Report on the macroinvertebrate community in the Deschutes River before and after surface water withdrawal at the Round Butte Dam

Prepared for: Deschutes River Alliance

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SUMMARY

This study addresses the findings of the Lower Deschutes River Macroinvertebrate and Periphyton Study released in 2016 by R2 Resource Consultants, Inc. (Nightengale et al. 2016) for Portland General Electric (hereafter called the PGE report). The purpose of the PGE study was to evaluate the effect of surface water withdrawal operations at the Round Butte Dam complex (from here forward referred to as the Dams) on the stream macroinvertebrate community above the Dams (above Lake Billy Chinook) and below the Dams (the lower Deschutes River). The authors of the PGE report found no major difference in the macroinvertebrate community either above or below the Dams after surface water withdrawal operations began. The methodology employed in the PGE study for evaluating the macroinvertebrate data was based on a comparison of several common invertebrate community metrics such as percent mayflies, stoneflies, caddisflies, functional feeding groups, and abundance of specific taxa, but did not use ordinations to examine the macroinvertebrate community as a whole in the lower Deschutes before and after surface water withdrawal operations were implemented.

In this study, I used a widely-accepted statistical technique for evaluating macroinvertebrate assemblage to examine the macroinvertebrate community before and after surface water withdrawal operations were implemented. The results of my analysis indicate that the macroinvertebrate community below the Dams changed significantly after surface water withdrawal was implemented (samples collected 2013-2015) when compared to the macroinvertebrate community before surface water withdrawal operations began (samples collected 1999-2001). The macroinvertebrate community present after surface water withdrawal contained more non-insect taxa, such as worms and snails, and other taxa that are tolerant to poor stream conditions and less mayfly, stonefly and caddisfly taxa that are sensitive to poor stream conditions.

INTRODUCTION

Background information

In 2016, the Lower Deschutes River Macroinvertebrate and Periphyton Study Report was released by R2 Resource Consultants, Inc. (Nightengale et al. 2016) for Portland General Electric. One of the main objectives of the PGE study was to "evaluate changes in abundance and taxonomic condition of benthic macroinvertebrates and periphyton downstream from the Pelton Round Butte Project following implementation of surface water withdrawal (SWW) operations" (PGE Report, pg. 20). To this end, benthic macroinvertebrates were collected in 2013 through 2015 and compared to samples collected in 1999 through 2001 before SWW operation began. Data analysis in the PGE study focused on traditional macroinvertebrate taxonomic measures (i.e. density, richness), functional metrics (i.e. feeding guilds) as well as analysis of the macroinvertebrate assemblage data.

The data contained in a sampled assemblage consists of a list of the taxa found and their abundances. The analytical approach of the PGE study used a wide range of statistical techniques including both univariate and multivariate techniques. The findings of the PGE study "did not identify large changes in the macroinvertebrate community before and after SWW implementation but seasonal changes in community composition were apparent" (PGE Report, pg 3).

The statistical approach used in the PGE study was misapplied in two important aspects. First, the study used a technique known as Principal Components Analysis (PCA) to create ordinations. PCA-based ordinations are not an appropriate method for macroinvertebrate assemblage data because the numerous zeros present in macroinvertebrate data cause distortion on ordination space (Beal 1984, McCune and Grace 2002). Second, the PGE study did not use ordinations to evaluate the macroinvertebrate assemblage prior to the change in SWW operation. In the PGE study, ordinations were used only to evaluate the post-SWW macroinvertebrate assemblage and did not include any of the pre-SWW assemblage data. This is important because without this analysis of the macroinvertebrate assemblage before the change in SWW operation, it is not possible to determine if the post-SWW macroinvertebrate assemblage is statistically different than the pre-SWW macroinvertebrate assemblage.

Study overview

The objectives of this investigation were to: 1) characterize the macroinvertebrate assemblage before and after SWW operations; 2) determine if the post-SWW macroinvertebrate assemblage was statistically different from the pre-SWW macroinvertebrate assemblage; and 3) use two metrics to examine the change in pollution tolerance of the macroinvertebrate community before and after SWW operations. The analytical approach of this study is based on well-known techniques commonly used in the analysis of stream macroinvertebrate data. Data for this analysis were obtained directly from the tables included in the PGE report.

METHODS

Methodological overview

In this study, a statistical technique called ordinations was used to display and explore macroinvertebrate assemblage data. Ordinations of invertebrate assemblage allow for the visualization of macroinvertebrate community as a "map" where each sample of assemblage data is displayed as a single point. In the ordination, points that are close together indicate macroinvertebrate communities that are similar to each other, whereas points that are far apart on the ordination represent macroinvertebrate communities that are relatively different. Using ordinations, I conducted an exploratory analysis using a visual-display technique called bubble plots to compare the general characteristics of the macroinvertebrate community before and after commencement of SWW operations. Bubble plots are symbols on the ordination that illustrate the size of a particular characteristic of the macroinvertebrate community, for example the percentage of predators in a sample. This was accompanied by a statistical test to determine if the downstream assemblage (below the Dams) after the SWW operation was significantly different from the pre-SWW assemblage (above the Dams). And finally, I used a paired t-test to statistically evaluate the change in two pollution tolerance metrics before and after SWW operations.

Data organization

Macroinvertebrate data were extracted from the PGE report using Acrobat DC. Data were organized in Excel and checked against the tables in the PGE report (Nightengale et al. 2016). To account for differences of taxonomy and lab processing in the pre and post-SWW data, a conservative approach to taxonomic harmonization was used. This was achieved by rolling up taxon to the coarsest taxonomic level (i.e. Oligochaeta) utilized in each data set and dropping taxa not typically used in bioassessments (e.g. *Manayunkia speciose*, *Urnatella gracilis* and Meiofauna such as Ostracoda). Both *Manayunkia* and *Urnatella* are difficult to accurately count in a typical stream benthic sample. Meiofauna are too small for a typical aquatic collecting-net and are found in bioassessment samples mainly as a by-catch. Taxonomically redundant family-level taxa were also removed if they were not present in both pre and post SWW samples. Appendix 1 lists the taxa used in this analysis. Macroinvertebrate count data were converted to relative abundance and square root transformed to minimize the influence of highly abundant taxa (Heino 2008).

Data for this analysis consisted of samples from 3 sites above the Dams and 8 sites below the Dams. Each site was sampled four times; twice before SWW operations and twice after SWW operations. Samples were collected each spring and fall in 1999 through 2001 (pre-SWW) and again in 2013 through 2015 (post-SWW) thus generating paired samples for each season before and after SWW operations (Figure 1). Only data from sites sampled both before and after SWW operations (sites: 1, 1S, 3, 5S, 7S, 9, 10, 12 ME, CR, DE) were used in this analysis. Macroinvertebrate samples were not collected in 2001 at Site 12, so only the data at Site 12 from 1999-2000 and 2013-2015 were included in this analysis. See PGE report for site location information and descriptions.

Exploratory analysis

Exploratory analysis of macroinvertebrate assemblages was conducted by examining ordinations of the relative abundance of taxa collected in each sample for all sites above and below the Dams and before and after SWW operations. Using ordinations to characterize the macroinvertebrate assemblages is the standard analytical approach for the type of data collected for the PGE report (Beals 1984, Legendre and Legendre 1998). Ordinations were plotted for all samples for each season (spring and fall) and for each sample habitat type (deep and shallow). Ordinations of macroinvertebrate relative abundance were generated using Non-Metric Multidimensional Scaling (NMDS) based on Bray-Curtis dissimilarities. NMDS is a technique that examines the overall similarity of a biologic assemblage among samples in an ordination. NMDS is often used with macroinvertebrate data because it tries to preserve the inter-site dissimilarities and thus better represents species dissimilarities (Legendre and Legendre 1998, McCune and Grace 2002).

Bubble plots were used to visually display different characteristics of the macroinvertebrate community in the ordinations. Bubble plots of the percentage of each major order, each feeding group and the general pollution tolerance were plotted in the ordinations. The size of the circle (i.e. bubble) in the plots is scaled to show the percent of the characteristic displayed in the ordination. The absence of a bubble indicates a zero value for that particular characteristic.

To determine if the macroinvertebrate assemblage composition shifted towards more pollution tolerant taxa, two pollution-tolerance metrics were evaluated (Waite et al 2010). The metrics, called percent EPT richness (EPTr) and richness tolerance (RICHTOL), have been used in an ecological setting similar to the

Deschutes system (Blue Mountains of eastern Oregon). EPTr is the percentage of the total macroinvertebrate richness (i.e. number of species) that is mayflies (E), stoneflies (P) and caddisflies (T). RICHTOL is the mean pollution tolerance value for each sample based on the taxa present. Tolerance values (Appendix 2) were assigned using the values found in Whittier and Van Sickle (2010).

Statistical Analysis (See "Definitions" at end of report for more explanation of statistical terms)

Statistical analysis was conducted for the assemblage groups displayed on the ordinations and the pollution metrics (EPTr and RICHTOL). Assemblages were statistically evaluated using dissimilarity matrices with each site considered to be an independent sample. Dissimilarity matrices were statistically evaluated using a permutation-based technique to sample groupings using the mean dissimilarities matrices for each site and tested grouping (PERMANOVA as implemented in the ADONIS package of the R statistical language, Anderson 2001). ADONIS was used to test Bray-Curtis dissimilarities between and within sites to determine if the assemblage was significantly different between downstream sample groups defined by habitat, season, and before and after SWW operations. ADONIS was used because it could accommodate the repeated sampling of the same sites when testing for between-group differences.

The mean assemblage dissimilarity matrices for each downstream site in post-SWW data were compared using ADONIS and treating the sites as blocks. Due to low sample size and the high variability in dissimilarity, the three upstream sites were not included in the ADONIS analysis. For the downstream sites, the same strategy was used for other grouping tests (season and habitat) in which the same sites were sampled in both groups. The ADONIS function can only evaluate one sample per site, so a mean dissimilarity matrix was calculated for the seasonal replicates: A (pre and post) and B (pre and post) for the downstream samples (Figure 1). Replicate A included samples from the first year of pre-sww sampling and from the first post-sww sampling year, while replicate B included samples from the second pre and post years of sampling. This gave similar elapsed times (13 and 14 years) between the pre and post years included in each replicate. For the statistical analysis of EPTr and RICHTOL, the mean value of the paired samples (two spring and two fall) was used to compare pre and post samples for each, except for site 12, which had only one spring and one fall sample collected in the pre SWW study. Due to the one to five-mile distance between the downstream sites, macroinvertebrate samples were considered independent. True sample independence and replication is difficult to achieve in ecological investigations (Hurlbert 1984), particularly in tributary systems with large dams. However, other studies involving upstream/downstream studies of dams have also assumed independence of the downstream macroinvertebrate samples (e.g. Tiemann et al 2004). It is my professional opinion that samples here are sufficiently independent for this analysis.

The difference in EPTr and RICHTOL between the pre and post-SWW samples was statistically analyzed for each season using a conservative two-tailed paired t-test. For each yearly replicate above and below the Dams, the mean EPTr and RICHTOL value was used to compare samples from the pre-SWW (n=7) and post-SWW (n=8) sites. To reduce the possibility that the results I obtained were due to chance, I applied a correcting factor to the data for each season so that the value for statistical significance (α = 0.05) was divided by two (corrected α = 0.025). This kind of correction is called a Bonferroni correction and is standard practice in these kinds of analysis (e.g. Tiemann et al 2004).

RESULTS

Exploratory Analysis

Exploratory analysis was conducted using macroinvertebrate data for all paired sites above and below the Dams. Samples included 125 taxa from a wide range of invertebrate groups including insect and non-insect taxa. Two-dimensional ordinations (stress ranged = 10-16) of the macroinvertebrate assemblage based on relative abundance were produced for: 1) all sites above and below the Dams (Figures 2A-D), 2) the paired downstream sites (Figures 3A-D and Figures 4C-D), and 3) the upstream sites (Figures 4A-B). Ordinations showed the macroinvertebrate assemblage at the upstream and downstream sites generally varied along NMDS axis 1 for both the fall and spring samples (Figures 2A-D). Downstream assemblages varied seasonally along NMDS axis 2 (Figures 3A-B) but there were no apparent patterns in the ordinations categorized by habitat (Figures 3C-D). This finding indicates that the analysis should be conducted separately for each season but can be combined for both deep and shallow habitat types. In the downstream sites, the macroinvertebrate assemblage between pre and post-SWW samples varied along NMDS axis 2 in the Fall and NMDS axis 1 in the spring (Figures 4C-D). In the upstream sites, there was no strong pattern observed between pre and post-SWW samples (Figures 4A-B).

