Definition and Assessment of Great Salt Lake Health

Prepared for

Great Salt Lake Advisory Council

Prepared by

SWCA Environmental Consultants

Applied Conservation

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DEFINITION AND ASSESSMENT OF GREAT SALT LAKE HEALTH

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Prepared by

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EXECUTIVE SUMMARY

Great Salt Lake is one of the most important and least understood ecosystems in Utah, and possibly North America. In its current form, it is of worldwide importance for migratory bird populations, and its shorelines represent some of the premier wetland areas in the United States. It is home to the most significant (largest) populations of *Artemia franciscana* (brine shrimp) in the Western hemisphere. It is influenced by an array of natural and human factors resulting in a dynamic and complex web of natural habitats and human uses. This project, commissioned by the Great Salt Lake Advisory Council, comprises a definition of health, an assessment of current health, and an identification of critical future stresses to Great Salt Lake health.

In the context of this project, the term *health* refers to ecological health, in particular how well the lake functions to support significant bird populations, brine shrimp, and stromatolitic structures. Human uses of the lake for public health, recreation, minerals extraction, and brine shrimp cyst harvest were not considered. Ecological health was based on the lake's current physical form, including dikes and causeways that segment the lake into four bays and impounded wetlands created to increase habitat for waterfowl and other birds. This project does not attempt to define health as the “natural” pre-settlement condition of the lake, because this condition is not feasibly attainable and it is unknown to what extent it would support current populations of significant species. The project does not form any policy or management recommendations. Rather, the information provided in this document is objective, based on science, and is intended to be used to advise government officials on the sustainable use, protection, and development of Great Salt Lake.

The definition of health was developed using the Conservation Action Planning (CAP) framework, drawing on the scientific expertise of lake researchers. The project's Science Panel consisted of a group of prominent scientists with extensive experience and knowledge of the varied Great Salt Lake habitats and species. The Panel chose to define health for eight separate ecological targets in and around Great Salt Lake up to an elevation of 4,218 feet (1,286 meters). The eight ecological targets are system-wide lake and wetlands, open water of bays, unimpounded marsh complex, impounded wetlands, mudflats and playas, isolated island habitat for breeding birds, alkali knolls, and adjoining grasslands and agricultural lands. Collectively, these eight ecological targets capture the full biological diversity of the lake ecosystem. Moreover, these targets support an array of significant species, including brine shrimp, migratory shorebirds, waterfowl, colonial nesting waterbirds, and other birds by providing diverse foraging, breeding, resting, and refuge habitat as well as distinctive habitats for reef-like stromatolitic structures. Health is defined separately for each ecological target found within each of the four distinct bays of Great Salt Lake: Gilbert Bay, Farmington Bay, Bear River Bay, and Gunnison Bay. Because salinities vary greatly between these bays, they support very different ecological communities, ranging from a strictly microbial community in hypersaline Gunnison Bay, brine shrimp and brine flies in Gilbert bay, to gnats (midges) and fish in fresher portions of Farmington and Bear River bays. In turn, the different bays support varying communities of birds.

Based on the definition of health developed through this project, most ecological targets surrounding Great Salt Lake are in good health; although, some of the ecological targets had a high level of uncertainty due to insufficient data and could not be ranked. Specifically, current health rankings for open water of bays and unimpounded marsh complex have a high degree of uncertainty. Several habitats are in poor or fair health, including alkali knolls around Bear River, Farmington, and Gilbert bays, the impounded wetlands around Farmington Bay, and the open water of Gunnison Bay. Of the four bays, Farmington Bay was the least healthy, with two ecological targets that were rated in poor condition (Figure ES1).

Although the lake's current health is relatively good, a number of future stresses are looming, which could degrade its condition. Many targets faced high to very high ranked stresses. The Panel ranked future stresses to each ecological target. In general, the three highest ranked stresses to Great Salt Lake ecosystems were as follows:

- Reduced lake levels that could cause myriad impacts on the ecosystem, including changes in salinity and increased vulnerability to predators of nesting birds on isolated islands, and stress to the brine shrimp population in Gilbert Bay
- Increased *Phragmites* and other undesirable plant cover throughout the habitats surrounding the lake and especially around Farmington Bay, also a consequence of reduced lake levels
- Additional permanent loss of alkali knolls, especially in Farmington and Bear River bays where there has already been significant habitat loss

In some cases, these stresses are projected to severely threaten the integrity of Great Salt Lake habitats and the ability of migratory bird species to use the lake ecosystem. In addition, additional loss of other habitats surrounding the lakes is of great concern because they support significant bird populations. There is also concern that increased water development and degraded water quality in the Great Salt Lake Basin could alter the hydrologic regime and delivery of high quality water necessary to support the health of unimpounded marsh complexes. Of all the bays, the habitats in and around Farmington Bay are clearly the most stressed followed by those in and around Bear River and Gilbert bays. Habitat surrounding Gunnison Bay are the least stressed. Overall stress to each bay is summarized in Figure ES1.

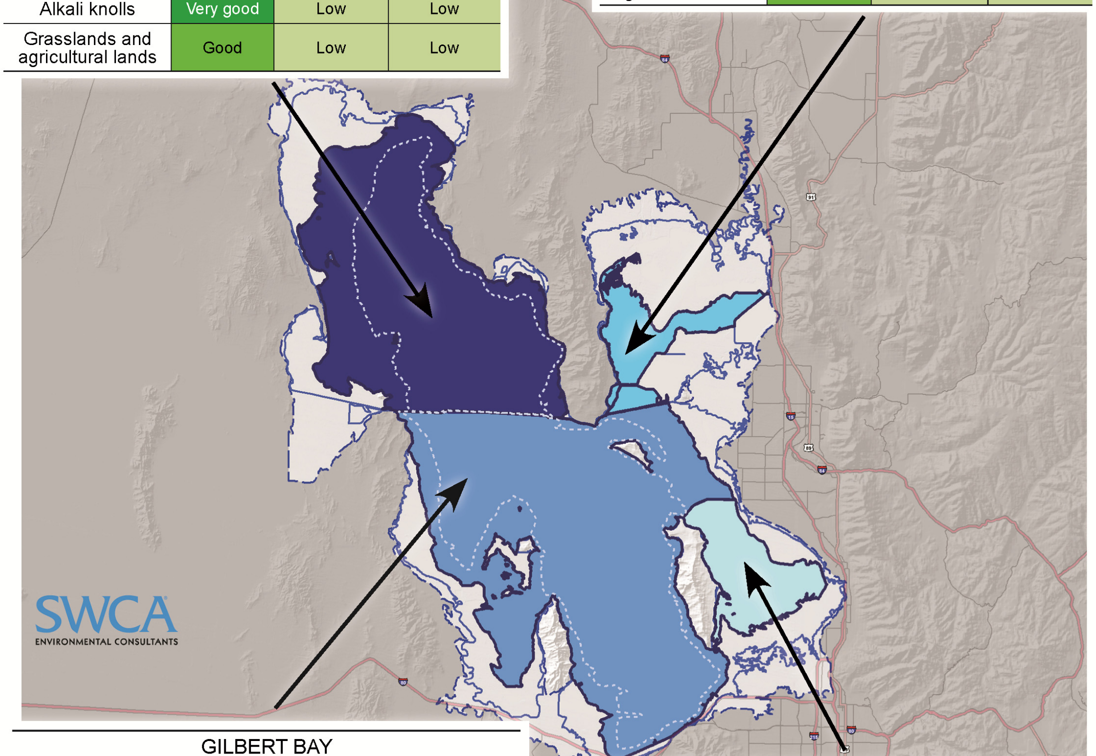
This project represents a first iteration of a definition and assessment of health for Great Salt Lake based on the best science available to the Panel as of December 2011. Ongoing research on the lake and its surrounding habitats will no doubt lead to the need to modify and improve the definition. The method used to define and assess health is based on the first several steps in the CAP process. The CAP workbook, delivered with this report, is set up to continue the process by identifying key sources of stress to the lake and developing effective strategies to protect and improve lake health. The CAP workbook will be most useful as a dynamic, adaptive management tool that is periodically updated by a body of active research scientists and used by lake managers in broad-scale lake planning, including future revisions of the Great Salt Lake Comprehensive Management Plan by the Division of Forestry, Fire, and State Lands.

GUNNISON BAY

Ecological Targets	Current Health	Health Uncertainty	Future Stress
Open water of bays	Not ranked	Very high	Low
Unimpounded marsh complex	Not ranked	High	Low
Impounded wetlands	Not ranked	Very high	Low
Mudflats and playas	Very good	Low	Low
Isolated island habitat for breeding birds	Good	Low	Very high
Alkali knolls	Very good	Low	Low
Grasslands and agricultural lands	Good	Low	Low

BEAR RIVER BAY

Ecological Targets	Current Health	Health Uncertainty	Future Stress
Open water of bays	Not ranked	Very high	High
Unimpounded marsh complex	Not ranked	High	Medium
Impounded wetlands	Good	Medium	Medium
Mudflats and playas	Good	Low	High
Alkali knolls	Poor	Low	High
Grasslands and agricultural lands	Good	Low	Low



GILBERT BAY

Ecological Targets	Current Health	Health Uncertainty	Future Stress
Open water of bays	Good	Medium	High
Unimpounded marsh complex	Not ranked	High	High
Impounded wetlands	Not ranked	Very high	Very high
Mudflats and playas	Good	Low	Medium
Isolated island habitat for breeding birds	Good	Low	Very high
Alkali knolls	Fair	Low	High
Grasslands and agricultural lands	Good	Low	High

FARMINGTON BAY

Ecological Target	Current Health	Health Uncertainty	Future Stress
Open water of bays	Not ranked	Very high	High
Unimpounded marsh complex	Not ranked	High	High
Impounded wetlands	Poor	Medium	Very high
Mudflats and playas	Good	Low	Very high
Alkali knolls	Poor	Low	Very high
Grasslands and agricultural lands	Good	Low	Medium

Figure ES1. Summary of Great Salt Lake current health, uncertainty, and future stress

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INTRODUCTION

Great Salt Lake is one of the most important and least understood ecosystems in Utah, and possibly North America. It is influenced by an array of natural and human factors resulting in a dynamic and complex web of natural habitats and human uses. The Great Salt Lake Advisory Council (the Council) is charged with advising Utah decision-makers on the sustainable use, protection, and development of Great Salt Lake and its resources. The Council seeks a scientific definition of a healthy lake to use as a benchmark in adaptive management, including assessing activities that affect the lake and expand planning efforts to consider the entire lake system. This project comprises a definition of health, an assessment of current health, and an identification of critical future stresses to Great Salt Lake health.

The definition of health for Great Salt Lake presented in this report was achieved through the Conservation Action Planning framework, drawing on the scientific expertise of lake researchers. The project does not form any policy or management recommendations. Rather, the information provided in this document is objective, based on science, and is intended to advise government officials on the sustainable use, protection, and development of Great Salt Lake.

In the context of this project, the term *health* refers to ecological health, in particular how well the lake functions to support significant bird populations, brine shrimp, and stromatolitic structures. Human uses of the lake for public health, recreation, minerals extraction, and brine shrimp cyst harvest were not considered. Ecological health was based on the lake's current physical form. The dikes and causeways that segment the lake into four unique bays are taken as historical physical modifications that have resulted in long-term changes to the lake ecosystem and its dynamics. Impounded wetlands are also physical modifications to the lake that have resulted in the creation of unique ecological communities. Great Salt Lake is of worldwide importance for migratory bird populations, and its shorelines represent some of the premier wetland areas in the United States. Thus, this definition of health is in the context of the current altered ecosystems and their current ecological importance to significant species. In this context, s*ignificant species* are keystone species, species of concern, and species with significant populations using the lake ecosystem.

The project does not attempt to define health as the “natural” pre-settlement condition of the lake, because this condition is not feasibly attainable and because it is unknown to what extent it would support current populations of significant species.

CONSERVATION ACTION PLANNING PROCESS

Conservation Action Planning (CAP) is a straightforward and proven approach for planning, implementing, and measuring success for large-scale conservation projects. A fundamental building block of CAP is a methodology to measure the health of ecosystems and species. CAP has been developed and refined over 20 years by The Nature Conservancy and others. The CAP process typically relies on facilitated workshops involving scientists who

- identify clearly defined ecological targets, including ecosystems and significant species;
- develop key ecological attributes that support the long-term health of the ecological targets, as well as measurable indicators of their health;
- rank the current health of the ecological targets;
- identify current and projected future stresses to the ecological targets and the sources of stress; and
- develop effective conservation strategies.

The core elements of the CAP framework described above were used for the project, excluding the ranking of future sources of stress and the development of conservation strategies. There are three major elements of the Great Salt Lake health project:

CAP Terminology

Ecological targets: The specific ecological communities, species, and other natural resources that we aim to conserve

Indicators: Measurable characteristics of the system for which a benchmark and goal can be identified

Indicator rating: A set of benchmarks that define the very good, good, fair, and poor categories for each indicator

Key ecological attributes: Those processes or characteristics that are critical to the long-term viability of ecological targets

Source: The primary cause of a stress

Stress: Something that destroys, degrades, or impairs conservation targets by impacting a key ecological attribute

1. **Ecological Targets: Ecosystems and Significant Species**. The habitats that comprise Great Salt Lake and its shoreline were identified, delineated, mapped, and described. These habitats (hereafter referred to as ecological targets) were stratified across the lake's four major bays. Within each ecological target for each bay, a set of significant species was also identified.

2. **Key Ecological Attributes, Indicators, and Ratings**
   a. Key Ecological Attributes. For each ecological target across all four bays, a set of key ecological attributes was identified. The key ecological attributes represent a parsimonious set of factors that largely account for the long-term viability or health of the ecological target and its species. The key attributes may include factors relating to *landscape context* (e.g., the ecological processes that sustain the ecological targets), *condition* (e.g., the composition and structure of the ecosystem), and *size* (e.g., the amount of habitat required to support the significant species).
   b. Indicators. For each key ecological attribute, an appropriate indicator was selected; the indicators reflect how the attributes were measured.
   c. Ratings. For each key attribute and indicator pair, the CAP's four-grade rating scale was used. A set of benchmarks defines the very good, good, fair, and poor categories for each indicator. Whenever possible, quantitative ratings were used, although well-defined qualitative benchmarks were used in some instances. This grading scale was then used to assess the current health of the ecological targets based on effects to significant species.

3. Stresses. Lastly, the potential future stresses to the ecological targets were identified, discussed, and ranked. Stresses are the "mirror images" of the key ecological attributes. In other words, a stress reflects a projected future impairment or degradation of a key ecological attribute. Stresses were ranked on two variables—their severity and the scope (geographic extent)—using CAP's four-grade scale of very high, high, medium, and low.

These three elements were developed over a series of three full-day workshops with the Science Panel (Panel), three web meetings, numerous small group meetings, and hundreds of email exchanges and telephone calls. Greg Low, a well respected CAP practitioner from Applied Conservation, facilitated the three workshops. The key ecological attributes (including indicators and ratings) and stresses each has a set of supporting notes and rationales for all decisions, which are available in table form as Appendices A and B of this report. The assessment process was iterative over the course of the three workshops. Each workshop's outcomes (e.g., ecological targets, attributes, indicators, indicator ratings, and stresses) were reviewed, further discussed, and refined as needed in subsequent sessions.

SCIENCE PANEL

The Science Panel (Panel) selected for the project consisted of a group of prominent scientists with extensive experience and knowledge of the varied Great Salt Lake ecosystems and species. The Panel reflected a wide range of academic and research disciplines, including hydrology and circulation, biogeochemistry, water quality, population dynamics, brine shrimp, migratory birds, and wetland science (Table 1). More detailed biographies of each Panel member are provided in Appendix C. Panel members were recommended by SWCA Environmental Consultants (SWCA), affirmed by the Council, and formally invited by the Council in August to participate in the project. Groups of eight to nine members of mixed expertise have been proven to be both effective and efficient in completing similar types of conservation assessments, including the development of conservation action plans, viability assessments, and monitoring plans for other areas featuring complex aquatic ecosystems. In addition, SWCA staff and Panel members themselves consulted dozens of peer-reviewed publications, research studies, and reached out to a number of other experts on particular subject areas and issues in completing the assessment.

The members of the Panel were as follows:

- Dr. Bonnie Baxter, Westminster College
- Dr. Gary Belovsky, University of Notre Dame
- Dr. John Cavitt, Weber State University
- Dr. Wally Gwynn, Independent Consultant, formerly with Utah Geologic Survey
- Dr. Heidi Hoven, The Institute for Watershed Sciences
- Craig Miller, P.E., Utah Division of Water Resources
- Dr. Theron Miller, Jordan River/Farmington Bay Water Quality Council
- Dr. David Naftz, U.S. Geological Survey
- Dr. Wayne Wurtsbaugh, Utah State University

Although the Panel sought to achieve consensus on decisions whenever possible, they agreed on a set of decision rules proposed by the facilitator to help manage their decision-making in light of a tight timeline. The key decision rules are shown in Table 2. In cases where there was no consensus by the committee, minority opinions are noted in the rationale tables included as Appendices A and B for indicators and stresses, respectively.

Table 1. Expertise of Science Panel Members

		Bonnie Baxter, Ph.D.	Gary Belovsky, Ph.D.	John Cavitt, Ph.D.	Wally Gwynn, Ph.D.	Heidi Hoven, Ph.D.	Craig Miller, P.E.	Theron Miller, Ph.D.	Dave Naftz, Ph.D.	Wayne Wurtsbaugh, Ph.D.
Abiotic	Geochemistry				x			x	x	x
	Limnology				x			x	x	x
	Salt balance				x		x			
	Nutrient dynamics		x					x	x	x
	Hydrology				x		x		x	
	Contaminants			x		x		x	x	x
Biotic	Shorebirds			x						
	Waterfowl			x						
	Brine shrimp		x							x
	Aquatic ecology		x			x		x		x
	Fish							x		x
	Impounded wetlands					x		x		
	Unimpounded wetlands					x				
	Microbes and algae	x	x					x		x
	Population dynamics		x	x						
	Invasive plants					x		x		

Table 2. Decision Rules for Great Salt Lake Health Science Panel Deliberations

Circumstance	**Decision**
Majority agreement with no strong dissents	Adopt
Majority agreement with 1 or 2 dissents	Adopt with minority opinion noted
1 or 2 proponents with 1 or 2 dissents	Do not adopt; attempt to resolve later
1 proponent, with peer review or equivalent support	Adopt
1 proponent, without peer review or equivalent support	Cite in notes, but do not adopt

GREAT SALT LAKE ECOSYSTEM STUDY BOUNDARIES

The Panel chose to define health for the main body of Great Salt Lake as well as for the ecological targets around the lake up to an elevation of 4,218 feet (1,286 meters [m]). Health is defined separately for each ecological target found within and adjoining each of the four distinct bays of Great Salt Lake: Gilbert Bay, Farmington Bay, Bear River Bay, and Gunnison Bay (Map 1, Appendix D).

DEFINITION OF HEALTH FOR ECOLOGICAL TARGETS AND SIGNIFICANT SPECIES

The Panel selected eight habitats as ecological targets for the Great Salt Lake system (Figure 1). These eight targets include the open water of the lake itself, various wetland types around the lake, islands, and adjoining grasslands and agricultural lands.

The ecological targets support significant species. Some of the significant species of birds that use Great Salt Lake (Paul and Manning 2002) are as follows:

- One of two of the largest staging populations (2,200,000) of Eared Grebes in North America
- Largest staging concentration in the world (500,000) of Wilson's Phalarope
- Large populations of American Avocets (250,000) and Black-necked Stilts (65,000)
- World's largest assemblage of Snowy Plover (10,000) representing 55% of the entire breeding population west of the Rocky Mountains
- One of the three largest colonies in the western United States of American White Pelicans
- World's largest breeding population of White-faced Ibis (21,600 breeding adults)
- Breeding populations of Long-billed Curlew, a Utah Species of Concern (UDWR 2011)

Ecological Targets

Ecological targets, in the context of this project, are the eight habitats that comprise Great Salt Lake and its shoreline. They are as follows:

- System-wide Lake and Wetlands
- Open Water of Bays
- Unimpounded Marsh Complex
- Impounded Wetlands
- Mudflats and Playas
- Isolated Island Habitat for Breeding Birds
- Alkali Knolls
- Adjoining Grasslands and Agricultural Lands

Significant Species

Significant species are keystone species (e.g., brine shrimp), species of concern, living stromatolitic structures, and species with significant populations using the lake ecosystem (e.g., globally, nationally, and regionally significant concentrations of migratory shorebirds, waterfowl, colonial nesting waterbirds, and other birds).

The open water of bays ecological target supports stromatolitic structures, which are unique biogeochemical formations found on the lake bottom that have important ecological value. They are the principal habitat for brine fly (*Ephydra* spp.) larvae, and may be crucial for their survival in the lake. Brine flies play a critical role in Great Salt Lake food chains and are a major prey of migratory and resident birds.

The extreme salinity of Gunnison Bay supports a unique assemblage of halophilic (salt-loving) algae and bacteria. Primary production in the less-saline Gilbert Bay supports brine shrimp and brine flies, whereas the brackish to saline water of Bear River and Farmington bays supports more diverse invertebrate populations. Most of the bird populations use Gilbert, Bear, and Farmington bays for nesting and foraging because of the abundant macroinvertebrate populations. Colonial species such as the American White Pelican use isolated islands in Gunnison and Gilbert bays for nesting.

Brine shrimp and brine flies are species uniquely adapted to the salinity of the lake, especially in Gilbert Bay. They are important links in the lake's food web. The brine shrimp (*Artemia franciscana*) population found in Great Salt Lake is significant because of the following:

- It is the largest population of this species in the world and one of the largest populations of *any* brine shrimp species in the world
- It serves a critical role as a grazer of phytoplankton in the lake ecosystem's functioning, especially in terms of nutrient cycling, energy transfer, and modifying physical characteristics (clarity, albedo, etc.)
- Its abundance makes it an important food resource for many waterbirds.

The habitats around the lake included in the assessment support significant bird populations, brine shrimp, brine flies, and stromatolitic structures (Map 2, Appendix D). For this reason, other habitats such as streamside riparian areas were not selected for the analysis. Although they serve an important ecological function, streamside riparian areas support a different array of species than the significant species supported by the lake and other surrounding habitats.

For each ecological target, the Panel identified a set of key ecological attributes that reflects its health, indicators to measure the key attributes, and ratings to define health for each indicator. A rating of good or very good for an indicator is considered to be a healthy condition for its associated key ecological attribute. Rationale for all indicator ratings and data used to assess current health are summarized in Appendix A.

Defining Health
A rating of good or very good for an indicator is considered to be a healthy condition for its associated key ecological attribute.

The definition and assessment of the lake's health is summarized at numerous levels, including by bay, by ecological target, or for the entire lake system. Health for the system-wide lake and wetlands ecological target is assessed system-wide because it affects the entire system and would otherwise be repeated in most of the wetland and open water ecological targets.

