Further Evaluation of Diatom Periphyton as Indicators of Cultivation and Grazing Impairment in Montana Wetlands

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for the

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by

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INTRODUCTION

This report presents results of a further evaluation of diatom assemblages in two sets of Montana wetlands. Initial results are in the report "An Evaluation of Diatom Periphyton as Indicators of Cultivation and Grazing Impairment in Montana Wetlands" (Charles 1999; ANSP Report 99-1F). Under a previous agreement, the Phycology Section at the Patrick Center for Environmental Research analyzed diatom periphyton assemblages from 12 sites each in Mission Valley (Nine Pipe) and Ovando Valley. The purpose of the analysis was to evaluate the potential of diatoms as indicators of impairment due to cultivation and grazing. After most of the work on this project was completed, I received a copy of Cynthia Borth's Master's Thesis (Borth 1998), "Effects of Land Use on Vegetation in Glaciated Depressional Wetlands in Western Montana." The purpose of her study was to identify characteristics of terrestrial vegetation that could be used as part of a multimetric index of biological integrity. Borth's thesis contains valuable environmental data on the same wetland sites from which the diatom periphyton samples we analyzed were collected, and that are relevant to understanding diatom distributions in those wetlands. The purpose of the work reported on here was to further analyze and interpret the variation in the wetland diatom assemblages using the environmental data in C. Borth's thesis. Our goal was to further understand the factors most responsible for influencing diatom distributions in the study wetlands, with the expectation that the information gained will be useful for further developing diatoms as wetland biocriteria indicators.

The findings of the original report were based only on diatom assemblage data and impairment categories of the wetlands. Results showed that it was difficult to distinguish categories of impairment, with the exception of the impaired Nine Pipe wetlands. This is presumably because the current levels of disturbance at the impaired sites are relatively minor and difficult to distinguish from the variation caused by the considerable range of natural factors, primarily differences in groundwater input.

This report should be read in conjunction with the first (Charles 1999). Data, methods, results and findings from the first are not repeated here.

The questions to be addressed in this study were:

- What environmental factors are most important in explaining variation in the diatom assemblages?
- How much of the variation in environmental factors among wetlands is due to natural factors and how much to cultivation and grazing? Is it possible to determine?
- How appropriate are the reference sites for comparison with the impaired sites? Are natural factor differences too significant?
- How similar in "natural" characteristics must wetlands be to be considered valid reference sites? Which characteristics are most important? Is it possible to specify ranges of characteristics to define appropriate reference sites?
- Can we frame impairment assessments in terms of specific environmental factors (e.g., phosphorus concentration, silty substrate). If there is a link to an anthropogenic cause,

then is it possible to consider a site impaired if specified characteristics are “out of range” with respect to expected values?

What characteristics of diatom assemblages can be used to distinguish impairment?

Are there diatom taxa that are good indicators of specific types of impairment for particular types of wetlands?

Are there metrics we have not tried, or could develop, that might be good indicators?

Data analysis to address the above questions proceeded in several steps.

1. Examine patterns of chemical and physical characteristics among the wetlands. Look for major gradients, differences between the two wetland areas, and the reference, semi-impaired, and impaired sites within each.

2. Use ordination techniques to investigate relationships between diatom assemblages and environmental characteristics. Try to distinguish roles of natural and anthropogenic factors.

3. Evaluate diatom taxa to determine which might be good indicators of impairment. Consider the possibilities for developing new diatom metrics.

4. Make recommendations for future research to develop diatoms as indicators of wetland impairment.

STUDY SITES AND ENVIRONMENTAL DATA

Study sites are described in Borth (1998), including the environmental data for the new analyses and results presented here: water chemistry, sediment chemistry, substrate, water level, groundwater input type, and other environmental characteristics. The characteristics used in analysis of diatom assemblages for this report are presented in Tables 1 to 5. Water chemistry characteristics were measured in June, July and August; tables present data for each month and for all three averaged. Data were not available for all parameters for all months. When a parameter was missing, the averaged values were calculated using the data that were available.

The original intent when study sites were selected was that they would all have similar natural conditions and that the primary variation among them would be due to the effects of grazing and cultivation. The potential to develop and test metrics and other indicators is compromised because this is not the case.

METHODS

Methods for preparation and analysis of diatom samples are in Charles (1999). Borth (1998) contains descriptions of methods used to generate the environmental data.

All ordinations were run with CANOCO version 4.0.; all plots were made using Canodraw followed by CanoPost. All environmental variables except pH, sediment pH, and groundwater category were log-transformed for use in multivariate analyses. Principal Components Analysis (PCA) was used to analyze the environmental data. Redundancy analysis (RDA) was used to examine relationships between diatom assemblage and environmental data. Analysis of diatom data using Detrended Canonical Correspondence Analysis (DCCA) showed that Axis 1 scores had a standard deviation of less than 1.5. This indicates that a linear model (e.g., RDA) would better represent species-environment relationships than a unimodal model (e.g., CCA). The number of diatom taxa on plots was limited to about 20 by restricting, in Canodraw, the number of taxa shown to those that contributed most to the fit of points on the plot.

RESULTS

Principal Components Analysis of Environmental Variables

The first step in data analysis was to evaluate the patterns and relative importance of environmental characteristics of the study wetlands. Principal Components Analysis (PCA) was performed on the chemistry data (18 variables; average of June, July and August measurements), physical habitat data, and all data combined (Tables 1 to 5; correlations among water chemistry variables shown in Table 6). The purpose of this analysis was to determine the major environmental gradients and identify the best individual variables to represent groups of closely correlated variables.

Water chemistry. When three month average chemistry data from all sites are included as input, the PCA analysis separates the NP and BC sites, and shows clear differences in chemistry (Fig. 1). These differences are also apparent in the data (Table 4). The Ovando Valley (BC) sites have higher concentrations of Ca and Mg. The Nine Pipe sites have higher concentrations of Mn, Fe, Na, Cl, N, P and K. Because these differences are consistent across impairment type, they are probably due to natural factors related to regional variation in geology and hydrology. Ranges of conductivity, pH and alkalinity overlap between the two groups of wetlands. Factors correlating most closely with the first axis were Ca, Mg, Fe, Mn, pH and alkalinity (Table 7). Factors correlating strongly with the second axis were SO_4, Na, Cl, and conductivity. The two most important factors on the third axis were K and Si. There are no clear relationships with site impairment.

When only the Nine Pipe sites are included in the analysis, there appears to be three main gradients corresponding with the first three axes (Fig. 2, Table 8). Factors strongly related to the first axis are conductivity, alkalinity, pH, Na, Cl, Mg and PO_4. This is clearly related to salinity and dissolved solids and probably reflects differences in runoff and groundwater recharge characteristics. The second axis may represent influence of groundwater: most important factors are Fe, Mn, Si and K. The third axis represents a nutrient gradient. Factors correlating most strongly in the positive direction are NO_3, total P, and PO_4; those correlating in the negative direction are Ca, Mg and K. The tendency for highest nutrient conditions to be in wetlands with lower cation concentrations suggests that nutrients come from surface runoff, and are not diluted much by low-nutrient groundwater. There appears to be a relationship between impairment and Fe and Mn, with more impaired sites having the highest values. This was especially apparent when looking at the August chemistry data.

When only Ovando Valley sites are analyzed, two strong chemistry gradients are apparent (Fig. 3, Table 9). One is related to salinity and dissolved solids and the other perhaps to a groundwater factor. There was no strong nutrient gradient like that for the Nine Pipe sites. The first axis correlated most strongly with SO_4, S, Na, conductivity, alkalinity, Cl and Mg. Variables strongly correlating with the second axis were Si, K and temperature. The impaired sites (24-26) generally were more dilute than the others; the semi-impaired sites (19-22) tended to have lower Si, K and temperature than the others; reference sites (15-18) were widely scattered.

Sediment chemistry and physical characteristics. Variables from Borth's thesis included in the PCA analysis were: sediment chemistry; percent component of substrate (sand, silt, clay); water depth; area of wetland in water, dry soil, algae, and litter; and groundwater recharge category (Table 5). Analysis of all sites together revealed three main gradients, though exactly what they represent is unclear (Fig. 4, Table 10). The first axis correlated most strongly and in a negative direction with Ca, TKN, and NO_3, and in a positive direction with P, NH_4 and percent sand. The second axis correlated most strongly with pH and conductivity, and the third with P and NO_3. Overall, sediment pH, conductivity, and nutrient concentrations seemed to be the most important. There were no clear relationships with impairment categories.

The PCA analysis of Nine Pipe samples alone shows strong correlations with variables on all four axes (Fig. 5, Table 11). The first axis correlated most strongly with Na, Ca, TKN and conductivity; the second axis with NH_4, pH, conductivity and %Dry Soil; the third with NO_3 and depth; and the fourth with %Clay, %Silt and %Surface Water.

For the set of Ovando Valley sites only, the first PCA axis correlates positively with Na and P, and negatively with Ca and %Algae (Fig. 6, Table 12). The second axis correlates most strongly with %Litter, NH_4, NO_3, Ca, Cond, Depth, and GW-charge category. The third axis has high correlations with TKN, NO_3 and P. And the fourth axis correlates with TKN, Mg and Sand and Silt. Overall, the most important factors seem to be those related to nutrients (P and N), Ca, conductivity, and substrate component. The impaired sites group together, separating from the others based on their greater depth, %SurfaceWater and %Silt. They also tended to have lower Sed-pH and Sed-Cond.

