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A Provisional Multi-Metric Index of Biological Integrity (MIBI) to Assess Water Quality in Utah Lake centered on Regulatory Directives

Technical Report

By

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Regarding society’s poor track record of environmental protection:
“*The complex reasons for failure center on the hubris of a society that behaves as if it could repeal the laws of nature. Plans generated by economists, technologists, engineers, and ecologists have too often assumed that lost or damaged components of ecological systems are unimportant or can be repaired or replaced.”* J. R. Karr, 1996

Cover image: Female cyclopoid copepod.
http://www.ulrichhopp.de/bilder/kleinkrebse/Kleink_03_Mesocyclops_leuckarti_003.jpg

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Introduction

Multimetric indices of biological integrity (MIBIs) are a type of bioassessment that rely on empirical knowledge of how a wide range of biological attributes respond to varying degrees of human influence (Karr 1993, Karr and Chu 1997). The most useful MIBIs explicitly embrace several attributes of the biotic assemblages, including; taxa richness (diversity) and composition, indicator taxa (e.g., tolerant and intolerant groups), population dynamics, production, and an assessment of processes that include trophic structure, feeding strategies and other functional traits (Allen and Polimene 2011; Calow 1987; Cao and Hawkins 2019). The goal of a MIBI is to measure and evaluate the consequences of human actions on biological systems (Karr 1993, Karr and Chu 1997) however, it should be emphasized that bioassessments, including MIBIs, are not science but are the link between scientists and managers, and thus some level of subjectivity (e.g. professional judgment and management objectives) is inherent and cannot be completely avoided. MIBIs are evaluative precursors to more intensive, stressor specific, monitoring programs. They are assessment tools not monitoring tools and should not be used as such, although more comprehensive MIBIs such as the one presented in this report can help guide managers as to the types and causes of impairment.

Utah Lake

Utah Lake is an underappreciated, unique, and ecologically important part of Utah's (and the nation's) natural heritage. It is one of the few freshwater remnants of pluvial Lake Bonneville, that likely outsized Lake Michigan in size and volume. Utah Lake has until recently supported one of the most diverse and productive molluscan faunas in the western USA with perhaps twenty snail, clam, and mussel taxa. These mollusks likely dictated much of Utah Lake's ecosystem function (Richards and Miller 2017; Richards and Miller 2019; Richards 2016, 2018, 2019). Unfortunately, the majority of these molluscan taxa have been extirpated from the lake and their populations have been drastically reduced throughout most of its drainage (Richards and Miller 2019; Richards and Miller 2017; Richards 2016,2017, 2018, 2019a). Utah Lake was also once home to at least a dozen native fishes, including the Bonneville Cutthroat Trout (extirpated), Utah Lake Sculpin (extinct), and June Sucker (endangered) due to in part its ancient lineage and isolation from other large bodied freshwater lakes. Most native fishes have been extirpated from Utah Lake.

Regrettably, Utah Lake is now a highly regulated and abused reservoir ecosystem that has undergone human induced ecological hysteresis and catastrophic shifts and no longer resembles its natural self, pre-Mormon settlement. Consequently, Utah Lake is biologically impoverished. According to Karr (1996), "if biotic impoverishment is the problem, then protecting the integrity of" Utah Lake's "biological system(s) must be the goal".

Sections 101(a) of the Clean Water Act (1987) legally mandates USEPA to protect the physical chemical, and ***biological integrity***[1],[2] of our nation's waters. In addition, the Clean Water Act

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[1] We adhere to the following definition of biological integrity throughout this document and during all of our research endeavors: ***Biological integrity*** refers to the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat … (Angermeier and Karr, 1994; Frey, 1975; Karr and Dudley, 1981; Karr et al., 1986).

necessitates protection and enhancement of shellfisheries[3], which many managers fail to realize, includes freshwater mollusks (mussels, snails, clams).

Under the provision of the Clean Water Act, the Utah Division of Water Quality (UDWQ) is mandated to protect Utah Lake's three designated biological beneficial uses:

1. Warm-water fisheries,
2. other aquatic life (e.g. bird populations), and the
3. aquatic life they depend on (UDWQ 2019).

UDWQ is also required to protect for recreational beneficial use of Utah Lake; the main impairment is considered toxin-producing cyanoHABs, and for agricultural uses[4].

Because Utah Lake: 1) is the last freshwater remnant of pluvial Lake Bonneville, 2) its large size (surface area ≈ 100,000 acres) in an semi-arid climate, 3) its unique molluscan and fish diversity heritage, and 4) no other 'reference' water bodies with which to compare; the index of metrics (MIBI) and baseline values presented in this report are site specific for Utah Lake. The index can, however, be modified for other lentic waters and will be for Farmington Bay of Great Salt Lake.

Metrics

Primary Metrics

The Utah Lake MIBI is composed of relatively easy to measure primary metrics specifically targeting designated beneficial uses (fisheries, shell fisheries (e.g. mollusks), birds, and the aquatic life they depend (e.g. zooplankton, benthic invertebrates) including:

1. Benthic macroinvertebrate diversity,
2. Benthic macroinvertebrate secondary production (biomass as a substitute),
3. Zooplankton diversity,
4. Zooplankton secondary production (biomass as a substitute),
5. Mollusk diversity,
6. Mollusk densities,
7. Fish condition index.

An easy to measure metric for recreational beneficial use (e.g. swimmable) will be:

1. Creation of a DNA identification code of toxin producing cyanoHABs and develop metric baseline values.

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[2] The combination of physical, chemical, and biological integrity = ecological integrity (Karr 1996).

[3] The Clean Water Act (1987) states that: "It is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, ***shellfish***, and wildlife and provides for recreation in and on the water be achieved."

[4] UDWQ (2019) documents that, "The state classifies waters based on their uses and develops water quality standards to protect those uses. Utah's designated uses include drinking water, recreation, aquatic wildlife, and agriculture. Utah Lake is protected for the following designated uses:

2B: Infrequent primary contact recreation such as boating, wading, or similar uses
3B: Warm-water species of game fish, including the necessary aquatic organisms in their food chain
3D: Other aquatic wildlife.
4: Agricultural uses including irrigation of crops and stock watering" (UDWQ 2019).

