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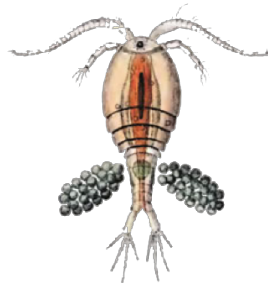


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Chapter 2

Zooplankton Assemblages in Highly Regulated Utah Lake: 2015-2018

Progress Report



by

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For
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Summary

We are conducting the most extensive evaluation of zooplankton assemblages in the highly regulated Utah Lake, to date. Zooplankton are the most important top-down controls of phytoplankton including cyanoHABs in Utah Lake. The analyses presented in this progress report are invaluable for understanding Utah Lake's ecology and foodweb and for informing sound management decisions. As we anticipated, zooplankton assemblages significantly varied spatially and temporally, which has indispensable ecological and management implications. Past taxonomic understanding of Utah Lake zooplankton was apparently faulty and if not remedied could bias any analyses conducted past, present, and future and negatively influence management decisions. We provide an updated taxonomic evaluation and suggest that this be used as the taxonomic authority for Utah Lake zooplankton and subsequently update genetic based taxonomic lists to assist in future analyses. Several reasons for why the present zooplankton assemblage is as it is are discussed including; metacommunity population dynamics, ancient Lake Bonneville legacy, eutrophication, and the effects of introduced planktivorous fish.

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Introduction

Zooplankton are by far the most important top-down regulator of phytoplankton in freshwater lentic ecosystems (Cole and Weihe 2016; Wetzel 2001). Zooplankton obviously have top down grazing effects on phytoplankton including cyanoHABs but are also in turn affected by phytoplankton (bottom up effects). Zooplankton assemblages can have top down control on phytoplankton assemblages via selective and non-selective grazing. Contrary to past assumptions, it is becoming apparent that many zooplankton taxa routinely and selectively rely on cyanoHABs as an important part of their diets (Motwani et al. 2017; Woodland et al. 2013; Koski et al. 2002; Vehmaa et al. 2013; Gorokhova and Engstrom-Ost 2009; and Hogfors et al. 2014; Jiang et al. 2013). Zooplankton excretion and respiration of nitrogen, phosphorus, and ammonia into the water column is immediately available and consumed by phytoplankton, often within minutes. In turn, phytoplankton assemblages can have bottom up control on zooplankton assemblages via several mechanisms, including relative abundance, digestibility, nutrient content, toxin production, etc. Zooplankton are also top-down controlled by planktivorous fishes.

Individual zooplankton taxa functional traits also determine interaction outcomes with phytoplankton. Their functional traits can include; feeding ecology, trophic group (e.g. herbivore, omnivore, predator, etc.), body size, environmental requirements (e.g. temperature, pH, salinity, etc.), nutrient requirements, and nutrient excretion rates, etc. All of these complex interactions directly and indirectly influence nutrient cycling in the water column and phytoplankton assemblage composition including cyanoHABs.

Justification

Very little is known about the spatial and temporal patterns of zooplankton assemblages in highly regulated Utah Lake despite the critical importance of their relationships with nutrient cycling, phytoplankton assemblages, cyanobacteria blooms (HABs), and other foodweb components in the lake. Richards and Miller (2017) and Richards (2018) provided the most recent and comprehensive analysis of zooplankton spatial and temporal patterns and interactions with phytoplankton based on data they collected in 2016. In addition, the taxonomy of zooplankton in Utah Lake is in need of revision, without which proper interpretation of ecological interactions within the food web cannot be made. This chapter of our 2019 progress report builds on the Richards and Miller (2017) report and includes analysis of Utah Lake's zooplankton assemblages from data collected between 2015 and 2018. It also includes updated taxonomic revisions courtesy of Mr. Brett Marshall at River Continuum Concepts, Manhattan, MT (see Attachment 1) and brief discussion of reasons for present zooplankton diversity in Utah Lake and remedies for rehabilitating its unbalanced ecosystem function. This report will be the foundation for subsequent chapters in our progress report(s), including a chapter on phytoplankton-zooplankton interactions and a chapter on nutrient-phytoplankton-zooplankton inter relationships in the lake's food web.

Methods

Sample Collection

Three hundred and fifty-five zooplankton samples were collected from various locations in Utah Lake from 2015 and 2018 by OreoHelix Consulting and Wasatch Front Water Quality Council. Most of the zooplankton samples were collected in the same locations and on the same dates as phytoplankton samples (see Chapter 1: Utah Lake Phytoplankton Assemblages) and many were collected concomitantly with nutrient and water chemistry data (see pending Nutrient and Water Chemistry chapter). Every attempt was made to collect zooplankton samples from the same locations where we sampled previously (e.g. Richards and Miller 2017).

Samples were collected using a 200 μm mesh net with a 30 cm opening similar to the image in Figure 1. The net was dropped to the bottom of the water column, moved slightly to either side of where it was dropped and then pulled up either to the boat or researcher wading along shoreline (i.e. ‘vertical tow’). Depth of water column was recorded to adjust zooplankton density estimates. Contents were emptied into labeled plastic jar using a pipette and spray bottle washer and either isopropyl or ethanol was added to the contents to about 70% concentration.



Figure 1. Plankton net similar to the one used in our studies.



Figure 2. Map of zooplankton sample locations. Location names are in Table 4.

Taxonomy

Valid taxonomic identification of microscopic zooplankton can be challenging and requires qualified taxonomists. We commissioned four zooplankton taxonomic labs throughout the duration of this study. Our primary taxonomist, Dr. Larry Gray at Utah Valley University, passed away in 2017, subsequently we then contracted three other taxonomic labs, including a genetics lab and River Continuum Concepts Inc., Manhattan, MT. Results from all four labs showed some potentially misidentifications and taxonomic discrepancies, which could have resulted in major errors in our ecological interpretations and analyses. We then had Brett Marshall, director of River Continuum Concepts, Inc. conduct a preliminary evaluation of taxonomic identifications and synonymies of the zooplankton from the four labs to help reconcile this dilemma. Results of his evaluation are presented in Attachment 1: Laboratory Observations Regarding Identifications and likely Synonymies among Zooplankton from Utah Lake (Marshall 2019) and will provide invaluable as a future reference in our research. The majority of the analysis conducted in this report uses zooplankton data that have been ‘rolled up’ to family level based on recommendations by Marshall (2019) and our professional experience in statistically analyzing ecological data consisting of taxa of questionable or differing levels of taxonomic effort (OTUs) and resolution. Unfortunately, much valuable ecological information is lost when working at levels higher than species level or even genus level, but this decision was our most judicious in

light of the problems with zooplankton taxonomy for Utah Lake. In situations where we could use species or genus level in our analysis, we did so.

Zooplankton Relativization by Body Lengths

Biomass of individual zooplankton varies substantially between taxa and within a taxon seasonally, temporally, and between sexes (Culver et al. 1985; Rosen 1981; Havens and Beaver 2011) Unfortunately, individual length or biomass estimates, or consistent sex identification were not made during taxonomic processing of our samples. Several researchers have derived length-weight regression estimates for many zooplankton taxa, particularly cladocerans and copepods, including for several species and genera found in Utah Lake (Culver et al. 1985; Rosen 1981). Biomass is the preferred measure of analyzing ecologic function of zooplankton in aquatic systems, including our preference, however incorporating biomass estimates from length regressions can add considerable error, especially when individual lengths are unknown. For example, we calculated dry weights of *Daphnia retrocurva*, a common taxon found in Utah Lake, based on length ranges (mean \pm std. dev.) available from the literature and the ranges of length-weight regression coefficients (a, b) derived for the Culver et al. (1985) equation: $weight (ug) = a * length (mm)^b$. The resulting derived minimum estimate of individual *D. retrocurva* biomass was 0.99 μ g and the maximum was 437.89 μ g. Extrapolating such wide ranges of biomass estimates from count data would therefore not be appropriate given the limitations of our data set and the goals of our analyzes presented in this report. However, given that count data fails to address important ecosystem effects of zooplankton size differences; we concluded that the most prudent solution was to relativize counts by a much less variable measure, body length derived from the literature with our full knowledge that body lengths don't completely correlate with biomass measures. Zooplankton estimated length values are presented in Table 1. Our count data was relativized by these lengths for all analyses presented in this report. If further reanalysis of results presented in this report using biomass estimates are desired it is simply a matter of readjusting our relativized counts presented in Table 1 and then selecting the most appropriate weight-length regressions available. However, we suggest that future analyses attempting to use length-weight regressions based on count only data when no body lengths are determined should do so with extreme caution.

Table 1. Length estimates of zooplankton found in our study based on values from literature. Count data analyzed for this report were relativized by these estimated length values. Length estimate sources: Central Michigan University website (accessed March 12, 2019), Culver et al. (1985), and NOAA Great Lakes Environmental Research Laboratory website (accessed March 12, 2019), Center for Freshwater Biology (accessed March 20, 2019). USGS (accessed March 20, 2019).

Taxon	Estimated length (mm)
Cladocera	
<i>Daphnia retrocurva</i> Forbes	1.14
<i>Daphnia pulex</i>	1.1
<i>Ceriodaphnia quadrangula</i>	0.75
<i>Bosmina longirostris</i>	0.41
<i>Chydorus sphaericus</i>	0.32

<i>Pleuroxus striatus</i>	0.55
<i>Leydigia leydigi</i>	0.56
<i>Leptodora kindtii</i>	1
<i>Ilyocryptus</i> sp.	0.73
<i>Diaphanosoma</i> sp.	0.56
Copepods	
<i>Leptodiaptomus (Diaptomus) sicilis</i>	1.01
<i>Acanthocyclops robustus</i>	1.13
<i>Eucyclops agilis</i>	0.80
<i>Attheyella</i> sp.	0.75
<i>Microcyclops rubellus</i>	0.64
Rotifers	
<i>Brachionus</i> sp.	0.18
<i>Keratella</i> sp.	0.16
<i>Asplanchna</i> sp.	0.8
Ostracoda sp.	0.7

Statistics

Spatial and Temporal Patterns of Zooplankton Assemblages: *Multivariate Models*

Non-metric multidimensional scaling (NMS) ordination was used to statistically and visually compare zooplankton assemblage relationships between sites and months. Ordination techniques are often more informative than hypothesis-testing approaches for exploring relationships between multivariate ecological assemblages or communities (McCune and Grace 2002). In general, ordination is the ordering of objects along axes according to their (dis)similarities; the main objective of ordination is to reduce many-dimensional relationships into a small number of more easily interpretable dimensions (i.e., axes on a plot). The strongest correlation structure in the data is extracted and is then used to position objects in ordination space. Objects that are close in the ordination space are more similar than objects distant in ordination space (McCune and Mefford 2011).

NMS was used in these analyses because it has been shown to be robust and highly informative for understanding ecological relationships. NMS ordination is often more broadly applicable for ecological studies than other ordination techniques because it does not require relationships among variables to be linear (McCune and Mefford 2011; Peck 2010). NMS ordination permits the visualization of the multidimensional relationships of zooplankton assemblages into a more easily visualized, lower dimensional space. Dimensional reduction obviously creates some distortion in relationships between samples. The level of reduction in distortion is measured as ‘stress’; where lower stress values equal less distortion. NMS plots with stress values of 15%

(0.15) or less are typically considered to be a good representation of the data and stress values lower than 10% (0.10) are considered excellent representations (McCune and Mefford 2011; Peck 2010).

A Sorensen (Bray-Curtis) or Relative Sorensen distance measure was used in the NMS analysis and run for 250 iterations using the real data and 250 iterations in randomized Monte Carlo simulations. The Sorensen distance measure is based on pairwise comparisons between all sample pairs (McCune and Mefford 2018). the Relative Sørensen distance ("relativized Manhattan" in Faith et al. 1987) is the same as Sørensen distance except that it builds in a standardization by sample unit totals, each sample unit contributing equally to the distance measure (McCune and Mefford 2018). Therefore, NMS ordinations were rotated using varimax rotation to maximize variation along the axes and extracted as univariate scores. Consequently, the final ordinations can be rotated either vertically or horizontally without effecting the results. The best model was chosen based on scree plots and final stress values. Centroid labels of sites were added to the ordinations to aid in the interpret the relationships. Convex hulls were also used on some ordinations to help interpret assemblage relationships. Post hoc proportion of variance represented by each axis was calculated based on the R^2 value between distance in the ordination space and distance in the original space.

MRPP (multi-response permutation procedure), a non-parametric multivariate method was used to formally test the hypothesis of no differences in zooplankton assemblages between months and sites. MRPP has the advantage of not requiring distributional assumptions such as multivariate normality and homogeneity of variance and thus is often preferred over MANOVA for analyzing multivariate ecological data (McCune and Grace 2002). A Sorensen (Bray-Curtis) distance measure was used in the MRPP analyses. The chance-corrected within-group test statistic, A (and associated p-value) was used to evaluate the hypothesis of no difference in the spatial and temporal groupings (McCune and Grace 2002). We also conducted indicator species analysis and blocked indicator species analysis grouped by months and sites using Dufrene's and Legendre's (1997) method (see McCune and Mefford 2018 for more details of indicator species analysis and blocked indicator species analysis). All multivariate analyses of Utah Lake zooplankton assemblage data were conducted using PC-ORD Version 7.07 (McCune and Mefford 2018).

Individual Zooplankton Taxa Temporal Patterns

Additional statistical analyses including taxon specific: pseudo time series graphs, boxplots, marginal predicted means and 95% CIs, ANOVAs, MANOVAs, Generalized Linear, truncated Poisson, truncated negative binomial, and fractional regressions were conducted based on the desired comparisons and effects and the distributions of the data using Stata 15.1 (StatCorp 2015). Fractional regression, truncated Poisson and truncated negative binomial regression methods were chosen because some diversity indices were proportions and individual

zooplankton taxa density estimates were count data that were truncated at zero and contained mostly zero counts. Typically, these types of data cannot be reasonably transformed to approximate normal Gaussian (normal) distributions using any transformation method, therefore linear models were rarely appropriate.

Results

Potentially fifty-six zooplankton taxa were collected in our study of Utah Lake zooplankton assemblages between 2015 and 2018 (Table 2). However as discussed in the Methods section, taxonomic resolution varied between taxonomy labs and most likely there were fewer taxa observed (see *Taxa Based* section). Taxa codes used throughout the results section of this report, scientific names, and those taxa found in three of the labs are in (Table 4). Family level taxa codes are in (Table 4).

Table 2. List of zooplankton taxa found in Utah Lake from our 2015 to 2018 sampling efforts. See Marshall (2019) in Attachment 1 for an evaluation of potential Utah Lake zooplankton taxonomic revisions

Phylum	Subphylum	Class	Subclass	Order	Suborder	Family	Genus	Species
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Bosminidae	Bosmina	<i>Bosmina liederi</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Bosminidae	Bosmina	<i>Bosmina longirostris</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Bosminidae	Bosmina	<i>Bosmina</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	<i>Alona</i>	<i>Alona setulosa</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	<i>Chydorus</i>	<i>Chydorus sphaericus</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	Leydigia	<i>Leydigia leydigi</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	Leydigia	<i>Leydigia lousi</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	<i>Pleuroxus</i>	<i>Pleuroxus aduncus</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	<i>Pleuroxus</i>	<i>Pleuroxus</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Chydoridae	<i>Pleuroxus</i>	<i>Pleuroxus striatus</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Ceriodaphnia	<i>Ceriodaphnia cf. acanthina</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Ceriodaphnia	<i>Ceriodaphnia dubia</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Ceriodaphnia	<i>Ceriodaphnia quadrangula</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Ceriodaphnia	<i>Ceriodaphnia</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia ambigua</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia exilis</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia galeata</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia magna</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia pulex</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia retrocurva</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	Daphnia	<i>Daphnia</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Daphniidae	<i>Simocephalus</i>	<i>Simocephalus vetulus</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Leptodoridae	Leptodora	<i>Leptodora kindtii</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Macrothricidae	Macrothrix	<i>Macrothrix</i> sp.

Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Moinidae	Moina	<i>Moina cf. micrura</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Moinidae	Moina	<i>Moina macrocopa</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Moinidae	Moina	<i>Moina</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Ilyocryptidae	<i>Ilyocryptus</i>	<i>Ilyocryptus</i> sp.
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Sididae	Diaphanosoma	<i>Diaphanosoma brachyurum</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Sididae	Diaphanosoma	<i>Diaphanosoma cf. heberti</i>
Arthropoda	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Cladocera	Sididae	Diaphanosoma	<i>Diaphanosoma</i> sp.
Arthropoda	Crustacea	Maxillopoda	Copepoda	Calanoida		Diaptomidae	Leptodiaptomus	<i>Leptodiaptomus sicilis</i>
Arthropoda	Crustacea	Maxillopoda	Copepoda	Cyclopoida		Cyclopidae	Acanthocyclops	<i>Acanthocyclops americanus</i>
Arthropoda	Crustacea	Maxillopoda	Copepoda	Cyclopoida		Cyclopidae	Acanthocyclops	<i>Acanthocyclops robustus</i>
Arthropoda	Crustacea	Maxillopoda	Copepoda	Cyclopoida		Cyclopidae	<i>Eucyclops</i>	<i>Eucyclops agilis</i>
Arthropoda	Crustacea	Maxillopoda	Copepoda	Cyclopoida		Cyclopidae	<i>Microcyclops</i>	<i>Microcyclops rubellus</i>
Arthropoda	Crustacea	Maxillopoda	Copepoda	Harpacticoida		Canthocamptidae	<i>Attheyella</i>	<i>Attheyella</i> sp.
Arthropoda	Crustacea	Maxillopoda	Copepoda	Harpacticoida		Canthocamptidae	<i>Cletocamptus</i>	<i>Cletocamptus</i> sp.
Arthropoda	Crustacea	Maxillopoda	Copepoda	Harpacticoida		Laophontidae	<i>Onychocamptus</i>	<i>Onychocamptus mohammed</i>
Arthropoda	Crustacea	Ostracoda	Podocopa	Podocopida		Cyprididae	Cypridopsis	<i>Cypridopsis vidua</i>
Arthropoda	Crustacea	Ostracoda	Podocopa	Podocopida		None	Podocopida	<i>Podocopida</i> sp.
Arthropoda	Crustacea	Ostracoda						<i>Ostracoda</i> sp.
Arthropoda	Chelicerata	Arachnida	Acari	Philodinida		Philodinidae	Dissotrocha	<i>Dissotrocha aculeata</i>
Rotifera		Eurotatoria		Flosculariaceae		Testudinellidae	<i>Filinia</i>	<i>Filinia</i> sp.
Rotifera		Monogononta		Ploima		Asplanchnidae	Asplanchna	<i>Asplanchna silvestrii</i>
Rotifera		Monogononta		Ploima		Asplanchnidae	Asplanchna	<i>Asplanchna</i> sp.
Rotifera		Monogononta		Ploima		Brachionidae	Brachionus	<i>Brachionus calyciflorus</i>
Rotifera		Monogononta		Ploima		Brachionidae	Brachionus	<i>Brachionus plicatilis</i>
Rotifera		Monogononta		Ploima		Brachionidae	Brachionus	<i>Brachionus quadridentatus</i>
Rotifera		Monogononta		Ploima		Brachionidae	Brachionus	<i>Brachionus variabilis</i>
Rotifera		Monogononta		Ploima		Brachionidae	Brachionus	<i>Brachionus</i> sp.
Rotifera		Monogononta		Ploima		Brachionidae	Keratella	<i>Keratella cochlearis</i>

Rotifera		Monogononta	Ploima		Brachionidae	Keratella	<i>Keratella</i> sp.
Rotifera		Monogononta	Ploima		Synchaetidae	Polyarthra	<i>Polyarthra dolichoptera</i>
Rotifera		Monogononta	Ploima		Synchaetidae	Polyarthra	<i>Polyarthra</i> sp.
Rotifera		Monogononta	Ploima		Synchaetidae	Polyarthra	<i>Polyarthra vulgaris</i>

Table 3. Comparison of zooplankton taxa found in Utah Lake and codes for three of the four labs. For more detailed discussion of taxonomic resolution and synonymies see Marshall (2019 in Attachment 1).