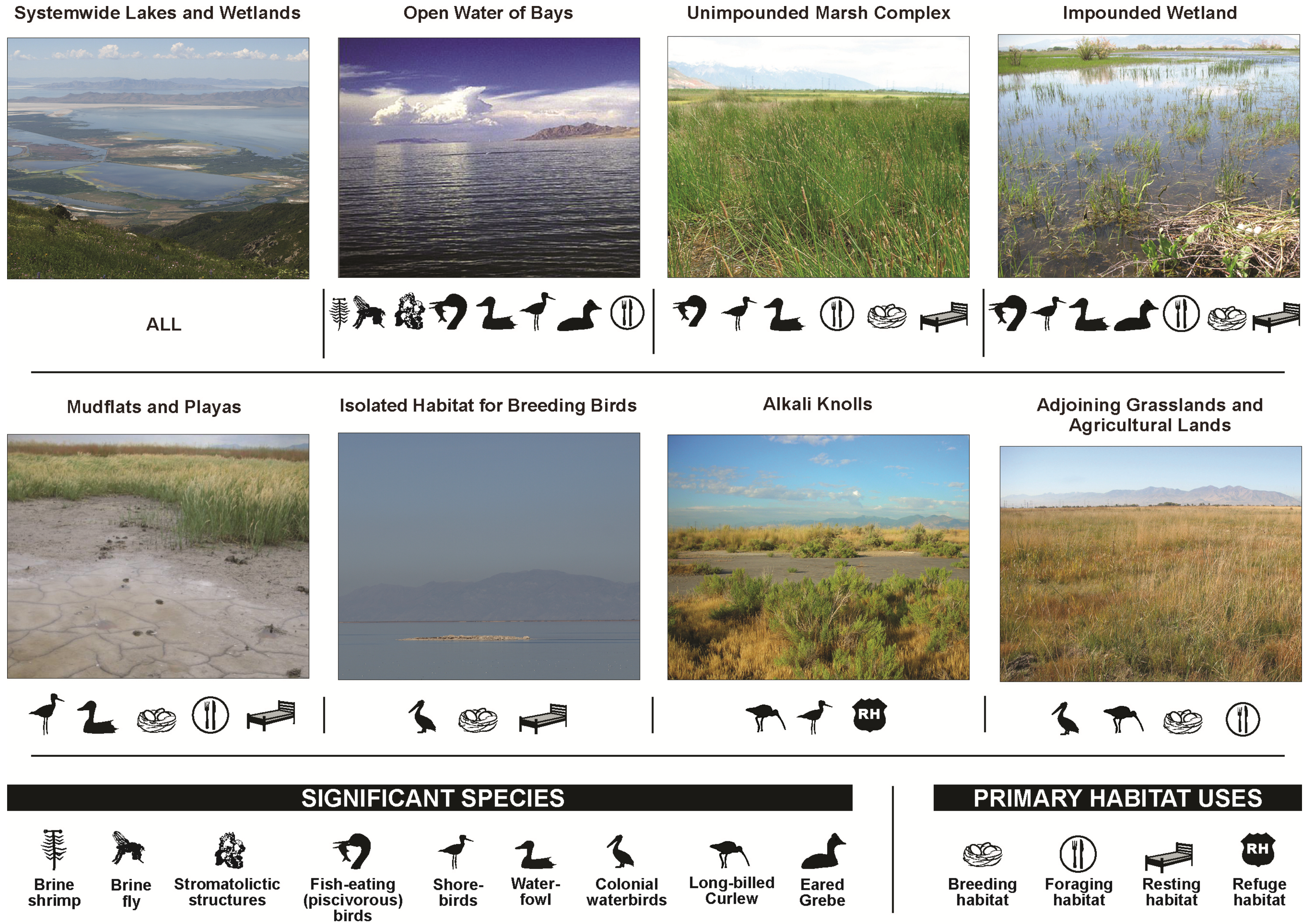

Figure 1. Ecological targets and significant species for Great Salt Lake.

System-wide Lake and Wetlands

Many linkages occur between the open water lake and wetland habitats across Great Salt Lake. Therefore, they are considered an integrated, focal ecological target for the purpose of evaluating key attributes such as lake level, lake fluctuation, and toxins.

Fluctuating lake levels ensure that the vegetation bordering the lake does not become dominated by invasive species. It is also critical to many biogeochemical cycling processes and helps to expose foraging and resting habitat for shorebirds and waterbirds during lower lake levels. Lake fluctuations restore habitat important to nesting and foraging shorebirds during high lake level years by killing off all shoreline vegetation. A healthy lake and wetland system should fluctuate in response to natural cycles of wet and dry years, as well as within the seasons of each year, and should have an average level sufficient to support the significant species. Therefore, a healthy lake level fluctuation regime is one in which the lake:

1) achieves a high level of 4,204 feet (1,281 m) and its modern low of 4,191 feet (1,278 m) every 50–100 years,
2) fluctuates by 0.3–0.6 m (1–2 feet) annually on average over a 10-year period, and
3) rises by 7.6–10.1 centimeters (3–4 inches) each spring during the snow melt and runoff period.

In addition, the system is healthy when the average lake level over 10 years is between 4,198 and 4,203 feet (1,280 and 1,281 m).

Toxins can interfere with the lifecycle and health of many of the significant species identified for Great Salt Lake, including brine shrimp, brine flies, and birds. Therefore, healthy conditions for the system-wide ecological target require levels of toxins that do not impair or impact these significant species. The most upstream ponds of impounded wetlands tend to be the first receivers of many toxins as they wash into the system from the watershed. These wetlands provide important filtration functions for the rest of the open water lake and wetland ecological target. The following indicators represent a healthy condition for the open water lake and wetlands ecological target with respect to toxins: concentrations of selenium in bird eggs that are less than 6.4 milligram (mg) per kilogram (kg) dry weight and concentrations of methylmercury in bird eggs and livers that are less than 1.3 and 2.0 mg/kg methylmercury wet weight, respectively. A healthy system also includes one in which very few birds die each year from avian botulism and in which other emerging toxins of concern are kept at low levels that are not harmful to birds or their food resources.

Open Water of Bays

The open water of bays ecological target comprises the entire lake and its wetted shoreline. This includes the entire water column (shallow and deep brine layers), bare sediments, and stromatolitic structures on the lake bottom. This ecological target does not include waters within the shoreline of the lake that are constrained by impoundments. The depth and spatial extent of this ecological target varies with seasonal and long-term fluctuations in climate and changes to watershed hydrology. Brine shrimp and brine flies are found in the open waters of Gilbert Bay, and diverse assemblages of other invertebrates occur in the other bays and are recognized as important links in Great Salt Lake food chains (Table 3). The fresher portions of Bear River and Farmington bays contain fish that are important forage items for piscivorous (fish-eating) birds. Stromatolitic structures are the principal habitat for brine fly larvae, and may be crucial for their survival in the lake. Brine flies play a critical role in Great Salt Lake food chains and are a major prey of migratory and resident birds (Table 3).

Stromatolitic Structures

Stromatolitic structures are reef-like structures that are prominent in Great Salt Lake. They provide an ideal living surface for cyanobacteria. Cyanobacteria photosynthesize; the byproduct of this photosynthesis is layers of calcium carbonate mineral. As cyanobacteria continue to colonize and grow on these layers, they create additional layers. These unique biogeochemical structures are found on the lake bottom. They are the principal habitat for brine fly (*Ephydra* spp.) larvae, and may be crucial for their survival in the lake.

Photo credit: Wayne Wurtsbaugh

The open water of bays ecological target also provides foraging habitat for portions of the 2.2 million Eared Grebes, portions of the 500,000 Wilson's Phalaropes, and fish-eating birds (e.g., American White Pelican, Double-crested Cormorant) that use Great Salt Lake (Table 3). Invertebrate populations are the primary food source for birds in the lake.

Healthy conditions are defined separately for each of the four bays in the sections to follow.

Table 3. Distribution of Significant Species for Open Water of Bays

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Brine Shrimp	x	x (high water years)	Rare	Rare
Brine fly (larvae)	x		Rare	Rare
Stromatolitic structures	x	x	x	x
Foraging habitat for significant fish-eating birds			x	x
Foraging habitat for Eared Grebes	x		x	x
Foraging habitat for Wilson's Phalaropes	x		x	x

Deep Brine Layer Influences on Great Salt Lake Health

At the culverts and causeway openings between Gilbert Bay and Gunnison Bay, fresher water flows from the south to the north and brine (very saline water) flows from the north to the south. The heavier brine from Gunnison Bay sinks and resists mixing with the fresher water in Gilbert Bay. As a result, the brine forms a fairly stable layer that covers nearly half the bottom of Gilbert Bay; this is called the *deep brine layer*. The same processes occur in Farmington Bay with intrusion of denser water from Gilbert Bay. The transport of salt from Gunnison Bay back to the Gilbert Bay via the deep brine layer helps stabilize salinity at levels better for brine shrimp in Gilbert Bay and thus contributes to the overall health of Gilbert Bay. However, because these deep brine layers remain stable for years at a time, nutrients in those layers are removed from circulation. Furthermore the decomposition of organic matter in the deep brine layer removes all oxygen so that brine shrimp, brine fly larvae, and other invertebrates cannot live there. The anoxic condition in the deep brine layers also contributes to sulfate reduction, the release of toxic hydrogen sulfide gas, and importantly, methylation of mercury. Mercury methylation and the loss of habitat clearly degrade the health of Great Salt Lake. The deep brine layer is clearly an important aspect of Great Salt Lake health; however, the Panel found that the tradeoffs between the positive aspects of salinity stabilization given the impacts of the Northern Railroad Causeway and the negative aspects of mercury methylation and habitat loss in the two bays could not be assessed at this time. The question of whether the deep brine layer is ‘good’ for Great Salt Lake health deserves additional research attention in the future.

Gilbert Bay

Gilbert Bay is the main southern bay of the lake and contains extensive high to moderately saline open water that extends south from the Northern Railroad Causeway to the southern shore of Great Salt Lake. This bay is stratified with an extremely salty deep brine layer because of movements of dense, highly saline water through the breach and other causeway openings from Gunnison Bay. The deep brine layer is clearly an important aspect of Great Salt Lake health that contributes to and detracts from lake health, as measured by other attributes and indicators (see box above).

Healthy conditions in Gilbert Bay include salinity levels from 9% to 16% that support a healthy food web consisting of phytoplankton, stromatolitic structures, periphyton on stromatolitic structures, brine fly populations, and brine shrimp populations. Levels of toxins should not impair brine shrimp, brine flies, stromatolitic structures, or foraging habitats for Eared Grebes, Wilson’s Phalaropes, and waterfowl. Elements of the food web are also good indicators of health. A healthy brine shrimp population is defined as 7.5–8.25 individuals per liter (948–1,043 micrograms [ug]/L) on average from April through November[1]. A healthy brine shrimp population relates to appropriate levels of phytoplankton measured as a maximum winter chlorophyll *a* concentration of 50–60 µg/L. A healthy brine fly population is defined as 12–16 grams of brine fly larvae (summer biomass dry weight) per m^2 of stromatolitic structures. Brine fly larvae depend on a healthy amount of periphyton on stromatolitic structures defined as summer values of 0.7 to 0.9 grams of chlorophyll a/m^2. The lake is healthy when the maximum summer chlorophyll *a* concentrations, concentrations of cyanotoxins, and concentrations of methylmercury in the sediment are not too high, although healthy thresholds for these parameters are currently unknown.

[1] Although at any one time, there will be more or less than this average.

Farmington and Bear River Bays

Farmington Bay extends from the Davis County Causeway south to the Southern Causeway. Bear River Bay extends from the Bear River delta southeast to Willard Bay and Reservoir and southwest to the Northern Railroad Causeway connecting the eastern shore to the Promontory Point (and then to the western shore). Farmington and Bear River bays both have highly variable salinities, ranging from fresh water during spring runoff and perennially where rivers and wastewater discharges enter, to hypersaline when the bays evaporate or when water from Gilbert Bay enters. Stratification of open water in Farmington Bay occurs in association with freshwater influxes and influxes of dense hypersaline water from Gilbert Bay. The brackish to saline water of Bear River and Farmington bays supports invertebrate populations ranging from zooplankton to macroinvertebrate grazers and predators including several species of midges and corixids.

Healthy conditions in Farmington and Bear River bays contribute directly to a healthy food web. In these two bays, healthy conditions comprise salinity gradients that vary by 8 percentage points across the bay, within the natural range of 0%–14%. A healthy food web comprises healthy populations of zooplankton (including brine shrimp), periphyton on stromatolitic structures, brine fly larvae, other benthic invertebrates, and fish. Also, levels of toxins should not cause bird mortalities or impair stromatolitic structures or foraging habitats for significant fish-eating bird species, Eared Grebes, or Wilson's Phalaropes. Farmington and Bear River bays are also healthy when their trophic condition supports the lake's unique food web. Although hypereutrophic conditions can occur in saline lakes, it is unclear whether the current trophic condition of the less saline Bear River and Farmington bays is healthy. Very little is understood about appropriate diversity or productivity levels for the brackish conditions in Farmington and Bear River bays. Salinity ranges alter invertebrate and phytoplankton diversity in ways that are not clear and may be unrelated to the productivity or nutrient concentrations of the bay. Additional research is necessary to define healthy algal and invertebrate communities. A healthy invertebrate community includes a diversity of species appropriate to the salinity gradient found in these bays, including species that require sufficient concentrations of oxygen to thrive.

Gunnison Bay

Gunnison Bay comprises extensive, highly saline open water of the main body of Great Salt Lake that extends from the Northern Railroad Causeway to the north shore of Great Salt Lake. Stratification is limited in this portion of the lake due to construction of the causeway, which limits interaction between water in Gunnison Bay and the rest of the lake.

Healthy conditions in Gunnison Bay require salinity levels from 9% to 14% at high lake levels (lake levels greater than 4,211 feet [1,284 m] above mean sea level [MSL]) to provide refuge habitat for brine shrimp when lake levels are high and salinity levels are too low in Gilbert Bay for brine shrimp to thrive. During these periods, a healthy population of brine shrimp in Gunnison Bay would be defined as it is for Gilbert Bay during other periods. Healthy conditions in Gunnison Bay also include living stromatolitic structures and levels of methylmercury that do not impair the algal or brine shrimp populations.

Unimpounded Marsh Complex

An unimpounded marsh complex contains a mosaic of wetlands that are intermittently or semi-permanently flooded and often inundated from spring through fall. Vegetation structure and composition varies spatially and seasonally due to variable salinity, and inundation depth and duration. Specifically, the unimpounded marsh complex ecological target comprises five wetland habitat types ranging from shallow to deep water: 1) wet meadow, 2) tall emergent marsh, 3) short emergent marsh, 4) hemi-marsh (half emergent vegetation and half open water), and 5) wetlands dominated by submerged aquatic vegetation (SAV)[2]. The wetland habitat type that occurs in a given place and time is defined primarily by water depth, inundation period, and salinity.

The unimpounded marsh complex ecological target provides breeding and foraging habitat for significant waterfowl and shorebirds (e.g., Redhead Cinnamon Teal, American Avocet, Snowy Plover, and Black-necked Stilt). Wet meadows provide breeding and foraging habitat for a portion of the largest global breeding population of White-faced Ibis and gulls (e.g., Franklin's Gull). In addition, hemi-marsh provides breeding and foraging habitat for a portion of the 65,000 Black-necked Stilts and the 500,000 Wilson's Phalaropes found around Great Salt Lake, as well as foraging habitat for fish-eating birds (e.g., Western Grebe and Forster's Tern) (Table 4).

Table 4. Distribution of Significant Species for Unimpounded Marsh Complex

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Breeding and foraging habitat for significant waterfowl populations	x	x	x	x
Breeding and foraging habitat for White-faced Ibis and gulls	x	x	x	x
Breeding and foraging habitat for Black-necked Stilts and Wilson's Phalaropes	x	x	x	x
Foraging habitat for significant fish-eating birds	x	x	x	x

Healthy conditions in the unimpounded marsh complex ecological target require delivery of a sufficient volume of high quality water by tributary streams and freshwater discharges to provide inundation or moist conditions from April to early July. The extent of wetlands created by good hydrologic conditions contributes to a variety of wetland habitats that support healthy populations of native plants, macroinvertebrates, and fish, which in turn provide foraging and breeding habitats for waterfowl, White-faced Ibis, gulls, Black-necked Stilts, Wilson's Phalaropes, and fish-eating birds. The structural and

[2] SAV in wetlands is outside of the wetted shoreline defining the Open Water of Bays ecological target and includes primarily pools within the unimpounded marsh complex.

compositional diversity of wetland habitat types is a key habitat component for the support of waterfowl, shorebirds, other waterbirds, and fish. Therefore, a healthy unimpounded marsh complex also includes the presence of all five wetland habitat types listed above. In addition, the wetlands should be dominated by at least 75% native and desirable nonnative plant species. A healthy food supply in the marsh complex includes a healthy macroinvertebrate population measured as at least 1.5 grams/m^2 of macroinvertebrates (other than snails and other gastropods). Sufficient acreage of contiguous unimpounded marsh habitat is a key habitat component for shorebirds and other staging and breeding birds. A healthy acreage of unimpounded marsh complex[3] should provide sufficient habitat at varying lake levels to support significant species; this size is at least 3,600 hectares (ha) (9,000 acres) adjoining Gilbert Bay, 1,200 ha (3,000 acres) adjoining Gunnison Bay, 3,200 ha (8,000 acres) adjoining Farmington Bay, and 8,100 ha (20,000 acres) adjoining Bear River Bay.

Impounded Wetlands

The impounded wetlands ecological target comprises wetlands ringed by emergent vegetation where the hydrology has been artificially modified by dikes, berms, ditches, culverts, or other structures that control or constrict the inflow and outflow of water. Impounded wetlands do not include evaporation ponds, but in a broader sense, can include naturally occurring impoundments and open water within them. Impounded wetlands occur on a gradient from deep water on the downslope side to wet meadow on the upslope and are typically managed for submerged aquatic vegetation (SAV), though sometimes salinity prevents SAV growth. SAV is an important structural component of impounded wetlands in that it provides forage and shelter for waterfowl and waterbirds and habitat for their prey (e.g., macroinvertebrates and fish). Dabblers acquire most of their energetic requirements from aquatic invertebrates, drupelets, and seeds; examples of dabblers are Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler, American Widgeon, and Cinnamon Teal. Divers eat primarily roots and tubers of SAV; examples of divers are Redhead, Canvasback, and Ring-necked Duck. The water control structures that constrain impounded wetlands do not allow natural hydrologic fluctuations in the timing, extent, and duration of inundation that occurs in unimpounded wetlands; but provide nesting, resting, and foraging habitat for waterfowl, waterbirds, and shorebirds, and serve an important function in water purification and nutrient cycling.

The impounded wetlands ecological target provides breeding and foraging habitat for significant populations of waterfowl (e.g., Cinnamon Teal, Redhead), occasionally for members of the largest global breeding population of White-faced Ibis and gulls (e.g., Franklin's Gull), and for significant shorebird populations (American Avocet, Black-necked Stilt, and Wilson's Phalarope) (Table 5).

[3] Defined as at least 70% of historic acreage; see Appendix A for rationale.

Table 5. Distribution of Significant Species for Impounded Wetlands

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Breeding and foraging habitat for significant waterfowl populations	x	x	x	x
Breeding and foraging habitat for White-faced Ibis and gulls	x	x	x	x
Breeding and foraging habitat for significant shorebird populations	x	x	x	x

Healthy conditions in the impounded wetlands ecological target require delivery of a sufficient volume of high quality water by tributary streams and rivers to support healthy populations of native emergent plant species, SAV, macroinvertebrates, and fish, which in turn provide habitats for waterfowl, White-faced Ibis, gulls, and shorebirds of regional and hemispheric significance. Healthy impounded wetlands are dominated by at least 75% native or desirable nonnative vegetation; this provides structural diversity that supports the food web. A healthy food supply in the impounded wetlands includes a healthy macroinvertebrate population measured as at least 1.5 grams/m^2 of macroinvertebrates (other than snails and other gastropods), which is supported by habitat provided by SAV. In addition, sufficient plant biomass in the form of tubers (starchy vegetative reproductive structure) and drupelets (fruiting body high in fat) both serve nutritional needs of waterfowl. Healthy amounts of tubers and drupelets are measured as at least 12 and 20 kilograms/m^2, respectively. A healthy SAV community, measured as branch density (35,000 branches with attached leaves/m^2) is also critical to the overall health of impounded wetlands. SAV helps to filter particulates and remove toxins from the water column and provide important nutrient and metal cycling functions[4]. SAV is sensitive to toxic metals and is therefore a good indicator of overall water quality in the impounded wetlands. Further research is needed to determine tolerance thresholds of SAV to toxins, bioavailabilty, and transfer of toxins up the food chain.

[4] Impoundments surrounding Great Salt Lake often occur in series or parallel with respect to their source water. Consequently the “upstream” impoundments (located closest to the source water) have received and continue to receive the greatest concentrations of toxic metals, sediments, nutrients, and organic matter delivered from the watersheds. In the case of Farmington Bay, Jordan River has received nearly the entire waste load from mining, smeltering, and urban development, including a superfund site (metal contamination) in Midvale. As such, the upstream impoundments have captured and settled a greater proportion of these contaminants than downstream impoundments. In this project, upstream impoundments were assessed both because there were sufficient ecological and toxicological data and because these ponds represent the most stressed or worst-case conditions within this ecological target.

Mudflats and Playas

The mudflats and playas ecological target comprises extensive saline habitats that are maintained by inter-annual or seasonal water fluctuations; they are frequently associated with Great Salt Lake's shoreline. Mudflats are low slope shoreline and depression habitats that have little or no vegetation cover. Playas are low slope shoreline or depressional habitats with salt-loving (halophytic) vegetation cover. Both habitat types are further distinguished by characteristic accumulation of alkaline salts on the soil surface. Mudflat and playa habitats support a community of halophytes and freshwater and saltwater macroinvertebrates that provide seasonal food for tens of thousands of migratory shorebirds, gulls, and waterfowl. Freshwater inputs into playa habitats drive the high productivity of vegetation and macroinvertebrates that support migratory shorebirds.

Mudflats and playas provide breeding and foraging habitat for Snowy Plover, American Avocet, Black-necked Stilt, and other significant shorebird populations (Table 6).

Table 6. Distribution of Significant Species for Mudflats and Playas

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Breeding and foraging habitat of significant shorebird populations	x	x	x	

Healthy conditions in the mudflats and playas ecological target require low cover (less than 25%) of invasive plant species, particularly *Phragmites*. In addition, sufficient habitat within 100 m (325 feet) of perennial fresh water is needed to support Snowy Plover and other significant shorebird populations. A healthy amount of mudflat and playa habitat within 100 m (325 feet) of perennial fresh water is estimated to be at least 2,500 ha (6,000 acres) around Gilbert Bay, 1,200 ha (3,000 acres) around Gunnison Bay, 1,200 ha (3,000 acres) around Farmington Bay, and 7, 300 ha (18,000 acres) around Bear River Bay.

Isolated Island Habitat for Breeding Birds

Isolated islands provide valuable nesting, brooding, and resting habitats for colonial birds that are naturally protected from land predators, grazing, and human disturbance at most lake elevations. Habitats on Great Salt Lake's isolated islands are primarily bare rock or sand bars with some upland vegetation on Fremont Island. Gunnison Island provides valuable nesting, brooding, and resting habitats for American White Pelicans that are naturally protected from land predators, grazing, and human disturbance at most lake elevations.

Isolated islands on Great Salt Lake also provide breeding habitat for significant populations of colonial waterbirds (e.g., American White Pelican, Double-crested Cormorant, and California Gull) (Table 7).

Table 7. Distribution of Significant Species for Isolated Habitat for Breeding Birds

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Breeding habitat for significant populations of colonial waterbirds	x	x		

Healthy conditions on isolated islands used by breeding birds require lake levels above approximately 4,195 feet (1,279 m) in elevation. This elevation prevents land-based predators from accessing possible nesting colonies of American White Pelican and other colonial waterbirds of regional and hemispheric significance. Lack of land-based predators on islands is a critical attribute of health for these systems. Although predators are most likely to access islands by crossing the lake bed during low lake levels, predators and grazers have also been intentionally introduced to some of the islands.

Alkali Knolls

The alkali knolls ecological target comprises depressions containing salt-loving shrub species and wet meadow grasses. These habitats are distinct from emergent marsh, playas, and mudflats because of their unique species composition, low vegetation structure, highly alkaline soils, and inundation period that is shorter than playa and emergent marsh habitats. They generally occur at elevations greater than 4,212 feet (1,284 m). These habitats have no outflow, which causes alkaline salts to concentrate on the soil surface as water evaporates. In addition to upland resting and cover areas, alkali knolls provide shallow water and wet meadow areas; these are unique and excellent foraging habitats for birds because they provide diverse and abundant macroinvertebrates.