Redundancy Analysis of Diatom Assemblage and Environmental Variables

Based on the PCA and on forward selection of environmental variables, a subset of water chemistry, sediment chemistry and physical factors was chosen to represent all the others. This limited set of variables was then used in RDA analysis with diatom assemblage data to examine relations between the two (Fig. 7, Table 13). Analysis of all 24 sites together shows that many factors have an important influence on diatom distributions. The most important variables on the first axis are Ca, Fe, and %Sand, which can be considered a sand to silt gradient. At one end of the axis are %Sand, phosphorus, K and Fe. At the other are Ca, %Clay, and Depth. The second axis seems related to groundwater input, with sediment and water pH and conductivity, and groundwater discharge, high at one end and low at the other. There is no clear relationship between impairment category and environmental variables.

The RDA of Nine Pipe sites alone (Fig. 8) also suggests the influence of a number of variables on diatom assemblage distributions. As in many graphs, sites NP1 and NP5 are near each other and associated with high pH and conductivity. This is not surprising because these are the only two reference sites that are groundwater recharge sites. The impaired sites are all at the top of the plot, associated with higher concentrations of TotP, Si, shallower depth, and higher silt (lower %Sand). An RDA plot of the diatom taxa that contribute most to the separation of sites (Fig. 9) shows common taxa that contribute most to the grouping of the sites. As noted in the previous report, it is difficult to relate abundance of most of the taxa to environmental conditions. Some apparent relationships are the occurrence of taxa associated with more dilute conditions in the left half of the plot and waters with higher dissolved materials and conductivity in the right half. Many of the *Nitzschia* and *Navicula* often associated with silty habitats are on the right side of the plot.

The RDA of only Ovando Valley sites (Fig. 10) suggests that two major, interrelated factors are most important; relative input of surface vs. groundwater, and water depth. It appears these two interact to produce a variety of ecological conditions. All impaired sites are grouped in the lower left portion of the plot. However, this probably occurs simply because the impaired sites have greater depth than the other sites. The plot of diatom taxa (Fig. 11) is difficult to decipher in terms of identifying taxa indicative of impairment. Some of the taxa that are often cited as indicators of poorer conditions, such as *Nitzschia palea* and *Gomphonema parvulum*, are on the right side of the plot along with the impaired sites, but these taxa are not uncommon in some other sites as well.

I ran and compared the RDA analysis of the 3-month average water chemistry data for all 24 sites with the same analysis for each month's water chemistry, individually. Overall, there was little difference in the patterns of distributions of sites, or relationships of the environmental variables to the PCA axes. There was a slight tendency for the correlation of pH and conductivity with the first axis to decline from June to August, and a slight tendency for the correlation of total phosphorus and temperature to increase. It is possible these tendencies may mean that hydrologic factors are more important earlier in the summer and nutrient factors more important later. In general, these results suggest that, in terms of relationships between diatom and water chemistry conditions, samples for wetland assessment could be collected anytime during the summer, but that late summer might be slightly better.

DISCUSSION

The following discussion is organized according to the questions which this study was intended to address.

What Environmental Factors Are Most Important in Explaining Variation in the Diatom Assemblages?

The factors explaining most of the variation in diatom assemblages varied between the Nine Pipe and Ovando Valley sites. In general, they seemed related most strongly to groundwater - surfacewater interaction; whether sites were recharged by groundwater inflow or received most water from surface runoff that then discharged to the ground. Each set of sites had some wetlands of each type. Nutrient concentrations and composition of substrate also played a role, but the extent to which they were influenced by grazing and cultivation is not clear. Specific environmental characteristics of importance were water and sediment pH and conductivity, Ca, K, Fe, P, water depth and percent of sand and silt in the substrate. There was no clear relationship between level of impairment and these factors other than with water depth in the case of the Ovando Valley sites and with K, phosphorus and percent of silt in the Nine Pipe sites.

There are some interesting chemistry interactions that deserve a closer look and that may relate to diatom distributions. Nine Pipe impaired sites have higher K concentrations than the other Nine Pipe sites. Is this related in any way to effects of cultivation? Or does it occur simply by chance? Are higher K concentrations somehow related to soil disturbance? For many of the sites, there is a strong negative correlation between water and sediment Ca, and water and sediment P and Fe (Figs. 4 and 7). Also, there is a tendency for higher total P concentrations to be associated with sites having a higher percent sand substrate.

How Much of the Variation in Environmental Factors among Wetlands Is Due to Natural Factors and How Much to Cultivation and Grazing? Is it Possible to Determine?

It is clear that most of the variation in factors influencing diatom assemblage distributions is due to natural factors, not anthropogenic. Even where there are relationships of environmental variables with impairment, it is not clear that those relationships are caused by impairment.

The situation in which diatom evidence for impairment seems strongest is the Nine Pipe impaired sites. Samples from these sites group separately from the other Nine Pipe sites on the RDA plot (Fig. 8), and these sites have the highest P and percent silt, two factors that could be increased by cultivation.

<u>How Appropriate Are the Reference Sites for Comparison with the Impaired Sites? Are Natural Factor Differences Too Significant?</u>

For any biological indicator to detect impairment among sites in this type of study, it is necessary that the variation among sites caused by that impairment be greater than the variation due to natural causes. It is also necessary that indicator metrics have sufficient resolution to detect the differences. In this study, the reference sites are not well suited to serve as a background against which impairment effects can be observed. For them to be appropriate, either they would need to have less natural variability, or the levels of impairment would need to be greater. Mayer and Galatowitsch (1999) found substantial variability in diatom assemblages in South Dakota wetlands and also point out the difficulty of finding good reference sites.

Three of the four impaired Ovando Valley sites have deeper water than the others, and for this reason they are not particularly good reference sites. These sites have distinctive assemblages, but this in large part may be due to depth/hydrologic factors and not to level of impairment.

<u>How Similar in “Natural” Characteristics must Wetlands Be to Be Considered Valid Reference Sites? Which Characteristics Are Most Important? Is it Possible to Specify Ranges of Characteristics to Define Appropriate Reference Sites?</u>

As discussed above, the level of similarity required among reference sites depends in part on the magnitude of the impairment to be detected, and on the possibility that “impaired” conditions might occur naturally (e.g., situations where one must distinguish a high Siltation Index caused by cultivation from one existing under natural conditions).

Either reference sites need to be more similar, level of impairment needs to be greater, or we need to have indicators that can detect finer levels of impairment effects.

One approach for future studies designed to test and develop diatom indicators might be to first identify the impaired sites to be studied, measure key environmental characteristics, and then choose reference sites with similar environmental characteristics. The environmental factors found important in this study would be good candidates to measure.

<u>Can We Frame Impairment Assessments in Terms of Specific Environmental Factors (E.g., Phosphorus Concentration, Silty Substrate). If There Is a Link to an Anthropogenic Cause, Then Is it Possible to Consider a Site Impaired If Specified Characteristics Are “Out of Range” with Respect to Expected Values?</u>

The approach of determining whether diatom assemblages or environmental characteristics are "out of range" of expected values for specified types of wetlands is a reasonable and desirable approach. In the case of this study, however, the variation of natural conditions is such that it is difficult to set a sufficiently narrow range of expected values that it would be possible to clearly and easily distinguish changes in conditions caused by impairment.

To do this successfully, one would first need to put wetlands in categories for which natural, expected diatom assemblages can be defined. These could then be used to compare with assemblages from other sites to see if they lie outside the expected range of assemblage composition.

What Characteristics of Diatom Assemblages Can Be Used to Distinguish Impairment?

Basic community measures (e.g., diversity) do not seem to be good indicators of impairment in the study wetlands (Charles 1999). The best assemblage characteristics will probably be those based on thorough knowledge of diatom taxa and expectations of whether they should occur in a site or not.

Are There Diatom Taxa That Are Good Indicators of Specific Types of Impairment for Particular Types of Wetlands?

Because the differences in level of impairment in the study wetlands is apparently not very large, it is difficult to distinguish taxa that are indicative of that impairment, no matter what type it may be. There are taxa that are indicative of silty substrates, higher total phosphorus, and high conductivity, but since it is not always clear in this study whether these conditions result from anthropogenic causes or arise naturally, the value of the taxa as impairment indicators is unclear. The most relevant information on ecological characteristics of diatoms in terms of their indicator value is in Charles et al. (1996, Appendix G).

The most logical approach for identifying diatom indicators in this study is to review the taxa most common in the NP11-14 wetland sites, those which appear most impaired, to see if there are taxa more common in these sites than others, and that might be good indicators. Though some taxa in the samples such as *Nitzschia palea*, *Gomphonema parvulum*, and *Cyclotella meneghiniana* are often considered as indicators of poor water quality, these taxa are relatively common in other samples as well (Charles 1999, Appendix C). Further evaluation of their occurrence would be necessary to confirm their value as indicators in Montana wetlands.

Are There Metrics We Have Not Tried, or Could Develop, That Might Be Good Indicators?

It is doubtful there are metrics I have not tried that would be good indicators of impairment at the study sites, for the reasons given above. Development of new metrics is impeded by the difficulty of not having appropriate sets of samples to calibrate or test metrics. It can be done, but it will require more data from wetland sites with widely divergent and well documented impairment.

One suggestion for a new metric would be to make a modified version of the Siltation Index that would include more truly motile taxa that are typically found on silty substrates. This would mean including more genera, and a species-by-species designation, instead of by genus. Perhaps a variant of the SI might be one that is limited to taxa more commonly found on disturbed than non-disturbed sites.