Taxon Code	Scientific Name (Genus species)	Lab 1	Lab 2	Genetics Lab
ACAM	<i>Acanthocyclops americanus</i>			X
ACRO	<i>Acanthocyclops robustus</i>	X	X	
ASSI	<i>Asplanchna silvestrii</i>			X
ASSP	<i>Asplanchna</i> sp.	X	X	X
ATSP	<i>Attheyella</i> sp.	X		
BOLI	<i>Bosmina liederii</i>			X
BOLO	<i>Bosmina longirostris</i>	X	X	
BOSP	<i>Bosmina</i> sp.			X
BRCA	<i>Brachionus calyciflorus</i>		X	X
BRPL	<i>Brachionus plicatilis</i>		X	X
BRQU	<i>Brachionus quadridentatus</i>			X
BRSP	<i>Brachionus</i> sp.	X		
BRVA	<i>Brachionus variabilis</i>			X
CEAC	<i>Ceriodaphnia cf. acanthina</i>			X
CEDU	<i>Ceriodaphnia dubia</i>			X
CEQU	<i>Ceriodaphnia quadrangula</i>	X	X	
CESP	<i>Ceriodaphnia</i> sp.			X
CHSP	<i>Chydorus sphaericus</i>	X	X	
CLSP	<i>Cletocamptus</i>		X	
CYVI	<i>Cypridopsis vidua</i>			X
DAAM	<i>Daphnia ambigua</i>			X
DAEX	<i>Daphnia exilis</i>			X
DAGA	<i>Daphnia galeata</i>			X
DAMA	<i>Daphnia magna</i>			X
DAPU	<i>Daphnia pulex</i>	X	X	
DARE	<i>Daphnia retrocurva</i>	X	X	
DASP	<i>Daphnia</i> sp.			X
DIBR	<i>Diaphanosoma brachyurum</i>			
DIHE	<i>Diaphanosoma cf. heberti</i>			X
DISP	<i>Diaphanosoma</i> sp.	X	X	X
DIAC	<i>Dissotrocha aculeata</i>			X
EUAG	<i>Eucyclops agilis</i>	X		
FISP	<i>Filinia</i> sp.	X		
ILSP	<i>Ilyocryptus</i> sp.	X		
KECO	<i>Keratella cochlearis</i>			X
KESP	<i>Keratella</i> sp.	X		

LEKI	<i>Leptodora kindtii</i>	X	X	X
LELE	<i>Leydigia leydigi</i>	X	X	
LELO	<i>Leydigia lousi</i>			X
LESI	<i>Leptodiaptomus sicilis</i>	X	X	X
MIRU	<i>Microcyclops rubellus</i>		X	
MASP	<i>Macrothrix</i> sp.			X
MOMA	<i>Moina macrocarpa</i>		X	
MOMI	<i>Moina cf. micrura</i>			X
MOSP	<i>Moina</i> sp.			X
OSSP	<i>Ostracoda</i> sp.	X	X	
PLAD	<i>Pleuroxus aduncus</i>		X	
PLSP	<i>Pleuroxus</i> sp.	X		
PLST	<i>Pleuroxus striatus</i>	X		
POSP	<i>Podocopida</i> sp.			X
PODO	<i>Polyarthra dolichoptera</i>			X
POSP	<i>Polyarthra</i> sp.			X
POVU	<i>Polyarthra vulgaris</i>			X
SIVE	<i>Simocephalus vetulus</i>		X	

Table 4. Zooplankton family and location codes used throughout most of this report.

Family	Code	Location	Code
Asplanchnidae	Asp	Goshen Bay	
Bosminidae	Bos	Lincoln Beach area	LB
Brachionidae	Bra	Lake Center	LC
Canthocamptidae	Can	Lindon Marina	LM
Chydoridae	Chy	Lindon-Pelican transect	LP
Cyclopidae	Cyc	Outlet	OUT
Daphniidae	Dap	Provo Airport area	PA
Diaptomidae	Dia	Provo Bay	PB
Ilyocryptidae	Ily	Pelican Marina	PM
Laophontidae	Lao	Sandy Beach	SB
Leptodoridae	Lep	Utah Lake State Park	SP
Macrothricidae	Mac	Saratoga Springs	SS
Moinidae	Moi		
Ostracoda	Ost		
Sididae	Sid		
Testudinellidae	Tes		

Rank abundances (relativized by length) of zooplankton families are in the following figure (Figure 3). Three families dominated the zooplankton assemblages: Cyclopidae (copepod), Diaptomidae (calanoid copepod), and Daphniidae (cladocerans)), with cyclopoid copepods the most abundant.

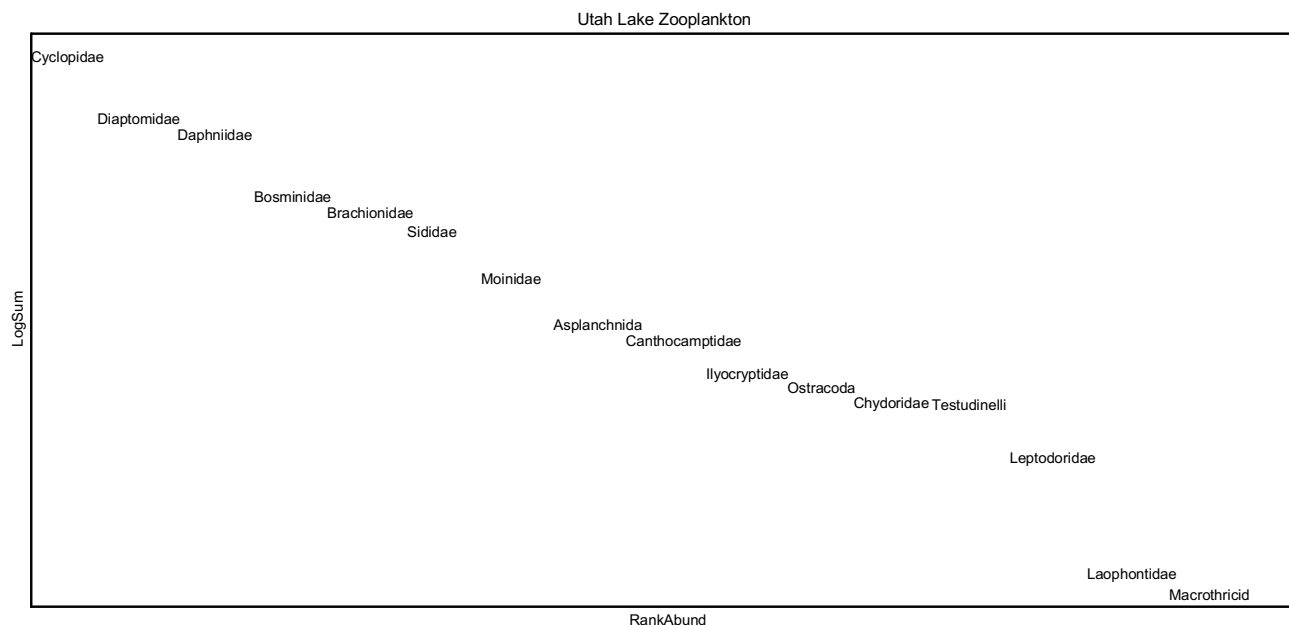


Figure 3. Utah Lake zooplankton family level rank abundance (logSum) from left to right.

Utah Lake Zooplankton Assemblages

We examined several dozen distance measures and transformations to find models with lowest dimensionality, final stress, and best predictive power. One sample collected from the west side of Utah Lake (sample code) and one sample from the confluence of American Fork (sample code) were outliers (> 2 std dev.) and omitted from multivariate analyses of whole lake zooplankton assemblages. Final N = 353 samples.

NMS

The best NMS ordination used a Relative Sorenson distance measure. Three zooplankton families with < 30 family occurrences ($< 10\%$ of total) were removed (Laophontidae, Macrothricidae, and Testudinellida); 12 families remained. Final stress for a 2-dimensional solution = 11.48; final instability = < 0.0001 ; using 76 iterations. Post hoc correlation resulted in an Axis $R^2 = 0.74$ and Axis 2 $R^2 = 0.17$.

Monthly Patterns

Utah Lake zooplankton assemblages clearly differed monthly (Figure 4). Late winter (January and February) and mid-spring (April) were similar to each other but much different than the other months. May, June, and July assemblages were similar to each other but different than the

other months, and August, September, and October assemblages were similar to each other but different than other months. Interestingly March and November assemblages were most similar to each other. MRPP A = 0.15, $p < 0.01$ confirmed that assemblages significantly differed by month. The months that did not significantly differ were August and October, August and September, July and May, June and May, March and November, October and November, and May and November (see Appendix 6 for MRPP results for all monthly comparisons).

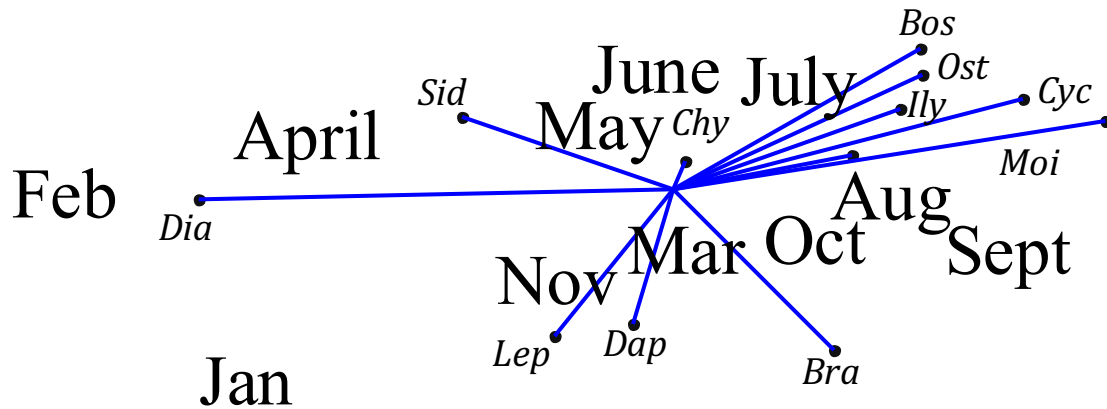
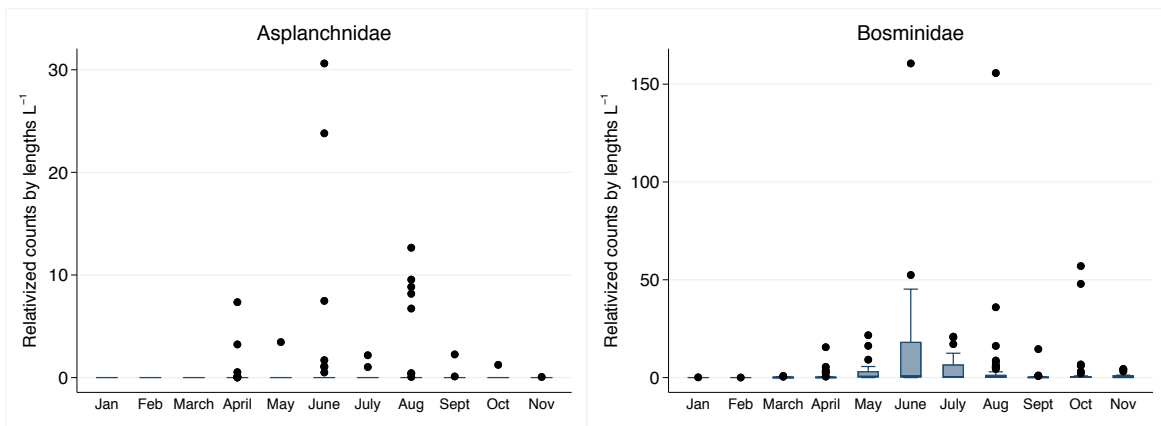
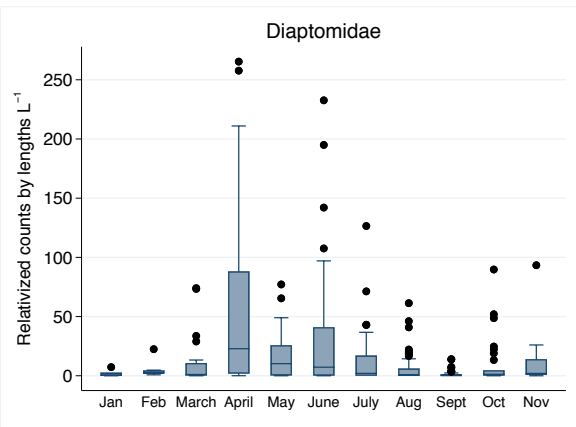
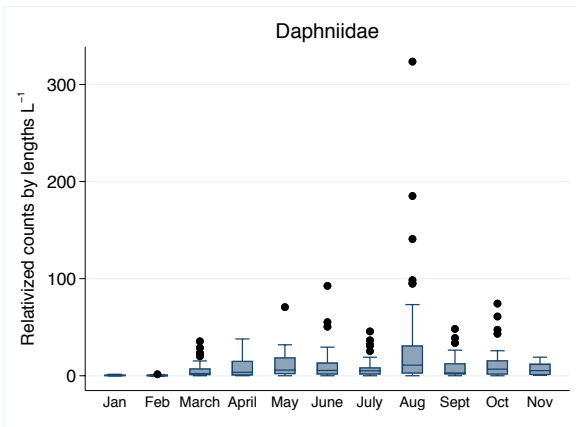
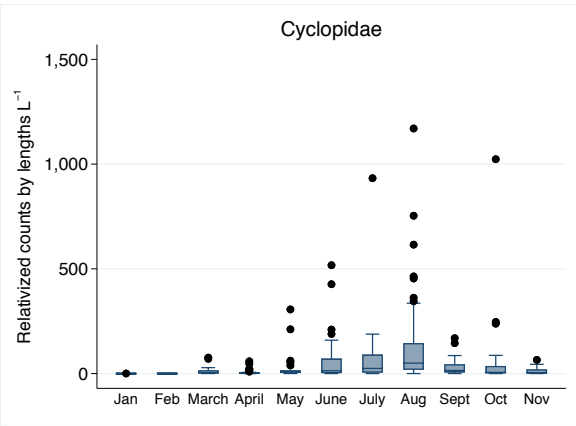
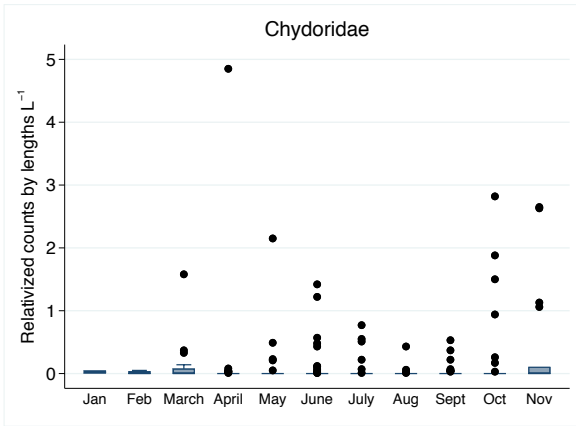
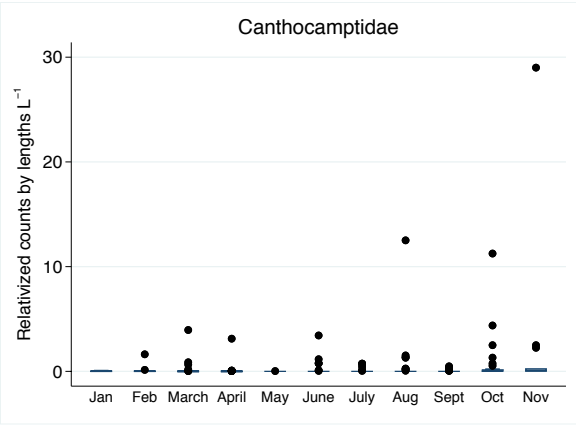
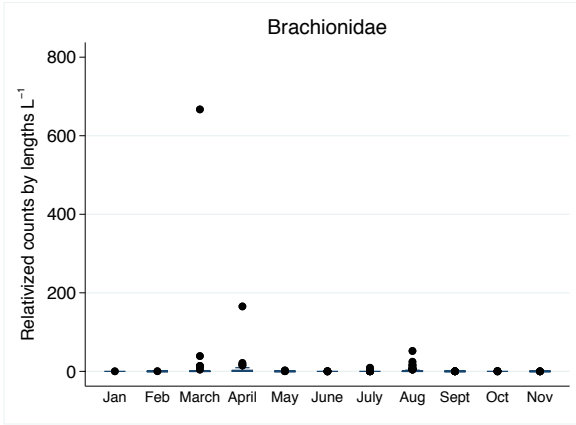


Figure 4. Utah Lake zooplankton assemblages 2015-2018 by month. See Table 4 for zooplankton family codes

Zooplankton Family Monthly Distributions

The following figure (Figure 5) shows zooplankton family distributions (relativized counts) by months throughout Utah Lake. Note that outliers (solid circles) are important when evaluation zooplankton assemblages and indicate population booms.





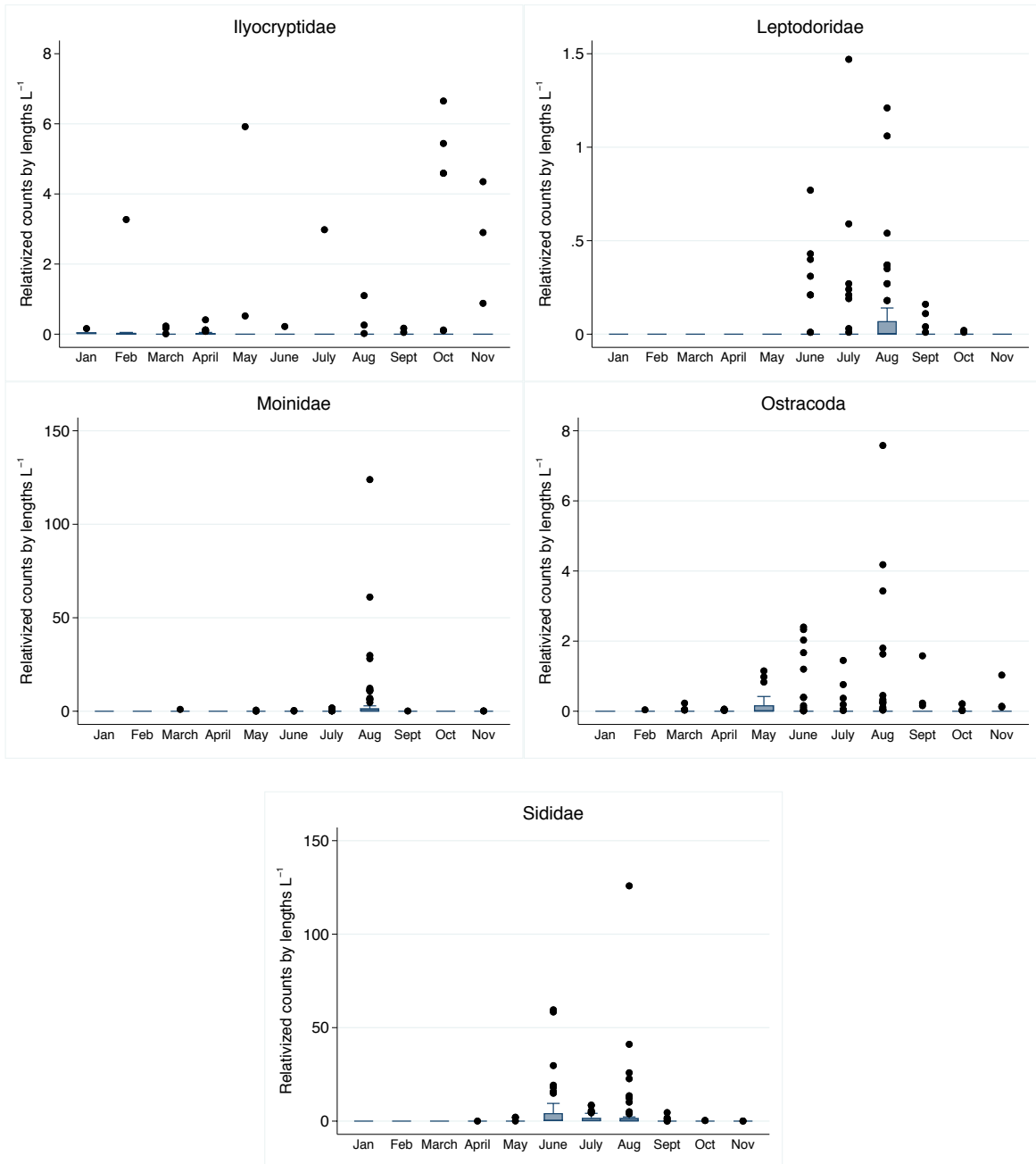


Figure 5. Utah Lake zooplankton families relativeized counts L^{-1} by month. Box plots depicting medians, 25th to 75th percentiles, ranges, and outliers (solid circles). Note: scales are different for each family. Also notice many outliers indicating population booms.