Alkali knolls provide refuge breeding, foraging, and resting habitat for significant shorebird populations during high water years. This ecological target served as an important refuge habitat for birds during the floods of the 1980s. In addition, this ecological target supports a portion of the 250,000 American Avocets that use the lake (Table 8). In Gilbert Bay, alkali knolls habitats on the eastern side of the lake near Ogden Bay are especially valuable to wildlife.

Table 8. Distribution of Significant Species for Alkali Knolls

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Refuge shorebird habitat during high water years	x	x	x	x

Healthy conditions in the alkali knolls ecological target require sufficient acreage to provide refuge habitats for migratory shorebirds during high water years. A healthy amount of alkali knoll habitat is at least 8,100 ha (20,000 acres) around Gilbert Bay, 400 ha (1,000 acres) around Gunnison Bay, 2,800 ha (7,000 acres) around Farmington Bay, and 2,000 ha (5,000 acres) around Bear River Bay.

Adjoining Grasslands and Agricultural Lands

The uplands surrounding Great Salt Lake are generally dominated by shadscale-greasewood associations adjacent to sparsely vegetated shorelines, but they often occur as a mosaic of shrublands, grasslands, agricultural lands, and barren areas. The upland grassland and agricultural lands ecological target serves as important waterfowl and shorebird nesting habitats that provide dry cover for nesting sites close to wetlands and open water. Uplands also provide important refuge habitats during high water years when marsh wetlands, playas and mudflats, and other wetland habitats become inundated. Grassland and agricultural lands isolated from human activity are necessary for successful Long-billed Curlew nesting; however, agricultural lands tend to be near areas of expanding development around Great Salt Lake.

The adjoining grasslands and agricultural lands ecological target provides breeding habitat for Long-billed Curlew. This ecological target supports approximately 5% of the global population of Long-billed Curlew, with a significant portion of the species' dwindling range. Flood-irrigated fields provide foraging habitat for White-faced Ibis, Long-billed Curlew, and Franklin's Gull (Table 9).

Table 9. Distribution of Significant Species for Adjoining Grasslands and Agricultural Lands

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Breeding habitat for Long-billed Curlew	x	x	x	x
Foraging habitat for White-faced Ibis, Long-billed Curlew, and Franklin's Gull	x	x	x	x

Healthy conditions in grasslands and agricultural lands adjoining Great Salt Lake require high cover (at least 75%) of native and desirable nonnative grasses and forbs with areas of low vegetation structure suitable for Long-billed Curlew nesting sites. Healthy conditions for this ecological target include sufficient acreage of flood-irrigated agricultural land to provide foraging habitats for Long-billed Curlew, White-faced Ibis, and Franklin's Gull. This is defined as at least 1,600 ha (4,000 acres) around Gilbert Bay, 800 ha (2,000 acres) around Farmington Bay, and 2,400 ha (6,000 acres) around Bear River Bay. In addition, sufficient acreage of grasslands and pasture at least 150 m (490 feet) from residential and commercial development is required to provide breeding habitat for Long-billed Curlew. This is defined as at least 3,200 ha (8,000 acres) around Gilbert Bay, 300 ha (800 acres) around Gunnison Bay, 2,400 ha (6,000 acres) around Farmington Bay, and 3,600 ha (9,000 acres) around Bear River Bay.

CURRENT HEALTH

Great Salt Lake is currently in relatively good health. This is based on the definition of health developed for each of the eight ecological targets, using the CAP system, including aggregating the ratings for multiple indicators for a given ecological target (Table 10). However, several of the ecological targets had a high level of uncertainty due to insufficient data to define and assess the current health of many of the ecological targets. Indicators identified as part of the definition of health but for which ratings could not be identified were assigned a rating of TBD (To Be Determined). For example, less than half of the indicators for open water and unimpounded marsh complex ecological targets could be evaluated and were rated TBD (Table 11). As a result, the overall health of these targets could not be ranked. More data are available to evaluate the health of other ecological targets surrounding Great Salt Lake. Most of these are in relatively good health, with the notable exceptions of alkali knolls around Bear River and Farmington Bay and the impounded wetlands around Farmington Bay. The poor health rating of alkali knolls is due to significant permanent habitat loss of these systems. The poor health ranking for impounded wetlands around Farmington Bay is due to unhealthy submerged aquatic vegetation (SAV) communities and invasion by undesirable and nonnative plants, such as *Phragmites*, that have come to dominate the systems and limit food availability for birds. The fair ranking for the Gunnison Bay open water ecological target is due to the loss of living stromatolitic structures in this bay due to high salinity values and salt cover.

Four-grade Scale used in CAP

Very good: The key attribute for a target is functioning at an ecologically desirable status and requires little if any human intervention

Good: The key attribute is functioning within its range of acceptable variation; it may require some human intervention

Fair: The key attribute is functioning outside of its range of acceptable variation and requires human intervention to restore a "Good" condition

Poor: Allowing the key attribute to persist in this condition would make restoration of the target practically impossible

A detailed summary of indicators, indicator ratings, and current health status is shown in Table 11. The indicator ratings are specific to each of the four bays around the lake. Where current data are available, current condition is indicated by coloring the appropriate indicator box. For example, the lake currently has a *Very Good* health rating with respect to selenium in bird eggs as indicated by the dark green box colored for that indicator. Full rationales and references for each indicator and current health rating are available in Appendix A.

Table 10. Current Overall Health of Eight Ecological Targets for Great Salt Lake Summarized by Bay

Ecological Targets	Gilbert Bay	Gunnison Bay	Bear River Bay	Farmington Bay	OVERALL RANKING	Uncertainty[1]
System-wide Lake and Wetland	Good				Good	Medium
Open Water	Good	Not ranked	Not ranked	Not ranked	Not ranked	Very High[2]
Unimpounded marsh complex	Not ranked	Not ranked	Not ranked	Not ranked	Not ranked	High
Impounded wetlands	Not ranked	Not ranked	Good	Poor	Not ranked	Very High
Mudflats and playas	Good	Very Good	Good	Good	Good	Low
Isolated island habitat for breeding birds	Good	Good	NA	NA	Good	Low
Alkali knolls	Fair	Very Good	Poor	Poor	Fair	Low
Adjoining grasslands and agricultural lands	Good	Good	Good	Good	Good	Low
SUMMARY					**Good**	**Medium**

[1] Ecological targets with very high uncertainty are those for which more than 75% of the indicators could not be evaluated with current data for at least 2 bays. Ecological targets with high uncertainty are those for which more than half of the indicators but less than 75% could not be evaluated with current data for at least two bays. Those with low uncertainty are those for which all indicators could be evaluated with current data. Those with medium uncertainty are those for which one or two indicators could not be evaluated. See Table 11 for a detailed summary of indicators for each ecological target and bay. Uncertainty ratings listed represent the most uncertain bay for each ecological target.
[2] Uncertainty for Open Water of Gilbert Bay is medium whereas the other three bays are very high.

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
System wide Lake and Wetlands						
Levels of toxins that do not impair significant species (e.g., bird populations)	Concentration of selenium in bird eggs (mg/kg dry weight)	Poor	>12.5			
		Fair	6.4–12.5			
		Good	3–6.4			
		Very Good	<3			
	Concentration of methylmercury in bird eggs (ppm MeHg ww)	Poor	>2.0			
		Fair	1.3–2.0			
		Good	0.5–1.3			
		Very Good	0–0.5			
	Concentration of methylmercury in bird liver (ppm MeHg)	Poor	>6.0			
		Fair	2.0–6.0			
		Good	0.89–2.0			
		Very Good	<0.89			
	Avian botulism (mortality from avian botulism (number of birds killed per year)	Poor	TBD			
		Fair	TBD			
		Good	TBD			
		Very Good	TBD			
	Other toxins (ethylene dichloride [EDC], estrogens, organics, other metals such as; arsenic of concern)	Poor	TBD			
		Fair	TBD			
		Good	TBD			
		Very Good	TBD			
Lake level fluctuation regime	Fluctuation of the lake on a multidecadal, annual, and seasonal basis	Poor	Lake level stagnates on a seasonal, annual, and decadal time frame.			
		Fair	Lake does not achieve 4,204 feet or drops to 4,191 feet with multidecadal frequency, or the lake fluctuates by less than 1 foot annually over a 10-year period, or rises by less than 3–4 inches during spring runoff period.			
		Good	Lake achieves a high of 4,204 feet and its modern low of 4,191 feet with multidecadal (50–100 years) frequency and over a 10 year period fluctuates annually by 1–2 feet and rises by 3–4 inches during spring runoff period			
		Very Good	TBD/Unknown			
Lake volume and area sufficient to support aquatic and wetland habitats and their significant species	Average lake level measured at Salt Air over 10 years (feet above MSL)	Poor	Average lake level of less than 4,195 or more than 4,204			
		Fair	4,195–4,198			
		Good	4,198–4,203			
		Very Good	TBD/Unknown			

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Open Water of Bays						
Salinity levels supportive of native biota	Average salinity from April through October (%)	Poor	<8% or >19%	>19% at high lake levels	n/a	n/a
		Fair	8%–10% or 16%–19%	8%–10 % or 16%–19% at high lake levels	n/a	n/a
		Good	9%–12% or 14%–16%	9%–12% or 14–16% at high lake levels	n/a	n/a
		Very Good	12%–14%	12%–14% at high lake levels	n/a	n/a
	Salinity gradient across the bay during the summer (June–August) that supports invertebrates, fish, and macrophytes (percentage point variation in gradient across the bay within the overall range of 0%–14%)	Poor	n/a	n/a	<3	<3
		Fair	n/a	n/a	3–8	3–8
		Good	n/a	n/a	8–13	8–13
		Very Good	n/a	n/a	14	14
Sufficient surface area of stromatolitic structures to support the food chain (used for periphyton growth)	Areal extent of living stromatolitic structures (km^2)	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	235–287	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD
Algal and macrophyte biomass supportive of food web	Phytoplankton winter maximum chlorophyll *a* (µg/L)	Poor	<20 or > than a maxTBD	n/a	n/a	n/a
		Fair	20–50	n/a	n/a	n/a
		Good	50–60	n/a	n/a	n/a
		Very Good	TBD	n/a	n/a	n/a
	Periphyton on stromatolitic structures (g chlorophyll *a*/m^2)	Poor	TBD	n/a	TBD	n/a
		Fair	TBD	n/a	TBD	n/a
		Good	0.7–0.9	n/a	TBD	n/a
		Very Good	TBD	n/a	TBD	n/a
	SAV branch density (leaves/m^2)	Poor	n/a	n/a	n/a	TBD
		Fair	n/a	n/a	n/a	TBD
		Good	n/a	n/a	n/a	TBD
		Very Good	n/a	n/a	n/a	TBD
Invertebrate population sufficient to	Zooplankton (non-Artemia) abundance	Poor	n/a	n/a	TBD	TBD
		Fair	n/a	n/a	TBD	TBD

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
support waterbirds	(#/m^3)	Good	n/a	n/a	TBD	TBD
		Very Good	n/a	n/a	TBD	TBD
	Brine fly larvae attached to stromatolitic structures (summer biomass g/m^2 dry weight)	Poor	TBD	TBD	TBD	n/a
		Fair	TBD	TBD	TBD	n/a
		Good	12–16	12–16 during high lake levels	TBD	n/a
		Very Good	TBD	TBD	TBD	n/a
Forage fish supportive of fish-eating birds	Fish indicator TBD (kg/m^2)	Poor	n/a	n/a	TBD	TBD
		Fair	n/a	n/a	TBD	TBD
		Good	n/a	n/a	TBD	TBD
		Very Good	n/a	n/a	TBD	TBD
Healthy brine shrimp population	Average shrimp density or biomass over the period from April through November (#/L or ug/L)	Poor	<5.5 #/L or <695 ug/L AND up to maximum density TBD	<5.5 #/L or <695 ug/L during high lake levels	n/a	n/a
		Fair	5.5–7.5 #/L or 695–948 ug/L	5.5–7.5 #/L or 695–948 ug/L at high lake levels	n/a	n/a
		Good	7.5–8.25 #/L or 948–1,043 ug/L	7.5–8.25 #/L or 948–1,043 ug/L at high lake levels	n/a	n/a
		Very Good	TBD	TBD	n/a	n/a
Trophic condition supportive of native biota	Phytoplankton summer mean chlorophyll *a* (ug/L)	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	TBD	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD
	Invertebrate diversity (TBD)	Poor	n/a	n/a	TBD	TBD
		Fair	n/a	n/a	TBD	TBD
		Good	n/a	n/a	TBD	TBD
		Very Good	n/a	n/a	TBD	TBD
Level of toxins that do not impair populations of significant species	Concentration of cyanotoxins/microcystin (ug/L)	Poor	n/a	n/a	TBD	TBD
		Fair	n/a	n/a	TBD	TBD
		Good	n/a	n/a	TBD	TBD
		Very Good	n/a	n/a	TBD	TBD
	Concentration of methylmercury in sediment (ng/g)	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	TBD	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Unimpounded Marsh Complex						
Maintain Natural Hydrologic Regime	Period in which complex is moist to inundated in most years	Poor	<=Apr – May	<=Apr – May	<=Apr – May	<=Apr – May
		Fair	April–June	April–June	April–June	April–June
		Good	Apr -early Jul	Apr -early Jul	Apr -early Jul	Apr -early Jul
		Very Good	TBD	TBD	TBD	TBD
	Deviation from natural hydrograph for a given storm event (TBD)	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	TBD	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD
Delivery of high quality water by tributaries into marshes and eventually the lake.	Stream visual assessment protocol scores of streams throughout watershed feeding wetlands	Poor	0–6	0–6	0–6	0–6
		Fair	6.1–7.4	6.1–7.4	6.1–7.4	6.1–7.4
		Good	7.5–8.9	7.5–8.9	7.5–8.9	7.5–8.9
		Very Good	9–10.4	9–10.4	9–10.4	9–10.4
Diversity of habitat types	Presence of hemi-marsh, submerged aquatic vegetation, short emergent, tall emergent, wet meadows at average lake levels	Poor	<3 present	<3 present	<3 present	<3 present
		Fair	3	3	3	3
		Good	4	4	4	4
		Very Good	5	5	5	5
Dominance of native and desirable nonnative plant species	Percentage cover of native and desirable nonnative plant species	Poor	<50%	<50%	<50%	<50%
		Fair	50%–74%	50%–74%	50%–74%	50%–74%
		Good	75%–90%	75%–90%	75%–90%	75%–90%
		Very Good	>90%	>90%	>90%	>90%
Forage fish supportive of fish-eating birds	TBD	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	TBD	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD
Healthy macroinvertebrate population supportive of waterfowl and other waterbirds	Total biomass g/m^2	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	1.5–2.5	1.5–2.5	1.5–2.5	1.5–2.5
		Very Good	TBD	TBD	TBD	TBD
Sufficient habitat to support significant shorebird populations	Acreage of habitat between 4,200 and 4,218 (thousand acres)	Poor	<6	<2	<6	<14
		Fair	6–9	2–3	6–8	14–20
		Good	9–11	3–4	8–11	20–26
		Very Good	>11	>4	>11	>26

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Impounded Wetlands						
Dominance of native and desirable nonnative plant species	Percentage cover of native and desirable nonnative plant species	Poor	<50%	<50%	<50%	<50%
		Fair	50%–74%	50%–74%	50%–74%	50%–74%
		Good	75%–89%	75%–89%	75%–89%	75%–89%
		Very Good	90%–100%	90%–100%	90%–100%	90%–100%
Food supply supportive of fish, waterfowl, and other waterbirds	Macroinvertebrate (non-gastropods) biomass (g/m^2) in upstream ponds in July/August	Poor	<0.5	<0.5	<0.5	<0.5
		Fair	0.5–1.5	0.5–1.5	0.5–1.5	0.5–1.5
		Good	1.5–2.5	1.5–2.5	1.5–2.5	1.5–2.5
		Very Good	>2.5	>2.5	>2.5	>2.5
	SAV tuber biomass (kg/m^2)	Poor	<2.5	<2.5	<2.5	<2.5
		Fair	2.5–12	2.5–12	2.5–12	2.5–12
		Good	12–24	12–24	12–24	12–24
		Very Good	>24	>24	>24	>24
	SAV druplet biomass in September (kg/m^2)	Poor	<5	<5	<5	<5
		Fair	5–20	5–20	5–20	5–20
		Good	20–29	20–29	20–29	20–29
		Very Good	>29	>29	>29	>29
	Fish indicator TBD	Poor	TBD	TBD	TBD	TBD
		Fair	TBD	TBD	TBD	TBD
		Good	TBD	TBD	TBD	TBD
		Very Good	TBD	TBD	TBD	TBD
Healthy SAV community	SAV branch density (thousand branches with leaves/m^2) in upstream ponds in July/August	Poor	<10	<10	<10	<10
		Fair	10–35	10–35	10–35	10–35
		Good	35–59	35–59	35–59	35–59
		Very Good	>60	>60	>60	>60
Delivery of high quality water by tributaries into marshes and eventually the lake.	SVAP of streams throughout watershed feeding wetlands	Poor	0–6	0–6	0–6	0–6
		Fair	6.1–7.4	6.1–7.4	6.1–7.4	6.1–7.4
		Good	7.5–8.9	7.5–8.9	7.5–8.9	7.5–8.9
		Very Good	9–10.4	9–10.4	9–10.4	9–10.4
Mudflats and Playas						
Sufficient habitat near freshwater for Snowy Plover population and other shorebirds	Acreage of mudflat habitat within 100 m of perennial freshwater (thousand acres)	Poor	<4	<2	<2	<13
		Fair	4–7	2–3	2–3	13–18
		Good	7–8	3–4	3–4	18–23
		Very Good	8–9	4–5	4–5	23–25

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Absence of *Phragmites*	Percentage cover of *Phragmites*	Poor	50%–100%	50%–100%	50%–100%	50%–100%
		Fair	25%–50%	25%–50%	25%–50%	25%–50%
		Good	10%–25%	10%–25%	10%–25%	10%–25%
		Very Good	0%–10%	0%–10%	0%–10%	0%–10%
Alkali Knolls						
Extensive enough to support migratory shorebirds as a refugia during high lake levels (4,205 and above)	Acreage of alkali knolls (thousand acres)	Poor	<14	<0.7	<5	<3
		Fair	14–20	0.7–1	5–7	3–5
		Good	20–26	1–1.5	7–9	5–6
		Very Good	26–29	>1.5	9–10	6 –7
Isolated Island Habitat for Breeding Birds						
Lake levels protective of isolated island habitat	Lake level (MSL) to occur no more than once per generation of significant species	Poor	<4,193	<4,193	n/a	n/a
		Fair	>4,204	4,193–4,195	n/a	n/a
		Good	4,193–4,195	4,195–4,198	n/a	n/a
		Very Good	4,195–4,204	>4,198	n/a	n/a
Lack of predators on islands	Absence of predators	Poor	Predators present on all islands	Predators present on Gunnison Island	n/a	n/a
		Fair	Predators present on most islands	No rating	n/a	n/a
		Good	Predators absent on most islands	No rating	n/a	n/a
		Very Good	Predators absent on all islands	Predators absent on Gunnison Island	n/a	n/a
Adjoining Grasslands and Agricultural Lands						
Enough foraging habitat for white ibis, long-billed curlews, and Franklin gull	Acreage of flood irrigated agricultural land (thousand acres)	Poor	<3	n/a	<1.5	<4
		Fair	3–4	n/a	1.5–2	4–6
		Good	4–5	n/a	2–3	6–8
		Very Good	Unknown	n/a	Unknown	Unknown
Vegetation composition	Percent cover of native and desirable nonnative vegetation (bunchgrasses, desirable forbs, desirable grasses, and agricultural species)	Poor	<50%	<50%	<50%	<50%
		Fair	50%–74%	50%–74%	50%–74%	50%–74%
		Good	75%–89%	75%–89%	75%–89%	75%–89%
		Very Good	90%–100%	90%–100%	90%–100%	90%–100%

Table 11. Detailed Summary of Indicators, Indicator Ratings, and Current Health Status for Great Salt Lake

Key Attribute	Indicator	Rating Category	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
Enough breeding habitat for current population of long billed curlew with low levels of human disturbance on the wetland-upland interface	Acreage of grasslands and pasture at least 150 meters from residential and commercial development for curlews (thousand acres)	Poor	<6	<0.6	<4	<6
		Fair	6–8	0.6–0.8	4–6	6–9
		Good	8–11	0.8–1.0	6–8	9–13
		Very Good	TBD	TBD	TBD	TBD

Note: If current data are available, the current condition is noted by coloring the appropriate indicator box.
MeHg = methylmercury
ng = nanogram
ppm = parts per million
ww = wet weight

FUTURE STRESSES

Every natural system is subjected to various disturbances. However, only the destruction, degradation, or impairment that is caused directly or indirectly by human sources is considered a stress. Stresses are caused by incompatible human uses of land, water, and natural resources. Every stress impairs a key ecological attribute associated with an ecological target's size, condition, or landscape context. In a sense, every stress is the opposite or antonym of a key ecological attribute.

Impairment of some ecological targets has already occurred due to past sources of stress, and this impairment is reflected in a fair or poor score of current condition. As part of the CAP process, the Panel participated in a stress assessment based on best professional judgment to identify which key ecological attributes for which ecological targets are likely to get worse, and how much worse. A stress might be caused by either a currently ongoing source that is likely to get worse or by a future source. As is typical with CAP processes, stresses were assessed based on their potential impact over the next 10 years, assuming continuation of existing management policies and practices, or those deemed likely to be in place.

The relative seriousness of future stresses is a function of two variables:

- **Severity of damage:** What level of damage to the ecological target can reasonably be expected within 10 years under current circumstances? Elimination or destruction (very high), serious degradation (high), moderate degradation (medium), or slight impairment (low)?
- **Scope of damage:** What is the geographic scope of impact to the ecological target expected within 10 years under current circumstances? Is the stress pervasive throughout the ecological target's occurrence (very high), widespread (high), localized (medium), or very localized (low)?

Stresses are ranked using a four-grade scale of very high, high, medium, and low (see Appendix B). An overall high ranked stress requires a combination of both a high severity and scope (or a very high rating for one factor and high rating for the other). On the other hand, a low rating for either severity or scope generates an overall low ranked stress. Stresses were summarized by bay and ecological target based on summarizing the individual stress rankings for each ecological attribute. The weighting for individual stress rankings was as follows: 1 for each low, 2.75 for each medium, 3.5 for each high, and 4 for each very high.

Stresses to all of the ecological targets were identified, discussed, and ranked by the Panel, using the best available information and best professional judgment. Details on the rationale for each stress ranking are provided in Appendix B. In general, the highest stresses were associated with invasive plant species and reduced lake levels. Farmington Bay was found to face the highest future stress, followed by Gilbert Bay. Gunnison Bay in general is expected to face low future stress (Table 12).

Table 12. Summary of Stresses to Great Salt Lake Ecological Targets Summarized by Bay

Ecological Targets	Gilbert Bay	Gunnison Bay	Bear River Bay	Farmington Bay	SUMMARY	Uncertainty[1]
System-wide lake and wetland	Medium				Medium	Medium
Open water of bays	High	Low	High	High	High	High
Unimpounded marsh complex	High	Low	Medium	High	Medium	High
Impounded wetlands	Very High	Low	Medium	Very High	High	Medium
Mudflats and playas	Medium	Low	High	Very High	High	Medium
Isolated island habitat for breeding birds	Very High	Very High	n/a	n/a	Very High	Low
Alkali knolls	High	Low	High	Very High	High	Low
Adjoining grasslands and agricultural lands	High	Low	Low	Medium	Medium	Low
SUMMARY					**High**	**Medium**

[1] Ecological targets with very high uncertainty are those for which more than half of the stresses could not be evaluated. Those with Low uncertainty are those for which all stresses could be evaluated. Ecological targets with medium uncertainty are those for which one or two indicators could not be evaluated. Ecological targets with high uncertainty are those with more than one but less than half of the stresses evaluated. See Appendix B for a detailed summary of stresses for each ecological target and bay.