The MIBI emphasizes the importance of Utah Lake's unique molluscan fauna, the importance of benthic invertebrates, particularly chironomids to its fisheries and birds, and the importance of zooplankton to its fisheries. Present values of each metric reported by Utah Lake researchers (e.g. Richards and Miller 2017; Richards 2016, 2018, 2019, UDWQ, and others) and/or those reported in the literature will be used as baseline values in which to compare future changes.

Secondary Metrics

There are also several dozen secondary metrics, including functional trait based metrics that are increasingly recognized as equally important or superior to taxa based metrics (Allen and Polimene 2011; Calow 1987; Dehling and Stouffer 2018; Monteiro and Faria 2018; Hayden et al. 2019), that will help fine tune and support the primary metrics and allow managers to better understand the levels and types of impairments affecting the lake.

<u>A brief summary of secondary metrics includes:</u>

- Phytoplankton, zooplankton, benthic invertebrate, mollusk, and fish taxa diversity indices, e.g. evenness, effective number of taxa,
- Zooplankton family relative abundances and ratios,
- Zooplankton, benthic invertebrate, mollusk, and fish functional traits indices: Particularly for zooplankton e.g. body size; mesotrophic vs. eutrophic zooplankton taxa ratio, taxonomic group changes (Cladocera, copepods, rotifers, etc.).

The use and validity of all of the primary and secondary metrics included in the MIBI (Table 1) are well grounded in the ecological and bioassessment literature (see Unabridged Literature Cited and References section).

Baseline Values

All of the metrics listed in Table 1 (Provo Bay specific as an example) will be populated from values based on recent and present conditions. These will be considered baseline scores to evaluate changes. Some metrics will increase or decrease depending on changes in water quality. No overall score(s) will be derived as is frequently done in other MIBIs. We contend that there is no statistical or ecological rational for weighting each metric and then subjectively combining them into a final score, therefore, we consider each metric as stand-alone. Each metric will either respond separately to different types and levels of impairment or compliment or add support to other metrics. Avoiding an overall score will allow researchers and managers the ability to observe more subtle changes in conditions and act accordingly.

Less Eutrophic Utah Lake Goal

Many of the metrics values will directly or indirectly change if and when Utah Lake moves along the primary production gradient from the current highly productive 'hyper eutrophic' condition to a lesser productive hyper eutrophic to eutrophic condition, as is the management goal of several agencies, including USEPA and UDWQ. Some metrics may have already exceeded a productivity threshold. For example, Utah Lake benthic invertebrate secondary production may or may not have exceeded a threshold value due to hyper-eutrophic conditions and could increase when primary production (e.g. eutrophication) is lowered. The appropriate value for benthic invertebrate secondary production would therefore be its maximum obtainable to protect for the designated beneficial uses of warm-water fisheries and bird populations.

Spatially and Temporally Derived MIBIs

We have confirmed that biological components including phytoplankton, zooplankton, benthic invertebrates, and fisheries, etc. vary both spatially and temporally in the lake (Richards and Miller 2017; Richards 2016, 2018, 2019, unpublished data and observations). MIBI baseline scores presented in the Table 1 example will therefore be provided for three locations that are mostly ecologically distinct based on others and our research:

1) Provo Bay,
2) Goshen Bay, and
3) Utah Lake proper.

That is, separate MIBIs will be required for each of the three sections of the lake.

Although marinas including Lindon Marina, Utah Lake State Park Marina, and Lincoln Marina experience quite different ecologies and baseline metric values compared to the other two locations, they will not have separate MIBIs. It is apparent that marinas function as a type of pollutant and should be treated as such.

The example MIBI presented in Table 1 includes metrics that reflect the temporal component of Provo Bay's ecology. Recommended times of year such as annual, seasonal, or monthly metric measurement are included in the MIBI.

Focus on Zooplankton Metrics

Zooplankton are a main focus of this MIBI. Zooplankton are in the pivotal position of transferring nutrients throughout aquatic food webs (bottom-up, top-down, trophic cascades) (Caroni and Irvine 2010; García-Chicote et al. 2018) and thus play an essential ecological role within Utah Lake. Zooplankton have a proportionally high indicator value that cannot be encompassed by phytoplankton or fish metrics (Carpenter et al. 1985; Jeppesen et al. 2011; García-Chicote et al. 2018; Naselli-Flores and Rossetti, 2010; Barnett and Beisner 2007). In addition, the response of zooplankton assemblage structure metrics can be both to specific disturbances and chronic changes ((Attayde and Bozelli, 1998; Cairns et al., 1993; García-Chicote et al. 2018). Subsequently, these ecological roles of zooplankton in Utah Lake are explicitly and implicitly captured in the MIBI.

Zooplankton Taxonomy

There are only about twenty or so zooplankton taxa in Utah Lake (Richards 2019; Marshall 2019), which makes species level identification relatively easy for trained taxonomists or geneticist using DNA barcoding. We consider the Marshall (2019) report to be the definitive taxonomic reference for Utah Lake zooplankton until further modified. This reference was used to develop baseline zooplankton metric scores presented in the MIBI (Table 1 example for Provo Bay).

Fish Assemblage Imbalance

Utah Lake's native fish assemblage no longer exists. Thirteen native species occurred in the lake upon arrival of Mormon settlers in the mid 1800s. The Bonneville Cutthroat Trout, Bonneville Redside Shiner, Mottled Sculpin, Utah Lake Sculpin, Leatherside Chub, Utah Chub, Speckled Dace, Longnose Dace, Mountain Whitefish, and Mountain Sucker no longer exist in Utah Lake.

The analog Utah Lake fish assemblage is now dominated by introduced species including Carp, Largemouth Bass, White Bass, Black Bullhead, Channel Catfish, Walleye, Goldfish, Yellow Perch, Blue Gill, and Black Crappie. The fish assemblage in the lake is most certainly out of balance.

