Great Salt Lake Aquatic Life Use Resident Taxa White Paper

Executive Summary

The purpose of this white paper is to document the existing aquatic taxa within Great Salt Lake (GSL) and report the conditions in which these taxa have been observed. Information referenced in this white paper is both from an extensive literature review and information captured from the Utah Division of Water Quality (UDWQ)- and U.S. Environmental Protection Agency (EPA)-supported Great Salt Lake Aquatic Life Use Workshop (the "Workshop"), held on March 24, 2015 in Salt Lake City, Utah (see workshop summary in Appendix A).

The GSL ecosystem support seven families of fish, 47 families of invertebrates, 19 families of vascular plants and 32 families of phytoplankton currently documented within the Lake. Many organisms have not yet been taxonomically identified at the species level and some bays lack targeted sampling of certain taxonomic groups (e.g., no fish studies in Farmington Bay and limited zooplankton sampling in Bear River Bay). Based on existing research, Farmington Bay supports the most invertebrate families, with 39 families observed within the bay, followed by Bear River Bay (31 observed invertebrate families), Gilbert Bay (six observed invertebrate families). Gunnison Bay primarily supports a microbial community and one family of phytoplankton. All fish taxa were sampled from Bear River Bay.

A comparison of the resident taxa lists demonstrates that Bear River Bay, Farmington Bay, Gilbert Bay, and Gunnison Bay support unique aquatic taxa. For example, Bear River Bay is the only bay where fish and caddisflies have been sampled. Additionally, Farmington Bay appears to support the most diverse zooplankton taxa, including 10 unique cladocerans. However, it is not clear if the differences in taxa are due to the unique habitat and water chemistry in each bay or the result of different study designs and sampling techniques. Data gaps identified during the Workshop and summarized in this white paper show that further research may be needed to accurately describe the diversity of aquatic organisms in GSL. The findings presented in this paper may be taken into consideration when developing future revisions to the water quality standards that apply to the Lake. The taxa database will be updated as further biological research is conducted in GSL.

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1.0 Introduction

1.1. Geography and Importance

The Great Salt Lake (hereafter GSL or the Lake), located in Utah is the largest lake in Utah, measuring approximately 7.5 miles long, 35 miles wide and, on average, 14 feet deep (UDWQ, 2014). GSL is a unique ecosystem in that it is a terminal lake with freshwater inputs coming primarily from precipitation and the Bear, Jordan, and Weber Rivers. The Lake is split into four distinct bays divided by constructed causeways and natural features: Gunnison Bay, Bear River Bay, Farmington Bay, and Gilbert Bay (Figure 1). Since circulation between the Bays is limited, and freshwater sources vary between the Bays, the salinity in the Lake varies, ranging from freshwater to 24.5%, or approximately seven times greater than the salinity of the ocean (UDWQ, 2014).

As the Lake has no outlet, water that flows into the Lake can only evaporate or percolate through sediments, leaving behind accumulating minerals and salt. The Lake area and water surface elevation are highly variable because they respond directly to variations in evaporation rates, precipitation and volume of stream inflows. The water-surface elevation of the southern part of the Lake is typically 0.5 to 2 feet higher than the northern part due to the majority of the inflow entering the south (USGS, 2013). The historic average elevation of the Lake between 1847 and 1986 has been 4,200 feet (UDWQ, 2014). Variation in aquatic habitats and organisms is dictated by seasonal and annual changes in lake levels and water chemistry. The freshwater stream inflows cause a gradient in salinity creating a variety of habitats with different salinities. All of these characteristics make GSL a very complex and unique ecosystem that requires a water quality management approach specific to the Lake (UDWQ, 2014).

In addition, approximately 360,000 acres of wetlands are located on the eastern shore of the Lake, which make up nearly 80 percent of all wetlands in Utah (UDWQ, 2014). Both fringe and impounded wetland ecosystems have species and vegetation compositions that are highly variable due to fluctuations in lake level (UDWQ, 2014). These wetland ecosystems provide important feeding and nesting areas for migratory birds, support aquatic life, and support recreational and tourist activities.

The lake salinity and chemistry were altered with the construction of the Southern Pacific Railroad (SPRR) causeway in 1959 (Gwynn, 2015). The 13-mile rock-fill causeway partitioned the lake into two parts, the North Arm and the South Arm. Three significant changes were observed in the lake post-causeway construction. First, a greater salinity imbalance between the South Arm and the North Arm was observed, because the major freshwater tributaries into the Lake flow into the South Arm, and the causeway prevents most of this freshwater from moving into the North Arm. Next, the surface elevation in the South Arm became higher than in the North Arm (Gwynn, 2015). Lastly, brine layers in the South Arm became stratified and the differences in density and water surface elevation between the two arms resulted in the bi-directional flow of a deep, dense brine layer below a less dense brine layer (UDWQ, 2014). These salinity and chemistry changes altered habitats and potentially the presence and location of existing taxa in the Lake.

The Lake serves an important role ecologically, recreationally, and for a variety of industries. It is reported that between 7 and 12 million birds, over 250 species, visit the Lake every year (Bioeconomics, 2012). The brine shrimp and brine flies are two well documented species within the Lake. Industries linked to the Lake contribute approximately $1.3 billion in total economic output each year (Bioeconomics, 2012). Industries such as mineral extraction, brine shrimp harvesting, duck hunting clubs, water fowl protection, and tourism all heavily rely on the vitality of the Lake.

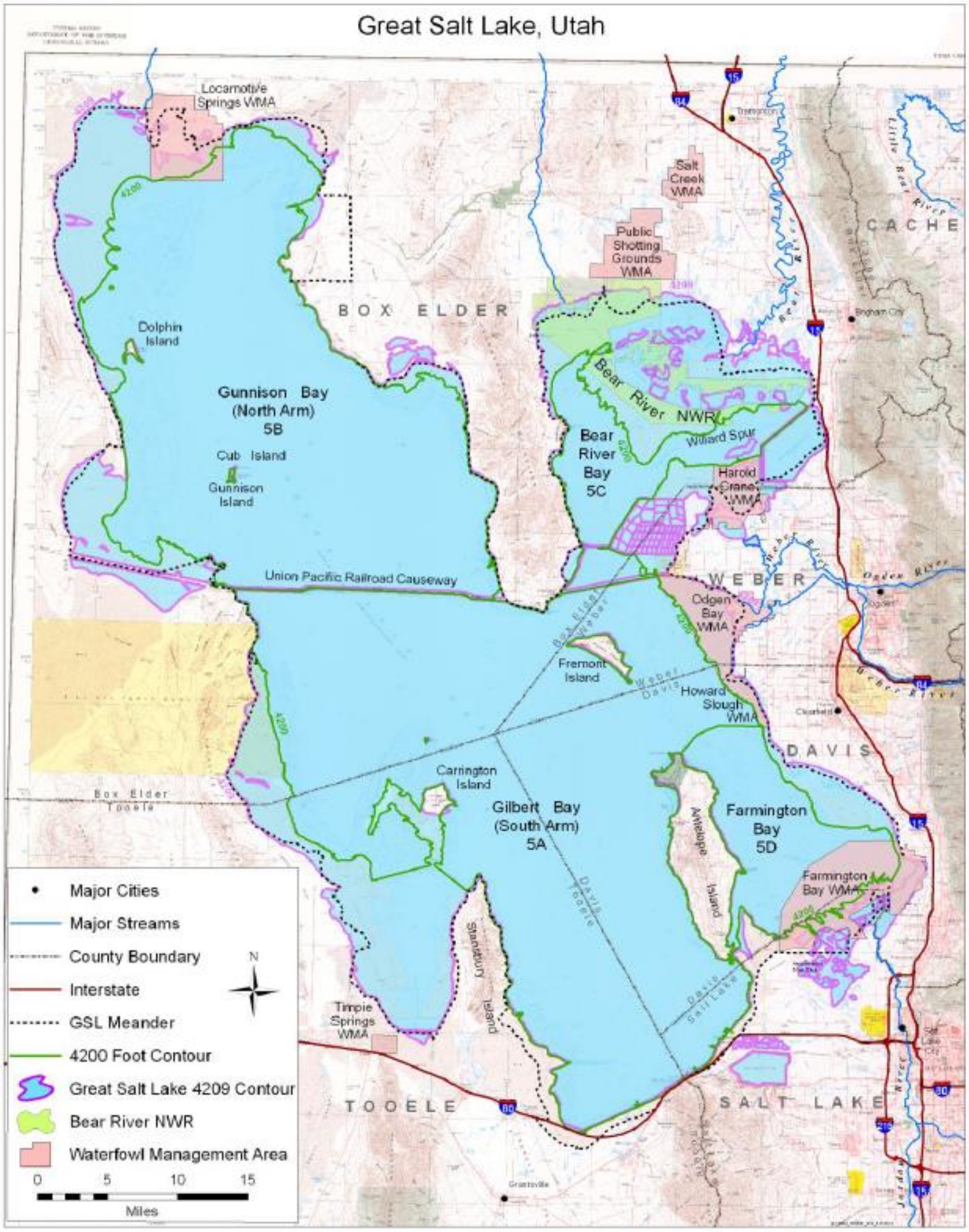

Figure 1. Great Salt Lake, Utah (Utah Department of Environmental Quality/Division of Water Quality, 2014)

1.2. GSL Water Quality Standards

Directed by both state law and the federal Clean Water Act (CWA), UDWQ is responsible for restoring and maintaining the chemical, physical, and biological integrity of Utah's water bodies. The CWA requires states to identify and adopt designated uses and the water quality criteria sufficient to protect those uses in state water quality standards. A designated use establishes how a water system will be used by humans and other organisms and a water quality goal. The designated uses assigned to the Lake "are primary and secondary contact recreation (e.g., water quality sufficient to swim at Antelope Island or wade while duck hunting at one of the Wildlife Management Areas) and wildlife protection (water quality sufficient for waterfowl, shorebirds, and other water-orientated wildlife including their necessary food chain)" (UDWQ, Core Component 1, 2014). GSL is unique in terms of its biology, chemistry, and hydrology because the seasonal and annual fluctuations in the Lake elevation can cause extreme changes in salinity. Therefore, EPA-derived fresh water and salt water numerical criteria may not be applicable (UDWQ, Core Component 1, 2014).

A key first step in determining the criteria necessary to protect the aquatic life use Lake is to understand the diversity of aquatic organisms that currently use the Lake. While a preliminary list of GSL species has been compiled by UDWQ, the purpose of the Workshop and this white paper is to update the existing list of resident taxa.

It is also important to understand the physical and chemical constituents that influence the presence or absence of specific species. The Lake's ecosystem evolved with a gradient of salinity. The spatial and temporal variably in salinity is one of many factors that determines what taxa will be present in the Lake. It can influence aquatic organisms survival, growth and reproduction. While other water quality parameters (e.g., pH, dissolved oxygen), habitat limitations, and biological interactions can also affect the presence or absence of aquatic organisms in GSL, the objective of this white paper is to document the range of salinity that has been observed at sampling events for each taxa. We also summarize the results of laboratory studies that provide data on species-specific salinity tolerance.

1.2.1. EPA Recalculation Procedure for Developing Numeric Criteria

When an aquatic ecosystem is very unique, such as GSL, and the species that occur in that ecosystem are substantially different from the species in the national dataset used to derive EPA's 304(a) state-wide criteria, the Recalculation Procedure can be used to develop site-specific water quality criteria. The taxa lists presented in this paper will be used by UDWQ and EPA to evaluate whether the EPA Recalculation Procedure is a practical option to site-specific criteria for areas of the lake that are not currently protected by numeric aquatic life criteria (Guenzel, GSL ALU Workshop 2015).

The first step of the process is to develop a resident species list by site that can be used in the recalculation procedure through a deletion process. First, species that occur at the site and are listed in the toxicity database are selected to be included in the site-specific toxicity dataset. Next, a step-wise process is used to determine which of the species in the national dataset may be deleted or must be included in the site-specific dataset. This step-wise process is done by evaluating species at higher taxonomical relationships (U.S. EPA, 1994). According to the U.S. EPA Standards Handbook Appendix L, the deletion process ensures that "(a) each species that occurs both in the national dataset and at the site also occurs in the site-specific dataset; (b) each species that occurs at the site but does not occur in the national dataset is represented in the site-specific dataset by all species in the national dataset that are in the same genus; (c) each genus that occurs at the site but does not occur in the national dataset is represented in the site-specific dataset by all genera in the national dataset that are in the same family; and (d) each order, class, and phylum that occurs both in the national dataset and at the site is represented in the site-specific dataset by the one or more species in the national dataset that are most closely related to a species that occurs at the site" (U.S. EPA, 1994).

1.3. Organization of White Paper

This white paper summarizes information collected through a literature review, data submitted by workshop participants, and discussions captured at the Workshop. Appendix A provides the workshop proceedings that summarizes the presentations and synthesizes pertinent questions and answers and discussions on data gaps. An Excel database synthesizes the literature review by providing the species taxonomical information, sampling location in the Lake, references, salinity range, other water quality conditions, and general notes. The database is summarized in tables within Section 2 and Appendix B. Section 2 is organized by bay and includes a habitat description, taxa summary, and salinity range information when available. Additional supporting information (e.g., life cycle, details on sampling location) can be found in Appendix B. Section 3 summarizes the vascular plants and phytoplankton observed in the GSL ecosystem. UDEQ anticipates that the taxa database and resident taxa lists will be updated as needed to incorporate future data collection and research conducted in GSL.

Salinity ranges presented in the tables within the paper characterize the range of conditions in which the species has been observed throughout GSL regardless of life stage or sampling location. For example, when a species was sampled from more than one habitat type (e.g., fringe wetland and open water), the table presents the minimum and maximum salinity observed at all sampling locations. If a species is found in more than one bay, the salinity range in each table within the white paper is summarized across all bays. Data gaps identified within each Bay are included in that section and summarized at the end of the white paper.

Salinity ranges are presented in weight percentage for the purpose of this white paper. Various research presents salinity in a variety of units, including parts per thousand and grams per liter. For the purposes of the workshop and the white paper, salinity information is presented as percentages.

Salinity data were converted into weight/weight percentage units from grams per liter using the salinity conversion equation reported in the Utah Division of Water Quality 2014 fringe wetland report. Several publications reported conductivity, which was converted to salinity via the site-specific relationship with total dissolved solids (UDWQ Great Salt Lake Fringe Wetland Survey, 2014). Salinity data are rounded to the nearest hundredth for purposes of this report, unless reported in their original publication as something different. Where salinity range information was originally provided in a unit other than weight percentage, the summary tables in Appendix B will note that the salinity range values were converted.

2.0 Resident Taxa

This section presents information on the aquatic life that 'occur at the site', i.e., within each bay. According to the U.S. EPA Water Quality Standards Handbook, "the phrase 'occur at the site' includes the species, genera, families, orders, classes and phyla that:

a. Are usually present at the site;
b. Are present only seasonally due to migration;
c. Are present intermittently because they periodically return to or extend their ranges into the site;
d. Were present in the past, are not currently present at the site due to degraded condition, but are expected to return when conditions improve; or
e. Are present in nearby bodies of water, are not currently present at the site due to degraded conditions, but are expected to be present at the site when conditions improve" (U.S. EPA, 1994).

In some cases, the organism was not classified down to the species or genus level. In these cases, the family or order name has been identified in parenthesis.

The taxa lists summarized in this white paper focus on the diversity of "food-chain species" sampled from the Lake, or aquatic organisms, and not on the diversity of bacteria and aquatic-dependent organisms such as birds. Workshop participants determined that the presentation of the archaea, bacteria, or fungi diversity does not align with the presentation of other taxonomic groups supported by the Lake, and therefore the paper does are not address these taxa in detail. Furthermore, a thorough survey of the waterfowl and shorebird use of GSL has already been documented by the Utah Department of Natural Resources (Paul and Manning 2002). This and other GSL bird reports will be considered by UDEQ for WQS development at a later time.

2.2. Gilbert Bay

2.2.1. Bay Description

Gilbert Bay is the largest bay and is located in the southern part of the Lake (Figure 1). The bay is hypersaline with salinity levels typically ranging between seven and 15 percent (UDWQ, 2014). The approximate area of the bay is 2400 square kilometers (Marcarelli et al., 2006). Gilbert Bay receives water, nutrient, and pollutant loads primarily from Farmington and Bear River bays, as well as the Weber River, Goggin Drain, and Lee Creek (Wurtsbaugh et al., 2008). The surface level within Gilbert Bay varies greatly with precipitation cycles (Wurtsbaugh et al., 2012).

The conditions in Gilbert Bay support brine shrimp production as the organism thrive in a hypersaline ecosystem with salinity ranging from 11 to 17 percent. Brine shrimp are ecologically important as the primary food source for the millions of migrating waterbirds and shorebirds each year, and for the cysts they produce. These cysts are commercially harvested and protecting the brine shrimp resource is important to the economic viability of the Lake (UDWQ, 2014).

