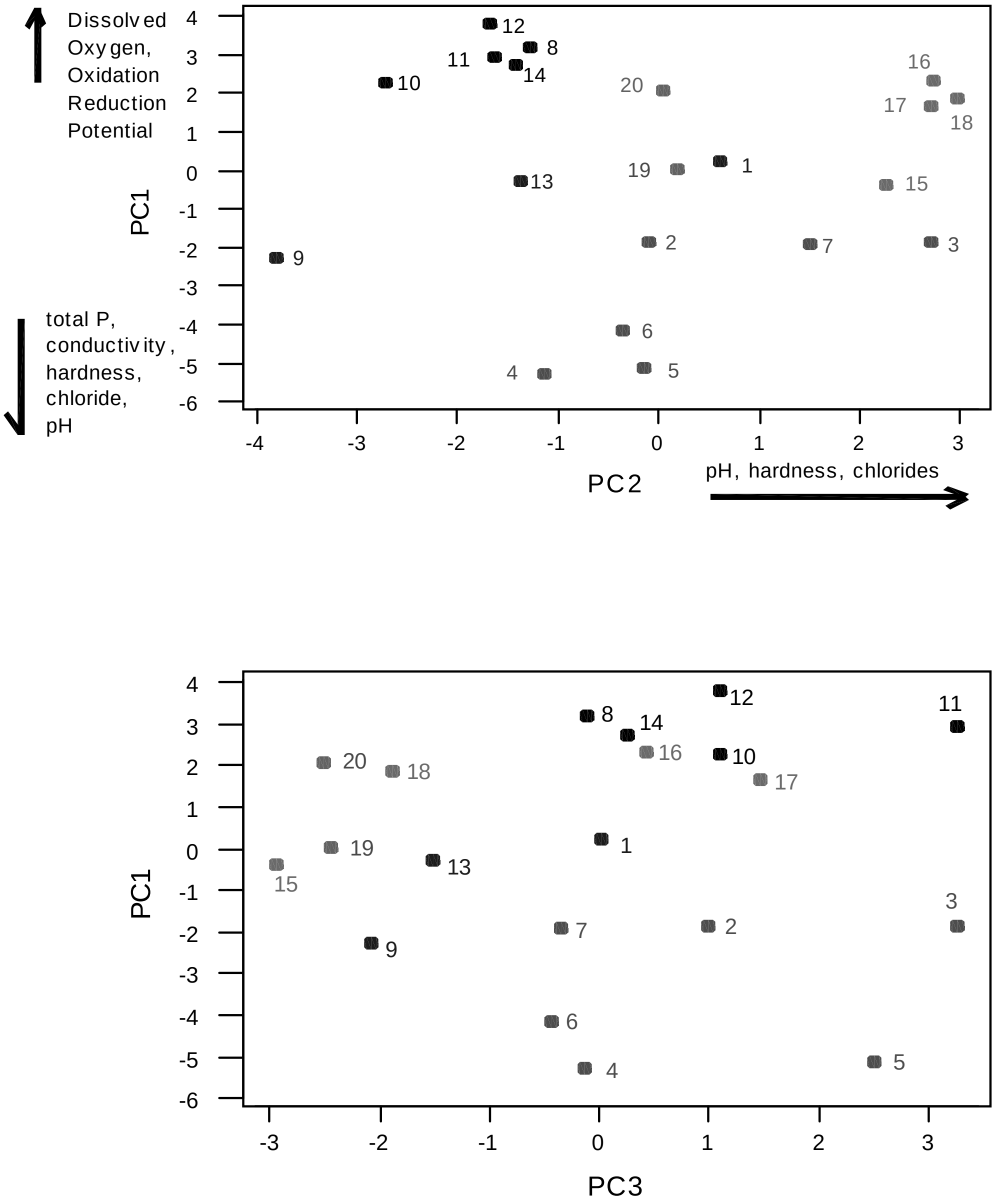

Figure 4. Principal component analysis of twenty-five most abundant taxa. Water quality parameters shown along axes were highly correlated ($P \leq 0.001$) to component scores; arrows signify direction of correlation.

Principal component analysis (PCA) identifies underlying linear combinations of variables (i.e., principal components) that explain as much of the total variation in the data as possible with as few of these components as possible (Figure 4). Components are extracted such that the first principal component (PC1) accounts for the largest amount of the total variation in the data. The second component (PC2) is uncorrelated with the first and explains the greatest amount of remaining variation not explained by PC1 (Dillon and Goldstein, 1984). Subsequent components are similarly extracted.

PCA performed on the log-transformed mean macroinvertebrate abundance of all 243 species was able to explain 32% of the total variation in the first three principal components (PC1-3). An acceptable PCA solution should account for at least 60% of the total variance (Hair et al., 1992). Datasets which include a large number of rare taxa result in substantial mathematical noise from the large number of zeros present. A common technique employed to provide an objective criterion for reduction of the quantity of zeros present is to examine a plot of overall species abundances. An inflection point in the abundance curve occurred at the twenty-fifth most-abundant species. These twenty-five species accounted for 76% of the total number of individuals collected. The first three principal components calculated from the twenty-five most abundant species (Appendix C) accounted for 61% of the total variance.

Each sampling site was located on the graphs (Figure 4) according to the magnitude and sign of its principal component scores. The x-y location on the above graphs is a function of each site's relationship to the major factors identified by PCA that characterize the macroinvertebrate community.

Table 3. Principal component loading by species for PC1.

Intolerant Species	**Loading**	**Rationale**	**Reference(s)**
Oxyethira sp.	0.288	Florida Index Class I prefers low pH Plant/periphyton assoc.	4,5,7,8,9
Oecetis sp.	0.263	Florida Index Class II Plant/periphyton assoc.	5,7,8,9,12
Hyalella azteca	0.195	Plant/periphyton assoc.	1,7,14
Parachironomus alatus	0.181	Nutrient/anoxia intolerant	13

Tolerant Species	**Loading**	**Rationale**	**Reference(s)**
Dero nivea	-0.205	nutrient tolerant	2,4,6
Dero sp.	-0.220	nutrient tolerant	2,4,6
Ancylidae	-0.282	hardness associated	11
Glyptotendipes sp. B	-0.284	nutrient tolerant	3,4,13
Polypedilum illinoense group	-0.294	Florida Index Class I nutrient tolerant	3,8,9,13
Polypedilum sp. A	-0.317		
Chironomus sp.	-0.326	nutrient tolerant	2,3,4,10,13

References: 1 - Bousfield, 1973; 2 - Brinkhurst, 1974; 3 - Epler, 1995; 4 - Johnson et al., 1993; 5 - Pescador, Rasmussen and Harris, 1995; 6 - Lauritsen et al., 1985; 7 - Rudolph and Strom, 1990; 8 - Ross, 1990; 9 - Ross and Jones, 1979; 10 - Saether, 1979; 11 - Brown, 1991; 12 - Harris and Lawrence, 1978; 13 - Beck, 1977; 14 - Hargrave, 1970.

The first principal component (PC1) explains 31.6% of the total variance. Examination of the factor loading upon PC1 indicates it was driven by the presence or absence of species tolerant or intolerant to degraded conditions associated with excess nutrients (references given in Table 3). Tolerant species exhibit negative factor loading such that increasing abundance of these species results in a decreased (more negative) PC1 score. Intolerant taxa have positive factor loading where increasing abundance of these species results in an increased PC1 score. The main effect of PC1 was to separate those sites in proximity to Indian River Estates (depicted in red) from the remainder of sites.

Differences in macroinvertebrate community structure resulting from stormwater were corroborated by the nonparametric Spearman rank correlations between principal component scores and environmental data (Table 4). PC1 was inversely correlated to concentrations of ortho and total phosphorus, total and Kjeldahl nitrogen, conductivity, pH, hardness, color and chloride. More negative values of PC1 were related to higher concentrations of these substances. PC1 was also directly correlated with dissolved oxygen and oxidation reduction potential (ORP) where higher values of PC1 were associated with higher levels of oxygen.

Table 4. Spearman rank correlation coefficients for highly significant (Pa 0.001) associations among principal component scores and water quality data; significant correlations are underlined (N=97, critical value = 0.332). Negative coefficients denote inverse relationships between variables.

Water Quality Variable	**PC1**	**PC2**	**PC3**
Diss. Oxygen	0.601	-0.015	0.245
pH	-0.345	0.665	0.042
Conductivity	-0.555	0.263	0.077
Total P	-0.534	0.104	0.174
Total N	-0.289	0.204	-0.075
ortho P	-0.257	0.039	0.168
TKN	-0.265	0.192	-0.066
Ammonia N	-0.122	0.057	-0.055
Nitrate+Nitrite	-0.063	0.070	-0.027
Hardness	-0.620	0.562	-0.028
Chloride	-0.607	0.365	0.094
Turbidity	-0.179	-0.110	0.024
Color	-0.239	-0.179	0.166
ORP	0.385	-0.037	0.191

The second principal component (PC2) accounted for 15.4% of the remaining variance. PC2 was controlled by the abundance of species, such as the midge Cladotanytarsus sp., that are intolerant to acidification (Bilyj and Davies, 1989). The main effect of PC2 was to separate sites in proximity to East Port St. Lucie (depicted in green) from those sites in natural, relatively unimpacted areas of the Reserve (in black). A similar shift was also apparent for sites adjacent to Indian River Estates (in red). The relationship between changes in species assemblages and pH was corroborated by the strong correlation of PC2 with pH and hardness. More positive values of PC2 were related to increases in pH and hardness, indicating a gradient in the macroinvertebrate communities due to these water quality variables.

The third component (PC3) explained 13.6% of the remaining variance and was inversely related to the abundance of some midge species (e.g., Zavreliella marmorata and Larsia spp.), the mayfly Caenis diminuta and predatory odonates. PC3 was not strongly correlated with any water quality variable. The third principal component may indicate a benthic community assemblage intermediate in tolerance between the reference and the Indian River Estates groups of sites. Certain organisms may possess an ecological advantage in such areas.