We have incorporated several metrics that reflect this imbalance directly and several indirectly. It is well known that planktivorous fish can alter entire lake food webs primarily by preferentially consuming larger bodied zooplankton which in turn preferentially prefer feeding on larger phytoplankton including cyanophytes (Sondergaard et al. 2008; Wetzel 2001; Cole and Weihe 2016; Havens et al. 2015a, 2015b; Gophen 1990; Cooke et al. 2016). All of the fish species currently residing in Utah Lake are planktivorous at least during their juvenile stages. Many studies have shown that removal or reduction of planktivorous fish populations improves water quality including reduction of cyanoHABs leading many researchers and managers to recommend biomanipulation as a relatively inexpensive remedy for controlling algal blooms compared to attempts at whole drainage nutrient control (Riedel-Lehrke 1997; Cooke 1986; Jeppesen et al. 2007; Richards 2019a). We have shown that at least one metric, *zooplankton body length* is reduced in Utah Lake compared to other temperate lakes and that body lengths of zooplankton in the lake vary temporally and spatially in a pattern consistent with planktivore feeding (Appendix 1). Several of the zooplankton metrics in the example MIBI (Table 1) will respond to changes in fish assemblage composition especially if a fisheries biomanipulation program is initiated in Utah Lake.

Species Variability as a Function of Ecosystem Stability

Individual plankton species abundances and assemblage composition variability increases disproportionally to other commonly measured environmental variables as ecosystems become more and more out -of -balance and unstable (e.g. loss of diversity; increased nutrients; other pollution and pollutants; trophic cascades; altered food webs; etc.) (Cottingham et al. 2000; Ptacnik et al. 2008; Zohary 2004; Thomas et al. 2018). The well-established population dynamics literature shows that widely fluctuating populations are a good indicator of disturbance and that at low population levels, extinction risk increases with increased variability (e.g. demographic stochasticity, environmental stochasticity) (Melbourne and Hastings 2008; Vucetich et al. 2000; Pimm et al. 1988). Many phyto- and zooplankton taxa in Utah Lake occur at low abundances that are highly variable (see relevant Richards citations). These taxa are more susceptible to extinction and are inherently useful indicators of impaired conditions. Several metrics in Table 1 reflect low taxa abundance and variability (e.g. CV metrics reflect the well-known theoretical predictions that extinction risk increases with an increase in temporal coefficient of variation in population size (CV) (Pimm et al. 1998)).

The development and refinement of this MIBI is designed to be a collaborative effort between agencies including UDWR fisheries program, UDWQ, WFWQC, and others.

The following table, Tables 1 is our proposed MIBI for Provo Bay and functions as a working guideline for Wasatch Front Water Quality Council researchers and their contractors who are collecting data on Utah Lake.

Table 1. Example of proposed multimetric index of biological integrity (MIBI) template for monitoring Utah Lake. ***Provo Bay MIBI.*** *Justification of metrics used in this MIBI can be found in Unabridged Literature Cited and Selected Reference Section. Metric values are in the process of being populated in this MIBI. TBD = To Be Determined.*

Provo Bay	Metric	Baseline Value	Improvement Change
Phytoplankton	All Divisions		
	Chl A[9] (monthly mean and 90% CI)	Jan: Feb: March: April: May: June: July: Aug: Sept: Oct Nov: Dec:	Decrease
	Total biovolume (cells L^{-1}) (monthly mean and 90% CI) [11]	Jan: 326 (91; 561) Feb: 2945 (1,989; 3,900) March: 7,333 (4,239; 10,427) April: 10,988 (6,024; 15,952) May: 75,806 (unk.; 179,259) June: 93,746 (unk.; 190,318) July: 2,289,270 (597,856; 3,980,684) Aug: 606,535 (397,855; 815,215) Sept: 668,899 (407,730; 930,068) Oct/Nov: 423,521 (290,408; 556,634)	Decrease

		Dec: unknown	
	Total biovolume CV	Jan: Feb: March: April: May: June: July: Aug: Sept: Oct Nov: Dec:	Decrease
	Toxin level ($\mu g\ L^{-1}$)[12] (monthly mean and 90% CI)	Jan: Feb: March: April: May: June: July: Aug: Sept: Oct Nov: Dec:	Decrease
	Mean cell size (V) ($\mu m^3\ cell^{-1}$) (monthly mean and 90% CI)	Jan: Feb: March: April: May: June: July: Aug: Sept:	Decrease

		Oct Nov: Dec:	
	Mean cellular C content (pg C $cell^{-1}$) (monthly mean and 90% CI)	Jan: Feb: March: April: May: June: July: Aug: Sept: Oct Nov: Dec:	Increase
	Mean C content/mean cell volume (C/V) (pg C μm^{-3}) (monthly mean and 90% CI)	Jan: Feb: March: April: May: June: July: Aug: Sept: Oct Nov: Dec:	Increase
	Taxa Based Diversity[15]		
	Richness (seasonal mean and 90% CI)	Winter Spring: Summer: Autumn:	Increase
	Evenness (seasonal mean and 90% CI)	Winter Spring:	Increase/Decrease[17]

		Summer: Autumn:	
	ENT[13] (seasonal mean and 90% CI)	Winter Spring: Summer: Autumn:	Increase/Decrease[17]
	Division Based Biovolume[11]		
	Proportion biovolume Cyanophytes (cells L^{-1}) (monthly mean and 90% CI)[11]	Jan: 0.00 Feb: 0.08 (0.00, 0.16) March: 0.09 (0.00, 0.18) April: 0.09 (0.04, 0.14) May: 0.21 (0.00, 0.44) June: 0.69 (0.59, 0.79) July: 0.87 (0.80, 0.95) Aug: 0.54 (0.46, 0.62) Sept: 0.68 (0.53, 0.83) Oct/Nov: 0.14 (0.05, 0.24) Dec:	Decrease
	Proportion biovolume Chlorophytes (cells L^{-1}) (monthly mean and 90% CI)[11]	Jan: 0.08 (0.00, 0.017) Feb: 0.10 (0.00, 0.24) March: 0.11 (0.05, 0.18) April: 0.44 (0.33, 0.54) May: 0.34 (0.10, 0.58) June: 0.22 (0.15, 0.29) July: 0.11 (0.04, 0.19) Aug: 0.40 (0.32, 0.49) Sept: 0.24 (0.13, 0.36) Oct/Nov: 0.83 (0.73, 0.94) Dec: unknown	Increase in summer months
	Proportion biovolume Bacillariophytes (cells L^{-1}) (monthly mean and 90% CI)[11]	Jan: 0.90 (0.82, 0.99) Feb: 0.82 (0.66, 0.98) March: 0.79 (0.69, 0.89) April: 0.45 (0.34, 0.55) May: 0.44 (0.18, 0.71)	Increase