The Union Pacific Railroad Causeway that is the boundary between Gunnison and Gilbert Bays created salt-stratification with an anoxic deep brine layer in Gilbert Bay due to density-driven flows from Gunnison Bay (Wurtsbaugh et al., 2012). The brine layer is located approximately six meters below surface level, making it much more stable and less prone to mixing events (Wurtsbaugh, GSL ALU Workshop 2015).

Ogden Bay is sometimes identified in research as a separate smaller bay within the Lake, but it is located within Gilbert Bay east of Fremont Island and is therefore included in the Gilbert Bay summary tables. Additional detail on the samples collected from Ogden Bay can be found in Appendix B.

2.2.2. Taxa Summary

Two different habitat types have been sampled in Gilbert Bay, including the open water and fringe wetlands. In the open water habitat, aquatic insects, brine shrimp, protozoa, and zooplankton have been observed in Gilbert Bay (Table 1). Phyla documented in the open water habitat of Gilbert Bay include Arthropoda, Ciliophora, Dinophyta, Nematoda, Protozoa, and Rotifera. Eleven genera in 11 different families have been taxonomically identified within the Bay, including six invertebrates and five zooplankton. Bioherms are also observed in the open water habitat of Gilbert Bay, which are stromatolite biostromes formed when carbonates precipitate to form rock-like structures. These bioherms are crucial for brine fly survival in the lake (Wurtsbaugh, 2009).

The majority of organisms observed in the open water habitat of Gilbert Bay have also been observed in Farmington Bay, however, based on current existing data, *Ephydra cinerea (gracilis)* as appears to be unique to Gilbert Bay.

The fringe wetlands in Gilbert Bay provide habitat and water chemistry that is substantially different from the open water habitat. For this reason, taxa that were observed in the fringe wetlands within Gilbert Bay are presented in a separate summary table (Table 2). Aquatic insects, mollusks, and other invertebrates have been reported in the fringe wetlands within Gilbert Bay, including the phyla Arthropoda, Mollusca, and Annelida. Twelve genera in 10 families have been taxonomically identified in the fringe wetlands of Gilbert Bay. No life cycle information was provided for the taxa. The only organism found to be unique to the fringe wetlands of Gilbert Bay and not observed in other areas of the Lake is the waterbug *Lethocerus* sp., in the order Hemiptra.

2.2.3. Salinity Ranges

Table 1 and Table 2 present the minimum and maximum salinity that the taxon has been observed in GSL, including all sampling locations, habitat types and lifecycles. More complete information specific to Gilbert Bay is provided in Table 5 and Table 6 in Appendix B.

The taxa observed in the open water of Gilbert Bay have been sampled in Lake conditions with a salinity range of 0.0% to 17.7% (Table 1). Even though this salinity range represents the range observed in the lake for these taxa, studies were located that sampled species in Ogden Bay at conditions with a salinity range between 5.4% and 13.7%. In addition, studies were located that sampled species in fringe wetlands within Gilbert Bay at conditions with a salinity range between 0.07% and 2.71% (Table 2).

Table 1. Taxa observed in the open water habitat of Gilbert Bay

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	Species	Common Name	Min	Max
Aquatic Insect				
(Diptera/Ephydridae)	sp.	midge	0.28	2.20
Ephydra	cinerea	brine fly	11.0	17.6
Ephydra	cinerea (gracilis)*	brine fly	9.4	17.7
Ephydra	hians	brine fly	11.0	17.6
Ephydra	sp.	brine fly	0.16	17.6
(Corixidae)	sp.	corixid	0	15.7
Trichocorixa	verticalis	corixid	0	16.00
Unidentified corixid	sp.	corixid	8.2	17.6
Brine Shrimp				
Artemia	franciscana	brine shrimp	0	17.6
Protozoan				
Unidentified protozoa	sp.	protozoan	8.2	17.6
Zooplankton				
Moina	sp.	cladoceran	0	15.7
Moina	macrocarpa Straus	cladoceran	0.1	8.8
(Ostracoda)	sp.	ostracod	0	15.7
Diaptomus	connexus	copepod		9.35
Leptodiaptomus	connexus Light	copepod	0.10	12.60
Calanoid copepod	sp.	copepod	5.4	15.7
(Cyclopoida)	sp.	copepod	0	15.7
Cletocamptus	albuquerquensis	copepod	1.10	16.0
(Harpacticoida)	sp.	copepod	0	16.4
Unidentified copepod	sp.	copepod	8.3	14.9
Brachionus	plicatilis (O.F.M.)	rotifer	0.3	14
Unidentified rotifer	sp.	rotifer	8.22	17.6
Other Invertebrate				
Euplotes	sp.	ciliate		
Ceratium	sp	dinoflagellate	8.84	9.52
Glenodinium	sp.	dinoflagellate	1.1	16.0
Unidentified nematode	sp.	worm	8.22	17.56
Other				
		Bioherm		

* taxa unique to open water habitat of Gilbert Bay

Table 2. Taxa observed in fringe wetland habitat of Gilbert Bay

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	**Species**	**Common Name**	**min**	**max**
Aquatic Insect				
Agabus	sp.	beetle	0.13	0.15
Laccophilus	sp.	diving beetle	0.16	0.23
Chironomus	sp.	midge	0.07	0.98
Subfam: Tanypodinae	sp.	midge	0.07	2.71
(Diptera/Culicidae)	sp.	biting midge	0.28	2.20
Lethocerus	sp.*	waterbug	0.13	0.14
Buenoa	sp.	backswimmer	0.28	0.43
Mollusk				
Stagnicola	sp.	snail	0.07	1.22
Physella	sp.	snail	0.07	1.22
Gyraulus	sp.	snail	0.07	0.62
Other Invertebrate				
Erpobdella	sp.	leech	0.13	0.25
Hyalella	azteca	scud	0.07	1.43

* taxa unique to fringe wetland habitat of Gilbert Bay

2.2.4. Data Gaps

The following data gaps have been identified:

- Brine fly life cycle requirements are not well understood and studies on bioherms in Gilbert Bay have been limited. Brine flies use bioherms to attach to for the pupae life stage. Currently, Wayne Wurtsbaugh is studying bioherm production;
- Biological sampling in Gilbert Bay does not typically target benthic species; however, the diversity of benthic species is expected to be low given the limited benthic invertebrate habitat observed in the open waters of the Lake (excluding habitat provided by bioherms); and
- Previous biological sampling techniques have likely limited the quantification of the diversity of rotifers and other micro-planktonic invertebrates. The mesh size of the sampling nets for the macroinvertebrates is too large to accurately capture and characterize the community of micro-planktonic invertebrates in Gilbert Bay and the rest of the Lake. Rotifers and other micro-planktonic invertebrates have primarily been observed in Gilbert Bay when the lake elevation was high and the salinity was approximately six percent (GSL ALU Workshop, Appendix A) Potential occurrence of these taxa at greater salinity cannot be evaluated with existing data and sampling techniques.

2.3. Bear River Bay

2.3.1. Bay Description

Bear River Bay is located in the northeast area of the Lake and is formed from the Bear River, the largest of the tributaries to the Lake (Figure 1). The typical salinity of Bear River Bay is between less than one and six percent (UDWQ, 2014). The Bay is very shallow and it receives the most inflow of freshwater and sediment loading compared to the other bays (Wurtsbaugh et al., 2012). The major tributaries to Bear River Bay include the Bear River, which flows through the Bird Refuge and into Willard Bay. During spring runoff season, the salinity in the Bay can be near freshwater levels. As freshwater inflows decrease, evaporation and intrusion of salts from neighboring bays can increase the salinity to greater than nine percent (Wurtsbaugh et al., 2012). Due to freshwater inflows, salinity levels can vary within the bay, from near fresh water at the outlets of the rivers to more saline water towards the causeway openings between bays (UDWQ, 2014).

Bear River Bay is well known for the Bear River Bay Migratory Bird Refuge, land set aside and managed by the U.S. Fish and Wildlife Service specifically to protect the wildlife that inhabit the fringe and impounded wetlands. During certain times of the year, the majority of water from the Bear River is diverted through the Refuge's impounded wetlands. Bear River Bay water that is not routed through the Refuge impounded wetlands passes through two causeway constrictions on the way to Gilbert Bay. Another unique ecosystem within Bear River Bay is Willard Spur at the southern end of the Refuge impounded wetlands. The Willard Spur is a dynamic ecosystem that can become isolated from the rest of Bear River Bay, usually in late summer, causing chemical and biological changes (Ostermiller, GSL ALU Workshop 2015). Adjacent to Bear River Bay is the Willard Bay Reservoir that supports a diverse freshwater fishery.

2.3.2. Taxa Summary

Studies conducted to date suggest that Bear River Bay supports a more diverse aquatic community than the other bays. Aquatic insects, brine shrimp, fish, mollusks, zooplankton, and other invertebrates have all been documented within the Bay, including taxa in the phyla Arthropoda, Chordata, Mollusca, and Annelida. Table 3 summarizes information with one line per species, regardless of the life cycle or the sampling location. More complete information is provided in Table 7 in Appendix B.

The Bear River Bay taxa list includes a total of 44 taxonomically identified genera identified in 37 families. More specifically, this includes nine genera in six families of fish and 35 genera in 31 families of invertebrates have been taxonomically identified in the Bay. In addition, one cladoceran (*Miona* sp.) and four orders of copepods (Calanoida, Cylopoida and Harpactocida) have been observed. There is much more biological diversity in the Diptera order, and subsequently, the aquatic insects, in Bear River Bay compared to other bays.

Species unique to Bear River and not observed in other bays include the following aquatic insects:

- 3 beetles (*Sticotarun* sp., *Gyrins* sp. and the family Chrysomelidae);
- 3 midges/flies (*Prionocera* sp., subfamily Ceratopogoninae; family Dolichopodidae)
- 1 mayfly (*Caenis amica*);
- 2 water boatman (*Hesperocoriza* sp. and *Notonecta* sp.);

- 1 damselfly (*Archilestes* sp.); and
- 2 caddisflies (*Ylodes* sp. and *Phryganea* sp.).

Bear River Bay is the only location were caddiflies have been observed in the GSL ecosystem. In addition, all fish observed in the Lake were sampled from Bear River Bay. Most of the species unique to Bear River Bay were observed within Willard Spur.

2.3.3. Salinity Ranges

Taxa were observed in Bear River Bay were sampled in Lake conditions with a salinity range of 0.0% to 17.6%. Taxa reported within the fringe wetlands in Bear River Bay were observed at a lower salinity range than taxa from the rest of Bear River Bay. While some fish species had no salinity information reported, others were observed at salinity less than 0.4%. Table 3 presents the minimum and maximum salinity that the taxon has been observed in GSL, including all sampling locations, habitat types and lifecycles. More detailed information specific to Bear River Bay is provided in Table 7 in Appendix B.

Table 3. Taxa observed in Bear River Bay

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	**Species**	**Common Name**	**Min**	**Max**
Aquatic Insect				
(Chrysomelidae)	sp.*	beetle	0.14	0.62
(Dytiscidae)	sp.	beetle	0.07	0.77
Agabus	sp.	beetle	0.13	0.15
Hydroporus	sp.	beetle	0.13[1]	
Laccophilus	sp.	diving beetle	0.16	0.23
Stictotarsus	sp.*	beetle	0.22	0.58
Gyrinus	sp.*	beetle	0.3	0.33
Berosus	sp.	beetle	0.09	2.71
Enochrus	sp.	beetle	0.07	2.71
Tropisternus	sp.	beetle	0.19	0.33
(Ceratopogonidae)	sp.	biting midge	0.42	0.64
Subfam: Ceratopogoninae	sp.*	midge	0.07	0.19
Chironomus	sp.	midge	0.07	0.98
Subfam: Orthocladiinae	sp.	midge	0.07	0.74
Subfam: Tanypodinae	sp.	midge	0.07	2.71
tribe Tanytarsini	sp.	midge	0.08	0.61
(Culicidae)	sp.	biting midge	0.28	0.46
(Dolichopodidae)	sp.*	midge	0.13	0.97
Ephydra	sp.	brine fly	0.16	17.6
(Stratiomydae)	sp.	midge	0.1	0.1
Caloparyphus	sp.	fly	0.23	0.32
Chrysops	sp.	midge	0.28	0.53

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	**Species**	**Common Name**	**Min**	**Max**
Prionocera	sp.*	cranefly	0.19	0.19
Callibaetis	sp.	mayfly	0.07	1.22
Caenis	amica*	mayfly	0.08	0.77
(Corixidae)	sp.	corixid	0	15.7
Corisella	sp.	water boatman	0.07	2.71
Hesperocoriza	sp.*	water boatman	0.07	0.62
Trichocorixa	verticalis	waterboatman	0.00	16.00
Buenoa	sp.	backswimmer	0.28	0.43
Notonecta	sp.*	water boatman	0.07	1.22
Aeshna	sp.	dragonfly	0.09	0.63
Archilestes	sp.*	damselfly	0.07	0.23
Ischnura	sp.	damselfly	0.07	1.43
Erythemis	sp.	dragonfly	0.08	0.63
Ylodes	sp.*	caddisfly	0.11	0.63
Phryganea	sp.*	caddisfly	0.3	0.33
Brine Shrimp				
Artemia	franciscana	brine shrimp	0	17.6
Fish				
Dorsoma	sp.*	gizzard shad		
Cyprinus	carpio*	common carp	0.2	0.4
Gila	atraria*	Utah chub	0.2	0.4
Pomoxis	nigromaculatus*	black crappie	0.2	0.4
Morone	chrysops+saxatilis*	wiper	0.2	0.4
Perca	flavascens*	yellow perch	0.2	0.4
Sander	sp.*	walleye		
Ameiurus	sp.*	black bullhead		
Ictalurus	sp.*	channel catfish		
Mollusk				
Stagnicola	sp.	snail	0.07	1.22
Physella	sp.	snail	0.07	1.22
Gyraulus	sp.	snail	0.07	0.62
Zooplankton				
Moina	sp.	cladoceran	0	15.7
(Ostracoda)	sp.	ostracod	0	15.7
(Calanoida)	sp.	copepod	0	10.00
(Cyclopoida)	sp.	copepod	0	15.7
(Harpacticoida)	sp.	copepod	0	16.4
Other Invertebrate				
(Erpobdellidae)	sp.	leech	0.08	0.09

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	Species	Common Name	Min	Max
Helobdella	stagnalis	leech	0.1	0.15
(Naididae)	sp.	worm	0.08	0.15
(Trombidiformes)	sp.*	water mite	0.08	0.8
Hyalella	azteca	scud	0.07	1.43
Caecidotea	sp.	aquatic sowbug	0.08	0.25

[1] Salinity is measured at one sampling event; * taxa unique to Bear River Bay.

2.3.4. Data Gaps

The following data gaps have been identified:

- Fish studies were conducted by Wurtsbaugh in Bear River Bay near the outfall of the Willard Bay impoundment to Willard Spur. As part of the project, a literature review found no prior fish studies in the Bay prior to that by Moore, 2011. Fish studies conducted in the lower Bear River Bay could help determine if conditions in the lower Bear River are similar to those near the outfall to Willard Spur. In addition, there is limited data for Bear River Bay north of the Refuge where water flows around the Refuge direct into Gilbert Bay;
- Only one study was identified that included zooplankton sampling (Wurtsbaugh, Naftz and Bradt, 2008). Most taxa were only identified to the order level so the diversity zooplankton is likely underrepresented in the dataset;
- Workshop participants asked whether information collected in Willard Spur can inform the greater Bear River Bay; and
- Benthic invertebrates in habitat other than the Willard Spur.

2.4. Farmington Bay

2.4.1. Bay Description

Farmington Bay is located in the southeast corner of the Lake. Typical salinity levels measured in the Bay are between two and six percent (UDWQ, 2014). Farmington Bay is 260 square kilometers in area (Wurtsbaugh and Marcarelli, 2006). Farmington Bay receives a number of freshwater sources, including the Jordan River (Wurtsbaugh, GSL ALU Workshop 2015). Similar to Bear River Bay, salinity levels can vary within the bay, from near fresh water at the outlets of the rivers to more saline towards the causeway openings between bays (UDWQ, 2014). Lower salinity conditions can support a greater range of aquatic life compared to the hypersaline bays.

The automobile causeway constructed across Farmington Bay to Antelope Island almost completely restricts water circulation from Gilbert Bay. This impediment causes a brine layer to form within Farmington Bay, typically present at one meter below the water surface (Wurtsbuagh, GSL ALU Workshop 2015). Farmington Bay has a strong salinity gradient as dense, high saline water enters from Gilbert Bay in the north, and fresh water enters from the South via the Jordan River and small creeks. This gradient has seasonal and inter-annual changes that can exert a strong control on biotic communities. Furthermore, since the brine layer in Farmington Bay is not very deep, high winds can cause a mixing event that could result in a large release of hydrogen sulfide into the water column which is toxic to aquatic life (Wurtsbaugh, GSL ALU Workshop 2015).