CONCLUSIONS

The following conclusions are considered supplemental to the those in the previous report (Charles 1999). None of the findings from this study contradicts the conclusions of the first study.

Cultivation appears to have had a greater impact on diatom assemblages in the Nine Pipe wetlands than grazing had on the Ovando Valley sites. Whatever impairment was caused by grazing and cultivation, it is difficult if not impossible to distinguish it from natural variability.

The main reason for difficulty in identifying impairment of study wetlands was the large amount of natural variability in chemical and physical habitat, as compared with the variability caused by cultivation and grazing.

The primary cause for natural differences in variability appears to be the interaction of groundwater and surface water input to the wetlands. No physical or chemical factors correlated strongly with level of impairment.

The best time to sample to detect impairment is probably late summer, though samples taken earlier in the summer would probably be nearly as informative.

RECOMMENDATIONS FOR FUTURE STUDIES

The following recommendations are nearly the same as those in the previous report (Charles 1999). Some have been modified and expanded.

Within-site Sampling

Take individual samples from specific microhabitats. Take several separate samples and count 100 valves from each. Detailed descriptions of physical habitat conditions where samples were taken is also necessary. Resulting data will provide information on physical habitats in which diatom taxa are most likely to be found. It will be easier to identify taxa that are good indicators of physical habitat impairment.

Take samples from different locations within wetlands. These will provide better indication of within-site variability. In the present study, there are no within-site data to compare with between-site data. Also, in some situations it may be possible to find impaired and unimpaired conditions in the same wetland. Comparison of samples from these locations could minimize the effect of natural between-site differences. Taking samples along an elevation gradient may be useful. Borth (1998) found that evidence of effects of land-use on higher vegetation varied with elevation. Also, consider taking samples from surface sediments in open water. The assemblages collected from there may provide a good representation of a larger portion of the wetland than periphyton collections, and may be more appropriate to compare with water chemistry samples collected from the middle of the wetlands.

Collect periphyton composites in a "systematic" way so that subsamples represent the relative occurrence of all microhabitats in the wetland area of interest, in proportion to their occurrence.

Measure water chemistry at the same time and place diatom samples are taken. Measure chemistry characteristics that are shown to have greatest influence on diatom distributions.

Another approach for reference site selection might be to find wetlands that are impaired in one areas only. Reference samples could be collected from the non-impaired portions.

Sampling Design

Take samples from additional wetlands to expand understanding of distributions of taxa under natural conditions, and how they respond to different types of impairment. Sites should be both natural (reference) and impaired. Study sites (reference and impaired) should be as similar as possible. Focus on one or limited kinds of impairment; include a significant number of sites with each type of impairment. The nature and magnitude of types of impairment at each site should be carefully described and quantified.

Take sediment cores from impaired wetlands and compare recent and past assemblages. The past assemblages have the potential to be much better reference samples than those currently used because differences in "natural" chemistry factors should be less (they should have changed relatively little over time. Any chemistry changes inferred from diatom assemblages could be attributed to impairment. Coring sites should be chosen carefully to help ensure that an adequate diatom record is collected; chemistry characteristics suggest that dissolution should not be a problem (salinity and pH are not high), but physical factors could be a problem (e.g., annual drying of sediments).

In future studies designed to develop impairment indicators, it would be best if reference sites should have less variability in chemical and physical conditions - in particular groundwater input, conductivity related chemistry, and exposed sediment characteristics.

Note added after final draft: After the final version of this report was completed and being reviewed, Randall Apfelbeck provided me with a copy of Ludden and Hauer's (2000) study of macroinvertebrates in wetlands in the Ovando and Nine-Pipe areas. The findings of their study have significant implications for interpretation of the diatom data. There was no time remaining, however, to modify my report to take into account their observations and conclusions.

A major purpose of Ludden and Hauer's study was to evaluate the ability of macroinvertebrate metrics to distinguish levels of impairment among wetlands. They studied the same wetland sites included in this study, plus a few more. However, they categorized site impairment very differently. In our diatom studies, and in Borth's study (1998), wetlands in each valley were divided equally into categories of unimpaired, semi-impaired, and impaired. Ludden and Hauer (2000) evaluated impairment using a different approach. They determined that all sites in the Ovando area were minimally disturbed and that all sites in the Nine Pipe area were highly disturbed. Specific criteria for making these determinations are not provided. To the extent it may be relevant, this classification is at least consistent with the difference in nutrient concentrations in wetlands in the two areas; concentrations are higher in Nine-Pipe.

The difference in impairment classification schemes has significant implications for evaluating the usefulness of diatoms as indicators. Perhaps diatoms did not clearly distinguish Borth's three levels of wetland impairment because the actual differences in impairment among sites were minimal. On the other hand, the large differences in diatom assemblages between Ludden and Hauer's "minimally-disturbed" Ovando wetlands and their "highly-disturbed" Nine-Pipe wetlands allows the possibility that diatoms may in fact be good impairment indicators. The reasons for the significant differences between the Borth (1998) and the Ludden and Hauer (2000) impairment classifications are not clear. Neither report describes specific environmental criteria for designating impairment. Vaguely described land-use differences seem to be the main factors. Therefore it is not possible to evaluate validity of the two approaches or to fully understand how the approaches might relate to the evaluation of diatom indicators. An interpretation based on geographic scale might make sense. Borth seems to have focused on levels of wetland impairment within prescribed small regions. Ludden and Hauer may have chosen to characterize impairment on a broader scale, based on comparisons with other wetlands in the State of Montana or larger geographic regions. If this is a reasonably accurate interpretation, then an assessment of usefulness of diatoms might turn out to be that they are good for distinguishing major differences in impairment over broad geographic scales, but not as useful for identifying lesser levels of impairment at smaller scales.

To further evaluate diatoms as indicators in relationship to the two impairment classifications would require a detailed review and reconsideration of impairment approaches, definition of specific criteria for impairment categories, rigorous application of those criteria to categorize each wetland, and re-evaluation of the diatom data to assess the value of diatoms as indicators. Careful attention would be necessary to avoid confusing differences in diatom assemblages due to natural factors with those due to land-use activities.

REFERENCES

Borth, C. 1998. Effects of land use on vegetation in glaciated depressional wetlands in western Montana. Masters Thesis. Montana State University. 113 pages.

Charles, D.F. 1999. An evaluation of diatom periphyton as indicators of cultivation and grazing impairment in Montana wetlands. Report Number 99-1F. Patrick Center for Environmental Research, The Academy of Natural Sciences, Philadelphia, PA. 45 pages.

Charles, D.F., F.W. Acker, and N.A. Roberts. 1996. Diatom periphyton in Montana lakes and wetlands: Ecology and potential as bioassessment indicators. Report submitted to the Montana Department of Environmental Quality. Patrick Center for Environmental Research, Academy of Natural Sciences, Philadelphia, PA. 67 pages plus appendices.

Ludden, V.E. and F.R. Hauer. 2000. The effects of natural variability on the use of macroinvertebrates as bioindicators of disturbance in intermontane depressional wetlands in northwestern Montana, USA. Flathead Lake Biological Station, The University of Montana (311 Bio Station Lane, Polson, MT 59860-9659), 157 pages.

Mayer, P.M. and S.M. Galatowitsch. 1999. Diatom communities as ecological indicators of recovery in restored prairie wetlands. Wetlands 19: 765-774.

Table 1. June water chemistry values for Nine Pipe and Ovando Valley wetland study sites. Data from Borth (1998).