Bubble plots and boxplots for the sites below the Dams showed that the proportion of the major orders appeared to be different in the post-SWW samples. In both the spring and fall samples, the proportion of stoneflies appeared to decrease (Figures 5C-D and 8B) in the post-SWW samples. In the spring post-SWW samples, dipterans (Figures 6C-D and 8D) appeared to decrease while non-insects (Figures 7A-B and 8E) appeared to increase. Bubble plots and boxplots of feeding group showed that shredders appeared to decrease in both the spring and fall post-SWW samples (Figures 9C-D and 12B), scrapers increased in the spring post-SWW samples (Figures 9A-B, 12A) and collector-gatherers appeared to decrease in the fall post-SWW samples (Figures 10A-B, 12C).

Appendix 3A-D show boxplots of the mean transformed relative abundance for mayfly, stonefly, caddisfly and non-insect taxa present in at least 10 downstream samples before or after SWW operations. Appendix 4A-D lists the untransformed mean relative abundance of the same taxa.

Statistical analysis

The ADONIS results (Table 1) revealed statistically distinct assemblages between spring and fall samples in both pre SWW ($p = 0.02$) and post SWW ($p = 0.01$) downstream samples, but no difference between deep and shallow habitat. The difference between the pre and post-SWW assemblages in both spring and fall seasons (Figures 4C-D, $p = 0.01$) at sites below the Dams was statistically significant. It should be noted that the p-values calculated for the ordinations using ADONIS are vulnerable to variance in the dissimilarities matrices and sample size. Ordinations with tightly clustered samples and low sample size may be statistically unstable (i.e. Figure 2B). However, in the ordinations of the samples below the Dams (Figures 3C-D), the variance in the ordinations and the sample size is similar, so the p-value is a more accurate representation of the statistical characteristics of the ordinations.

The composition of the macroinvertebrate assemblage shifted towards more pollution tolerant taxa below the Dams in all the post-SWW samples (Table 2). The mean EPTr value decreased in the post-SWW samples in both fall (0.49 pre to 0.45 post, Figures 13A-B) and spring seasons (0.62 pre to 0.47

post, Figures 13C-D), but the decrease was only statistically significant in the spring (Table 2). RICHTOL showed significant increases in post-SWW samples for both fall (4.0 pre and 4.3 post, Figures 13A-B) and spring (3.6 pre and 4.2 post, Figures 14C-D) (Table 2). In the samples above the Dams, the general pollution tolerance did not significantly change, though the small sample size and high variance of the data at the upstream sites reduces the statistical power to detect a change.

Grouping Variable	Sample size	Season	Pre/Post	*p* value
Pre/Post	N = 8/8	Fall	NA	$p = 0.01$
Pre/Post	N = 8/8	Spring	NA	$p = 0.01$
Fall/Spring	N = 8/8	NA	Pre	$p = 0.02$
Fall/Spring	N = 8/8	NA	Post	$p = 0.01$
Deep/Shallow	N = 5/3	Fall	Pre	$p = 0.75$
Deep/Shallow	N = 5/3	Spring	Post	$p = 0.62$
Deep/Shallow	N = 5/3	Fall	Pre	$p = 0.56$
Deep/Shallow	N = 5/3	Spring	Post	$p = 0.74$

Table 1: Results of ADONIS analysis comparing mean dissimilarity matrices for samples below the Dams. Grouping variable for each ADONIS test is shown.

Location	Metric	Season	Expected direction of change	N	Pre SWW mean	Post SWW mean	*p* value
Above	EPTr	Fall	No Change	3	0.50	0.46	$p = 0.38$
Above	EPTr	Spring	No Change	3	0.64	0.53	$p = 0.03$
Above	RICHTOL	Fall	No Change	3	3.5	3.6	$p = 0.61$
Above	RICHTOL	Spring	No Change	3	3.1	3.4	$p = 0.13$
Below	EPTr	Fall	Decrease	8	0.49	0.45	$p = 0.08$
Below	EPTr	Spring	Decrease	8	0.62	0.47	$p = 0.001$*
Below	RICHTOL	Fall	Increase	8	4.0	4.3	$p = 0.01$*
Below	RICHTOL	Spring	Increase	8	3.6	4.2	$p = 0.001$*

Table 2: Summary results for the paired t-tests of the pollution metrics before and after SWW operations above and below the Dams for each season. EPTr is the proportion of the total macroinvertebrate richness that is mayfly, stonefly and caddisfly. RICHTOL is the mean pollution tolerance value for each sample based on the richness only. The direction of change is the outcome that would be expected if the SWW operations were having a polluting effect on below-Dam sites and thus shifting the composition of the macroinvertebrate community to pollution-tolerant species. *Significant *p*-value reflecting Bonferroni-corrected alpha value (0.025).

DISCUSSION

Statistical analysis using NMDS ordinations showed that the post-SWW macroinvertebrate communities below the Dams appeared to be significantly different from the pre-SWW communities in both seasons. Exploratory analysis indicated the change in the macroinvertebrate communities was due to a shift towards more non-insect taxa, more pollution tolerant macroinvertebrates and less EPT taxa. Analysis of the EPTr and RICHTOL metrics showed the post-SWW community has significantly fewer mayflies, stoneflies and caddisflies taxa in the spring samples and significantly more tolerant macroinvertebrate taxa in the both the fall and spring samples.

It is not possible to determine the specific environmental factors that changed the macroinvertebrate assemblages below the Dams after SWW operations without analyzing associated environmental data; for example, basic water chemistry information, habitat conditions and flow data. However, the observed changes in the EPTr and the RICHTOL scores are known to be associated with declining stream condition in streams of eastern Oregon (Waite 2010) and the results of the ADONIS tests provide strong evidence that the change in macroinvertebrate community was likely due to the start of SWW operations.

The purpose of this analysis was to use ordinations to explore and compare the macroinvertebrate communities before and after surface water withdrawal operations above and below the Dams on the Deschutes River. The results of this analysis indicate the post-SWW macroinvertebrate assemblage below the Dams is different than the pre-SWW macroinvertebrate assemblage. The lack of a corresponding change in the macroinvertebrate community (EPTr and RICHTOL) above the Dams indicate the observed change in macroinvertebrate communities downstream is likely not due to factors such as differences in field sampling, lab processing or taxonomic issues. The lack of apparent change in the upstream sites provides evidence that the downstream sites were not altered by factors (environmental or sampling and lab procedures) other than the SWW operations. If such factors had altered the downstream sites, then the upstream sites would have changed as well.

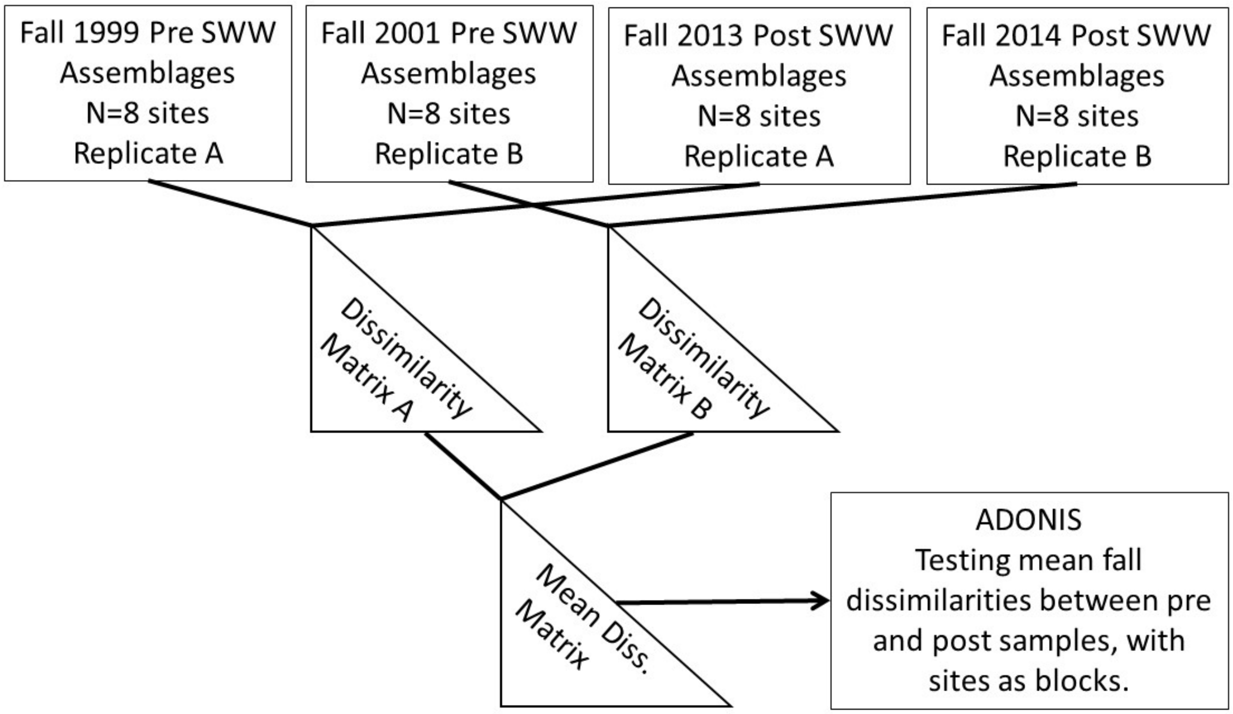


Figure 1: Schematic illustrating the ADONIS statistical evaluation of Fall assemblage downstream of the Dams. Dissimilarity matrices for replicates A and B were averaged to yield a single dissimilarity matrix that compared Pre and Post samples for the 8 sites. The sites were then treated as a blocking factor in the ADONIS analysis, while testing for Pre/Post differences as the main effect. This approach was used for other statistical comparisons of assemblage.

