"Midges and Worms, Midges and Worms" Life in Eternal Darkness: Utah Lake Water Quality Rates 'Very Poor' based on a Widely used Biotic Index

Technical Report · November 2022

David Richards
OreoHelix Ecological

Filename: Utah Lake Profundal Zone and Biotic Integrity Version 1.1

"Midges and Worms, Midges and Worms" Life in Eternal Darkness: Utah Lake Water Quality Rates 'Very Poor' based on a Widely used Biotic Index

Technical Report

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

Prepared By
David C. Richards, Ph.D.

OreoHelix Ecological, Vineyard UT 84059
Phone: 406.580.7816
Email: oreohelix@icloud.com

November 6, 2022

Table of Contents

Introduction 3
Limnological Zones 3
Utah Lake Physical Integrity 4
- Littoral Zone 4
- Limnetic Zone 5
- Profundal Zone: *The Zone of Eternal Darkness* 5

Profundal Zone Inhabitants 5
- Water Quality Evaluation using HBI/Tolerance Index 6
- HBI/Tolerance Results 7

Conclusion 8
Literature Cited 8

Introduction

The health[1], and biological and ecological integrity[2] of Utah Lake have been severely degraded over the past 150 years including a major degradation shift from a clear water state to a highly turbid state that has altered the lake's food web, water quality, and ecosystem function ((Janetski 1990, Richards 2022a, b, c, Richards 2019 a, b). There are many tools and methods used by water quality agencies worldwide to measure health and integrity of water bodies. One of the most widely used methods is to measure and assess the biological integrity of a water bodies' benthic invertebrate assemblage. The Hilsenhoff Biotic Index (HBI) also referred to as the Tolerance Index, measures pollution tolerance of benthic macroinvertebrates. With few exceptions the HBI/Tolerance Index is almost always incorporated into water quality assessment programs.

In this report, I will briefly discuss the loss of Utah Lake's physical integrity; from its past condition where a stable substrate allowed light to penetrate to most of the bottom of the lake and where benthic primary production dominated, to its present degraded condition where the lake's substrate is highly unstable due to loss of stabilizing biota, mostly aquatic plants, benthic algae, and bivalve mollusks, and where wave induced fine sediment resuspension prevents light penetration to the benthos and primary production is restricted to the top < 0.5 m layer of the lake (Richards 2022a).

I will also briefly discuss the status of Utah Lake's benthic invertebrate assemblage using data we have collected over several years. I will describe and use the HBI/Tolerance Index to illustrate and quantify the condition of the lake.

Limnological Zones

Limnologists often classify lakes into different zones based on light attenuation-availability that directly affects primary production: Littoral, limnetic, and profundal zones (Figure 1). The *littoral zone* is where light penetrates to the sediment substrate allowing aquatic plants and benthic algae to grow, typically along shorelines. However, in shallow fully functioning lakes the littoral zone can persist across much of the lake[3]. The *limnetic zone* is the depth to where

[1] "Integrity implies an unimpaired condition or the quality or state of being complete or undivided; it implies correspondence with some original condition. Health, on the other hand, implies a flourishing condition, well-being, vitality, or prosperity". "An ecosystem is healthy when it performs all its vital functions normally and properly; a healthy ecosystem is resilient, able to recover from many stresses; a healthy ecosystem requires minimal outside care" (Karr 1996).

[2] Ecological integrity is the sum of physical, chemical, and biological integrity (Karr 1993, 1996). 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, Karr and Dudley 1981, Karr et al. 1986).

[3] Historical records and paleo limnetic studies suggest that historically, Utah Lake had a littoral zone lush with aquatic plants, benthic algal and mollusk assemblages that extended across most of the lake (Richards and Miller 2019).

photosynthetically available light can penetrate in open water. In clear oligotrophic lakes, such as Lake Tahoe, the limnetic zone can reach 100 m. In shallow eutrophic lakes such as present Utah Lake, the limnetic zone is often < 0.5 m. The *profundal zone* is the area in a lake where photosynthetically available light is not available. This is what I refer to as '*the zone of eternal darkness*'. Most of Utah Lake' biota now dwells in this zone.