Zooplankton Family Locational Patterns and Distributions

Zooplankton assemblages in Utah Lake also clearly differed by location (Figure 6). There was a contrast between Goshen Bay, lake outlet, Lincoln Beach, and Pelican Marina with Provo Bay, Sandy Beach, and Lindon Marina assemblages which suggests a spatial distributional difference. MRPP results also showed significant differences in zooplankton assemblages between many locations (Overall $T = 0.07$, $p < 0.001$; Appendix 5).

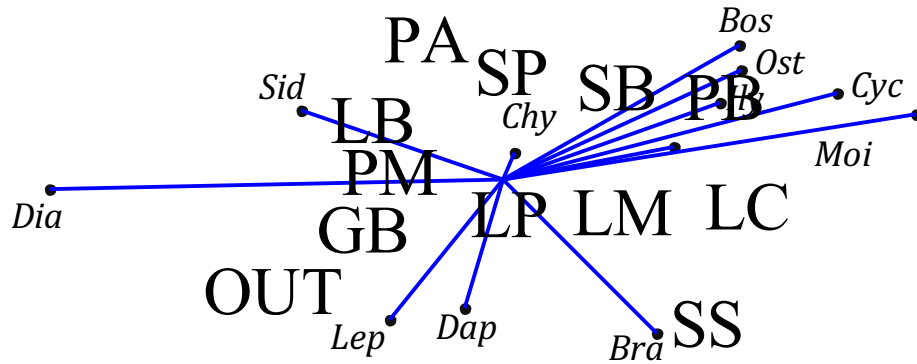
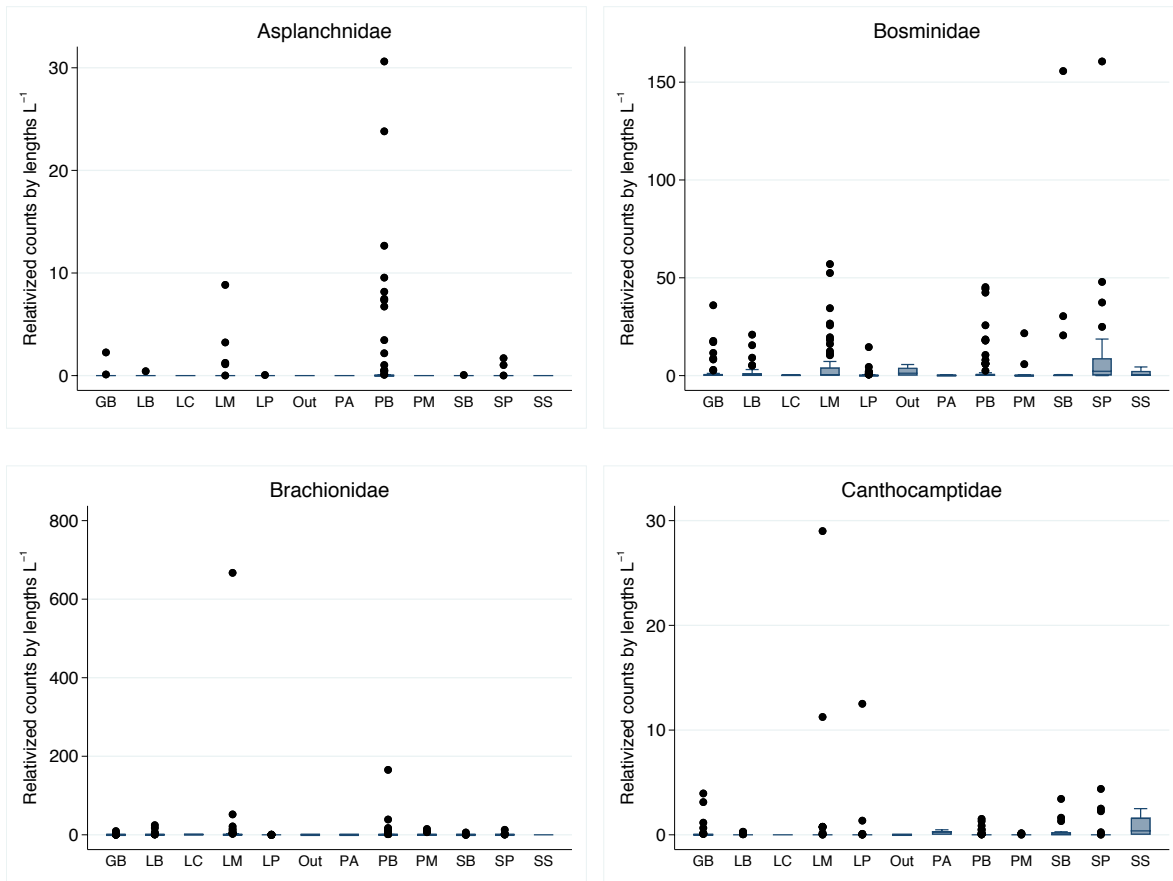
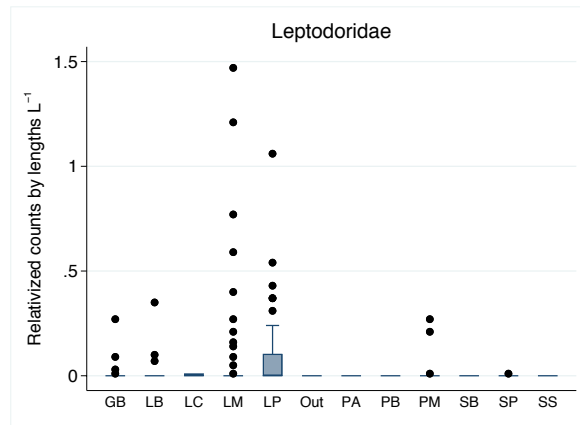
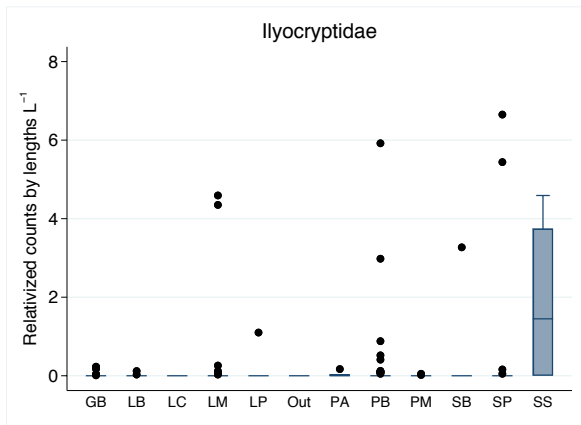
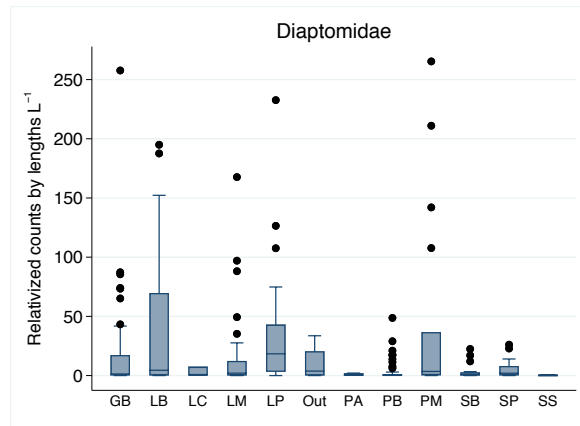
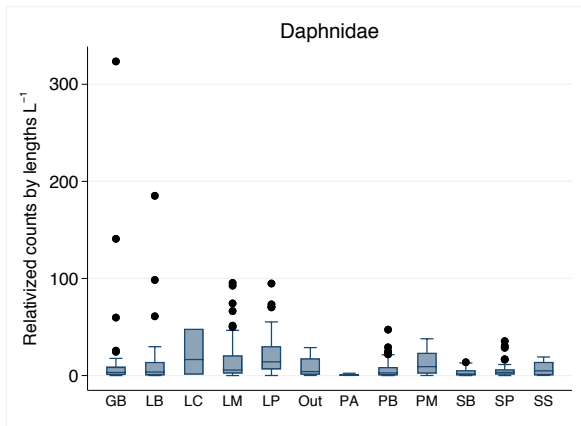
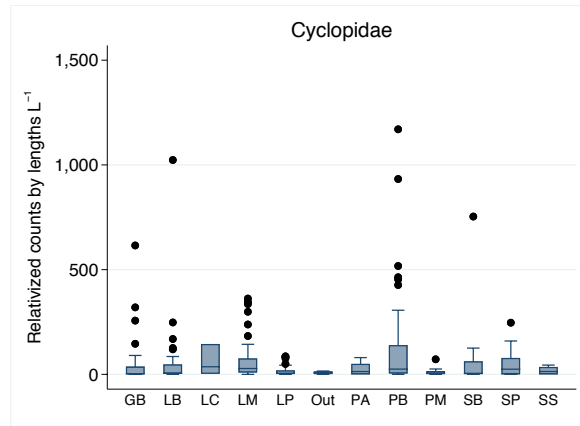
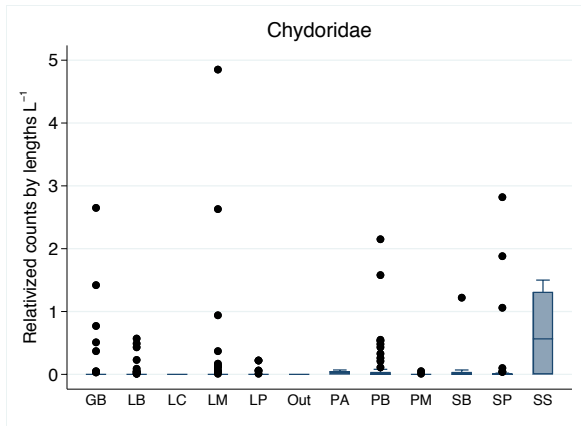


Figure 6 NMS ordination axis 1 and axis 2 of Utah Lake zooplankton assemblages 2015-2018 by location. See Table 4 for zooplankton family codes. Locations categories were inclusive of several locations within the vicinity and increased variability shown in the figure.

The following figure (Figure 5) shows zooplankton family distributions (relativized counts) by locations throughout Utah Lake. Note that outliers (solid circles) are important when evaluation zooplankton assemblages and indicate population booms.





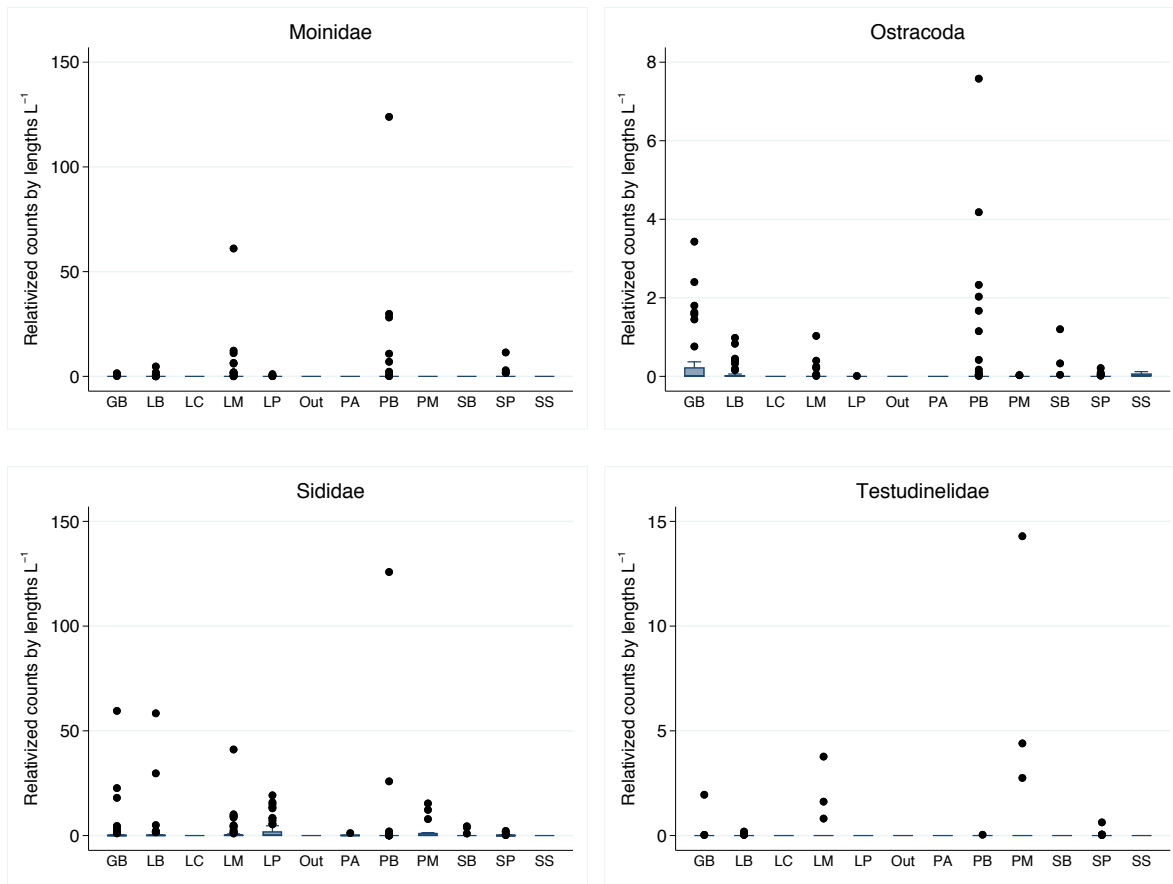


Figure 7. Utah Lake zooplankton families relativeized counts L^{-1} by locations. Box plots depicting medians, 25th to 75th percentiles, ranges, and outliers (solid circles). Note: scales are different for each family. Also notice many outliers indicating population booms. Locations categories were inclusive of several locations within the vicinity and increased variability shown in the figure.

Indicator Species Analysis

Results from Indicator Species Analysis (family level) showed that several zooplankton families were significant indicators of month (Table 5).

Table 5. Indicator species analysis of zooplankton families in Utah Lake by month. Significant indicators are highlighted in yellow. IV = indicator value (see McCune and Mefford 2018 for description of ISA).

Family	Month	Observed IV	Randomized IV	Std. Dev.	p- value
Asplanchnida	March	2.7	5.8	3.78	0.91
Bosminidae	April	18.9	16.1	4.35	0.22
Brachionidae	August	15	12.6	5.05	0.24
Canthocamptidae	November	18.4	8.5	3.75	0.03
Chydoridae	November	15.2	9	4.49	0.09
Cyclopidae	September	23	20	4.28	0.22
Daphniidae	September	18.4	19.5	3.77	0.55
Diaptomidae	February	29.9	17.6	3.87	0.01
Ilyocryptidae	February	14.7	6.5	3.83	0.04

Leptodoridae	July	8.3	5.5	2.76	0.11
Moinidae	April	26.9	6	3.46	0.00
Ostracoda	May	5.9	7.3	3.79	0.57
Sididae	June	20.3	10.9	5.32	0.07

Provo Bay Zooplankton Assemblages

Provo Bay zooplankton assemblage was significantly different than most of the locations in the lake (Figure 6; Appendix 5; Figure 16) including Goshen Bay, Lincoln Beach area (LB), Lindon Marina (LM), Lindon-Pelican transect (LP), and Utah Lake State Park (SP). Provo Bay's zooplankton assemblage also significantly varied seasonally (Figure 8; Figure 9; Figure 16; and Appendix 5).

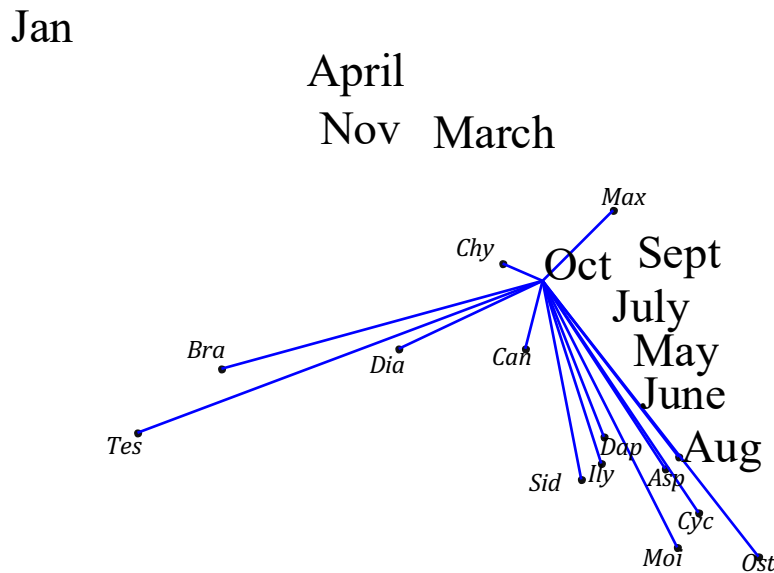
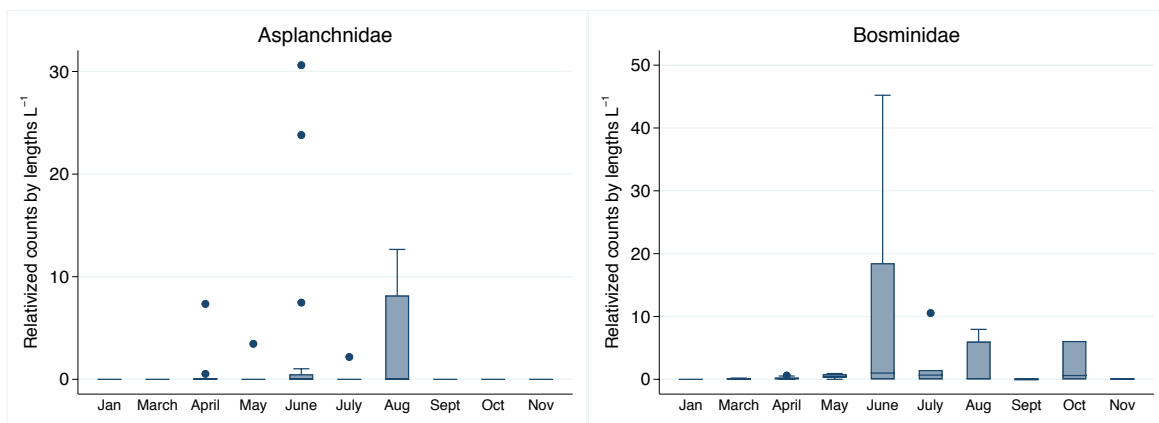
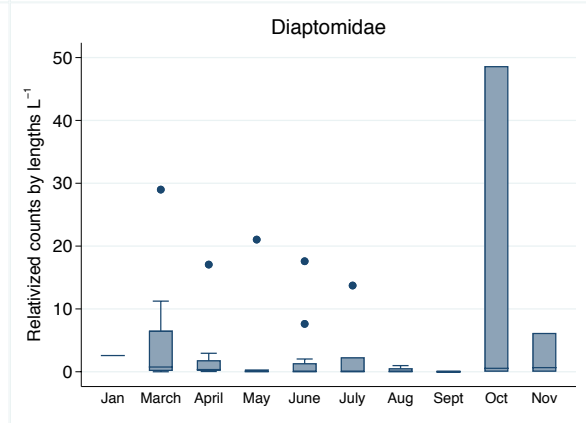
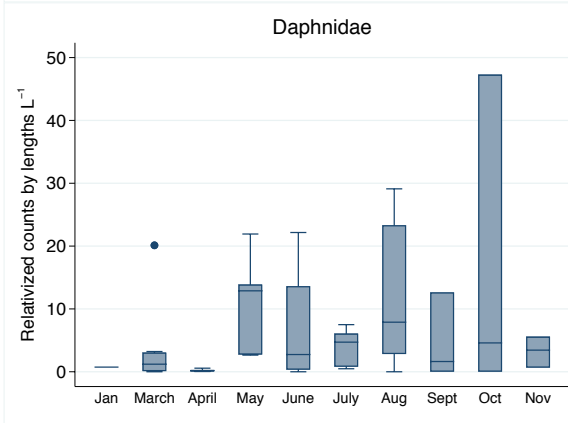
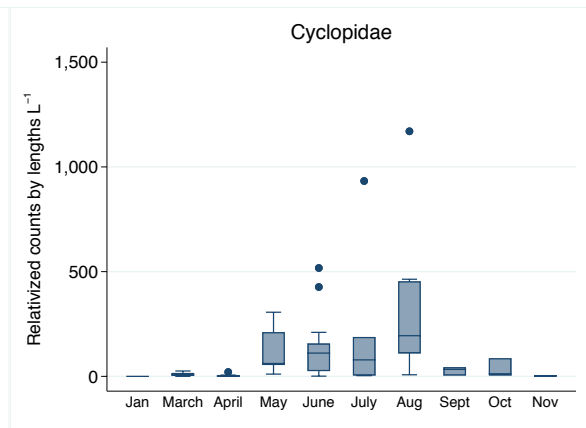
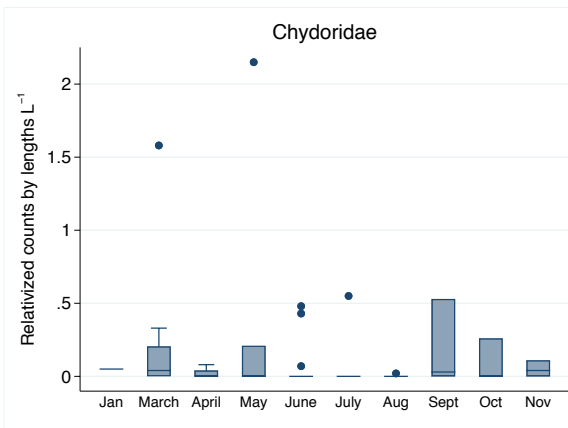
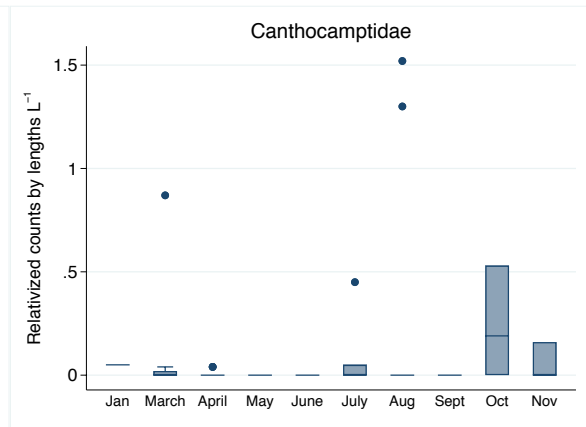
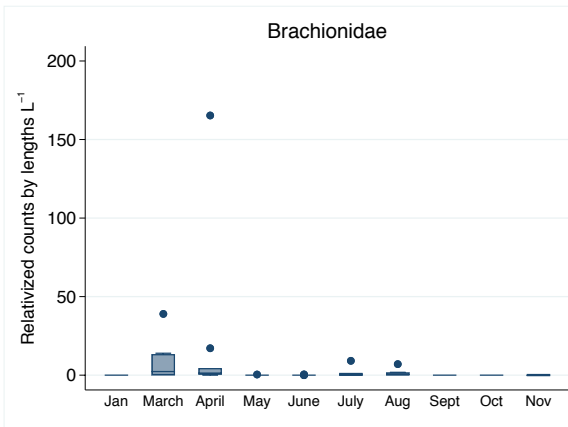