Seasonal ordinations of all sites above and below the Round Butte Dam Complex

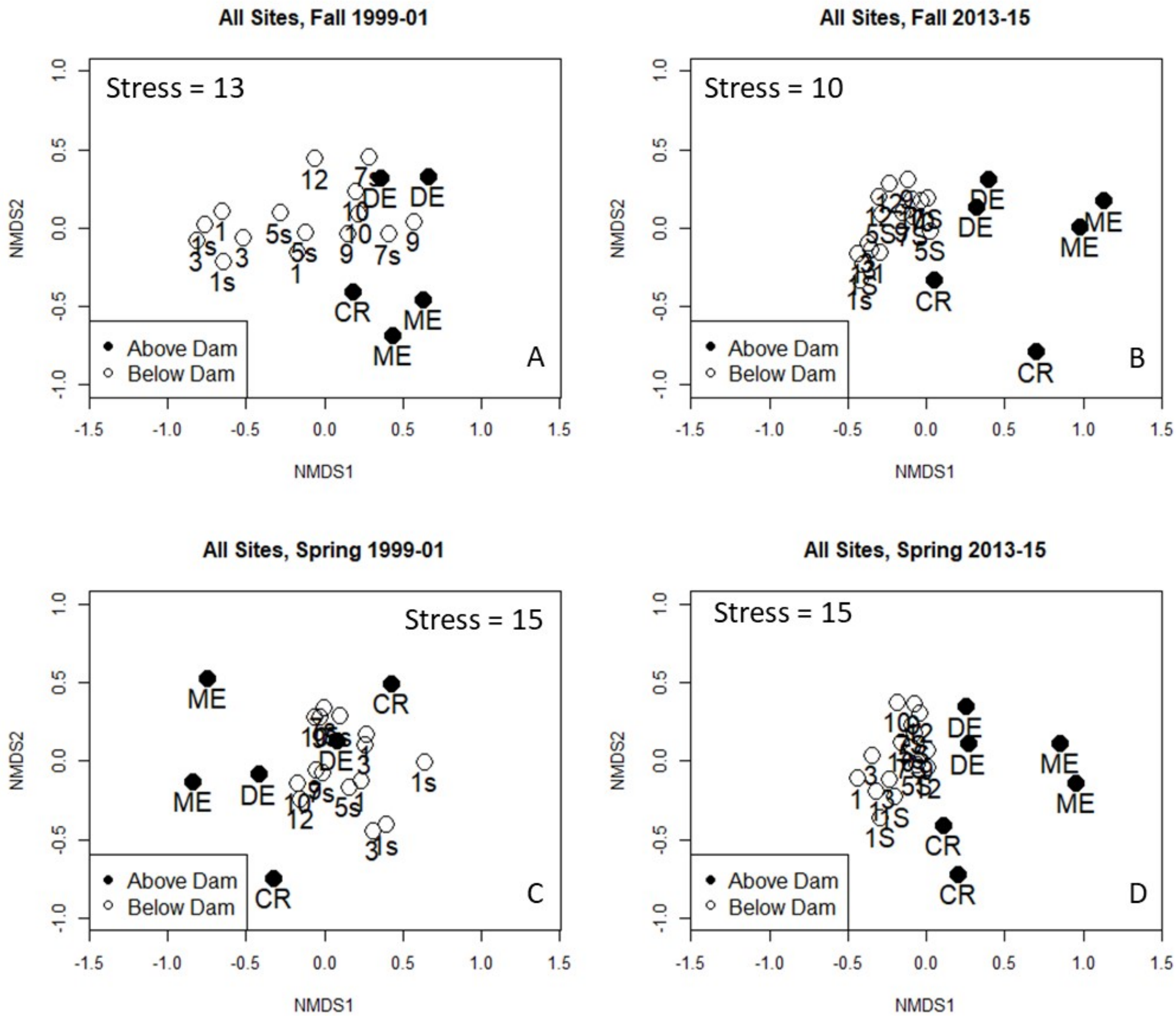


Figure 2: NMDS ordinations of fall and spring macroinvertebrate assemblage for all sites before (pre, 1990-91) and after (post, 2013-15) surface water withdrawal (SWW). Ordination plots show sites above the Dams (above Lake Billy Chinook) and below the Dams (lower Deschutes River) in each panel.

Ordinations of paired sites below the Dams before and after SWW, by season and by habitat

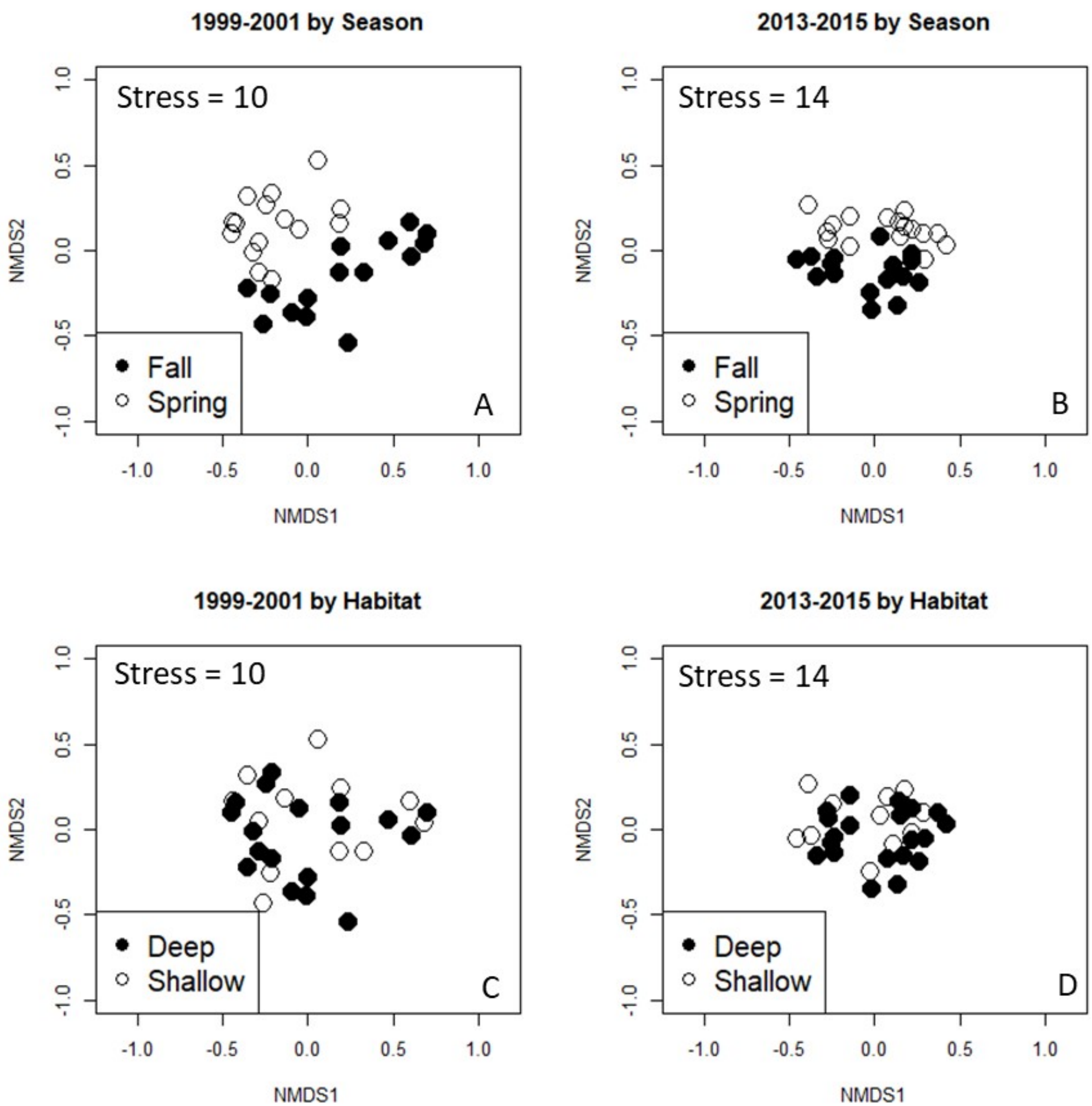


Figure 3: NMDS ordinations of macroinvertebrate assemblage for all sites below the Dams before (pre 1990-91) and after (post 2013-15) surface water withdrawal (SWW). Panels show season (A, B) and habitat (C, D).

Ordinations of sites above and below the Dams before and after surface water withdrawal.

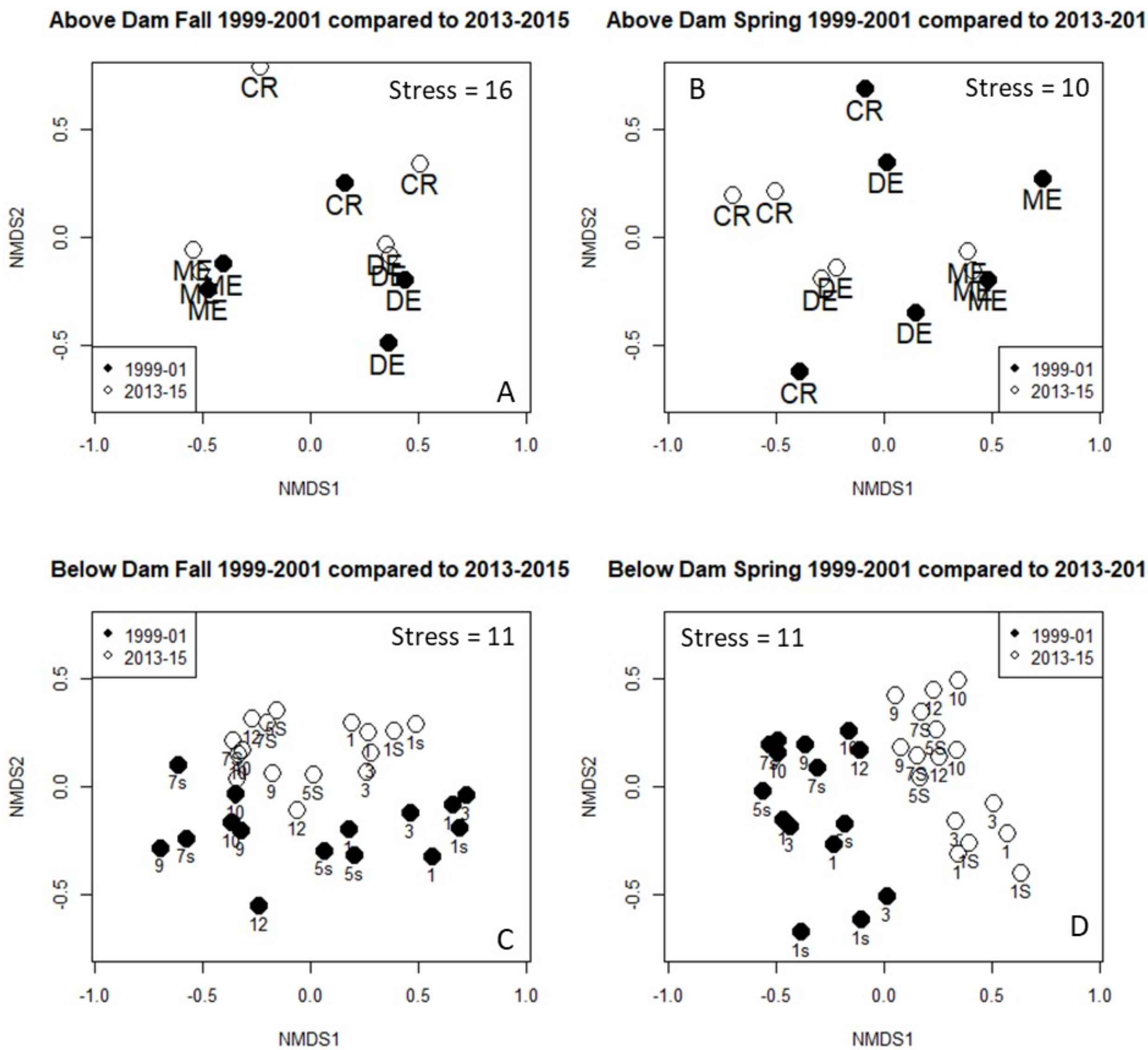


Figure 4: NMDS ordinations of macroinvertebrate assemblage above and below the dam. Charts show before (1999-01) and after (2013-15) SWW for fall and spring samples. Ordinations Stress and ADONIS results are shown in each panel. Site codes are shown for each sample.