It was apparent from PCA that sites possessing shared environmental conditions exhibited similar macroinvertebrate communities. This supports the inferences previously drawn from cluster analysis (Table 2). The Reference sites 8, 10, 11, 12 and 14 (in black) were within areas adjoined by natural undeveloped woodlands. This group of sites had a similar macroinvertebrate assemblage which appears indicative of natural conditions.

The six IRE sites adjacent to Indian River Estates (in red) received untreated stormwater. As a group, these sites possessed a distinct macroinvertebrate community along both PC1 and PC2. This indicates a difference in macroinvertebrate communities in response to lower dissolved oxygen and higher nutrients, pH and hardness. The four EPSL sites adjacent to East Port St. Lucie (in green) received treated stormwater. These sites differ from the reference sites (in black) by separation along PC2, indicating a difference in communities due to higher pH and hardness.

PC3 suggests that the aquatic macroinvertebrate communities present at the South group of sites, 19 and 20 (in magenta), shared some common community characteristics with sites 15 and 18 near East Port St. Lucie. The aquatic community sampled from these sites was in some regards different from that present at either the reference (in black) or Indian River Estates (in red) sites. These two sites may be impacted by runoff from the Sugar Hill subdivision to the east or from stormwater runoff from the East Port St. Lucie stormwater treatment system.

The Other group of sites, 9 and 13 (in blue), were at the mouths of canals that were assumed to provide drainage out of the Savannas; however, during periods of intense rainfall, it was observed that these canals flow backwards into the Reserve. These reversed flows may convey stormwater into the Reserve from areas to the west. Site 1 (also in blue) was in the St. Lucie County Recreation Area park north of Midway Road, and north of the Indian River Estates subdivision. Surficial drainage in the northern end of the Savannas, where Indian River Estates lies, was predominantly northward under Midway Road toward site 1.

Nonmetric Multidimensional Scaling

Multidimensional scaling (MDS) is a multivariate ordination procedure that represents the best fit between similarities and distances between samples in the resulting ordinated space using an iterative procedure (Clarke and Warwick, 1994). MDS maps objects in such a way that their relative positions in the reduced space reflect the degree of similarity between the objects (Hair et al., 1992). MDS was employed to overcome the limitations of PCA (Clarke and Warwicke, 1994; Norris and Georges, 1993). Nonmetric MDS (versus metric MDS) relates the rank order of the source data to the rank order of proximities depicted on the map. The degree to which the final map agrees with the structure of the source data is given by the "stress" value, where a smaller value of stress indicates a better degree of fit.

Rough guidelines for interpreting stress are (Clarke and Ainsworth, 1993):

Stress <0.1	good ordination with little likelihood of false inference.
Stress <0.2	usable; values near 0.2 increase potential to mislead.
Stress >0.2	map becomes increasingly inaccurate.
Stress>0.35	effectively randomized map possessing little relevance.

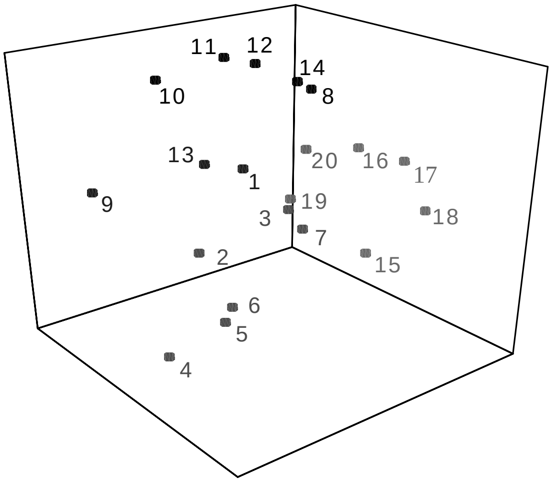

Figure 5. Nonmetric multidimensional scaling, stress = 0.08.

The stress value of the resulting MDS plot (Figure 5) was 0.08, indicating a good degree of fit. As shown by cluster analysis and PCA, five groups of sites are apparent. The separation, and thus the dissimilarity, was greatest between Reference (in black) and the IRE (red) groups.

Analysis of Means by Group

Analysis of Means (ANOM) was used to elucidate biological, physical and chemical differences among the five groups of sites (Schilling, 1973). In these graphs, the central line represents the overall sample mean. The significance of the upper and lower dashed limits is to reject the null hypothesis (at Pa0.05) that all group means are equivalent if any point lies beyond either line. Summaries of mean, minima and maxima for nutrient, physical and biological metric data are presented in Tables 5, 6 and 7, respectively.

Table 5. Summary of mean nutrient data with minima-maxima; concentrations in ppb.

Stormwater	Inflows		⇐	Five Site Groups		⇒	
	IRE Inflow	**EPSL Inflow**	**Reference**	**IRE**	**EPSL**	**South**	**Other**
No. obs.	18	6	41	48	32	19	25
N:P ratio	**4**	**112**	**122**	**37**	**174**	**166**	**107**
	2 - 7	34 - 217	47 - 330	9 - 119	22 - 710	21 - 405	29 - 375
Total N	**1300**	**760**	**783**	**917**	**820**	**971**	**791**
	683 - 2290	590 - 1220	530 - 1090	760 - 1180	22 - 1360	670 - 1320	560 - 1070
Total P	**329**	**13**	**8**	**35**	**7**	**9**	**10**
	152 - 616	3 - 35	2 - 18	7 - 132	1 - 14	2 - 42	2 - 28
NH3	**46**	**15**	**14**	**16**	**14**	**20**	**14**
	20 - 150	10 - 20	10 - 30	10 - 60	10 - 30	10 - 70	10 - 30
Nitrate+ Nitrite	**48**	**53**	**8**	**9**	**9**	**10**	**8**
	0 - 30	0 - 275	0 - 20	0 - 20	0 - 20	0 - 20	0 - 20

Note: "IRE Inflow" is a composite of storm event data from sites B, C and D. :
"EPSL Inflow" is a composite of storm event data from site F.

Table 6. Summary of mean physical data with minima-maxima.

Stormwater Inflows			⇐	Five Site Groups			⇒
	IRE Inflow	**EPSL Inflow**	**Reference**	**IRE**	**EPSL**	**South**	**Other**
No. obs.	16 - 21	5 - 6	41	46 - 52	28 - 32	18 - 19	23 - 25
Diss.	**2.7**	**4.3**	**6.9**	**2.7**	**5.8**	**3.5**	**3.8**
Oxygen	0.2 - 6.8	1.6 - 6.5	1.7 - 10.6	0.0 - 10.1	1.9 - 10.5	0 - 8.7	0 - 10.4
ORP	**92**	**99**	**179**	**57**	**156**	**74**	**126**
	[157]-205	33 - 209	5 - 315	[264]-430	10 - 263	[51]-217	5 - 262
Hardness	**115**	**39**	**10**	**33**	**19**	**17**	**19**
	55 - 205	33 - 45	5 - 11	13 - 62	10 - 40	13 - 24	5 - 45
pH	**6.7**	**6.4**	**5.1**	**6.0**	**6.0**	**5.6**	**5.5**
	6.2 - 7.7	6.2 - 6.6	4.5 - 5.7	4.5 - 6.8	5.5 - 6.9	4.3 - 6.5	4.3 - 7.2
chloride	**73**	**22**	**16**	**35**	**20**	**20**	**22**
	19 - 161	17 - 28	12 - 19	18 - 154	13 - 32	15 - 31	12 - 39
Conductivity	**513**	**122**	**71**	**172**	**87**	**97**	**105**
	143 - 1448	24 - 157	31 - 98	35 - 332	19 - 163	16 - 146	49 - 184

Notes: "IRE Inflow" is a composite of storm event data from sites B, C and D. : "EPSL Inflow" is a composite of storm event data from site F. Units: dissolved oxygen, chloride and hardness in mg/l, conductivity in µS, negative values in [brackets].

Table 7. Summary of mean biological metric data with minima-maxima.