Many targets faced high to very high ranked stresses. In general, the highest ranked projected stresses to Great Salt Lake ecosystems include the following:

- Very high stresses
    - Reduced lake levels that could cause myriad impacts on the ecosystem, including changes in salinity, increased vulnerability to predators of nesting birds on isolated islands, and stress to the brine shrimp population in Gilbert Bay
    - Increased *Phragmites* and other undesirable plant cover throughout the habitats surrounding the lake and especially around Farmington Bay, also a consequence of reduced lake level
    - Additional permanent loss of alkali knolls especially in Farmington Bay where there has already been significant habitat loss and where development pressure is highest

- High stresses
  - Reduced period of moisture for the unimpounded marsh complex especially in Farmington and Bear River bays
  - Reduced diversity and amount of habitat types in Farmington Bay unimpounded wetlands
  - Loss of habitat to support significant bird populations around Farmington and Bear River bays
  - Additional permanent loss of alkali knolls adjoining Gilbert and Bear River bays
  - Reduced flood-irrigated area around Gilbert Bay, which is important habitat for White-faced Ibis
  - Reduced water quality delivered to Farmington Bay impounded wetlands, unimpounded marsh complex, and open water
  - Increased undesirable plant cover in Farmington Bay grasslands and pasture
  - Reduced acreage of undisturbed Long-billed Curlew breeding habitat in grasslands and pasture adjoining Gilbert Bay

RESEARCH PRIORITIES

Although the Panel made excellent strides in assessing the health of Great Salt Lake ecosystems, many important questions remain unanswered. The CAP framework provides an indirect means of identifying key research priorities to help answer these important questions.

The Panel reached an agreement on the key ecological attributes required for ecosystem health, as well as indicators for most key attributes. However, it did not have the information or data to determine the indicator ratings for many key attributes. In other cases, sufficient information may have been available to develop the indicator ratings for one or two of the bays, but not the others. All of these missing links are reflected in the TBD (To Be Determined) entries in Table 11 (see Appendix A for rationales). Overall, TBD ratings were reflected for approximately one-third of the key ecological attributes. In the absence of indicator ratings, especially for good and poor condition, it is not possible to measure the health of a given key attribute.

In assessing future stresses, the Panel also engaged in considerable dialogue. However, in several instances, members of the Panel felt that they did not have sufficient knowledge to make an informed assessment. In these instances, the Panel judged the stress rank as unknown (Table 12).

The combination of unknown stress rankings (Appendix B) and TBD indicator ratings (Appendix A) provides a framework for helping establish top research priorities. All other things being equal, research should first be directed toward determining what constitutes good and poor condition for a key ecological attribute with a TBD indicator rating that also is expected to face high future stress. Using this approach, the top research priorities can be established as follows:

- High: Any key ecological attribute rated TBD across all four bays with a high ranked stress in at least one bay
- Medium: Any key ecological attribute rated TBD with future stress rated unknown
- Low: All other stresses rated unknown

Table 13 shows the highest priorities for future scientific research to more fully assess the health of Great Salt Lake using the criteria described above. Research priorities can be further refined by the potential availability of funding and lead researchers.

Table 13. Research Priorities

Priority*	Research Need
High	Level of toxins in water column and sediment that does not impair populations of significant species and current concentrations throughout the lake. These toxins include mercury (including methylmercury), arsenic, cyanotoxins, and avian botulism.
High	Maximum level of phytoplankton in winter and in summer that is healthy for Farmington, Bear River, and Gilbert bays
High	Brine fly larvae populations sufficient to support waterbirds
High	Forage fish (quantity and species) supportive of fish-eating birds in open water, unimpounded marsh complex, and impounded wetlands
High	Trophic condition supportive of native biota, especially in Farmington and Bear River bays, including thresholds for indicators such as summer chlorophyll *a* concentrations and invertebrate diversity
High	Sufficient surface area of stromatolitic structures supportive of the food chain (used for periphyton growth)
High	Linkage between submerged aquatic vegetation branch density and other measures of support for the food web in impounded wetlands and in the open water of Bear River and Farmington bays
High	Indicator of water quality delivered to unimpounded marshes and impounded wetlands. Impacts of various parameters such as toxics, nutrients, and sediments on wetland functions.
Medium	Impacts of flashy (high and fast peak flow) storms on bird nests in unimpounded wetlands and an appropriate indicator to measure deviation from the natural hydrograph
Medium	Healthy macroinvertebrate population supportive of waterfowl and other waterbirds in unimpounded marsh complex
Medium	Projected changes to hydrologic regime based on planned water development in the Great Salt Lake basin. This includes the likelihood of change to the timing or period of inundation of unimpounded marsh complexes
Low	Projected change in mudflat and playa habitat in the future

* Research priorities ranked as high are those for which the key ecological attribute is rated TBD across all four bays AND with a high ranked stress. Research priorities ranked as medium are those for which the key ecological attribute is rated TBD with future stress rated Unknown. Low research priorities are all other stresses rated as unknown.

RECOMMENDATIONS

This project represents a first iteration of a definition and assessment of health of Great Salt Lake related to ecology (e.g., birds, stromatolitic structures and brine shrimp) based on the best science available to the Panel as of December 2011. Ongoing research on the lake and its surrounding habitats, and the need to examine health with regard to other lake uses, will no doubt lead to the need to modify and improve the definition. The method used to define and assesses health is based on the first several steps in the Conservation Action Planning (CAP) process. The CAP workbook, delivered to the Great Salt Lake Advisory Council with this report, is set up to continue the process by identifying key sources of stress to the lake and developing effective strategies to evaluate lake health. The CAP workbook will be most useful as a dynamic, adaptive management tool that is periodically updated by a body of active research scientists and used by lake managers in broad scale lake planning, including future revisions the Great Salt Lake Comprehensive Management Plan by the Division of Forestry, Fire, and State Lands.

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Appendix A

Rationale for Key Ecological Attributes, Indicators, Ratings, and Current Condition Data

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Rationale for Native and Desirable Vegetation Cover Thresholds

Nonnative weed cover in wetland habitats is of concern due to decreased habitat quality for birds and other wetland species (Bertness et al. 2002) and due to impacts to Great Salt Lake as part of the Western Hemisphere Shorebird Reserve Network (Aldrich and Paul 2002). Invasive nonnative plant species impact biodiversity by altering nutrient cycles (Hooper and Vitousek 1998), and through competitive effects that alter community productivity, structure and functioning, and that threaten the resiliency of the system to perturbation (Tilman et al. 1997, Tilman 1999, Simberloff 2005).

At approximately 50% cover, invasive plant species have been shown to be significantly correlated with exponential declines in native vegetation diversity, cover, and biomass in sagebrush steppe communities (Davies 2011).

The key ecological attributes (KEA) thresholds for native vs. invasive plant cover were based on a literature review as well as the best professional judgment of the Advisory Panel (Hoven et al. 2011). These KEA thresholds are similar to those identified by Hoven and Paul (2010) in the Utah Wetlands Ambient Assessment Method;

- Hoven and Paul (2010) identified an upper threshold of 0%–5% (invasive plant cover) to represent a very good condition due to the disproportionate impacts of Phragmites on native wetland habitats at relatively low cover, and that the invasion can be relatively easily managed at low densities and does not impair the significant species.
- The ranking for good (5%–25% invasive plant cover) represents a condition in which some declines in native plant diversity, cover, and biomass have likely occurred, but the invader can be managed and does not likely directly impair the significant species.
- The threshold for fair (25%–50% invasive plant cover) represents a condition in which significant declines in native plant diversity, cover, and biomass have likely occurred (Davies 2011), and management to restore the system to good condition would require considerable inputs. Habitat for the significant species is significantly degraded or lost.
- A threshold of greater than 50% cover of invasive plant species was used as the ranking for poor because at this level of cover (a surrogate measure of biomass), the invader has likely caused profound changes in plant community species richness and diversity, as well as in overall vegetation structure and ecological functioning (Hejda et al. 2009). Habitat for significant species has been lost. The 50% cover threshold is a conservative threshold for large stature, rapidly spreading invasive species like *Phragmites.* Large invasive plant species have been shown to have significantly greater effects on species diversity than smaller invasive plants (Hejda et al. 2009).

Rationale for Habitat Extent Thresholds

Great Salt Lake is of regional and hemispheric biological importance due to its role as a major North American migratory bird flyway and as vital shorebird breeding habitat. The location of Great Salt Lake's alkaline and saline wetlands within an inland landscape is unique in North America and its location in the Great Basin desert provides a vitally important stopover for millions of migratory birds. For this reason, the conservation value of these habitats is vastly greater than the relatively tiny proportion of the landscape they occupy. The high ecological value of the ecological targets selected for Great Salt Lake has been quantified in the indicator ratings by setting relatively high minimum habitat loss thresholds. The rationale for these thresholds is described here.

For the whole Great Salt Lake system, overall habitat loss from historic conditions has been approximately 10%–30% with considerably greater loss at the higher elevation ranges around the lake. The indicator rating for very good for all ecological targets is the historic acreage of the habitat (i.e., no loss), which was estimated as the proportional acreage of natural habitats that would have occupied the entirety of a given elevational range, for example, 1,277–1,280 m (4,191–4,200 feet), 1,280–1,283 m (4,200–4,209 feet), and 1,283–1,286 m (4,209–4,218 feet).

Existing habitat acreages (including the losses of 10%–30%) have been used as the ranking for *good* for most ecological targets (using acres converted to anthropogenic land uses to estimate percent of habitat loss for each bay and elevation range). These values have generally been ranked as good because they appear to be supporting existing populations of the significant species. In one exception, the indicator rating for good for alkali knolls was based on the acres of the habitat that existed in the late 1980s during the most recent high lake level event. This rating assumes that the acres of alkali knolls that were available to the significant species at that time provided sufficient refugia to support them until lake levels dropped.

The indicator rating for poor is the 50% habitat loss threshold described below. However, where bird count and nest density data were available, the project used the minimum acreage required to support peak abundance of birds for a given significant species in its breeding habitat as the indicator rating for poor. Habitat size indicator ratings were based on habitat- or species-specific data where available. The 50% habitat loss threshold indicator rating for poor, described below, was used where habitat- or species-specific data were not available and minimum habitat size requirements could not otherwise be inferred.

50% Habitat Loss from Historic Poor Rating Threshold Rationale

A loss of 50% or more of total habitat acreage was used as the threshold for poor for the indicator ratings for several ecological targets. The 50% habitat loss threshold was selected because at this level of habitat loss in the Great Salt Lake system, some or all of the following parameters are likely to contribute to the decline and potential extinction of significant species. These parameters include the following:

- Habitat loss/reduction effects:
    - Reduced habitat quality for breeding and foraging (patch size effects)
    - Increased territory/habitat size requirements per individual due to reduced habitat quality
    - Reduced number of breeding territories of sufficient size
    - Increased competition between nesting pairs and foraging individuals
- Habitat fragmentation effects:
    - Increased habitat edge and reduced patch size
    - Reduced buffering capacity of agricultural matrix habitats (conversion to urban/industrial uses)
    - Increased impacts to habitat quality from invasive and generalist species (edge effects)
    - Increased habitat-related mortality/emigration (roads, predators, insufficient resources)
    - Increased Allee effects due to habitat fragmentation/isolation and habitat-related mortality

These effects may be more or less pronounced depending on the species' biology; behavior (territory requirements, breeding competition, brooding movements, etc.), ecological system, and type of matrix habitat associated with habitat fragments or edges (*sensu* Rhodes et al. 2008). A 50% threshold was selected as a conservative level at which some or all of the parameters listed above, and synergistic effects among multiple parameters, are likely to cause population declines. The 50% threshold also allows for delayed population responses to habitat loss (extinction debt; Tilman and May 1994), where the high threshold would illuminate potentially detrimental changes to habitat conditions before habitat loss has caused populations to cross extinction thresholds.

Habitat thresholds for species persistence range from ca. 20% to 75% (Fahrig 2001 and references therein). There is not a common threshold value that can be applied across species (Fahrig 2001, With and King 1999).

- Jager et al. 2006 identified threshold changes in animal survival and reproduction with the loss of 50% of habitat.

- The threshold at which Allee effects may be approaching a critical threshold indicating that population density is too low so that some fraction of eligible females fails to mate (ca. 20% at 50% habitat loss in Jager et al. 2006).

- Habitat quantity has been found to have a consistently positive effect and is the most important feature of forest bird populations in large landscapes (Smith et al. 2011). Habitat fragmentation has been found to exert greater influence on forest birds in small landscapes, but for some species habitat loss is important at all scales (Smith et al. 2011).

- Numerous conservation modeling studies have demonstrated the relative importance of habitat loss versus habitat fragmentation for conserving species (McGarigal and McComb 1995, Fahrig 1997; Fahrig 2001; Jager et al. 2006, Smith et al. 2011).

- Fahrig (1997) suggests as a general rule: breeding habitat should occupy 20% of the landscape (in any configuration) to ensure survival. Habitat specialists whose breeding habitats historically occupied less than 20% of the landscape are more vulnerable to habitat loss (Fahrig 1997). For these species *any* loss of habitat from existing conditions is potentially detrimental to population persistence. Great Salt Lake's unique habitats historically occupied a small proportion of the greater landscape, with current habitats certainly making up less than 20% of the urbanized Salt Lake Valley.

Table A1. Current and Historic Acreages for Great Salt Lake Ecological Targets

	Gilbert Bay	Gunnison Bay	Farmington Bay	Bear River Bay
TOTAL CURRENT				
Alkali knolls	18,200	1,566	3,453	2,343
Adjoining grasslands and agricultural lands	19,429	1,822	12,112	23,265
Pasture and grasslands for Long-billed Curlew breeding habitat >150 meters from development	*11,255*	*1,168*	*8,377*	*12,837*
Flood Irrigated Land	*5,268*	-	*3,095*	*8,325*
Mudflats and playas	186,780	172,858	76,733	108,669
Mudflats and Playas within 100 meters of water	*8,116*	*4,933*	*4,714*	*21,132*
Open Water of bays	52,970	38,630	17,978	1,619
Other	55,489	86,500	2,009	16,871
Unimpounded marsh complex	10,744	4,399	10,972	24,579
TOTAL HISTORIC				
Alkali knolls	28,768	1,566	10,310	6,654
Adjoining grasslands and agricultural lands	22,832	1,822	13,462	25,300
Pasture and grasslands for Long-billed Curlew breeding habitat >150 meters from development	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Flood Irrigated Land	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Mudflats and playas	205,461	173,086	77,178	125,861
Mudflats and Playas within 100 meters of water	*9,224*	*4,939*	*4,866*	*25,131*
Open water of bays	53,832	38,631	17,978	1,880
Unimpounded marsh complex	12,438	4,406	11,624	28,629