2.4.2. Taxa Summary

Aquatic insects, brine shrimp, mollusks, zooplankton and other invertebrates have been observed in Farmington Bay, including taxa from phyla Arthropoda, Mollusca, Dinophyta, Annelida, Rotifera and Platyhelminthes (

Table 4). Forty-four genera in 39 families have been taxonomically identified within the Bay. Twenty genera in19 families of aquatic insects and 14 genera in nine families of zooplankton have been observed in Farmington Bay. Nine genera in 10 families of other invertebrates have been taxonomically identified. The taxa list for Farmington Bay has the greatest number of taxa, especially zooplankton, compared to the other bays, which may be due to the variety and nutrient richness of the inflows, the relatively low salinity conditions in the Bay, and/or simply an artifact of different study designs since more studies have included zooplankton sampling.

Organisms found to be unique to Farmington Bay and not observed in other bays include:

- 3 midges/flies (*Holorusia* sp., *Eristalis* sp., and the family Tanypodinae)
- 1 amphipod (*Gammerus* sp.);
- an unidentified flatworm from the subphylum *Turbellaria*;
- 10 cladocerans (*Bosmina* sp., *Alona* sp., *Chydorus sphaericus*, *Pleuroxus* sp., *Pleuroxus striatus schoedler*, *Ceriodaphinia quadrangular*, *Daphnia dentifer*, *Daphnia pulex Leydig*; *Daphnia* sp.; *Simocephalus vetulus*);
- 1 copepod (*Eucyclops agilis*); and
- 1 rotifer (*Notholca acuminate Ehrenberg*).

Due to high nutrient loading, large populations of phytoplankton and cyanobacteria are present in Farmington Bay (Wurtsbaugh, GSL ALU Workshop 2015). This is evident in the observed phytoplankton in the Bay discussed in Section 3.0.

2.4.3. Salinity Ranges

Taxa sampled from Farmington Bay were observed in Lake conditions with a salinity range of 0.0% to 17.6%. Taxa reported within the fringe wetlands were observed at a lower salinity range than the rest of Farmington Bay.

Table 4 presents the minimum and maximum salinity that the taxon has been observed in GSL, including all sampling locations, habitat types and lifecycles. More detailed information specific to Farmington Bay is provided in Table 8 in Appendix B.

Table 4. Taxa observed in Farmington Bay

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	Species	Common Name	Min	Max

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	Species	Common Name	Min	Max
Aquatic Insect				
Hydroporus	sp.	diving beetle	0.14	0.32
Laccophilus	sp.	diving beetle	0.16	0.23
Berosus	sp.	beetle	0.09	2.71
Enochrus	sp.	beetle	0.07	2.71
Tropisternus	sp.	beetle	0.19	0.33
Cyphon	sp.	beetle	0.14	0.32
(Chironomidae)	sp.	midge	0.30	0.60
(Diptera/Chironomidae)	sp.	midge	0.28	2.20
Chironomus	sp.	midge	0.07	0.98
Subfam: Orthocladiinae	sp.	midge	0.07	0.74
Subfam: Tanypodinae	sp.	midge	0.07	2.71
(Diptera/Culicidae)	sp.	biting midge	0.28	0.46
(Diptera/Ephydridae)	sp.	midge	1.00	1.00
Ephydra	sp.	brine fly	0.16	17.6
(Diptera/Orthocladiinae)	sp.	midge	0.30	0.60
Sepedon	sp.	fly	0.14	0.32
Caloparyphus	sp.	fly	0.23	0.32
Eristalis	sp.*	fly	0.12	0.19
Chrysops	sp.	fly	0.28	0.53
(Diptera/Tanypodinae)	sp.*	midge	0.30	0.60
Holorusia	sp.*	cranefly	0.12	0.35
Callibaetis	sp.	mayfly	0.07	1.22
(Corixidae)	sp.	corixid	0	15.7
Corisella	decolor (Uhler)	corixid	0.30	0.30
Corisella	sp.	boatmen	0.07	2.71
Trichocorixa	sp.	corixid	0	16.00
Trichocorixa	verticalis	corixid	0	16.00
Buenoa	sp.	backswimmer	0.28	0.43
Aeshna	sp.	dragonfly	0.09	0.63
Ischnura	sp.	damselfly	0.07	1.43
Erythemis	sp.	dragonfly	0.08	0.63
Brine Shrimp				
Artemia	franciscana	brine shrimp	0	17.6
Mollusk				
Stagnicola	sp.	snail	0.07	1.22
Physella	sp.	snail	0.07	1.22
Gyraulus	sp.	snail	0.07	0.62
(Gastropoda)	sp.	snail	0.30	0.60

Taxonomic Identification			Salinity Range (%)	
Genus (Order/Family)	Species	Common Name	Min	Max
Zooplankton				
Moina	sp.	cladoceran	0	15.7
Moina	macrocarpa Straus	cladoceran	0.1	8.8
Bosmina	sp.*	cladoceran	0.50	10.00
Alona	sp.*	cladoceran	0.30	1.00
Chydorus	sphaericus (O.F.M.)*	cladoceran	0.50	0.50
Pleuroxus	sp.*	cladoceran	0.10	0.30
Pleuroxus	striatus Schoedler*	cladoceran	0.10	0.30
Ceriodaphinia	quadrangula *	cladoceran	0.10	0.50
Daphnia	dentifera (Sars)*	cladoceran	0.40	8.30
Daphnia	pulex Leydig*	cladoceran	0.50	0.50
Daphnia	sp.*	cladoceran	0.30	1.00
Simocephalus	vetulus (O.F.M.)*	cladoceran	0.20	0.50
Eucyclops	agilis (Koch)*	copepod	0.30	5.90
(Ostracoda)	sp.	ostracod	0	15.7
Diaptomus	connexus	copepod		9.35
Leptodiaptomus	connexus Light	copepod	0.10	12.60
(Calanoida)	sp.	copepod	0	10.00
(Cyclopoida)	sp.	copepod	0	15.7
Cletocamptus	albuquerquensis	copepod	1.10	16.00
(Harpacticoida)	sp.	copepod	0	16.4
Brachionus	plicatilis (O.F.M.)	rotifer	0.30	14.00
Notholca	acuminate Ehrenberg*	rotifer	2.50	2.50
Other Invertebrate				
Glenodinium	sp.	dinoflagellate	1.10	16.00
Erpobdella	sp.	leech	0.13	0.25
(Naididae)	sp.	worm	0.08	0.15
Helobdella	stagnalis	leech	0.10	0.35
Gammerus	sp.	scud	0.40	0.60
Hyalella	azteca	scud	0.07	1.43
Caecidotea	sp.	aquatic sowbug	0.08	0.25
(Turbellaria)	sp.	flatworm	0.10	0.13

* taxa unique to Farmington Bay

2.4.4. Data Gaps

The following data gaps were identified:

- Benthic invertebrates are a diverse community within Farmington Bay. However, they are not being sampled comprehensively. Further research would be needed to understand the diversity of these organisms;
- Periphytes and macrophytes have not been studied extensively (Wurtsbaugh, GSL ALU Workshop 2015); and
- Targeted fish sampling has not been conducted in Farmington Bay. Fish are thought to be present in Farmington Bay with evidence of pelicans and herons feeding on fish within the Bay (Workshop Proceedings, Appendix A). Fish in Farmington Bay may be different from the fish species observed in Bear River Bay because of the different types of inflows. In addition, the hydrology in Farmington Bay is different from Bear River Bay, as Farmington Bay is more connected to the rest of the Lake. Further studies on fish species in Farmington Bay would be needed to determine potential occurrence in the bay.

2.5. Gunnison Bay

2.5.1. Bay Description

Gunnison Bay is located in the northwest part of the Lake in the North Arm (Figure 1). The salinity is near saturation with historic salinity levels measured between 16 and 27 percent (UDWQ, 2014). Gunnison Bay is 2,520 square kilometers in area (Marcarelli et al., 2006). Gunnison Bay receives most of its waters from Gilbert Bay (Wurtsbaugh et al., 2012). In this hypersaline environment, few aquatic organisms can survive. Gunnison Bay serves an important economical role as the high concentration of salt sustains the mineral extraction industry. In addition, higher density water naturally flows to Gilbert Bay to maintain salt concentrations necessary to support brine shrimp and brine fly populations (UDWQ, 2014).

2.5.2. Taxa Summary

Microbial diversity within Gunnison Bay is complex and is underrepresented in the current taxa list, therefore, taxa in Gunnison Bay are not reported within this white paper. The majority of observed taxa in Gunnison Bay are halophilic Archaea (Baxter, GSL ALU Workshop 2015). Halophiles are a generic term referring to microorganisms that thrive in high saline environments close to the halite saturation concentration (Allred, 2015). Eukarya and Bacteria have also been observed in Gunnison Bay (Baxter, GSL ALU Workshop 2015) but no eukaryotic taxa have been identified. The microbial diversity is immense and diversity changes with time as microbial communities shift rapidly. Diversity also shifts with depth due to salinity changes in the vertical transect (Baxter, GSL ALU Workshop 2015). Considering these temporal and spatial changes, a “static” species list is not currently possible for the microbial communities present in Gunnison Bay.

2.5.3. Data Gaps

Temporal and spatial variations in diversity make it difficult to assess microbial communities since populations are not static. South Arm Gilbert Bay and North Arm Gunnison Bay have two distinct microbial communities (Baxter, GSL ALU Workshop 2015), both of which are under-represented in the current taxa list. Microbial diversity needs to be further examined within Gunnison Bay.

2.6. Historic Studies

During the literature review, several studies dated before 1980 were reviewed that documented taxa observed in GSL, yet did not identify where the samples were collected. In particular, Stephens 1974 and Rawley 1980 are two publications that provide a literature review documenting all the taxa previously reported in the Lake. These studies did not report any salinity range information and some of the taxa reported in these historic studies were not reported again in more recent literature (Appendix B, Table 12).

Construction of the SPRR causeway began in 1956 and it was completed in 1959, dividing the lake into the North Arm and the South Arm. The causeway construction significantly altered the natural conditions that existed in GSL before 1956 (Gwynn, 2015). Therefore, any taxa documented in the lake before 1956 and not reported in studies after 1959 may be due to the environmental changes from the causeway construction.

Alternatively, a few species presented in the table may still exist in the Lake but may have been taxonomically named differently more recently. For example, the two species of brine shrimp in the table, *Artemia salina* and *Artemia gracilis* are both historic classifications of this species. *Artemia salina* was the first *Artemia* species to be classified in England and is now considered extinct (Sorgeloos et al., 1995).

3.0 Vascular Plants and Phytoplankton

For the purposes of this white paper, vascular plants and phytoplankton species documented in the GSL ecosystem are reported separately from macroinvertebrates, zooplankton, fish and other species (Section 2.0). In general, the diversity of vascular plants supported by the fringe and emergent wetlands in each bay and the phytoplankton salinity range information is similar, therefore all taxa are summarized together.

3.1. Taxa Summary

The vascular plants documented in the GSL ecosystem include those from the Magnoliophyta and Charophyta phyla. There are 20 families of vascular plants and 54 identified species documented in the Lake (Appendix B, Table 9). The majority of the plants documented were sampled from fringe wetlands or emergent wetland habitat in Bear River Bay or Farmington Bay but the Gilbert Bay fringe and emergent wetlands also supports vascular plants.

The phytoplankton documented in the Lake includes diatoms, green algae, golden algae, and cyanobacteria from the phyla Bacillariophyta, Chlorophyta, Chrysophyte, and Cyanophyta. There are 32 families of phytoplankton and 35 identified species documented in the Lake (Appendix B, Table 10). Unlike the vascular plants, no specific sampling location other than the bay was reported (e.g., fringe wetland or open water). The majority of the studies that collected phytoplankton samples were conducted in Farmington Bay or Gilbert Bay. Since Farmington Bay can be nutrient rich, the bay typically has seen more problems with phytoplankton and cyanobacteria blooms.

The only species, other than microbes, observed in Gunnison Bay are phytoplankton of the genera *Dunaliella*. Both *Dunaliella salina* and *Dunaliella viridis* are reported to exist within Gunnison Bay, however, no salinity information is provided. No phytoplankton data were located for Bear River Bay.

3.2. Salinity Range

Vascular plants were observed in Lake conditions with a salinity range of 0.08% to 1.84%. Studies conducted Farmington Bay include sampling locations with lower salinity compared to Bear River Bay and Gilbert Bay. Phytoplankton were observed in Lake conditions with a salinity range of 1.1% to 35.0%. Some vascular plant and phytoplankton taxa data have no reported salinity information but have been observed in specific bays within GSL and are included in the table.

3.3. Data Gaps

The following data gaps were identified:

- No phytoplankton data were located for Bear River Bay.

4.0 Laboratory Data and Mesocosm Studies

Field collected salinity data and laboratory tolerance experiments will provide different information on the conditions in which a species would be expected to occur. In a laboratory environment where other conditions are held constant, salinity tolerances can be evaluated. Laboratory data are not generally indicative of field conditions where factors such as food resources and predation can change with variations in salinity or other environmental conditions. Biological interactions between organisms play a large role on the production, survival, and transition of taxa within the Lake, which cannot be replicated in the laboratory.

At the ALU Workshop, Gary Belovsky presented the results of several laboratory experiments that address salinity, temperature, and food resource (e.g., amount and type of food) effects on the survival, production, and/or transition of several species, mainly brine shrimp and brine fly from Gilbert Bay. His research showed that while some conditions proved to be important in the laboratory trials, the same condition was not as important in the field data (Workshop Proceedings, Appendix A).

Mr. Belovsky recommended that laboratory data be used to better understand salinity ranges but that the information should be used with a degree of caution. As both laboratory and field data can provide valuable information, the laboratory studies conducted on species observed in the Lake are summarized separately (Appendix B, Table 11). Studies where species were sampled from the Lake for laboratory experiments are noted in the table.

For some species studied in the laboratory, the reported salinity minimum and maximum are different than the conditions observed in the Lake. For example, the brine fly has a measured salinity tolerance between 2.5% and13.6%, with an average or optimal salinity of 5.75%. In Farmington Bay, they have been observed at salinities between 0.3% and 16.0%. A phytoplankton mesocosm study was also reviewed from the publications Marcarelli et al., 2003 and Marcarelli et al., 2006, including studying cyanobacteria and green algae. Samples were taken from Farmington Bay and Gilbert Bay, and in order to increase the algal diversity in the sample, researchers combined phytoplankton collected from several locations.

Certain taxa within the same genera or family may have different sensitivities to salinity and other water quality parameters. As such, it is cautioned to not combine together species, especially unidentified species, to describe a salinity range until they have been further studied in a laboratory experiment.

5.0 Discussion

5.1. Taxa Diversity

This effort documented 7 families of fish, 47 families of invertebrates, 19 families of vascular plants and 32 families of phytoplankton within the Great Salt Lake ecosystem. Many organisms have not yet been taxonomically identified at the species level.

Based on existing research, Farmington Bay supports the most diverse invertebrate community with 39 taxonomic families observed within the bay, followed by Bear River Bay (31 observed invertebrate families), Gilbert Bay (6 observed invertebrate families) and Gunnison Bay that primarily supports microbial community and one family of phytoplankton. Farmington Bay has the most taxa unique to the Bay, meaning, they have only been observed within Farmington Bay.

The taxa common to Bear River, Gilbert and Farmington bays include the brine shrimp, brine fly, corixid, cladoceran (*Moina sp*.), ostracod, and copepods (taxanomic orders of Cyclopoida and Harpacitocoida). Many of the taxa observed within Bear River Bay are also observed within Farmington Bay, however the resident taxa lists suggest there could be some unique taxa supported by the two bays of the Lake with lower salinity. For example, Bear River Bay is the only Bay where fish and caddisflies have been observed. Additionally, Farmington Bay appears to support the most diverse zooplankton taxa, including 10 unique cladocerans. However, differences in the taxa lists are confounded by the sampling designs since the sampling efforts in each bay were designed to answer different research questions and targeted different taxonomic groups (see Section 5.2 Summary of Data Gaps)

The only species reported in Gunnison Bay for the purposes of this paper include two species of the phytoplankton genera *Dunaliella*. Gunnison Bay has a diverse microbial community but it is severely under-represented within the existing literature. As such, bacteria are not discussed in detail in the white paper.

At the Workshop, the participants were asked to provide input as to whether they could reach consensus on if the taxa reported are being observed in the bays. Draft versions of the tables included in Appendix B were presented at the Workshop for the participants to review. During the Workshop, participants did not voice opposition to the taxa presented in the tables, as no one had any significant comments or queries.

5.2. Summary of Data Gaps

During the Workshop, several data gaps were discussed and others were identified while developing this white paper. The following organisms are under-represented and further research is likely needed to characterize those communities:

- Benthic invertebrates in all bays of the Lake;
- Micro-planktonic invertebrates in all bays of the Lake;
- Bioherms in Gilbert Bay;
- Protozoa in all bays of the Lake;
- Microbes in Gunnison Bay;

- Fish in greater Bear River Bay and Farmington Bay; and
- Phytoplankton and zooplankton in Bear River Bay.