		June: 0.08 (0.03, 0.13) July: 0.01 (0.00, 0.02) Aug: 0.05 (0.03, 0.06) Sept: 0.08 (0.02, 0.14) Oct/Nov: 0.02 (0.01, 0.03) Dec: unknown	
	Proportion biovolume other Divisions (cells L^{-1}) (monthly mean and 90% CI)[11]	Jan: 0.01 (0.00, 0.04) Feb: 0.00 March: 0.01 (0.00, 0.01) April: 0.03 (0.01, 0.05) May: 0.01 (0.01, 0.02) June: 0.01 (0.00, 0.01) July: 0.01 (0.00, 0.01) Aug: 0.01 (0.00, 0.02) Sept: 0.00 Oct/Nov: 0.00 Dec: unknown	Increase
	Division Based Diversity		
	Proportion Cyanophyte Taxa (seasonal mean and 90% CI)	Winter Spring: Summer: Autumn:	Decrease
	Proportion Chlorophyte Taxa (seasonal monthly and 90% CI)	Winter Spring: Summer: Autumn:	Increase
	Proportion Bacillariophyte Taxa (seasonal mean and 90% CI)	Winter Spring: Summer: Autumn:	Increase
	Proportion other Divisions Taxa (seasonal mean and 90% CI)	Winter Spring: Summer: Autumn:	Increase

Zooplankton			
	Assemblage Level Body Size		
	Length (mm) (seasonal mean and 90% CI)[5]	Winter: 0.66 (0.38, 0.95)[1] Spring: 0.68 (0.60, 0.75) Summer: 0.77 (0.72, 0.82) Autumn: 0.89 (0.72, 1.06)	Increase
	CV length[5] (seasonal)	Winter: 0.55 Spring: 0.30 Summer: 0.15 Autumn: 0.18	Decrease
	Body mass (mg) (seasonal mean and 90% CI)	TBD[10]	Increase
	Biovolume (mm^3) (seasonal mean and 90% CI)	TBD[10]	Increase
	Assemblage Level Production		
	Biomass ($mg\ L^{-1}$) (seasonal mean and 90% CI)	Winter: Spring: Summer: Autumn:	Increase
	Biomass ($mg\ L^{-1}$) *CV* (seasonal)	Winter: Spring: Summer: Autumn:	Decrease
	Assemblage Level Growth/Reproduction		
	Potential Growth Rate (seasonal mean and 90% CI)	TBD from Literature[4]	
	Reproduction Type/Frequency (seasonal mean and 90% CI)	TBD from Literature[4]	
	Offspring Size/Number (seasonal mean and 90% CI)	TBD from Literature[4]	
	Assemblage Level Consumption		
	Clearance Rate	TBD from Literature[4]	

	(seasonal mean and 90% CI)		
	Food Size Range (seasonal mean and 90% CI)	TBD from Literature[4]	
	Sloppy Feeding (seasonal mean and 90% CI)	TBD from Literature[4]	
	Assemblage Level Predator Avoidance		
	Vertical Migration (seasonal mean and 90% CI)	TBD from Literature[4]	Decrease
	Escape Response (seasonal mean and 90% CI)	TBD from Literature[4]	
	Transparency (seasonal mean and 90% CI)	TBD from Literature[4]	Decrease
	Cyclomorphosis/Defense (seasonal mean and 90% CI)	TBD from Literature[4]	Decrease
	Assemblage Level Waste/Loss		
	Egestion Rate (C, N, P) (seasonal mean and 90% CI)	TBD from Literature[4]	
	Fecal Pellet Sedimentation Rate (C, N, P) (seasonal mean and 90% CI)	TBD from Literature[4]	
	Excretion Rate (NH_4, PO_4) (seasonal mean and 90% CI)	TBD from Literature[4]	
	Assemblage Level Metabolism		
	Respiration Rate (seasonal mean and 90% CI)	TBD from Literature[4]	
	Digestion (seasonal mean and 90% CI)	TBD from Literature[4]	
	Assimilation (seasonal mean and 90% CI)	TBD from Literature[4]	
	Diversity[2]		
	Taxa Richness (annual)	6.79 (6.30, 7.29)	Increase
	Taxa Evenness	0.59 (0.55, 0.64)	Increase/Decrease[17]

	(annual)		
	ENT (annual)	3.18 (2.95, 3.40)	Increase/Decrease[17]
	Group Relative Abundance		
	Proportion Rotifera (seasonal)	Winter: 0.14 (0.05; 0.22) Spring: 0.13 (0.09; 0.17) Summer: 0.10 (.06; 0.14) Autumn: 0.03 (0.00; 0.06)	
	Proportion Rotifera CV (seasonal)	Winter: 0.99 Spring: 1.02 Summer: 1.00 Autumn: 1.62	Decrease
	Proportion Cladocera (seasonal)	Winter: 0.27 (0.24; 0.30) Spring: 0.33 (0.30; 0.36) Summer: 0.35 (0.31; 0.39) Autumn:0.34 (0.29; 0.38)	
	Proportion Cladocera CV (seasonal)	Winter: 0.20 Spring: 0.33 Summer: 0.30 Autumn: 0.30	Decrease
	Proportion Calanoida (seasonal)	Winter: 0.15 (0.08; 0.22) Spring: 0.10 (0.08; 0.13) Summer: 0.05 (0.02; 0.07) Autumn: 0.12 (0.04; 0.21)	
	Proportion Calanoida CV (seasonal)	Winter: 0.73 Spring: 0.91 Summer: 1.47 Autumn: 0.84	Decrease
	Proportion Cyclopoida (seasonal)	Winter: 0.22 (0.16; 0.28) Spring: 0.28 (0.23; 0.30) Summer: 0.32 (0.25; 0.39) Autumn: 0.29 (0.12; 0.45)	
	Proportion Cyclopoida CV (seasonal)	Winter: 0.42 Spring: 0.29	Decrease