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
System wide Lake and Wetlands			
Condition: Levels of toxins that do not impair significant species Concentration of selenium in bird eggs (mg/kg dry weight)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	The very good condition, 3 mg/kg, was determined to be background concentration. The fair condition, 6.4 mg/kg, is projected to cause a reduction in hatchability by 2%. It is the concentration at which a Level II Antidegradation review is initiated for all additional permits. Concentrations below 6.4 are assumed to prevent impairment of aquatic wildlife, including birds at Great Salt Lake. The good condition is between fair and very good. The poor condition, 12.5 mg/kg, is the tissue-based standard based on the complete egg/embryo of aquatic-dependent birds that use the waters of Gilbert Bay, Great Salt Lake. It is projected to cause a reduction in hatchability of 10%. Note: This target for Se does not take into account interactions between selenium and other toxins, such as mercury.	UDWQ selenium standard. http://www.deq.utah.gov/Issues/GSL_WQSC/docs/GLS_Selenium_Standards/index.htm Data used for current ranking: UDWQ egg monitoring program
Condition: Levels of toxins that do not impair significant species Concentration of methylmercury in bird eggs (pp MeHg)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds. Concentrations of methylmercury in bird eggs represent trophic transfer of mercury in birds while they are at Great Salt Lake during a critical life stage.	The very good condition of concentration of methylmercury (MeHg) in bird eggs is 0–0.5 ppm, which has a higher range than the EPA's standard of 0.3 ppm. Loon populations were observed to have a 0.2–0.3 ppm lowest observed adverse effect limit (LOAEL) for reproduction. The lethal concentration for 50% of test species (LC50) falls within this range for the following species: White Ibis, Snowy Egret, Osprey, Tri-colored Heron, Ring-necked Pheasant. Common Grackle, Herring Gull, Tree Swallow, Clapper Rail, and the Royal Tern (UDWQ 2011 and sources cited therein including Evers et al. 2004). The good condition is 0.5–1.3 ppm of MeHg. LOAEL for reproduction and growth have been observed within this range for Mallard and other birds. LC50 falls within this range for Canada Goose, Sandhill Crane, Hooded Merganser, Anhinga, Common Tern, Brown Pelican, and the Laughing Gull (UDWQ 2011 and sources cited therein including Evers et al. 2004). The fair condition has a concentration range of MeHg of 1.3–2.0 ppm. At this level, impacts have been observed on reproductive rates for the Ring-necked Pheasant and the Common Loon. LC50 has been observed in the Lesser Scaup and the Mallard (UDWQ 2011 and sources cited therein including Evers et al. 2004). The poor condition is defined as concentrations of MeHg of greater than 2.0 ppm. At this level, LC50 has been observed in Double-crested cormorant (2.42 ppm) and the American avocet (4.33 ppm). At 3.5 ppm, a 73% hatch failure was observed in the Common Tern and neurological impacts were observed in Mallards at 2.3 ppm (UDWQ 2011 and sources cited therein).	Evers, D. C., O. P. Lane, L. Savoy and W. Goodale. 2004. Assessing the impacts of methylmercury on piscivorous wildlife using a wildlife criterion value based on the Common Loon, 1998–2003. Report BRI 2004–05 submitted to the Maine Department of Environmental Protection. BioDiversity Research Institute, Gorham, Maine. UDWQ 2011. Ecosystem assessment of mercury in the Great Salt Lake, Utah 2008.
Condition: Levels of toxins that do not impair significant species Concentration of methylmercury in bird liver (ppm MeHg)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	The very good condition of concentration of methylmercury (MeHg) in bird livers is less than 0.89 ppm at which no known impacts upon bird species in the Great Salt Lake environment have been observed. The good condition is 0.89–<2.0 ppm of MeHg. LOAEL for reproduction have been observed at 0.89 ppm for Mallards and the no observed adverse effect limit for the Common tern was observed at 1.06 ppm (UDWQ 2011 and sources cited therein). The fair condition has a concentration range of MeHg of 2.0–6.0 ppm. At this level, reproductive impacts have been observed in Pheasants and Mallards, and effects upon hatchability of the Common loon have been observed as low as 5.0 ppm (UDWQ 2011 and sources cited therein). The poor condition is defined as concentrations of MeHg of greater than 6.0 ppm. At this level, a correlation has been observed with mortality and chronic disease and increased disease and emaciation in the Great White Heron, reduced nesting success has been observed in the Common tern, and impacts upon growth, appetite, and hygiene have been observed in Great egrets (UDWQ 2011 and sources cited therein). Liver samples from Northern Shovelers and Cinnamon Teals collected by the State of Utah recently were all less than 0.89 ppm (UDWQ 2011 and sources cited therein).	Evers, D. C., O. P. Lane, L. Savoy and W. Goodale. 2004. Assessing the impacts of methylmercury on piscivorous wildlife using a wildlife criterion value based on the Common Loon, 1998–2003. Report BRI 2004–05 submitted to the Maine Department of Environmental Protection. BioDiversity Research Institute, Gorham, Maine. Data used for current ranking: UDWQ 2011. Ecosystem assessment of mercury in the Great Salt Lake, Utah 2008.
Condition: Levels of toxins that do not impair significant species; avian botulism Mortality from avian botulism (number of birds killed per year)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	Avian botulism (botulism) is a paralytic disease of birds that results from the ingestion of a toxin produced by the bacterium *Clostridium botulinum*. Filter-feeding waterfowl and probing shorebirds are among the species at greatest risk and die-offs of these species could be a good indicator of presence of botulism Die-offs often indicative of botulism are typified by lines of carcasses coinciding with receding water levels and have been associated with blooms of cyanobacteria (Murphy et al. 2000). Outbreaks occur almost yearly in Utah, typically between July and September and estimated losses of birds have been reported in the hundreds of thousands. The number of dead birds during an outbreak is an indicator of the severity of a botulism outbreak. Indicator rankings could not be determined for this project.	United States Geologic Survey, 2000. Field Manual of Wildlife Diseases: General Field Procedures and Diseases of Birds. Chapter 38: Avian Botulism. Utah Division of Wildlife Resources. 2011. Wildlife Diseases in Utah: Avian botulism. Accessed online: http://wildlife.utah.gov/diseases/avian_botulism.php. Murphy, T., A. Lawson, C. Nalewajko, H. Murkin, L. Ross, K. Oguma, and T. McIntyre. 2000. Algal toxins—initiators of avian botulism? Environmental Toxicology and Chemistry 15:558–567.
Condition: Safe level of toxins Other toxins (EDCs, estrogens, organics, other metals such as; arsenic of concern)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	As additional toxins are identified in the Great Salt Lake system, additional standards and thresholds of health will need to be identified. Diaz et al. 2009 summarize concentrations of other trace elements present in the Great Salt Lake system. Naftz 2008 identified several emerging contaminants (EC) (organic compounds including hormones, food additives, detergents, and pharmaceuticals) present in the Great Salt Lake at much higher concentrations than national averages. ECs included coprostanol (fecal steroid from wastewater treatment), cholesterol, triclosan, and 4-n-octylphenol (endocrine disruptor). ECs found in Great Salt Lake brine shrimp included Phenol, d-limonene, and other compounds with potential origins of crude oil and coal tar.	Diaz, X., W. Johnson, D. Fernandez, and D. Naftz. 2009. Size and elemental distributions of nano- to micro-particulates in the geochemically-stratified Great Salt Lake. Applied Geochemistry 24: 1653–1665. Naftz, D.L., 2008, Loading and biogeochemical cycling of anthropogenic contaminants in Great Salt Lake (abstract), Annual Meeting of the European Geosciences Union, Vienna, Austria.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Landscape context: Lake level fluctuation regime Frequency of achieving modern high and/or low lake levels; annual lake level fluctuation.	Lake fluctuations are natural, to be expected, and are an integral component of the lake system. Fluctuating lake levels are integral to the dynamic nature of shoreline habitat, reduction of nonnative species (e.g., *Phragmites*), and periodic connectivity between the four bays of the lake. Lake level affects many of the other attributes identified in this health definition.	The very good rating was not determined. Historic fluctuation patterns are generally considered to be good. These fluctuations occur on a seasonal (intrannual), annual, and decadal time frame. Seasonally, the spring runoff period should result in lake levels increasing by 7–10 inches over 3 months (spring minimum to average between 1904 and 2010). The runoff helps to wash brine shrimp cysts from surrounding mudflats into the lake and also provides a flush of fresh water to Bear River and Farmington Bays. These seasonal patterns are considered to be healthy for the lake ecosystem. Regular annual fluctuation of the lake represents a less managed and modified hydrology of the system. Annually, the lake has fluctuated on average by 1.6 feet per year. Annual fluctuations of this magnitude (1–2 feet) are considered good. Finally, on a decadal scale the lake reaches extreme high and low levels every 30–100 years. Fluctuation of the lake between the modern high and low levels (1858–2008) has generally been supportive of the natural ecological targets around Great Salt Lake. However, inundation of impounded wetlands by high lake levels is detrimental and would have multi-year impacts on birds that use them. Therefore, the good condition is set at a multidecadal fluctuation up to 4,204 down to the modern low of 4,191. A poor condition is one in which the lake never achieves 4,204 or drops to 4,191 and does not experience interannual or seasonal fluctuation.	USGS gage data 10010000 Data used for current ranking: USGS gage data 10010000
Size: Lake volume and area sufficient to support aquatic and wetland habitats and their significant species Average lake level measured at Salt Air over 10 years (feet above MSL)	Lake volume and area are key determinants of many of the KEAs identified in this definition.	Using the resource matrix developed for the Great Salt Lake CMP, we identified the range of lake levels (directly tied to lake area and volume) that are beneficial to most of the ecological targets and their significant species. It is important that the area and volume of each bay be assessed independently because of the different habitats that each provide.	Division of Forestry, Fire and State Lands 2011. Lake level resource matrix. In *Draft Great Salt Lake Comprehensive Management Plan Revision*. Salt Lake City: Utah Department of Natural Resources, Division of Forestry, Fire and State Lands. Data used for current ranking: USGS gage data 10010000
Open Water of Bays			
Condition: Salinity levels supportive of native biota Average salinity from April through October (%)	In Gilbert and Gunnison Bays, salinity is a key determinant of brine shrimp and brine fly populations, both directly on their physiology, and indirectly via its effect on nutrients and phytoplankton. The shrimp and flies, in turn support large populations of many birds that utilize the lake.	Very good salinity is defined as the optimal salinity for adult brine shrimp (based on salinity effects on nutrients and phytoplankton) as demonstrated by lab and *in situ* ecosystem studies (Belovsky et al. 2011; Belovsky and Perschon in review). Note: Salinity range may be lower than the optimal salinity range for the brine shrimp harvest. In Gilbert Bay: poor = <8% or >19%; fair = 8%–10% or 16%–19%; good = 9%–12% or 14%–16%; very good = 12%–14% (current ranking = very good). In Gunnison Bay: poor > 19% at high lake levels; fair = 8%–10% or 16%–19% at high lake levels; good = 9%–12% or 14%–16% at high lake levels; very good = 12%–14% at high lake levels. Salinity levels supportive of brine fly larvae are less well documented.	Belovsky, G.E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Van Leeuwen, and D.V. Allen. 2011. The Great Salt Lake ecosystem (Utah, USA): Long term data and a structural equation approach. Ecosphere 2(3) (1-40, art33. doi:10.1890/ES10-00091.1) Belovsky, G.E., and C. Perschon. In review. A management case study for a new fishery: brine shrimp harvesting in the Great Salt Lake. Ecological Applications. Belovsky email 11/13/11. Data used for current ranking: UGS salinity data 2008–2010
Condition: Salinity levels supportive of native biota Salinity gradient across the bays that support invertebrates, fish, and macrophytes	In Bear River and Farmington Bays there needs to be a salinity gradient that supports the native biota. The gradient will vary seasonally with spring inflows and drying periods during other parts of the year.	Very good rating is assumed to be a salinity gradient ranging from fresh to the salinity found in Gilbert Bay. 14% was selected as the upper end to be consistent with the range of very good salinity defined for Gilbert Bay. A good rating is a narrower range of salinity defined as variation of at least 8 percentage points across the bay within the overall natural salinity gradient of 0 to 14% (e.g., 0 to 8% or 2 to 10%). This range of salinity would be broad enough to support a diverse set of biota including macrophytes, macroinvertebrates, and fish in the fresher portions of the bays. A fair condition is one in which the salinity range is very narrow with variation across the bay of 3 to 8 percentage points. A less than 3 percentage points spread across the bay (e.g., 0%–3% or 5%–8%) is considered to be a poor condition because it would reduce the diversity of biota across the bay. Within all of these ranges, the worst condition would be a gradient of 2%–5% because this range would allow for *Nodularia* dominance, a cyanobacteria that produces toxins in these bays (Wurtsbaugh and Marcarelli 2006).	Best professional judgment of the Advisory Panel. Wurtsbaugh, W.A., and A. M. Marcarelli. 2006. *Eutrophication in Farmington Bay, Great Salt Lake, Utah 2005 Annual Report.* Submitted to Central Davis Sewer Improvement District, Kaysville, Utah.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Size: Sufficient surface area of stromatolitic structures supportive of the food chain (used for periphyton growth) Areal extent of living stromatolitic structures	Stromatolitic structures are reef-like structures that form when carbonates precipitate out due to periphyton photosynthesis. They are the principal habitat for brine fly larvae. Brine flies play a critical role in Great Salt Lake food chains and are a major prey of migratory birds.	The area of the reef-like stromatolitic structures in Gilbert Bay were calculated by Wurtsbaugh et al. 2009 to be 261 km^2, and accounts for more than 20% of the lake's littoral zone. More recent unpublished estimates indicate that the areal extent of stromatolitic structures in Gilbert Bay could be as high as 500 km^2 (personal communication Robert Baskin). The health of stromatolitic structures is dependent upon water depth since photosynthesis is necessary for their formation and for periphyton growth. Health of current stromatolitic structures could therefore also be related to lake elevation. (Mean elevation during Wurtsbaugh et al. 2011 study was 1278.6 m and stromatolitic structures were located at water depths 0–3.9 m). Although the areal extent of stromatolitic structures in Gunnison Bay is unknown, it is clear that there are significant occurrences of structures most likely vestigial from periods when Gunnison Bay was less saline. Stromatolitic structures are not known to flourish at salinity levels found in Gunnison Bay, therefore the structures are assumed to be dead and are graded as being in poor condition (personal communication Robert Baskin and Bonnie Baxter). Stromatolitic structures also occur in Farmington Bay (Eardly 1938), but eutrophication in the bay now limits light penetration sufficiently to preclude growth of the periphyton necessary to maintain the structures. The extent to which the structures occur, or occurred historically, in Bear River Bay is unknown. The indicator ratings for both of these bays are therefore TBD.	Wurtsbaugh, W.A. 2009. Biostromes, Brine Flies, Birds and the Bioaccumulation of Selenium in Great Salt Lake, Utah. Pp 1–15 in: Q. Oren, D. Naftz, P. Palacios and W.A. Wurtsbaugh (eds.). Saline Lakes Around the World: Unique Systems with Unique Values. Natural Resources and Environmental Issues, volume XV. Wurtsbaugh, W.A., Gardberg, J., and Izdepski, C. 2011. Biostrome communities and mercury and selenium bioaccumulation in the Great Salt Lake. Science of the Total Environment; v. 409. Eardley, A.J. 1938. Sediments of the Great Salt Lake, Utah. Bull Am Assoc Pet Geol 22:1305–1411. Personal communication between Robert Baskin, Univ. of Utah Department of Geography and Erica Gaddis, SWCA, December 22, 2011 Personal communication between Bonnie Baxter, Westminster College, and Erica Gaddis, SWCA, December 22, 2011
Condition: Phytoplankton biomass supportive of food web Phytoplankton winter maximum chlorophyll *a* (µg/L)	In Gilbert Bay, the phytoplankton food base is the primary determinant of brine shrimp during the foraging period for Eared Grebes and other birds.	Phytoplankton abundance is the foundation of the Great Salt Lake open water ecosystem, i.e., the photosynthesis supporting all biota which, in Great Salt Lake, is limited by the nitrogen concentrations (Belovsky et al. 2011). Because phytoplankton are heavily grazed by brine shrimp to extremely low levels, the lake's potential to produce phytoplankton is more difficult to measure when brine shrimp are present; therefore, maximum phytoplankton abundance (measured as chlorophyll *a*: µg/L) is usually observed in winter. Unlike temperate zone freshwater lakes in winter, where the ice and snow cover limits light penetration and substantial photosynthesis (very low phytoplankton abundance), this is not the case in winter for Great Salt Lake with its high salinity and largely open water. Too low a phytoplankton abundance will not support the open water biota and too high an abundance may be associated with undesirable phytoplankton, such as toxic blue-green algae, or may not be nutritious or edible by brine shrimp (e.g., diatoms). High phytoplankton abundance can also lead to the loss of oxygen in the water column and sediments. The "health" rankings of phytoplankton abundances are based on a relationship between maximum observed chlorophyll *a* in a year and the observed annual abundance of brine shrimp developed using only 1994–2006 GSLEP (UDWR) data reported in Belovsky et al. (2011) and the GSLEP (UDWR) data continued to be collected (2007–2011). Good is defined as the winter maximum phytoplankton (chla ug/L) observed in Gilbert Bay found to be supportive of maximum brine shrimp concentrations in the water that are beneficial to Eared Grebe population. The rating for good (50–60 ug/L) is based on the relationship between this indicator and a healthy brine shrimp population (see brine shrimp indicator). The relationship is based on update to the equation found in Belovksy et al. 2011. The updated asymptotic equation is based on data collected from 1995–2010 and is: Average shrimp density (#/L) = $10.48–142.87/Chla_{max}$ $R = 0.63$, $N = 14$, $p < 0.01$. The poor rating is less than 20 ug/L because this represents phytoplankton levels that would support fewer brine shrimp population. In addition, there is a maximum level of phytoplankton that is undesirable because it reduces the likelihood that brine shrimp will form cysts, which are triggered by a food deficit, and because excessive concentrations of cyanobacteria could lead to concentrations of cyanotoxins that are harmful to birds (see cyanotoxin indicator). However, the threshold beyond which these occur cannot be determined with current data. In addition, the equations developed by Belovksy et al. 2011 could not be used to predict conditions outside of recent conditions in the lake (1995–2010), therefore a very good rating is left TBD. This indicator rating is not appropriate for Farmington and Bear River Bay because brine shrimp growth is not a dominant ecological process here. This indicator is only applicable to Gunnison Bay during high water years when the salinities decrease sufficiently so that the bay can be a refuge for brine shrimp. Note: It should be noted that chlorophyll *a* is not a perfect measurement of phytoplankton and food supply for brine shrimp because different species of phytoplankton carry different concentrations of chlorophyll *a* and because chlorophyll *a* may reside in the water column and sediments after phytoplankton have died. Despite these issues, chlorophyll *a* is the most common and simplest indicator of water column phytoplankton growth. Minority opinion: Wayne Wurtsbaugh raised a concern regarding the reliability of the chlorophyll *a* data used to develop the brine shrimp–phytoplankton regressions in Belovsky et al. 2011, and thus the magnitude and appropriateness of the winter chlorophyll maxima as a reliable predictor. The concern centers on differences in chlorophyll *a* measured by various labs that collect data around the lake including USU, the State of Utah Great Salt Lake Ecosystem project, and USGS. Because none of the data were collected at the same time, it is difficult to determine if these differences represent natural variability in the system or differences in collection and laboratory analysis protocols. This question will require further evaluation or research to resolve and could be best addressed through a round robin sampling effort for the labs in question.	Belovsky, G.E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Van Leeuwen, and D.V. Allen. 2011. The Great Salt Lake ecosystem (Utah, USA): Long term data and a structural equation approach. Ecosphere 2(3) 1-40, art33. doi:10.1890/ES10-00091.1. Belovsky, G.E., and C. Perschon. In review. A management case study for a new fishery: brine shrimp harvesting in the Great Salt Lake. Ecological Applications. Belovsky email 11/13/11. Data used for current ranking: Belovsky and Perschon in review.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Periphyton biomass supportive of food web Chlorophyll *a* in periphyton on stromatolitic structures (g/m^2)	Periphyton support one of two major food chains in Great Salt Lake. Periphyton is an important food source for brine fly larvae. Brine flies are fed upon by many shorebirds.	Assuming that current concentrations of periphyton are supportive of the food web, we have used current data to represent a 'good condition.' Wurtsbaugh 2009 measured 0.7 mg/m^2 of periphyton on stromatolitic structures. Wurtsbaugh et al. 2011 reported a concentration of 0.89 +/- 0.05 g/m^2 from September through December. Good = 0.7–0.9 g/m^2 based on Wurtsbaughs estimates in 2009 and 2011. Very good, fair and poor conditions could not be estimated (TBD).	Data used for current ranking: Wurtsbaugh, W.A., Gardberg, J., and C. Izdepski. 2011. Biostrome communities and mercury and selenium bioaccumulation in the Great Salt Lake (Utah, USA). Science of the Total Environment 409: 4425–4434. Wurtsbaugh, W.A. 2009. Biostromes, Brine Flies, Birds and the Bioaccumulation of Selenium in Great Salt Lake, Utah. Pp. 1–15 In: A. Oren, D. Naftz, P. Palacios and W.A.Wurtsbaugh (eds). Saline Lakes Around the World: Unique Systems with Unique Values. Natural Resources and Environmental Issues, volume XV. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA. URL: http://www.cnr.usu.edu/quinney/files/uploads/NREI2009online.pdf
Condition: Macroinvertebrate biomass and health supportive of food web Submerged aquatic vegetation(SAV) branch density (leaves/m^2)	SAV in Bear River Bay provide important habitat for macroinvertebrates that rely on this substrate to cling to and feed on periphyton. Gastropods, arthropods (including insects, crustacea and ostracods), and juvenile fish (Hoven et al. 2011) utilize this microhabitat.	Branch density is a more sensitive measure of health than percentage cover and is an early season indicator of overall health of open water habitats in Bear River Bay, and is an early indicator of excess nutrients, toxins, and sediment (Hoven et al. 2011; Hoven personal communication). Bear River Bay: indicator rankings TBD.	Hoven, H. 2011. Director of Institute for Watershed Sciences. Ogden, Utah: Visiting Research Professor, Weber State University, Department of Botany. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Hoven, H., D. Richards, W.P. Johnson, and G.T. Carling. 2011. Plant Metric Refinement for Condition Assessment of Great Salt Lake Impounded Wetlands. Submitted to Jordan River/Farmington Bay Water Quality Council.
Condition: Invertebrate population sufficient to support water birds such as Wilson's Phalarope Zooplankton abundance (#/m^3)	Zooplankton including copepods, cladocera, corixids, and sometimes brine shrimp are important components of the food web in Farmington and Bear River Bays.	Invertebrate abundance measured as concentration of invertebrates in the water column including copepods, cladocera, corixids, and brine shrimp. There is insufficient data to determine a 'good' category or to describe current conditions.	
Condition: Invertebrate population sufficient to support water birds Brine fly larvae on stromatolitic structures (g/m^2 dry weight)	Brine flies are a key link in one of the two main food chains in Great Salt Lake. Larvae grow on periphyton that is attached to stromatolitic structures.	Although macroinvertebrates in the Great Salt Lake are recognized as an important link in Great Salt Lake food chains, there is insufficient data to quantify healthy populations of macroinvertebrates. A good rating is based on existing measurements of brine fly density. We have used this data to represent a 'good condition.' Wurtsbaugh et al. 2011 reported a concentration of 14 g/m^2 dry weight of total brine fly biomass on stromatolitic structures. Good = 12–16 g/m^2 based on Wurtsbaugh's estimates in 2011. Very good, fair and poor conditions could not be estimated (TBD).	Wurtsbaugh, W. A. 2009. Biostromes, Brine Flies, Birds and the Bioaccumulation of Selenium in Great Salt Lake, Utah. In *Saline Lakes Around the World: Unique Systems with Unique Values,* edited by Q. Oren, D. Naftz, P. Palacios and W.A. Wurtsbaugh, pp. 1–15. Natural Resources and Environmental Issues, volume XV. Wurtsbaugh, W.A., Gardberg, J., and C. Izdepski. 2011. Biostrome communities and mercury and selenium bioaccumulation in the Great Salt Lake (Utah, USA). Science of the Total Environment 409: 4425–4434. Data used for current ranking: none.
Condition: Forage fish supportive of fish-eating birds Fish indicator TBD	When there are areas of fresh water in Bear River Bay and less frequently in Farmington Bay, fish provide food to many fish-eating birds including pelicans and terns.	Fish are an important food source for fish-eating birds. Although birds are generally not selective with respect to fish species, some of the fish eaten by birds, such as carp, are generally harmful to the structure and health of wetland ecosystems (Moyle 1976; Pimental et al. 2000; Mills et al. 2004; Miller and Crowl 2006). In this sense, there is some amount of carp that are undesirable in the system despite the food resource provided to birds. A metric of non-destructive fish biomass would be a better measure of health for this aspect of the avian food chain but could not be identified at this time. Several members of the Panel thought that total fish biomass would be the best indicator up to some maximum amount (assuming that carp would continue to dominate the system) whereas other members of the Panel thought that fish biomass preferably of non-destructive species would be the best indicator. There was no consensus on this issue so the indicator has been left as TBD.	Miller, S.A. and T.A. Crowl. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. *Freshwater Biology* 51:85–94. Mills, M.D., R.B. Rader, and M.C. Belk. 2004. Complex interactions between native and invasive fish: the simultaneous effects of multiple negative interactions. *Oecologia* 141:713–721. Moyle, P.B. 1976. Fish introduction in California: history and impact on native fishes. *Biological Conservation* 9:101–118 (includes discussion of Utah fish distributions). Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. *Bioscience* 50:53–65.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Healthy brine shrimp population Average brine shrimp density from April through November (#/L and mg/L)	Brine shrimp is a link in one of only two major food chains in Gilbert Bay, Great Salt Lake.	Based on the GSLEP (UDWR) data collected from 1994–2006 and reported in Belovsky et al. (2011), observed average brine shrimp numbers increase with observed maximum phytoplankton abundance (i.e., there are on average more brine shrimp when their food has greater potential productivity). Average shrimp numbers are the average number of all life stages from spring hatching to fall die-off (generally late March or early April through November or December). Adding the GSLEP (UDWR) data continued to be collected for 2007–2011, this relationship appears asymptotic: i.e., as phytoplankton abundance continues to increase shrimp numbers do not increase as rapidly or do not increase at all. This may be due to greater abundances of inedible or even toxic phytoplankton at the highest phytoplankton abundances (Belovsky et al. 2011). The “health” rankings of brine shrimp abundances are based on considerations of ample food resources for birds, especially Eared Grebes, which forage heavily on brine shrimp (Belovsky and Perschon in review; Belovsky et al. 2011). If there are too few brine shrimp, then bird numbers may decline. If there are too many brine shrimp, then the brine shrimp may not have sufficient phytoplankton to produce sufficient numbers of cysts, which can reduce the number of shrimp starting next year’s population and consequently, providing fewer shrimp for bird consumption. It was assumed that current brine shrimp concentrations are ‘good’. Further the asymptotic relationship between maximum winter chlorophyll *a* and average shrimp density from April through November indicates that the brine shrimp population levels off at a concentration of 7.5 to 8.2 shrimp/liter. Poor is a concentration so low that it could not support eared grebes or other birds dependent on the brine shrimp. Because brine shrimp vary tremendously in body mass over their life from hatching to adult stage, we also present shrimp abundances in terms of average biomass based on observed average abundances of each life stage category over the year and their estimated body masses (62% nauplii at 3.2 µg; 19% juveniles at 68 µg; 19% adults at 587 µg). Length to biomass conversion equations were derived from Reeve (1963) and are: Nauplii W = 3.14*L^0.56 post-nauplii W = 0.90*L^3.02 Gilbert Bay: poor <5.5/L or <695 ug/L and up to maximum density TBD; fair = 5.5–7.5/L (or 695 to 948 ug/L); good = 7.5–8.25/L or 948–1,043 ug/L. The rankings apply to Gunnison Bay during high lake levels.	Data used for current ranking: Belovsky, G.E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Van Leeuwen, and D.V. Allen. 2011. The Great Salt Lake ecosystem (Utah, USA): Long term data and a structural equation approach. Ecosphere 2(3) 1-40, art33. doi:10.1890/ES10-00091.1. Belovsky, G.E., and C. Perschon. In review. A management case study for a new fishery: brine shrimp harvesting in the Great Salt Lake. Ecological Applications.
Condition: Trophic condition supportive of native biota Invertebrate density (TBD)	Trophic condition is a measure of productivity in the lake typically applied to freshwater lakes. Bear River and Farmington Bays are ‘fresher’ bays that support a wider diversity of invertebrates and vertebrate species. For this reason, trophic condition is an important attribute of health.	Typical metrics of trophic condition in freshwater lakes include nutrient concentrations, mean summer chlorophyll *a*, Secchi depth (a measure of turbidity), water column dissolved oxygen, fish kills, and invertebrate diversity and biomass. Invertebrate biomass is already listed as an indicator of food supply from these systems. Two of these indicators have been selected as most appropriate for Farmington and Bear River Bays: invertebrate diversity and mean summer chlorophyll *a*. However, due to the unique nature of Farmington and Bear River Bays typical thresholds applicable to freshwater lakes are not appropriate for this system. Very little is understood about appropriate diversity or productivity for these brackish bays of Great Salt Lake. Ongoing paleolimnologic research may provide a baseline for these bays–depending on whether the resolution will allow a description of pre-settlement and pre-causeway conditions vs the shallow paleolimnologic record that reflects current conditions in the near future. Salinity ranges alter invertebrate and phytoplankton diversity in ways that are not clear and may be unrelated to the productivity or nutrient concentrations of the bay.	
Condition: Levels of toxins that do not impair populations of significant species Concentration of cyanotoxins/microcystin (µg/L)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	Harmful algal blooms (toxic phytoplankton) can stress and harm aquatic wildlife including birds. Although there are no generic wildlife-specific guidelines for cyanotoxins, there are recreational guidelines for harmful algal blooms in fresh water. The Panel found that recreation numbers were not appropriate for evaluation of ecological health, however, there are documented cases of bird deaths in other parts of the world associated with the same cyanotoxin class found at Great Salt Lake including water fowl in Spain (Lopez-Rodas et al. 2008) spot-billed ducks in Japan (Matsunaga et al. 1999), bald eagles in Northern California (Wilde et al. 2005) and eared grebes at the Salton Sea (Carmichael and Li 2006). A summary of these studies and their applicability to Great Salt Lake can be found in Wurtsbaugh 2011. Cyanotoxin levels in Farmington Bay are far higher than those found to have caused bird mortalities elsewhere (Wurtsbaugh 2011; Wurtsbaugh, unpublished data). However, because no general indicator of toxicity to Great Salt Lake avian species could be identified, the indicator ratings have been left to be determined (TBD) at a later date.	Wurtsbaugh, W. 2011. Relationships between eutrophication, cyanobacteria blooms and avian botulism mortalities in the Great Salt Lake. Lopez-Rodas, V., E. Maneiro, M. P. Lanzarot, N. Perdigones, and E. Costas (2008), Cyanobacteria cause mass mortality of wildlife in Doñana National Park (Spain), *Veterinary Record*, *162*(317–318). Matsunaga, H., K. I. Harada, M. Senma, Y. Ito, N. Yasuda, S. Ushida, and Y. Kimura (1999), Possible cause of unnatural mass death of wild birds in a pond in Nishinomiya, Japan: sudden appearance of toxic cyanobacteria, *Natural Toxins*, *7*(2), 81–84. Wilde, S. B., T. M. Murphy, C. P. Hope, S. K. Habrun, J. Kempton, A. Birrenkott, F. Wiley, W. W. Bowerman, and A. J. Lewitus (2005), Avian vacuolar myelinopathy linked to exotic aquatic plants and a novel cyanobacterial species, *Environmental toxicology*, *20*(3), 348–353 (Special Issue). Carmichael, W. W., and R. Li (2006), Cyanobacteria toxins in the Salton Sea., *Saline Systems 2*(5), doi: 10.1186/1746-1448-2-5. Data used for current ranking: none.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Levels of toxins that do not impair populations of significant species Concentration of methylmercury in sediment (ng/g)	Toxins can interfere with the life-cycle and health of many of the nested species identified for the Great Salt Lake including brine shrimp and birds.	Additional research is necessary to determine what sediment standard is appropriate for Great Salt Lake. Therefore the indicator ratings have been left TBD. Washington State's marine sediment THg standard is 410 ng/g. Concentrations of THg in 58 sediment samples collected beneath the south arm of Great Salt Lake by Naftz et al (2008) did not exceed WA state standard. However, ratio of MeHg to THg (in weight percent) was higher than worldwide baselines. 7 of 10 sediment samples collected in Farmington Bay Waterfowl Management Area had concentrations of THg that exceeded WA state standards, with the highest concentration exceeding 1,900 ng/g. This, however, was lower than concentrations measured by USFWS in 2000 (Waddell et al. 2009) in Farmington Bay which had concentrations exceeding 6,000 ng/g. Utah DWQ uses evidence of MeHg concentrations in algae, brine shrimp, brine flies, waterfowl, and shorebirds as indicators of Great Salt Lake ecosystem health with regards to mercury levels in Great Salt Lake water, sediment, and biota (UDWQ 2010).	Naftz, D.L., W.P. Johnson, M. Freeman, K. Beisner, and X. Diaz. 2008. Estimation of Selenium Loads Entering the South Arm of Great Salt Lake, Utah from May 2006 through March 2008. Scientific Investigations Report. USGS Investigations Report 2008-5069. Utah Division of Water Quality, 2010. 2010 Integrated Report (draft). Available online at http://www.waterquality.utah.gov/WQAssess/currentIR.htm#IR2010. Accessed 12/2011. Waddell, B., C. Cline, N. Darnall, E. Boeke, and R. Sohn. 2009. Assessment of contaminants in the wetlands and open waters of the Great Salt Lake, Utah 1996-2000 Final Report. Report Number R6/C-01-U/09. U.S. Fish and Wildlife Service Ecological Services, Utah Field Office, Salt Lake City, Utah. 238 pp. Washington State Legislature: Marine Sediment Quality Standards. 2003. WAC 173-204-320 (a). Available online at http://apps.leg.wa.gov/wac/default.aspx?cite=173-204-320
