Subject:	Utah Lake Water Quality Study Charge Questions Reporting
Sub-Topic:	Fish, Aquatic Life, and Birds
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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

1.3. What information do paleo records (eDNA/scales) provide on the population trajectory/growth of carp over time? What information do the paleo records provide on the historical relationship between carp and the trophic state and nutrient regime of the lake?

2.1. What are the impacts of carp on the biology/ecology and nutrient cycling of the lake and how are those impacts changing with ongoing carp removal efforts?

i. What contribution do carp make to the total nutrient budget of the lake via excretion rates and bioturbation? How much nutrient cycling can be attributed to carp?

ii. What is the effect of carp removal efforts on macrophytes, nutrients, secchi depth, turbidity, and primary productivity?

iii. How much non-algal turbidity and nutrient cycling is due to wind action versus carp foraging? How much does sediment resuspension contribute to light limitation, and does wind resuspension contribute substantially in the absence of carp?

2.5. For warm water aquatic life, waterfowl, shorebirds, and water-oriented wildlife:

i. Where and when in Utah Lake are early life stages of fish present?

ii. Which species are most sensitive and need protection from nutrient-related impacts?

3.0 Question Evaluation

1.3. What information do paleo records (eDNA/scales) provide on the population trajectory/growth of carp over time? What information do the paleo records provide on the historical relationship between carp and the trophic state and nutrient regime of the lake?

Evidence evaluation

The introduction of common carp to Utah Lake (~1881) aligns well with a rapid transition to eutrophic conditions (fewer macrophytes, higher phytoplankton and cyanobacteria presence) as identified in a multi-proxy analysis of lake sediment cores (transition point dated to 1869 +/- 25 years) (King 2019). Isotope geochemistry further indicates that wastewater treatment plant effluent subsequently increases over time (post-1869), identifying it as an important source of external nutrient loading contributing to the lake's current eutrophic state (King 2019). eDNA was attempted to be analyzed for fish populations, but data were inconclusive.

Confidence

Data to evaluate this question were sourced from one study of paleolimnological sediment core data. While the amount of independent sources of evidence is limited to one (and thus no agreement can be assessed), the evidence comprises direct samples for Utah Lake that were analyzed using commonly accepted analytical methods. Given the limited amount of evidence but high quality of the evidence, we conclude there is medium confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that the introduction of carp to Utah Lake circa 1881 is associated with a transition to eutrophic conditions, around the same time that evidence of wastewater treatment nutrient effluent loads were also detected. Given the concurrent timing of carp introduction and increases in anthropogenic nutrient loading, it is challenging to parse the specific mechanisms and magnitude of the impacts of carp alone on the trophic state of Utah Lake.

2.1. What are the impacts of carp on the biology/ecology and nutrient cycling of the lake and how are those impacts changing with ongoing carp removal efforts?

Specifics of this question are addressed as part of sub-questions 2.1.i through 2.1.iii below. Overall, there are several direct and indirect impacts of carp on the ecology and biogeochemistry of Utah Lake, including excretion, sediment resuspension, disturbance of macrophytes, and bioturbation. The assessments of confidence around these relationships are detailed as part of the response for each relevant sub-question.

2.1.i. What contribution do carp make to the total nutrient budget of the lake via excretion rates and bioturbation? How much nutrient cycling can be attributed to carp?

Evidence evaluation

Lakewide carp excretion estimates based on individual size, density, and regression (mean and 95 % credible interval) were 71,500 kg TP y-1 (51,100-117,000), 23,400 kg SRP y-1 (16,700-38,500), 694,000 kg TN y-1 (496,000-1,140,000), and 436,000 kg NH4+ y-1 (312,000-717,000) (Tetra Tech 2021). Importantly, carp excretion represents recycling, meaning that they may incorporate rapidly cycling pools of N and P that may pass through carp multiple times in a year rather than a distinct one-way flux of nutrients such as external loading or removal. Carp likely decrease the capacity for sediments to effectively sequester P due to bioturbation.