		Summer: 0.58 Autumn: 0.70	
	Proportion Harpacticoida (seasonal)	Winter: 0.03 (0.00; 0.06) Spring: 0.01 (0.00; 0.01) Summer: 0.02 (0.00; 0.03) Autumn: 0.05 (0.00; 0.10)	
	Proportion Harpacticoida CV (seasonal)	Winter: 1.61 Spring: 4.1 Summer: 2.15 Autumn: 1.16	Decrease
	Proportion Daphnia sp. (seasonal)	Winter: 0.19 (0.13; 0.24) Spring: 0.16 (0.14; 0.18) Summer: 0.17 (0.14; 0.19) Autumn: 0.18 (0.10; 0.26)	Increase
	Proportion Daphnia sp. CV (seasonal)	Winter: 0.49 Spring: 0.49 Summer: 0.43 Autumn: 0.55	Decrease
	Zooplankton-phytoplankton relationships		
	Z:P ratio (zooplankton biomass to phytoplankton biomass) (seasonal mean and 90% CI)	Winter: Spring: Summer: Autumn:	Increase
Non-Molluscan Benthic Invertebrates	Diversity		
	Taxa Richness (seasonal)	Winter: Spring: Summer: Autumn:	Increase
	Taxa Evenness (seasonal)	Winter: Spring: Summer: Autumn:	Increase

	ENT (seasonal)	Winter: Spring: Summer: Autumn:	Increase
	Production		
	Total biomass (mg dry weight m^{-2}) (seasonal)	Winter: na Spring: na Summer: 10,546 (Autumn. 10,961 (	Increase
	Total biomass CV (seasonal)	Winter: na Spring: na Summer: 0.84 Autumn: 0.89	Decrease
	Chironominae biomass (mg dry weight m^{-2}) (seasonal)	Winter: na Spring: na Summer: 3,304 (Autumn: 8,827 (	Increase
	Chironominae biomass CV (seasonal)	Winter: na Spring: na Summer: 1.23 Autumn: 1.01	Decrease
	Tanypodinae biomass (mg dry weight m^{-2}) (seasonal)	Winter: na Spring: na Summer: 6975 (Autumn: 1372 (	Increase
	Tanypodinae biomass CV (seasonal)	Winter: na Spring: na Summer: 1.23 Autumn: 1.03	Decrease
	Oligochaete biomass (mg dry weight m^{-2}) (seasonal)	Winter: na Spring: na Summer: 267 (Autumn: 761 (	Increase
	Oligochaete biomass CV	Winter: na	Decrease

		Spring: na Summer: 1.28 Autumn: 0.66	
	Corixid biomass (mg dry weight m^{-2}) (seasonal)	Winter: na Spring: na Summer: na Autumn: na	Increase
	Corixid biomass CV (seasonal)	Winter: na Spring: na Summer: na Autumn: na	Decrease
Mollusks	Diversity[16]		
	Native gastropod richness	Autumn: 2	Increase
	Invasive gastropod richness	Autumn: 0	Maintain
	Pulmonate richness	Autumn: 2	Increase
	Non-pulmonate richness	Autumn: 0	Increase
	Native bivalve richness	Autumn: 0	Increase
	Invasive bivalve richness	Autumn: 1	Decrease
Fishes	Condition		
	Biological Condition Index[3] (seasonal)	TBD	Increase
	Diversity		
	Proportion planktivore taxa (yearly)	TBD[3]	Decrease
	Proportion piscivore taxa (yearly)	TBD[3]	Increase
	Proportion benthic taxa (yearly)	TBD[3]	Decrease
	Proportion invasive taxa (yearly)	TBD[3]	Decrease
	Abundance[7]		

Submerged Aquatic Vegetation	*Proportion substrate cover* (yearly)	TBD	Increase
	Diversity[7]		
	Taxa Richness (yearly)	TBD	Increase

[1] More data needed to reduce variability estimates

[2] Taxa diversity metrics S, E, and ENT use annual value because there were no significant differences between seasons using bootstrapped (N = 500) mean and 90% CIs.

[3] Consultation with UDWR fisheries biologists needed for metric values

[4] Metric values need to be determined from literature and then confirmed with Utah Lake empirical values

[5] Zooplankton body lengths and CV metrics derived from Richards 2019 literature review and need to be confirmed with empirical data from future samples.

[6] Further refinements and justification of seasonal body length sub- metrics are in Appendix 1.

[7] Collaborative research needs to be initiated asap to estimate SAV metrics at all three locations

[8] Temperature data to be acquired from UDWQ Utah Lake database

[9] Data to be compiled from WFWQC and UDWQ Utah Lake database

[10] To be determined empirically

[11] Monthly means and 90% CIs based on lake wide values for 2017 only. Need to compile data from WFWQC and UDWQ and re analyzed

[12] A DNA based measure of toxin level detection is suggested

[13] ENT = effective number of taxa = exponentiated Shannon Diversity Index (*H*) (Jost 2006; Chao et al. 2010)

[15] Phytoplankton taxa diversity metric means and 90% CI values will be derived from UDWQ database from Rushforth Phycology and after taxonomic status and synonymies are accounted and adjusted for (see Richards 2018b for taxonomic updates).

[16] Utah Lake mollusk diversity metric values derived from Richards 2017 and unpublished data

[17] Evenness and ENT may either increase or decrease with changes in conditions and need to be evaluated based on baseline values (Cao and Hawkins 2019)

Discussion

This is a provisional MIBI illustrating metrics specific to Provo Bay but will include Goshen Bay and Utah Lake proper metric values (presently being populated). More literature review, data compilation, and consultation with fisheries biologist and other Utah Lake researchers will be essential to modify, evaluate, and complete it. Once metric values are populated for each location, researchers and managers will be able to confidently evaluate changes to the biological and ecological condition of Utah Lake as opposed to depending on professional judgment or highly simplified indices comprised of only a few easy to measure generalized metrics. Utah Lake is a unique body of water in the western USA with a remnant unique native biota that deserves our best efforts to assess and then monitor its present state. It is our responsibility to maintain and improve Utah Lake's condition and protect its biological and ecological integrity, including its beneficial uses for this and future generations.