	Reference	**IRE**	**EPSL**	**South**	**Other**
No. obs.	24	25	22	12	14
No. Individuals	**149**	**186**	**143**	**156**	**172**
	84 - 225	100 - 333	92 - 221	98 - 274	97 - 331
HBI	**7.53**	**7.37**	**7.10**	**7.28**	**7.18**
	6.6 - 8.0	6.7 - 8.5	6.7 - 8.3	6.6 - 7.9	6.6 - 7.7
EPT	**3.5**	**2.9**	**3.8**	**4.6**	**3.6**
	2 - 5	0 - 5	2 - 7	1 - 7	2 - 6
Species Diversity	**3.38**	**4.32**	**4.22**	**4.09**	**4.32**
	1.9 - 4.3	3.3 - 5.0	3.4 - 4.8	3.5 - 4.7	3.9 - 4.8
Equitability	**0.61**	**0.82**	**0.85**	**0.76**	**0.83**
	0.19 - 0.90	0.44 - 1.22	0.64 -1.04	0.45 - 0.98	0.53 - 1.13
Florida Index	**7.6**	**4.6**	**7.8**	**7.7**	**6.9**
	3 - 12	1 - 9	2 - 11	4 - 12	4 - 10
%Dominant Taxon	**39.5**	**21.8**	**19.5**	**26.6**	**23.8**
	18 - 76	8 - 44	10 - 39	12 - 45	10 - 41
% Crustacea+Mollusca	**40**	**25**	**17**	**24**	**23**
	15 - 76	6 - 50	2 - 41	8 - 45	2 - 41
% Filterers	**3.0**	**5.0**	**11.3**	**4.9**	**6.9**
	0 - 10	0 - 16	2.8 - 17	0 - 14	1 - 28
%Collector Gatherers	**21**	**30**	**32**	**24**	**26**
	9 - 39	11 - 63	19 - 52	13 - 44	14 - 45
% Filterer Gatherer	**24**	**35**	**44**	**29**	**33**
	10 - 41	12 - 63	29 - 62	19 - 44	16 - 61
% Shredders	**42**	**30**	**22**	**29**	**27**
	18 - 77	7 - 52	10 - 44	8 - 49	5 - 46
% Predators	**24**	**23**	**22**	**31**	**28**
	9 - 50	10 - 38	12 - 38	14 - 48	16 - 48
% Insecta	**50**	**57**	**70**	**65**	**60**
	16 - 76	25 - 86	52 - 83	50 - 83	40 - 80
% Crustacea	**39**	**18**	**16**	**23**	**20**
	15 - 76	2 - 47	1 - 41	4 - 45	1 - 41
% Oligochaeta	**7**	**13**	**11**	**7**	**11**
	0.5 - 26	0 - 58	0 - 32	0.8 - 27	0.7 - 35
% Odonata	**3**	**3**	**3**	**3**	**4**
	0 - 13	0 - 7	0 - 11	0 - 6	1 - 15
% Mollusca	**0.8**	**6.6**	**1.5**	**1.3**	**2.7**
	0 - 13	0 - 25	0 - 6	0 - 6	0 - 10
% air breather	**2.2**	**7.8**	**2.5**	**2.4**	**3.7**
	0 - 13	2 - 47	0 - 5	0 - 8	0 - 8
total taxa	**29**	**39**	**35**	**36**	**39**
	21 - 38	25 - 50	25 - 48	29 - 50	30 - 51
No. Crustacea Mollusca	**1.7**	**5.3**	**3.5**	**2.8**	**2.6**
	1 - 3	2 - 7	2 - 7	1 - 6	1 - 4
ETO	**5.3**	**4.9**	**5.6**	**6.8**	**5.8**
	4 - 8	2 - 8	2 - 9	4 - 10	3 - 8
No. Chironomidae	**12**	**14**	**14**	**15**	**16**
	8 - 17	9 - 20	10 - 18	10 - 18	10 - 22
% Chironomidae	**26**	**34**	**42**	**33**	**32**
	7 - 48	9 - 59	24 - 56	18 - 53	19 - 54

Nitrogen to Phosphorus Ratios

Dissolved inorganic nitrogen (nitrate, nitrite and ammonia) and phosphorus are elements that often control or limit plant growth (Mitsch and Gosselink, 1993). An N:P ratio greater than 22:1 is indicative of phosphorus limitation (Brenner et. al, 1990). Primary production in freshwater systems is most often limited by phosphorus (Steinman and Mulholland, 1996). Since all sites sampled within the Savannas possessed a N:P ratio greater than 22:1, the Reserve may be considered a phosphorus-limited oligotrophic ecosystem. The mean N:P ratio for the Indian River Estates group was 37:1; other Savannas' N:P ratios were over 100:1. N:P ratios above 100:1 are typical of those found in unimpacted areas of Everglades National Park (Walker, 1991) which is also a phosphorus limited system (Davis, 1994; Lodge, 1994; SFWMD, 1990).

N:P ratios for the EPSL and South groups were significantly higher than all others. N:P ratios from the IRE group of sites were significantly lower than all others. Although the stormwater from Indian River Estates contained higher levels of total nitrogen than that from East Port St. Lucie, the net increase in nitrogen was outweighed by the large amount of phosphorus carried by the stormwater.

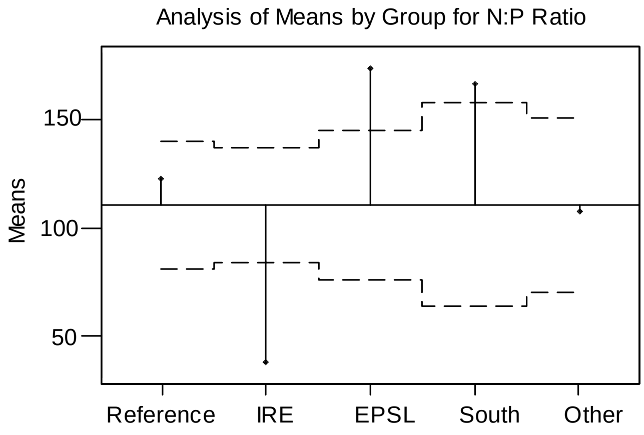

Figure 6. ANOM - N:P ratios.

Stormwater draining a subdivision such as Indian River Estates that is entirely unsewered might be expected to contain relatively high levels of ammonia nitrogen. Although ammonia nitrogen in stormwater from the Indian River Estates subdivision was higher than that in EPSL stormwater or that within the Savannas, ammonia levels did not reflect gross contamination. Nitrate-nitrite for both stormwater inflows was similar and exhibited pulses of higher concentration.

Total Phosphorus

The mean concentration of total phosphorus (TP) within the IRE group (35 ppb) was significantly higher than that observed for any other group, over four times that of the Reference group (8 ppb). Vegetative alteration was most conspicuous at the IRE sites. The mean TP concentration of stormwater entering the Reserve from the Indian River Estates drainage system was 329 ppb (Table 5).

The northern boundary of the Reserve is Midway Road in St. Lucie county, adjacent to Indian River Estates. During the course of the study, the St. Lucie County Park and Recreation staff recorded flow direction at the culverts under Midway Road. The predominant flow pattern was to the north. Total phosphorus in the four samples collected at the Midway Road culvert averaged 97 ppb. Sources of this phosphorus may include Indian River Estates runoff and drainage from the ditch which runs along Midway Road. Mean TP at site 1 was 14 ppb.

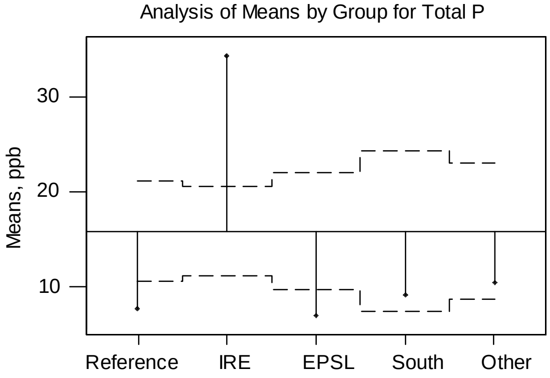

Figure 7. ANOM - Total Phosphorus, mg/l.

By comparison, mean total phosphorus concentration for the EPSL group of sites was 7 ppb, a level comparable to Reference group conditions. The mean TP concentration in samples of treated stormwater from the East Port St. Lucie treatment system was 13 ppb; however, two of these samples contained 20 and 35 ppb TP. This implies that during rain events when sufficient velocities exist, breakthrough occurs (i.e., washout or pass through of nutrients). This would account for the alteration in the plant community observed in the area north of the northernmost stormwater spillway which flows only during extreme rainfall events when breakthrough would be most likely. A large area of cattails also exists at the southernmost spillway, which is closest to the stormwater treatment pond. Water entering the Savannas from this spillway has not had the benefit of the additional treatment afforded by passage through the ditch system. The invasive cattail in the area adjacent to East Port St. Lucie appeared to be expanding its range. Dense stands of emergent macrophytes like cattail have been associated with anoxic conditions (Rose and Crumpton, 1996). Harvesting shoot biomass has been shown to regenerate nutrient removal capacity of wetland treatment systems (Adler et al., 1996).

Total P among the South group of sites (19 and 20) was comparable to Reference conditions (9 ppb). Site 20 was near the source of Warner Creek. Samples from Warner Creek collected at site H yielded a mean TP concentration of 48 ppb. The source of these higher downstream phosphorus levels was undetermined; it may be a result of runoff from the Sugar Hill or Port St. Lucie subdivisions.

Florida Index

The Florida Index (Beck, 1954, 1965) is compiled from a list of macroinvertebrate species that have been shown to reflect biological effects of elevated nutrients (Barbour et al. 1996b; Ross, 1990; Ross and Jones, 1979). There was a strong negative correlation (P‘0.005) between total P concentration and Florida Index. Higher phosphorus levels in the Reserve marsh related to a lower Florida Index. Florida Index for the IRE group of sites was significantly lower than that for all other groups.

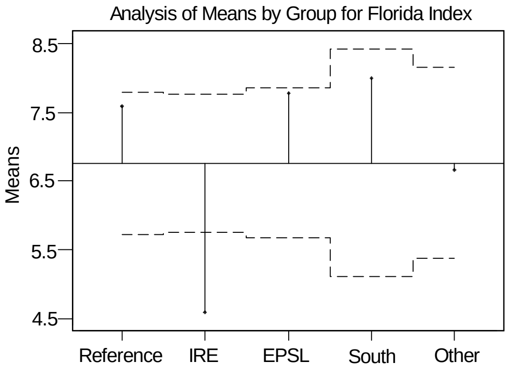

Figure 8. ANOM - Florida Index.

Dissolved Oxygen - % Air Breathers

Mean dissolved oxygen (DO) concentrations were highest at the Reference group of sites, with both the EPSL and Reference groups achieving the statute-mandated 5.0 mg/l standard (Figure 9). These groups were dominated by the aquatic plant *Eleocharis* sp. which produces rapidly decomposing debris that does not accumulate. Dissolved oxygen from the IRE group was significantly lower than DO from all other groups. Dense stands of emergent vegetation characterized the IRE group and have been associated with anoxic conditions (Rose and Crumpton, 1996). This anoxia was related to excess vegetative debris. Cattails, common in the IRE area, have been shown to produce persistent (slowly decomposing) plant litter (Harris et al., 1995). During the warmer months, periods of anoxia were also documented among the South and Other groups.

