Subject:	Utah Lake Water Quality Study Charge Questions Reporting
Sub-Topic:	Macrophytes and Diatoms
Science Panelists:	Janice Brahney, Soren Brothers, Mitch Hogsett, James Martin
Tetra Tech Team:	Kateri Salk, Michael Paul
Date:	2021-10-28

1.0 Background and Approach

Subgroups of the Utah Lake Water Quality Study (ULWQS) Science Panel (SP) have compiled interim responses to the ULWQS Charge Questions according to topic areas. Charge questions are listed below, followed by a traceable account of the evidence evaluation, interim answer statement, and assessment of confidence in the answer. The evaluation of charge questions has proceeded according to the *Utah Lake Water Quality Study—Uncertainty Guidance* document:

- The first consideration in communicating the validity of any statement of finding (e.g., a response to a charge question) is to characterize the evidence (as to type, amount, and quality) as well as the agreement among evidence underlying the finding or conclusion.
- The type of evidence refers to its derivation (e.g., literature, mechanistic model output, field observations, experimental evidence, or expert judgment).
- The amount of evidence refers to the quantity of independent evidence types.
- The quality of evidence refers to the rigor with which the evidence was derived. In previous applications of this approach, the terms “limited”, “medium”, and “high” have been used to describe the evaluation of evidence. The SP can decide how to weigh or combine these three elements into an assessment of the evidence. For example, one large, comprehensive, high quality study of the lake itself may constitute more evidence than results from several observational studies of dissimilar lakes.
- Finally, agreement refers to how results or conclusions among the different lines of evidence differ or concur and the terms “low”, “medium”, and “high” are used to describe agreement. Once again, the SP can decide what constitutes these qualitative statements of agreement.
- The amount and agreement of evidence form axes that define a space that informs estimates of confidence.

An assessment of likelihood is offered as an additional step in the uncertainty guidance framework but is only done if sufficient uncertainty information is provided and can be quantified. Given this is an interim evaluation of charge questions, likelihood has not been assessed at this time.

Moving toward final assessment of the charge questions on the next iteration of this effort, an evaluation of the quality of evidence regarding the type of evidence (e.g., data, presentation memo, SP-reviewed report, thesis/dissertation, peer-reviewed manuscript) will be conducted.

2.0 Charge Questions

1.1.ii. What were the environmental requirements for diatoms and extant and locally extirpated macrophyte species?

2.2 What are the environmental requirements for submerged macrophytes currently present at Utah Lake?

> i. What is the role of lake elevation and drawdown in macrophyte recovery? Are certain species more resilient to drawdowns and nutrient related impacts? Can some species establish/adapt more quickly?
>
> ii. What is the relationship between carp, wind, and macrophytes on non-algal turbidity and nutrient cycling in the lake? What impact could macrophyte reestablishment have?

4.2. Assuming continued carp removal and current water management, would nutrient reductions support a shift to a macrophyte-dominated state within reasonable planning horizons (i.e., 30-50 years)?

3.0 Question Evaluation

1.1.ii. What were the environmental requirements for diatoms and extant and locally extirpated macrophyte species?

Evidence evaluation

Stoneworts (*Characeae*), a submerged macrophyte, are considered to have been historically present in Utah Lake, and are experimentally shown to be a preferred foraging food source for invasive common carp in this lake (Miller and Crowl 2006; Miller and Provenza, 2007). Although stonewort meadows no longer occur in Utah Lake, they are elsewhere considered to indicate clear-water conditions in lakes (Lambert-Servien et al. 2006) and may improve water clarity by stabilizing sediments, precipitating calcite, and storing nutrients in their recalcitrant tissues (Kufel and Kufel, 2002). The only eDNA evidence that has been obtained for historical macrophyte presence is for hardstem bulrush, an emergent macrophyte in Goshen Bay; however, the lack of eDNA evidence for other species should not be interpreted as a historical absence. Charge question 1.1.i addresses additional evidence for macrophyte and diatom presence in the paleolimnological record.