The mesh size of the sampling nets for macro-planktonic invertebrates is likely too large to accurately characterize the micro-planktonic invertebrates in the Lake, such as rotifers. In addition, some micro-planktonic invertebrates reported in this white paper may only be due to an incidental encounter while sampling for other targeted biota. Further studies focusing on the presence of these under-represented organisms with the correct sampling methods will help to characterize their existence and conditions at which they are observed within the Lake. Although protozoan are under-represented in the lake, toxicity testing protocols are lacking for protozoan, so this is not a critical data gap for developing water quality criteria.

5.3. Outstanding Questions

During the Workshop, participants raised pertinent questions regarding existing and future research, and the information that it can provide:

- Recent GSL research has been conducted during a period of lower Lake elevations. Fluctuations in water levels can affect salinity conditions and taxa that occur in each bay. Workshop participants questioned whether these recent studies can adequately represent the Lake during higher elevations; and
- Can information and data collected in Willard Spur be used to inform decisions for the rest of Bear River Bay?

5.4. Considerations

In future discussions regarding documenting the diversity of biota within the Lake, the following points discussed at the Workshop should be considered:

- There are quite a few genera that have not been taxonomically identified to the species level. Certain species, identified as occurring in GSL, may have unique characteristics or sensitivities that differentiate them from other species with the same genus, therefore, general information provided on species should carry a caveat for their uniqueness.
- The workshop featured a discussion as to whether taxa observed in Farmington Bay at six percent salinity could inform stakeholders as to the conditions and taxa present in Gilbert Bay at six percent. Farmington Bay at six percent salinity has been studied quite comprehensively, whereas Gilbert Bay only recently reached six percent salinity and the taxa in this new condition have not been as broadly examined. The challenge with comparing one bay to another is that Farmington Bay receives greater nutrient and pollutant loads. These inflows cause conditions where ecological interactions are at play.
- Wayne Wurtsbaugh mentioned that in his brine fly microcosm experiments, exposure to higher salinities causes the larvae to pupate instead of undergoing further growth as expected. Premature pupation demonstrates a stress response. The experiments did not continue long enough to evaluate whether early pupation caused reproduction complications. This discussion demonstrates that laboratory studies are important to understand that salinity tolerances may be different for survival, growth, and reproduction.

5.5. Criteria Development

The information included in this white paper may be used to support future development of water quality criteria for GSL. Evident through the tables included in this paper, Bear River Bay, Farmington Bay, Gilbert Bay, and Gunnison Bay are all unique environments that can support different types and combinations of organisms. Differences in the existing and expected aquatic communities may be taken into consideration when developing site-specific criteria for the Lake. This white paper will be updated as further research within GSL is conducted.

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Appendix A
Great Salt Lake Aquatic Life Use Workshop Summary

Subject: Great Salt Lake Aquatic Life Use Workshop

Date and Time: March 24, 2015, 9:00 am – 4:30 pm

Location: Utah Department of Environmental Quality Offices –Salt Lake City, Utah

Purpose: To develop a resident species list for GSL to be used in future development of water quality criteria.

I. Introduction

Walt Baker, Director of the Utah Department of Environmental Quality (UDEQ) Division of Water Quality (UDWQ), officially welcomed the participants to the workshop. UDWQ conducted an economic analysis of Great Salt Lake (GSL) and found that the economic value of the lake amounted to approximately $1.3 billion. He asked the rhetorical question – “How people can put a value on nature?” Mr. Baker emphasized the importance of the workshop purpose in protecting the biological integrity of GSL and a necessary step in order for UDEQ to develop water quality standards for GSL. He wished the participants luck in achieving the workshop purpose.

Jim Berkley, U.S. Environmental Protection Agency (EPA) Region 8, introduced himself as the workshop facilitator. He provided a brief overview of the agenda and participant expectations. Mr. Berkley noted that expert participants would provide information as to which species should be in the resident species list. Participants from UDWQ and EPA were asked to provide clarification of regulatory processes as needed. Mr. Berkley explained that a white paper would be developed to document the outcomes of the workshop. He also noted that as water quality standards may be developed for GSL, a GSL subgroup may be developed, and anyone who may be interested in participating in the subgroup should contact Chris Bittner of UDWQ.

A summary table of species was provided to each participant during the workshop. Participants were asked to provide written comments or notes and submit them at the end of the day. It was noted that Gunnison Bay would be discussed without a table.

Chris Bittner, UDWQ Standards Coordinator, introduced himself and emphasized that the State is working to develop numeric criteria that will provide protection for the lake.

Lareina Guenzel, Water Quality Standards EPA Region 8, introduced herself and explained the regulatory process of developing water quality standards. EPA makes recommendations to states for water quality standards; these standards are broadly applicable for a wide variety of aquatic species and habitat types. The Great Salt Lake is very unique. It has been thought to be biologically unique, but UDEQ has not conducted a full literature review and research to identify which species should be protected if numeric criteria are developed for the lake. Ms. Guenzel reminded the participants that the workshop is going to focus on all potential “food chain species” of the lake, or the aquatic species, and not the aquatic-dependent organisms such as birds. Birds will not be included in the species list at this time and will be considered at a later time.

Recalculation procedure is one of the EPA-approved methods for developing site-specific water quality criteria. It is used when species that occur at the site are substantially different from the species in the dataset that is used to derive EPA's 304(a) criteria or state-wide criteria. EPA is looking to use the species lists that are presented in the final white paper to eventually support the development of GSL-specific species sensitivity distributions for priority pollutants. There has been a lot of biological data collected from GSL, and one of the goals of the workshop is to gather all of those data and summarize the existing data in a white paper. When a state is considering the development of recalculated criteria, the first step is to compile the site-specific biological data. Toxicity data will be considered later after the resident species list has been developed.

EPA gives a specific definition for a resident species in the EPA Water Quality Standards Handbook and further clarification of the definition in the revised deletion process document that was published with the new ammonia criteria document. Ms. Guenzel noted that the group is not going to address species that "were present in the past, are not currently present at the site due to degraded condition, but are expected to return when conditions improve", at the workshop, but the larger water quality standards workgroup will determine how this condition will be taken into consideration at a later date. The goal of the workshop today is to document all species that are known to occur in GSL.

- **Question:** We are calling this list a "species list," but most of the taxa are listed only down to the family or genus level. I suggest calling it a "taxa list" since we do not have all the species names.
  Response: We would like to have the highest possible taxonomic identification, including the species names, but we acknowledge that this is not always available. We should reconsider calling the end product a taxa list.

- **Question:** Is there a point where there isn't enough information, and EPA has to do more research?
  Response: Yes, that is a part of our goal today. We may find that there are certain areas in the Lake where we haven't looked at some species. We will add this to the area of uncertainty and unknowns.

- **Question:** How will you define degraded condition?
  Response: That is a bigger discussion than what we are here to do today. There is a list of activities that EPA considers human-induced and irreversible degradation but it is broadly interpreted by different states. It is not something that EPA has strictly defined.

I. Bear River Bay

Jeff Ostermiller, of UDWQ, gave a presentation on Bear River Bay aquatic life based on Willard Spur investigations. The current species list of the aquatic life in Bear River Bay is sparse. Data on all organisms populated in the summary table were derived from two investigations. Mr. Ostermiller asked if anyone is aware of other studies that could help fill data gaps to provide information.

Mr. Ostermiller's team conducted a study in association with a wastewater treatment plant (WWTP) coming online. Willard Spur is a subset of Bear River Bay and a dynamic ecosystem. It becomes isolated from the rest of the Lake year to year. During the study's first year, there were unusually high water levels, so the area was not isolated from the rest of the Lake. When Willard Spur becomes isolated, many chemical and biological changes occur and the living organisms in the ecosystem change under the varying conditions of wet and dry years.

There are two key periods in Willard Spur: late spring to early summer. When there are lower nutrients and salinity, there are lower salinity concentrations, and the predominant birds in the area are waterfowl and piscivores. There are a lot of fish that live in the ecosystem during this time. As it dries out, the ecosystem is in a green water phase, with higher nutrients, and there is a switch from primary production consisting of macrophytes to primary production of algae. The avian community shifts to shorebirds.

What causes the switch? The complicating factor is that there are a lot of changes occurring chemically and biologically. One graph, presented by Mr. Ostermiller, showed the abundance of submerged aquatic vegetation (SAV). In a wet year, there was high SAV abundance, and it remained high throughout the season and throughout the distance from the outfall. In a dryer year, salinity increased, SAV abundance changed and dictated the quantity of macroinvertebrates and zooplankton.

As part of this study, Utah's Division of Wildlife Resources (DWR) conducted a fish survey. Little was known of what fish species existed in Bear River Bay or Willard Spur. Wayne Wurtsbaugh conducted one fish survey in Bear River Bay. As part of the study, nets were placed in the outfall to Willard spur. They also asked DWR to conduct a literature review. The predominant fish observed was carp and a variety of other fish taxa that were also present in Willard Spur. Closer to the reservoir, there is more diversity of fish. Moving further out in the ecosystem, carp and chub are the most predominate. The literature review reported no fishery surveys prior to Moore, 2011. Mr. Wurtsbaugh noted that it would be interesting to find out if similar studies have been conducted in the lower Bear River, as conditions may be similar to those near the outfall to the reservoir. In general, it would be good to expand research to Bear River.

Another workshop participant mentioned that he conducted research on Willard Spur macroinvertebrate counts in 2011 (wet) and 2012 (dry). Of the species across all the sampling points in multiple years, the macroinvertebrates observed in Willard Spur were similar to those in other wetlands across the lake, depending on sample. The dry year was much more productive, illustrating an increase in macroinvertebrates by total count and total biomass, throughout all seasons. The study findings illustrated that shorebirds were feeding on macroinvertebrates throughout the fall, and zooplankton became abundant during the fall as they are very tolerant of extreme environmental conditions.

Mr. Ostermiller noted that varying salinity can change the resident species at the site. Moreover, salinity may work as a surrogate, but it is important to note that there are other factors that are changing at the same time. Mr. Ostermiller recommended that if salinity is used to define when or where different criteria apply, the Agency should note that it is a surrogate for other factors. The goal is to protect most of the species, but the relative sensitivity of these species is going to change from year to year, and it will be hard to predict.

Mr. Ostermiller ends his presentation by asking if observations from Willard Spur can be extracted to inform on the greater Bear River Bay.

Discussion:

Wayne Wurtsbaugh mentioned that he conducted research in Willard Spur and Bear River Bay 10 years ago and can provide information and data to the group. His research includes a lot of information on macroinvertebrates, and they recorded approximately 97 taxa. He also mentioned that Scott Miller from Utah State also did some research in this area.

Mr. Ostermiller said that they decided to include fringe wetland information in the GSL species list. He said that Mr. Wurtsbaugh's team has been studying impounded wetlands and asked how comfortable they would be using that information for the entire Bear River Bay?

Mr. Wurtsbaugh answered that his group has studied those wetlands for 10-11 years including sites in Bear River Bay. He stated that the impounded wetlands are separate systems from the open waters of the Bay and have much fresher waters than open waters of the Bear River Bay. If the transition areas where water goes from freshwater to higher salinities is where the focus of the discussion is today, then maybe a separate workshop on wetlands, impoundments and sheet flow is needed.

Chris Bittner interjected that the focus of this workshop is for open water. EPA does not have a definition of what constitutes "open water." The criteria that will be supported by the findings of this workshop will be written for open water versus sheetflow wetlands. Mr. Bittner acknowledged that UDEQ has not explicitly defined "open waters." The impounded wetland data should be reviewed to determine if it can inform criteria development for the open waters.

- **<u>Question:</u>** Bear River Bay Migratory Bird Refuge already has criteria. Can the Refuge criteria be used inform for nearby areas with no criteria?
  Response: The Refuge does not have any recent data, but there could be historic data.

Mr. Wurtsbaugh mentioned that students of John Kadlec did some research during the flooding in the mid-1980s and findings from that research could be a possible data source.

- **<u>Question:</u>** Are non-native species equally considered with other species or can they be discounted?
  Response: Invasive species can be discounted. A lot of the time, they end up being surrogates for native species. If there is an invasive species, and it hasn't replaced a function of a native species, it can be given a different consideration. There is some flexibility depending on the economic and ecological importance of the species.

- **<u>Question:</u>** Where do carp fit in?
  Response: Fish are coming from Willard Reservoir, and they are living in Willard Spur for some period of time. Where do they go? Although they may not be indigenous to the Lake, they are an important food species for birds. All the fish in the Willard Spur are lost when Willard Spur dries up to a mudflat.

There was disagreement as to whether or not Willard Spur dries up completely. A participant commented that aerial photos illustrate that water is present through the 1980s and 1990s. Since 1999, the water has been reduced. Willard Spur functions like an impounded wetland and becomes very saline.

- **<u>Question:</u>** From a standpoint of developing criteria, water quality criteria needs to support the protection of these species even after periods of dry years. One of the goals of criteria is to not have water quality at a level difficult for species to overcome. The number that is set should not be so that organisms will not be in biological stress as they

try to recover from the dry years. For example, will the salinity today or the salinity 10 years from now apply?
Response: This is more of an implementation issue. The criteria are intended to protect species under specified conditions. Criteria will be based off survival, growth and reproduction and not just survival.

Gary Belovsky commented that if the discussion is about water quality, there has to be water present to begin with. If enough water is not entering the Lake, extreme conditions are happening. There is a natural hydrologic cycle that must be considered, as well as hydrologic changes that occur with changes in water uses.

Ms. Guenzel focused the discussion back to the species list and asked if this list is representative of Willard Spur/Bear River Bay. She also asked if anyone knew of salinity information for the flood years in the 1980s and about the ecological role of fish in Bear River Bay. Fish are washed into Bear River Bay from the bird refuge and Willard reservoir. It is a one-way street. Once the fish enter Willard Spur with spring snowmelt and high flow events, they do not typically leave. The presence of fish is ecologically important because they are a food source for several species of piscivorous birds.

- **<u>Question:</u>** How does EPA differentiate between present species and species that are necessary for the food chain?
  Response: EPA does not differentiate. Although Utah has clearly defined the designated uses for GSL, this workshop is covering the full range of aquatic life use of the lake and is not just focusing the food chain species.

A participant suggested removing the use of "food chain" and change the term to "food web."

II. Gilbert Bay

Gary Belovsky, of the University of Notre Dame, presented on his research in Gilbert Bay. One focus of his presentation was on the differences between field data and laboratory data. He stated that using field data alone, it is hard to determine tolerances that could impact the species as different environmental conditions in the lake are not independent of each other. On the other hand, laboratory data help researchers examine independent environment conditions (e.g., salinity, food resources). However, laboratory data may not be representative of field conditions.

Field data between 1995 and 2014 measured temperature and salinity during each month of each year. For different species, Mr. Belovsky's team looked at salinity, temperature and food importance on primary production and brine shrimp (nauplii, juveniles, adult survival, and adult reproduction) in the field and in the laboratory. The research team did not collect a lot of data on the productivity of bioherms in the Bay.

For bioherms production temperature is the most important, followed by nutrients second and finally by salinity (Anderson and Belovsky, unpublished). Experiments are ongoing.

Similar to brine shrimp, Mr. Belovsky is conducting a similar study with brine fly larvae. Looking at the survival of larvae and the proportion that enters the pupil stage, the researchers found that survival is most affected by salinity, whereas the proportion that pupates is dictated by temperature.

For phytoplankton, Mr. Belovsky found that nutrients are important both in the laboratory trials and the field data. Temperature appeared to be important in the lab studies, but not in the field data. This highlights the problem related to outcomes from only taking measurements from the lake and developing tolerances from this data. The same type of comparison has been done with the other species.

Discussion:

- **Question:** Did you separate out by food?
  Response: You cannot separate out the food in GSL. Mr. Belovsky said that he made the type of food and amount of food one single category.

- **Question:** This year, GSL research grants have a focus area on bioherms. The funding is available if anyone is interested in it.
  Response: Wayne Wurtsbaugh currently has two studies on bioherm production.

- **Question:** When you varied one factor, did you keep the other factors at an optimum level?
  Response: In the laboratory, everything was constant. Everything is made independently of each other.

- **Question:** Is the food independent of everything else you measured?
  Response: It isn't independent in the lake, which is why it is important to verify these findings out in the lake.

- **Question:** Is part of the reason why you think there is a difference between laboratory data and field data because there could be synergistic effects of stress on the species?
  Response: There are biological interactions between different species in the Lake. These are held constant in the laboratory but not constant in GSL.

- **Question:** Did you simulate day versus night?
  Response: No, it was not simulated, but it would be interesting to conduct those tests.

- **Question:** Could you talk about the difficulties in culturing brine fly in the lab?
  Response: We have been able to establish colonies of flies in the lab but it is difficult to do at a high production level.