Site June	pH	EC µS/cm	Temp °C	Total alk. mg $CaCO_3$/L	NO_3 mg/L	NH_4 mg/L	P mg/L	PO_4 mg/L	Ca mg/L	Cl mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	S mg/L	Si mg/L	SO_4 mg/L
Label	**pH**	**Cond**	**Temp**	**Alk**	**NO3**	**NH4**	**TotP**	**PO4**	**Ca**	**Cl**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**S**	**Si**	**SO4**
NP1	7.6	675	27.1	340	0.07	0.12	1.27	2.89	10.6	11.2	1.59	11.5	12.7	0.13	136.1	4.92	14.6	10.81
NP3	6.7	290	17.9	138	0.02	0.05	0.48	0.64	10.9	8.32	2.98	12.3	5.3	0.68	42.9	1.12	2.4	0.75
NP4	6.4	250	18.0	110	0.02	0.07	0.25	0.3	7.7	7.5	1.41	16	3.4	0.24	36.8	1.49	1.5	1.58
NP5	7.1	586	20.1	283	0.06	0.13	2.27	5.33	6.2	14	2.48	9.3	4.1	0.44	131.9	2.54	8.6	1.92
NP7	6.5	270	16.7	118	0.01	0.2	0.76	0.45	6.2	8.45	3.63	15.8	3.8	0.43	39	0.97	3.8	1.09
NP8	6.5	238	17.2	105	0.08	0.11	0.36	0.23	6.6	7.3	2.28	12.9	3.6	0.31	33.3	1.2	1.0	1.12
NP9	6.8	259	17.5	113	0.01	0.09	0.51	0.37	7.7	6.18	2.57	16	3.7	0.15	35.9	1.53	2.6	1.97
NP10	6.8	328	23.7	133	0.02	0.14	0.58	0.29	6.8	9.85	3.28	15.2	4.4	0.29	56.9	1.76	2.0	1.67
NP11	7.6	581	17.3	273	0.02	0.08	0.97	1.7	17.3	15.7	1.54	22.5	8.7	0.1	96.1	2.87	9.6	5.46
NP12	7.1	560	18.7	258	0.02	0.18	1.48	2.21	17.5	13.7	3.25	33.4	10.6	0.6	74.1	1.75	17.4	1.69
NP13	6.7	240	20.7	110	0.02	0.13	0.62	0.32	8.9	6.66	4.18	18	4.4	0.56	28.9	1.64	17.0	2.14
NP14	6.9	274	23.1	118	0.03	0.05	0.27	0.27	6.9	10.7	1.41	21.9	4.5	0.17	35.3	1.11	13.4	0.4
BC15	7.4	381	19.8	193	0	0.03	0.08	0	51.1	0.9	0.03	5.1	12	0.01	4.3	0.27	5.5	0.25
BC16	7.5	784	24.3	350	0.02	0.07	1.01	1.6	58.2	13.9	0.04	32.6	38.5	0.11	32.3	15.59	29.0	43.15
BC17	7.5	453	25.4	225	0.02	0.03	0.13	0	32.1	2.64	0.1	21.7	27.4	0.08	8.8	0.56	6.3	0.52
BC18	7.0	492	16.0	255	0	0.01	0.13	0	49.5	1.38	0.05	4.6	26.9	0.06	5.5	1.18	8.9	2.15
BC19	7.3	688	17.9	330	0.02	0.02	0.15	0	64.2	6	0.01	9.6	33.1	0.05	19.7	7.08	8.0	17.98
BC20	7.3	664	13.7	295	0.02	0.01	0.15	0	64.3	4.27	0.01	4	27.9	0.02	17.4	9.77	7.3	21.78
BC21	7.5	698	14.5	335	0.01	0.01	0.14	0	67	5.52	0.01	5.1	31.5	0.01	24.6	0.03	4.9	27.3
BC22	7.1	577	15.1	290	0.01	0.02	0.17	0	65.2	2.72	0.05	8.1	24.1	0.06	10.1	2.13	13.2	4.24
BC23	7.4	683	15.4	333	0.02	0.03	0.08	0	68.9	5.02	0.02	20.8	32.7	0.06	10	1.36	30.0	1.87
BC24	6.7	229	15.8	108	0.02	0.05	0.08	0	25.9	2.3	0.11	6.5	8.5	0.1	2.8	0.28	12.7	0.16
BC25	6.9	390	17.4	183	0.01	0.02	0.13	0	45.2	3.67	0.06	8.3	13.7	0.08	4.3	0.75	12.9	0.97
BC26	7.5	499	18.8	230	0.02	0.03	0.09	0	52.4	4.33	0.06	16.1	20.9	0.11	7.1	0.77	19.0	0.96

Table 2. July water chemistry values for Nine Pipe and Ovando Valley wetland study sites. Data from Borth (1998).

Site July	pH	EC uS/cm	Temp °C	Total Alk. mg $CaCO_3$/L	NO_3 mg/L	NH_4 mg/L	P mg/L	PO_4 mg/L	Ca mg/L	Cl mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	S mg/L	Si mg/L	SO_4 mg/L
Label	**pH**	**Cond**	**Temp**	**Alk**	**NO3**	**NH4**	**TotP**	**PO_4**	**Ca**	**Cl**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**S**	**Si**	**SO_4**
NP1	7.3	750	17.8	350	0.04	0.08	1.12	n/a	13.6	n/a	0.73	10.5	14.6	0.08	135.1	4.04	12.7	n/a
NP3	6.8	305	19.6	123	0.03	0.05	0.36	n/a	10.9	n/a	2.61	12.5	5.3	0.37	42.3	1.06	0.3	n/a
NP4	7.2	240	25.1	110	0.03	0.06	0.26	n/a	7.9	n/a	1.84	13.4	3.3	0.19	35.8	1.33	0.5	n/a
NP5	7.2	582	21.7	273	0.08	0.16	2.34	n/a	6.5	n/a	2.44	8.0	4.1	0.56	130.6	2.53	6.3	n/a
NP7	6.5	263	19.6	113	0.03	0.12	0.67	n/a	6.0	n/a	2.8	15.6	3.8	0.42	38.5	0.96	1.7	n/a
NP8	6.5	232	22.4	98	0.02	0.07	0.34	n/a	6.7	n/a	2.11	12.3	3.7	0.57	32.6	1.13	0.3	n/a
NP9	6.6	261	26.8	115	0.07	0.11	0.60	n/a	7.9	n/a	2.81	15.8	3.9	0.19	36.5	1.53	1.1	n/a
NP10	6.9	335	20.5	138	0.05	0.10	0.61	n/a	6.7	n/a	3.32	14.7	4.3	0.42	55.3	1.73	1.5	n/a
NP11	8.4	640	17.4	288	0.04	0.14	1.13	n/a	19.2	n/a	2.04	21.6	9.4	0.67	101.9	2.35	4.8	n/a
NP12	6.9	600	18.0	253	0.04	0.08	1.47	n/a	18.5	n/a	3.38	35.2	11.0	0.6	78.8	1.56	9.9	n/a
NP13	6.5	274	18.0	113	0.03	0.07	0.92	n/a	10.4	n/a	5.92	19.0	4.9	1.01	30.8	1.46	16.2	n/a
NP14	6.7	301	21.2	110	0.03	0.03	0.34	n/a	7.6	n/a	1.46	23.5	4.8	0.17	37.2	1.18	11.8	n/a
BC15	7.9	337	22.1	165	0.01	0.01	0.05	n/a	44.4	n/a	0.01	5.5	12.2	0.01	4.3	0.23	3.8	n/a
BC16	7.7	811	23.9	348	0.01	0.06	0.81	n/a	60.3	n/a	0.02	35.0	41.0	0.07	34.2	15.35	31	n/a
BC17	6.9	466	18.5	223	0.01	0.04	0.20	n/a	33.5	n/a	0.16	23.3	28.4	0.33	9.2	0.47	5.9	n/a
BC18	7.4	484	20.6	235	0.01	0.08	0.11	n/a	48.2	n/a	0.05	4.5	29.4	0.04	6	0.93	3.7	n/a
BC19	7.5	669	23.5	315	0.01	0.03	0.08	n/a	66.5	n/a	0.01	9.4	34.7	0.03	20.1	6.75	5.9	n/a
BC20	7.0	654	14.7	290	0.01	0.05	0.11	n/a	65.9	n/a	0.01	5.1	33.1	0.02	19	11.66	5.8	n/a
BC21	7.4	695	16.7	328	0	0.04	0.13	n/a	68.3	n/a	0.02	5.6	34.3	0.01	27	8.8	3.8	n/a
BC22	7.1	587	22.3	288	0.01	0.01	0.13	n/a	68.3	n/a	0.04	8.3	26.4	0.07	10.9	1.87	12.8	n/a
BC23	8.1	668	26.7	323	0.01	0.03	0.12	n/a	70.1	n/a	0.01	21.3	35.1	0.02	11	1.24	31.2	n/a
BC24	7.5	235	26.4	110	0.01	0.06	0.09	n/a	27.6	n/a	0.07	6.7	9.1	0.06	3	0.3	13	n/a
BC25	7.5	370	23.8	170	0.01	0.04	0.10	n/a	46.2	n/a	0.04	8.5	14.6	0.03	4.5	0.7	10.6	n/a
BC26	7.8	490	20.3	238	0.01	0.07	0.15	n/a	53.7	n/a	0.05	16.3	21.8	0.06	7.4	0.75	19.1	n/a

Table 3. August water chemistry values for Nine Pipe and Ovando Valley wetland study sites. Data from Borth (1998).