Confidence

Data to evaluate this question were sourced from one study that incorporates carp population sampling in Utah Lake as well as approaches that evaluated carp excretion rates in experimental settings. The amount of independent sources of evidence is limited to one (and thus no agreement can be assessed), and the evidence extrapolates uncertainty across the dimensions of individual carp size, population density in Utah Lake, and excretion rates. Thus, we conclude there is a low confidence in the mean values but a medium amount of confidence in the ranges of possible carp nutrient excretion rates in Utah Lake.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that carp excrete a substantial amount of N and P in Utah Lake and decrease the capacity for sediments to permanently sequester nutrients due to bioturbation. . Thus, carp play a mediating role in determining how much of the nutrients that enter the lake are housed within the sediments vs. water column. Carp excretion is not a new discrete source of N and P to Utah Lake, but represents nutrient recycling, so comparisons of excretion rates with external loading are not equivalent.

Follow-up Items

A calculation requested by the SP is to calculate the amount of N and P currently contained within the carp population of Utah Lake, which can be achieved by multiplying the biomass of carp in Utah Lake by the percentage of N and P in fish tissue, which tends to be conservative across populations.

2.1.ii. What is the effect of carp removal efforts on macrophytes, nutrients, secchi depth, turbidity, and primary productivity?

Evidence evaluation

Experimental studies using exclosures in Utah Lake have shown that carp can have a negative effect on macrophyte growth and abundance (due to bioturbation that disrupts root stabilization, as well as direct herbivory; Miller and Provenza 2007), as well as macroinvertebrate abundance and diversity (Miller and Crowl, 2006). Carp impacts on nutrient recycling are summarized in question 2.1.i and may impact the pool of bioavailable nutrients available for phytoplankton. However, interannual variability in recent years (2016-2018) in Utah Lake does not provide strong support that submerged macrophytes are returning with decreased carp populations due to removal efforts (Landom et al. 2019). This may be due to the fact that submerged macrophytes do not necessarily return rapidly on their own following improved water clarity (Jeppesen et al. 2005; Hilt et al. 2006), and successful recovery may require physical planting of macrophytes to re-establish communities (Liu et al. 2018). Also, lake restoration measures that focus solely on internal remediation (i.e., carp removal) without including external nutrient loading reductions may result in unstable intermediate macrophyte recovery states (Hilt et al. 2018), which may be reflective of the unusual patchiness in macrophyte distribution described in Utah Lake in recent years (Landom et al. 2019). Answering this question is also dependent on our understanding of wind-driven sediment resuspension and impacts of changing lake level (see question 2.1.iii, 2.2, and 2.3.vi)

Confidence

Data to evaluate this question were sourced from three studies in Utah Lake and supported by several studies from the literature. The high amount of evidence, with medium to high quality (for literature-based and Utah Lake studies, respectively) and high agreement leads to a conclusion that there is high confidence in answering this question.

Interim Synthesis Statement

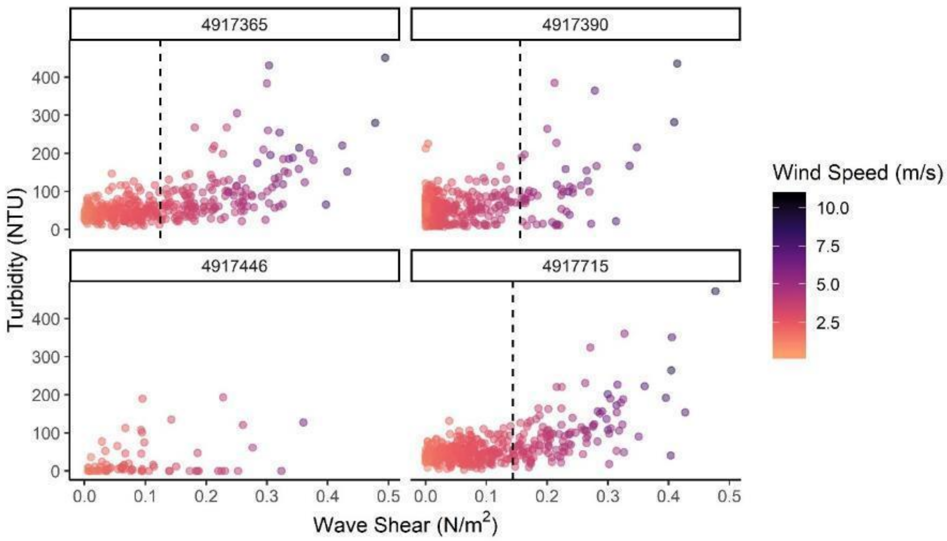
Given the available information, the SP has high confidence that carp removal efforts relieve negative pressures on macrophyte community growth and reestablishment, reduce nutrient recycling through the carp population, reduce bioturbation that mobilizes sediments and creates more turbid conditions. Macrophyte reestablishment is unlikely to occur spontaneously with carp removal efforts alone and may require active planting efforts and/or external nutrient loading reductions. Carp removal efforts may have mixed impacts on phytoplankton growth, because carp bioturbation and recycling have the capacity to both reduce transparency and also mobilize sediment nutrient pools into the water column.