Ordinations and bubble plots of percent Mayflies and Stoneflies in the sites below the Dams before and after surface water withdrawal

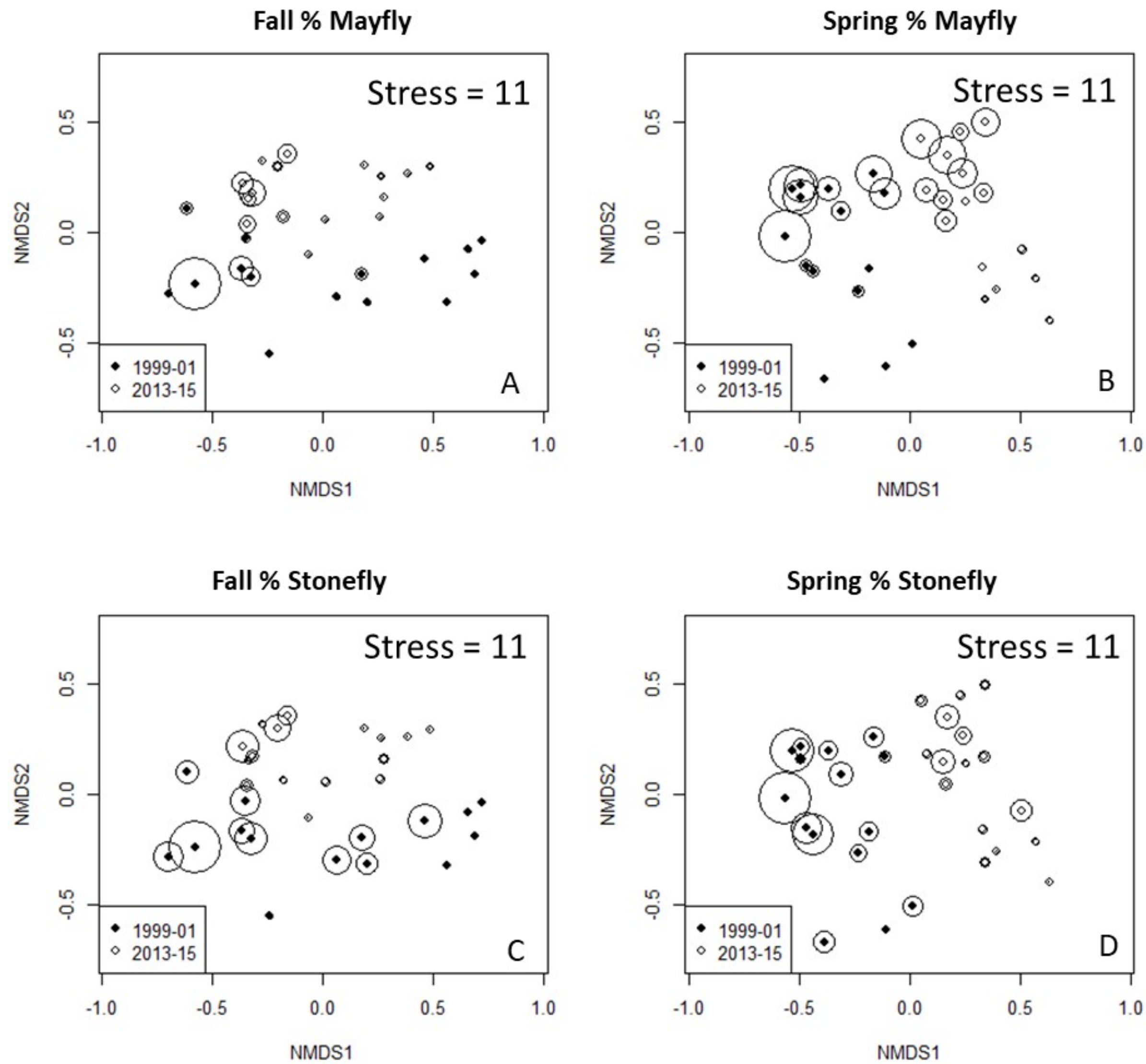


Figure 5: NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of Mayfly and Stonefly.

Ordinations and bubble plots of percent Caddisflies and Diptera in the sites below the Dams before and after surface water withdrawal

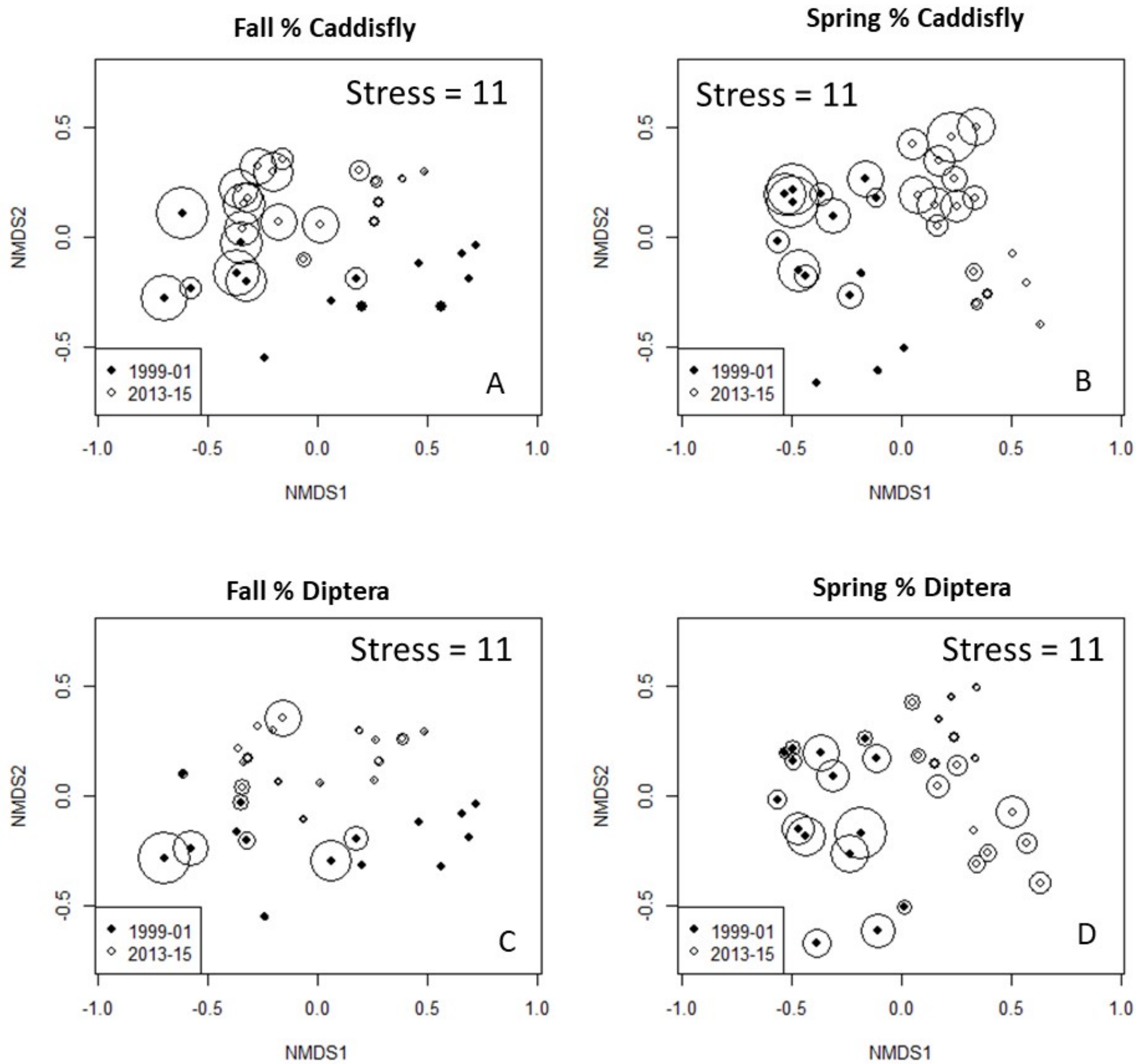


Figure 6: NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of Caddisfly and Diptera.

Ordinations and bubble plots of percent non-insect in the sites below the Dams before and after surface water withdrawal

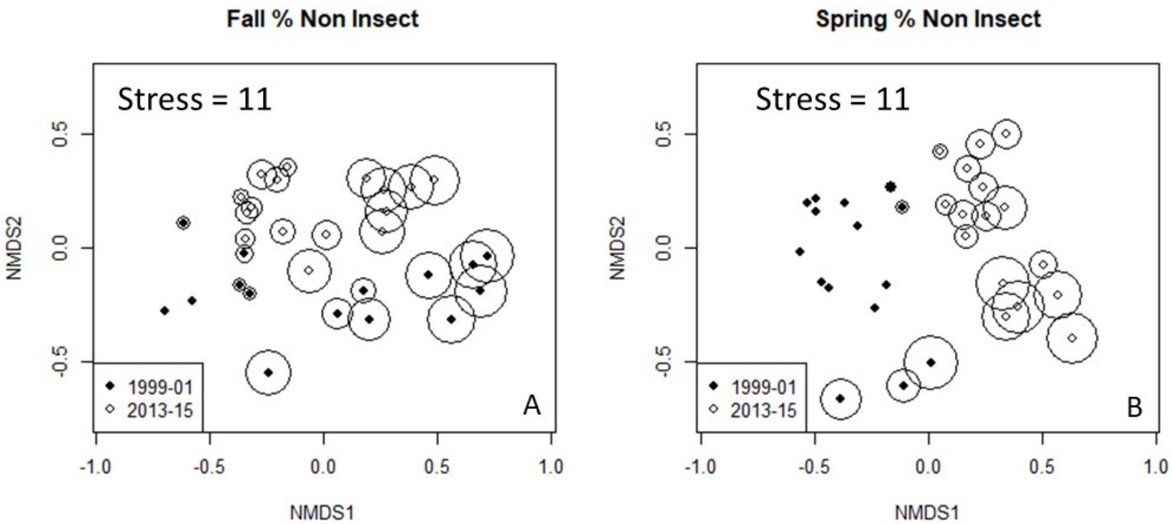
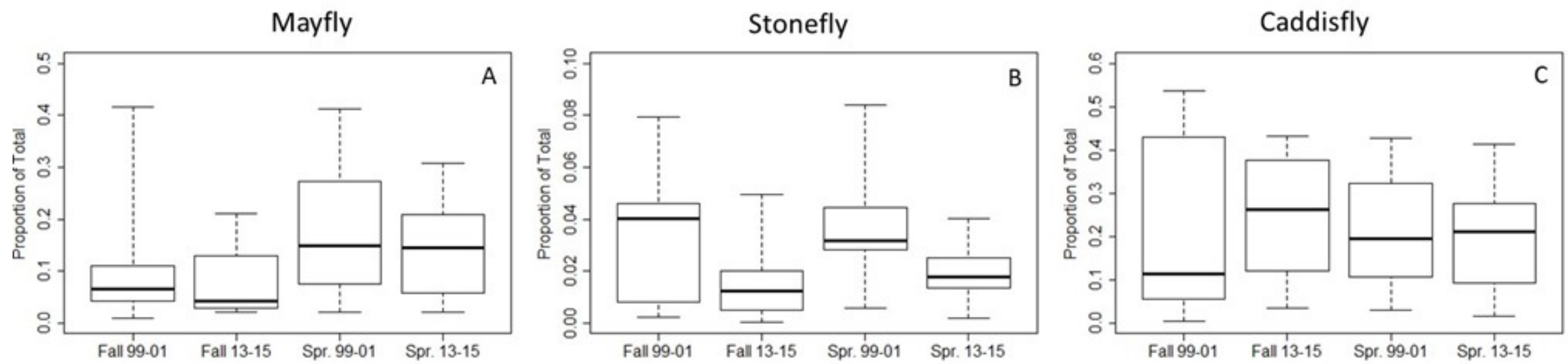


Figure 7: NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of non-Insects

Boxplots of Insect order and non-insects in the sites below the Dams before and after surface water withdrawal for each season



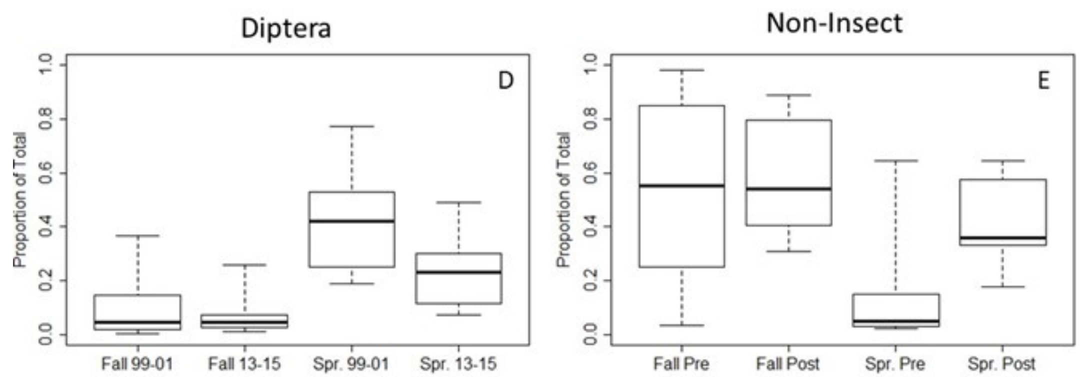


Figure 8: Boxplots showing the untransformed proportion of the abundance for each taxonomic order before (1999-01) and after (2013-15) surface water withdrawal for fall and spring (spr.) samples.