Confidence

Limited paleolimnological data is available to characterize the environmental requirements of locally extirpated macrophyte species in Utah Lake, but historical records and present-day information about macrophytes in Utah Lake are available. There is thus a medium amount of information to answer this question, and the quality of this evidence ranges from low (literature-derived information from other systems) to high (eDNA for paleolimnological data) with high agreement. We conclude there is medium confidence in answering this question.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that historical macrophyte communities in Utah Lake were made up of clear-water submerged species including stoneworts as well as emergent macrophytes such as hardstem bulrush. Charge question 1.1.i addresses additional evidence for macrophyte and diatom presence in the paleolimnological record, and charge question 2.2 addresses evidence for environmental requirements of extant macrophyte species in Utah Lake.

2.2. What are the environmental requirements for submerged macrophytes currently present at Utah Lake?

Evidence evaluation

General requirements for submerged macrophytes in freshwater systems include light availability, water level, appropriate sediment substrate, and sheltering from mechanical disturbance including wave action and ice heaving. Light compensation points for species documented in Utah Lake (*Ceratophyllum demersum, Elodea canadensis, Myriophyllum spicatum, Potamogeton pectinatus, Potamogeton praelongus*; Brotherson 1981, Miller and Crowl 2006, Landom et al. 2019) range from 3.5-45 μmol m-2 s-1 (Madsen et al. 1991, Sand-Jensen and Madsen 1991, Spencer and Rejmanek 2010). *C. demersum*, a submerged macrophyte documented in the most recent report (Landom et al. 2019), was found to have a light compensation point of 7.2 μmol m-2 s-1, within the range of compensation points for seven species (6.9 ± 1.9 μmol m-2 s-1; Sand-Jensen and Madsen 1991). Multiple factors impact light level in Utah Lake, including sediment resuspension, carp bioturbation, and phytoplankton shading. Modeling studies have also indicated that carp and epiphytic algae can act together to eliminate submerged macrophyte communities in lakes (Hidding et al. 2016), providing support for concurrent internal (carp removal) and external (nutrient loading reduction) efforts. Water clarity and benthic primary production models indicate a historical clear-water state, featuring a self-stabilizing submerged macrophyte community would likely require mean phytoplankton chlorophyll *a* concentrations < 18 μg/L and mean Secchi depths of ~ 1 m (considering 2018 water levels), compared to 2018 mean chlorophyll *a* concentrations of 40 μg/L and Secchi depths of 0.25 m (King 2019). A consideration that may impact these requirements is whether a given macrophyte species maintains biomass low to the ground, hence requiring light conditions to be maintained throughout the growing season, or if the species grows nearer to the water surface throughout the growing season and thus may only need requisite light conditions to be maintained at the start of the growing season.

Confidence

Evidence to evaluate this question is derived from a combination of observational studies in Utah Lake, theoretical modeling for Utah Lake, and experimental studies on specific macrophyte species. There is a high amount of information to answer this question, and the quality of this evidence ranges from medium (literature-derived information on specific taxa) to high (studies in Utah Lake) with high agreement. We conclude there is medium confidence in answering this question.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that submerged macrophytes in Utah Lake require higher water clarity than currently exists in Utah Lake. Additional considerations that will impact macrophyte recovery in the lake include sediment substrate and sheltering from mechanical disturbance, which have not been evaluated in Utah Lake to date, as well as water level, which is evaluated as part of charge question 2.2.i.

2.2.i. What is the role of lake elevation and drawdown in macrophyte recovery? Are certain species more resilient to drawdowns and nutrient related impacts? Can some species establish/adapt more quickly?

Evidence evaluation

Landom et al. (2019) found that declining lake levels were associated with a decrease in macrophyte coverage across three sampled locations in Utah Lake. Seasonal changes in species composition were variable, and lake level had less of an association with native emergent species, Alkali bulrush (*Bolboschoenus maritimus*) and cattail (*Typha latifolia*). Studies in other lakes have shown that regulating water levels in tandem with natural local hydrological inter-seasonal variability (Zhao et al. 2012), while also maintaining internal concurrent bioremediation efforts (Beklioglu et al. 2017), may improve submerged macrophyte recovery in shallow eutrophic lakes.