- **Question:** What species of brine fly are you studying?
  Response: *Hians*.

Ms. Guenzel asked the workshop participants if there should be a hybrid of laboratory and field data used when trying to obtain salinity tolerances. Typically, there is a ranking system for laboratory versus field data.

Gary Belovsky answered that his perspective is to rely on laboratory data but to use a degree of caution. There are other biological interactions going on in the field that are not being expressed in the laboratory data. Ms. Guenzel commented that it would be important to distinguish between the laboratory data and the field data.

A participant mentioned that the main survival factor for these organisms is food, and the food should be protected. Mr. Belovsky responded that it is not just about the amount of food available, but the types of food that are available. For example, diatoms are not good food for the brine shrimp.

A general note was made to make sure that results from Mr. Belovsky's laboratory and field studies were represented in the Gilbert Bay species list.

- **Comment:** Mr. Wurtsbaugh mentioned that during sampling in the 1980s, the dominant species was copepods at 6% salinity. He believes that rarer species are currently being washed in from other bays.
  Response: We will note if the species is rare or only intermittently sampled in the final taxa list if this information is available.

- **Question:** Rotifers were dominant in Farmington Bay in the 1980s. Are existing sampling techniques used for other zooplankton accurately capturing the diversity of rotifers in GSL?
  Response: We may not have captured all potential rotifers based on sampling techniques. The mesh size of the sampling nets for macro-planktonic invertebrates is likely too large to accurately characterize the micro-planktonic invertebrates in the lake, such as rotifers. Mr. Belovsky mentioned that his lab is finding the rotifers in the phytoplankton samples. Rotifers and other micro-planktonic species have primarily been observed in Gilbert Bay when lake elevation is high and salinity was around 6%. The lake salinity is currently much greater than 6%, and current conditions may persist. The potential for rotifers and other micro-planktonic species to occur in Gilbert Bay when salinity is greater than ~6% is one of the data gaps.

Ms. Baxter commented that the protozoa of GSL are also understudied. Researchers are excited about the protozoan diversity, and they want to study it. This is a current data gap.

- **Question:** Why can't Farmington Bay at 6% salinity inform us of what will happen in Gilbert Bay at 6%?
  Response: It would be different, but it could give some insight.

Mr. Belovsky commented that he would be concerned about nutrient loading. Mr. Wurtsbaugh said that Farmington Bay becomes anoxic whereas Gilbert Bay does not. Anthropogenic impacts are much higher in Farmington Bay than Gilbert Bay. It might be a good way to start, but the ecological interactions must be considered.

- **Question:** Do you think the predator/prey relationship would be the same in Gilbert Bay as in Farmington Bay?
  Response: Mr. Wurtsbaugh answered that when the Lake was at 6% salinity, there were moderate to high concentrations of corixids in Gilbert Bay but not as high as numbers recorded in Farmington Bay. The main reason that brine shrimp were lost in Gilbert Bay was because of predation. An alternative theory is that the eggs were sinking at a higher salinity.

Ms. Guenzel mentioned that sampling locations of open water sites as they correlate to fringe wetland sites needs to be mentioned in the Farmington Bay species tables.

III. Farmington Bay

Wayne Wurtsbaugh, of Utah State University, presented research from Farmington Bay. He started by presenting an overview of the food web in Farmington Bay, and indicating that periphytes and macrophytes have not been studied extensively. Mr. Wurtsbaugh provided an overview of the sampling conducted in the northern part of Farmington Bay. Some sampling stations are located in Bear River Bay and Gilbert Bay, which serve as comparison sites.

There are number of sources that feed Farmington Bay, including Jordan River, small creeks, a WWTP outfall, and sewer canal. It is estimated that 30% of all water coming into the Bay is from the WWTP. During spring runoff, a large portion of water is diverted from Farmington Bay via the Goggin drain. Heavy nutrient loading, large populations of phytoplankton, and cyanotoxins, are all issues in Farmington Bay.

Saltier, denser water from Gilbert Bay enters Farmington Bay through a deep-brine layer as fresher, less dense water flows from Farmington Bay into Gilbert Bay. It is hard to estimate the extent of the deep brine layer, but it has been estimated based on higher lake elevation years. The deep brine layer in Gilbert Bay is stable and anoxic. Complete water column anoxia is common in Farmington Bay at night, followed by supersaturation during the daytime. Supersaturation can be toxic to some taxa.

The deep brine layer is typically present at 1 meter below the water surface in Farmington Bay. It is easy to mix up the layer during high wind events and the result is a few days of anoxia. It may be likely that this mixing event can happen in Gilbert Bay, but the deep brine layer is much deeper at about 6 meters below surface level.

Seasonal salinity differences are beginning with freshwater in the spring, and conditions are becoming more saline as water entering the Bay is reduced. A strong salinity gradient exists in Farmington Bay due to Gilbert Bay water entering from the North and fresh water entering from the south. This gradient has seasonal and inter-annual changes, and the changes exert strong control on the biotic communities. In McCulley's thesis (2012), researchers measured the zooplankton composition gradients in Farmington Bay from south to north and found that in the north, zooplankton populations were lower. Seasonal dynamics of zooplankton are also pronounced in Farmington Bay, and diversity is much higher than in the hypersaline Gilbert Bay. Benthic invertebrates are more diverse and in large populations at sampling stations near the sewage canal. Bird species' composition changes significantly from the shallow, fresher south end to the deeper and more saline north end of Farmington Bay.

Mr. Wurtsbaugh's team conducted microcosm studies in the laboratory with water and sediment samples collected from the Lake. They conducted the studies at a salinity range from 10-225 g/L while measuring artemia and brine fly larvae length. During the biomass study, they observed fewer invertebrates because the fish were likely preying on them. As salinity increased, the biomass of artemia reduced dramatically. For the brine fly biomass, higher salinities resulted in less larvae growth, but there was a high proportion of biomass tied up in the pupae. Mr. Wurtsbaugh noted that he believes that when the brine fly are very stressed, rather than trying to grow, they will pupate. Pupation was demonstrated as a stress response.

- **<u>Question:</u>** Regarding the anoxic events due to the wind events, do you think that these events are widespread or are they localized within the Bay?
  Response: It has not been documented, but it is likely widespread. In addition to mixing up the deep brine layer, it could also occur as a result of aggravation from waves to the top one-third of the sediments.

- **<u>Question:</u>** When measuring the length of brine shrimp, did you measure males and females? Were females separated out by females with eggs versus females with cysts?
  Response: The brine shrimp were mature adults, and we measured both females and males. The females were all with egg sacs. To facilitate potential hatching, when water was added to maintain the salinity, a surface layer of freshwater was added before the solution was aerated. This was done to provide a hydration event for cysts.

- **<u>Question:</u>** Over what period of time were the microcosm experiments conducted?
  Response: They were conducted over one month.

- **<u>Question:</u>** With the brine fly, is it possible to do any further studies on reproduction to confirm if it is a stress response to pupate?
  Response: The microcosms were not conducted long enough to see if the pupation would have resulted in successful reproduction. They would likely reproduce but may result in less egg numbers.

Theron Miller, of Farmington Bay Jordan River Water Quality Council, presented research on the factors influencing cyanobacteria blooms in Farmington Bay. Mr. Miller and Brad Marden, Parliament Fisheries, are conducting a multi-year study with the goal of identifying key factors that influence phytoplankton, in particular cyanobacteria, and evaluate if there are spatial and temporal changes in zooplankton populations, as well as if nodularia has an effect on zooplankton.

Phosphorous is the primary nutrient influencing cyanobacteria growth in Farmington Bay. The Bay is dominated by nodularia starting in May and nodularia is intolerant of salinity above 5-6%.

Mr. Miller's team has 8 sampling sites within the Bay and one site north of the causeway. Salinity is measured each month at the sampling sites, and observations indicate that salinity experiences seasonal changes.

Halophilic artemia were present in the northern sites, likely because of diminishing numbers of corixids. Diatom taxa dominated the phytoplankton in March and April, however zooplankton numbers did not increase until the end of May, lead by dominance of rotifers followed by cladocerans and copepods. An increase in zooplankton was concurrent with an increase in nodularia, suggesting that there is no link to between nodularia toxins and zooplankton toxicity. All zooplankton declined with emergence of corixids.

- **<u>Question:</u>** On the pie charts sorted seasonally identifying phytoplankton locations, are you doing that with microscopy?
  Response: This was a temporal study for only site 1. The research team is using microscopy every two weeks. It is in the report that came out a few weeks ago.

<u>Discussion</u>

Mr. Wurtsbaugh commented that most existing research is sampling the easy stuff, the plankton community and not the benthic community, and that further research is needed in the benthic community to better understand those systems.

Mr. Miller's research has not focused on benthic invertebrates. The draft taxa list does include invertebrates from fringe wetland studies conducted by UDEQ. Ms. Guenzel asked the group if they think that the fringe wetland species could provide insight to the benthic species expected in the open water habitat, or are these species not representative of open waters. She asked if studies from fringe wetlands should be shown on separate species tables or if there is there enough overlap to present one species list for Farmington Bay.

- **Question:** What is the definition of fringe wetlands?
  Response: Sheet flow wetland that are commonly found below the outlets from impounded wetlands, wastewater treatment facilities, and other low-gradient surface channels or small streams. They are also associated with groundwater discharge such as springs or seeps.

One participant commented that there is going to be overlap in the vegetation, but ecologically, those environments are going to change. Another participant mentioned that there is a difference between phyto and benthic bugs; meaning that there are differences between bugs associated with sediments versus bugs that are associated with plants.

One participant mentioned that there is a salinity gradient and a water persistence gradient. The participant suggested that it is most likely easier to make one table with all the information and observe overlap unless there is insufficient information.

Ms. Guenzel answered that she put all information into one table for Farmington Bay. The location-specific information from transect studies in Farmington Bay have not yet been entered into the table, so there are a number of questions marks in the table since we did not know if the species was collected from Farmington Bay or Gilbert Bay. Once we have these additional data from the transect studies, we should have a more comprehensive view of the aquatic life in Farmington Bay than Bear River Bay.

- **Question:** Were any new species discovered during the studies Mr. Miller and Mr. Wurtsbaugh?
  Response: The results were fairly similar, and there were no surprises in species. The two studies were in general agreement.

Mr. Belovsky commented with a word of caution when looking for a correlation in changing salinity and the abundance of invertebrates. He noted that people should be careful with the life cycle of invertebrates because it does not necessarily correlate with salinity.

Mr. Wurtsbaugh mentioned that using birds as an endpoint for the food web could be a weakness in that not a lot of good diet data on birds in GSL exists. Mr. Miller said that limited research has been done, and only 25 birds are included in each study. Leland Myers has some bird studies available on his website.

Ms. Guenzel asked the group if information on fish is available in Farmington Bay, or if this is a data gap. One participant responded that one key difference is the source water of Farmington Bay and Bear River Bay. Bear River Bay has more types of warm water fish species than the inflows of Farmington Bay. This will likely determine what is found in the freshwater sections.

Another participant responded that the hydrology is different in Farmington Bay as a flow through area, whereas Bear River Bay is impounded in the refuge wetlands or because of inadequate flows to connect with the Lake. There is evidence of fish in Farmington Bay, proven by pelicans and herons observed feeding on fish.

- **<u>Question:</u>** Does the Farmington Bay Waterfowl Management Area staff have more data on fish? The fish may be in the ponds. Rich Hanson is the person to contact.
  Response: He has fish data from pelicans caught in Farmington Bay, and it was predominately chub.

A participant commented that fish data is a data gap, but that it is not hard to place nets in low water levels to sample.

A participant suggested that the first step should be to identify habitats (e.g., ponds, fringe wetlands, and open waters). Habitat complexity for invertebrates is very important. When habitats have been identified, species can be placed in areas where they are most likely to be found. For example, corixids need complex habitats because they like to hide.

One participant commented that there is concern over determining salinity ranges from field data when the species tolerance range has not been determined in the laboratory. Until the species salinity tolerance is determined in the lab, they should not be grouped together based simply on co-occurrence in the field.

Ms. Guenzel asked if is it better to provide a generalization on salinity tolerance or no information at all in cases where the species salinity tolerance information is not determined.

One participant responded that the current taxa list is very large. The group could decide to choose a few taxa and test them thoroughly to obtain more information. While it is wonderful to get a species list for GSL, it may become too much if we are concerned with every species.

Another participant responded that it is a matter of sensitivity. If an organism is unclassified, it drives more studies to understand the threshold to see the sensitive taxa. It would be good to taxonomically identify what is sensitive.

Another participant commented that this process is concerned with the uniqueness of GSL and the biota. There may be species that are unique to GSL that deserve attention and should not rely on surrogates from other ecosystems.

Chris Bittner interjected that the screening of toxicity data is frequently done at the family level (i.e., nonresident tested species can represent a taxonomically similar resident species without toxicity data), so even if there is no species classification information, we will be able to consider the higher taxonomic information. The toxicity dataset must contain data for at least eight diverse families. EPA has used this procedure since 1984. The four most sensitive genera and the total number of genera represented in the toxicity dataset determine the final criteria values. A robust toxicity dataset may have 50 genera or approximately 70 species in it; however, water quality criteria have been derived from much smaller toxicity datasets. EPA has established minimum data requirements for national criteria recommendations, but there will likely be special considerations for GSL because for some bays, eight families won't exist.

A participant mentioned that research has been conducted in the Netherlands in eutrophic lakes that showed how some species have adapted in eutrophic conditions for a long time. It may be worth considering that the local species have adaptive attributes that may not be identified in the literature.

- **<u>Question:</u>** One of the big picture issues is that currently, the lake is at very low elevations and taxa are being challenged due to the high salinity. In general, is there any sort of trend or correlation between lake level and salinity or another representative parameter?

In terms of water quality criteria, how do we determine if there is something that is driving the system when the system is under stress? At what point do co-stressors combine to overload the system?
Response: Chris Bittner answered that the toxicity tests conducted using EPA protocols are under ideal conditions and not under stress conditions.

- **Question:** Do you end up with appropriate regulations if the system is not under stress?
Response: The answer is not known. The toxicity data is mostly acute tests, and water quality criteria need chronic tests, so EPA adjusts the data to simulate results from chronic tests by applying an acute to chronic ratio estimated from toxicity tests that measured both acute and chronic toxicity.

IV. Gunnison Bay

Bonnie Baxter, of Westminster College, presented on archaea in Gunnison Bay. She started her presentation by saying that the current species list is underrepresented for microbial diversity. Ms. Baxter suggested removing bacteria entirely rather than having them underrepresented. She will contribute a paragraph to the white paper regarding how complicated microbial diversity is and why it may not matter with the current scope.

Halophiles is a generic term that refers to microorganisms that live in high salt areas. Approximately 90% of what is observed in Gunnison Bay is archaea. Halophiles that live in the hypersaline Gunnison Bay fall under archaea. Archaea are in between the bacteria and eukarya domains. South Arm Gilbert Bay and North Arm Gunnison Bay are two distinct microbial communities. Most of Ms. Baxter's studies are in North Arm Gunnison Bay. Microbial diversity can be assessed by microscopy, cultivation, or genetics. Microscopy does not identify the species, so cultivation and genetics are typically used. However, cultivation gives a limited picture of what is present because 90% of what grows in GSL cannot be grown in the laboratory.

There is a wide temporal diversity between different sampling periods as microbial communities shift rapidly. Spatial diversity is also very different. There is diversity in the vertical transect as salinity changes.

Ms. Baxter suggested that bacteria/archaea/fungi should be left out of the species list because it is so diverse. In Gunnison Bay, microbial life comes from all three domains. The diversity is immense, and it shifts both temporally and spatially. A static "list" is not possible.

- **Question:** How long does it take to culture in order to change the species genetics to be more salt tolerant?
Response: There is a machine that forces organisms to evolve and develop genetic capacities that are normally not present. Halophiles build up lipids and sugars, which is why we have been exploring biofuels.

- **Question:** If Gunnison Bay is 90% archaea, what is it about the archaea that allows them to be more populous than bacteria?
Response: There are very few bacteria that have genetic capabilities to pump out salt and build up other things. Cell walls of the halophiles are different from cell walls of bacteria which allow them to behave differently and be more stable.

V. Overview and Next Steps

Ms. Guenzel addressed next steps, "parking lot" issues and other outstanding items brought up during the workshop. She asked the group if there any other relevant studies that still need to be collected to inform the development of the species list, and if the current species list accurately represents the studies that have already been collected. EPA and UDEQ will collect additional studies for two weeks following the workshop. The white paper will be drafted during the 2 to 4 weeks following the final data submission deadline. The white paper will be available on the project's SharePoint site so that everyone can provide comments in one copy. A final white paper will address appropriate comments, and it will be made available through UDEQ. The white paper will be a guiding document describing aquatic life in the GSL ecosystem and informing decisions on data gaps.

- **Question:** At what point does that recalculation process get brought in? What is the purpose of the white paper in that process?
  Response: The species list will be a resident species list by salinity or by habitat. Once a resident species list is developed, UDEQ will gather the existing toxicity data and identify what data are still needed to develop criteria.