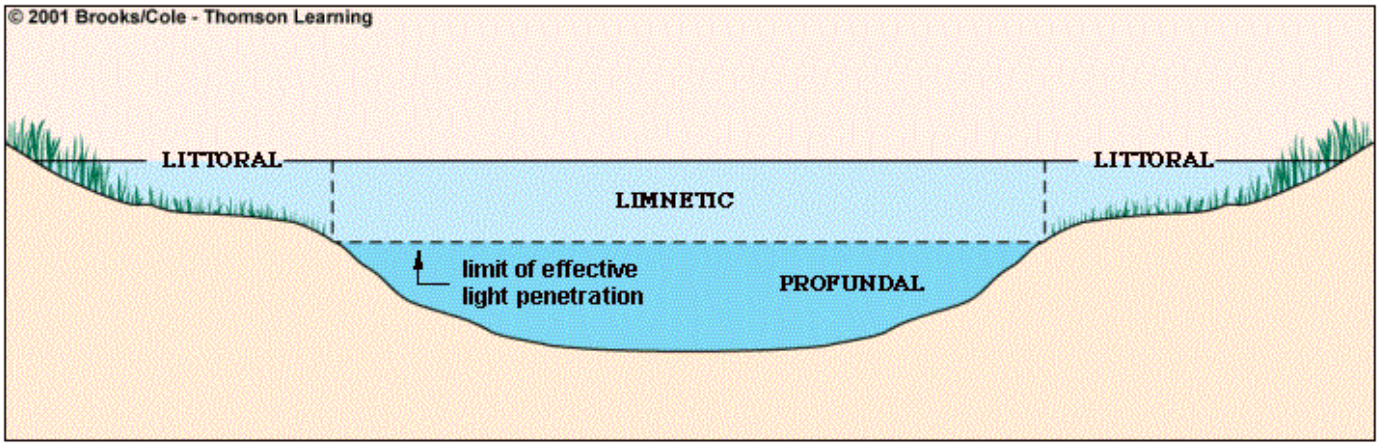

Figure 1. Three generalized limnetic zones of a lake, littoral, limnetic, and profundal.

Utah Lake Physical Integrity

Littoral Zone

Utah Lake once had a littoral zone that extended as far out into the lake as early explorers could see from its shoreline (Janetski 1990, Carter 2005). The Timpanogos Tribe, a subgroup of Utes that lived in the area were also known as the "Reed People" attesting to the bounty of aquatic vegetation (macrophytes) that thrived along Utah Lake's shores and littoral zone wetlands. The lake was characterized by stable substrate due to stabilizing biota that included aquatic macrophytes, benthic algae, and bivalve mollusks (Richards 2022a, Richards and Miller 2019). Utah Lake's diverse and abundant molluskan assemblage was likely unsurpassed in the western USA (Richards 2017), a true Utah natural heritage that has all but been lost. The synergy between aquatic macrophytes, benthic algae, and bivalves insured that water clarity in such a shallow lake was able to penetrate to most of lakes benthic substrate (Richards 2022a). Utah Lake's littoral zone began to suffer and rapidly decline soon after settlement by migrants of European descent in the late 1800's. Reasons for this decline were numerous including diversions, pollutants, and introduction of bioturbating Common Carp (*Cyprinus carpio*), and the tragic loss of native mollusks, among other factors (Janetski 1990, Carter 2005, Richards 2022, Richards and Miller 2017, 2019). Photosynthetically available light reaching the substrate is now typically between 10 to 50 cm (Richards unpublished data). This means that most of the lake resides outside of the littoral zone. Presently, aquatic vegetation does not cover the entire littoral zone and coverage is between 1 and 5% of the lake. Unfortunately, aquatic macrophytes, benthic algae, and bivalves are no longer able to provide sediment stabilizing ecosystem service due to strong wave action that easily disturbs suspended sediments and dislodges their benthic habitat making it mostly unstable and uninhabitable.

Limnetic Zone

The open water limnetic zone in Utah Lake also varies from about 10 to 50 cm depending on conditions. This zone is now almost exclusively where primary production occurs in the form of photosynthetic phytoplankton that includes cyanobacteria. This is also where phytoplanktonic grazers, zooplankton reside and consequently the majority of secondary production (Richards 2022). Domination by limnetic zone primary and secondary production indicates severe degradation of Utah Lake from past conditions and is the reason the lake is often classified as eutrophic or hyper-eutrophic (Richards 2022a).