Ordinations and bubble plots of Scrapers and Shredders in the downstream sites before and after surface water withdrawal

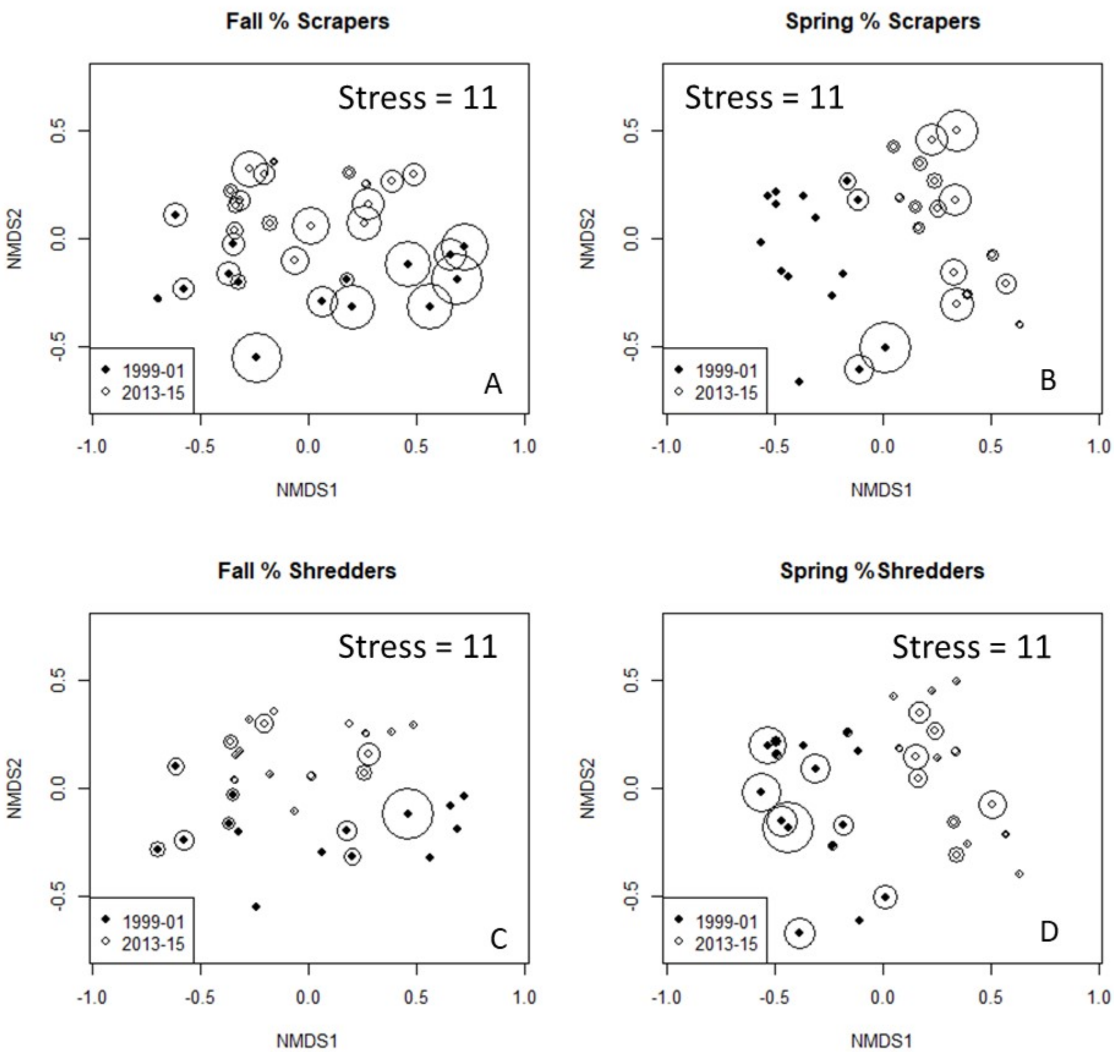


Figure 9: Results of exploratory of functional feeding group. NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of scrapers and shredders.

Ordinations and bubble plots of collector-gatherers and collector-filterers in the downstream sites before and after SWW

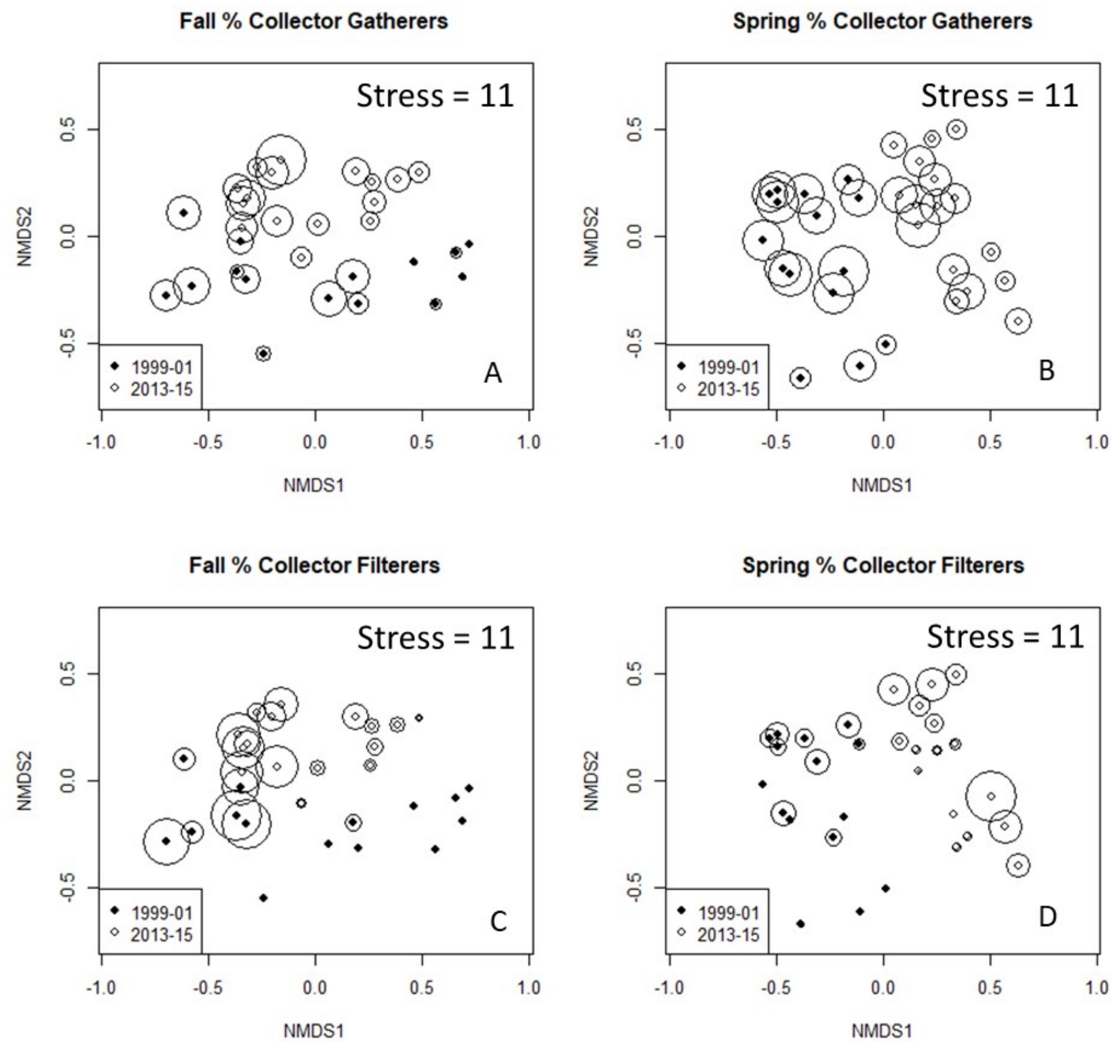


Figure 10: Results of exploratory of functional feeding group. NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of collector-gatherers and collector-filterers.

Ordinations and bubble plots of Predators in the downstream sites before and after SWW

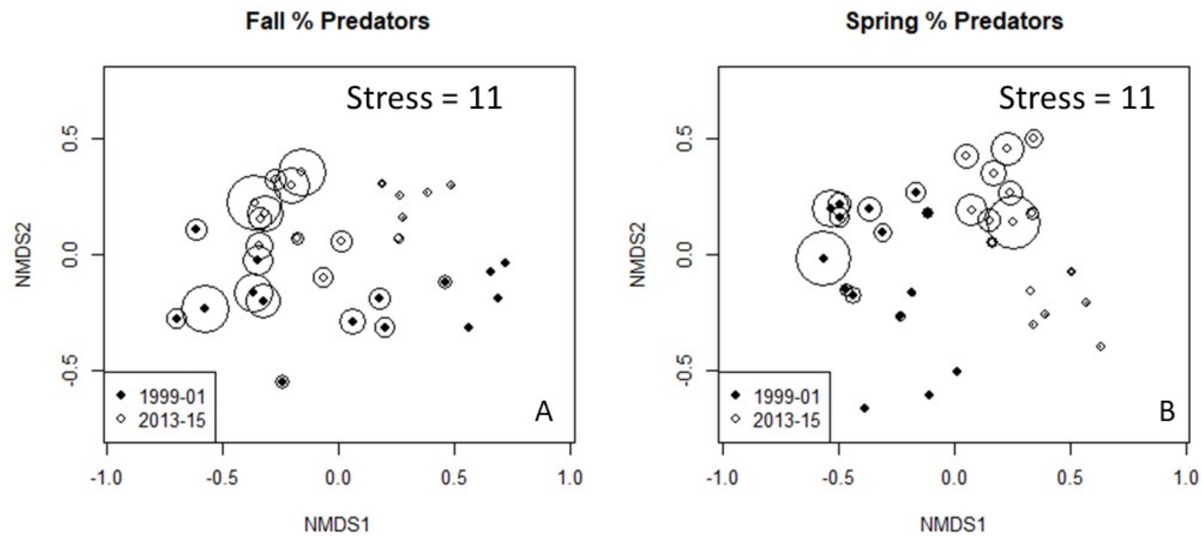


Figure 11: Results of exploratory of functional feeding group. NMDS ordinations of macroinvertebrate assemblage before (1999-01) and after (2013-15) SWW for fall and spring samples. Bubble plots show percentage of predators.