Unimpounded Marsh Complex			
Landscape Context: Maintain Natural Hydrologic Regime Period in which complex is moist to inundated	Surface and groundwater flows from the surrounding watershed provide diverse wetland conditions.	The inundation regime from April to July is based on the breeding season of birds that use the unimpounded marsh complex and the natural hydrologic regime of the area, defined by peak spring melt followed by a dry summer.	Helmers, D. 1992. Shorebird Management Manual. Manomet, Massachusetts: Western Hemisphere Shorebird Reserve Network. Paul, D.S., and A.E. Manning. 2002. Great Salt Lake Waterbird Survey Five-Year Report (1997-2001). Publication No. 08-38. Salt Lake City: Utah Division of Wildlife Resources, Great Salt Lake Ecosystem Program. Data used for current ranking: best professional judgment based on wetlands work around Great Salt Lake
Condition: Maintain Natural Hydrologic Regime Deviation from natural hydrograph for a given storm event (TBD)	Wetlands respond both to the duration and seasonality of inundation (indicator above) as well as flow during a specific storm event.	As the watersheds upstream of the wetlands become more developed, increased impervious cover will result in flashier flows (higher peak storm flow) as well as reduced baseflow due to reduced infiltration to groundwater systems that feed streams during dry periods. Indicators for this attribute could be percent impervious cover of the watershed or percent deviation from the hydrograph as measured by a flow duration curve analysis. Literature from Washington indicates that watersheds with more than 50% urban cover result in degraded stream function (Morley and Karr 2002). However, indicator rankings for these indicators could not be developed for Great Salt Lake wetlands.	Morley, S.A. and J.R. Karr. 2002. Assessing and restoring the health of urban streams in the Puget Sound Basin. *Conservation Biology* 16 (6): 1498–1509.
Condition: Delivery of high quality water by tributaries into marshes and eventually the lake SVAP along streams throughout watershed	Good water quality is an important attribute over the long-term health of wetland systems. This includes delivery of water without excessive toxins, nutrients, or sediment.	Water quality of Great Salt Lake tributaries is also important to the health of both the impounded wetlands and the unimpounded emergent marsh. This concern emerges from the concept that as riparian corridors and buffer zones are susceptible to activities such as channelization, tree removal, agricultural and grazing practices, or urban development. When such activities occur, the typical filtering, assimilation, hydrologic energy dispersal and water absorption properties become diminished. Potential stressors that were identified include sediment loading and mobilization, dissolved metals, nutrients and contaminants of emerging concern (CECs) such as pharmaceuticals and personal care products. Although incredibly difficult to measure, the efficacy of healthy riparian corridors and flood plains in removing sediments, toxics and CECs is expected to diminish as riparian communities and buffer zones are reduced or removed. The result is that these stressors will be delivered to the wetland complexes in greater concentrations or frequency, followed by enhanced accumulation and diminished ability of the wetland to assimilate these potential stressors. Stream function, as measured by riparian health, is a good predictor of water quality in receiving waters. The Stream Visualization and Assessment Protocol is a comprehensive tool for evaluation of riparian health and includes metrics of channel width, riparian cover, stream bank erosion, and nutrient loading. A system that has intact riparian corridors will contribute to overall watershed health and impart less demand on downstream wetlands to improve water quality. Current condition could not be ranked because SVAP data is not available for all streams throughout the watershed.	Natural Resources Conservation Service. 1998. Stream Visual Assessment Protocol. National Water and Climate Center, Technical Note 99–1.
Condition: Diversity and amount of habitat types Presence of hemi marsh, submerged aquatic vegetation, short emergent, tall emergent, and wet meadows at most lake levels	Structural and compositional diversity of wetland habitat types is a key habitat component for the support of waterfowl, shorebirds, other waterbirds and fish.	The presence/absence of the five marsh wetland habitat types is a measure of habitat quality for waterfowl, shorebirds, other waterbirds and fish. Structural integrity (as measured by plant diversity) is the presence of physical plant surfaces or plant community features that allow a wetland to provide habitat and water improvement functions (Hoven and Paul 2010). Habitat functions may be related to protective cover, breeding, and / or forage, for aquatic, wetland, riparian or upland species. Water improvement functions may be related to filtration of particulates, absorption and adsorption of nutrients and other pollutants, and nutrient cycling.	Data used for current ranking: best professional judgment based on wetlands work around Great Salt Lake Hoven, H.M. and D.S. Paul. 2010. Utah Wetlands Ambient Assessment Method, Version 1.2. The Institute for Watershed Sciences, Kamas UT.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Dominance of native and desirable nonnative plant species Percentage cover of native and desirable nonnative plant species	Native and desirable nonnative plant species provide structural diversity and support the food web. Cover of native and desirable nonnative plant species is a surrogate measure of structural and compositional diversity. Cover of invasive plant species (particularly *Phragmites*) is an indicator of little or no structural diversity and low habitat quality.	Cover of native and desirable nonnative plant species is a surrogate measure of structural and compositional diversity. Dominance of invasive plant species (particularly *Phragmites*), especially in target wetland types that support emergent vegetation, is an indicator of little or no structural diversity and low habitat quality (Aldrich and Paul 2002). *Phragmites australis* cover around Great Salt Lake has increased from 20% to 56% over 27 years (1977–2004; Kulmatiski et al. 2010). Historic records of the native strain distribution in northern Utah indicate that the density, extent and range of nonnative *Phragmites* have dramatically increased (Kettering pers comm., with Hope Hornbeck, SWCA). Nonnative weed cover in wetland habitats is of concern due to decreased habitat quality for birds and other wetland species (Bertness et al. 2002), and impacts to Great Salt Lake as part of the Western Hemisphere Shorebird Reserve Network (Aldrich and Paul 2002). Invasive nonnative plant species impact biodiversity by altering nutrient cycles (Hooper and Vitousek 1998), and through competitive effects that alter community productivity, structure and functioning, and that impair the resiliency of the system to perturbation (Tilman et al. 1997, Tilman 1999, Simberloff 2005). At about 50% cover, invasive plant species have been shown to be significantly correlated with exponential declines in native vegetation diversity, cover and biomass in sagebrush steppe communities (Davies 2011). The KEA thresholds for native vs. invasive plant cover were based on literature review as well as the best professional judgment of the Advisory Panel (Hoven pers. Comm.). These KEA thresholds are similar to those identified by Hoven and Paul (2010) in the Utah Wetlands Ambient Assessment Method. An upper threshold of 0%–5% (invasive plant cover) represents **“very good”** condition due to the disproportionate impacts of *Phragmites* on native wetland habitats at relatively low cover, and that the invasion can be relatively easily managed at low densities and does not impair the significant species. The ranking for **“good”** (5%–25% invasive plant cover) represents a condition in which some declines in native plant diversity, cover, and biomass have likely occurred, but the invader can be managed and likely does not directly impair the significant species. The threshold for **“fair”** (25%–50% invasive plant cover) represents a condition in which significant declines in native plant diversity, cover and biomass have likely occurred (Davies 2011), and management to restore the system to “good” condition would require considerable inputs. Habitat for the significant species is significantly degraded or lost. A threshold of greater than 50% cover of invasive plant species was used as the ranking for **“poor”** because at this level of cover (a surrogate measure of biomass), the invader has likely caused profound changes in plant community species richness and diversity, as well as in overall vegetation structure and ecological functioning (Hejda et al. 2009). Habitat for significant species has been lost. The 50% cover threshold is a conservative threshold for large stature, rapidly spreading invasive species like *Phragmites.* Large invasive plant species have been shown to have significantly greater effects on species diversity than smaller invasive plants (Hejda et al. 2009).	Aldrich, T. W. and D. S. Paul. 2002. Avian ecology of Great Salt Lake. Pages 343–374 in J. W. Gwynn (ed). Great Salt Lake: An overview of change. Utah Department of Natural Resources, Salt Lake City, Utah. Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. PNAS 99: 1395–1398. Davies, K. W. 2011. Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass. Oecologia 167: 481–491. Hejda, M., P. Pyšek and V. Jarošik. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97: 393–403. Hooper, D. U. and P. M. Vitousek. 1998. Effects of plant composition and diversity on nutrient cycling. Ecological Monographs 68: 121–149. Hoven, H.M. and D.S. Paul. 2010. Utah Wetlands Ambient Assessment Method, Version 1.2. The Institute for Watershed Sciences, Kamas UT. Hoven, H. 2011. Director of Institute for Watershed Sciences. Ogden, Utah: Visiting Research Professor, Weber State University, Department of Botany. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Kulmatiski, A., K. H. Beard, L. A. Meyerson, J. R. Gibson, and K. E. Mock. 2010. Non-native *Phragmites australis* invasion into Utah wetlands. Western North American Naturalist 70(4): 541–552. Simberloff, D. 2005. Non-native species threaten the natural environment. Journal of Agricultural and Environmental Ethics 18: 595–607. Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80: 1455–1474. Tilman, D., C. L. Lehman, and K. T. Thomson. 1997. Plant diversity and ecosystem productivity: theoretical considerations. Proceedings of the National Academy of Sciences USA 94: 1857–1861.
Condition: Forage fish supportive of fish-eating birds Fish indicator TBD	Several of the significant species are fish-eating birds. Therefore, some measure of their food supply should be incorporated as a metric of health.	Although some nonnative fish, such as carp, provide food to fish-eating birds, they are generally harmful to the structure and health of wetland ecosystems (Moyle 1976; Pimental et al. 2000; Mills et al. 2004; Milller and Crowl 2006). Therefore a metric of native fish biomass is a better measure of health for this aspect of the avian food chain. More research is needed to determine what a ‘healthy’ amount of native fish biomass would be for the system.	Miller, S. A. and T. A. Crowl. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. Freshwater Biology 51: 85–94. (Utah Lake) Moyle, P. B. 1976. Fish introduction in California: history and impact on native fishes. Biological Conservation 9: 101–118 (includes discussion of Utah fish distributions) Mills, M. D., R. B. Rader, and M. C. Belk. 2004. Complex interactions between native and invasive fish: the simultaneous effects of multiple negative interactions. Oecologia 141: 713–721. Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. Bioscience 50: 53–65. Data used for current ranking: none
Condition: Healthy macroinvertebrate population supportive of waterfowl, other waterbirds Total macroinvertebrate biomass (non-gastropod) mg/m^2	Macroinvertebrates are a key component of the food web that supports waterfowl, shorebirds and other waterbirds.	Total macroinvertebrate biomass in g per square meter is a widely-used measure. A value of 2 g/m^2 is a threshold commonly used for shorebird diet needs (John Cavitt, pers comm.). A range of 1.5–2.5 g/m^2 is assumed to be good. Values identified as fair and poor in impounded wetlands are also used here.	Cavitt, J. 2011. Distinguished Professor of Zoology and Director, Office of Undergraduate Research. Ogden, Utah: Weber State University. Personal communication with J. Hope Hornbeck, SWCA Environmental Consultants, November 28, 2011.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Size Sufficient habitat to support significant species (e.g., American Avocets and Black-necked Stilts) Acreage of habitat between 4,200 and 4,218 feet elevation	Contiguous unimpounded marsh habitat is a key habitat component for shorebirds and other staging and breeding birds.	Historic acreages are assumed to be 'very good'. A range of 10%–30% loss from historic acreage is assumed to be 'good' based on the assumption that the current acreage is supporting the current bird populations. With the exception of Farmington Bay, acreage in all of the bays currently meets the 30% threshold. 'Fair' is loss of 30%–50% of historic acreage. 'Poor' is considered more than 50% loss of the habitat (Fahrig 2001 and references therein; see rationale statement in binder). All acreages refer to wetlands found to be in good condition with respect to the vegetation indicators. Increased habitat dominated by *Phragmites* is not considered to be a healthy change for the ecosystem.	Cavitt, J. 2011. Distinguished Professor of Zoology and Director, Office of Undergraduate Research. Ogden, Utah: Weber State University. Personal communication with J. Hope Hornbeck, SWCA Environmental Consultants, November 28, 2011. Fahrig, L. 2001. How much habitat is enough? *Biological Conservation* 100:65–74.
Impounded Wetlands			
Condition: Dominance of native and desirable nonnative plant species Percentage cover of native and desirable nonnative plant species	Native and desirable nonnative plant species provide structural diversity and support the food web.	Cover of native and desirable nonnative plant species is a surrogate measure of structural and compositional diversity. Dominance of invasive plant species (particularly *Phragmites*), especially in target wetland types that support emergent vegetation, is an indicator of little or no structural diversity and low habitat quality (Aldrich and Paul 2002). *Phragmites australis* cover around Great Salt Lake has increased from 20% to 56% over 27 years (1977–2004; Kulmatiski et al. 2010). Historic records of the native strain distribution in northern Utah indicate that the density, extent and range of nonnative *Phragmites* have dramatically increased. Nonnative weed cover in wetland habitats is of concern due to decreased habitat quality for birds and other wetland species (Bertness et al. 2002), and impacts to Great Salt Lake as part of the Western Hemisphere Shorebird Reserve Network (Aldrich and Paul 2002). Invasive nonnative plant species impact biodiversity by altering nutrient cycles (Hooper and Vitousek 1998), and through competitive effects that alter community productivity, structure and functioning, and that impair the resiliency of the system to perturbation (Tilman et al. 1997, Tilman 1999, Simberloff 2005). At about 50% cover, invasive plant species have been shown to be significantly correlated with exponential declines in native vegetation diversity, cover and biomass in sagebrush steppe communities (Davies 2011). The KEA thresholds for native vs. invasive plant cover were based on literature review as well as the best professional judgment of the Advisory Panel (Hoven pers. comm.). These KEA thresholds are similar to those identified by Hoven and Paul (2010) in the Utah Wetlands Ambient Assessment Method. Hoven and Paul (2010) identified an upper threshold of 0%–5% (invasive plant cover) to represent a **"very good"** condition due to the disproportionate impacts of *Phragmites* on native wetland habitats at relatively low cover, and that the invasion can be relatively easily managed at low densities and does not impair the significant species. The ranking for **"good"** (5%–25% invasive plant cover) represents a condition in which some declines in native plant diversity, cover, and biomass have likely occurred, but the invader can be managed and does not likely directly impair the significant species. The threshold for **"fair"** (25%–50% invasive plant cover) represents a condition in which significant declines in native plant diversity, cover and biomass have likely occurred (Davies 2011), and management to restore the system to "good" condition would require considerable inputs. Habitat for the significant species is significantly degraded or lost. A threshold of greater than 50% cover of invasive plant species was used as the ranking for **"poor"** because at this level of cover (a surrogate measure of biomass), the invader has likely caused profound changes in plant community species richness and diversity, as well as in overall vegetation structure and ecological functioning (Hejda et al. 2009). Habitat for significant species has been lost. The 50% cover threshold is a conservative threshold for large stature, rapidly spreading invasive species like *Phragmites*. Large invasive plant species have been shown to have significantly greater effects on species diversity than smaller invasive plants (Hejda et al. 2009).	Aldrich, T. W. and D. S. Paul. 2002. Avian ecology of Great Salt Lake. Pages 343–374 in J. W. Gwynn (ed). Great Salt Lake: An overview of change. Utah Department of Natural Resources, Salt Lake City, Utah. Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. PNAS 99: 1395–1398. Davies, K. W. 2011. Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass. Oecologia 167: 481–491. Hejda, M., P. Pyšek and V. Jarošik. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97: 393–403. Hooper, D. U. and P. M. Vitousek. 1998. Effects of plant composition and diversity on nutrient cycling. Ecological Monographs 68: 121–149. Hoven, H.M. and D.S. Paul. 2010. Utah Wetlands Ambient Assessment Method, Version 1.2. The Institute for Watershed Sciences, Kamas UT. Kulmatiski, A., K. H. Beard, L. A. Meyerson, J. R. Gibson, and K. E. Mock. 2010. Non-native *Phragmites australis* invasion into Utah wetlands. Western North American Naturalist 70(4): 541–552. Simberloff, D. 2005. Non-native species threaten the natural environment. Journal of Agricultural and Environmental Ethics 18: 595–607. Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80: 1455–1474. Tilman, D., C. L. Lehman, and K. T. Thomson. 1997. Plant diversity and ecosystem productivity: theoretical considerations. Proceedings of the National Academy of Sciences USA 94: 1857–1861.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Food supply supportive of waterfowl, and other water birds Macroinvertebrate (non-gastropods) biomass (g/m^2) in upstream ponds in July/August	Macroinvertebrates are an important food source for fish, waterfowl and other water birds. Upstream ponds are good indicators of health for impounded wetlands because they are the first to be affected by water quality, changes in flow, etc.	Total macroinvertebrate biomass in mg per square meter is a widely used measure. A value of 2.0 g/m2 is a threshold commonly used for bird diet needs (John Cavitt, pers comm.). Assuming that impounded wetlands are currently supportive of waterfowl populations, the measured biomass of macroinvertebrates in reference and target ponds was used to determine the indicator ratings (Miller et al. 2011).	Cavitt, J. 2011. Distinguished Professor of Zoology and Director, Office of Undergraduate Research. Ogden, Utah: Weber State University. Personal communication with J. Hope Hornbeck, SWCA Environmental Consultants, November 28, 2011. Miller, T.G. 2011. Research Scientist, Jordan River/Farmington Bay Water Quality Council. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Miller, T.G., D. Richards, H.M. Hoven, W.P. Johnson, M. Hogset, and G.T. Carling. 2011. *Macroinvertebrate Communities in Great Salt Lake Impounded Wetlands, their Relationship to Water and Sediment Chemistry and to Plant Communities and Proposed Modifications to the MMI*. Report prepared for the Jordan River/Farmington Bay Water Quality Council and Utah Division of Water Quality. Unpublished data used for current ranking: Miller et al. 2011.
Condition: Food supply supportive of waterfowl and other water birds SAV tuber biomass (g/m^2)	SAV tuber biomass is a surrogate measure for the overall health and abundance of SAV. SAV biomass in Great Salt Lake wetlands provide important habitat for macroinvertebrates that rely on substrate to cling to, gastropods, arthropods (including insects, crustacea and ostracods), and juvenile fish (Hoven et al. 2011) and supports an important food source for macroinvertebrates that graze on associated periphyton. Tubers and druplets are also an important food source for waterfowl and other water birds (Chamberlain 1959; Anderson and Low 1976).	Indicator rating thresholds for tuber biomass were determined from the 2010 data presented by Hoven et al. (2011). Seasonal trends in the data were used to select thresholds specific to certain months and September thresholds were selected to show availability of biomass upon the arrival of fall migrating waterfowl that depend on SAV tubers as a food resource. Poor rating (<2500 g/m^2) represents SAV from impoundments with the lowest tuber biomass compared to other impoundments, which was consistent June through September. Fair (2500–11K) represents the intermediate range of tuber biomass of the impoundments that were assessed during September. Good (12–24K) represents the highest range recorded at the reference site during September. Very good (≥ 25K) represents the potential for greater biomass production. These rating thresholds were developed from one year of data and may be revised after a more robust database is available. Josh Vest of Intermountain Joint Ventures is working on a revised duck use days (DUD) model that could be used as a potential indicator in the future.	Anderson, M.G., & J.B. Low. 1976. Use of sago pondweed by waterfowl on Delta Marsh, Manitoba. J. Wildl. Manage. 40:233-242. Chamberlain, J. L. 1959. Gulf coast marsh vegetation as food of wintering waterfowl. Journal of Wildlife Management 23(1):97-102. Hoven, H., Richards, D., Johnson, W.P., and G.T. Carling. 2011. Plant metric refinement for condition assessment of Great Salt Lake impounded wetlands. Report to Jordan River/Farmington Bay Water Quality Council. Miller, T.G. 2011. Research Scientist, Jordan River/Farmington Bay Water Quality Council. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Data used for current ranking: Hoven et al. 2011.
Condition: Food supply supportive of waterfowl and other water birds SAV drupelet biomass (g/m^2)	SAV drupelet biomass is a surrogate measure for the overall health and abundance of SAV. SAV biomass in Great Salt Lake wetlands provide important habitat for macroinvertebrates that rely on substrate to cling to, gastropods, arthropods (including insects, crustacea and ostracods), and juvenile fish (Hoven et al. 2011) and supports an important food source for macroinvertebrates that graze on associated periphyton. Tubers and druplets are also an important food source for waterfowl and other water birds (Chamberlain 1959; Anderson and Low 1976).	Indicator rating thresholds for drupelet biomass were determined from the 2010 data presented by Hoven et al. (2011). Seasonal trends in the data were used to select thresholds specific to certain months and September thresholds were selected to show availability of biomass upon the arrival of fall migrating waterfowl that depend on SAV drupelets as a food resource. Poor rating (<5 kg/m2) represents SAV from impoundments with the lowest drupelet biomass compared to other impoundments, which was consistent June through September. Fair (6,000–19,000) represents the intermediate range of drupelet biomass of the impoundments that were assessed during September. Good (20,000–29,000) represents the highest range recorded at the reference site during September. Very good (≥ 30K) represents the highest densities that were recorded during July at the reference site. These rating thresholds were developed from one year of data and may be revised after a more robust database is available. Drupelet biomass may be an indicator of excess nutrients, toxins, and sediment quality (Hoven et al. 2011). Josh Vest of Intermountain Joint Ventures is working on a revised duck use days (DUD) model that could be used as a potential indicator in the future.	Anderson, M.G., & J.B. Low. 1976. Use of sago pondweed by waterfowl on Delta Marsh, Manitoba. J. Wildl. Manage. 40:233-242. Chamberlain, J. L. 1959. Gulf coast marsh vegetation as food of wintering waterfowl. Journal of Wildlife Management 23(1):97-102. Hoven, H., Richards, D., Johnson, W.P., and G.T. Carling. 2011. Plant metric refinement for condition assessment of Great Salt Lake impounded wetlands. Report to Jordan River/Farmington Bay Water Quality Council. Miller, T.G. 2011. Research Scientist, Jordan River/Farmington Bay Water Quality Council. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Data used for current ranking: Hoven et al. 2011.
Condition: Food supply supportive of waterfowl, and other water birds Fish indicator TBD	Several of the significant species are fish-eating birds. Therefore, some measure of their food supply should be incorporated as a metric of health.	Fish are an important food source for fish-eating birds. Although birds are generally not selective with respect to fish species, some of the fish eaten by birds, such as carp, are generally harmful to the structure and health of wetland ecosystems (Moyle 1976; Pimental et al. 2000; Mills et al. 2004; Miller and Crowl 2006). In this sense, there is some amount of carp that are undesirable in the system despite the food resource provided to birds. A metric of non-destructive fish biomass would be a better measure of health for this aspect of the avian food chain but could not be identified at this time. Several members of the Panel thought that total fish biomass would be the best indicator up to some maximum amount (assuming that carp would continue to dominate the system) whereas other members of the Panel thought that fish biomass preferably of non-destructive species would be the best indicator. There was no consensus on this issue so the indicator has been left as TBD.	Miller, S. A. and T. A. Crowl. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. Freshwater Biology 51: 85–94. (Utah Lake) Moyle, P. B. 1976. Fish introduction in California: history and impact on native fishes. Biological Conservation 9: 101–118 (includes discussion of Utah fish distributions) Mills, M. D., R. B. Rader, and M. C. Belk. 2004. Complex interactions between native and invasive fish: the simultaneous effects of multiple negative interactions. Oecologia 141: 713–721.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
			Pimental, D. L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. Bioscience 50: 53–65. Data used for current ranking: none
Condition: Healthy SAV community SAV branch density (# branches with attached leaves/m^2) in upstream ponds in July/August	SAV help purify the water through filtration, and nutrient and metal cycling (Hoven et al. 2011). Some SAV are sensitive to some toxic metals, while tolerant of others.	Branch density, as number of branches with attached leaves/m^2, provides a quantitative measure for what is observed and may be sensitive to declining SAV trends before it becomes evident in the canopy as determined by percent cover. Plants display phenotypic plasticity yet form and stature of the SAV tend to be specific by impoundment (Hoven personal observation), which could be related to the environmental conditions of each impoundment. Indicator rating thresholds were determined from the 2010 data presented by Hoven et al. (2011). Seasonal trends in the data were used to select thresholds specific to certain months and August thresholds were selected to show availability of biomass prior to the arrival of fall migrating waterfowl that depend on SAV as a food resource. Poor rating (< 10,000 branches/m2) represents SAV from impoundments with the lowest branch densities compared to other impoundments, which was consistent June through September. Fair (10,000–34,000) represents the intermediate range of branch density of the impoundments that were assessed during August. Good (35,000–59,000) represents the highest range recorded at the reference site during August. Very good (>60,000) represents the highest densities that were recorded during July at an impoundment that later declined due to water management issues. These rating thresholds were developed from one year of data and may be revised after a more robust database is available.	Hoven, H., Richards, D., Johnson, W.P., and G.T. Carling. 2011. Plant metric refinement for condition assessment of Great Salt Lake impounded wetlands. Report to Jordan River/Farmington Bay Water Quality Council. Hoven, H. 2011. Director of Institute for Watershed Sciences. Ogden, Utah: Visiting Research Professor, Weber State University, Department of Botany. Personal communication with Erica Gaddis, SWCA Environmental Consultants, November 2011. Data used for current ranking: Hoven et al. 2011.
Condition: Delivery of high quality water by tributaries into marshes and eventually the lake. SVAP along streams throughout watershed	Good water quality is an important attribute over the long-term health of wetland systems. This includes delivery of water without excessive toxins, nutrients, or sediment.	Water quality of Great Salt Lake tributaries is also important to the health of both the impounded wetlands and the unimpounded emergent marsh. This concern emerges from the concept that as riparian corridors and buffer zones are susceptible to activities such as channelization, tree removal, agricultural and grazing practices, or urban development. When such activities occur, the typical filtering, assimilation, hydrologic energy dispersal and water absorption properties become diminished. Potential stressors that were identified include sediment loading and mobilization, dissolved metals, nutrients and contaminants of emerging concern (CECs) such as pharmaceuticals and personal care products. Although incredibly difficult to measure, the efficacy of healthy riparian corridors and flood plains in removing sediments, toxics and CECs is expected to diminish as riparian communities and buffer zones and are reduced or removed. The result is that these stressors will be delivered to the wetland complexes in greater concentrations or frequency, followed by enhanced accumulation and diminished ability of the wetland to assimilate these potential stressors. Stream function, as measured by riparian health, is a good predictor of water quality in receiving waters. The Stream Visualization and Assessment Protocol is a comprehensive tool for evaluation of riparian health and includes metrics of channel width, riparian cover, stream bank erosion, and nutrient loading. A system that has intact riparian corridors will contribute to overall watershed health and impart less demand on downstream wetlands to improve water quality. Current condition could not be ranked because SVAP data is not available for all streams throughout the watershed.	Natural Resources Conservation Service. 1998. Stream Visual Assessment Protocol. National Water and Climate Center, Technical Note 99–1.
Mudflats and Playas			
Size: Sufficient habitat near freshwater for Snowy Plover population Acres of mudflat habitat within 100 meters of perennial freshwater (4,191–4,218 feet elevation range)	Contiguous playa and mudflat habitat is a key habitat component for shorebirds and other staging and breeding birds. Proximity to freshwater is required for staging and breeding.	Snowy Plover requires mudflat habitat that is within 100 meters of perennial water. Historic acreage of this habitat is considered to be very good. Historic acreage was estimated by comparing the total acreage lost between 4,200–4,209 feet and 4,209–4,218 feet and applying the percentage loss proportionally to all current habitats in each elevation range. A good condition is assumed to be 70% to 90% of 'historic' habitat and a poor condition is considered to be less than 50% of historic habitat (see separate acreage threshold rationale). Nest density estimates in Page et al. (1983) and Powell and Collier (2000) indicate a maximum average nest density of approximately 1.35 nests/acre. Current peak population estimates for each bay from the Great Salt Lake Waterbird survey (Paul and Manning 2002) were used to calculate habitat acreage needs. The minimum acreage required to maintain the current peak population falls within the poor ranking determined as 50% of historic.	Page, G. W., F. C. Bidstrup, W. Winkler, and C. W. Swarth. 1983. Spacing out at Mono Lake: breeding success, nest density, and predation on the snowy plover. Auk 100: 13–24. Powell, A. N. and C. L. Collier. 2000. Habitat use and reproductive success of western snowy plovers at new nesting areas created for California least terns. Journal of Wildlife Management 64(1): 24–33. Paul, D. S. and A. E. Manning. 2002. Great Salt Lake Waterbird Survey Five-Year Report (1997–2001). Publication Number 08-38. Great Salt Lake Ecosystem Program, Utah Division of Wildlife Resources, Salt Lake City, Utah. December 2002. 64 pp. John Cavitt personal communication.