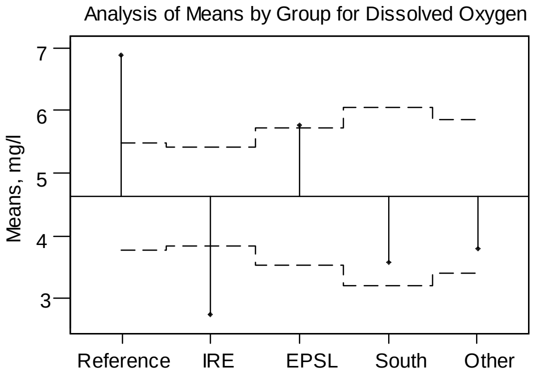

Figure 9. ANOM - Dissolved Oxygen, mg/l.

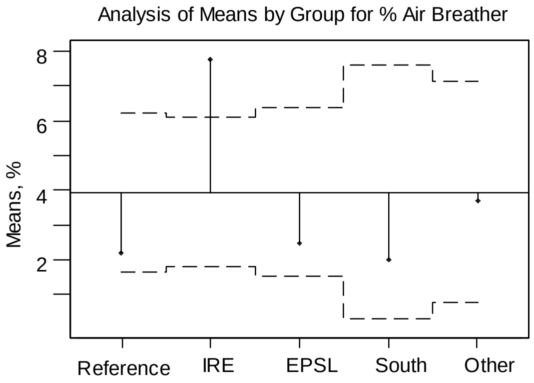

Figure 10. ANOM - Percent Air Breathers.

Certain organisms, such as the Noterid beetles of the genera *Hydrocanthus* and *Suphis*, are able to use atmospheric oxygen for respiration. This provides them a selective advantage in environments prone to anoxia. A strong inverse correlation ($P \leq 0.001$) existed between dissolved oxygen concentration and percent air breathers, with the highest percentage of air breathers found at sites adjacent to Indian River Estates (Figure 10).

Hardness - Percent Mollusca

Water hardness primarily refers to the concentration of calcium and magnesium dissolved in water. Historically, the major source of water to the Reserve wetlands was direct rainfall which is naturally soft. Thus Reference group conditions were characterized by very low hardness (10 mg/l). Mean hardness of stormwater at inflows to the Savannas from Indian River Estates (115 mg/l) was higher than that from the East Port St. Lucie subdivision (39 mg/l), suggesting that the latter's stormwater treatment system was partially effective in reducing hardness. Due to discharge of untreated high-hardness stormwater, hardness measured for the IRE group was significantly greater than elsewhere in the Savannas.

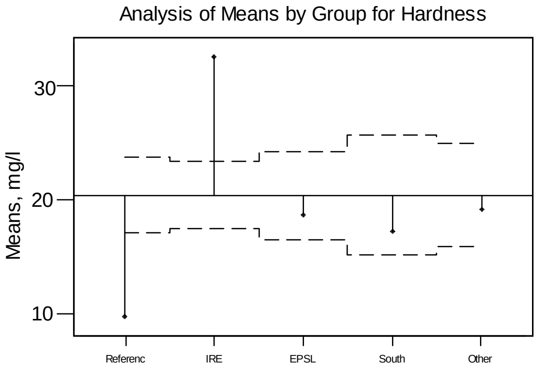

Figure 11. ANOM - Hardness, mg/l.

Water hardness has been shown to be a good predictor of mollusc species richness and abundance (Lonergam and Rasmussen, 1996). Calcium and magnesium availability for shell construction may have allowed organisms such as the snail *Planorbella scalaris* and limpets of the family Ancylidae to occur in significantly higher numbers within samples from the IRE group of sites.

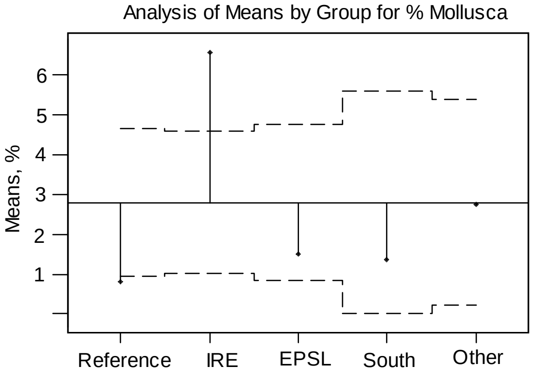

Figure 12. ANOM - Number molluscan taxa.

pH regime

Mean pH (5.1) from the Reference group of sites was moderately acidic, characteristic of a poorly-buffered, low conductivity system. The mean pH from both groups of sites that were near major sources of stormwater was 6.0, significantly higher than that measured in the unimpacted areas. Mean pH of the stormwater discharge to the IRE and EPSL groups was 6.7 and 6.4, respectively, indicating that the higher pH of these groups was indicative of stormwater inflow.

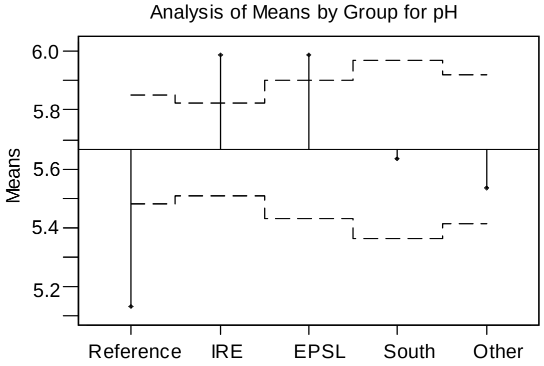

Figure 13. ANOM - pH.

Chloride and Conductivity

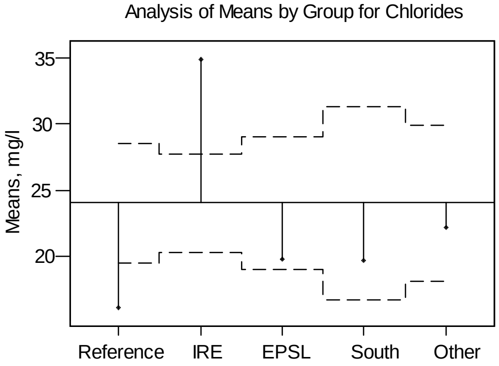

Figure 14. ANOM - Chloride, mg/l.

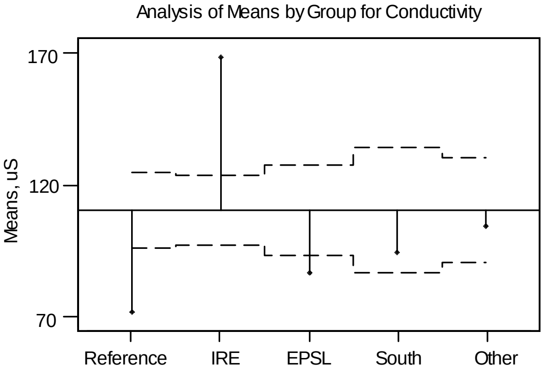

Figure 15. ANOM - Conductivity, TS.

Chloride is one of the major inorganic ionized substances in surface water. Conductivity is a numerical expression of water's ability to carry an electric current and depends on the total concentration of dissolved ions. Conductivity and chloride are indicative of the amount of dissolved matter in water. Reference conditions were characterized by significantly lower amounts of dissolved ions. Savannas waters near Indian River Estates had significantly higher levels of chloride and conductivity.

Species Diversity

The Shannon-Weiner diversity index was derived from information theory (Margalef, 1957) and adapted for use with biological data (Lloyd et al., 1968; Pielou, 1966; Shannon and Weaver, 1963). This index reflects the number of taxa and the numbers of individuals in each taxa. Samples with more taxa and/or those with an even distribution of individuals among taxa will have higher Shannon-Weiner diversity values.

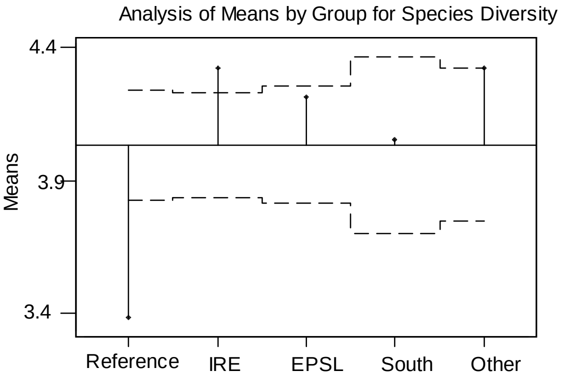

Figure 16. ANOM - Species Diversity Index.

Low nutrient concentrations (and a general lack of dissolved chemicals) in the waters of unimpacted Reference areas of the Savannas limited the numbers of species found there, resulting in a significantly lower mean species diversity. Background Everglades areas are naturally low in macroinvertebrate diversity (Lodge, 1994; SFWMD, 1990), presumably also because of low nutrient availability. Among the apparent causes for low numbers of taxa were the absence of molluscs due to low hardness; numbers of opportunistic, tolerant species were also lower in the Reference areas.

Species Equitability

Equitability is a measure of the degree of uniformity in distribution of individuals among taxa, first proposed by Lloyd and Ghelardi (1964). It compares the distribution of species abundances to MacArthur's broken stick model, which has a distribution frequently observed in nature (Klemm et. al, 1990; MacArthur, 1957). It is a measure of the evenness of the distribution of individuals among taxa in comparison to MacArthur's model. The mean equitability for the Reference group was significantly less than the means for the remainder of sites.

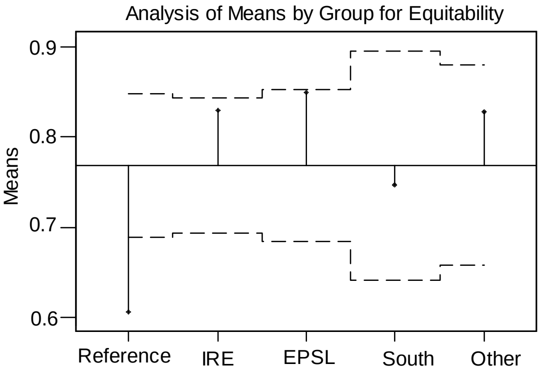

Figure 17. ANOM - Equitability.