Figure 8. NMS ordination axis 1 and axis 2 of Provo Bay zooplankton assemblages by month. See Table 4 for zooplankton family codes





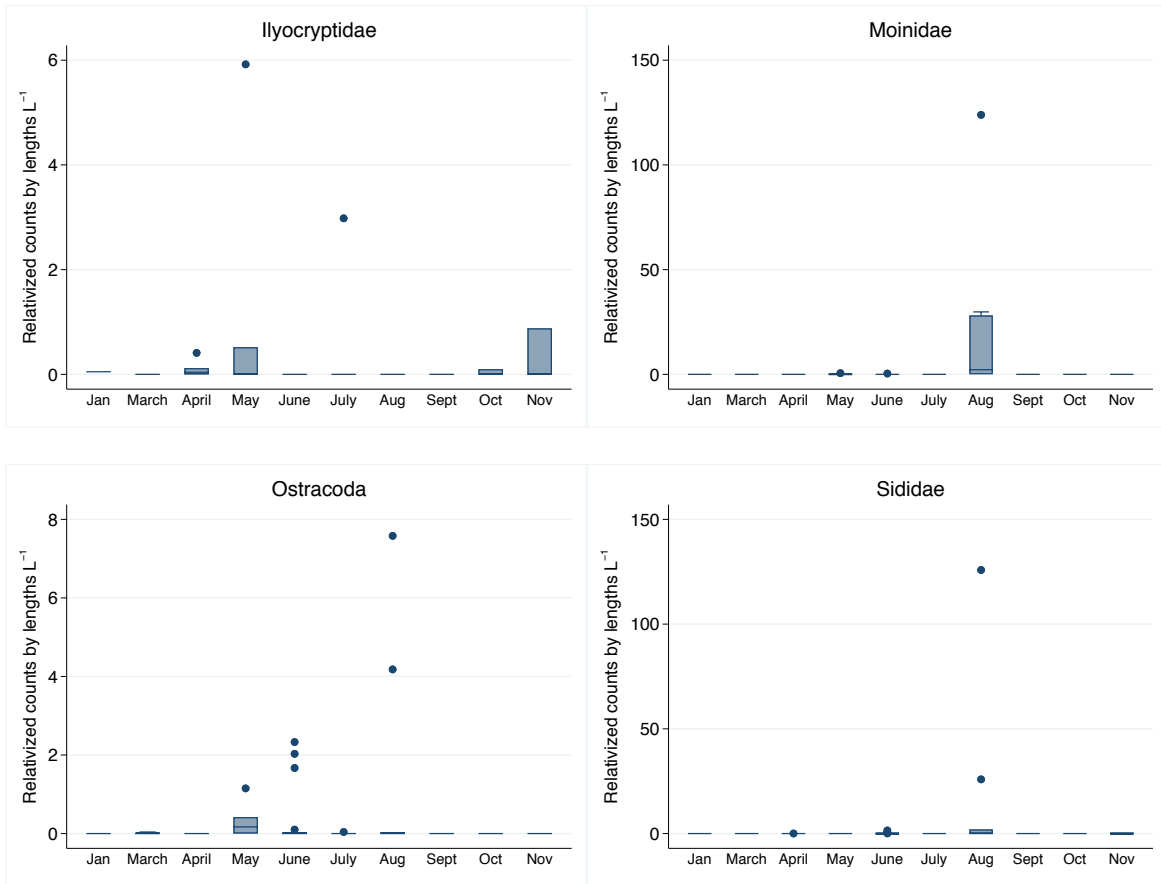


Figure 9. Provo Bay zooplankton families relatived counts L^{-1} by months. Notice outliers which are population booms.

Several zooplankton families were significant indicators of month in Provo Bay

Table 6. Indicator Species Analysis (family level) of zooplankton in Provo Bay by month. Max group is indicator families' month. IV = indicator value (see McCune and Mefford 2018 for description of ISA).

Family	Max group	Observed Value (IV)	Randomized Mean (IV)	Std. Dev.	p-value
Asplanchnidae	September	17.3	18.6	9.86	0.41
Bosminidae	June	41.6	25.8	8.88	0.06
Brachionidae	April	56.5	31.6	14.23	0.05
Canthocamptidae	October	21.5	16.9	9.71	0.19
Chydoridae	May	15.6	19.3	9.97	0.57
Cyclopidae	September	34.8	27.1	6.43	0.13
Daphniidae	October	18.5	21.8	5.09	0.71
Diaptomidae	October	30.9	26	9.83	0.26
Ilyocryptidae	May	24.3	18.4	10.85	0.23
Macrothricidae	May	20	13.4	8.62	0.21
Moinidae	September	63	18.8	11.02	0.00
Ostracoda	September	16.2	19.9	10.75	0.56

Sididae	September	36	23.3	13.24	0.11
Testudinellidae	April	10	13.4	8.72	0.58

Lindon-Pelican Transect Zooplankton Assemblages

Zooplankton assemblages significantly differed between transects across the lake in our Lindon-Pelican transect (Figure 10; Table 7). The best-fit NMS two-dimensional model had a final stress = 5.88; final instability < 0.001; at 106 iterations. Post hoc correlations: Axis 1 $R^2 = 0.65$; Axis 2 $R^2 = 0.34$. Overall MRPP $A = 0.05$; $p = 0.05$.

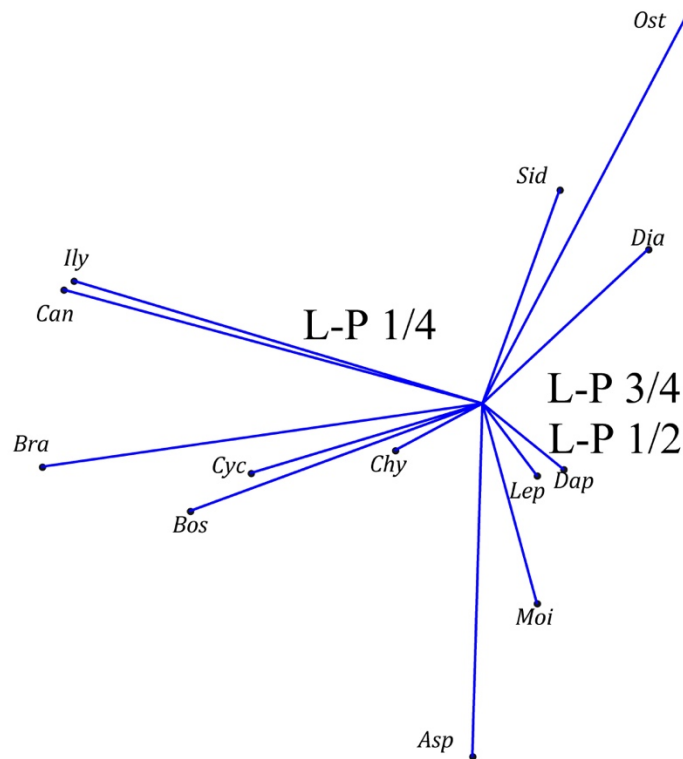


Figure 10. Lindon-Pelican transect by site. See Table 4 for zooplankton family codes

One family, Canthocamptidae was a significant indicator of L-P 1/4, all others were not significant indicators of transect sites.

Table 7. Lindon-Pelican transect blocked Indicator Species Analysis for the three transect sites. Sites were blocked by month.

Family	Site	Observed IV	Randomized Mean IV	Std. dev.	p-value
Asplanchnidae	LP-1/4	5	5.3	0.28	1.00
Bosminidae	LP-1/4	28	27.2	6.62	0.38
Brachionidae	LP-1/4	10.6	10.5	4.31	0.39
Canthocamptidae	LP-1/4	29.2	10.6	4.46	0.00
Chydoridae	LP-1/4	15.7	8.8	4.3	0.14
Cyclopidae	LP-1/4	37.6	39.2	4.65	0.58

Daphniidae	LP-1/2	39.2	41.1	4.2	0.63
Diaptomidae	LP-3/4	36.9	39.4	4.49	0.68
Ilyocryptidae	LP-1/4	5	5.3	0.28	1.00
Leptodoridae	LP-1/2	23.6	19	5.51	0.18
Moinidae	LP-1/4	10.3	8.6	3.92	0.31
Ostracoda	LP-1/4	5	5.4	0.28	1.00
Sididae	LP-1/4	26.8	27.1	6.32	0.46

Assemblages also significantly differed between months in the Lindon-Pelican transect (Figure 11). MRPP = 0.23; $p < 0.0001$. See Appendix 16 for MRPP monthly comparisons of assemblages.

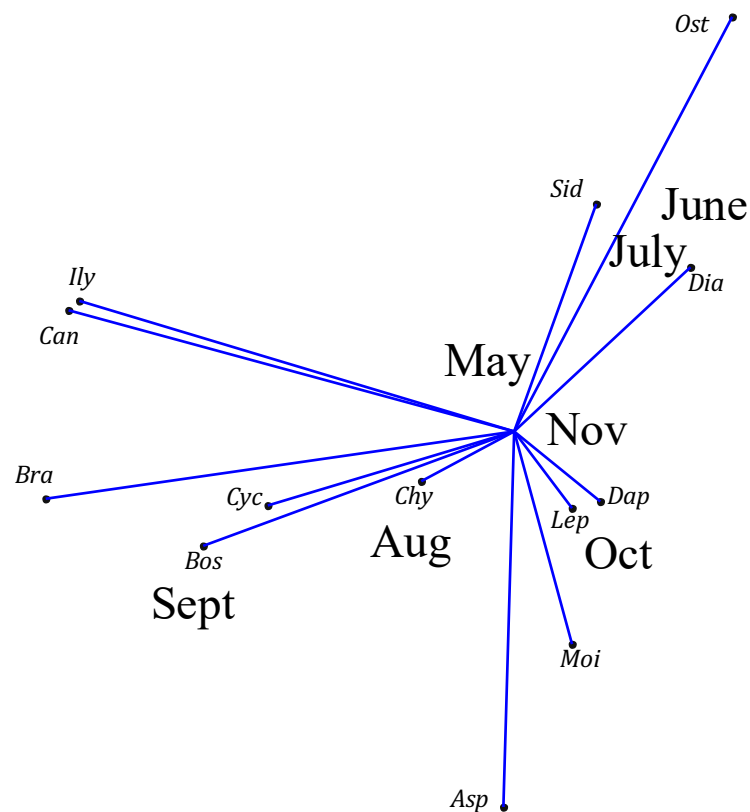


Figure 11. Lindon-Pelican transect by NMS ordination Axis 1 and Axis 2 by month. See Table 4 for zooplankton family codes

Lindon Marina Zooplankton Assemblages

Lindon Marina is often a cyanoHABs hotspot. The best fit NMS two-dimensional model had a final stress = 10.50; final instability < 0.001 at 59 iterations. Post correlation Axis 1 $R^2 = 0.29$; Axis 2 $R^2 = 0.65$. Zooplankton assemblages at Lindon Marina also significantly differed between months (MRPP A = 0.08; $p = 0.01$). See Appendix 13 for MRPP results for monthly differences.

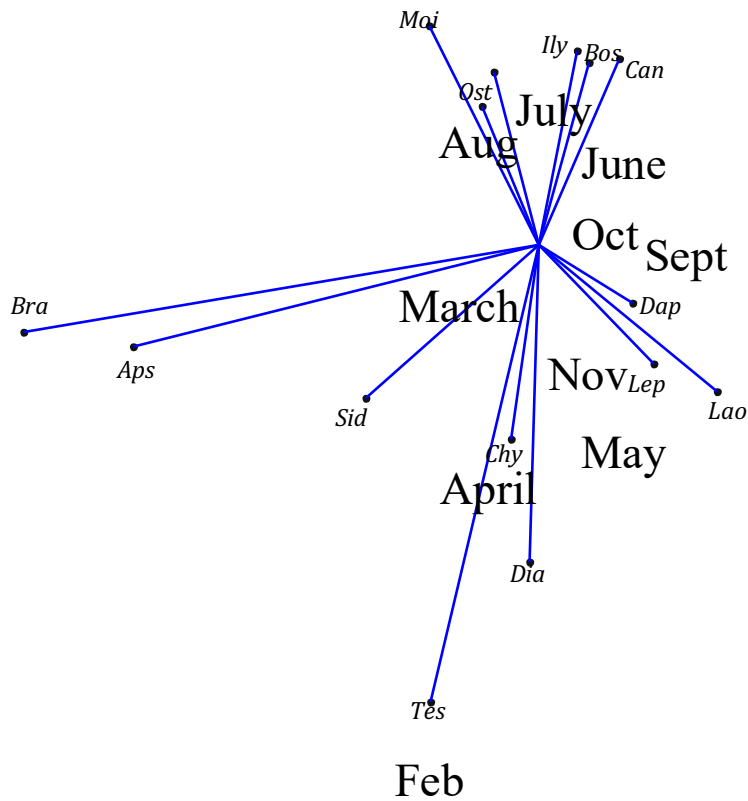


Figure 12. Lindon Marina NMS ordination Axis 1 and Axis 2 by month. See Table 4 for zooplankton family codes. Note: Axis 2 explained 0.65 variability, whereas Axis 1 only explained 0.29 variability.

Several zooplankton families were significant (or close to significant) monthly indicators in Lindon Marina (Table 8).

Table 8. Indicator Species Analysis (family level) of zooplankton in **Lindon Marina** by month. Max group is indicator families' month. IV = indicator value (see McCune and Mefford 2018 for description of ISA).

Family	Month	Observed IV	Randomized Mean IV	Std. dev.	p-value
Asplanchnidae	February	16.5	17.7	10.39	0.43
Bosminidae	May	39	27.4	7.96	0.09
Brachionidae	June	92	47.6	17.42	0.03
Canthocamptidae	November	24.9	22.8	12.16	0.35
Chydoridae	February	16.8	21.9	11.64	0.60
Cyclopidae	January	27.4	23	4.5	0.15
Daphniidae	August	18.7	22.3	4.25	0.81
Diaptomidae	February	42.9	28.6	8.29	0.07
Ilyocryptidae	August	22.2	19.1	9.87	0.27
Laophontidae	April	13.8	16.5	8.3	0.70
Leptodoridae	April	24.1	18.2	9.56	0.20

Moinidae	January	50.2	22.3	12.57	0.05
Ostracoda	November	24.8	18.4	10.54	0.21
Sididae	April	31.1	24.5	11.85	0.23
Testudinellidae	February	60	16.4	8.73	0.01

Goshen Bay Zooplankton Assemblages

Zooplankton assemblages in Goshen Bay also significantly differed by months (MRPP A = 0.29; $p < 0.001$). The best-fit NMS model had a final stress = 10.48; final instability < 0.0001 at 65 iterations. Post hoc correlation Axis 1 $R^2 = 0.63$; Axis 2 $R^2 = 0.26$. Figure 13 clearly shows the difference between summer/autumn assemblages and late winter/spring assemblages.