2.1.iii. How much non-algal turbidity and nutrient cycling is due to wind action versus carp foraging? How much does sediment resuspension contribute to light limitation, and does wind resuspension contribute substantially in the absence of carp?

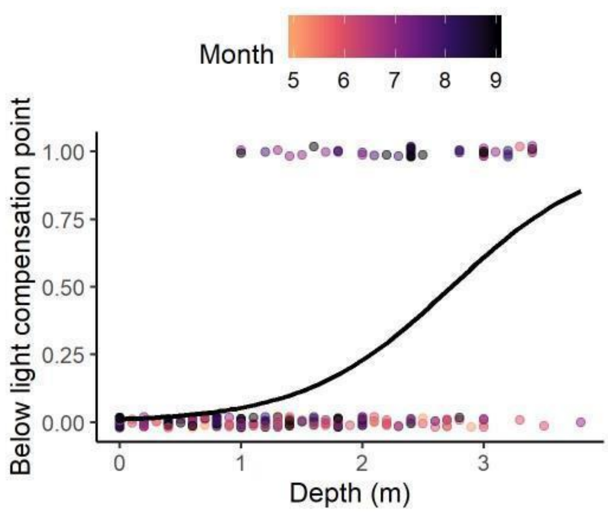
Evidence evaluation

No experimental studies have been conducted in Utah Lake to directly quantify the causal impacts of carp on clarity. However, carp exclosure experiments revealed stronger negative outcomes for macrophytes and macroinvertebrates in large exclosures compared to smaller ones, as well as differences between lake sides, indicating that resuspension and wave action are important controls on Utah Lake macrophytes as well (Miller and Crowl 2006). Data across recent years also indicated an important role for lake level as a control of submerged macrophyte abundance (Landom et al. 2019). Wind conditions in the lake are sometimes, but not usually, sufficient to entrain sediments into the water column (typically wind speeds above 3-4.5 m/s depending on site).

Critical shear was exceeded for 24% of samples at the North site, 7 % of samples at the State Park site, and 15% of samples at the South site (Tetra Tech 2021). Light attenuation from non-algal turbidity made up 74 ± 8% (mean ± standard deviation) of total light attenuation (Tetra Tech 2021). Non-algal turbidity is likely made up of a combination of wind action and bioturbation, but the relative contribution of these sources has not been quantified.



Assuming a light compensation point for macrophyte growth of 10 µmol m^{-2} s-1, 22% of sampled light conditions in Utah Lake are below the compensation point. Time of year had a significant effect as well. The probability of being below the light compensation point was 5% at 1 m depth, 23% at 2 m depth, and 61% at 3 m depth. The depth at which there were equal odds of being above and below the compensation point was 2.73 m (Tetra Tech 2021).



Confidence

Carp and wind impacts on non-algal turbidity have each been evaluated by one study in Utah Lake, indicating a limited amount of evidence but high quality of evidence given the direct analysis of Utah Lake data. There is thus medium confidence in answering the question for carp and wind impacts separately, and low confidence in assessing their relative magnitudes given the lack of comparative evidence.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that carp and wind both contribute to increased non-algal turbidity and light limitation of photosynthesis in Utah Lake, with wind being the primary hypothesized driver of increases in non-algal turbidity. However, there is low confidence in the ability to assess the relative impacts of carp and wind, because available studies did not evaluate these impacts concurrently.

2.5.i. For warm water aquatic life, waterfowl, shorebirds, and water-oriented wildlife, where and when in Utah Lake are early life stages of fish present?

Evidence evaluation

PSOMAS and SWCA (2007) evaluated the spawning and rearing habitat for 16 species of fish in Utah Lake as well as the relative percentage of time spawning conditions are met for those species across 14 lake sites.