Site Aug.	pH	EC uS/cm	Temp °C	Total Alk. mg $CaCO_3$/L	NO_3 mg/L	NH_4 mg/L	P mg/L	PO_4 mg/L	Ca mg/L	Cl mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	S mg/L	Si mg/L	SO_4 mg/L
Label	**pH**	**Cond**	**Temp**	**Alk**	**NO3**	**NH4**	**TotP**	**PO_4**	**Ca**	**Cl**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**S**	**Si**	**SO_4**
NP1	7.67	840	21.9	415	0.05	0.06	0.96	2.07	17.9	n/a	0.35	13.2	18.7	0.12	172	4.6	8.6	n/a
NP3	6.35	370	17.5	160	0.05	0.14	0.35	0.09	13.6	n/a	3.34	15.3	6.7	0.31	55	1.27	2.4	n/a
NP4	6.62	280	20.5	130	0.04	0.10	0.43	0.33	9.0	n/a	2.94	14.4	3.7	0.66	48.6	1.68	1.1	n/a
NP5	7.37	810	19.4	383	0.11	0.18	2.73	6.06	8.8	n/a	3.25	10.1	5.3	0.5	198	4.12	6.5	n/a
NP7	6.59	320	18.3	140	0.03	0.06	0.77	0.48	5.7	n/a	3.73	19.5	4.6	0.34	51.7	1.54	3.1	n/a
NP8	6.55	260	18.3	110	0.02	0.05	0.39	0.12	5.4	n/a	3.04	13.3	4.3	0.36	41.8	1.31	1.3	n/a
NP9	6.85	280	24.3	128	0.03	0.17	0.48	0.38	8.0	n/a	2.3	16.9	4.1	0.48	48.4	1.74	2.1	n/a
NP10	7.83	430	20.1	178	0.04	0.06	0.56	0.28	8.6	n/a	3.74	19.9	5.5	0.81	78.3	2.19	0.7	n/a
NP11	6.52	830	19	363	0.04	0.08	0.62	0.66	24.3	n/a	1.1	27	42.8	0.28	142.4	2.12	2.5	n/a
NP12	7.21	840	19.3	370	0.05	0.22	1.35	1.39	24.7	n/a	3.05	50	15.6	1.86	128.8	2.15	5.6	n/a
NP13	6.84	340	22.8	148	0.03	0.09	1.35	0.47	13.4	n/a	8.39	23.3	6.2	1.14	45.8	1.73	16.5	n/a
NP14	7.05	420	23.6	170	0.03	0.12	1.06	0.59	10.4	n/a	5.16	34.3	6.3	1.38	60.9	2.03	8.5	n/a
BC15	7.56	346	18.7	168	0.19	0.09	0.04	0.00	45.4	n/a	0.01	6.5	13.9	0.01	4.7	0.28	9.4	n/a
BC16	8.08	879	24.2	408	0.03	0.06	0.18	0.08	64.3	n/a	0.01	43.5	51.2	0.02	42.9	15.77	31.4	n/a
BC17	6.5	542	16.1	260	0.03	0.44	0.44	0.67	38.3	n/a	0.15	31.6	32.4	0.33	11.1	0.68	3.5	n/a
BC18	7.97	402	15.3	203	0.02	0.05	0.06	0.28	28.5	n/a	0.02	5.3	31	0.01	6.8	0.47	0.1	n/a
BC19	7.34	683	16.7	340	0.02	0.45	0.06	0.00	67.5	n/a	0.01	10.4	37.6	0.01	21.4	5.96	1.1	n/a
BC20	7.27	726	18.9	365	0.01	0.02	0.05	0.00	82.9	n/a	0.03	7.2	42.8	0.05	24.5	13.82	5.5	n/a
BC21	6.94	745	13.7	358	0.02	0.38	0.06	0.00	77.5	n/a	0.03	5.3	36.7	0.03	27.9	7.22	2	n/a
BC22	7.05	625	19.4	320	0.03	0.06	0.06	0.00	72.1	n/a	0.04	9.6	30	0.07	12.3	1.59	10.5	n/a
BC23	7.3	716	15.2	363	0.02	0.10	0.08	0.00	65.4	n/a	0.01	21.9	39.9	0.03	12.5	1.05	30.7	n/a
BC24	6.84	241	20.4	120	0.02	0.03	0.11	0.00	29.1	n/a	0.07	7.4	10.2	0.05	3.3	0.27	17	n/a
BC25	6.89	391	15.6	193	0.02	0.28	0.06	0.00	47.8	n/a	0.05	9.3	16	0.04	4.9	0.5	8.2	n/a
BC26	7.22	525	19	258	0.01	0.07	0.08	0.00	54.6	n/a	0.03	18.5	23.9	0.02	8.1	0.7	13.4	n/a

Table 4. June, July and August average water chemistry values for Nine Pipe and Ovando Valley wetland study sites. Data from Borth (1998).

Site 3 Mo.	pH	EC uS/cm	Temp °C	Total Alk. mg $CaCO_3$/L	NO_3 mg/L	NH_4 mg/L	P mg/L	PO_4 mg/L	Ca mg/L	Cl mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	S mg/L	Si mg/L	SO_4 mg/L
Label	**pH**	**Cond**	**Temp**	**Alk**	**NO3**	**NH4**	**TotP**	**PO_4**	**Ca**	**Cl**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**S**	**Si**	**SO_4**
NP1	7.52	755	22.3	368	0.05	0.09	1.12	2.48	14.0	11.20	0.89	11.73	15.33	0.11	147.7	4.52	12.0	10.81
NP3	6.62	322	18.3	140	0.03	0.08	0.40	0.37	11.8	8.32	2.98	13.37	5.77	0.45	46.7	1.15	1.7	0.75
NP4	6.74	257	21.2	117	0.03	0.08	0.31	0.32	8.2	7.50	2.06	14.60	3.47	0.36	40.4	1.50	1.0	1.58
NP5	7.22	659	20.4	313	0.08	0.16	2.45	5.70	7.2	14.00	2.72	9.13	4.50	0.50	153.5	3.06	7.1	1.92
NP7	6.53	284	18.2	124	0.02	0.13	0.73	0.47	6.0	8.45	3.39	16.97	4.07	0.40	43.1	1.16	2.9	1.09
NP8	6.52	243	19.3	104	0.04	0.08	0.36	0.18	6.2	7.30	2.48	12.83	3.87	0.41	35.9	1.21	0.9	1.12
NP9	6.75	267	22.9	119	0.04	0.12	0.53	0.38	7.9	6.18	2.56	16.23	3.90	0.27	40.3	1.60	1.9	1.97
NP10	7.18	364	21.4	150	0.04	0.10	0.58	0.29	7.4	9.85	3.45	16.60	4.73	0.51	63.5	1.89	1.4	1.67
NP11	7.51	684	17.9	308	0.03	0.10	0.91	1.18	20.3	15.70	1.56	23.70	20.30	0.35	113.5	2.45	5.6	5.46
NP12	7.07	667	18.7	294	0.04	0.16	1.43	1.80	20.2	13.70	3.23	39.53	12.40	1.02	93.9	1.82	11.0	1.69
NP13	6.68	285	20.5	124	0.03	0.10	0.96	0.40	10.9	6.66	6.16	20.10	5.17	0.90	35.2	1.61	16.6	2.14
NP14	6.88	332	22.6	133	0.03	0.07	0.56	0.43	8.3	10.65	2.68	26.57	5.20	0.57	44.5	1.44	11.2	0.40
BC15	7.62	355	20.2	175	0.07	0.04	0.06	0.00	47.0	0.90	0.02	5.70	12.70	0.01	4.4	0.26	6.2	0.25
BC16	7.76	825	24.1	369	0.02	0.06	0.67	0.84	60.9	13.85	0.02	37.03	43.57	0.07	36.5	15.57	30.5	43.15
BC17	6.97	487	20.0	236	0.02	0.17	0.26	0.34	34.6	2.64	0.14	25.53	29.40	0.25	9.7	0.57	5.2	0.52
BC18	7.46	459	17.3	231	0.01	0.05	0.10	0.14	42.1	1.38	0.04	4.80	29.10	0.04	6.1	0.86	4.2	2.15
BC19	7.38	680	19.4	328	0.02	0.17	0.10	0.00	66.1	6.00	0.01	9.80	35.13	0.03	20.4	6.60	5.0	17.98
BC20	7.19	681	15.8	317	0.01	0.03	0.10	0.00	71.0	4.27	0.02	5.43	34.60	0.03	20.3	11.75	6.2	21.78
BC21	7.28	713	15.0	340	0.01	0.14	0.11	0.00	70.9	5.52	0.02	5.33	34.17	0.02	26.5	5.35	3.6	27.30
BC22	7.08	596	18.9	299	0.02	0.03	0.12	0.00	68.5	2.72	0.04	8.67	26.83	0.07	11.1	1.86	12.2	4.24
BC23	7.60	689	19.1	340	0.02	0.05	0.09	0.00	68.1	5.02	0.01	21.33	35.90	0.04	11.2	1.22	30.6	1.87
BC24	7.01	235	20.9	113	0.02	0.05	0.09	0.00	27.5	2.30	0.08	6.87	9.27	0.07	3.0	0.28	14.2	0.16
BC25	7.10	384	18.9	182	0.01	0.11	0.10	0.00	46.4	3.67	0.05	8.70	14.77	0.05	4.6	0.65	10.6	0.97
BC26	7.51	505	19.4	242	0.01	0.06	0.11	0.00	53.6	4.33	0.05	16.97	22.20	0.06	7.5	0.74	17.2	0.96

Table 5. Sediment chemistry, percent substrate, water depth, percent cover type, and groundwater category for Nine Pipe and Ovando Valley wetland study sites. Data from Borth (1998). [1]Groundwater types; 1= recharge, 2 = discharge.