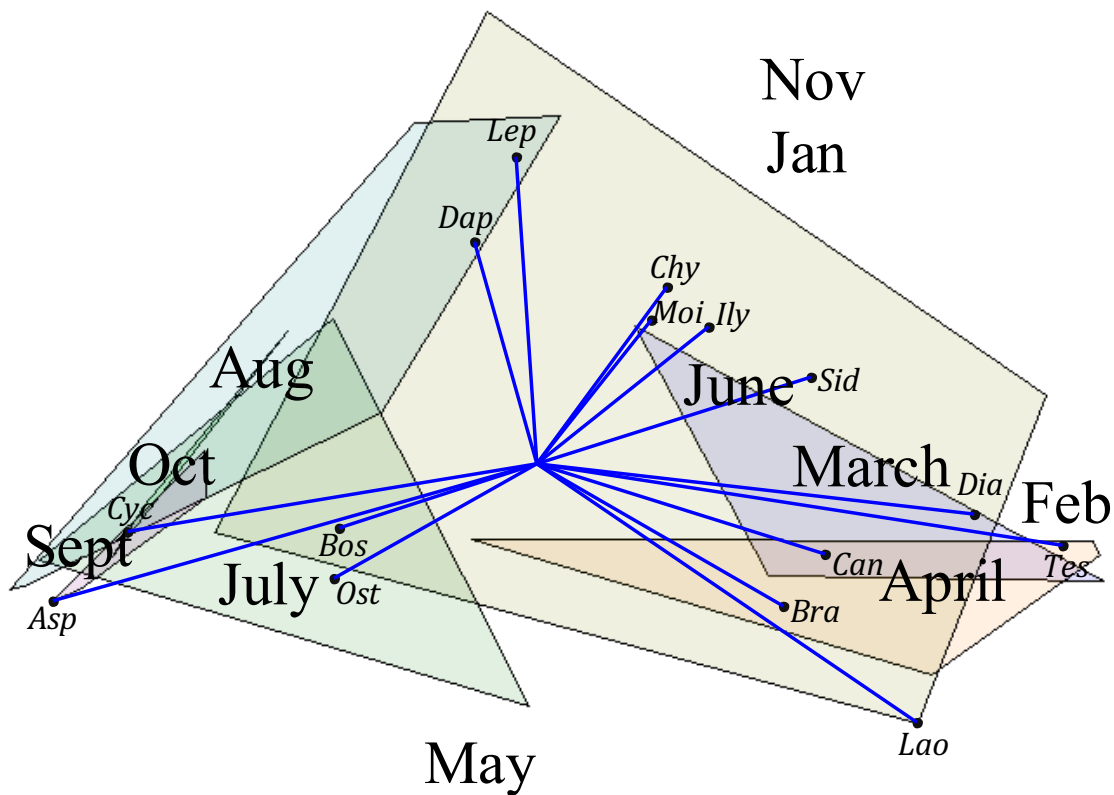


Figure 13. NMS Axis 1 and Axis 2 ordination for zooplankton assemblages in Goshen Bay. See Table 4 for zooplankton family codes. Colored areas are convex hulls.

Several zooplankton families were significant indicators of month in Goshen Bay (Table 9).

Table 9. Indicator Species Analysis (family level) of zooplankton in Goshen Bay by month. Max group is indicator families' month. IV = indicator value (see McCune and Mefford 2018 for description of ISA).

Family	Month	Observed	Randomized	Std. dev.	p-value
--------	-------	----------	------------	-----------	---------

		IV	Mean IV		
Asplanchnidae	September	40	23.9	13.69	0.19
Bosminidae	May	22.6	32.8	11.43	0.83
Brachionidae	April	54.5	28.4	14.09	0.06
Canthocamptidae	March	40.8	27.9	14.16	0.14
Chydoridae	November	35.1	23.4	12.95	0.14
Cyclopidae	May	66.4	37.9	10.27	0.01
Daphniidae	May	59.5	47.3	11.47	0.18
Diaptomidae	April	48.4	31	10.76	0.11
Ilyocryptidae	March	49.3	21.6	11.83	0.04
Laophontidae	July	12.5	22.6	12.28	1.00
Leptodoridae	May	21.5	23.1	14.01	0.41
Moinidae	March	13.7	21.9	12.5	0.60
Ostracoda	May	30.2	23.3	10.44	0.20
Sididae	July	32.4	28.6	14.62	0.33
Testudinellidae	April	60	25.4	14.06	0.01

Additional Spatial and Temporal Relative Abundance Comparisons

None of the zooplankton family-level relativized counts L^{-1} were close to being normally (Gaussian) distributed, therefore arithmetic means were an inappropriate measure for any type of statistical analyses. Most distributions approached a truncated negative binomial distribution, subsequently we elected to use medians (50th percentiles) and 90th percentiles to assist in comparing relative abundances across months and locations. As also shown in the previous NMS and MRPP results; there was a seasonal progression of zooplankton families within and between locations. There were also several noticeable differences between median and 90th percentiles indicating large population booms for a few taxa.

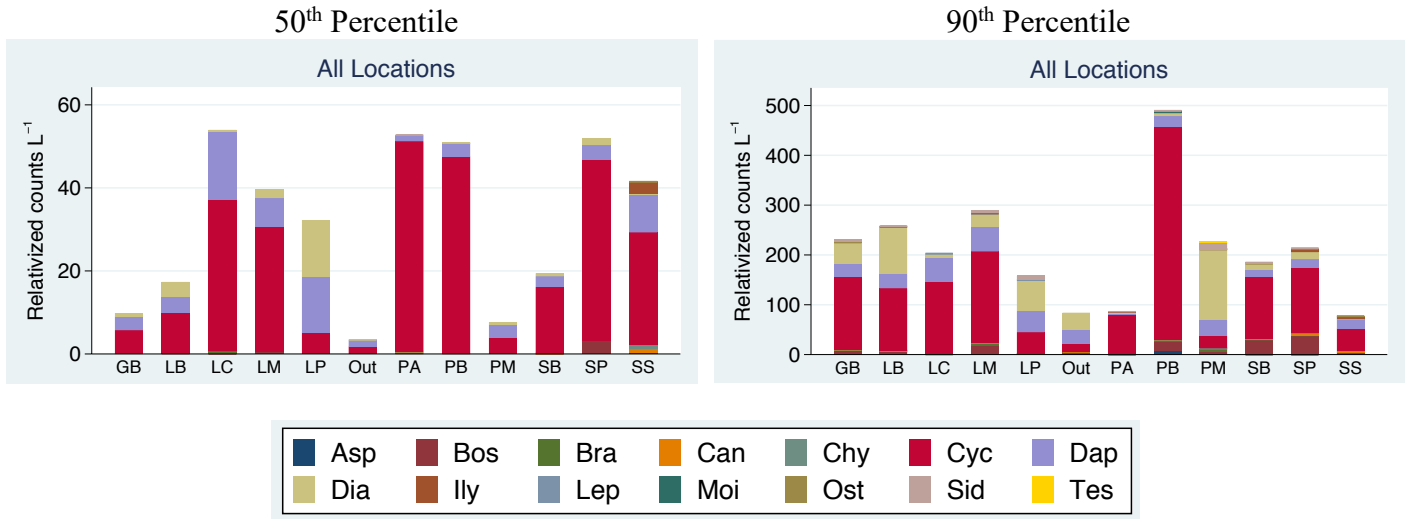


Figure 14. Relative abundances of zooplankton families at the different sites. Note: y axis scales are not the same. See Table 4 for family names based on codes in legend.

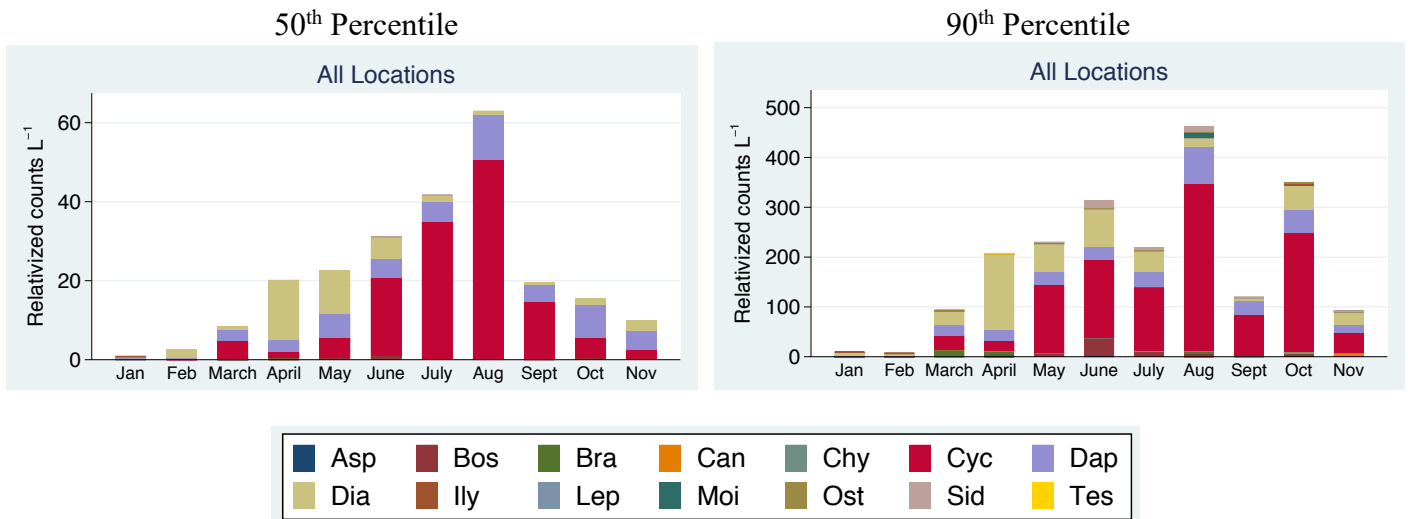


Figure 15. Relative abundances of zooplankton families at the different months based on 50th and 90th percentiles. Note: y axis scales are not the same. See Table 4 for family names based on codes in legend.

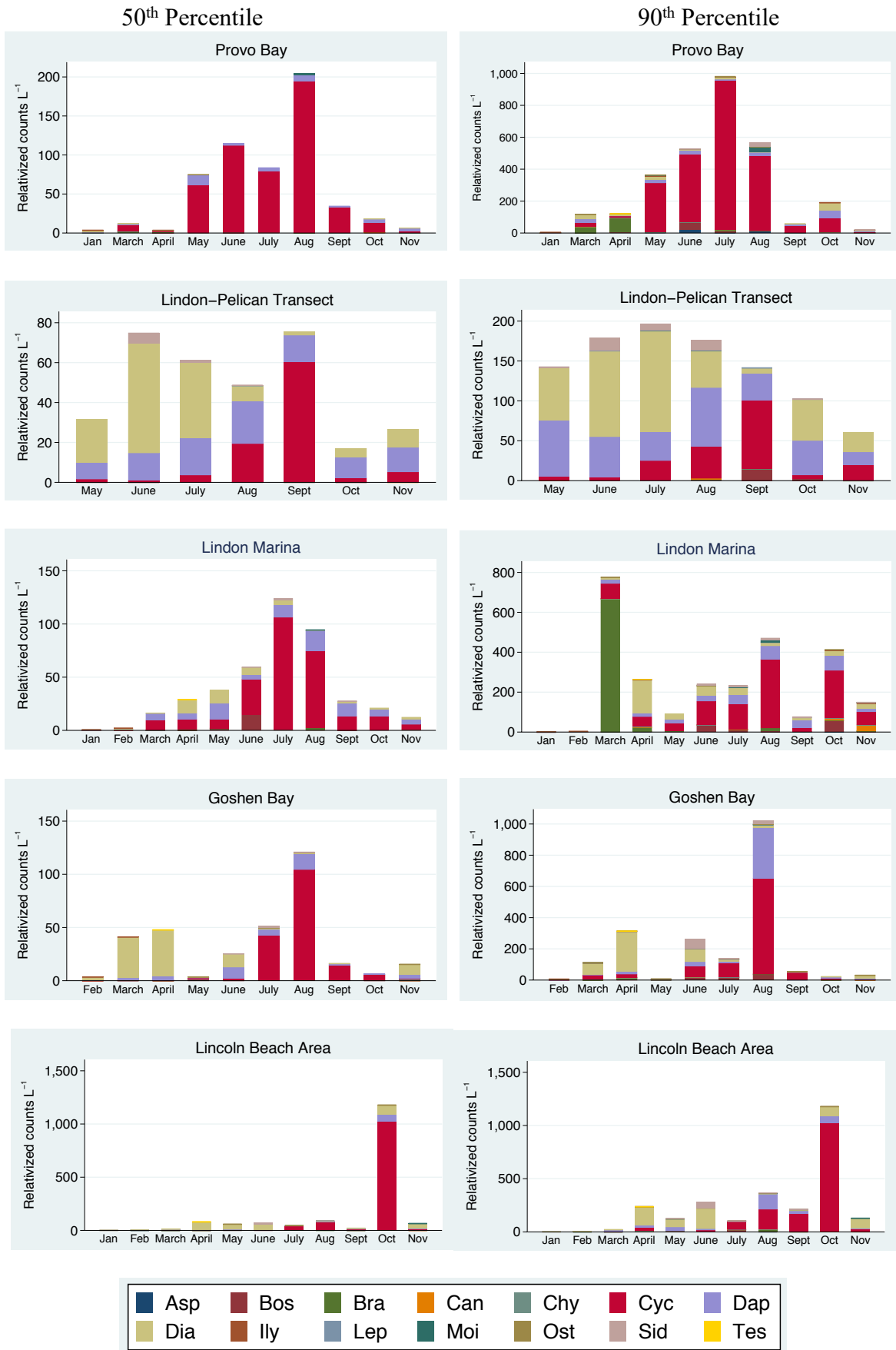


Figure 16. Relative abundances of zooplankton families at the different months based on 50th and 90th percentiles. Note: x and y scales are much different between sites See Table 4 for family names based on codes in legend.

Taxa Based Diversity Metrics

We also analyzed 2015 to 2107 data separately from 2018 data to reduce discrepancy problems between taxonomy labs and to obtain better resolution and more information. The following results are based on lowest practical taxon (mostly genus, species) and not family level.

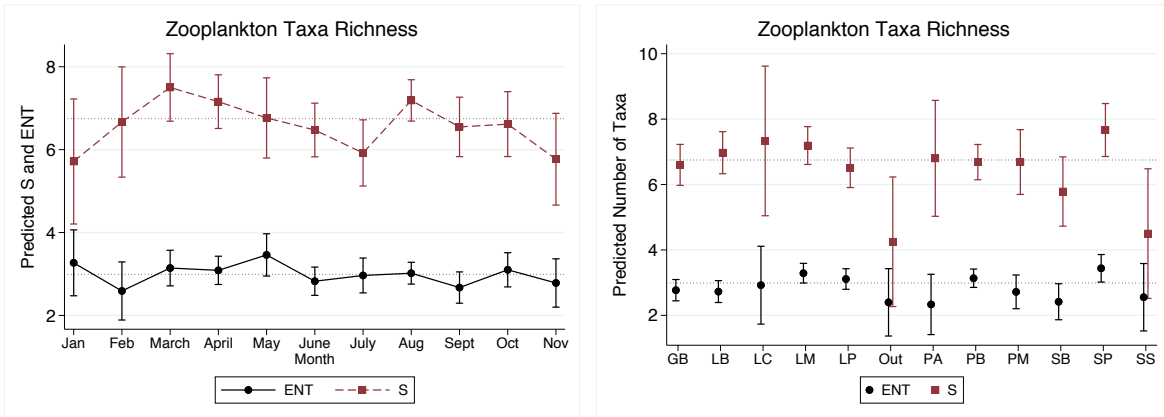


Figure 17. Zooplankton taxa richness (S) and effective number of taxa (ENT) by month and site. Taxa richness is number of taxa per sample. 2015 to 2017 data only.

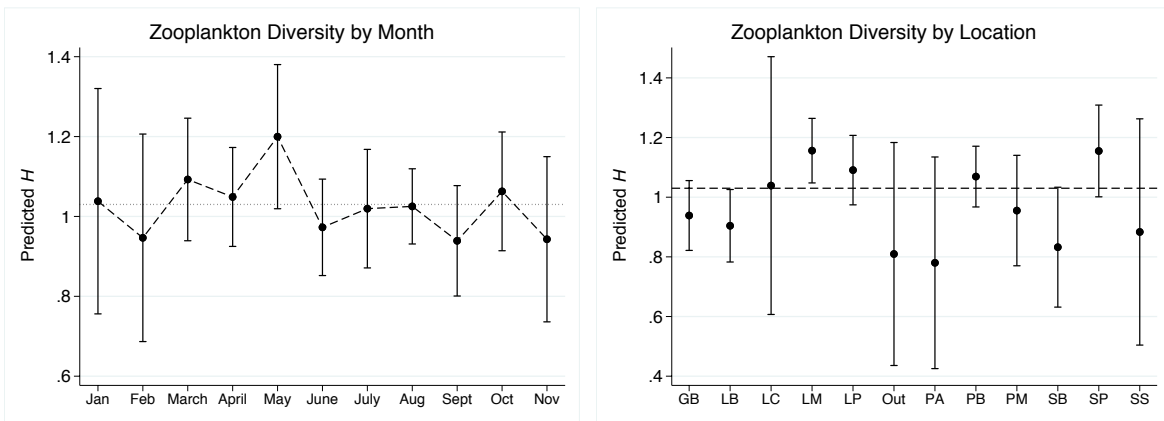


Figure 18. Zooplankton diversity (H) by month and location. 2015 to 2017 data only.

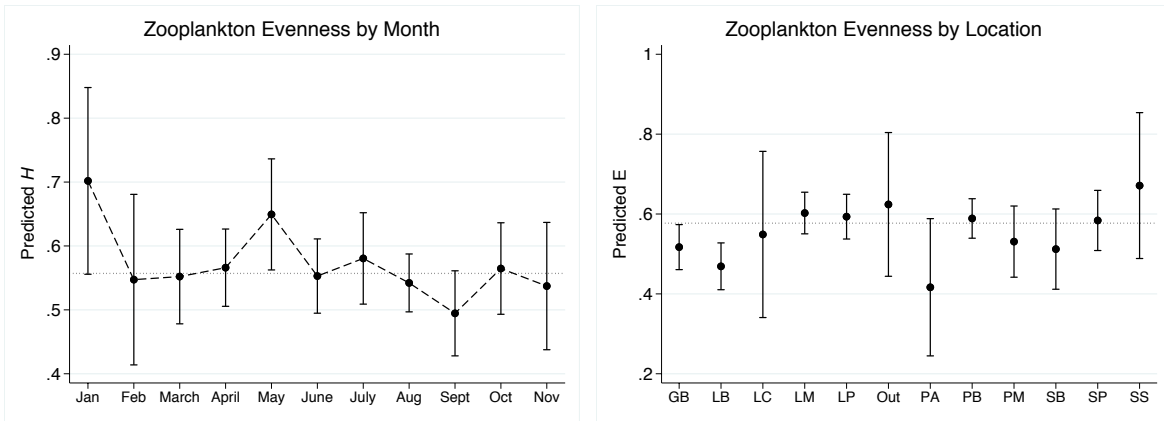


Figure 19. Zooplankton evenness (E) by month and site. Note y axis should be labeled E , not H in month graph. 2015 to 2017 data only.

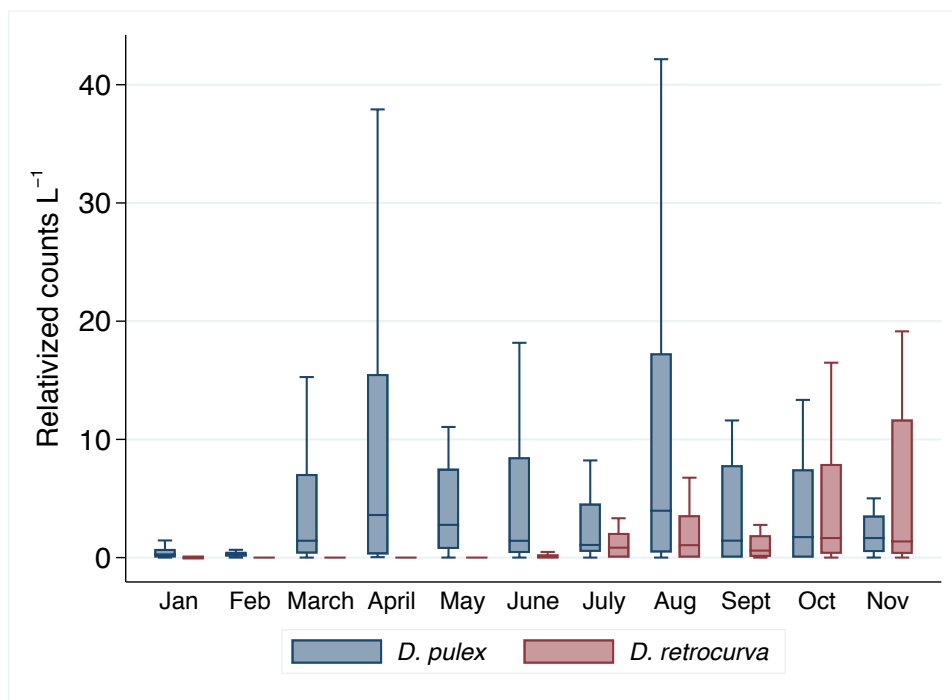


Figure 20. Realized niche separation by month for two daphnia species in Utah Lake, *Daphnia pulex* and *Daphnia retrocurva*. 2015 to 2017 data only. Assumes these are valid species. Could simply be labeled species 1 and species 2. Shows seasonal shift between two species in the same genus and infers different ecological niches. See Attachment 1 for discussion on taxonomic synonyms.