Percent Dominant Taxon

Percent dominant taxon is the fraction of sample comprising the single most abundant species (taxon). Samples from Reference sites were often dominated by the amphipod *Hyalella azteca*, resulting in a significantly higher mean value for percent dominant taxon (i.e., H. *azteca*) than at other sites.

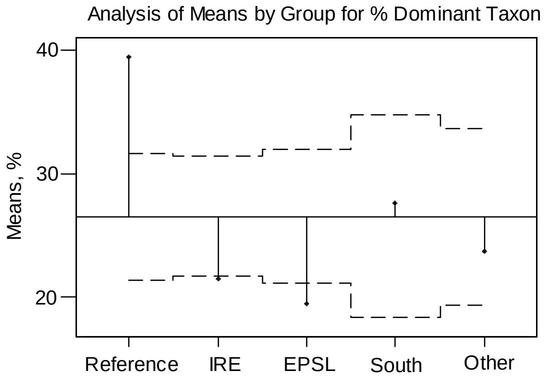

Figure 18. ANOM - Percent dominant taxon.

Total Taxa

The mean number of species present in the Reference area was significantly less than that observed for other groups. Numbers of taxa for the IRE group were significantly higher than all other groups.

The prevailing opinion that increased pollution will always result in a corresponding increase in percent dominant taxa and a reduction in Shannon-Weiner species diversity, equitability index and number of total taxa (Barbour et al., 1996a,b: Klemm et al, 1990; Resh and Jackson, 1993) seems unsound, at least when applied to oligotrophic south Florida wetlands. In this study, these biological metrics failed to respond as is generally presupposed.

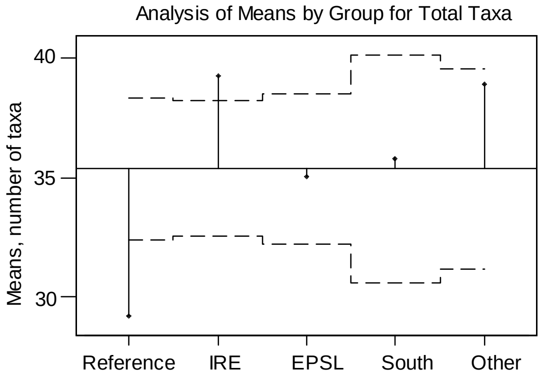

Figure 19. ANOM - Total taxa.

Biological and Water Quality Variables Linked by MDS

Clarke and Ainsworth (1993) suggested an adjunct to MDS to objectively identify the environmental factor or set of factors that best explain the observed biotic structure. The procedure compares the biotic similarity matrix with a series of many separate similarity matrices calculated from the environmental data using all possible combinations of parameters. The set of water quality variables which yield the highest weighted rank correlation (ρ_w) with the biotic matrix is thus determined.

Dissolved oxygen, pH, conductivity, total phosphate, total ortho-phosphate, total nitrogen, total inorganic nitrogen, total Kjeldahl nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, N:P ratio, hardness, chloride and oxidation-reduction potential were examined to identify those water quality parameters that resulted in the highest correlations with the observed variation in the Reserve's macroinvertebrate communities. Dissolved oxygen, pH and chloride were subsequently identified as the optimal subset of water quality variables that best correlated (ρ_w = 69%) with the biotic MDS.

Correlations between Species Abundance and Water Quality Variables

Spearman rank correlations were used to identify species whose abundances were highly correlated (P≤0.01) with water quality factors previously identified as important in macroinvertebrate community structure (Table 7). Total P, hardness and chloride were strongly (P≤0.001) autocorrelated.

Table 8. Significant correlations of common species' abundances to water quality factors. Critical values, N=97: 0.261 at P≤0.01, 0.331 at P≤0.001.

Species	**Total P**	**Hardness**	**pH**	**DO**	**Chloride**
Oxyethira sp.	-0.464	-0.488		0.290	-0.565
Parachironomus alatus	-0.441	-0.300			-0.411
Chironomini Genus III (Epler)	-0.303	-0.487	-0.429		-0.399
Orthotrichia sp.	-0.298				
Labrundinia neopilosella	-0.291	-0.529	-0.318	0.327	-0.516
Pseudochironomus sp.					-0.344
Oecetis sp.		-0.266		0.489	-0.413
Hyalella azteca		-0.292		0.507	
Dicrotendipes sp.				0.332	
Ablabesmyia rhamphe group		-0.314			-0.298
Ablabesmyia peleensis		-0.365	-0.296		
Orbatei unid. sp.		-0.281	-0.328		

Cladotanytarsus sp.			0.381		
Bratislavia unidentata				-0.271	
Larsia berneri				-0.301	
Dasyhelea sp.		0.266		-0.314	
Polypedilum illinoense group					0.285
Dero furcata	0.272				
Hydrocanthus sp.	0.280			-0.377	0.347
Physella sp.	0.287	0.269			
Corixidae unid. sp.	0.289				0.375
Chironomus sp.	0.307				0.286
Haemonais waldvogeli	0.307	0.304			0.307
Planorbella scalaris	0.348	0.516	0.406		0.452
Polypedilum sp. A (Epler)	0.348	0.334	0.289	-0.262	0.329
Micromenetus dilatatus	0.361	0.429	0.275		0.326
Palaemonetes paludosus	0.384	0.531	0.561		0.312
Ancylidae unid. sp.	0.393	0.286			0.335
Limnesia sp.	0.395	0.364			0.462
Guttipelopia guttipennis	0.421	0.304		-0.363	0.456
Glyptotendipes sp. B (Epler)	0.536	0.445			0.548

Species identified in the preceding table fall into two general categories (delineated by the dashed line): those associated with conditions previously shown to be typical of reference conditions and those associated with stormwater impacted areas. Species associated with reference conditions were correlated with dissolved oxygen and inversely correlated with phosphorus, hardness, pH or chloride. Among these species were the Florida Index organisms *Oxyethira* sp., *Oecetis* sp., *Labrundinia neopilosella*, and two species of *Ablabesmyia*. Correlations for Chironomini Genus III (Epler) indicate that this taxon is a candidate for use as a good-water quality indicator.

Species associated with stormwater impacted conditions were correlated with phosphorus, hardness, pH or chloride and inversely correlated with dissolved oxygen. Among these were the poor-water quality indicative organisms *Chironomus* sp., *Haemonais waldvogeli* and *Guttipelopia guttipennis*. Also present were organisms associated with high-hardness, higher-pH conditions like *Cladotanytarsus* sp., *Physella* sp., *Planorbella scalaris* and *Palaemonetes paludosus*. Correlations for *Polypedilum* sp. A (Epler) indicate that this taxon is a candidate for use as a poor-water quality indicator.

Taxa Similarity Percentages

The relative contribution of each taxon to the Bray-Curtis dissimilarity was used to identify those species which were good discriminators between any two groups of sites (Clarke, 1993). These results are presented in Tables 9a, 9b and 9c. Species are listed in order of relative importance to the dissimilarity between groups.

Taxa driving differences between the Indian River Estates and Reference groups are given in Table 9a. Associated with Indian River Estates were the tolerant (poor water quality indicative) insects *Chironomus* sp., *Glyptotendipes* sp. B (Epler) and the oligochaetes *Dero* spp. and *Haemonais waldvogeli*. Also associated with IRE were the hardness-associated molluscs *Micromenetus dilatatus* and Ancylidae. The Reference group was characterized by the insects of the *Cricotopus politus* group and Chironomini Genus III (Epler).

Taxa driving the differences between the East Port St. Lucie and Reference groups are given in Table 9b. Important taxa associated with East Port St. Lucie included the tolerant (poor water quality indicative) *Dero digitata*. Also present were the hardness associated molluscs *Micromenetus dilatatus*. The Reference group was characterized by the insect *Cricotopus politus* and the crustacean *Hyalella azteca*, which feeds on periphyton (Hargrave, 1970). Alteration of periphyton communities in Florida oligotrophic marshes is known to occur when even small amounts of phosphorus are added (McCormick and O'Dell, 1996; McCormick et al., 1996).

Table 9a. Mean abundance and percent contribution by taxon to total dissimilarity (dissimilarity = 0.475) between IRE and Reference.

Taxon	Mean Abundance IRE	Mean Abundance Reference	Contribution to Dissimilarity Percent
Micromenetus dilatatus	4.4	0.05	1.91
Chironomus sp.	7.24	0.18	1.77
Glyptotendipes sp. B (Epler)	4.92	0.18	1.72
Guttipelopia guttipennis	3.08	0.1	1.65
Dero furcata	2.64	0.0	1.61
Cricotopus politus group	0.0	1.38	1.59
Polypedilum sp. A (Epler)	7.97	0.38	1.50
Chironomini Genus III (Epler)	0.0	1.12	1.49
Haemonais waldvogeli	1.43	0.03	1.41
Palaemonetes paludosus	4.14	0.32	1.38
Cumulative % Dissimilarity			16.03

Table 9b. Mean abundance and percent contribution by taxon to total dissimilarity (dissimilarity = 0.377) between EPSL and Reference

Taxon	Mean Abundance EPSL	Mean Abundance Reference	Contribution to Dissimilarity Percent
Pseudochironomus sp.	10.00	1.12	2.28
Cricotopus politus	0.0	1.38	2.12
Cladotanytarsus sp.	5.52	0.25	1.98
Dasyhelea sp.	2.65	0.05	1.96
Palaemonetes paludosus	2.83	0.32	1.6
Micromenetus dilatatus	0.94	0.05	1.54
Hyalella azteca	18.48	63.72	1.5
Parachironomus sp.	0.31	0.0	1.46
Dero digitata	2.06	0.97	1.34
Polypedilum sp.	0.63	0.0	1.29
Cumulative % Dissimilarity			17.07

Table 9c. Mean abundance and percent contribution by taxon to total dissimilarity (dissimilarity = 0.380) between IRE and EPSL.