Profundal Zone: *The Zone of Eternal Darkness*

Almost all lakes have a well-developed profundal zone. The area that a lake's profundal zone covers is dependent on many factors including topography, climate, benthic substrate, trophic state, and the health and balance of biota in its food web. Most healthy lakes have a balance between littoral, limnetic, and profundal zones. This is not the case for Utah Lake; it is now almost completely dominated by the profundal zone. The lake's profundal zone substrate is comprised of a thick unconsolidated, easily disturbed, nutrient laden sediment that is homogenous throughout most of the lake bottom with very little structural habitat. Its benthic habitat is only inhabited by any biota that can survive under very low or no light conditions, low levels of dissolved oxygen (hypoxia), and unstable fine sediments that provides almost no structural habitat diversity. The lake's profundal zone only allows for primary and secondary production derived from heterotrophic decomposition including detrital 'rain' that falls from the limnetic zone primarily in summer months (Richards 2022a, b, c). As I will show in the next section, only a few tolerant benthic invertebrate taxa now survive in Utah Lake.

Profundal Zone Inhabitants

Our team, Wasatch Front Water Quality Council, OreoHelix Ecological, and River Continuum Concepts have collected, taxonomically identified, and analyzed the most benthic invertebrate data of any other group with the possible exception of Utah State University researchers. However, our collections focused on the dominate habit within the profundal zone, whereas USU researchers primarily focused on remaining and limited littoral zone habitat.

We collected over eighty benthic invertebrate samples in our monitoring program and dozens of samples in our ongoing mesocosm study. Results of our monitoring program are summarized in Figure 2. Midges and worms almost completely dominated our samples, primarily three taxa: *Chironomus* sp. (midge), *Tanypus* sp.(midge), and Oligochaeta (segmented worms) (Figure 2). Other taxa made up only abut 1% of total biomass (Figure 2).

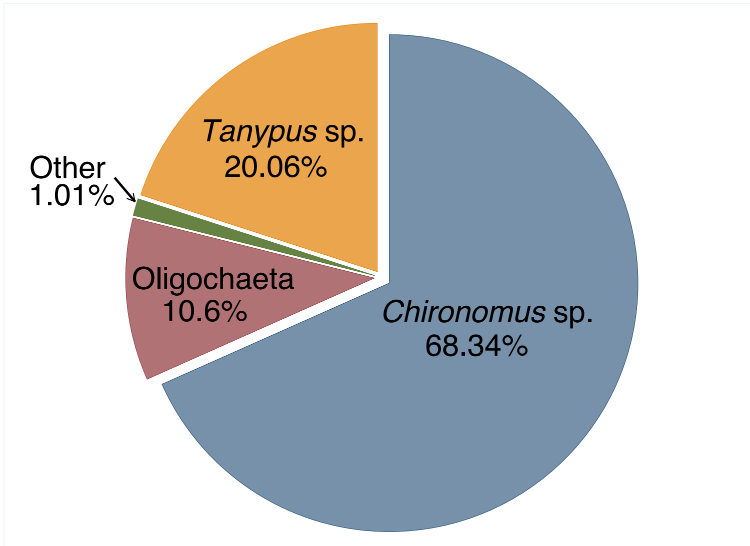

Figure 2. Percent benthic macroinvertebrate biomass at all sites in Utah Lake. 'Other' category includes Corbicula, other Chironomidae taxa, Hyalella, Helobdella, Oreodytes, Physa, Stagnicola, Tipulidae sp., Tabanidae sp. and Ostracoda.

Benthic invertebrate samples from our ongoing mesocosm study were comprised by similar taxa to our lake wide study including the following:

Oligochaeta (worms)
Chironomus decorus grp. (midge)
Nematoda/Nemata (unsegmented worm)
Polypedilum sp. (pupae) (midge)
Polypedilum halterale grp. (midge)
Chironomus sp. (pupae) (midge)
Chironomus crassicaudatus (midge)
Corbicula sp. (clam)
Cladotanytarsus sp. (midge)
Tanypus neopunctipennis (midge)
Orthocladiinae (pupae) (midge)
Cryptochironomus sp. (midge)

As presented above, the benthic invertebrate assemblage in the profundal zone of Utah Lake is almost completely dominated by midges and worms, midges and worms, and more midges and worms.