Discussion

Zooplankton assemblages in Utah Lake obviously differ spatially and temporally as we have demonstrated in this progress report and other reports (Richards and Miller 2017; Richards 2018; Richards 2016). We clumped assemblages into somewhat loosely based location groupings and a less sensitive temporal category, month for our analyses. Given the variability in some of our results in this progress report, assemblages likely differ spatially and temporally more so than we have shown. Understanding that zooplankton assemblages can significantly vary at different times of the year and locations in Utah Lake is a first step in determining relationships between zooplankton and other factors in the lake's food web. Without this understanding management goals and strategies would be purely subjective.

Taxa Richness

We found that zooplankton taxa richness was somewhat low in Utah Lake during our research, on average about 20 or so β –diversity richness but were not sure how this low diversity related to other locations and what might cause such low diversity. We then developed an additional zooplankton diversity predictive model for Utah Lake zooplankton and discuss these findings with what is known from the literature.

We predicted an expected number of pelagic zooplankton taxa derived from a best fit regression analysis on data obtained from the North Temperate Lakes Information Management System (2019). The original model was based on Dodson (1992). Predictor variables in the data set included:

- Latitude
- Longitude
- Elevation (m)
- Lake area (m²)
- Maximum depth (m)
- Mean depth (m)
- Conductivity
- Distance from nearest lake to lake (km)
- Number of lakes within 20 km
- Primary productivity (mg C m⁻³ d⁻¹)

Dodson (1992) determined that the best linear model of expected zooplankton taxa (S) was:

$$\text{Log}_{10}(S) = \text{constant} + \text{log}_{10}(\text{lake area}) + \text{log}_{10}(\text{average rate of photosynthesis}) - \text{log}_{10}(\text{average rate of photosynthesis})^2 + \text{log}_{10}(\text{number of lakes within 20km})$$

however, his analysis was conducted on 66 lakes.

We reanalyzed an updated version of the Dodson (1992) dataset that included 3 additional lakes that were shallower and more eutrophic using linear combinations of nine of the variables listed above (longitude excluded), including the quadratic \log_{10} average rate of photosynthesis that accounted for an expected decrease in number of zooplankton taxa under hyper eutrophic conditions (Dodson 1992). We then evaluated several dozen models based on combinations of the 9 predictor variables using linear, Poisson, and negative binomial regression models and evaluating all models using log likelihood ratio, AIC, BIC, and R^2 .

The best fit model of the updated data set was simply a linear model:

$$\text{Log}_{10}(S) = \text{constant} + \log_{10}(\text{lake area}) \text{ with an } R^2 = 0.54.$$

See Table 10 for regression results.

Table 10. Our best fit regression model for predicting zooplankton taxa richness based on Dodson (1992) and North Temperate Lakes Information Management System (2019) dataset.

Source	SS	df	MS	Number of obs	=	68
				F(1, 66)	=	78.11
Model	3.19987162	1	3.19987162	Prob > F	=	0.0000
Residual	2.70362729	66	.04096405	R-squared	=	0.5420
				Adj R-squared	=	0.5351
Total	5.90349891	67	.088111924	Root MSE	=	.2024

logS	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
logArea	0.089	0.010	8.84	0.00	0.069	0.109
_cons	0.838	0.027	30.99	0.00	0.784	0.892

Based on the regression results for \log_{10} lake area, constant coefficients and their 95% CIs (Table 10); we estimated that zooplankton taxa richness for a lake the size of Utah Lake ($\approx 95,000$ acres) should have ranged from a 95% CI low = 24 to a 95% CI high = 67 with mean = 40 taxa. The observed number of zooplankton taxa in our studies was only 20 or so, significantly lower than the lowest 95% CI of 24 and almost half of the mean number of taxa = 40 predicted by our best fit regression model.

Even given the problems with taxonomic resolution described in the Methods section and Attachment 1, this is still a very low number of zooplankton taxa in Utah Lake and is concerning. In addition, the effective number of zooplankton taxa in Utah Lake was only about 3 or 4 taxa. Several likely explanations for this low taxonomic richness include: Utah Lake's distance to other suitable zooplankton waters; reduced zooplankton richness associated with

hyper eutrophic conditions (Dodson 1992); the lakes shallowness and low habitat heterogeneity; and limited amounts of submerged aquatic vegetation for protection from planktivorous fish (see Ecological Effects of Fish Planktivory on Utah Lake's Zooplankton Assemblages and Food Web section below).

Utah Lake, Great Salt Lake, and Ancient Lake Bonneville Legacy

Zooplankton assemblages in Utah Lake did not colonize and evolve in static spatial and temporal isolation. Assemblages we find in Utah Lake today are a result of past and present biotic and abiotic conditions, connectivity with other water bodies, and its ancient Lake Bonneville legacy. Utah Lake and Great Salt Lake (GSL) are but small remnants of once immense Lake Bonneville that existed 75,000 to 8,000 years ago (Brimhall and Merritt 1981). Many of the zooplankton taxa found in Utah Lake today evolved in this ancient lake. Zooplankton also survived and evolved in terminal GSL as Lake Bonneville retreated. Great Salt Lake became increasingly saline because it was at the terminal end of its drainage, geologic parent material inputs, low precipitation, few freshwater tributaries, and its increasingly shallow nature and thus less hospitable for many native zooplankton taxa. Utah Lake is slightly saline, more so than Lake Bonneville, but much less so than GSL due to several inflowing freshwater tributaries and regular flushing outflow into the Jordan River. Utah Lake is also very shallow. Farmington Bay of GSL is a relatively new freshwater addition to GSL due to the flow reducing causeway built several decades ago. Farmington Bay is also the downstream recipient of Utah Lake water via transport from the Jordan River, subsequently zooplankton assemblages in Farmington Bay are more similar to those in Utah Lake than other parts of GSL (Wasatch Front Water Quality Council unpublished data). Zooplankton dispersal between Utah Lake and Farmington Bay is predominantly unidirectionally downstream from Utah Lake to Farmington Bay but there is likely some limited recruitment of zooplankton upstream from Farmington Bay via wind or biotic transport. There are few if any other upstream sources of zooplankton to Utah Lake within its drainage mostly because Utah Lake is slightly brackish and warm in summer, whereas most other potential sources are colder water bodies¹. Consequently, zooplankton assemblages in Utah Lake follow classic metacommunity dynamics, i.e. limited connectivity, isolation from other sources, and increased extinction risk due to isolation but less so if it was completely isolated from rescue effects from limited dispersal from Farmington Bay.

Utah Lake and Farmington Bay zooplankton assemblages are inherently connected via their umbilicate Jordan River, close proximity to one another, ecological similarity, and ancient heritage. We have collected dozens of zooplankton samples from Farmington Bay and are continuing to do so. Analyses are in progress. Contrasts and comparisons between these two similar waterbodies are an important component of our research and will shed light onto anthropogenic induced causes of differences in zooplankton assemblages between the two.

¹ However, there are some man-made lakes, ponds, and reservoirs, as well as wetlands in the Utah Lake drainage that may support zooplankton taxa whose niches are compatible with Utah Lake environment and may on occasion colonize or recolonize Utah Lake.

Although preliminary results show that zooplankton assemblages in Utah Lake and Farmington Bay are taxonomically quite similar, there are some differences, the most visibly obvious is the much larger body size of zooplankton collected from Farmington Bay.

Based on our knowledge of zooplankton ecology and the literature; we hypothesize that the larger body size of zooplankton in Farmington Bay is primarily a result of reduced planktivorous fish predation. Farmington Bay has very few resident fish except for low abundances of invasive carp (*Cyprinus carpio*). Utah Lake on the other hand supports a tremendous fishery consisting of perhaps a dozen introduced fish species that at one time or another during their life cycle are planktivores, including carp that feed on zooplankton throughout their lives. Annual secondary and tertiary fish production in Utah Lake is easily measured by the ton, indicative of an unnatural top down effect on the lake's zooplankton assemblages and eutrophic conditions, which in turn affects individual zooplankton species life histories and ecologies. These predation effects of introduced fishes on zooplankton in Utah Lake also reverberate throughout its food chain, including phytoplankton assemblage composition, algal blooms, and cyanoHABs.

Ecological Effects of Fish Planktivory on Utah Lake's Zooplankton Assemblages and Food Web

It has been well documented that planktivory by introduced fish can alter food webs and can often result in unwanted algal blooms (Sondergaard et al. 2008). Introductory fisheries management students are well aware that predatory fish play a basic role in maintaining the equilibrium of a lake by controlling planktivorous fish, which favors grazing zooplankton abundance, which in turn reduces phytoplankton abundance (Wetzell 2001; Cole and Weihe 2016). For example, Sondergaard et al. (2008) showed that removal of planktivorous fish resulted in a significant decline in total algal biomass, particularly that of cyanobacteria, whereas the biomass of cryptophytes (type of algae) increased, indicating enhanced grazing pressure by zooplankton. Sondergaard et al. (2008) also reported that concentrations of chlorophyll a (Chla), total phosphorus (TP), total nitrogen (TN), and suspended solids (SS) in the water column decreased to 50–70% of the level prior to fish removal. Crisman and Beaver (1990) reported that large-bodied cladocerans such as daphnia can reduce algal biomass significantly in temperate lakes if freed from fish predation.

Typically, as planktivorous fish become more abundant zooplankton abundance decreases and in particular, larger sized zooplankton species are diminished leading to dominance by smaller sized species (Gophen 1990). Larger zooplankton are able to consume a wider range of algae types compared to smaller zooplankton. As the ratio of planktivores to piscivores widens, the ability of piscivores to control planktivore populations is reduced (Cooke 1986). This is likely what is happening in highly regulated Utah Lake and may in part be a cause of cyanoHABs and leads us to suggest that adaptive fisheries management of Utah Lake may be an important tool for controlling cyanoHABs.

Biomanipulation

Even though some scientists and managers argue against biomanipulation of planktivorous fish, it continues to be a relatively effective method of lake restoration in shallow lakes compared to nutrient management (Riedel-Lehrke 1997). Nutrient management strategies are not typically long-term solutions to eutrophication problems in shallow lakes (i.e. Utah Lake), whereas biomanipulation is often more cost effective and potentially a more long-term solution and appears to produce desirable results in most instances (Cooke 1986; Riedel-Lehrke 1997; Shapiro 1990). Since Utah Lake suffers from eutrophication, new insights are needed into trophic interactions, including planktivorous fish-zooplankton-phytoplankton interactions and potential lake restoration methods, especially since eutrophication is expected to increase in the future due to human economic activity and global warming (Jeppesen 2007). As we have affirmed in several reports (Richards and Miller 2017; Richards 2018; Richards 2016):

Utah Lake's ecosystem is now a second-rate, highly regulated, analog of its historic past; we can manipulate it any way we see fit.

Other Factors

As we eluded to previously, Utah Lake's distance to similar lakes is < 20 km and the number of similar lakes in the vicinity is likely only one: Farmington Bay, a recently evolved lake. Dodson's (1992) taxa richness model included the number of lakes within 20 km as an important factor in determining the number of zooplankton species in a lake. We emphasize that:

Isolation = ↑ Extinction Rates,

and with increased extinction rates comes less ability to regulate phytoplankton blooms.

Zooplankton richness is also affected by eutrophication. As eutrophication increases from oligotrophic to eutrophic zooplankton richness tends to increase but at some threshold towards hyper eutrophication conditions, richness decreases (Dodson 1992). Utah Lake is considered hyper-eutrophic and the low effective number of taxa that we reported may very well be related in part to excessive eutrophication.

Shallower lakes often have fewer zooplankton taxa and of course, Utah Lake is very shallow. Utah Lake has lost much of its habitat heterogeneity due to increased shallowness and other anthropogenic factors that we have discussed in past reports, including loss of submerged aquatic vegetation due to grazing and feeding by invasive carp (Richards and Miller 2017; Richards 2018; Richards 2016).

Taxonomy and Functional Traits

Unfortunately, taxonomic resolution and status of Utah Lake's zooplankton assemblages are still not quite resolved. This is a large problem that needs to be addressed as soon as possible before researchers begin to analyze any more zooplankton data from the lake. As Dodson (1992) stated:

Taxonomic problems will affect the species lists. The problem is not with what a species is called, but with groups of species that tend to be lumped under one name. For example, the name "*Acanthocyclops vernalis*" is applied to a group of at least four genetically and morphologically distinct species (e.g. Smith 1981) and the "Daphnia pulex" group likely contains several cryptic species (e.g. Dodson 1981; Hebert et al. 1989). Thus, the length of a species list will be affected by the taxonomic taste and skill of the author.

We have taken the lead in determining the taxonomy of Utah Lake's zooplankton and suggest that the analysis that River Continuum Concepts has presented in Attachment 1 should be the baseline and authority until otherwise determined invalid. We are encouraging several genetics labs to update their zooplankton DNA databases to account for these taxonomic changes and once accomplished, costs of processing samples will be substantially reduced.

We are also compiling the most complete database of Utah Lake zooplankton functional traits. This dataset will be invaluable for our analysis of interactions within Utah Lake's food web and will help us to better understand causes and potential remedies for cyanoHABs in the lake.

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Appendices

Appendix 1. Non metric multidimensional scaling (NMS) best fit model Measures of Fitness results for zooplankton assemblages (family level) in Utah Lake 2015-2018.

MEASURES OF FIT

R²n (nonmetric fit) = 0.9868 Intrinsic measure for NMS. Null: all points co-located.

R²l (linear fit) = 0.9474 Null: all ordination distances equal.

R²m (metric fit) = 0.9371 Null: no linear relationship with observed dissimilarities.

CHANCE-CORRECTED EVALUATIONS

Improvement: I = 0.7321

Null model: final configuration no better than initial random configuration.

Interpretation: 0 = random expectation, 1 = perfect fit, <0 = worse than random expectation

Basis: 2 dimensions

200 = number of random initial configurations used

42.8758 = average initial stress

11.4871 = final stress

Association: A = 0.3214

Null model: relationships among columns no stronger than expected chance, based on shuffling within columns.

Interpretation: 0 = random expectation, 1 = perfect fit, <0 = worse than random expectation

Basis: 2 dimensions

449 = number of randomizations used

16.9270 = average final stress from randomizations

11.4871 = final stress

Appendix 2. NMS Axis 1 and Axis 2 coordinates by site for zooplankton assemblages in Utah Lake 2018-2018.

site	axis1	axis2
GB1Apr17	-0.030	0.181
GB1Aug16	-0.236	-0.340
GB1Aug17	0.218	-1.138
GB1Feb17	1.376	0.191

GB1Jul16	-0.458	0.378
GB1Jun16	0.355	-1.170
GB1Jun17	1.189	0.689
GB1Jun18	0.691	-0.155
GB1Mar17	0.434	-0.551
GB1Oct16	-0.781	0.198
GB1Sep16	-0.631	0.058
GB2Apr17	1.513	0.090
GB2Aug16	-0.390	-0.014
GB2Aug17	-0.139	-0.853
GB2Feb17	1.465	0.045
GB2Jul16	-0.986	0.421
GB2Jul17	-0.290	-0.436
GB2Jun16	0.081	-1.405
GB2Jun17	1.309	-0.071
GB2Mar16	0.805	0.261
GB2Mar17	1.112	0.167
GB2May17	-0.511	0.376
GB2Oct16	-0.374	-0.389
GB2Sep16	-0.638	0.152
GB3Apr17	1.528	0.105
GB3Aug16	-1.043	0.380
GB3Aug17	-1.025	0.359
GB3Jun16	-0.608	0.306
GB3Sep16	-0.999	0.388
GB4Apr17	1.452	0.072
GB4Aug17	-0.095	-1.088
GB4Sep16	-0.909	0.328
GB5Apr17	1.142	0.612
GB5Aug17	-1.078	0.385
GBJan17	0.707	-1.144
GBJul17	-0.518	0.274
GBJul18	0.301	0.836
GBJun17	1.438	-0.278
GBJun18	1.312	-0.105
GBMar18	1.542	0.156
GBMay17	0.721	1.350
GBNov16	0.103	-1.912
GBNov17	1.166	-0.258

GBOct15	-0.856	0.289
GBSep15	-0.931	0.348
LB10Apr17	1.546	0.161
LB1Apr17	1.269	-0.185
LB1Aug16	-0.206	-0.313
LB1Feb17	1.267	-0.253
LB1Jun17	1.406	0.312
LB1Mar17	-0.021	-1.024
LB1May17	1.192	0.412
LB1Sep16	-0.452	-0.414
LB2Apr17	1.669	0.197
LB2Aug16	-0.474	-0.050
LB2Aug17	-0.710	-0.592
LB2Feb17	1.491	0.063
LB2Jun17	0.276	0.301
LB2Mar17	-0.863	0.370
LB2Sep16	-0.294	-0.660
LB3Apr17	0.858	-0.273
LB3Aug16	-0.904	0.314
LB3Sep16	-0.382	-0.526
LB4Apr17	1.507	0.150
LB4Sep16	-0.807	0.245
LB5Apr17	1.435	0.145
LB5Jun17	1.414	0.270
LB6Apr17	1.211	-0.224
LB7Apr17	0.354	0.362
LB8Apr17	1.262	0.245
LB9Apr17	1.452	0.169
LBAug17	-0.387	-0.606
LBB1Aug17	-0.170	-0.905
LBB2Aug17	0.138	-0.567
LBJan17	0.419	-1.465
LBJul16	-0.103	0.134
LBJun17	0.310	0.817
LBM1Aug17	-0.972	0.518
LBM2Aug17	-1.052	0.410
LBM2Jul17	-1.014	0.356
LBMAug17	-1.064	0.397
LBMay17	1.350	0.191

LBMay18	1.102	-0.239
LBMJul17	-0.846	0.552
LBMJul18	-0.832	0.588
LBNov16	-1.015	0.355
LBNov18	1.492	0.113
LBOct16	-0.716	0.310
LBSep17	0.758	0.109
LCMar16	-0.309	-0.120
LCOct15	-0.578	-0.112
LCSep15	-0.571	0.007
LM10Aug17	-0.920	0.483
LM11Aug17	-1.050	0.292
LM12Aug17	-0.974	0.348
LM1Apr17	0.104	-0.410
LM1Aug16	-0.364	-0.477
LM1Aug17	-0.960	0.197
LM1Feb17	0.952	-0.617
LM1Jul18	-0.193	-0.454
LM1Jun17	-0.764	0.617
LM1Jun18	0.485	-0.720
LM1Mar17	-0.302	-0.245
LM1May18	0.753	-0.875
LM1Oct15	-0.607	-0.016
LM1Sep16	-0.069	-0.731
LM2Apr17	0.435	0.133
LM2Aug16	0.148	-0.906
LM2Aug17	-0.643	-0.034
LM2Feb17	1.474	0.155
LM2Jul17	-0.676	0.252
LM2Jun17	-0.606	0.592
LM2Jun18	-0.508	0.901
LM2Mar17	-0.488	-0.359
LM2Oct15	-0.682	0.460
LM2Sep16	-0.839	0.242
LM3Apr17	1.420	0.104
LM3Aug16	0.633	1.832
LM3Aug17	-0.697	0.162
LM3Jun17	-0.936	0.450
LM3Jun18	0.304	-0.514

LM3Mar17	-0.684	-1.647
LM3Oct16	-0.557	0.184
LM4Apr17	1.507	0.117
LM4Aug16	0.050	-0.499
LM4Aug17	-0.973	0.340
LM4Jun17	-0.240	0.684
LM4Jun18	-0.396	0.370
LM4Oct16	0.266	-0.769
LM5Apr17	-0.797	-0.009
LM5Aug16	-0.341	-0.612
LM5Aug17	0.641	-0.517
LM5Jun17	1.241	0.190
LM6Aug17	-0.920	0.307
LM7Aug17	-1.066	0.331
LM8Aug17	-0.947	0.334
LM9Aug17	-0.933	0.338
LMJan17	1.175	0.256
LMJul16	-0.172	-0.033
LMJul17	-0.836	0.379
LMJul18	-0.852	0.392
LMJun16	-0.285	0.103
LMJun17	-1.023	0.385
LMJun18	-0.733	-0.501
LMMar16	-0.578	-0.117
LMMar18	1.052	0.368
LMMay16	0.581	-0.323
LMMay17	-0.320	0.278
LMMay18	0.618	-0.281
LMNov15	-0.754	-0.261
LMNov16	-0.024	-0.383
LMNov17	1.398	0.236
LMOct17	0.454	-0.096
LMSep15	-0.853	0.226
LMSep17	0.170	-0.642
LP1aAug16	-1.078	-0.037
LP1aAug17	0.459	-0.316
LP1aJul17	0.873	0.143
LP1aJun18	1.209	-0.261
LP1Aug17	-0.088	-0.978