Site	Sed-pH	Sed-Cond	Sed-TKN	Sed-NH4	Sed-NO3	Sed-Na	Sed-Ca	Sed-Mg	Sed-P	Clay	Sand	Silt	Depth	SurfWat	DrySoil	Algae	Litter	GW[1]
		µS/cm	%N	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	%	%	cm	%	%	%	%	
NP1	9.0	2043	0.37	28	2	712	2462	440	29	38	22	40	97	0.78	0.03	0.17	0.17	2
NP3	7.6	369	0.73	15	17	82	11320	1080	16	29	43	28	105	0.68	0.13	0.08	0.32	1
NP4	7.4	223	0.59	58	4	272	1458	880	31	42	32	25	80	0.31	0.04	0.00	0.17	1
NP5	8.6	1462	0.50	45	14	1184	1698	1060	43	34	27	39	73	0.46	0.35	0.00	0.05	2
NP7	7.8	461	0.42	82	3	250	1294	1880	60	32	35	33	96	0.65	0.00	0.03	0.04	1
NP8	7.3	423	0.47	59	5	224	1456	1840	38	35	37	38	124	0.60	0.05	0.11	0.01	2
NP9	7.3	340	0.52	125	9	162	1422	1260	52	39	41	20	73	0.65	0.00	0.32	0.01	1
NP10	7.5	659	0.39	81	2	382	1092	580	53	25	46	28	84	0.68	0.00	0.16	0.02	1
NP11	8.2	822	0.35	40	2	448	1850	1660	45	35	29	36	72	0.57	0.02	0.04	0.01	1
NP12	7.8	656	0.49	64	9	392	1466	1020	52	17	20	63	65	0.84	0.04	0.05	0.03	1
NP13	7.4	358	0.34	79	2	134	1270	700	77	16	27	56	81	0.69	0.01	0.13	0.05	1
NP14	7.6	490	0.64	64	14	200	1540	860	51	45	26	29	50	0.69	0.03	0.01	0.15	1
BC15	7.8	320	0.52	13	10	44	5124	880	9	48	11	40	213	0.58	0.00	0.32	0.01	2
BC16	8.5	780	0.81	53	21	96	10480	1260	40	48	18	34	86	0.60	0.00	0.06	0.02	2
BC17	7.6	270	0.73	65	10	70	3306	306	84	41	12	47	86	0.90	0.02	0.00	0.01	1
BC18	7.9	500	0.87	36	15	46	5322	558	32	45	23	32	114	0.32	0.06	0.06	0.02	1
BC19	8.4	540	1.12	26	14	136	10720	330	17	48	11	40	114	0.79	0.00	0.07	0.07	2
BC20	8.2	720	1.16	7	37	180	11960	318	39	35	18	48	47	0.51	0.00	0.12	0.25	2
BC21	8.1	460	1.05	9	18	148	13280	276	17	45	10	45	59	0.57	0.00	0.06	0.21	2
BC22	8.4	440	0.49	46	10	1068	1662	274	45	48	13	40	104	0.77	0.00	0.01	0.05	1
BC23	8.1	500	1.38	37	42	88	9220	482	23	38	10	53	114	0.81	0.01	0.12	0.03	1
BC24	7.9	290	1.43	39	25	56	6600	394	19	41	10	49	187	0.80	0.02	0.01	0.04	1
BC25	8.2	450	0.93	42	16	62	11320	226	25	47	9	45	216	0.68	0.01	0.11	0.01	1
BC26	7.5	360	0.61	14	7	72	8040	418	15	38	13	49	265	0.88	0.00	0.04	0.04	1

Table 6. Correlation matrix of all water chemistry variables used in this study (Table 4).

	pH	Cond	Temp	Alk	NO3	NH4	TotP	PO4
pH	1.0000							
Cond	.7444	1.0000						
Temp	-.0053	-.2518	1.0000					
Alk	.7700	.9921	-.2751	1.0000				
NO3	-.0044	-.0566	.3828	-.0718	1.0000			
NH4	-.2077	.1309	-.0240	.1019	.1885	1.0000		
TotP	-.1237	.1523	.3171	.0878	.6549	.4553	1.0000	
PO4	.0780	.3229	.2872	.2827	.7019	.4138	.9354	1.0000
Ca	.6691	.5978	-.3965	.6542	-.5344	-.2592	-.6165	-.4592
Cl	-.1149	.2275	.2591	.1258	.3033	.3914	.7638	.6675
Fe	-.6562	-.4586	.2614	-.5358	.4486	.3179	.6921	.4535
K	-.1006	.0607	.4840	-.0183	.0268	.2797	.4546	.3068
Mg	.7363	.7710	-.3706	.8082	-.5124	-.1416	-.4372	-.2633
Mn	-.5741	-.3112	.2084	-.3911	.3648	.3895	.7052	.4730
Na	-.1631	.2122	.1825	.1242	.5125	.4113	.8375	.7671
S	.3401	.6470	-.0616	.5971	-.0814	.0712	.2007	.2393
Si	.5483	.4751	.1953	.4884	-.1754	-.2511	.0338	.0823
SO4	.4521	.7004	-.2047	.6768	-.2392	.0492	.0119	.0785

	Ca	Cl	Fe	K	Mg	Mn	Na	S
Ca	1.0000							
Cl	-.5140	1.0000						
Fe	-.9038	.6159	1.0000					
K	-.3038	.6235	.4408	1.0000				
Mg	.9290	-.3079	-.8382	-.1382	1.0000			
Mn	-.7384	.5863	.9151	.5787	-.6656	1.0000		
Na	-.6153	.9035	.6978	.4386	-.3875	.6228	1.0000	
S	.2581	.4651	-.1455	.0423	.4081	-.1611	.4322	1.0000
Si	.5189	-.0371	-.3929	.2397	.5144	-.2048	-.2376	.1466
SO4	.4491	.2824	-.3364	-.0914	.5863	-.3549	.2636	.9385

	Si	SO4
Si	1.0000	
SO4	.1698	1.0000

Table 7. Correlation of water chemistry variables with PCA axes, all Nine Pipe and Ovando Valley sites.

PCA Canonical axes: 0 Covariables: 0 Scaling: 2

Cent./stand. by samples: 0 0 by species: 1 0
No transformation
Spec: Species scores (adjusted for species variance)

N	NAME 1	AX1	AX2	AX3	AX4	WEIGHT	
	EIG	.4615	.3305	.1082	.0382		
1	pH	.6961	.2856	-.2583	.3297	1.00	1.00
2	Cond	.5917	.6769	-.2111	.3331	1.00	1.00
3	Temp	-.3348	.0272	-.3954	-.2638	1.00	1.00
4	Alk	.6514	.6055	-.1968	.3789	1.00	1.00
5	NO3	-.5366	.1637	-.1280	.5175	1.00	1.00
6	NH4	-.3003	.2905	.0066	.1778	1.00	1.00
7	TotP	-.6182	.5701	-.3698	.2406	1.00	1.00
8	PO4	-.4451	.5846	-.3536	.4742	1.00	1.00
9	Ca	.9825	-.0258	-.0354	.0168	1.00	1.00
10	Cl	-.5219	.7665	-.2067	-.1192	1.00	1.00
11	Fe	-.9378	.1671	-.0703	-.1343	1.00	1.00
12	K	-.3465	.3101	-.6108	-.3848	1.00	1.00
13	Mg	.9352	.2147	-.0816	.0841	1.00	1.00
14	Mn	-.8088	.1629	-.2802	-.1235	1.00	1.00
15	Na	-.6173	.7690	-.0312	.1266	1.00	1.00
16	S	.3101	.8699	.2328	-.1945	1.00	1.00
17	Si	.5301	.1203	-.7755	-.1441	1.00	1.00
18	SO4	.5017	.7880	.3030	-.1499	1.00	1.00

Table 8. Correlation of water chemistry variables with PCA axes, all Nine Pipe sites.

```
 PCA   Canonical axes:      0      Covariables:          0     Scaling:      2
Cent./stand.       by samples:    0      0     by species:    1      0
No transformation
Spec: Species scores (adjusted for species variance)
```

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	1
	EIG	.6206	.1704	.1024	.0621		
1	pH	.8791	-.2704	-.1057	-.0341	1.00	1.00
2	Cond	.9684	-.1219	.0317	-.2075	1.00	1.00
3	Temp	-.0427	.0048	.2026	.5279	1.00	1.00
4	Alk	.9702	-.1668	.0526	-.1566	1.00	1.00
5	NO3	.5106	-.3759	.7094	-.0067	1.00	1.00
6	NH4	.3715	.0719	.4336	-.3659	1.00	1.00
7	TotP	.7679	.1326	.5496	-.1123	1.00	1.00
8	PO4	.8206	-.1469	.5184	-.1024	1.00	1.00
9	Ca	.7005	.1848	-.5686	-.2034	1.00	1.00
10	Cl	.8080	-.0647	.0477	-.5055	1.00	1.00
11	Fe	-.4469	.6528	.2542	-.1052	1.00	1.00
12	K	.1358	.6651	-.5179	-.4097	1.00	1.00
13	Mg	.8380	-.0086	-.5168	-.0971	1.00	1.00
14	Mn	-.0259	.7710	.1100	-.4183	1.00	1.00
15	Na	.9169	-.3083	.1795	-.1639	1.00	1.00
16	S	.8693	-.3122	.1470	.2981	1.00	1.00
17	Si	.7150	.6570	.1042	.2019	1.00	1.00
18	SO4	.7434	-.3590	-.2795	.4592	1.00	1.00

Table 9. Correlation of water chemistry variables with PCA axes, all Ovando Valley sites.