Taxon	Mean Abundance IRE	Mean Abundance EPSL	Contribution to Dissimilarity
Guttipelopia guttipennis	3.08	0.0	2.23
Cladotanytarsus sp.	0.97	5.52	1.71
Pseudochironomus sp.	1.53	10.0	1.7
Parachironomus schneideri	1.04	0.0	1.52
Ancylidae unid. sp.	4.06	0.23	1.52
Oxyethira sp.	3.15	12.9	1.38
Dero digitata	0.87	2.06	1.36
Dero furcata	2.64	0.44	1.33
Oecetis sp.	1.18	3.42	1.26
Chironomus sp.	7.24	0.79	1.22
Cumulative % Dissimilarity			15.23

A comparison between the two major stormwater-affected areas was performed to illuminate differences in the relative degree of impact (Table 9c). Associated with Indian River Estates were the tolerant (poor water quality indicative) insects *Chironomus* sp., *Glyptotendipes* sp. B (Epler) and the oligochaetes *Dero* spp. The hardness associated mollusc Ancylidae was also associated with IRE reflecting greater hardness (i.e., greater calcium availability for shell growth). The East Port St. Lucie group was characterized by the insect *Cladotanytarsus* sp. which is intolerant of acid conditions and is indicative of consistently elevated pH (Table 6). Also present at EPSL were the intolerant, good water quality indicative caddisflies *Oecetis* sp. and *Oxyethira* sp. *Pseudochironomus* sp. is found primarily under meso- to oligotrophic conditions (Saether, 1979). This indicates that EPSL retains a lower nutrient regime (trophic status) relative to IRE.

The Indian River Estates and East Port St. Lucie areas supported different macroinvertebrate communities in comparison to the Reference group. Species driving the differences between stormwater impacted and Reference areas were either tolerant of nutrient enrichment or those which thrive where hardness is higher. The comparison of the important organisms driving differences between Indian River Estates and East Port St. Lucie showed that the former was dominated by tolerant species while the latter still supported some clean water species. These results confirm inferences previously drawn from correlation analyses. Both treated and untreated stormwater disposal into the Savannas Reserve affected the aquatic macroinvertebrate community. The community associated with Indian River Estates' untreated stormwater discharges appeared more severely altered than that impacted by treated stormwater from East Port St. Lucie.

Aquatic Plant Community - Water Quality Associations

Relationships between aquatic plant presence-absence and water quality variables were explored by examining Spearman rank correlations for significance (Table 10) for species of plants considered common (observed ten or more times). Species negatively associated with nutrients, hardness, conductivity and pH, and positively associated with dissolved oxygen were more frequent in areas removed from stormwater sources. Species which were positively associated with nutrients, hardness, conductivity and pH, and negatively associated with dissolved oxygen were more frequent in areas adjacent to stormwater sources (Table 11).

What is known of the water quality requirements of aquatic plants in Florida agrees with the relative frequency of occurrence in impacted versus unimpacted areas. The occurrence of *Eleocharis* spp. and *Rhynchospora inundata* has been associated with low (<18 ppb) levels of phosphorus (Richardson et al. 1995). *Rhynchospora inundata* has also been associated with low conductivity (<100 µS) and low pH (<5.9). *Hypericum* spp. has been associated with low conductivity and phosphorus concentration conditions (Hoyer et al., 1996). *Cabomba* spp. occurs where pH ranges from 4 to 6 units (Tarver et al., 1986). The above species were most common in the unimpacted areas of the Reserve where low levels of phosphorus, conductivity and pH were typical.

Table 10. Highly significant correlations ($P \leq 0.01$) of presence/absence of common aquatic plants with water quality. Critical values, N=81: 0.285 at $P \leq 0.01$, 0.361 at $P \leq 0.001$.

Species	TKN	TP	Hardness	Chloride	pH
Intolerant Species					
Eleocharis spp.	-0.289	-0.440		-0.374	
Cabomba spp.	-0.342		-0.488	-0.570	-0.342
Rhynchospora inundata			-0.314		
Spartina bakeri	-0.338		-0.365		-0.338
Hypericum spp.		-0.290			
Tolerant Species					
Typha spp.		0.317	0.293	0.336	
Salvinia minima		0.420	0.346	0.396	
Sagittaria lancifolia		0.327		0.301	
Cladium jamaicense					0.351
Scirpus californicus	0.334	0.430	0.433	0.412	

Table 11. Number of occurrences of common aquatic plants having significant correlations with water quality (by site group).

Species	**IRE**	**EPSL**	**Reference**	**South**	**Other**	**Total**
Intolerant Species						
Eleocharis spp.	7	15	19	8	7	56
Cabomba spp.	3	4	13	2	5	27
Rhynchospora inundata	2	4	9	5	6	26
Spartina bakeri		1	5		6	12
Hypericum spp.	1	8	13	5	2	29
Tolerant Species						
Typha spp.	7	4				11
Salvinia minima	10					10
Sagittaria lancifolia	14	4	5		1	24
Cladium jamaicense	4	8			3	15
Scirpus californicus		7		4	3	14
Total Observations	24	16	20	9	12	81

Cattail (Typha spp.) was found only in areas of the Savannas enriched with stormwater; its presence has been similarly associated with phosphorus enrichment in the Everglades and Lake Okeechobee, Florida (Richardson et al., 1995; Lodge, 1994; Davis, 1994). Salvinia minima was only observed in the impacted area adjacent to Indian River Estates and is known to occur in “still water areas with a high organic content” (Tarver et al., 1986). Occurrence of this species and Sagittaria lancifolia has been associated with mean phosphorus concentrations greater than 40 ppb. Scirpus californicus and Typha spp. prefer alkaline, hardwater conditions (Hoyer et al., 1996). Thus, the differences in plant communities reflect the differences in macroinvertebrate communities and water quality resulting from stormwater inflow.

Differences in plant distribution can also be linked to hydroperiod differences. However, Typha spp. and other dense emergent plants have invaded both short and long hydroperiod areas in the Savannas. Expansion of cattails in the Everglades is also believed to be influenced more by phosphorus influx than by water level (Craft and Richardson, 1997; David, 1996; Davis, 1994).

Stormwater Borne Pesticides and Heavy Metals

To check for the presence of other pollutants carried by stormwater, fourteen sites were sampled once for pesticides and base-neutral extractable substances (in water and sediments) and heavy metals (in sediment). Positive detections are summarized in Table 12. Samples were obtained from stormwater discharge points within Indian River Estates (Sites B, C, and D) and from a stormwater overflow from the East Port St. Lucie stormwater treatment system (site G). Sites 8 and 11 sites were randomly selected from among the Reference group and were sampled as controls.

Table 12. Summary of pesticide and heavy metal concentrations from selected sites.

medium		**water**	**sediment**	**⇒**					
Site	**Group**	**Atrazine µg/L**	**Chlordane mg/Kg**	**Ametryn mg/Kg**	**DDE-p,p' mg/Kg**	**Zinc mg/Kg**	**Mercury µg/Kg**	**Chromium mg/Kg**	**Copper mg/Kg**
D	IRE STM	0.039	5.6	1.2		38	10	1	5
6	IRE	0.014				1			2
7	IRE	0.015				1			2
B	IRE STM		6.7			25	5	3	4
2	IRE	0.011				2		1	1
3	IRE	0.011				1			
C	IRE STM	0.021			2.1	20	11	2	3
4	IRE	0.034				14			
5	IRE	0.036				4			
G	EPSL STM	0.32			1.6	15	31	16	6
18	EPSL	0.14				1			
17	EPSL	0.13				2		1	
8	Reference					9			
11	Reference					16	12		

Note: IRE = sites near Indian River Estates residential subdivision; EPSL = sites near East Port St. Lucie subdivision; STM = stormwater discharge monitoring sites.

No pesticides were detected in background samples collected from Site 8 and 11. The herbicide atrazine was present in water samples from all sites associated with stormwater runoff except the Scott Street ditch (site B). The insecticide chlordane and the herbicide ametryn were detected in sediments from the Indian River Estates stormwater ditches but not at the East Port St. Lucie stormwater overflow (site G). DDE was detected from both the East Port St. Lucie stormwater discharge as well as from the Howard Street ditch (site C) in Indian River Estates.

The triazine herbicides ametryn and atrazine are used to control residential and roadside weeds (Bintein and Devillers, 1996; Mayer, 1987). Atrazine is the most commonly used herbicide in the United States and historically has been the most frequently detected pesticide (Shiping et al., 1996). Atrazine has been shown to be persistent (Widmer and Spalding, 1996), to negatively affect aquatic biota (Langan and Hoagland, 1996; Lemieux and Lum, 1996) and has been frequently found in surface water (Lakshminarayan et al., 1996). The chlorinated hydrocarbon insecticide chlordane is a restricted pesticide used to control termites (Pfeuffer, 1985; Haunert, 1988). This chemical has been shown to be very toxic to aquatic animals indigenous to the Savannas (Cardwell et al., 1977) and is common in runoff (Stewart, 1975). DDE is a degradation product of the hydrocarbon insecticides DDT (currently banned) or dicofol (which formerly contained DDT). DDE is highly toxic and persistent in the environment (USEPA, 1985; Haunert, 1988; Pfeuffer, 1985, 1991).

Chromium and copper were present at detectable concentrations only from sites associated with stormwater discharge. Concentrations of copper and chromium were highest from the discharge ditches, implying that stormwater was the source of these heavy metals to the Reserve. Zinc concentrations were highest in the Indian River Estates stormwater ditches. Chromium, copper and zinc can occur in runoff due to erosion of asphalt roadbeds, through leakage of fuel and lubricants, or wear of motor vehicle parts and components (Lindgren, 1996; Sansalone and Buchberger, 1997). Additionally, copper and chromium have been shown to leach in considerable quantities from the widespread use of pressure treated wood (Stilwell and Gorny, 1997). Copper may also be used as an herbicide in roadside ditches (Haunert, 1988).