LP1bAug16	-0.348	0.063
LP1bJul17	0.865	-0.036
LP1cAug16	-0.286	0.454
LP1dAug16	-0.555	-0.082
LP1Jul17	1.123	0.063
LP1Jul18	0.993	-0.590
LP1Jun16	-0.211	-0.608
LP1Jun17	1.511	0.241
LP1Jun18	1.379	-0.008
LP1May16	-1.001	0.353
LP1May18	0.988	-0.722
LP1Nov16	0.367	-0.070
LP1Oct16	-0.896	0.359
LP1Sep15	-0.718	0.204
LP1Sep16	-0.673	0.497
LP2aAug16	0.066	-0.349
LP2aJul17	0.832	-0.302
LP2aOct16	0.144	-0.889
LP2Aug17	0.775	-0.825
LP2bAug16	0.405	-0.617
LP2bOct16	0.283	-1.243
LP2cAug16	0.295	-0.855
LP2dAug16	-0.053	-0.497
LP2Jul18	1.297	-0.142
LP2Jun16	0.787	-0.573
LP2Jun17	1.491	0.384
LP2Jun18	1.350	-0.105
LP2May16	1.086	-0.267
LP2Nov16	0.457	-0.666
LP2Oct16	1.175	-0.419
LP2Oct17	1.176	-0.387
LP2Sep15	-0.718	0.115
LP2Sep16	-0.227	-0.694
LP3aAug16	0.618	-0.106
LP3aJun18	0.970	-0.607
LP3aOct16	0.436	-1.048
LP3Aug17	0.616	-0.711
LP3bAug16	0.110	-0.361
LP3bOct16	0.263	-0.740

LP3cAug16	0.093	-0.617
LP3dAug16	-0.442	0.006
LP3Jul17	0.372	-0.343
LP3Jul18	1.308	-0.176
LP3Jun16	1.395	0.022
LP3Jun17	1.447	0.263
LP3Jun18	1.263	-0.290
LP3May16	1.110	-0.213
LP3Nov16	0.380	-0.434
LP3Sep15	-0.720	0.158
LP3Sep16	0.166	-0.909
LP3Sep17	1.234	-0.257
OUTJun16	0.711	-0.457
OUTMar16	0.568	-0.375
OUTMay16	-0.600	0.527
OUTSep15	-0.666	-0.007
PA1Feb17	1.398	-0.038
PA1Sep16	-0.784	0.252
PA2Feb17	1.495	0.067
PA2Sep16	-1.079	0.379
PA3Sep16	-0.937	0.317
PB0ug17	-1.054	0.155
PB1Apr17	-0.081	0.692
PB1Aug16	-0.827	-0.237
PB1Aug17	-1.079	0.280
PB1Jul16	-0.342	0.218
PB1Jun16	-0.546	-0.043
PB1Jun17	-0.879	0.251
PB1Jun18	-0.990	0.443
PB1Mar16	0.715	-0.340
PB1Mar17	-0.696	-0.810
PB1May17	-0.716	-0.065
PB1Nov16	-0.057	-0.814
PB1Oct16	-0.247	-0.485
PB1Sep16	-0.695	0.039
PB2Apr17	-0.471	-0.646
PB2Aug16	-1.094	0.380
PB2Aug17	-1.031	0.330
PB2Jul16	-0.806	0.191

PB2Jul17	-0.952	0.349
PB2Jun16	0.070	0.160
PB2Jun17	-1.069	0.391
PB2Jun18	-0.607	0.278
PB2Mar16	-0.110	-0.147
PB2Mar17	-0.449	-0.476
PB2May17	-0.866	0.241
PB2Nov16	-0.542	-0.314
PB2Oct16	-1.084	0.386
PB2Sep16	-1.085	0.385
PB3Apr17	-0.266	-0.184
PB3Aug16	-0.476	0.698
PB3Aug17	-0.987	0.352
PB3Jul16	-0.488	0.159
PB3Jun16	-0.939	0.323
PB3Jun17	0.279	0.222
PB3Jun18	-0.835	0.660
PB3Mar17	-0.824	-0.169
PB3May17	-0.779	0.331
PB3Oct16	0.015	-0.076
PB3Sep16	-0.630	-0.060
PB4Apr17	1.333	-0.498
PB4Aug16	-0.678	0.095
PB4Aug17	-1.050	0.350
PB4Jun18	-0.831	0.401
PB4Mar17	-0.649	0.677
PB5Apr17	0.811	0.930
PB5Jun18	-0.328	0.359
PB5Mar17	-0.491	0.765
PB6Apr17	0.966	0.420
PB6Jun18	-0.761	0.556
PB7Apr17	0.279	0.316
PB7Jun18	-0.851	0.549
PB8Apr17	-0.808	0.406
PB9Apr17	0.241	1.835
PBApr18	0.261	1.159
PBJan17	1.302	-0.200
PBJul17	-0.899	0.282
PBJul18	-0.815	0.351

PBMay18	-0.748	0.116
PBNJun17	-0.802	0.228
PBS1Aug17	-0.995	0.326
PBS1Jun17	-0.850	0.234
PBS2Jun17	-0.979	0.324
PBSAug17	-1.062	0.373
PBSJul17	-1.046	0.378
PBSJun18	-0.861	0.389
PBSMar18	0.565	1.249
PBSMay17	-0.922	0.319
PBSNov17	1.328	0.093
PM1Apr17	1.261	-0.060
PM1Aug16	-0.364	-0.585
PM1Oct16	0.491	-0.501
PM2Apr17	1.379	0.008
PM2Aug16	-1.006	0.136
PM2Oct16	-0.338	-0.503
PM3Apr17	1.389	0.032
PM3Aug16	-0.943	0.266
PMAug17	-0.857	0.278
PMJul17	0.703	0.024
PMJun16	1.322	-0.011
PMJun17	1.321	0.522
PMJun18	1.197	-0.374
PMMar16	-0.044	-0.415
PMMay16	-0.100	-0.835
PMNov16	-0.674	0.158
PMSep16	-0.602	0.055
SB1Aug16	-0.898	0.525
SB1Jul16	1.106	0.125
SB1Mar17	-0.663	0.246
SB1Oct16	-0.769	0.290
SB1Sep16	-0.488	-0.245
SB2Aug16	1.277	0.402
SB2Jul16	-1.079	0.384
SB2Mar17	0.564	-0.020
SB2Oct16	-1.002	0.372
SB2Sep16	-0.719	0.121
SB3Sep16	-0.811	0.226

SBFeb17	1.696	0.206
SBJan17	0.237	-1.673
SBJul18	0.189	0.423
SBJun18	-0.637	0.411
SBNov16	0.032	-1.156
SP1Apr17	0.832	-0.685
SP1Aug17	-0.782	0.190
SP1Jan17	1.277	-0.069
SP1Jun17	-0.388	0.388
SP1Mar17	0.128	-1.088
SP1Oct15	-0.950	0.470
SP2Apr17	0.407	-1.199
SP2Aug17	-0.956	0.332
SP2Jan17	1.741	0.153
SP2Jul17	-1.036	0.362
SP2Jun17	-1.023	-0.138
SP2Mar17	-0.282	-0.109
SP2May17	0.029	0.798
SP2Oct15	-0.797	0.482
SP3Apr17	0.971	-0.031
SP3Jul17	-1.002	0.332
SP4Apr17	0.849	0.024
SP4Jul17	-0.319	0.658
SP5Apr17	1.212	-0.310
SP6Apr17	1.197	0.053
SPAug16	-0.498	0.486
SPJul16	-0.799	0.318
SPJul18	-0.645	0.370
SPJun17	-0.660	0.843
SPJun18	-0.547	0.963
SPMay17	0.161	0.643
SPNov15	-0.480	-0.052
SPNov17	1.347	0.263
SS1Oct15	-0.651	-0.126
SS2Oct15	-0.464	-0.440
SSNov15	-0.539	-0.127
SSSep15	-0.084	-1.186

Appendix 3. NMS Axis 1 and Axis 2 coordinates for zooplankton family assemblages in Utah Lake 2015-2018.

Family	Axis 1	Axis 2
Bosminidae	-0.552	0.412
Brachionidae	-0.361	-0.479
Canthocamptidae	-0.400	0.096
Chydoridae	-0.026	0.080
Cyclopidae	-0.781	0.265
Daphniidae	0.089	-0.398
Diaptomidae	1.061	-0.031
Ilyocryptidae	-0.508	0.235
Leptodoridae	0.268	-0.438
Moinidae	-0.968	0.197
Ostracoda	-0.556	0.335
Sididae	0.471	0.209

Appendix 4. NMS zooplankton family correlations and p-values with NMS Axis 1 and Axis 2.

Family	Axis 1	Axis 2
Asplanchnidae	0.13	0.17
p-value	0.01	0.00
Bosminidae	0.18	0.23
p-value	0.00	0.00
Brachionidae	0.04	-0.09
p-value	0.46	0.10
Canthocamptidae	0.07	0.03
p-value	0.20	0.61
Chydoridae	0.01	0.04
p-value	0.90	0.50
Cyclopidae	0.39	0.22
p-value	0.00	0.00
Daphniidae	-0.05	-0.38
p-value	0.33	0.00
Diaptomidae	-0.56	-0.03
p-value	0.00	0.61
Ilyocryptidae	0.10	0.08
p-value	0.05	0.13
Laophontidae	-0.06	-0.03
p-value	0.27	0.60
Leptodoridae	-0.07	-0.37

p-value	0.18	0.00
Macrothricidae	0.04	-0.01
p-value	0.40	0.90
Moinidae	0.14	0.05
p-value	0.01	0.38
Ostracoda	0.14	0.14
p-value	0.01	0.01
Sididae	-0.12	0.09
p-value	0.03	0.10
Testudinellidae	-0.16	0.01
p-value	0.00	0.91

Appendix 5. Multiple response permutation procedure results for zooplankton assemblage relations between locations.

Site Locations			T	A	p
GB	vs.	LB	0.53	0.00	0.62
GB	vs.	LC	-1.56	0.02	0.08
GB	vs.	LM	-1.75	0.01	0.06
GB	vs.	LP	-4.76	0.03	0.00
GB	vs.	OUT	0.14	0.00	0.45
GB	vs.	PA	0.31	0.00	0.52
GB	vs.	PB	-11.56	0.06	0.00
GB	vs.	PM	0.45	0.00	0.57
GB	vs.	SB	0.11	0.00	0.41
GB	vs.	SP	-0.49	0.00	0.22
GB	vs.	SS	-1.80	0.02	0.06
LB	vs.	LC	-1.73	0.03	0.06
LB	vs.	LM	-3.65	0.02	0.01
LB	vs.	LP	-3.92	0.03	0.01
LB	vs.	OUT	-0.13	0.00	0.35
LB	vs.	PA	0.29	0.00	0.51
LB	vs.	PB	-14.49	0.08	0.00
LB	vs.	PM	0.48	-0.01	0.59
LB	vs.	SB	-0.78	0.01	0.16
LB	vs.	SP	-1.51	0.01	0.08
LB	vs.	SS	-2.11	0.03	0.04
LC	vs.	LM	-0.87	0.01	0.17
LC	vs.	LP	-3.08	0.04	0.01
LC	vs.	OUT	-0.43	0.05	0.30

LC	vs.	PA	-0.96	0.12	0.16
LC	vs.	PB	-0.94	0.01	0.15
LC	vs.	PM	-1.38	0.06	0.10
LC	vs.	SB	-1.01	0.04	0.14
LC	vs.	SP	-1.34	0.03	0.10
LC	vs.	SS	-0.62	0.04	0.24
LM	vs.	LP	-13.05	0.07	0.00
LM	vs.	OUT	0.44	0.00	0.59
LM	vs.	PA	-0.15	0.00	0.33
LM	vs.	PB	-5.55	0.02	0.00
LM	vs.	PM	-1.41	0.01	0.09
LM	vs.	SB	0.54	0.00	0.63
LM	vs.	SP	-0.57	0.00	0.21
LM	vs.	SS	-1.33	0.01	0.10
LP	vs.	OUT	-0.22	0.00	0.32
LP	vs.	PA	-2.11	0.02	0.04
LP	vs.	PB	-33.24	0.17	0.00
LP	vs.	PM	-0.34	0.00	0.26
LP	vs.	SB	-5.75	0.05	0.00
LP	vs.	SP	-8.80	0.07	0.00
LP	vs.	SS	-2.99	0.04	0.01
OUT	vs.	PA	-0.29	0.03	0.28
OUT	vs.	PB	-1.35	0.01	0.10
OUT	vs.	PM	0.27	-0.01	0.51
OUT	vs.	SB	0.17	-0.01	0.46
OUT	vs.	SP	0.23	-0.01	0.49
OUT	vs.	SS	-0.29	0.03	0.31
PA	vs.	PB	-0.42	0.00	0.25
PA	vs.	PM	0.04	0.00	0.39
PA	vs.	SB	0.64	-0.02	0.70
PA	vs.	SP	0.02	0.00	0.39
PA	vs.	SS	-1.62	0.14	0.06
PB	vs.	PM	-8.75	0.06	0.00
PB	vs.	SB	-1.24	0.01	0.11
PB	vs.	SP	-6.11	0.04	0.00
PB	vs.	SS	-2.81	0.02	0.02
PM	vs.	SB	-0.56	0.01	0.21
PM	vs.	SP	-1.22	0.02	0.11
PM	vs.	SS	-1.60	0.06	0.07

SB	vs.	SP	0.40	-0.01	0.55
SB	vs.	SS	-1.26	0.04	0.11
SP	vs.	SS	-1.81	0.04	0.06

Appendix 6. Multiple response permutation procedure (MRPP) results for zooplankton assemblage relations between months.

Compared			T	A	p
April	vs.	Aug	-35.914	0.202	0.000
April	vs.	Feb	-3.291	0.043	0.014
April	vs.	July	-17.409	0.153	0.000
April	vs.	June	-12.386	0.080	0.000
April	vs.	March	-9.462	0.089	0.000
April	vs.	Oct	-17.809	0.165	0.000
April	vs.	Sept	-30.413	0.291	0.000
April	vs.	May	-6.502	0.063	0.001
April	vs.	Jan	-2.226	0.029	0.038
April	vs.	Nov	-5.103	0.053	0.003
Aug	vs.	Feb	-23.375	0.195	0.000
Aug	vs.	July	-3.273	0.019	0.016
Aug	vs.	June	-12.132	0.057	0.000
Aug	vs.	March	-6.992	0.042	0.000
Aug	vs.	Oct	-1.116	0.007	0.114
Aug	vs.	Sept	-1.292	0.008	0.097
Aug	vs.	May	-5.631	0.038	0.002
Aug	vs.	Jan	-11.292	0.098	0.000
Aug	vs.	Nov	-6.334	0.044	0.001
Feb	vs.	July	-12.700	0.225	0.000
Feb	vs.	June	-9.492	0.103	0.000
Feb	vs.	March	-11.388	0.218	0.000
Feb	vs.	Oct	-13.632	0.273	0.000
Feb	vs.	Sept	-21.784	0.413	0.000
Feb	vs.	May	-8.085	0.185	0.000
Feb	vs.	Jan	-1.999	0.100	0.049
Feb	vs.	Nov	-6.523	0.175	0.001
July	vs.	June	-1.826	0.013	0.059
July	vs.	March	-5.214	0.049	0.002

July	vs.	Oct	-2.070	0.021	0.047
July	vs.	Sept	-4.855	0.044	0.003
July	vs.	May	-1.037	0.012	0.124
July	vs.	Jan	-7.633	0.127	0.000
July	vs.	Nov	-3.488	0.042	0.013
June	vs.	March	-5.160	0.036	0.003
June	vs.	Oct	-4.485	0.034	0.005
June	vs.	Sept	-12.445	0.090	0.000
June	vs.	May	0.327	-0.003	0.490
June	vs.	Jan	-4.597	0.050	0.004
June	vs.	Nov	-1.892	0.016	0.056
March	vs.	Oct	-2.299	0.024	0.036
March	vs.	Sept	-10.427	0.101	0.000
March	vs.	May	-1.462	0.017	0.086
March	vs.	Jan	-5.214	0.093	0.001
March	vs.	Nov	-0.541	0.007	0.223
Oct	vs.	Sept	-2.271	0.026	0.039
Oct	vs.	May	-1.378	0.018	0.091
Oct	vs.	Jan	-6.077	0.121	0.001
Oct	vs.	Nov	-1.219	0.016	0.109
Sept	vs.	May	-8.057	0.095	0.000
Sept	vs.	Jan	-13.186	0.239	0.000
Sept	vs.	Nov	-8.615	0.108	0.000
May	vs.	Jan	-3.563	0.079	0.009
May	vs.	Nov	0.030	0.000	0.374
Jan	vs.	Nov	-1.947	0.050	0.052

Appendix 7. Blocked Indicator Species Analysis for family level-based zooplankton assemblages by month in Utah Lake 2015-2018. Blocked by site.

Family	Month	Observed IV	Randomized IV	Std. Dev.	p- value
Asplanchnida	March	2.7	5.8	3.78	0.91
Bosminidae	April	18.9	16.1	4.35	0.22
Brachionidae	August	15	12.6	5.05	0.24
Canthocamptidae	November	18.4	8.5	3.75	0.03
Chydoridae	November	15.2	9	4.49	0.09
Cyclopidae	September	23	20	4.28	0.22
Daphniidae	September	18.4	19.5	3.77	0.55
Diaptomidae	February	29.9	17.6	3.87	0.01

Ilyocryptidae	February	14.7	6.5	3.83	0.04
Leptodoridae	July	8.3	5.5	2.76	0.11
Moinidae	April	26.9	6	3.46	0.00
Ostracoda	May	5.9	7.3	3.79	0.57
Sididae	June	20.3	10.9	5.32	0.07

Appendix 8. NMS results for **Provo Bay** zooplankton assemblages (family level).