Species	Spawning Season	Spawning time	Spawning Temperature	Spawning Habitat	Nursery Habitat
June sucker	May-June	Night	11.6–17 ° C (53–63 ° F)	shallow riffles 0.3 to 0.8 m deep; water velocity about 0.6 ft/sec; mixture of coarse gravel and cobble	littoral habitat with cover
carp	March-April	Day and Night	18–22° C (64–72° F)	shallow lake margins, submerged vegetation	littoral habitat with cover
white bass	mid April-mid June	Day and Night	14–21° C (58–69° F)	rocky substrate, Lincoln Beach and tributaries including Provo River	littoral habitat with cover
black crappie	March-July	Day	15–20° C (59–68° F)	nest in or near shallow vegetated backwaters and littoral areas over soft mud, sand, or gravel	nest guarded by the male, fry are pelagic
yellow perch	mid March-mid April	Night	8–11° C (46–52° F)	submerged vegetation	larvae are pelagic
channel catfish	May-mid June	Night	21–24° C (70–75° F)	nest cavities or burrows	guarded by the male
walleye	mid March-mid April	Night	4–10° C (40–50° F)	rocky substrate, Lincoln Beach and tributaries including Provo River	larvae and juveniles are pelagic
black bullhead	June-August	Night	21–30° C (70–86° F)	sandy substrate, shallow backwaters or lake margin in 1-4 feet depth	young form large pelagic schools
largemouth bass	June-July	Day	15–17° C (59–62° F)	nest in or near shallow vegetated backwaters and littoral areas over soft mud, sand, or gravel substrates	nest guarded by the male, juveniles form pelagic schools
smallmouth bass	June-July	Day	15–17° C (59–62° F)	nest in or near shallow vegetated backwaters and littoral areas over soft mud, sand, or gravel substrates near cover	nest guarded by male
fathead minnow	mid May-mid August	Day	15–32° C (59–90° F)	build nest on the underside of submerged objects	guarded by the male
bluegill	May-September	Day	20–28° C (68–82° F)	nest in or near shallow vegetated backwaters and littoral areas over firm sand or gravel substrates, often nest in colonies	nest guarded by the male, juveniles remain in littoral habitats
green sunfish	May-September	Day	20–28° C (68–82° F)	nest in or near shallow vegetated backwaters and littoral areas over firm sand or gravel substrates	nest guarded by the male, juveniles remain in littoral habitats
brown trout	mid September-November	Day	2–6° C (36–43° F)	builds redds in riffle areas of tributaries including the Provo River	backwaters and small side channels
mosquitofish	May-September	Day	18–32°+ C (65–90°+ F)	warm shallow water with dense vegetation, livebearer	warm shallow water with dense vegetation
rainbow trout	March-April	Day	12–13° C (54–56° F)	builds redds in riffle areas of tributaries including the Provo River	backwaters and small side channels

Species		white bass	black crappie	yellow perch	channel catfish	walleye	black bullhead	largemouth bass	smallmouth bass	bluegill	green sunfish	brown trout	rainbow trout
Spawning period		mid Apr-mid Jun	Mar-Jul	mid Mar-mid Apr	May-mid Jun	mid Mar-mid Apr	Jun-Aug	Jun-Jul	Jun-Jul	May-Sep	May-Sep	mid Sep-Nov	Mar-Apr
Spawning time, N=Night, D=Day		D,N	D	N	N	N	N	D	D	D	D	D	D
Spawning temperature [a]		14–21° C (58–69° F)	15–20° C (59–68° F)	8–11° C (46–52° F)	21–24° C (70–75° F)	4–10° C (40–50° F)	21–30° C (70–86° F)	15–17° C (59–62° F)	15–17° C (59–62° F)	20–28° C (59–90° F)	20–28° C (68–82° F)	2–6° C (36–43° F)	12–13° C (54–56° F)
Dissolved Oxygen [b]		$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L	$\geq$ 5 mg/L
Station ID	**Description**												
	In-Lake Sites												
491762	Goshen Bay midway off main point on east shore [c]	100%	> 50%	100%	100%	> 75%	100%	25%	25%	100%	100%	-	-
491750	3 miles west-northwest of Lincoln Beach [c]	75%	25%	50%	100%	25%	100%	< 25%	< 25%	100%	100%	-	-
491777	Outside entrance to Provo Bay	-	> 25%	> 75%	100%	-	100%	< 25%	< 25%	100%	100%	-	-
491739	4 miles west of Provo Airport, 4 miles north of Lincoln Point	-	25%	50%	100%	-	100%	0%	0%	100%	100%	-	-
491734	East of Provo Boat Harbor, 6 miles north of Lincoln Beach	-	> 25%	**50%** [d]	100%	-	100%	25%	25%	100%	100%	-	-
491737	4 miles north of Pelican Point, 5 miles west of Geneva	-	< 25%	50%	100%	-	100%	0%	0%	100%	100%	-	-
491731	0.5 miles west of Geneva discharge #15-A	-	25%	50%	100%	-	100%	0%	0%	100%	100%	-	-
491752	2 miles east of Saratoga Springs #12	-	25%	50%	100%	-	100%	0%	0%	100%	100%	-	-
	Tributary Sites												
591986	Beer Creek	> 75%	-	-	-	< 25%	-	-	-	-	-	<25%	75%
499558	Spanish Fork River (Lakeshore)	> 75%	-	-	-	75%	-	-	-	-	-	<25%	> 75%
499600	Dry Creek at Count Road 77 Crossing	> 75%	-	-	-	50%	-	-	-	-	-	0%	100%
499669	Provo River at Utah-114 crossing	100%	-	-	-	100%	-	-	-	-	-	<25%	100%
499496	American Fork Creek 2.5 miles south of American Fork City	> 75%	-	-	-	ND	-	-	-	-	-	<25%	ND
499479	Jordan River at Utah Lake outlet, Utah-121 crossing	> 75%	-	-	-	> 50%	-	-	-	-	-	<25%	> 50%