PCA Canonical axes: 0 Covariables: 0 Scaling: 2
Cent./stand. by samples: 0 0 by species: 1 0
No transformation
Spec: Species scores (adjusted for species variance)

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	1
	EIG	.7276	.1682	.0469	.0282		
1	pH	.3127	.3392	-.0391	.4053	1.00	1.00
2	Cond	.8793	.1472	.3412	.2901	1.00	1.00
3	Temp	-.1404	.7273	-.1711	-.3642	1.00	1.00
4	Alk	.8464	.1242	.3831	.3421	1.00	1.00
5	NO3	-.3346	-.0490	-.0320	.0600	1.00	1.00
6	NH4	.1638	-.1203	.5270	-.4903	1.00	1.00
7	TotP	.5293	.5514	.0288	-.4656	1.00	1.00
8	PO4	.4091	.4833	.1567	-.5076	1.00	1.00
9	Ca	.7446	-.0347	.0617	.6026	1.00	1.00
10	Cl	.8138	.4703	-.1141	-.1247	1.00	1.00
11	Fe	-.5232	.1345	.3581	-.6450	1.00	1.00
12	K	.2205	.8994	.3035	-.2150	1.00	1.00
13	Mg	.8167	.1250	.4829	.1801	1.00	1.00
14	Mn	-.2078	.3383	.5720	-.5980	1.00	1.00
15	Na	.9737	.0558	.1842	-.0066	1.00	1.00
16	S	.9762	-.0540	-.1302	-.0756	1.00	1.00
17	Si	.0382	.9001	-.3740	.1994	1.00	1.00
18	SO4	.9843	-.1457	-.0813	-.0170	1.00	1.00

Table 10. Correlation of physical and sediment chemistry variables with PCA axes, all Nine Pipe and Ovando Valley sites.

```
 PCA   Canonical axes:      0      Covariables:          0     Scaling:      2
Cent./stand.       by samples:    0      0     by species:    1      1
No transformation
Spec: Species scores (adjusted for species variance)
```

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	1
	EIG	.3151	.1674	.1197	.0911		
1	Sed- pH	-.3419	.7344	-.3594	.1898	1.00	1.00
2	Sed- Cond	.1527	.8168	-.3085	.2619	1.00	1.00
3	Sed- TKN	-.8296	-.0395	.0752	-.3746	1.00	1.00
4	Sed- NH4	.7275	-.3469	-.2034	-.0884	1.00	1.00
5	Sed- NO3	-.7383	.1063	.1292	-.3755	1.00	1.00
6	Sed- Na	.5888	.6010	-.3002	-.0002	1.00	1.00
7	Sed- Ca	-.9221	.0781	.1458	-.0462	1.00	1.00
8	Sed- Mg	.6752	.0210	.3613	.1649	1.00	1.00
9	Sed- P	.7282	-.0185	-.3431	-.3574	1.00	1.00
10	Clay	-.5472	.0819	.3099	.1181	1.00	1.00
11	Sand	.8438	.1025	.4129	-.0354	1.00	1.00
12	Silt	-.4243	-.0009	-.7304	-.0387	1.00	1.00
13	Dept h	-.4392	-.4796	-.0495	.4944	1.00	1.00
14	Surf Wat	-.1766	-.3213	-.6720	.0891	1.00	1.00
15	DryS oil	.2140	.5376	.1235	-.1686	1.00	1.00
16	Alga e	.0055	-.1584	.2691	.6895	1.00	1.00
17	Litt er	-.1919	.4617	.3882	-.3818	1.00	1.00
18	GW-C harg	-.2955	.6539	.1203	.4139	1.00	1.00

Table 11. Correlation of physical and sediment chemistry variables with PCA axes, all Ovando Valley sites.

```
 PCA   Canonical axes:      0      Covariables:         0     Scaling:      2
Cent./stand.       by samples:    0      0     by species:    1      1
No transformation
Spec: Species scores (adjusted for species variance)
```

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	1
	EIG	.2549	.1969	.1703	.1338		
1	Sed- pH	.5897	.3232	-.2562	.3701	1.00	1.00
2	Sed- Cond	.8129	.3499	-.1323	.0064	1.00	1.00
3	Sed- TKN	.4454	-.4778	-.1764	-.5174	1.00	1.00
4	Sed- NH4	-.5586	.3643	-.4416	-.1352	1.00	1.00
5	Sed- NO3	.6566	-.2528	-.1993	-.4444	1.00	1.00
6	Sed- Na	.2303	.0793	-.5879	.6887	1.00	1.00
7	Sed- Ca	.6343	-.3452	.3483	-.2695	1.00	1.00
8	Sed- Mg	.0744	.5266	.5135	-.2031	1.00	1.00
9	Sed- P	-.0480	.3004	-.8339	-.1136	1.00	1.00
10	Clay	-.1641	.6118	.2403	.4600	1.00	1.00
11	Sand	.2931	.6970	-.1627	-.3533	1.00	1.00
12	Silt	-.0804	-.9605	-.1439	-.0211	1.00	1.00
13	Dept h	-.7103	-.1271	.5165	-.0218	1.00	1.00
14	Surf Wat	-.5015	-.5737	-.2369	.3567	1.00	1.00
15	DryS oil	-.2920	.3824	-.1550	-.7680	1.00	1.00
16	Alga e	.2122	.0119	.7992	.0688	1.00	1.00
17	Litt er	.7931	-.3296	-.1725	.1288	1.00	1.00
18	GW-C harg	.7352	.1289	.4124	.3331	1.00	1.00

Table 12. Correlation of physical and sediment chemistry variables with PCA axes, all Nine Pipe sites.

```
 PCA   Canonical axes:     0     Covariables:        0     Scaling:     2
Cent./stand.       by samples:    0      0     by species:    1      1
No transformation
Spec: Species scores (adjusted for species variance)
```

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	1
	EIG	.2665	.2445	.1289	.1160		
1	Sed- pH	.0098	.9323	.0091	-.1088	1.00	1.00
2	Sed- Cond	-.1630	.9113	-.0429	-.1359	1.00	1.00
3	Sed- TKN	.8254	-.2805	.1984	.3463	1.00	1.00
4	Sed- NH4	-.7295	-.5081	.3327	.0099	1.00	1.00
5	Sed- NO3	.6199	-.0365	.2745	.4770	1.00	1.00
6	Sed- Na	-.3100	.7967	.4010	-.1503	1.00	1.00
7	Sed- Ca	.8566	.1330	-.4206	.0425	1.00	1.00
8	Sed- Mg	.0628	-.3289	.4035	-.0757	1.00	1.00
9	Sed- P	-.8976	-.2023	.1880	.2130	1.00	1.00
10	Clay	.4268	.0126	.5623	-.4135	1.00	1.00
11	Sand	.2962	-.6458	.0061	-.5343	1.00	1.00
12	Silt	-.4431	.5077	-.3382	.4282	1.00	1.00
13	Dept h	.2259	.0100	-.3838	-.6976	1.00	1.00
14	Surf Wat	-.2600	.0976	-.7195	.2381	1.00	1.00
15	DrySoil	.4359	.5519	.4003	.1171	1.00	1.00
16	Alga e	-.2187	-.2830	-.4453	-.4640	1.00	1.00
17	Litt er	.8400	.0917	-.2902	.1670	1.00	1.00
18	GW-C harg	.0710	.6963	.1360	-.4418	1.00	1.00

Table 13. Correlation matrices of selected water chemistry, sediment chemistry, other environmental variables, and species and environmental axes. Results based on RDA analysis of data for Nine Pipe and Ovando Valley wetland sites, combined and alone. Selected values are those that explained most of the variation in the diatom assemblage data set.

Ovando and Nine Pipe sites - ALL sites

From log file moncoml.log

**** Correlation matrix ****

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	-.0245	1.0000						
SPEC AX3	-.0135	.0180	1.0000					
SPEC AX4	-.0232	.0178	-.0055	1.0000				
ENVI AX1	.9628	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.9681	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.9322	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.9486	.0000	.0000	.0000	1.0000
pH	.2441	.1904	-.0916	.1402	.2535	.1966	-.0983	.1478
Cond	.2861	.6398	.3784	-.1297	.2971	.6608	.4059	-.1368
TotP	-.4187	.5663	-.0577	-.3532	-.4349	.5850	-.0619	-.3723
Ca	.7649	-.1136	.3166	-.1227	.7944	-.1174	.3396	-.1294
Fe	-.6958	.0517	-.1587	-.0661	-.7227	.0534	-.1702	-.0697
K	-.5792	.0920	.1980	-.1440	-.6016	.0950	.2124	-.1518
Si	-.0247	.0263	.4031	-.3283	-.0257	.0272	.4325	-.3461
Sed-pH	.2533	.6485	.0235	.1290	.2630	.6699	.0252	.1360
Sed-Cond	.0977	.7936	.1944	.1710	.1015	.8197	.2086	.1803
Sed-TKN	.3572	-.2773	.3607	.2066	.3710	-.2865	.3869	.2178
Sed-P	-.4275	.1254	.3252	.1020	-.4440	.1295	.3488	.1075
.Clay	.4666	-.0406	.0157	-.0725	.4846	-.0420	.0169	-.0765
.Sand	-.5725	.0918	.0115	.4798	-.5946	.0948	.0123	.5058
Depth	.3430	-.0266	-.2595	.2762	.3563	-.0275	-.2784	.2912
GW-Charg	.3740	.3902	.0868	.2454	.3884	.4031	.0931	.2587
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

pH	1.0000				
Cond	.1066	1.0000			
TotP	.0000	.1741	1.0000		
Ca	.0531	.2717	-.4336	1.0000	
Fe	-.1760	-.2001	.5428	-.7890	1.0000

	pH	Cond	TotP	Ca	Fe	K	Si	Sed-pH
K	.0000	.1140	.3637	-.3217	.4807	1.0000		
Si	.0000	.0000	.1741	.4076	-.2168	.1899	1.0000	
Sed-pH	.3557	.4666	.2234	.2905	-.3466	-.0292	.2566	1.0000
Sed-Cond	.3326	.5672	.2924	.1195	-.2041	.0273	.1963	.6999
Sed-TKN	-.1195	.1019	-.4880	.5839	-.5889	-.3194	.0510	.2224
Sed-P	-.1531	.1306	.3333	-.3902	.5268	.4364	.0000	-.0670
.Clay	.1814	.1237	-.4146	.3236	-.6638	-.3490	.0928	.1508
.Sand	-.1090	-.1859	.1780	-.6575	.6240	.4428	-.3904	-.2338
Depth	-.0256	-.3054	-.2089	.2934	-.3961	-.3008	.1091	.0728
GW-Charg	.3125	.5330	.0000	.2124	-.3519	-.2673	.0000	.3830