Water Quality Evaluation using HBI/Tolerance Index

The Hilsenhoff Biotic Tolerance Index (HBI) was created by William Hilsenhoff in 1977 to measure the effects of oxygen depletion (BOD) in Wisconsin streams resulting from organic or nutrient pollution. HBI is a quantitative diagnostic metric used to identify samples with a high degree of pollution tolerant organisms. based on the predetermined pollution tolerances of the observed taxon. This index is on a scale from 0 to 10 with higher values indicating more tolerant organism, and more polluted conditions and lower values indicating sensitive taxa and less polluted conditions. HBI estimates the overall tolerance of the community in a sampled area, weighted by the relative abundance of each taxonomic group (family, genus, etc.).

The formula is $\sum (n_i * t_i) / N$, where

n_i is the number of individuals of the "i"th taxon,
t_i is the tolerance index value of that taxon,
N is the total number of individuals in the sample assigned a Hilsenhoff Biotic Tolerance value.

EPA and other water quality agencies use Tolerance Values derived from HBI values and vary slightly from region to region for each taxon. (Barbour et al. 1999). Tolerance Values are error prone when combining species to genus or family level taxonomy or when values are unknown and estimated using best professional judgement.

Although extremely useful, HBI is but one of many metrics that should be used in an assessment. Most county, state, federal and tribal water quality agencies understand the limitations of using only a single metric to measure biological/ecological integrity and incorporate HBI into a suite of metrics for assessing water quality (e.g., Multimetric Index of Biological Integrity), with the exception of UT that relies on a single metric, Observed/Expected taxa.

HBI is mostly used in stream and river assessments but can and should be incorporated into lake assessments, such as Utah Lake. Richards and Miller (2019a) are developing a Multimetric Index of Ecological Integrity for Utah Lake that includes HBI/Tolerance Index as one of many informative metrics.

HBI/Tolerance Results

The cumulative HBI for our eighty monitoring samples was 9.85 (Figure 2). The following table, Table 1 summarizes HBI/Tolerance Values for our mesocosm benthic invertebrate sample results. Cumulative mean HBI/Tolerance Value for mesocosm benthic invertebrates = 9.12. This value should actually be somewhat higher because of the arbitrary assignment of 5 to Nematoda/Nemata[4].

Table 1. From TSSD mesocosm study

Taxon	Count	% RA	HBI/Tolerance Values
Oligochaeta	306	64.42%	9.5
Chironomus decorus grp.	99	20.84%	10
Nematoda/Nemata	33	6.95%	5
Polypedilum sp. (pupae)	13	2.74%	6
Polypedilum halterale grp.	6	1.26%	7.2
Chironomus sp (pupae)	4	0.84%	10

[4] HBI/Tolerance Values for Nematoda/Nemata were assigned 5 based on extremely limited studies, large number of taxa within that group that vary in organic pollution tolerances, and subsequently an arbitrarily assigned mean value (River Continuum Concepts personal communication)

Chironomus crassicaudatus	4	0.84%	10
Corbicula sp.	4	0.84%	6.3
Cladotanytarsus	3	0.63%	7
Tanypus neopunctipennis	1	0.21%	10
Orthocladiinae (pupae*)*	1	0.21%	6
Cryptochironomus sp.	1	0.21%	8
Mean			**9.12**

Based on water quality agency (including EPA) ranking of HBI/Tolerance Value ranks water quality in Utah Lake is considered 'very poor' and its degree of organic pollution is 'severe' (Table 2).

Table 2. HBI Water Quality Ranks

HBI	Water Quality	Degree of Organic Pollution
0.00-3.50	Excellent	No apparent organic pollution
3.5-4.50	Very Good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Pair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.5-8.50	Poor	Very significant organic pollution
8.5-10.0	Very Poor	Severe organic pollution

This rating of very poor water quality impairment can also be illuminated by basic knowledge of taxa present in our samples. For example, *Chironomus* sp. larvae are known as 'blood worms. This is because *Chironomus* sp. are the only invertebrate to evolve hemoglobin, a molecule that has an affinity to oxygen and helps remove oxygen from hypoxic profundal zone waters. The near absence of mollusk taxa, some of which are relatively pollution tolerant (e.g., Physidae, Lymnaeidae, isopods, and amphipods) should be flourishing in the benthos. These taxa could also be absent from not only organic pollution (i.e., hypoxia) but unstable thick loose sediment. These taxa are common in areas in the lake where aquatic plants and benthic algae are present.