Mercury was detected in all four stormwater discharge samples, but also at the background site 11. Mercury has been previously detected in Savannas sediments (Rood et al., 1995); a health advisory has been in effect since 1989 due to high mercury levels in Savannas' largemouth bass. Pathways for mercury transport are complex and include atmospheric deposition. Elevated mercury in fish and ambient waters has been associated elsewhere with low nutrients, hardness and pH (D'Itri, 1991), which are typical of water quality conditions at the Savannas Reference sites.

Conclusions

Due to its oligotrophy, the Savannas Reserve marsh is extremely sensitive to disturbance. The natural source of water entering the Savannas ecosystem is rainfall. Water quality in areas removed from stormwater outfalls was characterized by low nutrient levels and acidic soft waters. These natural waters meet State standards and support a healthy, specially-adapted macroinvertebrate community.

The effects of stormwater introduction on the structure of the aquatic macroinvertebrate community was explored using objective statistical analyses. Hierarchical cluster analysis of species data identified five groups of sites possessing similar macroinvertebrate abundances. Principal component analysis (PCA) was employed to identify important factors among macroinvertebrate species communities, and these factors were subsequently related to differences in dissolved oxygen, total phosphorus, hardness and pH. Such changes were attributed to proximity to sources of stormwater inflow. Multidimensional scaling (MDS) ordination was used to evaluate the relative similarity among macroinvertebrate communities, which showed that natural sites differed from those adjacent to Indian River Estates and East Port St. Lucie stormwater discharges. Analysis of means was used to examine differences in macroinvertebrate communities as a function of differences in water quality and biotic metrices. Further data analysis indicated that dissolved oxygen, pH and chloride were the water quality parameters best explaining the MDS ordination. Since chloride was highly correlated with total phosphorus and hardness, the key factors driving the observed differences in the macroinvertebrate communities were dissolved oxygen, pH, hardness and total phosphorus. The relative abundances of thirty-one macroinvertebrate species were related to these five water quality factors; many of these species were tolerant or intolerant organisms whose abundances were correspondingly related to poor or good water quality conditions. Two of these taxa (Chironomini Genus III [Epler] and *Polypedilum* sp. A [Epler]) are proposed for use as water quality indicator organisms.

Species were identified that characterized the observed differences between the Reference, Indian River Estates and East Port St. Lucie groups. Several species associated with the Reference group were intolerant (indicative of good water quality), with abundances inversely correlated with total phosphate, hardness, chloride and pH or positively correlated with dissolved oxygen. Species diversity, species richness and percent molluscs were significantly lower, and percent dominant taxa was significantly higher for the Reference group in comparison to all other groups. Many species associated with the Indian River Estates group were generally tolerant (indicative of poor water quality), with abundances positively correlated to total phosphate, hardness, chloride and pH or inversely correlated to dissolved oxygen. Diversity, species richness, percent air-breathers and percent molluscs were significantly higher, and the Florida index and percent dominant taxa was significantly lower for the Indian River Estates group compared to all the other groups. Both tolerant and intolerant species were associated with the East Port St. Lucie group, with the difference from the Reference group being largely a product of species positively correlated with higher pH.

The natural condition of the waters in the Savannas is acidic. By comparison, stormwater was nearly neutral. The pH regime of a body of water regulates a host of biological and chemical processes. Both Indian River Estates and East Port St. Lucie stormwater disposal areas showed apparent alterations of natural pH, conductivity and chloride regimes.

The presence of aquatic plants was also correlated with differences in water quality. Certain species were associated with oligotrophic conditions, while others typified areas requiring higher nutrient levels. In many regards, the Savannas ecosystem is similar to that of the Everglades where the introduction of excess nutrients promoted the invasion of plants that could not normally survive in naturally low-nutrient waters. Stormwater-borne nutrients fertilize the Savannas plant community, causing them to grow in profusion. The resultant increase in decaying plant litter reduces dissolved oxygen. This decrease in oxygen makes it difficult for sensitive aquatic organisms to survive, and gives opportunistic tolerant species a competitive advantage. Anoxic conditions were frequently observed adjacent to Indian River Estates, while East Port St. Lucie stormwater appears to have been sufficiently treated to avoid such problems. Presumably this was a consequence of the degree of treatment, but may also have been a function of the comparatively short time the East Port St. Lucie stormwater treatment system has been in existence.

Areas of the Savannas adjacent to both major subdivisions (Indian River Estates or East Port St. Lucie) exhibited modifications to the plant community. Modifications were typified by stands of cattails, known to be associated with nutrient enrichment of oligotrophic marsh systems. Phosphorus levels in the treated East Port St. Lucie stormwater were much lower than that entering the Savannas from Indian River Estates, but periodic stormwater breakthroughs of total phosphorus were documented.

Water in Savannas areas remote from residential stormwater flows was extremely low in conductivity and chloride; higher levels indicated that the natural character of the water was altered. The area adjacent to Indian River Estates exhibited elevated levels of chloride and conductivity which were attributed to runoff from the subdivision. Stormwater runoff from the East Port St. Lucie treatment system also resulted in slightly higher conductivity and chloride levels compared to Reference conditions.

The detection of pesticides and heavy metals is a concern. Some of these are known to have adverse effects on aquatic biota. Pesticides and heavy metals were detected near both the Indian River Estates and East Port St. Lucie subdivisions.

Samples collected from the Other and South groups violated state standards for dissolved oxygen. Data analysis suggests a relationship of the South group of sites to discharge of treated stormwater from East Port St. Lucie. In addition, elevated phosphorus levels in Warner Creek which drains the south end of the reserve suggests that the Sugar Hill subdivision may be altering the ecology of this part of the Savannas.

Violations of applicable State of Florida Administrative Code water quality rules associated with stormwater inflows include lowered dissolved oxygen [62-302.530(31)], release of “substances which result in the dominance of nuisance species” [62-302.530(47)], alteration of nutrient concentrations “so as to cause an imbalance in natural populations of aquatic flora or fauna” [62-302.530(48)] and causing degradation of a Florida outstanding water (62-302.700). These alterations were most pronounced in association with untreated stormwater runoff from the Indian River Estates subdivision.

The Florida Department of Environmental Protection mission to "protect, conserve and manage Florida's natural resources" coupled with the substantial public investment in the Savannas State Reserve compels the continued protection of this system. Restoration in the area of Indian River Estates can ameliorate further stormwater impacts, with the added benefit of enhancing flood control. In addition, such restoration may make it possible for the FDEP Park Service to select management options which best serve to restore and protect the natural communities of the Reserve. Various options for restoration are on the agenda of the "Savannas State Reserve Task Force" which was convened to address the water management problems in this area.

Recommendations

- No new developments should use the Reserve for disposal of stormwater.

- The Indian River Estates subdivision should be retrofitted with an appropriate stormwater treatment system to ameliorate stormwater inputs to the Savannas.

- Maintenance of the East Port St. Lucie stormwater treatment system is advised to prevent further proliferation of nuisance vegetation and alteration of aquatic communities. Removal of plant biomass and muck sediments may increase the ability of the treatment system to absorb nutrients and reduce releases of phosphorus to the Reserve.

- Harvesting of invasive plants in the areas of the Savannas Reserve marsh impacted by stormwater could improve water quality.

- It is recommended that the contribution of stormwater nutrients to the Savannas from the Sugar Hill development via the Henderson Pond canal be evaluated to assess its affects on the Reserve.

- Goals to protect and enhance the Savannas should be evaluated. Restoration goals may include no further degradation of wetlands (no further increase in impact zones) and limitation of discharges of treated stormwater to those quantities deemed natural. Water quality and biological health goals for protection and enhancement should approach those found at back ground (Reference group) areas.

- Long term monitoring of inflowing and ambient water quality and macroinvertebrate communi ties should be performed to document restoration efforts. Studies of aquatic plants, periphyton and fish may also be appropriate.

- Ditches which were designed to drain the Savannas (Hog Pen and the Savanna Drainage ditches) should be modified to limit back-flows into, and thus impacts to, the reserve.

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Appendix A

Aquatic plant species sampled or observed.

Plant taxa	Common name
Azolla caroliniana	azolla
Bacopa caroliniana	lemon bacopa
Brasenia schreberi	water shield
Cabomba spp.	fanworts
Cephalanthus occidentalis	buttonbush
Ceratophyllum demersum	coontail
Chlorophyta	green algae
Cladium jamaicense	sawgrass
Crinum americanum	swamp lily
Eleocharis baldwini	road grass
Eleocharis spp.	spike rush
Gramineae	aquatic grass
Hydrocotyle spp.	water pennyworts
Hypericum spp.	St. John's wort
Lachnanthes caroliniana	redroot
Lachnocaulon spp.	bog buttons
Ludwigia spp.	water primrose
Najas guadelupensis	southern naiad
Nitella spp.	stonewort
Nymphaea odorata	fragrant water lily
Nymphoides aquatica	bannana lily
Phragmites australis	giant reed
Pontederia cordata	pickerelweed
Rhynchospora inundata	beak rush
Sagittaria graminea	strap leaf sag
Sagittaria lancifolia	duck potato
Salvinia minima	water fern
Scirpus californicus	giant bulrush
Spartina bakeri	cordgrass
Typha spp.	cattails
Utricularia gibba	cone spur bladderwort
Utricularia purpurea	purple bladderwort
Utricularia spp.	bladderworts
Xyris spp.	yellow eyed grassess

Appendix B

Macroinvertebrates collected by dipnet from the Savannas marsh, Florida October, 1995 through July, 1996.