Table A2. Rationale Table for all Indicators

Ecological Target Category • **Key Attribute** • **Indicator**	**Key Attribute Comment**	**Indicator Comment**	**Reference**
Condition: Absence of *Phragmites* Percentage cover of *Phragmites*	Contiguous playa and mudflat habitat is a key habitat component for shorebirds and other staging and breeding birds. Large, contiguous habitat is also an indicator of low invasive weed cover (particularly *Phragmites*).	Absence of *Phragmites* is an indicator of open mudflat and playa habitat that is suitable for significant species (Snowy Plover). High cover of *Phragmites* indicates low quality habitat or the loss of these habitats for shorebirds (Bertness et al. 2002, Aldrich and Paul 2002). Cover of native and desirable nonnative plant species is a surrogate measure of structural and compositional diversity. Dominance of invasive plant species (particularly *Phragmites*) especially in the open water portions of the wetlands is an indicator of little or no structural diversity and low habitat quality (Aldrich and Paul 2002). *Phragmites australis* cover around Great Salt Lake has increased from 20% to 56% over 27 years (1977–2004; Kulmatiski et al. 2010). Historic records of the native strain distribution in northern Utah indicate that the density, extent and range of nonnative *Phragmites* have dramatically increased. Nonnative weed cover in wetland habitats is of concern due to decreased habitat quality for birds and other wetland species (Bertness et al. 2002), and impacts to Great Salt Lake as part of the Western Hemisphere Shorebird Reserve Network (Aldrich and Paul 2002). Invasive nonnative plant species impact biodiversity by altering nutrient cycles (Hooper and Vitousek 1998), and through competitive effects that alter community productivity, structure and functioning, and that impair the resiliency of the system to perturbation (Tilman et al. 1997, Tilman 1999, Simberloff 2005). At about 50% cover, invasive plant species have been shown to be significantly correlated with exponential declines in native vegetation diversity, cover and biomass in sagebrush steppe communities (Davies 2011). The KEA thresholds for native vs. invasive plant cover were based on literature review as well as the best professional judgment of the Advisory Panel (Hoven pers. comm.). These KEA thresholds are similar to those identified by Hoven and Paul (2010) in the Utah Wetlands Ambient Assessment Method. Hoven and Paul (2010) identified an upper threshold of 0%–5% (invasive plant cover) to represent a **"very good"** condition due to the disproportionate impacts of *Phragmites* on native wetland habitats at relatively low cover, and that the invasion can be relatively easily managed at low densities and does not impair the significant species. The ranking for **"good"** (5%–25% invasive plant cover) represents a condition in which some declines in native plant diversity, cover, and biomass have likely occurred, but the invader can be managed and does not likely directly impair the significant species. The threshold for **"fair"** (25%–50% invasive plant cover) represents a condition in which significant declines in native plant diversity, cover and biomass have likely occurred (Davies 2010), and management to restore the system to "good" condition would require considerable inputs. Habitat for the significant species is significantly degraded or lost. A threshold of greater than 50% cover of invasive plant species was used as the ranking for **"poor"** because at this level of cover (a surrogate measure of biomass), the invader has likely caused profound changes in plant community species richness and diversity, as well as in overall vegetation structure and ecological functioning (Hejda et al. 2009). Habitat for significant species has been lost. The 50% cover threshold is a conservative threshold for large stature, rapidly spreading invasive species like *Phragmites*. Large invasive plant species have been shown to have significantly greater effects on species diversity than smaller invasive plants (Hejda et al. 2009).	Aldrich, T. W. and D. S. Paul. 2002. Avian ecology of Great Salt Lake. Pages 343–374 in J. W. Gwynn (ed). Great Salt Lake: An overview of change. Utah Department of Natural Resources, Salt Lake City, Utah. Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. PNAS 99: 1395–1398. Davies, K. W. 2011. Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass. Oecologia 167: 481–491. Hejda, M., P. Pyšek and V. Jarošik. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97: 393–403. Hooper, D. U. and P. M. Vitousek. 1998. Effects of plant composition and diversity on nutrient cycling. Ecological Monographs 68: 121–149. Hoven, H.M. and D.S. Paul. 2010. Utah Wetlands Ambient Assessment Method, Version 1.2. The Institute for Watershed Sciences, Kamas UT.45 pp. Kulmatiski, A., K. H. Beard, L. A. Meyerson, J. R. Gibson, and K. E. Mock. 2010. Non-native *Phragmites australis* invasion into Utah wetlands. Western North American Naturalist 70(4): 541–552. Simberloff, D. 2005. Non-native species threaten the natural environment. Journal of Agricultural and Environmental Ethics 18: 595–607. Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80: 1455–1474. Tilman, D., C. L. Lehman, and K. T. Thomson. 1997. Plant diversity and ecosystem productivity: theoretical considerations. Proceedings of the National Academy of Sciences USA 94: 1857–1861.
Isolated Island Habitat for Breeding Birds			
Landscape Context: Lake levels protective of isolated island habitat Lake level (MSL) [ever or no more than one per generation of significant species]	Large colonies of nesting birds (particularly American white pelicans on Gunnison Island) exist due to the isolation of the island from land-based predators.	At respective lake levels of 4,193 and 4,195 or below Egg and Whiterock Islands, in Gilbert Bay, become accessible by land allowing access to predators from Antelope Island. These elevations represent the poor and fair conditions for Gilbert Bay. At lake elevations of 4,193 to 4,195 the water between the mainland and Gunnison island becomes shallow increasing the likelihood that a predator could access the island; this is assumed to be a fair condition. At a lake elevation 4,193 and below (the poor condition), Gunnison island because accessible by land. At a lake level greater than 4,204 Gunnison Island is substantially inundated limiting the habitat available to breeding birds.	Information came from the lake level matrix in the Great Salt Lake CMP, originated from John Neill staff. Data used for current ranking: USGS gage data 10010000
Condition: Lack of predators on islands Absence of predators	Large colonies of nesting birds (particularly American White Pelicans on Gunnison Island) exist due to the isolation of the island from land-based predators.	When predators access islands, bird colonies will be decimated. Birds generally will not return to the island in future years after being decimated by predators once (J. Cavitt pers comm.). Low lake levels are the most likely mechanism by which predators would access islands, although there are known instances of intentional predator introductions such as Russian Wild Boar on Freemont Island. In Gilbert Bay, there are multiple islands so a very good ranking means that predators are absent on all the islands. A good indicator means that predators are absent on most islands. Fair means that predators are present on most islands and poor means that predators are present on all islands. In Gunnison Bay, there is only one island. A very good status is that predators are absent on Gunnison Island and a poor status means that predators are present on Gunnison island. There is no fair or good rating for Gunnison Island.	John Cavitt personal communication. Behle, 1958. The bird life of Great Salt Lake. Salt Lake City, University of Utah Press.

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Ecological Target Category • Key Attribute • Indicator	Key Attribute Comment	Indicator Comment	Reference
Alkali Knolls			
Size: Sufficient acreage to support migratory shorebirds as refugia during high lake levels (4,205 and above) Acreage of alkali knolls	Alkali knoll habitat occurs in association with specific soil types in uplands surrounding the Great Salt Lake ecosystem. The habitat is characterized by shallow depressions, alkaline soils, and sparse, salt-loving vegetation. This habitat type provided refugia for shorebirds during the high lake years. Observations (Paul pers. comm., Sorensen pers. comm 2010) during flooding in the late 1980s showed that shorebirds used these habitats when other wetland habitats are inundated.	Sufficient acres of alkali knolls refugia are required to support migratory shorebirds during high lake levels (Paul et al. 2010; Sorensen 2010; SWCA 2005; SWCA 2007). The indicator ratings are based on the historic distribution and extent of this habitat. Very good is based on the known distribution of alkali depressions soil types (i.e., alkali depressions) surrounding the lake (between elevations 4,209 and 4,218) in the SURRGO/STATSGO soils database and is assumed to be representative of historic acreage. The acreage of alkali knolls that existed during the high lake level event in the late 1980s was supportive of migratory shorebird populations and is therefore assumed to be sufficient (good). This acreage also overlaps with the 70% to 90% range of historic habitat for all bays (also defined as good; see separate acreage thresholds rationale). In most bays, alkali knoll habitat remained relatively undisturbed with the maximum percentage loss at 8% in Farmington Bay. Acreages of alkali knolls habitat at 50% and 70% of historic acreages are ranked as the upper thresholds of poor and fair respectively. To determine the extent of alkali knolls valued as refuge habitat, we examined Great Salt Lake Waterbird Survey data (Paul and Manning 2002) in Gilbert Bay to see if significant species used alkali knolls habitats there in 1997–2001. Although there are no sampling locations in alkali knolls habitats, survey areas in shoreline habitats elsewhere in Gilbert Bay had large numbers of shorebirds. In Survey Area 43, a maximum of 2,621 American Avocets and 3,600 Wilson's Phalarope were counted. In Survey Area 40, a maximum of 3,600 American Avocets and 119,789 Wilson's Phalarope were counted. Franklin's Gull, California Gull, Least Sandpiper, and Red-necked Phalarope also noted in large numbers in these survey areas. Because large numbers of shorebirds use shoreline and adjacent wetlands and uplands on the western shore of Gilbert Bay, we are considering Alkali Knolls habitat areas there as potential refugia for shorebirds during high water years. During a high lake, flooding, period these habitats presumably would be valuable habitat because there would be more access to freshwater, a factor that limits the use of these habitats during drier periods.	Paul, D. S. and A. E. Manning. 2002. Great Salt Lake Waterbird Survey Five-Year Report (1997–2001). Publication Number 08-38. Great Salt Lake Ecosystem Program, Utah Division of Wildlife Resources, Salt Lake City, Utah. December 2002. 64 pp. Bender et al. 1998. Habitat loss and population decline: A meta-analysis of the patch size effect. Ecology 79(2): 517–533; Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100: 65–74; Paul, D.S. 2010. Avian Biologist, Avian West Inc., Utah. Observation of bird use in alkali knolls habitats in western Davis County and northern Salt Lake County during high lake levels. Personal Communication. Sorensen, E. 2010. Conservation Scientist, Utah. Observation of bird use in alkali knolls habitats in western Davis County and northern Salt Lake County during high lake levels. Personal Communication. SWCA. 2005. Legacy Nature Preserve Adaptive Management Plan. Final report submitted by SWCA Environmental Consultants, Salt Lake City, to Utah Department of Transportation, Salt Lake City. SWCA. 2007. Legacy Nature Preserve Habitat Management Plan. Final report submitted by SWCA Environmental Consultants, Salt Lake City, to Utah Department of Transportation, Salt Lake City.
Adjoining Grasslands and Agricultural lands			
Landscape Context: Enough foraging habitat for White-faced Ibis, Long-billed Curlew, and Franklin's Gull Acreage of flood-irrigated agricultural land	White-faced Ibis, Long-billed Curlews, and Franklin's Gull use flood-irrigated agricultural lands for foraging.	The current acres of this habitat are assumed to be good because they are supporting the current populations for white-faced ibis and long-billed curlews. A very good condition could not be assigned because flood irrigated lands are not a natural habitat. Acreages of adjoining grasslands and agricultural habitat at 50% and 75% of current acreages are ranked as the upper thresholds of poor and fair, respectively (see separate habitat acreage threshold rationale).	J. Cavitt personal communication (November 28, 2011). Data used to assess current state: Water-related land use, class "irrigated agricultural lands."
Condition: Vegetation composition Percentage cover of native and desirable nonnative vegetation defined as bunchgrasses, desirable forbs and grasses, and agricultural species	Diverse vegetation composition and structure composed of bunchgrasses, desirable forbs and annual grasses, and agricultural species provide suitable nesting, brooding, and foraging habitat for shorebirds and waterbirds.	Long-billed curlews prefer low-profile grassland habitats or bunchgrass edges for nesting, and diverse grassland/agricultural pasture or alfalfa fields for brooding their young. Invasive weeds tend to degrade the quality of these grasslands and the presence of too many invasive weeds can render the habitat unusable by nesting birds. Dominance of mature bunchgrasses and native forbs and grasses provide the appropriate vegetation structure for nesting birds. Cheatgrass is also favored by nesting Long-billed Curlews due to the low stature of this invasive grass species (J. Cavitt pers. comm.).	J. Cavitt personal communication (November 28, 2011). Data used to assess current state: best professional judgment based on work around the lake.
Size: Enough breeding habitat for current population of Long-billed Curlew with low levels of human disturbance on the wetland-upland interface Acreage of grasslands and pasture 150 meters from residential and commercial development for curlews	Long-billed Curlews use the grassland and pasture portions of this habitat for nesting. However, human activities, such as dispersed recreation, domestic predators and other urban predators, associated with residential and commercial development disrupt or impede nesting for Long-billed Curlews and other shorebirds (J. Cavitt personal communication).	Long-billed Curlews use the grassland and pasture portions of this habitat for nesting. Direct and indirect impacts to nesting shorebirds include predation of young, mosquito abatement activities that reduce food availability, and suburban and recreation activities that disturb nesting and foraging habitats. The current acreage of grassland and agricultural lands more than 150 meters (Cavitt pers. comm.) from residential and commercial development is ranked as "good" because it is supporting the current Long-billed Curlew population (J. Cavitt pers. comm.). Very good is defined by historic acreage of this habitat. We assumed that current pasture lands were historically native grasslands and therefore remain in the same habitat type. Additional historic acreage of native grasslands, lost to development and other uses, was calculated as the difference between current total habitat acreage and total available acreage. The percentage loss was assigned proportionately to the natural habitats (unimpounded wetlands, grasslands, mudflats and playas, and lower riparian zones). Impounded wetlands, islands, and agricultural lands were not included in the historic estimates. Alkali knoll historic estimates were calculated using soils data and were removed from the historic analysis of other habitats. Poor is assumed to be 50% of the historic acreage of this habitat. This ranking was checked by calculating the minimum amount of habitat needed by recorded peak populations of Long-billed Curlews in each bay, as measured by the Great Salt Lake Water Bird Survey. Each nesting pair of Long-billed Curlews requires ca. 30 acres of habitat (Pampush and Anthony 1993). In Gilbert Bay, the minimum acreage is equal to 50% of the historic acreage. In Farmington and Bear River Bays, the minimum habitat needed is less than the 50% threshold. In Gunnison Bay the minimum value needed is greater than the current acreage of grasslands; however estimates of historic acreages of this habitat around Gunnison Bay are more uncertain because spatial data for this part of the lake is less detailed. Also, because there are no agricultural lands in this area, the Long-billed Curlews may use other less preferred habitats.	Data used to assess current state: NLCD 2006 data (pasture), SWReGAP (grasslands). Pampush, G. J. and R. G. Anthony. 1993. Nest success, habitat utilization and nest-site selection of long-billed curlews in the Columbia Basin, Oregon. The Condor 95(4): 957–967. John Cavitt personal communication (November 28, 2011). 150-meter buffer (pers. comm. with John Cavitt, November 28, 2011). Data used to assess current state: NLCD 2006 data (pasture), SWReGAP (grasslands), water related land use layer (development and agriculture).