Conclusion

Utah Lake's health/integrity is in very poor condition. The HBI/Tolerance Value results presented here support this conclusion and point to our understanding of the lake's current food web and ecosystem function that is obviously out of balance. Improving the health of the lake will require intensive restoration efforts focused on reestablishing sediment stabilizing aquatic plants, benthic algae, and native mollusks.

Literature Cited

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives: Protecting biotic resources. BioScience 44:690-697.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Carter, D.R. 2005. Utah Lake: Legacy. June Sucker Recovery Implementation Program.

Hilsenhoff, W. L. 1977. Use of Arthropods to Evaluate Water Quality of Streams. Wis. Dep. Nat. Resour. Technical Bulletin, 100.

Hilsenhoff, William L. 1998. "A Modification of the Biotic Index of Organic Stream Pollution to Remedy Problems and Permit Its Use Throughout the Year," The Great Lakes Entomologist, vol 31 (1). Available at: https://scholar.valpo.edu/tgle/vol31/iss1/1.

Hilsenhoff, William L. 1987. "An Improved Biotic Index of Organic Stream Pollution," The Great Lakes Entomologist, vol 20 (1). Available at: https://scholar.valpo.edu/tgle/vol20/iss1/7.

Hilsenhoff, William L. 1988. "Seasonal Correction Factors for the Biotic Index," The Great Lakes Entomologist, vol 21 (1). Available at: https://scholar.valpo.edu/tgle/vol21/iss1/3.

Karr, J. R. 1993. Defining and assessing ecological integrity: Beyond water quality. Environmental Toxicology and Chemistry, 12: 1521-1531. doi:10.1002/etc.5620120902

Karr, J.R. 1996. Ecological integrity and ecological health are not the same: The folly of the status quo. Pages 97-109 in: National Academy of Engineering 1996. Engineering Within Ecological Constraints. Washington, DC: The National Academies Press. https://doi.org/10.17226/4919.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Richards, D.C. 2022a. The health and integrity of Utah Lake 2022: A brief ecological evaluation. Report to Wasatch Front Water Quality Council, Salt Lake City, UT. OreoHelix Ecological, Vineyard, UT.

Richards, D.C. 2022b. Development of a Mass Balance Foodweb Model for Utah Lake. Proof-of-Concept. Draft using preliminary data. Submitted to Wasatch Front Water Quality Council, Salt Lake City, UT. OreoHelix Consulting, Vineyard, UT.

Richards, D.C. 2022c. Plankton biomass, diets, production-biomass ratios, and ecotrophic efficiency estimates for Utah Lake foodweb model development. Report to Wasatch Front Water Quality Council, Salt Lake City, UT. OreoHelix Consulting, Vineyard, UT.

Richards, D.C. and T. Miller. 2019a. A Provisional Multi-Metric Index of Biological Integrity (MIBI) to Assess Water Quality in Utah Lake centered on Regulatory Directives. Draft Technical Report to Wasatch Front Water Quality Council, Salt Lake City, UT. OreoHelix Ecological, Vineyard, UT.

Richards, D.C. and T. Miller. 2019b. Factors Effecting the Ecological Health and Integrity of Utah Lake with a Focus on the Relationships between Water Column Regulators, Benthic Ecosystem Engineers, and CyanoHABs. Progress Report to Wasatch Front Water Quality Council. Salt Lake City, UT.

Richards, D. C. 2017a. Native Unionoida Surveys, Distribution, and Metapopulation Dynamics in the Jordan River-Utah Lake Drainage, UT. Report to Wasatch Front Water Quality Council. Salt Lake City, UT. OreoHelix Consulting, Vineyard, UT. Version 1.5 May, 26, 2017. Available at:http://wfwqc.org/wp-content/uploads/2017/04/Native-Unionoida-Surveys-and-Metapopulation-Dynamics-in-the-Jordan-River-Utah-Lake-drainage-UT-Version-1.5-compressed.pdf.

Richards, D. C. and T. Miller. 2017a. A preliminary analysis of Utah Lake's unique foodweb with a focus on the role of nutrients, phytoplankton, zooplankton, and benthic invertebrates on HABs. Utah Lake Research 2016. Progress Report. Wasatch Front Water Quality Council, Salt Lake City, UT.