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Appendices

Appendix 1

Spatial and Temporal Variability of Zooplankton Body Lengths in Utah Lake

Technical Memo

By
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To:
Wasatch Front Water Quality, Council, Salt Lake City, UT

April 16, 2019

Introduction

Body lengths of zooplankton are a widely used metric for evaluating conditions in lakes. Zooplankton body lengths typically decrease with increased; temperature, eutrophication, DIN:DP ratio, pollutants, fish predation, and interactions between these factors (Havens and Hanazato 1993; Havens et al. 2015; Havens and Beaver 2011;Trommer and Stibor 2019; Barnett and Beisner 2007; Gliwicz and Lampert 1990; Richman and Dodson 1983; Gillooly and Stanley 2000; others). Body size is extremely important in algal bloom dynamics because larger sized zooplankton are often better at feeding on larger strands of algal particularly cyanobacteria, therefore the loss of larger sized zooplankton may result in cyanoHABs (Carpenter and Kitchell 1988; Caroni 2010; Jeppesen et al. 2011; Attayde and Bozelli 1998 ; Carpenter et al. 1985; Jeppeson et al 2000; Jeppesen et al 2003; Lamper et al 1986; Gannon and Stemberger 1978; others). Richards (2019a) is developing a multi-metric index of biological integrity to monitor water quality in Utah Lake and Farmington Bay using zooplankton body length as an important metric.

Even though water quality managers are very concerned about cyanoHABs in Utah Lake, there have been no estimates of zooplankton body length spatial and temporal patterns in in Utah Lake, despite their well-known importance as a metric for monitoring water quality. We have remedied this situation by conducting statistical analyses on spatial and temporal patterns of zooplankton body lengths in Utah Lake with results presented in this memo and Richards (2019a in progress).

Methods

We used zooplankton data collected from Wasatch Front Water Quality Council and OreoHelix Consulting over the last several years as was presented in Richards 2019b. We then determined sample weighted zooplankton body lengths based on abundance data and lengths reported in Richards (2109b). We then conducted best-fit regression analyses, marginal analyses, and predicted mean and 95% CI body lengths for each location and month in Utah Lake.

Results

Zooplankton body lengths significantly varied spatially and temporally in Utah Lake with a relatively small to medium- small mean length = 0.85 mm (std. dev. = 0.19). Overall, body lengths were smallest from March through August and mostly significantly smaller than the mean (Figure 1). Body lengths were also significantly smaller than average in Provo Bay, Lindon Marina, and Utah Lake State Park Marina and significantly larger than average in the mid sections of the lake (labeled LP) (Figure 2).

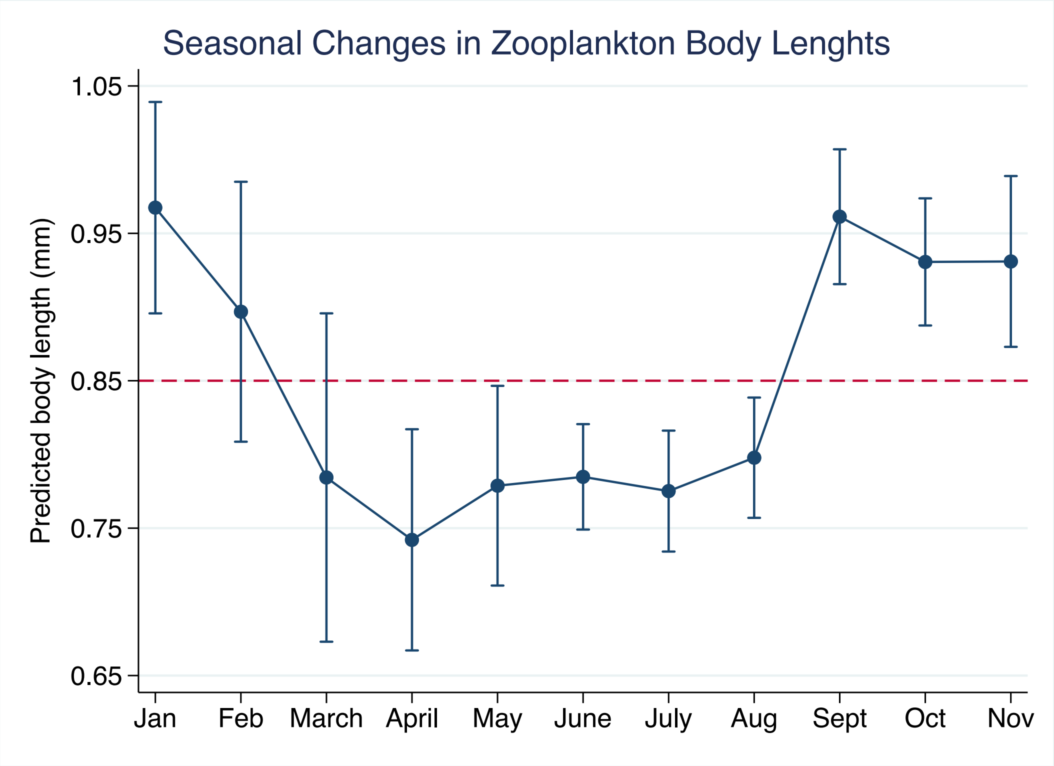

Figure 1. Predicted mean and 95% CIs for zooplankton body lengths from best fit regression models in Utah Lake seasonally.