Boxplots of Insect feeding groups in the sites below the Dams before and after surface water withdrawal for each season

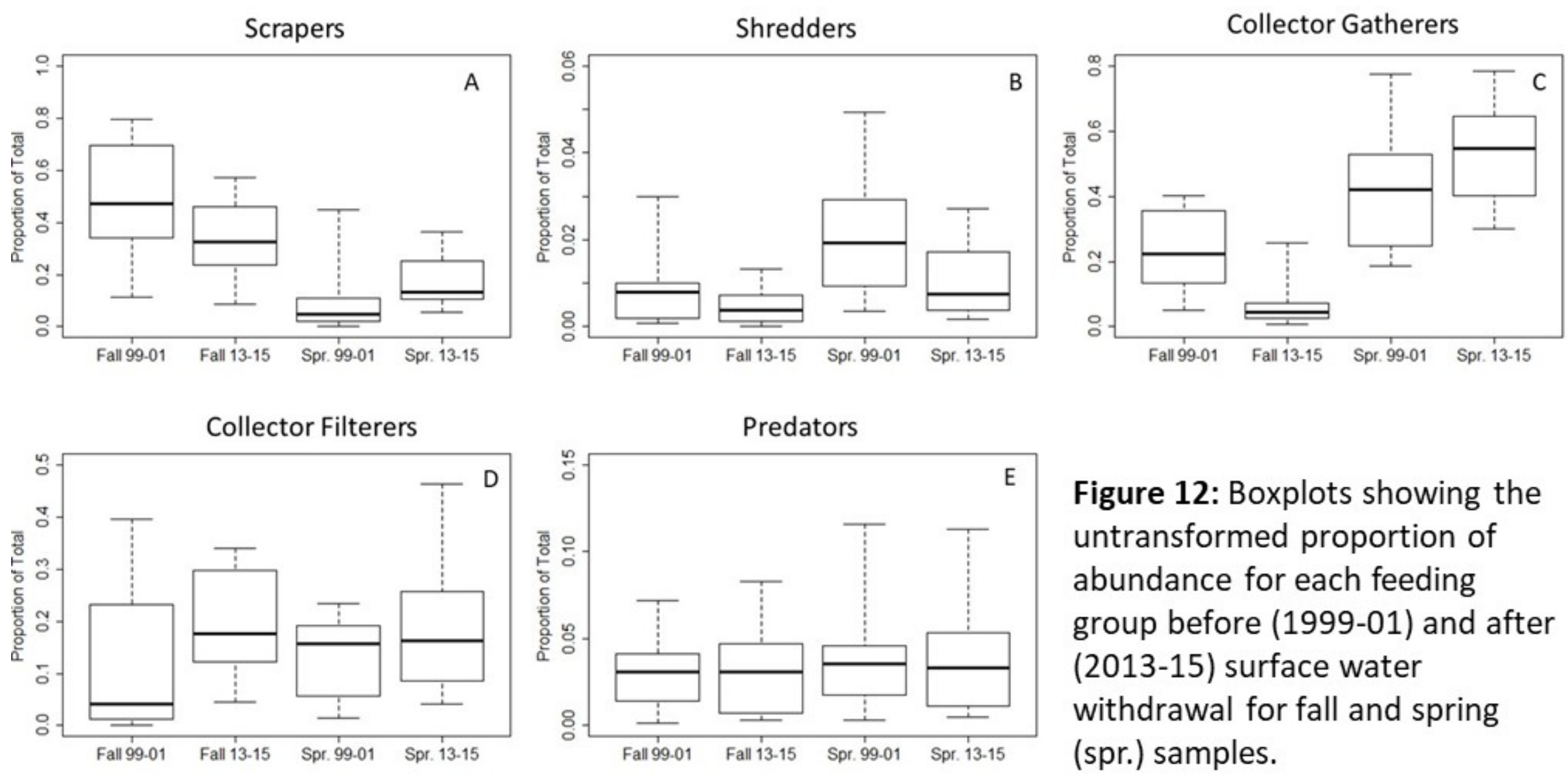


Figure 12: Boxplots showing the untransformed proportion of abundance for each feeding group before (1999-01) and after (2013-15) surface water withdrawal for fall and spring (spr.) samples.

Comparison of % EPT richness (EPTr) in the downstream sites before and after SWW for each season

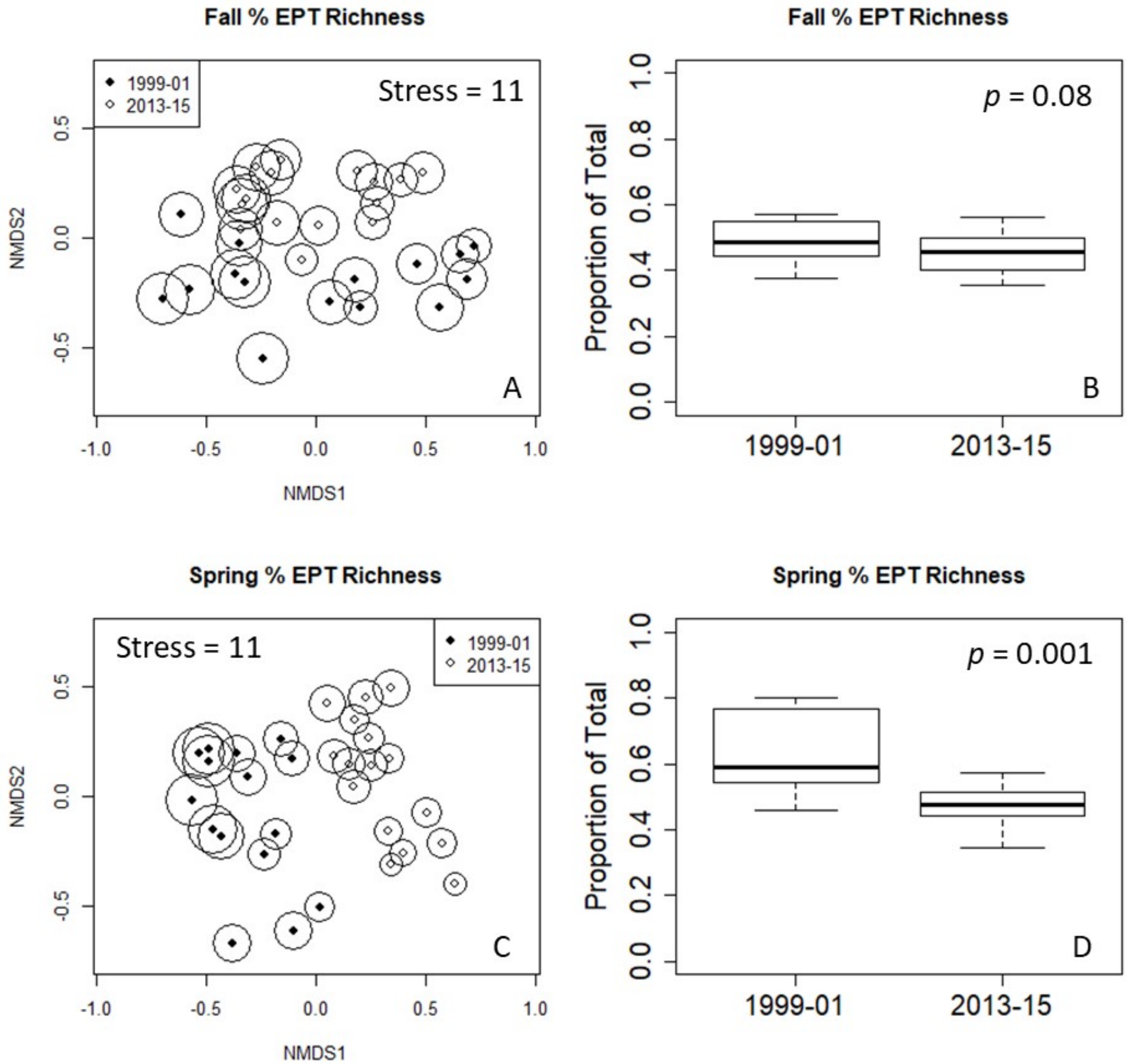


Figure 13: Results of analysis comparing % EPT richness (EPTr) before (1999-01) and after (2013-15) SWW operations. Results of t-test are shown in the boxplots. Bubble plots show mean EPTr for each sample.

Comparison of tolerance by richness (RICHTOL) in the downstream sites before and after SWW for each season

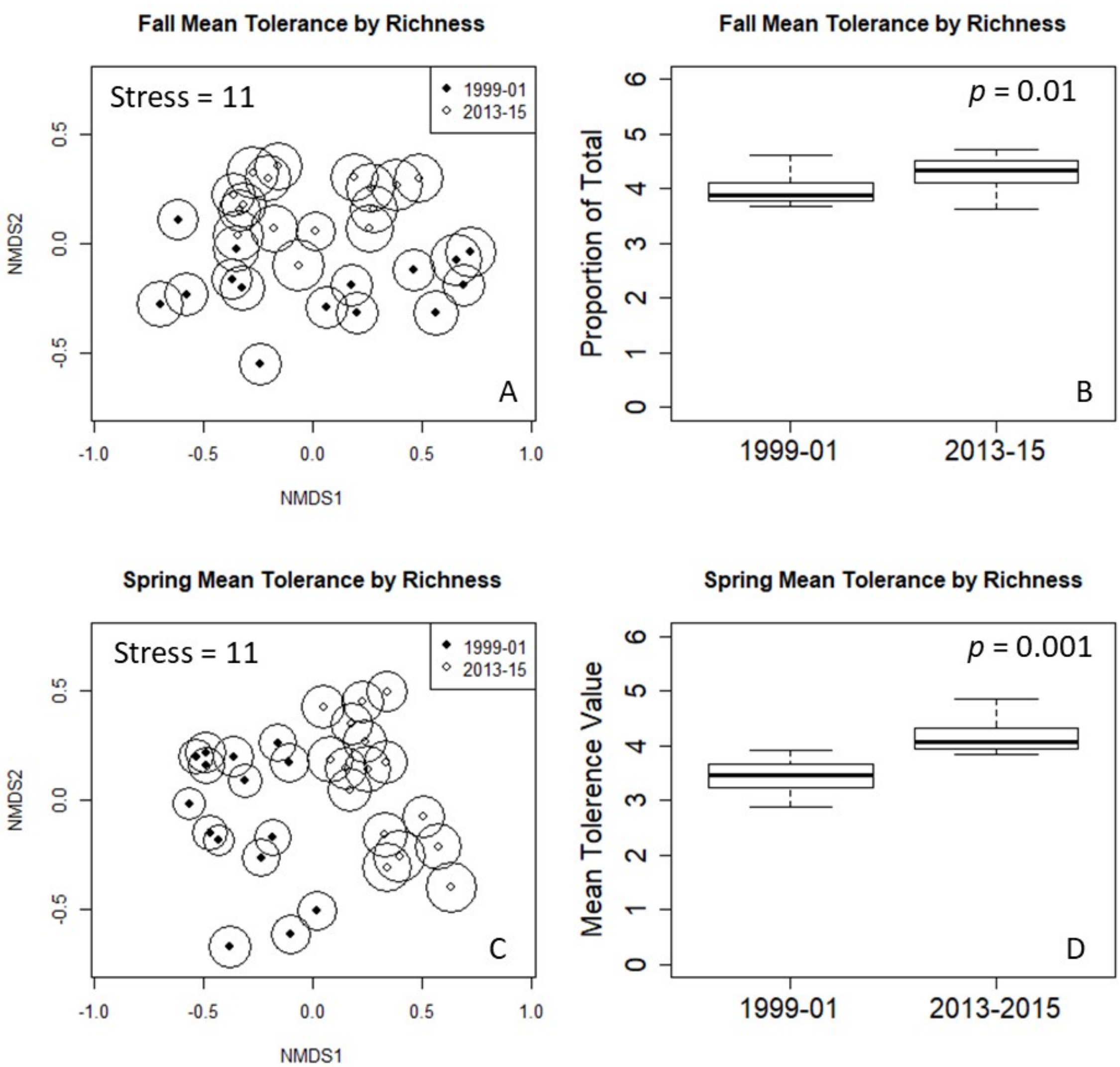


Figure 14: Results of analysis comparing mean tolerance by richness (RICHTOL) before (1999-01) and after (2013-15) SWW operations. Results of t-test are shown in the boxplots. Bubble plots show mean RICHTOL for each sample.