Confidence

There is one direct study in Utah Lake that provides relevant evidence to directly answer this question, which is bolstered by evidence from published studies in other systems. While the amount of evidence is low for direct Utah Lake studies, the quality of evidence is high and has high agreement with the literature-based studies. We conclude there is medium confidence in answering this question.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that low water levels in Utah Lake negatively impact the growth and reestablishment of submerged macrophytes, while emergent macrophytes are less affected by variable water levels. If Utah Lake historically experienced seasonal changes in water level, macrophyte communities may be more resilient to water level-related changes if they mimic natural variability in magnitude and timing.

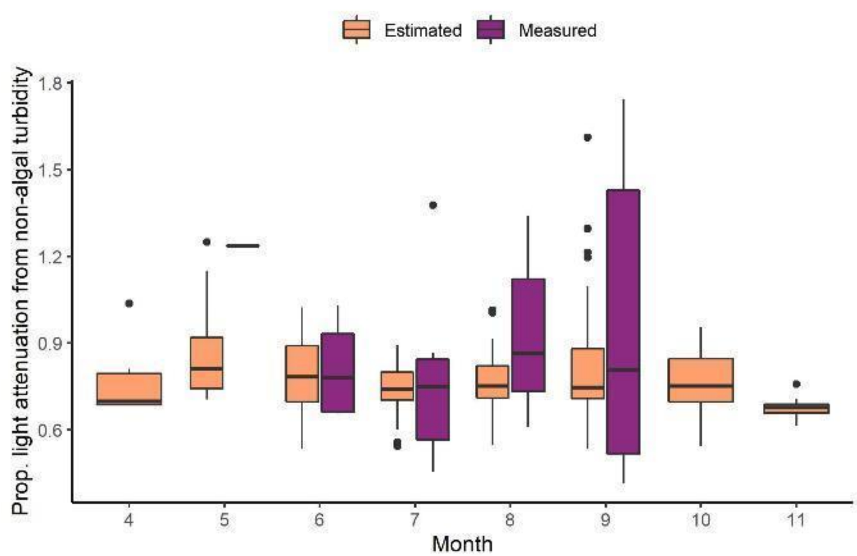
Follow-up Items

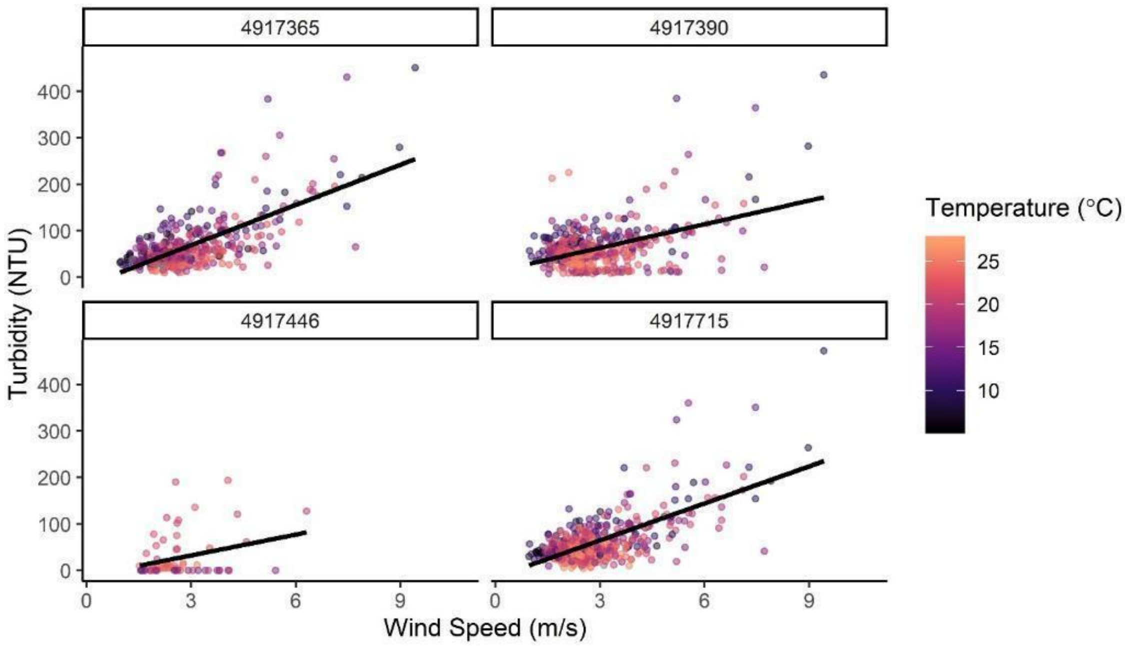
An analysis of the impacts of water level fluctuations on macrophytes both within and across years was suggested as an additional exploration to inform this question.