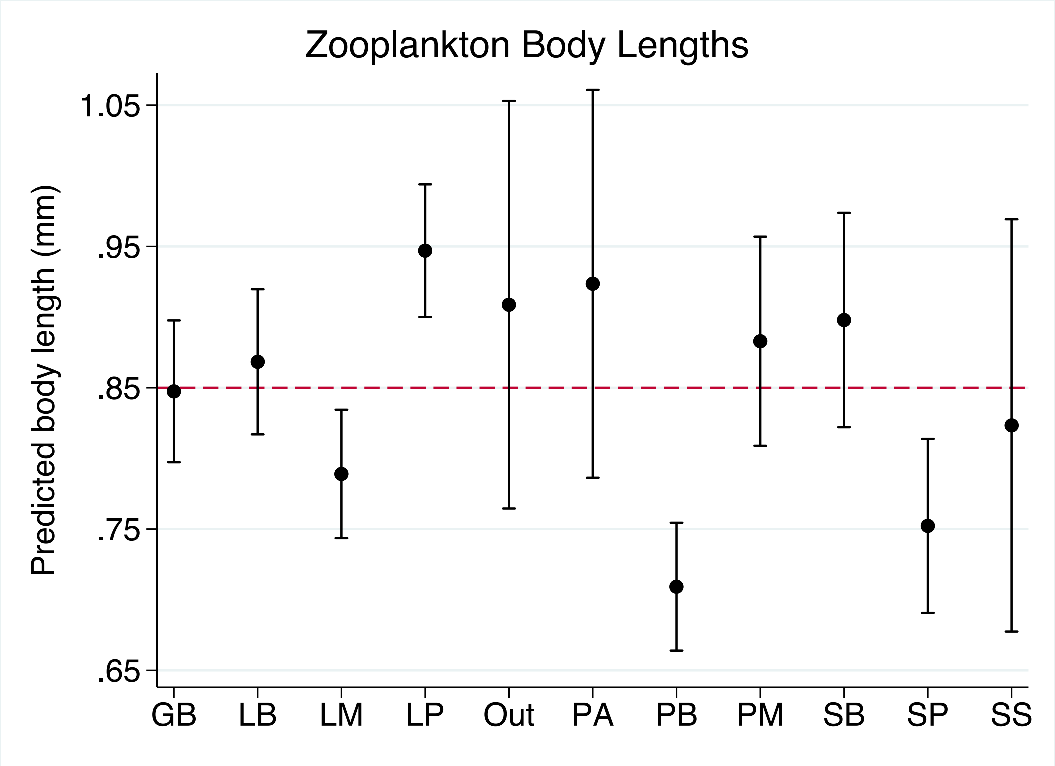

Figure 2. Predicted mean and 95% CIs for zooplankton body lengths from best fit regression models in Utah Lake by location.

Zooplankton body lengths were relatively uniformly small in Lindon Marina throughout the seasons (Figure 3) but significantly smaller than average in Provo Bay in March and April (Figure 4) and smaller than average from May to August at Utah Lake State Park Marina (Figure 5).

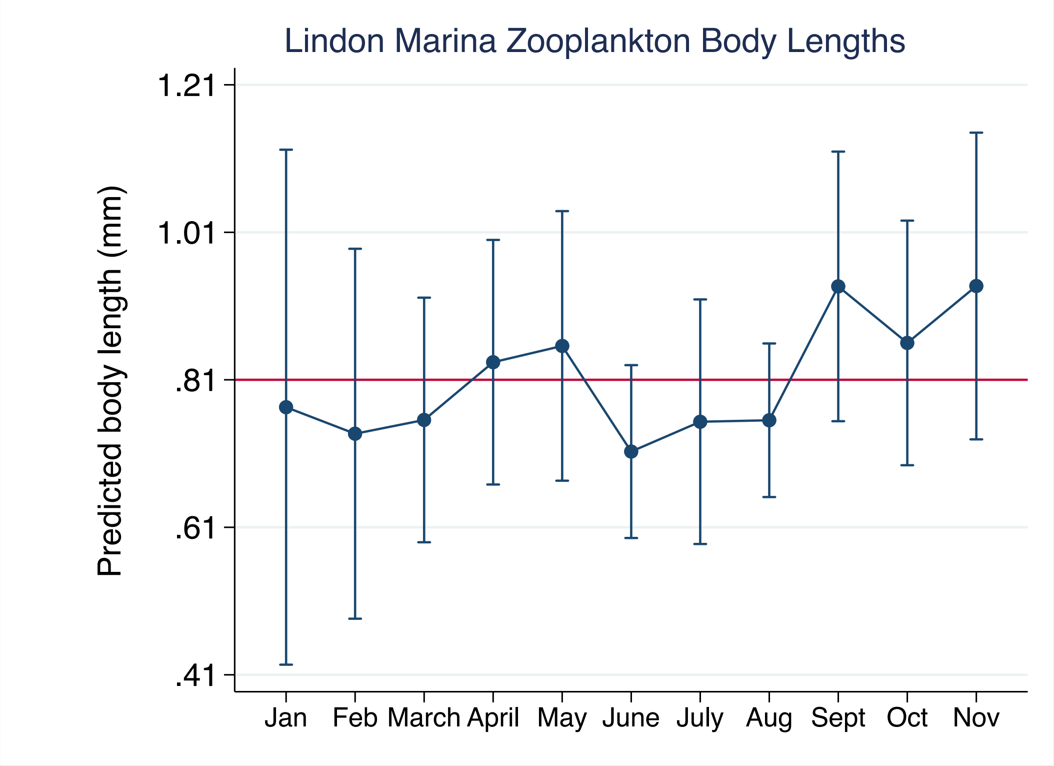

Figure 3. Predicted mean and 95% CIs for zooplankton body lengths from best fit regression models in Lindon Marina.