One topic that was raised during the workshop is how salinity should be presented in the white paper. Salinity is collected and expressed in different ways. Workshop participants agreed to have the white paper present salinity as weight percentages. The white paper will identify where salinity data has been converted. Well known and confirmed equations exist to convert from parts per thousand or grams per liter to percentages. U.S. Geological Survey (USGS) documents typically have these conversion tables at the beginning of their reports.

Ms. Guenzel thanked everyone for their participation in the workshop. Information on next steps will be provided to participants in future emails.

Appendix B
Species Tables

For the purposes of the following tables, the following abbreviations have been made:

BRB	Bear River Bay
GB	Gilbert Bay
FB	Farmington Bay
GUN	Gunnison Bay
WS	Willard Spur

Where the organism was not classified at the species or genus level, the order or family were reported in the genus column in parenthesis.

Table 5. Taxa observed in Gilbert Bay

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	Genus (Order/Family)	Species	Common Name	Life Cycle	Sampling Location	Other Bays	@ sampling event	min	max	Converted
Aquatic Insect										
Ephydridae	(Diptera/Ephydr idae)	sp.	midge			FB	2.2-13.6			
Ephydridae	Ephydra	cinerea	brine fly	larvae				11	17.6	g/L
Ephydridae	Ephydra	cinerea (gracilis)	brine fly					9.4	17.6	g/L
Ephydridae	Ephydra	hians	brine fly	larvae				11	17.6	g/L
Ephydridae	Ephydra	sp.	brine fly			FB, BRB		8.2	17.6	g/L
Ephydridae	Ephydra	sp.	brine fly	adult		FB, BRB		1.1	16.5	g/L
Ephydridae	Ephydra	sp.	brine fly	larvae		FB, BRB		1.1	16.5	
Ephydridae	Ephydra	sp.	brine fly	pupae		FB, BRB		1.1	16.2	
Ephydridae	Ephydra	sp.	brine fly	adult	Ogden Bay	FB, BRB		5.4	13.2	
Ephydridae	Ephydra	sp.	brine fly	larvae	Ogden Bay	FB, BRB		5.4	13.2	
Ephydridae	Ephydra	sp.	brine fly	pupae	Ogden Bay	FB, BRB		5.4	13.2	
Corixidae	(Corixidae)	sp.	corixid	adult		FB, BRB		9.5	15.7	
Corixidae	(Corixidae)	sp.	corixid	adult	Ogden Bay	FB, BRB		5.4	13.2	
Corixidae	Trichocorixa	verticalis	corixid			FB, BRB		1.1	16.0	g/L
Corixidae	Trichocorixa	verticalis	waterboatman			FB, BRB		0	9.0	g/L
Corixidae	Trichocorixa	verticalis (Fieber)	corixid	adults, juveniles		FB		0.4	12.8	
Corixidae	Unidentified corixid	sp.	corixid					8.2	17.6	g/L
Brine Shrimp										
Artemiidae	Artemia	franciscana	brine shrimp			FB, BRB		1.0	11.5	g/L
Artemiidae	Artemia	franciscana	brine shrimp	nauplii		FB, BRB		1.1	17.6	
Artemiidae	Artemia	franciscana	brine shrimp	juvenile		FB, BRB		1.1	17.6	
Artemiidae	Artemia	franciscana	brine shrimp	adult		FB, BRB		1.1	17.6	
Artemiidae	Artemia	franciscana	brine shrimp	cysts		FB, BRB		8.2	17.6	
Artemiidae	Artemia	franciscana	brine shrimp	eggs		FB, BRB		9.5	16.5	

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Artemiidae	Artemia	franciscana	brine shrimp	adult	Ogden Bay	FB, BRB		5.4	13.2	
Artemiidae	Artemia	franciscana	brine shrimp	cysts	Ogden Bay	FB, BRB		5.4	13.2	
Artemiidae	Artemia	franciscana	brine shrimp	eggs	Ogden Bay	FB, BRB		5.4	13.2	
Artemiidae	Artemia	franciscana	brine shrimp	juvenile	Ogden Bay	FB, BRB		5.4	13.2	
Artemiidae	Artemia	franciscana	brine shrimp	nauplii	Ogden Bay	FB, BRB		5.4	13.2	
Zooplankton										
Moinidae	Moina	sp.	cladoceran			FB		1.1	15.2	
Moinidae	Moina	sp.	cladoceran	adult		FB, BRB		9.5	15.7	
Moinidae	Moina	sp.	cladoceran	adult	Ogden Bay	FB, BRB		5.4	13.2	
Moinidae	Moina	macrocarpa Straus	cladoceran			FB		0.1	8.8	
(Ostracoda)	(Ostracoda)	sp.	ostracod	adult		FB, BRB		9.5	15.7	
(Ostracoda)	(Ostracoda)	sp.	ostracod	adult	Ogden Bay	FB, BRB		5.4	13.2	
Diaptomidae	Diaptomus	connexus	copepod			FB			9.35	g/L
Diaptomidae	Leptodiaptomus	connexus Light	copepod	adults, juveniles		FB		0.1	12.6	
	(Calanoida)	sp.	copepod	adult		FB		9.5	15.7	
	(Calanoida)	sp.	copepod	adult	Ogden Bay	FB, BRB		5.4	13.2	
	Unidentified copepod	sp.	copepod					8.3	14.9	g/L
	(Cyclopoida)	sp.	copepod	adult		FB, BRB		9.5	15.7	g/L
	(Cyclopoida)	sp.	copepod	adult	Ogden Bay	FB, BRB		5.4	13.7	
	(Cyclopoida)	sp.	copepod			FB, BRB		1.1	15.2	
Canthocamptidae	Cletocamptus	albuquerquensis	copepod			FB		4.0	16.0	g/L
Harpacticoid	Cletocamptus	sp.	copepod	adult, Juvenile		FB		1.5	12.6	
	(Harpacitocoida)	sp.	copepod	adult		FB		9.5	16.4	
	(Harpacitocoida)	sp.	copepod	adult	Ogden Bay	FB, BRB		5.4	13.2	
Brachionidae	Brachionus	plicatilis (O.F.M.)	rotifer			FB		0.3	14	g/L

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
	Unidentified rotifer	sp.	rotifer					8.22	17.6	g/L
Other										
Euplotidae	Euplotes	sp.	ciliate		Marshes		No salinity information reported			
Ceratiaceae	Ceratium	sp	dinoflagellate					8.84	9.52	g/L
Glenodiniaceae	Glenodinium	sp.	dinoflagellate			FB		4.0	16.0	g/L
	Unidentified protozoa	sp.	protozoan					8.2	17.6	g/L
	Unidentified nematode	sp.	worm					8.22	17.56	g/L

Table 6. Taxa observed in the fringe wetlands in Gilbert Bay

Taxonomic Identification				Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Dytiscidae	Agabus	sp.	beetle	GB Fringe wetlands		0.15	0.13	0.15	g/L
Dytiscidae	Laccophilus	sp.	diving beetle	GB Fringe wetlands	FB and BRB	0.18	0.16	0.23	g/L
Chironomidae	Chironomus	sp.	midge	GB Fringe wetlands	FB and BRB	0.26	0.23	0.3	g/L
Chironomidae	Subfam: Tanypodinae	sp.	midge	GB Fringe wetlands	FB and BRB	0.18	0.15	0.23	g/L
Culicidae	(Diptera/Culicidae)	sp.	biting midge	GB Fringe wetlands	FB and BRB	0.35	0.28	0.46	g/L
Belostomatidae	Lethocerus	sp.	waterbug	GB Fringe wetlands		0.14	0.13	0.14	g/L
Notonectidae	Buenoa	sp.	backswimmer	GB Fringe wetlands	FB and BRB	0.34	0.28	0.43	g/L
Lymnaeidae	Stagnicola	sp.	snail	GB Fringe wetlands	FB and BRB	0.23	0.2	0.26	g/L
Physidae	Physella	sp.	snail	GB Fringe wetlands	FB and BRB	0.19	0.17	0.23	g/L
Planorbidae	Gyraulus	sp.	snail	GB Fringe wetlands	FB and BRB	0.23	0.18	0.28	g/L
Erpobdellidae	Erpobdella	sp.	leech	GB Fringe wetlands	FB	0.17	0.13	0.25	g/L
Hyalellidae	Hyalella	azteca	scud	GB Fringe wetlands	FB and BRB	0.34	0.27	0.45	g/L

Table 7. Taxa observed in Bear River Bay

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	Genus (Order/Family)	Species	Common Name	Life Cycle	Sampling Location	Other Bays	@ sampling event	min	max	Converted
Aquatic Insect										
Chrysomelidae	(Chrysomelidae)	sp.	beetle		Willard Spur			0.14	0.62	g/L
Dytiscidae	(Dytiscidae)	sp.	beetle	early instar larvae	Willard Spur			0.07	0.77	g/L
Dytiscidae	Agabus	sp.	beetle		Willard Spur			0.14		g/L
Dytiscidae	Hydroporus	sp.	beetle		Willard Spur			0.13		g/L
Dytiscidae	Laccophilus	sp.	diving beetle		Fringe wetlands	GB, FB	0.18	0.16	0.23	g/L
Dytiscidae	Stictotarsus	sp.	beetle		Willard Spur			0.22	0.58	g/L
Gyrinidae	Gyrinus	sp.	beetle		Fringe wetlands		0.31	0.3	0.33	g/L
Hydrophilidae	Berosus	sp.	beetle	larvae	Willard Spur			0.09	2.71	g/L
Hydrophilidae	Enochrus	sp.	beetle		Fringe wetlands	FB	0.24	0.19	0.33	g/L
Hydrophilidae	Enochrus	sp.	beetle		Willard Spur			0.07	2.71	g/L
Hydrophilidae	Tropisternus	sp.	beetle	adult	Willard Spur			0.1	0.74	g/L
Hydrophilidae	Tropisternus	sp.	beetle		Fringe wetlands	FB	0.24	0.19	0.33	g/L
Ceratopogonidae	(Ceratopogonidae)	sp.	biting midge		Fringe wetlands		0.5	0.42	0.64	g/L
Ceratopogonidae	Subfam: Ceratopogoninae	sp.	midge		Willard Spur			0.07	0.19	g/L
Chironomidae	Chironomus	sp.	midge		Willard Spur			0.07	0.98	g/L
Chironomidae	Chironomus	sp.	midge		Fringe wetlands	GB, FB	0.26	0.23	0.3	g/L
Chironomidae	Subfam: Orthocladiinae	sp.	midge		Fringe wetlands	FB	0.2	0.17	0.25	g/L
Chironomidae	Subfam: Orthocladiinae	sp.	midge		Willard Spur			0.07	0.74	g/L
Chironomidae	Subfam: Tanypodinae	sp.	midge		Fringe wetlands	GB, FB	0.18	0.15	0.23	g/L
Chironomidae	Subfam: Tanypodinae	sp.	midge		Willard Spur			0.07	2.71	g/L
Chironomidae	tribe Tanytarsini	sp.	midge		Willard Spur			0.08	0.61	g/L

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Culicidae	(Culicidae)	sp.	biting midge		Fringe wetlands	GB, FB	0.35	0.28	0.46	g/L
Dolichopodidae	(Dolichopodidae)	sp.	midge		Willard Spur			0.13	0.97	g/L
Dolichopodidae	(Dolichopodidae)	sp.	fly		Fringe wetlands		0.7	0.55	0.95	g/L
Ephydridae	Ephydra	sp.	brine fly		Willard Spur			0.15	0.74	g/L
Ephydridae	Ephydra	sp.	brine fly	adult		GB, FB		0	1.2	
Ephydridae	Ephydra	sp.	brine fly	larvae		GB, FB		0	1.2	
Ephydridae	Ephydra	sp.	brine fly	pupae		GB, FB		0	1.2	
Ephydridae	Ephydra	sp.	brine fly		Fringe wetlands	FB	0.2	0.16	0.25	g/L
Stratiomydae	(Stratiomydae)	sp.	midge		Willard Spur			0.1	0.1	g/L
Stratiomyidae	Caloparyphus	sp.	fly		Fringe wetlands	FB	0.27	0.23	0.32	g/L
Tabanidae	Chrysops	sp.	midge		Willard Spur			0.28	0.28	g/L
Tabanidae	Chrysops	sp.	fly		Fringe wetlands	FB	0.37	0.28	0.53	g/L
Tipulidae	Prionocera	sp.	cranefly		Willard Spur			0.19	0.19	g/L
Baetidae	Callibaetis	sp.	mayfly		Willard Spur			0.07	1.22	g/L
Baetidae	Callibaetis	sp.	mayfly		Fringe wetlands	FB	0.27	0.23	0.32	g/L
Caenidae	Caenis	amica	mayfly		Willard Spur			0.08	0.77	g/L
Corixidae	(Corixidae)	sp.	corixid	adult		GB, FB		0	1.2	
Corixidae	Corisella	sp.	water boatman		Willard Spur			0.07	2.71	g/L
Corixidae	Corisella	sp.			Fringe wetlands	FB	0.23	0.2	0.25	g/L
Corixidae	Hesperocoriza	sp.	water boatman		Willard Spur			0.07	0.62	g/L
Corixidae	Trichocorixa	verticalis	waterboatman			GB, FB		0	9.0	g/L
Notonectidae	Buenoa	sp.	backswimmer		Fringe wetlands	GB, FB	0.34	0.28	0.43	g/L
Notonectidae	Notonecta	sp.	water boatman		Willard Spur			0.07	1.22	g/L
Aeshnidae	Aeshna	sp.	dragonfly		Willard Spur			0.09	0.63	g/L
Aeshnidae	Aeshna	sp.	dragonfly		Fringe wetlands	FB	0.27	0.23	0.36	g/L
Coenagrionidae	Archilestes	sp.	damselfly		Willard Spur			0.07	0.23	g/L
Coenagrionidae	Ischnura	sp.	damselfly		Willard Spur			0.07	1.43	g/L
Coenagrionidae	Ischnura	sp.	damselfly		Fringe wetlands	FB	0.3	0.25	0.4	g/L
Libellulidae	Erythemis	sp.	dragonfly		Willard Spur			0.08	0.63	g/L

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Libellulidae	Erythemis	sp.	dragonfly		Fringe wetlands	FB	0.21	0.18	0.25	g/L
Leptoceridae	Ylodes	sp.	caddisfly		Willard Spur			0.11	0.63	g/L
Phryganeidae	Phryganea	sp.	caddisfly		Fringe wetlands		0.31	0.3	0.33	g/L
Brine Shrimp										
Artemiidae	Artemia	franciscana	brine shrimp	adult		GB, FB		0	1.2	
Artemiidae	Artemia	franciscana	brine shrimp	cysts		GB, FB		0	1.2	
Artemiidae	Artemia	franciscana	brine shrimp	eggs		GB, FB		0	1.2	
Artemiidae	Artemia	franciscana	brine shrimp	juvenile		GB, FB		0	1.2	
Artemiidae	Artemia	franciscana	brine shrimp	nauplii		GB, FB		0	1.2	
Fish										
Clupeidae	Dorsoma	sp.	gizzard shad		Willard Spur		No salinity information reported			
Cyprinidae	Cyprinus	carpio	common carp		Willard Spur			0.2	0.4	
Cyprinidae	Gila	atraria	Utah chub		Willard Spur			0.2	0.4	
Centarchidae	Pomoxis	nigromaculatus	black crappie		Willard Spur			0.2	0.4	
Moronidae	Morone	chrysops+ saxatilis	wiper		Willard Spur			0.2	0.4	
Percidae	Perca	flavascens	yellow perch		Willard Spur			0.2	0.4	
Percidae	Sander	sp.	walleye		Willard Spur		No salinity information reported			
Ictaluridae	Ameiurus	sp.	black bullhead		Willard Spur		No salinity information reported			
Ictaluridae	Ictalurus	sp.	channel catfish		Willard Spur		No salinity information reported			
Mollusk										
Lymnaeidae	Stagnicola	sp.	snail		Willard Spur			0.07	1.22	g/L
Lymnaeidae	Stagnicola	sp.	snail		Fringe wetlands	GB, FB	0.23	0.2	0.26	g/L
Physidae	Physella	sp.	snail		Willard Spur			0.07	1.22	g/L
Physidae	Physella	sp.	snail		Fringe wetlands	GB, FB	0.19	0.17	0.23	g/L
Planorbidae	Gyraulus	sp.	snail		Willard Spur			0.07	0.62	g/L
Planorbidae	Gyraulus	sp.	snail		Fringe wetlands	GB, FB	0.23	0.18	0.28	g/L
Zooplankton										
Moinidae	Moina	sp.	cladoceran	adult		GB, FB		0	1.2	