2.2.ii. What is the relationship between carp, wind, and macrophytes on non-algal turbidity and nutrient cycling in the lake? What impact could macrophyte reestablishment have?

Evidence evaluation

Non-algal turbidity makes up ~3/4 of turbidity in Utah Lake, and increases in turbidity are associated with wind events (Tetra Tech 2021). Thus, wind-driven sediment resuspension is hypothesized as the main driver of non-algal turbidity in Utah Lake. Forthcoming information from the EFDC/WASP application for Utah Lake will allow for an examination of the causal relationship between wind and turbidity. Carp bioturbation may also increase turbidity and disrupt rooted macrophytes, the latter of which has been demonstrated as part of controlled carp enclosure experiments in Utah Lake (Miller and Crowl, 2006). Paleolimnological sediment core data on chlorophyll degradation products indicates the impacts of carp as well, supporting the idea that macrophytes stabilized sediment prior to carp introduction (Brahney et al. 2021).





James et al. (2004) demonstrated a 46 and 63% reduction in bed shear for two different species of macrophytes at low biomass (<20 g/m2), and Wang et al. (2010) demonstrated a 20-80% reduction in bed shear when macrophytes were present. Assuming that sampled dates and locations are representative of the lake, resuspension events would be nearly eliminated if macrophyte cover reduced bed shear by 60% or more (Tetra Tech 2021). It appears that macrophytes would reduce sediment resuspension events, but the question remains how slow particle sinking rates and epiphyte growth would impact macrophyte establishment.

Confidence

Three direct studies in Utah Lake are available to answer this question, with multiple analyses making up the conclusions of each study. Additionally, several literature-based studies are available to answer this question and fill in knowledge gaps that direct Utah Lake studies have not addressed. Thus, there is a high amount of evidence to answer this question, and the quality of the evidence ranges from medium to high with a high degree of agreement. We thus conclude the SP has high confidence in answering this question, with greater uncertainty around the estimates of macrophyte recovery on sediment stabilization.

Interim Synthesis Statement

Given the available information, the SP has high confidence that wind and carp increase non-algal turbidity in Utah Lake, with wind being the primary hypothesized driver of increases in turbidity and carp being a contributing factor. Macrophyte recovery has the capacity to stabilize sediments and reduce sediment resuspension events, although there is a good deal of uncertainty around the magnitude of this relationship.

Follow-up Items

An analysis of the potential impacts of reductions in non-algal turbidity on algae was suggested. Hypothesized mechanisms driving this relationship include whether phytoplankton growth is currently light-limited and whether phytoplankton in Utah Lake have competitive advantages to grow at low light (e.g., regulation of buoyancy, low light half saturation values).

4.2. Assuming continued carp removal and current water management, would nutrient reductions support a shift to a macrophyte-dominated state within reasonable planning horizons (i.e., 30-50 years)?

Evidence evaluation

Studies from other lakes have shown that the positive effects of nutrient reduction on water clarity can take 10-15 years to be apparent (Jeppesen et al. 2005), and that concurrent macrophyte recovery is best attained with active planting (Liu et al. 2018). Modeling of benthic and planktonic primary producers in Utah Lake indicated that high-water periods may present optimum conditions for macrophyte recovery efforts due to decreased resuspension (King 2019). Macrophyte recovery would also depend on adequate lake level (depth and variability) and sediment stabilization. Forthcoming information from the EFDC/WASP application for Utah Lake will evaluate management scenarios, which could provide insights into the impacts of nutrient reduction on water clarity and the potential for macrophyte restoration.

Confidence

Modeling efforts in Utah Lake have provided one line of evidence for the requisite conditions needed to support macrophyte recovery, and the upcoming EFDC-WASP application will specifically analyze scenarios over which requisite conditions can be evaluated over 30-50 year planning horizons. Additional information is available from the literature, but with lower evidence quality. The SP has low to medium confidence in the assessment of this question with presently available information, but forthcoming analyses will increase the evidence amount and quality, thus increasing the SP's confidence in answering this question.