Acari	*Doroneuria*	*Malenka*	*Protoptila*
Acentrella	*Drunella doddsi*	*Megaleuctra*	Psephenidae
Ameletus	*drunella sp.*	*Micrasema*	*Psychomyia*
Amiocentrus	*Drunella spinifera*	*Moselia*	*Pteronarcys californica*
Ampumixis	*Eocosmoecus*	*Narpus*	*Rhithrogena*
Antocha	*Epeorus*	*Nematoda*	*Rhyacophila Alberta Gr.*
Arctopysche grandis	*Ephemerella*	*Nemertea*	*Rhyacophila Angelita Gr.*
Atherix	*Ephemerellidae*	*Neophylax*	*Rhyacophila arnaudi*
Attenella	*Ferrissia*	*Ochrotrichia*	*Rhyacophila Betteni Gr.*
Baetis bicaudatus	*Fisherola nuttalli*	Oligochaeta	*Rhyacophila Brunnea Gr.*
Baetis tricaudatus	*Fluminicola*	*Oligophlebodes*	*Rhyacophila coloradensis gro*
Blephariceridae	*Fossaria*	*Onocosmoecus*	*Rhyacophila Hyalinata Gr.*
Brachycentridae	*Gammarus*	*Optioservus*	*Rhyacophila narvae*
Capniidae	*Glossosoma*	*Oreogeton*	*Rhyacophila Sibirica Gr.*
Caudatella	*Hemerodromia*	Orthocladiinae	*Rhyacophila sp.*
Chelifera	*Heptagenia*	*Osobenus*	*Rhyacophila vemna/Brunnea*
Cheumatopsyche	*Heptagenia/Nixe/Leurocuta*	*Pacifasticus*	*Serratella tibialis*
Chironominae	*Hesperoperla pacifica*	*Palpomyia*	*Sialis*
Cinygmula	*Heterlimnius*	*Paracapnia*	*Simulium*
Claassenia	*Hexatoma*	*Paraleptophlebia*	*Skwala*
Cleptelmis	*Hirudinea*	*Pedomoecus*	Sphaeriidae
Clinocera	*Hyalella*	*Petrophila*	*Stratiomyidae*
Coenagrionidae	*Hydrobiidae*	*Physella*	*Sweltsa*
Corixidae	*Hydropsyche*	Planariidae	Tanypodinae
Cultus	*Hydroptilidae*	Planorbidae	*Tricorythodes*
Dasyhelea	*Isoperla*	Pleuroceridae	Tubificidae
Diamesinae	*Isopoda*	*Plumiperla*	*Vorticifex*
Dicosmoecus	*Juga*	*Potamopyrgus antipodarum*	*Yoroperla*
Dicranota	*Lara*	*Probezzia*	*Zaitzevia*
Diphetor hageni	*Lepidostoma*	*Prodiamesinae*	*Zapada cinctipes*
Dolophilodes	*Leucotrichia*	*Protanyderus*	*Zapada Oregonensis Gr.*
	Limnophila		

Appendix 1: List of taxon used in this analysis.

Taxon	Tolerence Value	Taxon	Tolerence Value	Taxon	Tolerence Value	Taxon	Tolerence Value	Taxon	Tolerence Value
Oreogeton	0	Rhyacophila Brunnea	1.3	Antocha	2.5	Optioservus	3.6	Gammarus	5.8
Pedomoecus	0	Rhyacophila vemna	1.3	Psephenidae	2.5	Onocosmoecus	3.7	Ceratopogonidae	5.9
Caudatella	0.4	Sweltsa	1.3	Skwala	2.5	Sialis	3.7	Turbellaria	6
Drunella doddsi	0.6	Zapada Oregonensis	1.3	Amiocentrus	2.7	Baetis notos	3.9	Crangonyx	6.1
Rhyacophila narvae	0.7	Dolophilodes	1.4	Heptageniidae	2.7	Crambidae	4	Simulium	6.1
Baetis bicaudatus	0.8	Arctopysche grandis	1.6	Dicosmoecus	2.8	Empididae	4	Chironominae	6.4
Blephariceridae	0.8	Ephemerellidae	1.6	Diphetor hageni	2.8	Pacifasticus	4	Sphaeriidae	6.7
Epeorus	0.8	Heterlimnius	1.7	Lara	2.8	Petrophila	4	Tanypodinae	6.7
Rhithrogena	0.8	Ampumixis	1.8	Paraleptophlebia	2.8	Juga	4.1	Lymnaeidae	6.8
Rhyacophila Hyalinata	0.8	Diamesini	1.8	Attenella	2.9	Pleuroceridae	4.1	Hemerodromia	6.9
Rhyacophila Sibirica	0.8	Limnephilidae	1.8	Baetis tricaudatus	2.9	Acari	4.3	Pisidium	6.9
Yoroperla	0.8	Serratella tibialis	1.8	Zaitzevia	2.9	Protoptila	4.3	Ferrissia	7
Ameletus	0.9	Planariidae	1.9	Zapada cinctipes	2.9	Baeitidae	4.5	Hydropsychidae	7.1
Cinygmula	0.9	Clinocera	2	Ochrotrichia	3	Dasyhelea	4.6	Planorbidae	7.1
Epeorus longimanus	0.9	Drunella grandis	2	Brachycentridae	3.1	Orthocladiinae	4.7	Gastropoda	7.3
Rhyacophila Angelita	0.9	Glossosomatidae	2	Isoperla	3.1	Psychomyia	4.8	Coenagrionidae	7.5
Drunella coloradensis	1	Neumouridae	2	Rhyacophilidae	3.1	Acentrella	5	Hydrobiidae	7.5
Drunella spinifera	1	Perlodidae	2	Cleptelmis	3.2	Atherix	5.1	Physella	7.5
Rhyacophila Betteni	1	Rhyacophila colorad.	2	Epeorus albertae	3.2	Elmidae	5.1	Hirudinea	7.7
Glossosoma	1.1	Diamesinae	2.2	Pteronarcys	3.2	Fossaria	5.2	Probezzia	7.7
Moselia	1.1	Ephemerella	2.2	Dicranota	3.3	Tanytarsini	5.2	Hyalella	7.9
Oligophlebodes	1.1	Hesperoperla	2.2	Hexatoma	3.3	Nematoda	5.3	Oligochaeta	7.9
Doroneuria	1.2	Lepidostoma	2.2	Stratiomyidae	3.3	Prodiamesinae	5.4	Heptagenia	8.9
Neophylax	1.2	Micrasema	2.2	Tipulidae	3.3	Pentaneurini	5.5	Nixe/Leurocuta	8.9
Rhyacophila Alberta	1.2	Capniidae	2.3	Chelifera	3.4	Tipula	5.5	Cheumatopsyche	9.1
Rhyacophila arnaudi	1.2	Malenka	2.3	Leucotrichia	3.4	Hydropsyche	5.7	Corixidae	9.3
Rhyacophila sp.	1.2	Narpus	2.3	Helicopsyche	3.6	Hydroptilidae	5.7	Ephydridae	10
Drunella flavilinea	1.3	Limnophila	2.4			Tricorythodes	5.7		

Appendix 2: List of taxa and their associated tolerance Value (Whittier and Van Sickle, 2010).

Mayflies	Pre Rel. Abund. mean (range)	Post Rel. Abund. mean (range)
Acentrella	0.023 (0 - 0.060)	0.015 (0 - 0.042)
Baetis bicaudatus	0.006 (0 - 0.033)	0.007 (0 - 0.030)
Baetis tricaudatus	0.047 (0 - 0.101)	0.043 (0 - 0.070)
Drunella spinifera	0.006 (0 - 0.030)	0.004 (0 - 0.027)
Epeorus	0.012 (0 - 0.038)	0.013 (0 - 0.059)
Ephemerella	0.038 (0 - 0.135)	0.037 (0 - 0.088)
Heptagenia/Nixe/Leurocuta	0.005 (0 - 0.027)	0.004 (0 - 0.026)
Rhithrogena	0.022 (0 - 0.114)	0.008 (0 – 0.037)
Paraleptophlebia	0.004 (0 - 0.019)	0.002 (0 - 0.012)

Appendix 3A: Summary results for Mayfly taxa below the Dams and present in at least 10 samples in either the pre or post data. Data are presented as relative abundance (Rel. Abund.).

Stoneflies	Pre Rel. Abund. mean (range)	Post Rel. Abund. mean (range)
Hesperoperla pacifica	0.031 (0 - 0.059)	0.017 (0 - 0.040)
Pteronarcys californica	0.028 (0 - 0.068)	0.019 (0 - 0.043)
Skwala	0.004 (0 - 0.026)	0.002 (0 - 0.015)
Sweltsa	0.001 (0 - 0.006)	0 (0 - 0)
Zapada cinctipes	0.001 (0 - 0.017)	0.001 (0 - 0.011)

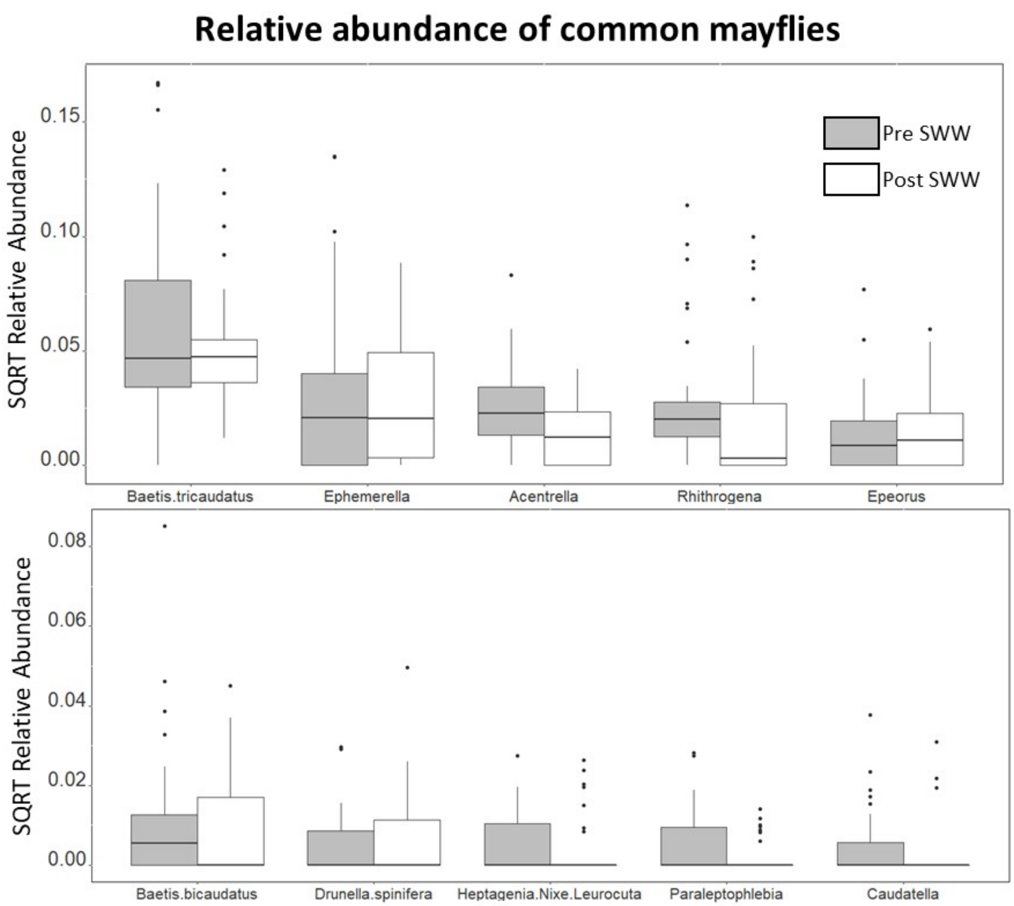
Appendix 3B: Summary results for Stonefly taxa below the Dams and present in at least 10 samples in either the pre or post data. Data are presented as relative abundance (Rel. Abund.).