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
(Ostracoda)	(Ostracoda)	sp.	ostracod	adult		GB, FB		0	1.2	
	(Calanoida)	sp.	copepod	adult		GB, FB		0	1.2	
	(Cyclopoida)	sp.	copepod	adult		GB, FB		0	1.2	
	(Harpacticoida)	sp.	copepod	adult		GB, FB		0	1.2	
Other										
Erpobdellidae	(Erpobdellidae)	sp.	leech		Willard Spur			0.08	0.09	g/L
Glossiphoniidae	Helobdella	stagnalis	leech		Willard Spur			0.1	0.15	g/L
Naididae	(Naididae)	sp.	worm		Willard Spur			0.08	0.15	g/L
	(Trombidiformes)	sp.	water mite		Willard Spur			0.08	0.8	g/L
Hyalellidae	Hyalella	azteca	scud		Fringe wetlands	GB, FB	0.34	0.27	0.45	g/L
Hyalellidae	Hyalella	azteca	scud		Willard Spur			0.07	1.43	g/L
Asellidae	Caecidotea	sp.	aquatic sowbug		Willard Spur			0.08	0.08	g/L

Table 8. Taxa observed in Farmington Bay

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	Genus (Order/Family)	Species	Common Name	Life Cycle	Sampling Location	Other Bays	@ sampling event	min	max	Converted
Aquatic Insect										
Dytiscidae	Hydroporus	sp.	diving beetle		Fringe wetlands	BRB	0.21	0.14	0.32	g/L
Dytiscidae	Laccophilus	sp.	diving beetle		Fringe wetlands	GB, BRB	0.18	0.16	0.23	g/L
Hydrophilidae	Berosus	sp.	beetle		Fringe wetlands		0.15	0.12	0.19	g/L
Hydrophilidae	Enochrus	sp.	beetle		Fringe wetlands	BRB	0.24	0.19	0.33	g/L
Hydrophilidae	Tropisternus	sp.	beetle		Fringe wetlands	BRB	0.24	0.19	0.33	g/L
Scirtidae	Cyphon	sp.	beetle		Fringe wetlands		0.21	0.14	0.32	g/L
Chironomidae	(Chironomidae)	sp.	midge					0.30	0.60	
Chironomidae	(Diptera/Chironomidae)	sp.	midge					0.40	2.20	
Chironomidae	Chironomus	sp.	midge		Fringe wetlands	GB, BRB	0.26	0.23	0.30	g/L
Chironomidae	Subfam: Orthocladiinae	sp.	midge		Fringe wetlands	BRB	0.20	0.17	0.25	g/L
Chironomidae	Subfam: Tanypodinae	sp.	midge		Fringe wetlands	GB, BRB	0.18	0.15	0.23	g/L
Culicidae	(Diptera/Culicidae)	sp.	biting midge		Fringe wetlands	GB, BRB	0.35	0.28	0.46	g/L
Ephydridae	(Diptera/Ephydridae)	sp.	midge			GB	2.2-13.6			
Ephydridae	Ephydra	sp.	brine fly		Fringe wetlands	BRB	0.20	0.16	0.25	g/L
Ephydridae	Ephydra	sp.	brine fly	adult		GB, BRB		0.30	16.00	
Ephydridae	Ephydra	sp.	brine fly	pupae		GB, BRB		0.30	16.00	
Ephydridae	Ephydra	sp.	brine fly	larvae		GB, BRB		0.30	16.00	
Ephydridae	(Diptera/Ephydridae)	sp.	brine fly					1.00	1.00	
Orthocladiinae	(Diptera/Orthocladiinae)	sp.	midge					0.30	0.60	
Sciomyzidae	Sepedon	sp.	fly		Fringe wetlands		0.21	0.14	0.32	g/L
Stratiomyidae	Caloparyphus	sp.	fly		Fringe wetlands	BRB	0.27	0.23	0.32	g/L
Syrphidae	Eristalis	sp.	fly		Fringe wetlands		0.15	0.12	0.19	g/L
Tabanidae	Chrysops	sp.	fly		Fringe wetlands	BRB	0.37	0.28	0.53	g/L
Tanypodinae	(Diptera/Tanypodinae)	sp.	midge					0.30	0.60	
Tipulidae	Holorusia	sp.	cranefly		Fringe wetlands		0.20	0.12	0.35	g/L

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Baetidae	Callibaetis	sp.	mayfly		Fringe wetlands	BRB	0.27	0.23	0.32	g/L
Corixidae	(Corixidae)	sp.	corixid					0.40	1.00	
Corixidae	(Corixidae)	sp.	corixid	adult		GB, BRB		0.30	11.00	
Corixidae	Corisella	decolor (Uhler)	corixid					0.30	0.30	
Corixidae	Corisella	sp.	boatmen		Fringe wetlands	BRB	0.23	0.20	0.25	g/L
Corixidae	Trichocorixa	sp.	corixid					0.30	1.00	g/L
Corixidae	Trichocorixa	verticalis	corixid			GB, BRB	7.70	1.00	16.00	g/L
Corixidae	Trichocorixa	verticalis	waterboatman			GB, BRB		0.00	9.00	g/L
Corixidae	Trichocorixa	verticalis (Fieber)	corixid	adults, juveniles		GB		0.40	12.80	
Notonectidae	Buenoa	sp.	backswimmer		Fringe wetlands	GB, BRB	0.34	0.28	0.43	g/L
Aeshnidae	Aeshna	sp.	dragonfly		Fringe wetlands	BRB	0.27	0.23	0.36	g/L
Coenagrionidae	Ischnura	sp.	damselfly		Fringe wetlands	BRB	0.30	0.25	0.40	g/L
Libellulidae	Erythemis	sp.	dragonfly		Fringe wetlands	BRB	0.21	0.18	0.25	g/L
Brine Shrimp										
Artemiidae	Artemia	franciscana	brine shrimp				7.70	2.00	10.20	g/L
Artemiidae	Artemia	franciscana	brine shrimp	adult		GB, BRB		0.30	16.00	g/L
Artemiidae	Artemia	franciscana	brine shrimp	juvenile		GB, BRB		0.30	16.00	g/L
Artemiidae	Artemia	franciscana	brine shrimp	nauplii		GB, BRB		0.30	16.00	g/L
Artemiidae	Artemia	franciscana	brine shrimp	cysts		GB, BRB		0.30	11.00	
Artemiidae	Artemia	franciscana	brine shrimp	eggs		GB, BRB		0.30	11.00	
Artemiidae	Artemia	franciscana Kellogg	brine shrimp	adults, juveniles		GB		0.50	13.60	
Mollusk										
Lymnaeidae	Stagnicola	sp.	snail		Fringe wetlands	GB, BRB	0.23	0.20	0.26	g/L
Physidae	Physella	sp.	snail		Fringe wetlands	GB, BRB	0.19	0.17	0.23	g/L
Planorbidae	Gyraulus	sp.	snail		Fringe wetlands	GB, BRB	0.23	0.18	0.28	g/L
(Gastropoda)	(Gastropoda)	sp.	snail					0.30	0.60	
Zooplankton										

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
Bosminidae	Bosmina	sp.	cladoceran					0.50	10.00	
Moinidae	Moina	sp.	cladoceran			GB		0.40	15.20	
Moinidae	Moina	sp.	cladoceran	adult		GB, BRB		0.30	4.60	
Moinidae	Moina	macrocarpa Straus	cladoceran			GB		0.10	8.00	
Chydoridae	Alona	sp.	cladoceran					0.30	1.00	
Chydoridae	Chydorus	sphaericus (O.F.M.)	cladoceran					0.50	0.50	
Chydoridae	Pleuroxus	sp.	cladoceran					0.10	0.30	
Chydoridae	Pleuroxus	striatus Schoedler	cladoceran					0.10	0.30	
Daphniidae	Ceriodaphinia	quadrangula	cladoceran					0.10	0.50	
Daphniidae	Daphnia	dentifera (Sars)	cladoceran					0.40	8.30	
Daphniidae	Daphnia	pulex Leydig	cladoceran					0.50	0.50	
Daphniidae	Daphnia	sp.	cladoceran					0.30	1.00	
Daphniidae	Simocephalus	vetulus (O.F.M.)	cladoceran					0.20	0.50	
	(Ostracoda)	sp.	ostracod					0.30	2.80	
	(Ostracoda)	sp.	ostracod	adult				0.30	3.60	
Diaptomidae	Diaptomus	connexus	copepod			GB			9.35	g/L
Diaptomidae	Leptodiaptomus	connexus Light	copepod	adults, juveniles		GB		0.10	12.60	
	(Calanoida)	sp.	copepod	adult		GB, BRB		0.30	5.00	
	(Calanoida)	unidentifed species	copepod					4.00	10.00	g/L
Cyclopidae	Eucyclops	agilis (Koch)	copepod	adults, juveniles				0.30	5.90	
	(Cyclopoida)	sp.	copepod			GB		0.30	1.00	
	(Cyclopoida)	sp.	copepod	adult		GB, BRB		0.30	3.80	g/L
	(Cyclopoida)	unidentifed	copepod					1.10	15.20	g/L

Taxonomic Identification and Life Cycle					Location		Salinity Ranges (%)			
Family	**Genus (Order/Family)**	**Species**	**Common Name**	**Life Cycle**	**Sampling Location**	**Other Bays**	**@ sampling event**	**min**	**max**	**Converted**
		species								
Canthocamptidae	Cletocamptus	albuquerque nsis	copepod			GB		1.10	16.00	g/L
Harpacticoid	Cletocamptus	sp.	copepod	adult, Juvenile		GB		1.50	12.60	
	(Harpacticoida)	sp.	copepod					0.30	0.50	
	(Harpacticoida)	sp.	copepod	adult				0.30	11.00	
Brachionidae	Brachionus	plicatilis (O.F.M.)	rotifer			GB		0.30	14.00	
Brachionidae	Notholca	acuminate Ehrenberg	rotifer					2.50	2.50	
Other										
Glenodiniaceae	Glenodinium	sp.	dinoflagellate			GB		1.10	16.00	g/L
Erpobdellidae	Erpobdella	sp.	leech		Fringe wetlands	GB	0.17	0.13	0.25	g/L
Naididae	(Naididae)	sp.	worm		Fringe wetlands		0.08	0.08	0.10	g/L
Glossiphoniidae	Helobdella	stagnalis	leech		Fringe wetlands	BRB	0.20	0.10	0.35	g/L
Gammaridae	Gammerus	sp.	scud					0.40	0.60	
Hyalellidae	Hyalella	azteca	scud		Fringe wetlands	GB, BRB	0.34	0.27	0.45	g/L
Asellidae	Caecidotea	sp.	aquatic sowbug		Fringe wetlands	GB	0.16	0.10	0.25	g/L
	(Subphylum: Turbellaria)	sp.	flatworm		Fringe wetlands		0.13	0.10	0.13	g/L

Table 9. Vascular Plants observed in the Great Salt Lake Ecosystem

Taxanomic Identification			Location					Salinity Ranges (%)			
Genus	**Species**	**Common Name**	**Sampling Location**	**BRB**	**FB**	**GB**	**WS**	**@ sampling event**	**min**	**max**	**Converted**
Lemna	minor	common duckweed	Fringe Wetland	x	x			0.17	0.15	0.21	g/L
Carex	praegracilis	clustered field sedge	Fringe Wetland		x			0.08	0.08	0.10	g/L
Eleocharis	palustris	common spikerush	Emergent wetland habitat	x			x	No salinity information reported			
Eleocharis	palustris	common spikerush	Fringe Wetland	x	x			0.20	0.16	0.25	g/L
Schoenoplectus	acutus	hard stem bulrush	Emergent wetland habitat	x			x	0.10		0.22	mmhos/cm
Schoenoplectus	americanus	Olney's three square bulrush	Emergent wetland habitat	x			x	0.10	0.34-0.45	0.45	mmhos/cm
Schoenoplectus	maritimus	alkalai bulrush	Emergent wetland habitat	x			x	0.12			mmhos/cm
Schoenoplectus	acutus	hardstem bulrush	Fringe Wetland	x				0.23	0.23	0.23	g/L
Schoenoplectus	americanus	chairmaker's bulrush	Fringe Wetland	x	x			0.25	0.21	0.33	g/L
Schoenoplectus	maritimus	cosmopolitan bulrush	Fringe Wetland	x	x			0.19	0.15	0.25	g/L
Alopecurus	arundinaceus	Creeping meadow foxtail	Fringe Wetland		x			0.08	0.08	0.10	g/L
Bromus	tectorum	cheatgrass	Fringe Wetland			x		0.25	0.25	0.25	g/L
Distichlis	spicata	salt grass	Fringe Wetland	x	x	x		0.25	0.21	0.31	g/L
Distichlis	spicata	salt grass	Emergent wetland habitat	x			x	0.19	0.45-0.57	0.87	mmhos/cm
Hordeum	jubatum	foxtail barley	Emergent wetland habitat	x			x	No salinity information reported			
Hordeum	jubatum	foxtail barley	Fringe Wetland	x	x	x		0.27	0.23	0.34	g/L
Phalaris	arundinaceae	reed canarygrass	Fringe Wetland		x			0.10	0.10	0.10	g/L
Phragmites	australis	common reed	Emergent wetland habitat	x			x	0.74		0.80	mmhos/cm
Phragmites	australis	common reed	Fringe Wetland	x	x	x		0.25	0.21	0.30	g/L
Poa	palustris	fowl bluegrass	Fringe Wetland		x			0.14	0.10	0.23	g/L
Polypogon	monspeliensis	annual rabbitsfoot grass	Fringe Wetland	x	x			0.31	0.25	0.41	g/L
Thinopyrum	intermedium	intermediate wheatgrass	Fringe Wetland		x			0.20	0.10	0.35	g/L

Taxonomic Identification			Location					Salinity Ranges (%)			
Genus	**Species**	**Common Name**	**Sampling Location**	**BRB**	**FB**	**GB**	**WS**	**@ sampling event**	**min**	**max**	**Converted**
Unknown	Grass	Unk Grass	Fringe Wetland	x	x			0.41	0.33	0.55	g/L
Juncus	arcticus	artic rush	Emergent wetland habitat	x			x	No salinity information reported			
Juncus	arcticus	arctic rush	Fringe Wetland		x			0.08	0.08	0.10	g/L
Potamogeton	crispus	curly pondweed	Fringe Wetland		x			0.08	0.08	0.10	g/L
Stuckenia	filiformis	fine leaf pondweed	Open water wetland habitat	x			x	0.86		1.84	mmhos/cm
Stuckenia	pectinata	sago pondweed	Open water wetland habitat	x			x	0.12			mmhos/cm
Stuckenia	pectinata	sago pondweed	Fringe Wetland	x	x			0.19	0.16	0.25	g/L
Typha	sp.	cattail	Emergent wetland habitat	x			x	0.52			mmhos/cm
Typha	domingensis	southern cattail	Fringe Wetland	x	x			0.20	0.17	0.25	g/L
Typha	latifolia	broadleaf cattail	Fringe Wetland	x	x			0.17	0.15	0.20	g/L
Bidens	cernua	nodding beggartick	Fringe Wetland		x			0.16	0.10	0.23	g/L
Cirsium	foliosum	elk thistle	Fringe Wetland		x			0.14	0.13	0.14	g/L
Grindellia	squarosa	curlycup gumweed	Fringe Wetland		x			0.20	0.10	0.35	g/L
Lactuca	serriola	prickly lettuce	Fringe Wetland	x	x	x		0.32	0.26	0.42	g/L
Solidago	canadensis	Canada goldenrod	Fringe Wetland		x			0.14	0.13	0.14	g/L
Cardaria	draba	whitetop	Fringe Wetland	x	x	x		0.23	0.20	0.28	g/L
Lepidium	perfoliatum	clasping pepperweed	Fringe Wetland			x		0.25	0.25	0.25	g/L
Nasturtium	officinale	watercress	Fringe Wetland		x			0.20	0.10	0.35	g/L
Sisymbrium	altissimum	tall tumblemustard	Fringe Wetland			x		0.25	0.25	0.25	g/L
Unknown mustart		Unknown mustart	Fringe Wetland		x			0.10	0.10	0.10	g/L
Spergularia	maritima	media sandspurry	Fringe Wetland		x			0.20	0.10	0.35	g/L
Atriplex	sp.	saltbush	Emergent wetland habitat	x			x	No salinity information reported			
Atriplex	micrantha	twoscale saltbush	Fringe Wetland	x	x	x		0.35	0.30	0.41	g/L
Bassia	scoparia	kochia	Fringe Wetland	x	x	x		0.38	0.30	0.52	g/L
Chenopodium	album	lambsquarters	Fringe Wetland	x				0.23	0.23	0.23	g/L
Sarcocornia	utahensis	Utah swampfire	Fringe Wetland	x	x	x		0.30	0.25	0.38	g/L