Interim Synthesis Statement

Given the available information, the SP hypothesizes that nutrient management and carp removal efforts will improve environmental conditions relevant for macrophyte reestablishment. However, direct evidence about the potential magnitude of these improvements is not currently available, and this statement thus has low confidence. Upcoming work with the ULWQS is expected to increase confidence to assess this question.

Follow-up Items

A clarification of this question for future iterations of analysis is whether reductions in nutrients would support a shift to a macrophyte-dominated state in the absence of carp.

4.0 Evidence

Cited Studies and Analyses

Beklioğlu M, Bucak T, Coppens J, Bezirci G, Tavşanoğlu ÜN, Çakıroğlu Aİ, Levi EE, Erdoğan Ş, Filiz N, Özkan K, Özen A. 2017. Restoration of eutrophic lakes with fluctuating water levels: A 20-Year monitoring study of two inter-connected lakes. Water 9(2): 127. https://doi.org/10.3390/w9020127

Bolland RF. 1974. Paleoecological interpretation of the diatom succession in the recent sediments of Utah Lake, Utah. University of Utah PhD Dissertation.

Brahney J. et al. 2021. Paleolimnology of Utah Lake Update. Presentation to the Utah Lake Science Panel.

Brahney J. et al. 2021. What did Utah Lake look like 200 years ago? Utah Lake Symposium.

Brotherson JD. 1981. Aquatic and semiaquatic vegetation of Utah Lake and its bays. Great Basin Naturalist Memoirs 5: article 5.

Hidding B, Bakker ES, Hootsmans MJM, and Hilt S. 2016. Synergy between shading and herbivory triggers macrophyte loss and regime shifts in aquatic systems. Oikos 125(10), 1489–1495. doi:10.1111/oik.03104

Jeppesen E, Søndergaard M, Jensen JP, Havens KE, Anneville O, Carvalho L, … and Winder M. 2005. Lake responses to reduced nutrient loading - An analysis of contemporary long-term data from 35 case studies. Freshwater Biology 50(10): 1747–1771. doi:10.1111/j.1365-2427.2005.01415.x

King, LR. 2019. The response of Utah Lake's plant and algal community structure to cultural eutrophication. Master's Thesis, Utah State University.

Kufel L and Kufel I. 2002. Chara beds acting as nutrient sinks in shallow lakes – A review. Aquatic Botany 72(3-4): 249-260. doi: 10.1016/S0304-3770(01)00204-2

Lambert-Servien E, Clemenceau G, Gabory O, Douillard E, and Haury J. 2006. Stonewords (Characeae) and associated macrophyte species as indicators of water quality and human activities in the Pays-de-la-Loire region, France. Hydrobiologia 570: 107–115. doi:10.1007/978-1-4020-5390-0

Landom K, Dillingham R, Gaeta JW. 2019. Seasonal and annual changes in the near-shore Utah Lake macrophyte community. Annual report submitted to the June Sucker Recovery Implementation Program.

Liu Z, Hu J, Zhong P, Zhang X, Ning J, Larsen SE, … and Jeppesen E. 2018. Successful restoration of a tropical shallow eutrophic lake: Strong bottom-up but weak top-down effects recorded. Water Research 146: 88– 97. doi:10.1016/j.watres.2018.09.007

Miller SA and Crowl TA. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. Freshwater Biology 51: 85-94.

Miller SA and Provenza FD. 2007. Mechanisms of resistance of freshwater macrophytes to herbivory by invasive juvenile common carp. Freshwater Biology 52(1): 39–49. doi:10.1111/j.1365-2427.2006.01669.x

Tetra Tech. 2021. Utah Lake Water Quality Study Analysis Update. Draft Report submitted to Utah Division of Water Quality.

Section 2.5: Environmental requirements of diatoms and macrophytes

Section 2.7: Turbidity and Macrophytes

Zhao D, Jiang H, Cai Y, and An S. 2012. Artificial regulation of water level and its effect on aquatic macrophyte distribution in Taihu Lake. PLoS ONE doi:10.1371/journal.pone.0044836

Forthcoming Studies and Analyses

Mechanistic lake (EFDC-WASP) and watershed modeling (Tetra Tech)