	Sed-Cond	Sed-TKN	Sed-P	.Clay	.Sand	Depth	GW-Charg
Sed-Cond	1.0000						
Sed-TKN	-.0122	1.0000					
Sed-P	.1880	-.2928	1.0000				
.Clay	.1856	.2254	-.2666	1.0000			
.Sand	.0223	-.4482	.5874	-.4871	1.0000		
Depth	-.0890	.0856	-.5640	.1262	-.1562	1.0000	
GW-Charg	.5116	.1195	-.1531	.3627	-.2180	-.0512	1.0000

Nine Pipe sites only

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	.0000	1.0000						
SPEC AX3	.0000	.0000	1.0000					
SPEC AX4	.0000	.0000	.0000	1.0000				
ENVI AX1	1.0000	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	1.0000	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	1.0000	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	1.0000
pH	.2676	-.1871	.2296	.0715	.2676	-.1871	.2296	.0715
Cond	.8273	.2712	.2482	.0780	.8273	.2712	.2482	.0780
TotP	.4738	.4491	-.4032	.1633	.4738	.4491	-.4032	.1633
Ca	.3834	.3376	-.0486	-.2615	.3834	.3376	-.0486	-.2615
Fe	-.5089	.1261	-.2920	.0691	-.5089	.1261	-.2920	.0691
K	-.3825	.4526	.2178	.1527	-.3825	.4526	.2178	.1527
Si	.2536	.6632	-.3472	.1271	.2536	.6632	-.3472	.1271
Sed-pH	.8336	-.0529	-.0335	.3992	.8336	-.0529	-.0335	.3992
Sed-Cond	.8904	-.0648	.2815	.0579	.8904	-.0648	.2816	.0579
Sed-TKN	-.1039	-.2121	-.2578	.0856	-.1039	-.2121	-.2578	.0856
Sed-P	-.1441	.1805	.3135	.0547	-.1441	.1805	.3135	.0547
.Clay	.2162	.0812	.5175	.1332	.2162	.0812	.5176	.1332
.Sand	-.4335	-.7825	.0931	-.1110	-.4335	-.7825	.0931	-.1110
Depth	.2235	-.6671	-.2095	-.0060	.2235	-.6671	-.2095	-.0060
GW-Charg	.5384	-.3453	.0456	.3771	.5384	-.3453	.0456	.3771
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

pH	1.0000							
Cond	.2390	1.0000						
TotP	.1690	.3536	1.0000					
Ca	-.1429	.4781	.1690	1.0000				
Fe	-.0710	-.5941	.1400	-.3550	1.0000			
K	-.0286	-.1195	.1690	.2000	.2130	1.0000		
Si	.1309	.2739	.7746	.3928	.1085	.1309	1.0000	
Sed-pH	.2870	.6860	.4851	.2050	-.3057	-.2050	.1879	1.0000
Sed-Cond	.4099	.7348	.3464	.4099	-.5336	-.2928	.2683	.7562
Sed-TKN	-.6625	-.2132	-.3015	.3568	-.1267	-.0510	-.2335	.0731
Sed-P	.0976	.0000	.1925	-.2928	.5659	.0976	.1491	-.1400
.Clay	.1429	.2390	-.1690	-.3143	-.4971	-.2000	-.1309	.0410
.Sand	-.1429	-.5976	-.5071	-.3714	.2130	-.1429	-.6547	-.2870
Depth	-.1195	-.1250	.0000	.1195	-.2970	-.1195	-.2739	.1715
GW-Charg	.2928	.4082	.1925	-.0976	-.5659	-.4880	.1491	.4201

	pH	Cond	TotP	Ca	Fe	K	Si	Sed-pH
Sed-Cond	1.0000							
Sed-TKN	-.1044	1.0000						
Sed-P	-.0667	-.5222	1.0000					
.Clay	.2928	-.3568	-.0976	1.0000				
.Sand	-.2928	.3568	.0976	-.3143	1.0000			
Depth	.2449	.4264	-.4082	-.1195	.4781	1.0000		
GW-Charg	.6000	-.1741	-.1111	.4880	-.0976	.4082	1.0000	
	Sed-Cond	Sed-TKN	Sed-P	.Clay	.Sand	Depth	GW-Charg	

Ovando sites only

**** Correlation matrix ****

SPEC AX1	1.0000							
SPEC AX2	.0000	1.0000						
SPEC AX3	.0000	.0000	1.0000					
SPEC AX4	.0000	.0000	.0000	1.0000				
ENVI AX1	1.0000	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	1.0000	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	1.0000	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	1.0000
pH	-.1892	-.0123	.7219	-.3548	-.1892	-.0123	.7219	-.3548
Cond	-.2936	.8055	-.0561	-.0270	-.2936	.8055	-.0561	-.0271
Ca	-.2843	.3853	-.2533	.4757	-.2843	.3853	-.2533	.4757
K	.4957	.3599	.4567	.3623	.4957	.3599	.4567	.3623
Si	.5755	.1044	.0250	.3581	.5755	.1044	.0250	.3582
Sed-pH	.1490	.4358	.4331	.0613	.1490	.4358	.4331	.0613
Sed-Cond	.1281	.8099	.1078	-.1198	.1281	.8099	.1078	-.1198
Sed-TKN	.3745	.2753	-.1559	-.5324	.3745	.2753	-.1559	-.5324
Sed-P	.3287	.5755	-.1345	.3543	.3287	.5755	-.1345	.3543
.Sand	.1564	.3757	.3660	.4116	.1564	.3757	.3660	.4116
Depth	-.1927	-.4845	.3438	.2057	-.1927	-.4845	.3438	.2057
GW-Charg	-.4390	.4888	-.2426	-.3243	-.4390	.4888	-.2426	-.3243
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

	pH	Cond	Ca	K	Si	Sed-pH	Sed-Cond	Sed-TKN
pH	1.0000							
Cond	.0000	1.0000						
Ca	-.2582	.5976	1.0000					
K	.2255	.2784	.2911	1.0000				
Si	-.2108	-.1464	.2449	.5705	1.0000			
Sed-pH	.5222	.3223	.1348	.7458	.3303	1.0000		
Sed-Cond	.2582	.4781	.2000	.4076	.2449	.6742	1.0000	
Sed-TKN	-.1111	.3086	-.2582	.0752	-.2108	.1741	.2582	1.0000
Sed-P	-.2425	.2245	.1879	.3828	.1534	.3800	.5636	.2425
.Sand	.1925	.0000	.0000	.3906	.0000	.3015	.4472	-.1925
Depth	-.0808	-.4491	-.1879	-.1641	.1534	-.3800	-.5636	-.5659
GW-Charg	.2928	.6325	.3780	-.0220	-.1852	.3568	.5292	.0976

	Sed-P	.Sand	Depth	GW-Charg
Sed-P	1.0000			
.Sand	.7001	1.0000		
Depth	-.5294	-.1400	1.0000	
GW-Charg	-.0710	-.1690	-.4971	1.0000

Click here for image of Figure 1

Figure 1. Principal Components Analysis (PCA) of all average water chemistry characteristics (Table 4) for all Nine Pipe and Ovando Valley wetland sites. Impaired sites are shown as black dots.

Click here for image of Figure 2

Figure 2. Principal Components Analysis (PCA) of all average water chemistry characteristics (Table 4) for all Nine Pipe wetland sites. Impaired sites are shown as black dots.

Click here for image of Figure 3

Figure 3. Principal Components Analysis (PCA) of all average water chemistry characteristics (Table 4) for all Ovando Valley wetland sites. Impaired sites are shown as black dots.

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Figure 4. Principal Components Analysis (PCA) of sediment chemistry and physical characteristics (Table 5) for all Nine Pipe and Ovando Valley wetland sites. Impaired sites are shown as black dots.

Click here for image of Figure 5

Figure 5. Principal Components Analysis (PCA) of sediment chemistry and physical characteristics (Table 5) for all Nine Pipe wetland sites. Impaired sites are shown as black dots.

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Figure 6. Principal Components Analysis (PCA) of sediment chemistry and physical characteristics (Table 5) for all Ovando Valley wetland sites. Impaired sites are shown as black dots.

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Figure 7. Redundancy Analysis (RDA) of diatom data and selected water chemistry, sediment chemistry and physical characteristics (Table 5) for all Nine Pipe and Ovando Valley wetland sites. Impaired sites are shown as black dots.

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Figure 8. Redundancy Analysis (RDA) of diatom data and selected water chemistry, sediment chemistry and physical characteristics (Table 5) for all Nine Pipe wetland sites. Impaired sites are shown as black dots.

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Figure 9. Diatom taxa plot from Redundancy Analysis (RDA) of diatom data and selected water chemistry, sediment chemistry and physical characteristics (Table 5) for all Nine Pipe wetland sites. Impaired sites are shown as black dots.

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Figure 10. Redundancy Analysis (RDA) of diatom data and selected water chemistry, sediment chemistry and physical characteristics (Table 5) for all Ovando Valley wetland sites. Impaired sites are shown as black dots.

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Figure 11. Diatom taxa plot from Redundancy Analysis (RDA) of diatom data and selected water chemistry, sediment chemistry and physical characteristics (Table 5) for all Ovando Valley wetland sites. Impaired sites are shown as black dots.