Provo Bay

7.62885 = final stress for 2-dimensional solution

0.00000 = final instability

56 = number of iterations

Sample Label	Axis 1	Axis 2
PB0ug17	0.19965	-1.35392
PB1Apr17	-0.21656	1.01170
PB1Aug16	0.35916	-0.36579
PB1Aug17	0.03785	-0.90060
PB1Jul16	0.02873	0.76325
PB1Jun16	0.13724	0.63991
PB1Jun17	0.14066	-0.92299
PB1Jun18	0.22198	-0.95497
PB1Mar16	-0.56769	-0.03167
PB1Mar17	-0.08776	2.41097
PB1May17	0.21612	0.31257
PB1Nov16	-0.14166	0.68289
PB1Oct16	0.02342	0.57837
PB1Sep16	0.21021	-0.27855
PB2Apr17	-0.16326	1.42221
PB2Aug16	0.36567	0.55908
PB2Aug17	0.18189	-1.26733
PB2Jul16	0.19635	0.92658
PB2Jul17	0.05632	-0.70925
PB2Jun16	-0.10065	1.08788
PB2Jun17	0.25690	0.02821
PB2Jun18	-0.00982	-0.47614

Family	Axis 1	Axis 2
Asplanchnida	0.15948	-0.85728
Bosminidae	0.19198	-0.82128
Brachionidae	-0.75639	-0.25804
Canthocampti	-0.03916	-0.30284
Chydoridae	-0.06997	0.09966
Cyclopidae	0.13661	-1.09760
Daphniidae	0.04677	-0.71724
Diaptomidae	-0.33287	-0.27467
Ilyocryptida	-0.06023	-0.85288
Macrothricid	0.21612	0.31257
Moinidae	0.16812	-1.23218
Ostracoda	0.21490	-1.32119
Sididae	0.01706	-0.89018
Testudinelli	-0.98031	-0.50243

Post hoc R Squared		
Axis	Increment	Cumulative
1	.098	.098
2	.454	.552

PB2Mar16	-0.04289	0.62365
PB2Mar17	0.36391	2.20282
PB2May17	0.13244	-0.94401
PB2Nov16	0.19101	0.55467
PB2Oct16	0.36092	0.32244
PB2Sep16	0.33201	-0.12704
PB3Apr17	0.12385	1.95229
PB3Aug16	-0.05513	-1.00951
PB3Aug17	0.11106	-0.56769
PB3Jul16	0.01705	0.11956
PB3Jun16	0.26592	0.57550
PB3Jun17	-0.06780	1.39110
PB3Jun18	0.40773	-0.83396
PB3Mar17	-0.15547	0.03124
PB3May17	-0.09710	-0.99597
PB3Oct16	-0.22022	-0.66893
PB3Sep16	0.20306	0.75583
PB4Apr17	-0.92738	0.42757
PB4Aug16	0.17249	-0.69922
PB4Aug17	0.17423	-0.75878
PB4Jun18	0.24698	-0.76478
PB4Mar17	-0.12494	-0.00637
PB5Apr17	-0.68150	0.98479
PB5Jun18	-0.09049	-0.52916
PB5Mar17	-0.19015	0.54156
PB6Apr17	-0.58988	1.40344
PB6Jun18	0.10462	-0.38646
PB7Apr17	-0.18460	1.70756
PB7Jun18	0.27866	-0.84775
PB8Apr17	0.19988	0.68299
PB9Apr17	-0.98031	-0.50243
PBApr18	-0.47073	0.98581
PBJul17	0.16583	-0.48499
PBJul18	-0.00258	-0.80152
PBMay18	0.18006	-0.40223
PBNJun17	0.09443	-0.68141
PBS1Aug17	0.09252	-0.92408
PBS1Jun17	0.18845	-0.67981
PBS2Jun17	0.16812	-1.29938

PBSAug17	0.23813	-1.66534
PBSJul17	0.08819	-1.53316
PBSJun18	0.22778	-1.23807
PBSMar18	-0.79892	0.10097
PBSMay17	0.15913	-0.29067
PBSNov17	-0.95314	1.11651

Appendix 9 MRPP results for **Provo Bay** zooplankton assemblages by month

Chance-corrected within-group agreement, A = 0.23536040

A = 1 - (observed delta/expected delta)

Amax = 1 when all items are identical within groups (delta=0)

A = 0 when heterogeneity within groups equals expectation by chance

A < 0 with more heterogeneity within groups than expected by chance

Probability of a smaller or equal delta, p = 0.00000000

Compared			T	A	p
August	vs.	April	-9.620	0.307	0.000
August	vs.	July	-0.514	0.016	0.243
August	vs.	June	-1.564	0.027	0.077
August	vs.	March	-8.354	0.240	0.000
August	vs.	May	-0.373	0.013	0.284
August	vs.	November	-4.756	0.184	0.002
August	vs.	October	-1.244	0.062	0.110
August	vs.	September	-0.467	0.023	0.247
April	vs.	July	-6.934	0.287	0.000
April	vs.	June	-11.068	0.262	0.000
April	vs.	March	-0.529	0.016	0.242
April	vs.	May	-5.721	0.270	0.001
April	vs.	November	-1.331	0.055	0.101
April	vs.	October	-1.920	0.088	0.049
April	vs.	September	-4.029	0.222	0.004
July	vs.	June	0.028	-0.001	0.405
July	vs.	March	-6.218	0.234	0.000
July	vs.	May	0.767	-0.038	0.772
July	vs.	November	-3.903	0.207	0.005
July	vs.	October	-0.619	0.051	0.212

GB1Oct16	-0.90228	-0.11394	Diaptomidae	0.99948	-0.13860
GB1Sep16	-0.76503	0.04017	Ilyocryptida	0.38994	0.37569
GB2Apr17	1.26760	-0.20757	Laophontidae	0.86634	-0.70574
GB2Aug16	-0.59175	0.10035	Leptodoridae	-0.04807	0.83932
GB2Aug17	-0.32695	0.72751	Moinidae	0.25896	0.39435
GB2Feb17	1.21240	-0.14715	Ostracoda	-0.46776	-0.31215
GB2Jul16	-1.13984	-0.25991	Sididae	0.62386	0.23909
GB2Jul17	-0.46843	0.39867	Testudinelli	1.20090	-0.22425
GB2Jun16	-0.11659	1.24151			
GB2Jun17	1.03759	0.05041			
GB2Mar16	0.52519	-0.30289			
GB2Mar17	0.80547	-0.18276			
GB2May17	-0.61066	-0.40281			
GB2Oct16	-0.57166	0.36740			
GB2Sep16	-0.76013	-0.08998			
GB3Apr17	1.28476	-0.24568			
GB3Aug16	-1.17673	-0.33178			
GB3Aug17	-1.15603	-0.31960			
GB3Jun16	-0.73781	-0.18546			
GB3Sep16	-1.11338	-0.37714			
GB4Apr17	1.20426	-0.21851			
GB4Aug17	-0.28270	0.93498			
GB4Sep16	-1.03227	-0.30651			
GB5Apr17	0.89879	-0.57605			
GB5Aug17	-1.20780	-0.34098			
GBJan17	0.58475	0.91887			
GBJul17	-0.61144	-0.24179			
GBJul18	-0.02069	-0.65970			
GBJun17	1.15958	0.18944			
GBJun18	0.99841	-0.00411			
GBMar18	1.29153	-0.31882			
GBMay17	0.37599	-1.27783			
GBNov16	0.26804	1.71439			
GBNov17	0.89551	0.17329			
GBOct15	-0.97398	-0.25124			
GBSep15	-1.04942	-0.33986			

Appendix 11. MRPP results for **Goshen Bay** zooplankton assemblages by month

Chance-corrected within-group agreement, A = 0.28809527

$A = 1 - (\text{observed delta}/\text{expected delta})$

$A_{\text{max}} = 1$ when all items are identical within groups ($\text{delta}=0$)

$A = 0$ when heterogeneity within groups equals expectation by chance

$A < 0$ with more heterogeneity within groups than expected by chance

Compared		T	A	p-value
April	vs. August	-5.221	0.290	0.001
April	vs. February	0.100	-0.008	0.439
April	vs. July	-4.101	0.326	0.006
April	vs. June	-1.335	0.056	0.101
April	vs. March	0.291	-0.019	0.518
April	vs. October	-3.207	0.420	0.014
April	vs. September	-4.939	0.532	0.003
April	vs. May	-1.019	0.123	0.149
April	vs. November	-0.371	0.025	0.319
August	vs. February	-3.402	0.306	0.010
August	vs. July	-0.243	0.013	0.306
August	vs. June	-2.997	0.124	0.014
August	vs. March	-4.099	0.239	0.003
August	vs. October	-0.078	0.007	0.367
August	vs. September	-1.550	0.104	0.078
August	vs. May	-0.145	0.013	0.391
August	vs. November	-1.188	0.094	0.121
February	vs. July	-3.368	0.434	0.010
February	vs. June	-1.337	0.094	0.097
February	vs. March	-0.134	0.011	0.392
February	vs. October	-2.166	0.641	0.000
February	vs. September	-3.684	0.704	0.010
February	vs. May	-1.414	0.334	NaN
February	vs. November	-1.408	0.110	NaN
July	vs. June	-3.198	0.149	0.011
July	vs. March	-3.958	0.303	0.006
July	vs. October	-0.253	0.019	0.348
July	vs. September	-2.139	0.103	0.039
July	vs. May	0.764	-0.053	0.764
July	vs. November	-2.372	0.176	0.018
June	vs. March	-0.645	0.029	0.212
June	vs. October	-2.823	0.196	0.016

June	vs.	September	-5.351	0.321	0.001
June	vs.	May	-0.553	0.037	0.223
June	vs.	November	0.509	-0.031	0.640
March	vs.	October	-3.058	0.423	0.014
March	vs.	September	-4.857	0.535	0.003
March	vs.	May	-1.604	0.141	0.062
March	vs.	November	-0.096	0.008	0.410
October	vs.	September	0.450	-0.035	0.590
October	vs.	May	-0.739	0.064	0.000
October	vs.	November	-1.774	0.270	0.000
September	vs.	May	-2.004	0.106	0.041
September	vs.	November	-3.408	0.368	0.011
May	vs.	November	-1.414	0.073	NaN

Appendix 12. NMS results for *Lindon Marina* by month.

Lindon Marina Zooplankton Multivariate Results

dropped Macrothricidae

Relative Sorenson R Squared
removed outliers Axis Increment Cumulative

	1	.292	.292
	2	.649	.941

List of sites exceeding user's cutoff value

ENTITY RANK	AVERAGE NAME	STANDARD DISTANCE	DEVIATIONS

1	LMSep15	0.97108	2.38910
2	LMJan17	0.96582	2.33994
3	LM1Oct15	0.94267	2.12344
4	LM2Feb17	0.93119	2.01605

10.49576 = final stress for 2-dimensional solution

0.00000 = final instability

59 = number of iterations

LM10Aug17	-0.50646	0.74208
LM11Aug17	-0.48152	0.81782

Asplanchnida	-1.44334	-0.33398
Bosminidae	0.17849	0.60248

LM12Aug17	-0.34788	0.83250
LM1Apr17	0.43159	-0.38144
LM1Aug16	0.64011	0.13444
LM1Aug17	-0.41221	0.71727
LM1Jul18	0.56740	-0.07456
LM1Jun17	0.07577	0.95293
LM1Jun18	0.69861	-0.85859
LM1Mar17	0.28156	0.06447
LM1May18	0.81476	-1.19808
LM1Sep16	0.78557	-0.29477
LM2Apr17	-0.20973	-0.58733
LM2Aug16	0.90416	-0.56460
LM2Aug17	0.07278	0.46906
LM2Feb17	-0.41986	-1.79143
LM2Jul17	-0.22101	0.56590
LM2Jun17	0.13797	0.83722
LM2Jun18	0.51425	0.95113
LM2Mar17	0.41139	0.19234
LM2Oct15	0.02913	0.79347
LM2Sep16	-0.24794	0.71208
LM3Apr17	-0.32389	-1.75729
LM3Aug16	-2.09794	-0.67628
LM3Aug17	-0.16663	0.57030
LM3Jun17	-0.21879	0.91880
LM3Jun18	0.54444	-0.60540
LM3Mar17	-1.97338	-0.34962
LM3Oct16	-0.15251	0.43755
LM4Apr17	-0.39677	-1.82076
LM4Aug16	0.52685	-0.35299
LM4Aug17	-0.35370	0.81925
LM4Jun17	0.51915	0.64873
LM4Jun18	-0.02500	0.37771
LM4Oct16	0.77748	-0.62656
LM5Apr17	-0.65163	0.30802
LM5Aug16	0.70145	0.00190
LM5Aug17	0.46932	-0.97835
LM5Jun17	-0.31894	-1.57668
LM6Aug17	-0.32702	0.78171
LM7Aug17	-0.41055	0.89495

Brachionidae	-1.83363	-0.28718
Canthocampti	0.28780	0.61235
Chydoridae	-0.09882	-0.63766
Cyclopidae	-0.15974	0.57213
Daphniidae	0.33380	-0.18918
Diaptomidae	-0.02991	-1.04456
Ilyocryptida	0.13702	0.64039
Laophontidae	0.63538	-0.48074
Leptodoridae	0.40995	-0.38902
Moinidae	-0.39219	0.72273
Ostracoda	-0.19936	0.45725
Sididae	-0.61494	-0.50318
Testudinelli	-0.38575	-1.50405

LM8Aug17	-0.38242	0.78361
LM9Aug17	-0.33574	0.80058
LMJul16	0.12169	-0.00230
LMJul17	-0.23021	0.78263
LMJul18	-0.22880	0.79614
LMJun16	0.02478	0.14973
LMJun17	-0.33640	0.93134
LMJun18	0.75691	0.62820
LMMar16	0.16451	0.36051
LMMar18	-0.61718	-1.22773
LMMay16	0.31218	-0.85987
LMMay17	-0.19762	0.20571
LMMay18	0.23413	-0.88673
LMNov15	0.39643	0.63866
LMNov16	0.42255	-0.24488
LMNov17	-0.43980	-1.71068
LMOct17	0.04975	-0.68711
LMSep17	0.64489	-0.50467

Appendix 13. MRPP results for *Lindon Marina* by month.

Chance-corrected within-group agreement, $A = 0.07811638$

$A = 1 - (\text{observed delta}/\text{expected delta})$

$A_{\text{max}} = 1$ when all items are identical within groups ($\text{delta}=0$)

$A = 0$ when heterogeneity within groups equals expectation by chance

$A < 0$ with more heterogeneity within groups than expected by chance

Probability of a smaller or equal delta, $p = 0.01338831$

Compared			T	A	p
August	vs.	April	-3.869	0.118	0.006
August	vs.	July	0.197	-0.006	0.445
August	vs.	June	-2.906	0.059	0.020
August	vs.	March	-0.540	0.015	0.228
August	vs.	May	-3.043	0.117	0.017
August	vs.	November	-0.121	0.005	0.358
August	vs.	October	-0.111	0.004	0.339
August	vs.	September	-0.615	0.022	0.220

April	vs.	July	-2.561	0.191	0.020
April	vs.	June	-2.438	0.095	0.030
April	vs.	March	-0.301	0.022	0.287
April	vs.	May	-0.237	0.017	0.371
April	vs.	November	-0.938	0.088	0.165
April	vs.	October	-0.447	0.033	0.287
April	vs.	September	0.827	-0.095	0.806
July	vs.	June	-0.733	0.025	0.191
July	vs.	March	-0.968	0.049	0.161
July	vs.	May	-2.302	0.225	0.036
July	vs.	November	-0.175	0.023	0.319
July	vs.	October	0.157	-0.013	0.429
July	vs.	September	-0.499	0.035	0.240
June	vs.	March	-1.141	0.034	0.125
June	vs.	May	-2.194	0.100	0.040
June	vs.	November	-0.730	0.034	0.195
June	vs.	October	0.324	-0.013	0.530
June	vs.	September	0.183	-0.008	0.475
March	vs.	May	-0.613	0.037	0.219
March	vs.	November	0.352	-0.023	0.596
March	vs.	October	0.578	-0.032	0.676
March	vs.	September	0.762	-0.067	0.765
May	vs.	November	-0.365	0.040	0.330
May	vs.	October	0.162	-0.018	0.446
May	vs.	September	0.629	-0.050	0.699
November	vs.	October	0.614	-0.085	0.680
November	vs.	September	0.554	-0.047	0.658
October	vs.	September	1.088	-0.088	0.916

Appendix 14.NMS results for Lindon-Pelican transect.

5.87712 = final stress for
2-dimensional solution

0.00000 = final instability
106 = number of
iterations

R Squared

Axis	Increment	Cumulative
1	.647	.647

Sample label	Axis 1	Axis 2
LP1aAug16	-1.777	0.200
LP1aAug17	0.095	-0.053
LP1aJul17	0.164	0.763
LP1aJun18	0.661	0.583
LP1Aug17	-0.034	-1.094
LP1bAug16	-1.068	0.045
LP1bJul17	0.274	0.564
LP1cAug16	-1.311	0.380
LP1dAug16	-1.089	-0.484
LP1Jul17	0.405	0.862
LP1Jul18	0.700	0.048
LP1Jun16	-0.451	-0.869
LP1Jun17	0.657	1.204
LP1Jun18	0.668	0.947
LP1May16	-1.813	-0.204
LP1May18	0.742	-0.133
LP1Nov16	-0.146	0.182
LP1Oct16	-1.712	-0.164
LP1Sep15	-1.436	-0.189
LP1Sep16	-1.627	-0.485
LP2aAug16	-0.255	-0.416
LP2aJul17	0.417	0.207
LP2aOct16	0.134	-0.893
LP2Aug17	0.628	-0.402
LP2bAug16	0.219	-0.440
LP2bOct16	0.460	-1.165
LP2cAug16	0.251	-0.763
LP2dAug16	-0.274	-0.632
LP2Jul18	0.647	0.772
LP2Jun16	0.540	-0.150
LP2Jun17	0.541	1.303
LP2Jun18	0.663	0.854
LP2May16	0.594	0.450

LP2Nov16	0.298	-0.465
LP2Oct16	0.731	0.364
LP2Oct17	0.697	0.398
LP2Sep15	-1.355	-0.278
LP2Sep16	-0.310	-0.902
LP3aAug16	0.113	0.289
LP3aJun18	0.688	-0.002
LP3aOct16	0.476	-0.871
LP3Aug17	0.455	-0.390
LP3bAug16	-0.197	-0.374
LP3bOct16	0.151	-0.746
LP3cAug16	-0.069	-0.652
LP3dAug16	-0.993	-0.280
LP3Jul17	0.025	-0.153
LP3Jul18	0.685	0.744
LP3Jun16	0.726	0.963
LP3Jun17	0.581	1.183
LP3Jun18	0.732	0.639
LP3May16	0.566	0.530
LP3Nov16	0.101	-0.270
LP3Sep15	-1.403	-0.229
LP3Sep16	0.157	-0.898
LP3Sep17	0.677	0.572

NMS coordinates

Family	Axis 1	Axis 2
Asplanchnida	-0.034	-1.094
Bosminidae	-0.937	-0.334
Brachionidae	-1.411	-0.196
Canthocampti	-1.344	0.351
Chydoridae	-0.279	-0.145
Cyclopidae	-0.743	-0.217
Daphniidae	0.258	-0.205
Diaptomidae	0.530	0.477
Ilyocryptida	-1.311	0.380
Leptodoridae	0.175	-0.226
Moinidae	0.176	-0.619
Ostracoda	0.657	1.204
Sididae	0.247	0.661

Appendix 15. Lindon-Pelican MRPP by site

Chance-corrected within-group agreement, $A = 0.03157848$
 $A = 1 - (\text{observed delta}/\text{expected delta})$
 $A_{\text{max}} = 1$ when all items are identical within groups ($\text{delta}=0$)
 $A = 0$ when heterogeneity within groups equals expectation by
 chance
 $A < 0$ with more heterogeneity within groups than expected by
 chance

Probability of a smaller or equal delta, $p = 0.04932373$

Compare			T	A	p-value
LP1	vs.	LP2	-2.964	0.050	0.019
LP1	vs.	LP3	-1.580	0.027	0.076
LP2	vs.	LP3	0.899	-0.017	0.933

Appendix 16. Lindon-Pelican transect MRPP by month.

Chance-corrected within-group agreement, $A = 0.22353972$
 $A = 1 - (\text{observed delta}/\text{expected delta})$
 $A_{\text{max}} = 1$ when all items are identical within groups ($\text{delta}=0$)
 $A = 0$ when heterogeneity within groups equals expectation by
 chance
 $A < 0$ with more heterogeneity within groups than expected by
 chance

Probability of a smaller or equal delta, $p = 0.00000085$

Compare			T	A	p-value
8	vs.	7	-8.222	0.207	0.000
8	vs.	6	-9.863	0.244	0.000
8	vs.	5	-1.282	0.043	0.105
8	vs.	11	-0.429	0.016	0.264
8	vs.	10	-1.491	0.037	0.084
8	vs.	9	-2.193	0.071	0.041
7	vs.	6	-0.237	0.008	0.300
7	vs.	5	0.869	-0.033	0.808

7	vs.	11	-2.290	0.164	0.033
7	vs.	10	-2.646	0.105	0.026
7	vs.	9	-6.969	0.403	0.000
6	vs.	5	0.264	-0.010	0.522
6	vs.	11	-2.846	0.173	0.018
6	vs.	10	-3.048	0.113	0.018
6	vs.	9	-7.496	0.371	0.000
5	vs.	11	-0.568	0.043	0.256
5	vs.	10	0.524	-0.036	0.652
5	vs.	9	-1.701	0.161	0.067
11	vs.	10	-0.688	0.041	0.207
11	vs.	9	-2.253	0.247	0.037
10	vs.	9	-2.732	0.165	0.022