[a] Preferred spawning conditions are listed on a species-specific basis and do not represent state water quality criteria. The State of Utah has not defined criteria for water temperature of spawning warm water game fish species.
[b] The dissolved oxygen data available to this process were instantaneous readings only. Therefore, construction of accurate, representative 30-day or 7-day averages was not possible. The identified criteria of no less than 5.0 mg/L dissolved oxygen as a 1-day average for early life stages was selected as the best fit for evaluation of the available data, with the assumption that grab sample concentrations were representative of daily average dissolved oxygen concentrations.
[c] These two sites represented the closest monitoring locations to Lincoln Beach where white bass and walleye have been observed to spawn. They were therefore used as surrogates to assess possible temperature and dissolved oxygen conditions at Lincoln Beach. It was assumed that the water quality conditions at these locations would not deviate substantially from those at Lincoln Beach during the respective spawning periods.
[d] Bold text indicates both temperature and dissolved oxygen concentrations are outside of the range of preferred spawning conditions for at least a portion of the spawning period.

Confidence

Data to evaluate this question were sourced from one study that incorporates fish and biogeochemical data from Utah Lake as well as literature-derived habitat information. While the amount of independent sources of evidence is limited to one (and thus no agreement can be assessed), the evidence comprises direct samples for Utah Lake that were analyzed using commonly accepted methods. Given the limited amount of evidence but high quality of the evidence, we conclude there is medium confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that spawning and rearing habitat meets the needs for some species in certain in-lake and tributary sites in Utah Lake but does not for other species and sites. The tables above provide more detail on specific species and sites.Further analysis will determine where and when early life stages of fish and birds are present.

Follow Up Items

Data on and distribution maps for early life stages of different fish species in Utah Lake will be solicited from the relevant resource programs including the June Sucker Recovery program, and then organized to specifically answer where early life stages occur. Steering Committee member Heidi Hoven has provided information about bird species and habitat in Utah Lake, which will also be incorporated into the response to this question.

2.5.ii. For warm water aquatic life, waterfowl, shorebirds, and water-oriented wildlife, which species are most sensitive and need protection from nutrient-related impacts?

Evidence evaluation

The June Sucker recovery program focuses on habitat-related recovery efforts but does not focus specifically on nutrient-related impacts. A potential future way to evaluate this question would be to relate the spatial aspects of HABs and the potential toxin-related impacts on aquatic life in those zones and then to the species that are utilizing those zones for spawning and rearing habitat (e.g., Provo Bay, Lincoln Beach, littoral zones).

Confidence

There is not yet enough available information to evaluate the confidence in addressing this question.

Interim Synthesis Statement

Given the available information, the SP is not prepared to assess which species are in need of protection from nutrient-related impacts.

4.0 Evidence

Cited Studies and Analyses

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

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

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Section 2.1: Carp excretion

Section 2.6: Wind and turbidity

Section 2.7: Light extinction