Porifera
  Eunapius sp.
  Spongilla sp.
Turbellaria
  Turbellarian unid. sp.
Ectoprocta
  Ectoprocta unid. sp.
  Plumatella repens
Oligochaeta
  Enchytraeidae unid. sp.
  Lumbriculidae
    Eclipidrilus palustris
    Lumbriculidae unid. sp.
  Naididae
    Allonais paraguayensis
    Bratislavia unidentata
    Dero botrytris
    Dero digitata
    Dero furcata
    Dero nivea
    Dero obtusa
    Dero spp.
    Dero vaga
    Haemonais waldvogeli
    Naididae unid. sp.
    Pristina aequiseta
    Pristina leidyi
    Pristina sp.
    Slavina appendiculata
  Tubificidae
    Aulodrilus pigueti
    Limnodrilus hoffmeisteri
    Tubificidae unid. sp. w/ hair setae
    Tubificidae unid. sp. w/o hair setae
Hirudinea
  Desserobdella phalera
  Erpobdellidae unid. sp.
  Glossiphoniidae unid. sp.
  Helobdella fusca
  Helobdella cf. fusca
  Helobdella triserialis
  Piscicolidae unid. sp.
  Placobdella translucens
Mollusca
  Bivalvia
    Byssanodonta cubensis
    Sphaeriidae unid. sp.
  Gastropoda
    Ancylidae unid. sp.
    Gastropoda unid. sp.
    Hebetancylus excentricus
    Laevapex fuscus
    Laevapex peninsulae
    Laevapex sp.
    Lymnaeidae unid. sp.
    Micromenetus dilatatus
    Physella sp.
    Planorbella scalaris
    Planorbella sp.
Arthropoda
  Acari
    Arrenurus apopkensis
    Arrenurus problecornis
    Arrenurus spp.
    Arrenurus zorus
    Hydrachna sp.
    Hydrodroma sp.
    Hydryphantes sp.
    Koenikea sp.
    Krendowskia sp.
    Limnesia sp.
    Limnochares sp.
    Neumania sp.
    Orbatei unid. sp.
    Oxus sp.
    Piona sp.
    Unionicola sp.
    Acari unid. sp.
  Crustacea
    Amphipoda
      Hyalella azteca
    Decapoda
      Procambarus sp.
      Palaemonetes paludosus
  Insecta
    Collembola
      Bourletiella sp.
      Isotomurus sp.

- Ephemeroptera
  - Baetidae
    - unid. sp.
    - *Callibaetis pretiosus*
    - *Callibaetis* spp.
  - Caenidae
    - *Caenis diminuta*
- Odonata
  - Anisoptera
    - Aeschnidae
      - *Anax junius*
      - *Coryphaeschna ingens*
      - unid. sp.
    - Anisoptera unid. sp.
    - Corduliidae unid. sp.
      - *Epitheca princeps regina*
      - *Epitheca stella*
      - *Epitheca* sp.
    - Gomphidae unid. sp.
    - Libellulidae
      - *Erythemis simplicicollis*
      - *Erythemis* sp.
      - unid. sp. .
  - Zygoptera
    - Coenagrionidae unid. sp.
      - *Enallagma pollutum*
      - *Enallagma* sp.
      - *Ischnura* sp.
  - Zygoptera unid. sp.
- Hemiptera
  - *Belostoma* spp.
  - *Buenoa* spp.
  - *Corixidae unid.* spp.
  - Hemiptera unid. spp.
  - *Hydrometra* spp.
  - *Limnoporus* spp.
  - *Merragata brunnea*
  - *Merragata hebroides*
  - *Merragata* spp.
  - *Mesovelia mulsanti*
  - *Mesovelia* spp.
  - *Neoplea striola*
  - Notonectidae unid. spp.
  - *Pelocoris femoratus*
  - *Ranatra fusca*
  - *Ranatra* spp.
  - *Sigara compressoidea*
  - *Sigara signata*
  - *Sigara* spp.
  - *Trichocorixa sexcinta*
- Neuroptera
  - Sisyridae unid. sp.
- Coleoptera
  - *Bagous* sp.
  - *Berosus* sp.
  - *Celina grossula*
  - *Celina slossoni*
  - *Celina* sp.
  - *Copelatus caelatipenni princeps*
  - Curculionidae unid. sp.
  - *Cyrtobagous salviniae*
  - *Derallus altus*
  - *Derallus* sp.
  - *Dineutus* sp.
  - *Donacia palmata*
  - *Enochrus hamiltoni*
  - *Enochrus* sp.
  - Gyrinidae unid. sp.
  - *Gyrinus marginellus*
  - *Gyrinus* spp.
  - *Haliplus* spp.
  - *Haliplus triopsis/pantherinus* group
  - *Hydraena marginicollis*
  - *Hydrocanthus cf. oblongus*
  - *Hydrocanthus oblongus*
  - *Hydrocanthus regius*
  - *Hydrocanthus* spp.
  - Hydrophilidae unid. spp.
  - *Hydrovatus* spp.
  - *Liodessus* spp.
  - *Paracymus* spp.
  - *Peltodytes muticus*
  - *Peltodytes* spp.
  - Scirtidae unid. spp.
  - Staphylinidae unid. sp.
  - *Suphis inflatus*
  - *Suphisellus puncticollis*
  - *cf. Hydrobiomorpha* sp.
- Diptera
  - Ceratopogonidae
    - *Atrichopogon* sp.
    - Ceratopogonidae unid. sp.
    - *Dasyhelea* sp.
  - Chaoboridae
    - *Chaoborus albatus*
    - *Chaoborus* sp.
  - Culicidae
    - *cf. Aedes* sp.
    - *Culex erraticus*
    - *Culex* sp.
    - *Mansonia titillans*
  - Ephydridae unid. sp.
  - Stratiomyiidae unid. sp.
  - Tabanidae unid. sp.
  - Chironomidae
    - Chironominae

- Chironomini
  - Chironomini Genus III (Epler)
  - Chironomini unid. sp.
  - *Chironomus crassicaudatus*
  - *Chironomus ochreatus*
  - *Chironomus* sp.
  - *Cladopelma* sp.
  - *Cryptochironomus* sp.
  - *Dicrotendipes leucoscelis*
  - *Dicrotendipes nervosus*
  - *Dicrotendipes* sp.
  - *Endochironomus* sp.
  - *Glyptotendipes* sp. B (Epler)
  - *Goeldichironomus amazonicus*
  - *Goeldichironomus cf. natans*
  - *Goeldichironomus* sp.
  - *Hyporhygma quadripunctatum*
  - *Kiefferulus* sp.
  - *Nilothauma* sp.
  - *Parachironomus alatus*
  - *Parachironomus carinatus*
  - *Parachironomus hirtalatus*
  - *Parachironomus schneideri*
  - *Parachironomus* spp.
  - *Parachironomus sublettei*
  - *Paratendipes subaequalis*
  - *Polypedilum halterale* group
  - *Polypedilum illinoense* group
  - *Polypedilum* spp.
  - *Polypedilum* sp. A (Epler)
  - *Polypedilum trigonus*
  - *Polypedilum tritum*
  - *Pseudochironomus* sp.
  - *Stictochironomus* sp.
  - *Xenochironomus xenolabis*
  - *Zavreliella marmorata*
- Tanytarsini
  - *Cladotanytarsus* spp.
  - *Paratanytarsus* spp.
  - *Tanytarsini unid.* spp.
  - *Tanytarsus* spp.
  - *Tanytarsus* sp. C (Epler)
  - *Tanytarsus* sp. F (Epler)
- Orthocladinae
  - *Acamptocladius* sp.
  - *Corynoneura* sp.
  - *Cricotopus politus* group
  - *Cricotopus* spp.
  - *Cricotopus sylvestris* group
  - *Nanocladius* spp.
  - Orthocladiinae unid. spp.
  - *Parakiefferiella* spp.
  - *Psectrocladius* spp.
  - *Thienemanniella* spp.
  - *cf. Psectrocladius* spp.
- Tanypodinae
  - *Ablabesmyia mallochi*
  - *Ablabesmyia peleensis*
  - *Ablabesmyia rhamphe* group
  - *Ablabesmyia* spp.
  - *Clinotanypus* sp.
  - *Djalmabatista pulcher*
  - *Fittkauimyia* sp.
  - *Guttipelopia guttipennis*
  - *Labrundinia neopilosella*
  - *Labrundinia pilosella*
  - *Labrundinia* sp.
  - *Labrundinia* sp. A (Epler)
  - *Larsia* spp.
  - *Paramerina* sp.
  - *Procladius* sp.
  - Tanypodinae unid. spp.
  - *Tanypus* sp.
- Trichoptera
  - Hydroptilidae
    - *Orthotrichia* sp.
    - *Oxyethira* sp.
  - Leptoceridae
    - *Oecetis cinerascens*
    - *Oecetis* sp.
  - Polycentropodidae
    - *Neureclipsis* sp.
  - Trichoptera unid. sp.
- Lepidoptera
  - Pyralidae
    - *Eoparagyractis floridalis*
    - *Munroessa gyralis*
    - *Neargyractis* sp.
    - *Parapoynx* sp.
    - Pyralidae unid. sp.

Appendix C

Twenty Five Species selected by Rank Abundance for PCA

Species	**Number**
Hyalella azteca	3561
Oxyethira sp.	952
Ceratopogonidae unid. sp.	663
Parachironomus Alatus	612
Caenis diminuta	552
Dicrotendipes sp.	535
Tanytarsus sp.	427
Dero sp.	414
Dero nivea	387
Corixidae unid. sp.	357
Polypedilum sp. A (Epler)	335
Pseudochironomus sp.	308
Polypedilum illinoense group	288
Oecetis sp.	274
Bratislavia unidentata	270
Chironomus sp.	252
Zavreliella marmorata	225
Palaemonetes paludosus	214
Ablabesmyia peleensis	210
Larsia berneri	197
Cladotanytarsus sp.	195
Coenagrioidae unid. sp.	177
Anisoptera unid. sp.	171
Glyptotedipes sp. B (Elper)	166
Ancylidae unid. sp.	163