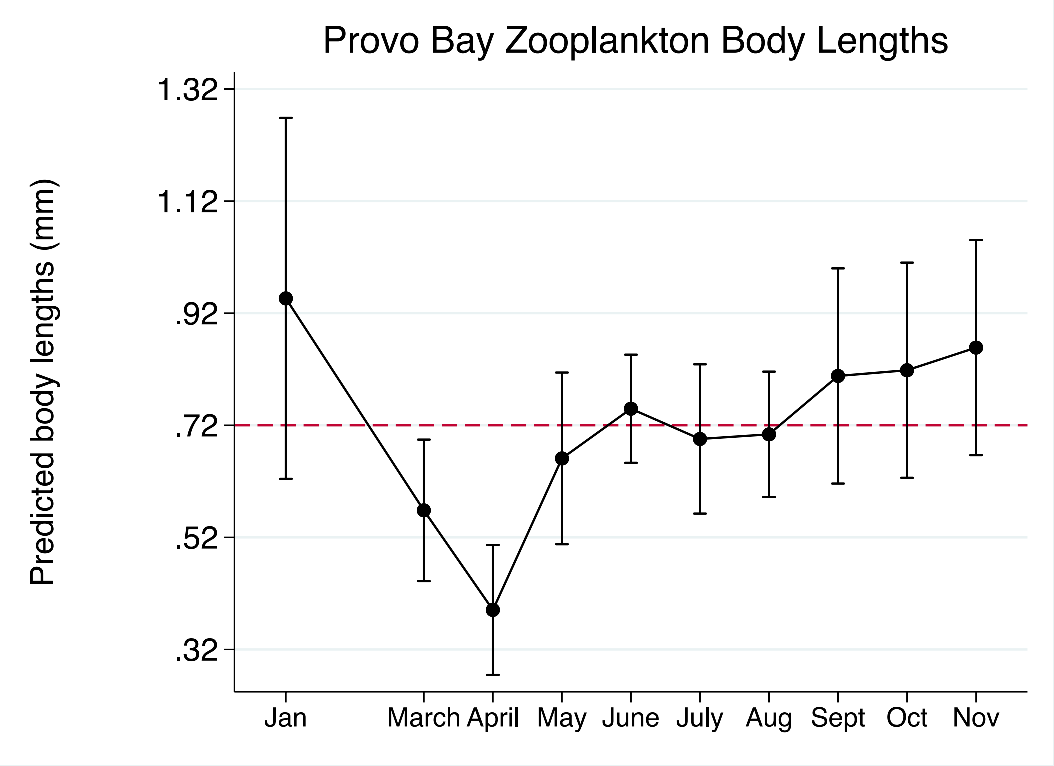

Figure 4. Predicted mean and 95% CIs for zooplankton body lengths from best fit regression models in Provo Bay.

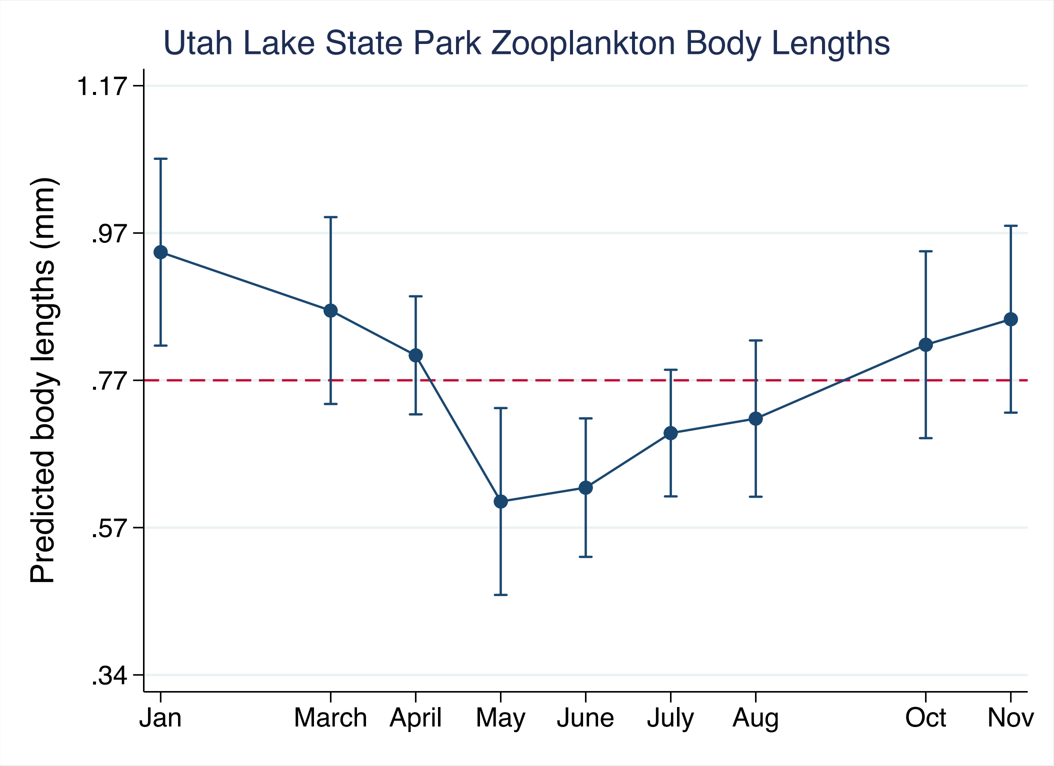

Figure 5. Predicted mean and 95% CIs for zooplankton body lengths from best fit regression models in Utah Lake State Park marina.

Discussion

Results presented in this memo show that zooplankton body lengths were relatively small compared to other temperate lakes (see References) and are a highly useful metric for monitoring water quality in Utah Lake. Body lengths significantly varied spatially and temporally. We suggest that other than the typical seasonal progression of zooplankton assemblages, was also due to the effects of planktivorous fish predation. Body lengths were typically smallest from spring through summer when fish are most actively feeding and when water clarity was often the best for visual planktivore feeding. The reason zooplankton body size was smallest in Provo Bay compared to most other sites was likely because this bay has the greatest planktivorous fish densities in the entire lake. Planktivorous fish prefer larger sized zooplankton.

2019 was a relatively high-water year in Utah Lake that resulted in a highly successful carp spawn and subsequently a boom in YOY juvenile carp production (Richards personal observation). Planktivorous juvenile carp require substantially more energy/individual body mass during growth than do larger adult carp maintaining body mass, thus zooplankton consumption rates should be higher in 2019 and subsequent years until the 2019 carp age class reaches adulthood than in previous less successful spawn years. Other planktivorous fish in the lake may have also produced more YOY than previous years. This phenomenon may alter zooplankton biomass and assemblage structure and requires careful monitoring.

Increased body sizes in late summer reported here were possibly due to increased algal bloom induced turbidity in mid-summer, which reduced visual ability of planktivores to find larger zooplankton, and subsequently allowed larger zooplankton such as *Daphnia* sp. to be able to consume larger sized phytoplankton, which then was partially responsible for decreased algal blooms in late summer/early autumn (Carpenter 1988; Chislock et al. 2019; Richards 2019b). Other causal factors for reduced zooplankton body size in Utah Lake are under investigation, including relationships between zooplankton body size and phytoplankton traits, pollution effects, and temperature effects. Results of these analyses will be directly applicable to the MIBI that is being produced by Richards (2019a).

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