Taxanomic Identification			Location					Salinity Ranges (%)			
Genus	**Species**	**Common Name**	**Sampling Location**	**BRB**	**FB**	**GB**	**WS**	**@ sampling event**	**min**	**max**	**Converted**
Suaeda	calceoliformis	Pursh seepweed	Fringe Wetland	x	x	x		0.30	0.25	0.38	g/L
Medicago	sativa	alfalfa	Fringe Wetland		x			0.08	0.08	0.10	g/L
Epilobium	ciliatum	fringed willowherb	Fringe Wetland		x			0.10	0.10	0.10	g/L
Ceratophyllum	demersum	coon's tail	Fringe Wetland	x				0.31	0.30	0.33	g/L
Polygonum	aviculare	prostrate knotweed	Fringe Wetland		x			0.10	0.10	0.10	g/L
Polygonum	lapathifolium	curlytop knotweed	Fringe Wetland		x			0.10	0.10	0.10	g/L
Polygonum	persicaria	spotted ladysthumb	Fringe Wetland		x			0.10	0.10	0.10	g/L
Polypogon	monspeliensis	rabbit foot grass	Emergent wetland habitat	x			x	No salinity information reported			
Rumex	crispus	curly dock	Fringe Wetland	x	x			0.18	0.17	0.18	g/L
Ranunculus	cymbalaria	alkali buttercup	Fringe Wetland	x				0.70	0.55	0.95	g/L
Veronica	anagallis-aquatica	water speedwell	Fringe Wetland		x			0.14	0.13	0.14	g/L
Convolvulus	arvensis	field bindweed	Fringe Wetland		x			0.08	0.08	0.10	g/L
Solanum	dulcamara	climbing nightshade	Fringe Wetland		x			0.08	0.08	0.10	g/L
Tamarix	chinensis	five-stamen tamarisk	Fringe Wetland	x		x		0.39	0.35	0.48	g/L
Asclepias	speciosa	showy milkweed	Emergent wetland habitat	x			x	No salinity information reported			
Ruppia	maritima	widgeon grass	Open water wetland habitat	x			x	0.86		1.84	mmhos/cm
Salix	sp.	willows	Emergent wetland habitat	x			x	No salinity information reported			
Xanthium	strumarium	cocklebur	Emergent wetland habitat	x			x	No salinity information reported			
Zannichellia	palustris	horned pondweed	Open water wetland habitat	x			x		1.89		mmhos/cm

Table 10. Phytoplankton observed in Great Salt Lake

Taxonomic Identification				Location				Salinity Ranges (%)				
Family	**Genus**	**Species**	**Common Name**	**FB**	**GB**	**Gun**	**No Specific Bay**	**@ sampling event**	**min**	**avg/optimal**	**max**	**Converted**
Bacillariaceae	Nitzschia	acicularis	diatom	x				No salinity information reported				
Bacillariaceae	Nitzschia	epithemoides	diatom	x	x			No salinity information reported				
Bacillariaceae	Nitzschia	fonticola	diatom	x	x				1.1		16.0	g/L
Bacillariaceae	Nitzschia	palea	diatom	x					1.1		10.0	g/L
Chaetocerotaceae	Chaetoceros	muelleri	diatom	x				No salinity information reported				
Chaetocerotaceae	Chaetoceros	sp.	diatom	x					1.1		10.0	g/L
Cymbellaceae	Cymbella	sp.	diatom				x	No salinity information reported				
Naviculaceae	Navicula	graciloides	diatom	x	x				1.1		16.0	g/L
Naviculaceae	Navicula	lanceolata	diatom	x	x				4.0		16.0	g/L
Naviculaceae	Navicula	sp.	diatom	x	x			No salinity information reported				
Naviculaceae	Navicula	sp. (45-100 um)	diatom	x	x				1.1		16.0	g/L
Naviculaceae	Navicula	tripunctata	diatom	x	x				4.0		16.0	g/L
Naviculaceae	Navicula	tripunctata var schizonemoides	diatom	x	x				4.0		16.0	g/L
Phaeodactylaceae	Phaeodactylum	sp.	diatom	x					4.0		10.0	g/L
Entomoneidaceae	Entomoneis	pulchra(?)	diatom	x	x			No salinity information reported				
Rhopalodiaceae	Rhopalodia	musculus	diatom	x	x				13.0		16.0	g/L
Surirellaceae	Surirella	striatula	diatom	x	x			No salinity information reported				
Catenulaceae	Amphora	coffeaeformis	diatom	x	x				1.1		16.0	g/L
Catenulaceae	Amphora	delicatissima	diatom	x	x				4.0		16.0	g/L
Catenulaceae	Amphora	sp.	diatom	x	x				1.1		16.0	g/L
Bidulphiaceae	Biddulphia	levis	diatom	x	x			No salinity information reported				
Ulnariaceae	Synedra	sp.	diatom	x					1.1		5.1	g/L
Stephanodiscaeae	Cyclotella	meneghiniana	diatom	x					7.0	12.0	17.0	g/L
Stephanodiscaeae	Cyclotella	sp.	diatom	x					1.1		10.0	g/L
	Unidentified bacillariophyta	sp.	diatom		x				8.2		17.6	g/L
Chlamydomonadaceae	Carteria	sp.	green algae	x	x				1.1		16.0	g/L

Taxonomic Identification				Location				Salinity Ranges (%)				
Family	**Genus**	**Species**	**Common Name**	**FB**	**GB**	**Gun**	**No Specific Bay**	**@ sampling event**	**min**	**avg/optimal**	**max**	**Converted**
Chlamydomonadaceae	Chlamydomonas	sp.	green algae				x	No salinity information reported				
Chlamydomonadaceae	Sphaerellopsis	gloeocystiformis	green algae	x				No salinity information reported				
Chlamydomonadaceae	Sphaerellopsis	sp.	green algae	x					4.0		10.0	g/L
Dunaliellaceae	Dunaliella	salina	green algae	x	x				3.0	12.0	35.0	g/L
Dunaliellaceae	Dunaliella	salina	green algae		x	x		No salinity information reported				
Dunaliellaceae	Dunaliella	sp.	green algae	x					1.2		17.0	g/L
Dunaliellaceae	Dunaliella	viridis	green algae	x	x					7.4	23.2	g/L
Dunaliellaceae	Dunaliella	viridis	green algae		x	x		No salinity information reported				
Dunaliellaceae	Spermatozopsis	exultans(?)	green algae	x				No salinity information reported				
Dunaliellaceae	Spermatozopsis	sp.	green algae	x	x				1.1		15.2	g/L
Tetrasporaceae	Tetraspora	lubrica var. lacunosa	green algae				x	No salinity information reported				
Treubariaceae	Treubaria	triappendiculata	green algae	x					4.0		10.0	g/L
Hydrodictyaceae	Pediastrum	sp.	green algae	x					1.1		5.1	g/L
Scenedesmaceae	Scenedesmus	sp	green algae	x					1.1		5.1	g/L
Oocystaceae	Oocystis	parva	green algae	x	x				1.1		16.0	g/L
Ulvaceae	Enteromorpha	tubulosa	green algae				x	No salinity information reported				
	Unidentified chlorophyta	sp.	green algae		x				8.2	12.4	17.6	g/L
Cryptomonadaceae	Cryptomonas	sp.	golden algae	x	x				1.1		15.2	g/L
	Unidentified chrysophyte	sp.	golden algae	x	x				1.1		16.0	g/L
Spirulinaceae	Spirulina	sp.	cyanobacteria	x	x				1.1		16.0	g/L
Chroococcaceae	Coccochloris	elebans	cyanobacteria		x					24.0		
Cyanobacteriaceae	Aphanothece	packardii	cyanobacteria				x	No salinity information reported				
Cyanobacteriaceae	Aphanothece	Utahensis	cyanobacteria				x	No salinity information reported				
Entophysalidaceae	Entophysalis	rivularis	cyanobacteria				x	No salinity information reported				
Microcystaceae	Microcystis	packardii	cyanobacteria				x	No salinity information reported				
Aphanizomenonaceae	Nodularia	spumigena	cyanobacteria	x	x			1.5	1.1		20.0	g/L
Nostocaceae	Nodularia	sp.	cyanobacteria	x					4.0		10.0	g/L

Taxonomic Identification				Location				Salinity Ranges (%)				
Family	**Genus**	**Species**	**Common Name**	**FB**	**GB**	**Gun**	**No Specific Bay**	**@ sampling event**	**min**	**avg/optimal**	**max**	**Converted**
Oscillatoriaceae	Oscillatoria	tenuis var. natans	filamentous blue-green				x	No salinity information reported				
Oscillatoriaceae	Oscillatoria	tenuis var. tergestina	filamentous blue-green				x	No salinity information reported				
Rivulariaceae	Dichothrix	utahensis	cyanobacteria				x	No salinity information reported				
Microcoleaceae	Microcoleus	lynghyaceus	cyanobacteria	x	x			No salinity information reported				
Microcoleaceae	Microcoleus	sp.	cyanobacteria	x	x				1.1		16.0	g/L
Microcystaceae	Polycystis	packardii	cyanobacteria				x	No salinity information reported				
Pseudanabaenaceae	Pseudanabaena	sp.	cyanobacteria	x	x				1.1		16.0	g/L
	Unidentified cyanophyta	sp.	cyanobacteria		x				8.2	11.1	17.6	g/L

Table 11. Laboratory studies and mesocosm experiments conducted with GSL species

Family	Genus	Species	Common Name	Life stage	min	avg/optimal	max	Converted	References
Aquatic Insect									
Ephydridae	Ephydra	sp.	brine fly	pupae	2.5	5.75	9		Belovsky unpublished studies
Ephydridae	Ephydra	sp.	brine fly	larvae	2.5	5.75	13.6		Belovsky unpublished studies
Ephydridae	Ephydra	hians	brine fly				13.58	g/L	Jones and Stokes Associates, 1993
Ephydridae	Ephydra	hians	brine fly	larvae	2.5	6	13.6	g/L	Herbst 1988
Corixidae	Trichocorixa	verticalis	waterboatman		0	4.5	8.49	g/L	Mellison 2000
Corixidae	Trichocorixa	verticalis	corixid	egg, nymph and adult	0	0-10	30		Herbst 2006, Kelts 1979
Brine Shrimp									
Artemiidae	Artemia	franciscana	brine shrimp	adult	1	6.5	12		Belovsky unpublished studies
Artemiidae	Artemia	franciscana	brine shrimp	nauplii	1	6.5	12		Belovsky unpublished studies
Artemiidae	Artemia	franciscana	brine shrimp	juvenile	1	6.5	12		Belovsky unpublished studies
Artemiidae	Artemia	franciscana	brine shrimp			11.46		g/L	Brix et al., 2002
Phytoplankton									
Chlamydomonadaceae	Carteria	sp.	green algae		5.15		9.36	g/L	Marcarelli et al., 2006
Chroococcaceae	Coccochloris	sp.	cyanobacteria		2.98	4.40	11.93	g/L	Marcarelli et al., 2003 (mesocosm study)
Cyanobacteriaceae	Aphanothece	sp.	cyanobacteria		1.14		11.93	g/L	Marcarelli et al., 2003 (mesocosm study)
Microcoleaceae	Microcoleus	sp.	cyanobacteria		5.15	5.79	11.93	g/L	Marcarelli et al., 2003 (mesocosm study); Marcarelli et al., 2006
Dunaliellaceae	Dunaliella	salina	green algae		5.15		9.36	g/L	Marcarelli et al., 2006
Dunaliellaceae	Dunaliella	viridis	green algae		5.15		9.36	g/L	Marcarelli et al., 2006
Oocystaceae	Oocystis	sp.	green algae		5.15		9.36	g/L	Marcarelli et al., 2006
Zooplankton									
Bosminidae	Bosmina	coregoni	cladoceran	adult			24		Ellis and Macisaac, 2009
Cercopagididae	Bythotrephes	longimanus	cladoceran	adult			24		Ellis and Macisaac, 2009
Cercopagididae	Cercopagis	pengoi	cladoceran	adult			24		Ellis and Macisaac, 2009

Brachionidae	Brachionus	plicatilis	rotifer		5	17	60		Lowe et al., 2007
Other									
			Bioherm (Cyano & Diatom)	bioherm	2.5	8.75	15		Anderson and Belovsky unpublished lab studies

Table 12. Historic Studies of GSL

Family	Genus	Species	Common Name	Location	Notes	Reference
Aquatic Insect						
Ceratopogonidae	Culicoides	sp.	biting gnat	Not Bay specific		Rawley, E.V., 1980
Ceratopogonidae	Leptoconops	kerteszi	biting gnat	Not Bay specific		Rawley, E.V., 1980
Chironomidae	Tendipes	sp.	nonbiting gnat	Not Bay specific		Rawley, E.V., 1980
Culicidae	Aedes	dorsalis	mosquito	Not Bay specific		Rawley, E.V., 1980
Culicidae	Culex	arythrothorax	mosquito	Not Bay specific		Rawley, E.V., 1980
Culicidae	Culex	tarsalis	mosquito	Not Bay specific		Rawley, E.V., 1980
Culicidae	Culistea	inornata	mosquito	Not Bay specific		Rawley, E.V., 1980
Tabanidae	Atylotus	incisuralis	fly	Not Bay specific		Rawley, E.V., 1980
Tabanidae	Chrysops	aestuan	fly	Not Bay specific	Genera sampled in BRB and FB	Rawley, E.V., 1980
Tabanidae	Chrysops	discalis	deer fly	Not Bay specific	Genera sampled in BRB and FB	Rawley, E.V., 1980
Tabanidae	Chrysops	fulvaster	fly	Not Bay specific	Genera sampled in BRB and FB	Rawley, E.V., 1980
Tabanidae	Hybomitra	sonornensis	horse fly	Not Bay specific		Rawley, E.V., 1980
Tabanidae	Tabanus	productus	midge	Not Bay specific		Rawley, E.V., 1980
Tabanidae	Tabanus	punctifer	midge	Not Bay specific		Rawley, E.V., 1980
Tabanidae	Tabanus	similis	midge	Not Bay specific		Rawley, E.V., 1980
Brine Shrimp						
Artemiidae	Artemia	gracilis	brine shrimp	Not Bay specific		Stephens 1974 (Jensen 1918)
Artemiidae	Artemia	salina	brine shrimp	Not Bay specific		Stephens 1974 (Quinn 1940; Woodbury 1948)
Other						
Amoebidae	Amoeba	(linax)	amoeba	Not Bay specific		Rawley, E.V., 1980
Amoebidae	Amoeba	flowersii	amoeba	Not Bay specific		Rawley, E.V., 1980; Stephens 1974 (Vorhies 1917; Kirkpatrick 1934; Woodbury 1936; Jones 1944)
Euplotidae	Euplotes	sp.	ciliate	Gilbert Bay	Collected from marshes	Stephens 1974 (Evans and Thompson 1964; Reddy 1971); Rawley, E.V., 1980
Euplotidae	Euplotes sp.	parsalinus	ciliate	Not Bay specific		Stephens 1974 (Evans and Thompson 1964; Reddy 1971)
Cyclidiidae	Cristigera	sp.	ciliate	Not Bay specific		Rawley, E.V., 1980 (Evans, 1960)

Family	Genus	Species	Common Name	Location	Notes	Reference
Cyclidiidae	Cyclidium	sp.	ciliate	Not Bay specific		Stephens 1974 (Evans 1960)
Urostylidae	Uroleptus	packii	ciliate	Not Bay specific		Pack, 1919; Jaschof and Schwartz, 1961; Post et al., 1983
Pseudocohnilembidae	Pseudocohnilernbus	persalinus	ciliate	Not Bay specific		Stephens 1974 (Evans 1960; Evans and Thompson 1964)
Podophryidae	Podophrya	sp.	ciliate	Not Bay specific		Stephens 1974 (Evans 1960)
Prorodontidae	Prorodon	utahensis	ciliate	Not Bay specific		Pack, 1919
Euglenaceae	Euglena	sp.	euglena	Not Bay specific		Rawley, E.V., 1980 (Vorhies, 1917)
Euglenaceae	Euglena	chamberlini	euglena	Not Bay specific		Stephens 1974 (Vorhies 1917; Kirkpatrick 1934; Jones 1944)
	Chilophyra	utahensis	protozoan	Not Bay specific		Felix, E.A., and S. R. Rushforth, 1980 (Pack, 1919); Stephens 1974 (Evans 1960)
	Crystigera	sp.	protozoan	Not Bay specific		Rawley, E.V., 1980; Stephens 1974 (Evans, 1960)
	Oikomonas	sp.	protozoan	Not Bay specific		Stephens 1974 (Evans 1960)
Pachycormidae	Urolepus	packii	protozoan	Not Bay specific		Felix, E.A., and S. R. Rushforth, 1980 (Pack, 1919)
Phytoplankton						
Spirulinaceae	Spirulina	major	cyanobacteria	Farmington Bay		Felix, E.A., and S. R. Rushforth, 1980
Chroococcaceae	Coccochloris	clabens	cyanobacteria	Not Bay specific		Stephens 1974 (Flowers and Evans 1960)
Vascular Plant						
Characeae	Chara	contraria	muskgrass	Not Bay specific		Stephens 1974 (Tilden 1898)

Appendix C
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