Caddisflies	Pre Rel. Abund. mean (range)	Post Rel. Abund. mean (range)
Amiocentrus	0.059 (0.02 - 0.130)	0.036 (0.003 - 0.100)
Cheumatopsyche	0.016 (0 - 0.082)	0.024 (0 - 0.072)
Glossosoma	0.018 (0 - 0.056)	0.029 (0 - 0.096)
Hydropsyche	0.074 (0.011 - 0.146)	0.081 (0.033 - 0.135)
Leucotrichia	0.004 (0 - 0.029)	0.004 (0 - 0.025)
Protoptila	0.011 (0 - 0.060)	0.010 (0 - 0.079)
Psychomyia	0.008 (0 - 0.033)	0.001 (0 - 0.015)
Rhyacophila Hyalinata Gr.	0.003 (0 - 0.015)	0 (0 - 0)

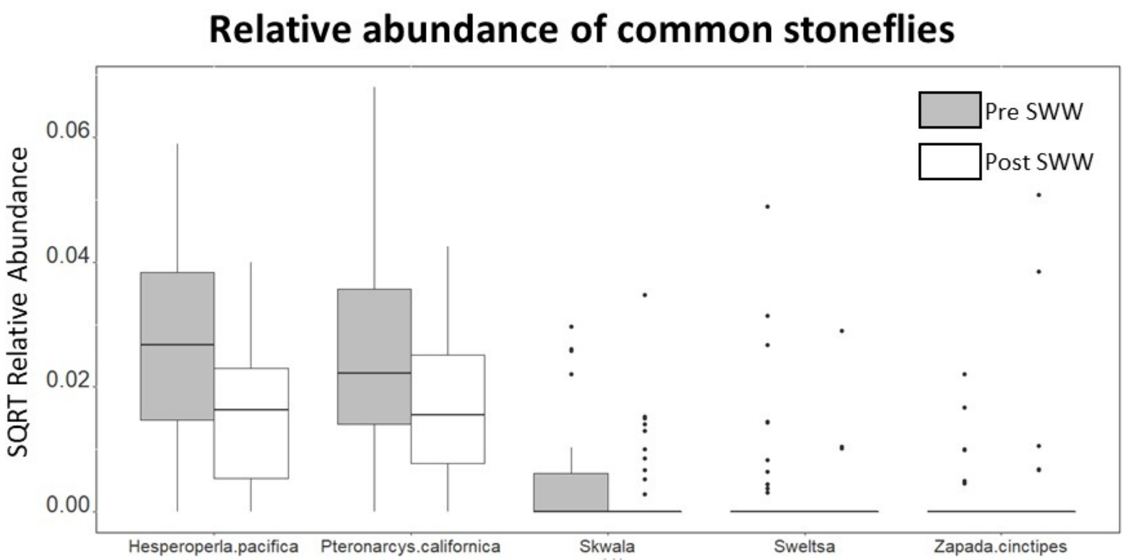
Appendix 3C: Summary results for Caddisfly taxa below the Dams and present in at least 10 samples in either the pre or post data. Data are presented as relative abundance (Rel. Abund.).

Non-Insect	Pre Rel. Abund. mean (range)	Post Rel. Abund. mean (range)
Acari	0.015 (0 - 0.038)	0.031 (0.012 - 0.073)
Fisherola nuttalli	0 (0 - 0)	0.005 (0 - 0.028)
Fluminicola	0.038 (0 - 0.232)	0.060 (0.007 - 0.148)
Fossaria	0.019 (0 - 0.158)	0.012 (0 - 0.029)
Gammarus	0.009 (0 - 0.055)	0.016 (0 - 0.067)
Juga	0.001 (0 - 0.022)	0.020 (0 - 0.071)
Nematoda	0.020 (0 - 0.053)	0.028 (0.003 - 0.086)
Oligochaeta	0.038 (0 - 0.091)	0.105 (0.045 - 0.174)
Physella	0.021 (0 - 0.131)	0.012 (0 - 0.050)
Planariidae	0.051 (0 - 0.269)	0.045 (0 - 0.186)
Vorticifex	0.079 (0 - 0.285)	0.064 (0.010 – 0.155)

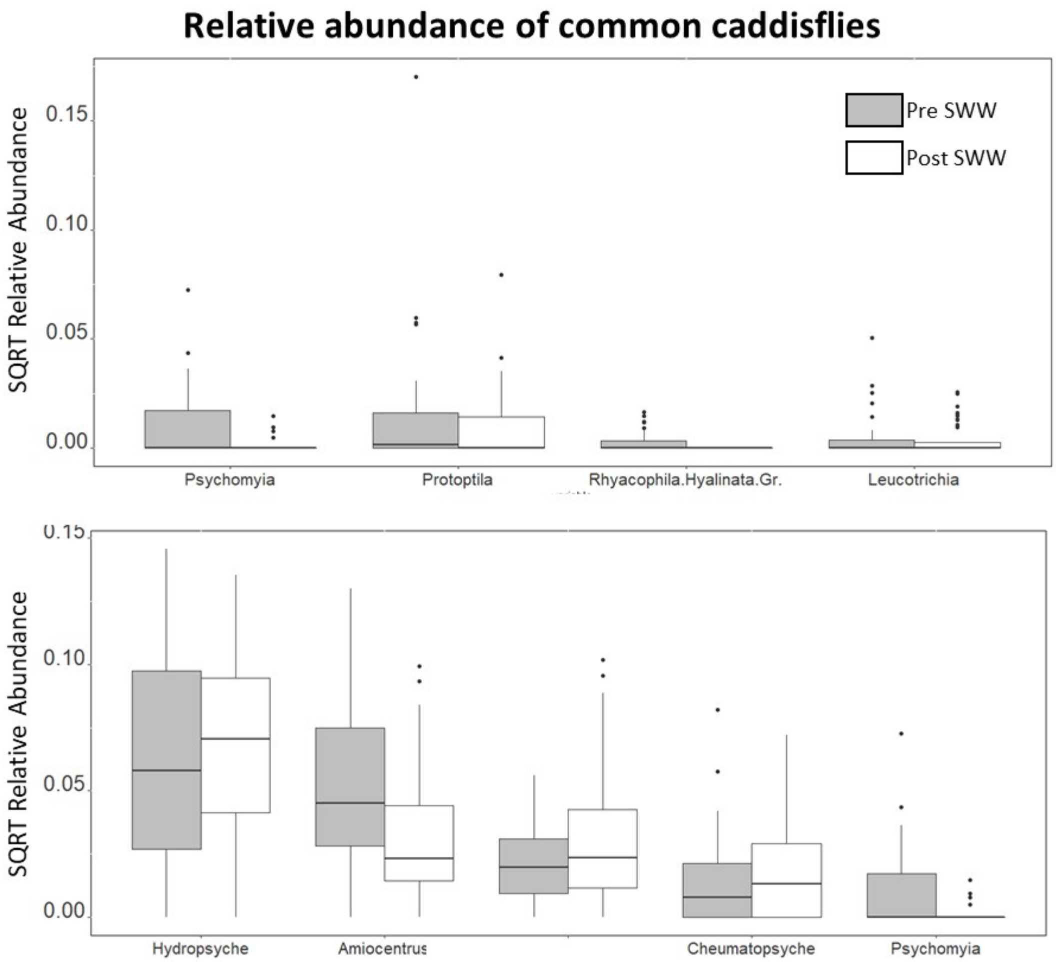
Appendix 3D: Summary results for non-insect taxa below the Dams and present in at least 10 samples in either the pre or post data. Data are presented as relative abundance (Rel. Abund.).



Appendix 4A: Square Root (SQRT) transformed boxplots of mayfly taxa below the Dams and present at least 10 sites before or after surface water withdrawal operations began.

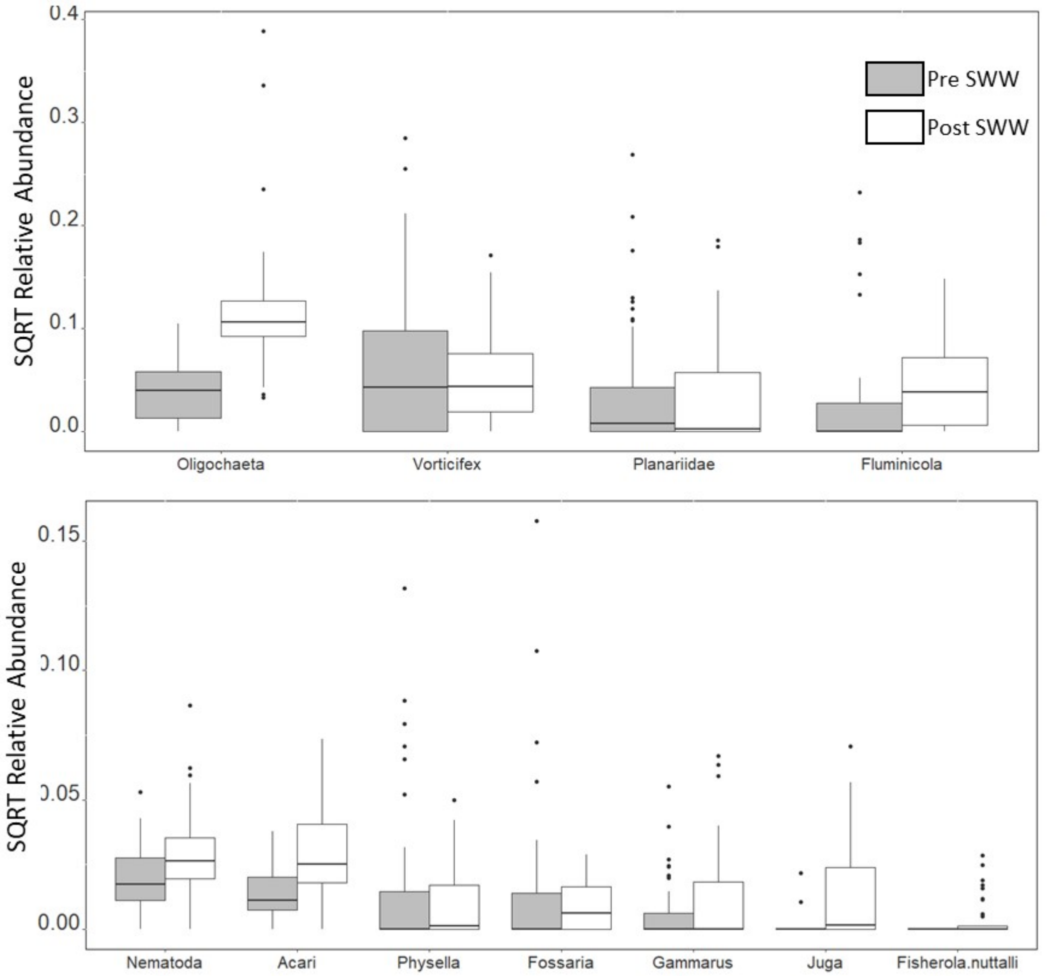


Appendix 4B: Square Root (SQRT) transformed boxplots of stonefly taxa below the Dams and present at least 10 sites before or after surface water withdrawal operations began.



Appendix 4C: Square Root (SQRT) transformed boxplots of caddisfly taxa below the Dams and present at least 10 sites before or after surface water withdrawal operations began.

Relative abundance of common non-insect



Appendix 4D: Square Root (SQRT) transformed boxplots of non-insect taxa below the Dams and present at least 10 sites before or after surface water withdrawal operations began.

DEFINITIONS

Bubble Plot: A visual display method that scales the symbols on an ordination to a characteristic of the data; for example, the percent of predators in a macroinvertebrate sample.

EPTr: The total number of taxa that are mayflies, stoneflies and caddisflies expressed as a percentage of the total richness for the sample.
Formula: EPTr = ∑ EPT richness / total richness

Dissimilarity Matrices: A data set containing the "distances" between assemblages; similar to a mileage map where the distance between all cites in the map is represented by a "triangular mileage chart." In this study the distances are represented using the Bray-Curtis distance measures.

NMDS: Non-Metric Dimensional Scaling is a computational method used to create an ordination.

Ordination: A visual representation of data. In this study, ordinations were used to display macroinvertebrate assemblage data in two-dimensional space. Points on an ordination that are close together represent samples with macroinvertebrate communities are similar.

p value: A statistical value that ranges from 0-1 and is the probability that the mean of two data sets are the same. A p-value less than 0.05 is considered to indicate the means are significantly different.

Relative abundance: Equals the percent abundance of an individual taxa relative to the total abundance of invertebrates in the entire sample. Example: 10 individuals of taxa A in a sample with total of 200 invertebrates, the relative abundance of taxa A is 0.05, or 5%.

R statistic: Is a statistical value that indicates the strength of the differences between samples in an ordination. The R statistic ranges from 0-1 and is used in an ANOSIM analysis to determine if groups of samples in an ordination are statistically different. An R value of 0 indicates a random grouping of samples in the ordination and an R value 1 indicates 100% dissimilarity of samples in an ordination.

Richness: The total number of different kinds of organisms. Richness is a commonly used metric in bioassessment. Also called "total taxa" or "taxa richness."

RICHTOL: The mean tolerance value based on each taxon present. Expressed as a mean value for the sample.

Formula: RICHTOL = ∑ tolerance scores / total richness

Stress: Occurs when samples are displayed in an ordination. Stress is similar to the distortion of the earth that can be observed on maps. Stress values over 20 indicate that the ordination does not accurately represent the samples and should not be used in interpretation.

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