Appendix B

Stress Rating Rationale

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
System wide Lake and Wetlands				
Increased Level of Se in bird eggs	System wide	Severity	Medium	Although there are known future sources of selenium, they are unlikely to tip the concentration in bird eggs to be higher than 6.4 mg/kg.
		Scope	Low	Extent is relatively isolated with the area of greatest concern near Kennecott outfall in Gilbert Bay.
Increased level of mercury in bird eggs	Gilbert	Severity	Medium	Projected to increase but not likely to severely impact birds. There is some concern that the railroad causeway could increase the extent of the deep brine layer in Gilbert Bay and therefore increase methylation rates.
		Scope	Very high	Deep brine layer is relatively large in Gilbert Bay so extent of methylation is higher than in other bays. The major source of mercury is atmospheric deposition, which falls equally across the bay.
	Gunnison	Severity	Medium	Projected to increase but not likely to severely impact birds.
		Scope	Medium	No deep brine layer so methylation of mercury should be less extensive than in Gilbert Bay. The major source of mercury is atmospheric deposition, which falls equally across the bay.
	Farmington	Severity	Medium	Projected to increase but not likely to severely impact birds.
		Scope	High	Smaller deep brine layer than Gilbert Bay but anoxic conditions exist during the summer and could increase the extent of methylation of mercury. The major source of mercury is atmospheric deposition, which falls equally across the bay.
	Bear	Severity	Medium	Projected to increase but not likely to severely impact birds.
		Scope	Medium	No deep brine layer so methylation of mercury should be less extensive than in Gilbert Bay. The major source of mercury is atmospheric deposition, which falls equally across the bay.
Increased frequency of botulism	System wide	Severity	Medium	It is unclear what the key triggers of avian botulism are around Great Salt Lake. Recent trends suggest that outbreaks may be becoming more frequent.
		Scope	Very High	If botulism outbreaks were to occur, the geographic extent would likely be wide.
Other toxins (EDC, emerging contaminants, arsenic)	System wide	Severity	Unknown	Most of the other toxins are of emerging concern and very little is understood about their cycling in Great Salt Lake or their impacts on biota.
		Scope	High	Other toxins to the lake would likely affect the entire system.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
Impaired lake level fluctuations	System wide	Severity	Low	The timing of water coming into the Great Salt Lake system is likely to remain relatively similar to past trends. It is unclear whether there will be more consumptive withdrawals of water in the future as land is converted from agricultural to developed uses.
		Scope	Very High	Any changes to lake level fluctuation would occur lake wide.
Reduced lake volume and area	System wide	Severity	High	Projected additional withdrawals of water from Great Salt Lake could reduce average lake levels (over a 10-year period) to below 4,194, which would be a fair condition of health, a shift down from the current good rating for this indicator.
		Scope	Very High	Any changes to lake level would occur lake wide.
Open Water of Bays				
Altered salinity levels supportive of native biota	Gilbert	Severity	High	As lake levels go down, salinity will change in Gilbert Bay to levels that are less optimal for brine shrimp, phytoplankton, stromatolitic structures, and brine flies. This is due to complex hydrologic conditions that could cause the bay to become saltier in the short-run and fresher in the long-run as lake level drops below 4,194.
		Scope	Very high	Any changes to salinity would occur bay-wide.
	Gunnison	Severity	Low	This parameter is only applicable during high lake levels and salinity cannot get worse with lower lake levels.
		Scope	Very High	Any changes to salinity would occur bay-wide.
	Farmington	Severity	High	As Gilbert Bay drops, it becomes more disconnected from Farmington Bay. As lake levels drop, Farmington Bay would be dominated by freshwater inputs and less saline.
		Scope	Very High	Any changes to salinity would occur bay-wide.
	Bear	Severity	High	As Gilbert Bay drops, it becomes more disconnected from Bear River Bay. As lake levels drop, Bear River Bay would be dominated by freshwater inputs and less saline.
		Scope	Very High	Any changes to salinity would occur bay-wide.
Reduced aerial extent of stromatolitic structures	Gilbert	Severity	High	Low lake levels would expose, and possibly damage stromatolitic structures. Acidification effects in saline system, associated with rising CO_2 levels in the atmosphere, are uncertain but there is not good buffering capacity in the lake. This is a secondary stress to these structures.
		Scope	Very High	Most stromatolitic structures are found around the edge of the bay and would be uniformly impacted by reduced lake levels.
	Gunnison	Severity	Low	Stromatolitic structures in Gunnison appear to be dead. Periphyton cannot live in Gunnison anyway due to salinity so there is very little threat of conditions worsening.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	Low	Already all dead so there is very little more to lose.
	Farmington		Unknown	The extent and condition of stromatolitic structures is unknown in Farmington Bay. Low light penetration due to eutrophication likely limits their capacity to grow.
			Unknown	Unknown.
	Bear	Severity	Unknown	The extent and condition of stromatolitic structures is unknown in Bear River Bay.
		Scope	Unknown	Unknown.
Altered algal biomass supportive of food web	Gilbert	Severity	Unknown	Impacts to the base of the food web, including phytoplankton and periphyton could be severe with lowered lake levels, changes in salinity, and increased nutrients over a 10-year time frame. There is the potential to alter brine shrimp population dynamics through changes in composition and quantity of phytoplankton. For example, when diatoms dominate the water column the brine shrimp populations are devastated. However, there is not enough known to understand the underlying linkages and thresholds between the food web and stresses to the system.
		Scope	Very High	Any changes to the food-web associated with salinity, lake level, or nutrient loads would likely occur throughout the bay.
	Farmington	Severity	Unknown	Impacts to the food web, including phytoplankton, zooplankton, and benthic macroinvertebrates could be severe with lowered lake levels, changes in salinity, and increased nutrients over a 10-year time frame. However, there is not enough known to understand the underlying linkages and thresholds between the food web and stresses to the system.
		Scope	Very High	Any changes to the food-web associated with salinity, lake level, or nutrient loads would likely occur throughout the bay.
	Bear	Severity	Unknown	Change in salinity, more nutrients from wastewater.
		Scope	Very High	Any changes to the food-web associated with salinity, lake level, or nutrient loads would likely occur throughout the bay.
Reduced invertebrate population	Gilbert	Severity	High	If salinity increases with lake level drops, brine fly populations will be reduced. Invertebrate populations could be reduced due to reduced water levels.
		Scope	Very High	Any changes in brine fly populations associated with salinity, lake level, or nutrient loads would likely occur throughout the bay.
	Farmington	Severity	Unknown	There is very little known about invertebrates in Farmington Bay. Avocets and stilts favor corixids and midges but Phalaropes spend a lot of time in open water. As lake level drops and the bays begin to dry up, all biota in the lake would be threatened. Eutrophication-driven anoxia in the deep brine layer precludes invertebrates from inhabiting a large portion of the bay.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	High	Any changes in invertebrate populations associated with salinity, lake level, or nutrient loads would likely occur throughout much of the bay.
	Bear	Severity	Unknown	Invertebrate populations could be reduced due to reduced water levels. The severity of this impact could not be predicted.
		Scope	High	Any changes in invertebrate populations associated with salinity, lake level, or nutrient loads would likely occur throughout much of the bay.
Reduced brine shrimp population	Gilbert	Severity	High	As salinity increases with lake level drops, brine shrimp populations will be reduced.
		Scope	Very High	Any changes in brine shrimp populations would likely occur throughout the bay.
	Gunnison	Severity	Low	Brine shrimp are inconsequential during low lake levels. Gunnison Bay is likely to remain a refugia during high lake levels. The probability of refugia may be reduced due to lower lake levels.
		Scope	Very High	Any changes in brine shrimp populations would likely occur throughout the bay.
	Farmington	Severity	Unknown	Brine shrimp occurrence in Farmington is very low. Current impacts are greater on other zooplankton.
		Scope	Very High	Any changes in brine shrimp populations would likely occur throughout the bay.
Increased eutrophication	Farmington and Bear River Bays	Severity	Unknown	It is unclear to what extent the current trophic level of the lake is problematic. Further, it is difficult to predict whether the lake will become more eutrophic in the future.
		Scope	Medium	Any changes in trophic condition would likely occur close to nutrient inflows to each bay.
Increased toxic algal species	Gilbert	Severity	Low	Cyanobacteria are important food source for brine shrimp. Currently there are not large concentrations of toxic species in Gilbert Bay. Although there is the possibility of shifting to more toxic species, the probably of this happening is unknown.
		Scope	Medium	Plume from Farmington Bay does not affect much of Gilbert Bay.
	Gunnison	Severity	Low	Cyanobacteria are an important food source for brine shrimp during refuge periods.
		Scope	Low	Impacts from Farmington Bay are unlikely to affect Gunnison Bay.
	Farmington	Severity	Unknown	Nodularia relates directly to salinity and changes in salinity and nutrient inputs could increase the probability of shifting towards additional toxic species of cyanobacteria. Unfortunately, we do not really understand the underlying drivers of these shifts in Farmington Bay.
		Scope	High	Any changes to cyanobacteria occurrences would likely occur across the bay.
	Bear	Severity	Unknown	If salinities frequently enter the range of 1-5%, the *Nodularia* concentrations would also increase. However, the probability of toxic species occurring in the future is unknown.
		Scope	High	Any changes to cyanobacteria occurrences would likely occur across the bay.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
Increased methylmercury in sediment	Gilbert	Severity	Unknown	There will likely be an increased load of atmospheric mercury to the lake in the future and the deep brine layer, one of the primary locations of mercury methylation, is likely to persist into the future. Methylation is likely to continue to occur in sediments and deep brine layer throughout Gilbert Bay but the severity of this occurring is unknown. Paleolimnetic core data suggest that there are lower mercury levels now than during the 1900-1950 era.
		Scope	Unknown	Unknown.
	Gunnison	Severity	Unknown	Unknown.
		Scope	Unknown	Unknown.
	Farmington	Severity	Unknown	The anoxic zone in Farmington Bay includes extremely high concentrations of sulfides in the deep brine layer. Methylation is likely to occur in sediments throughout Farmington Bay and become diluted when mixed into the water column. The severity of this happening is unknown.
		Scope	Unknown	Unknown.
	Bear	Severity	Unknown	Unknown.
		Scope	Unknown	Unknown.
Unimpounded Marsh Complex				
Period in which complex is moist to inundated	Gilbert	Severity	Medium	Many factors could affect the drying up of marshes. However, it is unclear when and if wetland inundation regimes will be affected. The Weber River Basin is currently the most developed and managed basin draining to Great Salt Lake.
		Scope	High	If marshes did begin to dry, it would be likely for it to occur everywhere.
	Gunnison	Severity	Medium	Groundwater fed wetlands, such as locomotive springs, could be affected by groundwater development in Idaho.
		Scope	High	Groundwater fed wetlands likely to be impacted together.
	Farmington	Severity	High	Although there are other managed water sources around Farmington Bay that could provide water to wetlands during drought periods, this stress is ranked as high because the drying of these wetlands would be a greater concern due to the threat of *Phragmites* spread.
		Scope	High	If marshes did begin to dry, it would be likely for it to occur everywhere.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
	Bear	Severity	High	During a drought, more water will be captured in the Bear Lake system and not as much water will be delivered to the lake. Bear River is likely to be the most impacted during a drought because of its dependence on agricultural returns that would be reduced during drought periods. This basin also has the most opportunity for additional water storage in the future. As lake levels drop in Bear River Bay, the hydrostatic pressure for groundwater upstream in the wetlands would be reduced and wetlands will dry out faster. Higher risk/scope than the others.
		Scope	High	If marshes did begin to dry, it would be likely for it to occur everywhere.
More deviation from natural hydrograph for a given storm event	All bays	Severity	Unknown	Changes to hydrology due to land and water management changes in the Great Salt Lake basin are unknown.
		Scope	Unknown	Unknown.
Reduced quality of water delivered to wetlands	Gilbert	Severity	High	Development pressure in the watersheds draining to Gilbert Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Most wetlands are fed by the Weber River system.
	Gunnison	Severity	Low	There is very little development planned for the watersheds draining to Gunnison Bay.
		Scope	Low	
	Farmington	Severity	High	Development pressure in the watersheds draining to Farmington Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Majority of the wetlands receive water from Jordan River, which is projected to become more degraded in the future.
	Bear	Severity	Moderate	Development pressure in the watersheds draining to Bear River Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Most wetlands receive water from the Bear River, which is likely to become more degraded in the future.
Reduced diversity and amount of habitat types	Gilbert	Severity	Very High	Monotypic stands of *Phragmites* are outcompeting other wetland habitats including wet meadows, hemi-marsh, and SAV.
		Scope	Medium	There are problems at Pintain Flats near Ogden Bay. Harold Crane Waterfowl Management Area has a lot of *Phragmites*
	Gunnison	Severity	Very high	Monotypic stands of *Phragmites* are outcompeting other wetland habitats including wet meadows, hemi-marsh, and SAV.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	Low	Invasion is lower in Gunnison Bay.
	Farmington	Severity	Very high	Likely conversion of vegetation to *Phragmites* and *Typha* in the future.
		Scope	High	Likely to continue to occur throughout the wetlands around Farmington Bay.
	Bear	Severity	Very high	Likely conversion of vegetation to *Phragmites* and *Typha* in the future.
		Scope	Medium	Retaining more salts reduces the spread of *Phragmites*.
Increased undesirable plant cover	Gilbert	Severity	High	Likely to become dominated by *Phragmites* in the next 10 years under current management.
		Scope	Very high	Spread is not being contained through management.
	Gunnison	Severity	Low	Based on best professional judgment by the Panel and field observations.
		Scope	Low	Invasion is lower in Gunnison Bay.
	Farmington	Severity	Very high	Likely to become dominated by *Phragmites* (more than 50%) in the next 10 years under current management.
		Scope	Very high	Spread is not being contained through management.
	Bear	Severity	Medium	Based on best professional judgment by the Panel and field observations.
		Scope	Medium	Wetlands around Bear River Bay dry out more frequently and for a longer duration than other bays. *Phragmites* does not take hold as well under those conditions. Management efforts underway to control the extent of spread.
Reduced macroinvertebrate biomass	Gilbert	Severity	Unknown	Unknown
		Scope	Unknown	Unknown
	Gunnison	Severity	Unknown	Unknown
		Scope	Unknown	Unknown
	Farmington	Severity	Unknown	Invertebrate biomass is tied to the vegetation structure and to period of inundation. Plants provide more surface area and habitat diversity but some macroinvertebrates (e.g., midges) can be found in mud etc.
		Scope	Unknown	Unknown
	Bear	Severity	Unknown	Unknown
		Scope	Unknown	Unknown
Loss of habitat between 4,200 and 4,218	Gilbert	Severity	Very high	Development of habitat into residential and commercial areas makes the habitat unusable for significant species. This loss is relatively permanent.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	High	Loss of additional acreage associated with development is likely to tip the total acreage to the fair category (7,389 acres). Number of new households is 245.
	Gunnison	Severity	Very high	Development of habitat into residential and commercial areas makes the habitat unusable for significant species. This loss is relatively permanent.
		Scope	Low	Low development pressure.
	Farmington	Severity	Very high	Development of habitat into residential and commercial areas makes the habitat unusable for significant species. This loss is relatively permanent.
		Scope	Medium	Estimated development increase of 81 households is a 65% increase in development in unimpounded marsh complexes. This would not tip the acreage lost into the fair zone.
	Bear	Severity	Very high	Development of habitat into residential and commercial areas makes the habitat unusable for significant species. This loss is relatively permanent.
		Scope	Medium	Predicted additional loss of 725 acres by 2020. Would not push the ecological target to the fair category. Total additional households is only 121 so medium rating given. Very little development projected for unimpounded marshes. However, Box Elder County is not included in the analysis so stress left at medium.
Impounded Wetlands				
Increased undesirable plant cover	Gilbert	Severity	Very high	Likely to become dominated by *Phragmites* in the next 10 years under current management.
		Scope	Medium	Spread is not being contained through management but only around Ogden Bay.
	Gunnison	Severity	Low	Based on best professional judgment by the Panel and field observations.
		Scope	Low	Based on best professional judgment by the Panel and field observations.
	Farmington	Severity	High	Likely to continue to be dominated by *Phragmites* (more than 25%) in the next 10 years under current management.
		Scope	Medium	Spread is being contained through management though resources are not spread equally among areas of concern.
	Bear	Severity	Medium	Based on best professional judgment by the Panel and field observations.
		Scope	Medium	Wetlands around Bear River Bay dry out more frequently than other bays. *Phragmites* does not take hold as well under those conditions. Management efforts underway to control the extent of spread.
Reduced food supply supportive of fish and birds	All bays	Severity	Unknown	Largest concern is toxins rather than hydrology or other water quality parameters
		Scope	Unknown	Unknown

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
Reduced quality of water delivered to wetlands	Gilbert	Severity	High	Development pressure in the watersheds draining to Gilbert Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Most wetlands are fed by the Weber River system.
	Gunnison	Severity	Low	There is very little development planned for the watersheds draining to Gunnison Bay.
		Scope	Low	Based on best professional judgment by the Panel and field observations.
	Farmington	Severity	High	Development pressure in the watersheds draining to Farmington Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Majority of the wetlands receive water from Jordan River, which is projected to become more degraded in the future.
	Bear	Severity	Moderate	Development pressure in the watersheds draining to Bear River Bay could affect the riparian condition of streams in the watershed and therefore affect the quality of water delivered to wetlands.
		Scope	High	Most wetlands receive water from the Bear River, which is likely to become more degraded in the future.
Mudflats and Playas				
Loss of habitat near freshwater	All bays	Severity	Unknown	Changes in hydrologic regime could cause loss of habitat. As lake levels go down however, mudflat habitat could expand. Development pressure is likely to be low compared to other habitats because mudflats occur at lower elevations and poorer soil conditions. Countering forces could make it worse or better at any one location and it is unclear what the overall status will be in the future.
		Scope	Unknown	Although we know the extent of development, this is not the primary factor driving loss of mudflats. It is difficult to determine the scope of this problem.
Increased *Phragmites* in mudflats used by significant species (within 100 m of water)	Gilbert	Severity	Very high	Likely to become dominated by *Phragmites* in the next 10 years under current management.
		Scope	Medium	Spread is not being contained through management.
	Gunnison	Severity	Very high	Based on best professional judgment by the Panel and field observations.
		Scope	Low	There is very little disturbance or introduction of invasive species to mudflats around Gunnison Bay.
	Farmington	Severity	Very high	Likely to become dominated by *Phragmites* (more than 50%) in the next 10 years under current management.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	Very high	Spread is not being contained through management.
	Bear	Severity	Very high	Likely to become dominated by *Phragmites* in the next 10 years under current management.
		Scope	High	Not as large a problem due to weed management efforts. It is a problem in the refuge; not taking over like Farmington Bay. Likely to affect many areas, especially below the impoundments. Willard Spur is in better shape because it is saltier and drier.
Alkali Knolls				
Reduced size to support birds during high lake levels	Gilbert	Severity	Very high	Where loss occurs, the habitat is completely lost. Especially due to habitat fragmentation.
		Scope	High	Most of the alkali knolls remaining around Gilbert Bay are found on the west side of the lake where there is less development pressure. Additional development is likely to eliminate nearly all of the remaining alkali knolls along the Eastern Edge.
	Gunnison	Severity	Very high	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Low	There is very little disturbance around Gunnison Bay.
	Farmington	Severity	Very high	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Very high	Additional development is likely to eliminate nearly all of the remaining alkali knolls along Farmington Bay leaving only 504 acres.
	Bear	Severity	Very high	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	High	Estimated increase in development could result in the loss of 346 additional acres. This is significant considering how much historic habitat loss there has already been. The ecological target would push further into the poor category.
Isolated Island Habitat for Breeding Birds				
Reduced lake levels	Gilbert and Gunnison Bays	Severity	Very high	Projected reduced lake levels could drop the lake to an average elevation of 4,194 feet above MSL on average over 10 years. Low lake levels over a decade could even lower and would threaten the island breeding colonies in Gilbert and Gunnison Bays.
		Scope	Very high	Impacts would likely occur on all islands that are currently isolated and hosting breeding bird colonies.
Increased predators on islands	Gilbert and Gunnison Bays	Severity	Very high	If lake levels drop, it is very likely that predators would access the islands. In addition, there are known occurrences of introducing predators (e.g., Russian Wild Boar) to Freemont Island in Gunnison Bay.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
		Scope	Very high	Impacts would likely occur on all islands that are currently isolated and hosting breeding bird colonies.
Adjoining grasslands and agricultural lands				
Reduced flood irrigated acreage	Gilbert	Severity	High	Grasslands and pasture are being converted to developed areas. Foraging habitat is important to a large number of birds.
		Scope	High	High ranking based on a projected increase of 174% in estimated households from 2007 to 2020 with a total of 2,551 new households projected based on Wasatch Front Regional Council projections. Would likely tip the ecological target to fair based on acreage without human disturbance.
	Gunnison	Severity	Low	Very little if any flood irrigated lands currently so very little could be lost.
		Scope	Low	There is very little disturbance or introduction of invasive species to mudflats around Gunnison Bay.
	Farmington	Severity	High	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Medium	Medium ranking based on additional 1,767 households projected to be developed based on Wasatch Front Regional Council projections. The acreage without human disturbance will be reduced as development increases but will likely stay on the good/fair threshold.
	Bear	Severity	High	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Low	More acreage protected and likely to stay in agricultural production (compared to areas around Farmington/Gilbert Bays). Only 2 additional households projected by 2020 based on Wasatch Front Regional Council projections. Note: Box Elder County is not included in the analysis.
Increased undesirable plant cover	Gilbert	Severity	High	Weeds seriously impact the structure and uses of this habitat.
		Scope	Medium	Based on best professional judgment by the Panel.
	Gunnison	Severity	High	Weeds seriously impact the structure and uses of this habitat.
		Scope	Low	Less disturbance here than in other bays.
	Farmington	Severity	High	Weeds seriously impact the structure and uses of this habitat.
		Scope	High	Large problem with upland invasive species
	Bear	Severity	High	Weeds seriously impact the structure and uses of this habitat.
		Scope	Medium	More weed management in managed areas in Bear River uplands compared to Farmington.

Table B1. Stresses to Great Salt Lake

Stress	Bay	Priority	Rating	Rationale
Reduced breeding habitat (grasslands and pasture) for long billed curlew without human disturbance	Gilbert	Severity	High	Grasslands and pasture are being converted to developed areas Breeding habitat is more important but for a smaller number of birds than foraging habitat above.
		Scope	High	High ranking based on a projected increase of 174% in estimated households from 2007 to 2020 with a total of 2,551 new households projected based on Wasatch Front Regional Council projections. Would likely tip the ecological target to fair based on acreage without human disturbance.
	Gunnison	Severity	High	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Low	Very little development pressure around Gunnison Bay.
	Farmington	Severity	High	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Medium	Medium ranking based on additional 1,767 households projected to be developed based on Wasatch Front Regional Council projections. The acreage without human disturbance will be reduced as development increases but will likely stay on the good/fair threshold.
	Bear	Severity	High	Where loss occurs, the habitat is completely lost so very severe. Especially due to habitat fragmentation.
		Scope	Low	More acreage protected and likely to stay in agricultural production (compared to areas around Farmington/Gilbert Bays). Only 2 additional households projected by 2020 based on Wasatch Front Regional Council projections. Note: Box Elder County is not included in the analysis.

Appendix C

Science Panel Biographies

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Dr. Bonnie Baxter, Ph.D., Director of the Great Salt Lake Institute and Professor of Biology, Westminster College

Dr. Baxter has been studying the microbial communities of Great Salt Lake for fifteen years, applying her background in cellular biochemistry to the physiology of halophilic archaea, which dominate in the lake's saltiest brines. This expertise has led to many discoveries relating to DNA damage and repair mechanisms, carotenoid photobiology, microbial diversity, microbial mercury methylation, and stromatolite formation. In 2008, Dr. Baxter and colleagues created Great Salt Lake Institute at Westminster College, which serves to enhance research, education and stewardship of Great Salt Lake. Through this non-profit organization, the institute pulls together researchers from all around the world to study this unique ecosystem and share their discoveries.

Selected Great Salt Lake publications:

Pugin, P, Blamey, J.M., Baxter, B.K. and Wiegel, J. *Amphibacillus cookii* sp. nov., a facultatively aerobic, sporeforming, moderate halophilic, alkalithermotolerant bacterium from Great Salt Lake, Utah. *Intnl. J. Systematic and Evol. Microbiol*., in press, 2012.

Baxter, BK, *Mangalea, M.R., Willcox, S., Sabet, S., *Nagoulat M.N. and Griffith, J.G. Haloviruses of Great Salt Lake: a model for understanding viral diversity, In: Ventosa, A., Oren, A and Ma,Y., eds., *Halophiles and Hypersaline Environments: Current Research and Future Trends*. Springer, the Netherlands, 2011.

Oren, A., Baxter, B.K. and Weimer, B.C. Microbial Communities in Salt Lakes: Phylogenetic Diversity, Metabolic Diversity, and in situ Activities: Summary of a Roundtable Discussion on our Current Understanding, Limitations to our Knowledge, and Future Approaches. In: Oren, A., Naftz, D.L., and Wurtsbaugh, W.A. (eds.), Saline lakes around the world: unique systems with unique values. The S.J. and Jessie E. Quinney Natural Resources Research Library, published in conjunction with the Utah State University College of Natural Resources, vol XV: 257-263, 2009.

Baxter, B.K., *Eddington, B., *Riddle, M.R., *Webster, T.N. and Avery, B.J. Great Salt Lake Halophilic Microorganisms as Models for Astrobiology: Evidence for Desiccation Tolerance and Ultraviolet Radiation Resistance. In: Hoover, R.B., Levin, G.V., Rozanov, A.Y., and Davies, P. C.W. (eds.) *Instruments, Methods, and Missions for Astrobiology X*, 6694:669415. SPIE, Bellingham, WA, 2007.

Baxter, B.K.,Litchfield, C.D., Sowers, K., Griffith, J. D., DasSarma, P.A. and DasSarma, S. Great Salt Lake Microbial Diversity. In: Gunde-Cimerron, N., Oren, A., Plemenita, A. (eds.) Adaptation to Life in High Salt Concentrations in Archaea Bacteria, and Eukarya. Springer, the Netherlands, 2005.

Education	**Areas of Expertise**
B.S., Major/department, Institution M.S., Major/department, Institution Ph.D., Major/department, Institution	• Photobiology of halophiles • Astrobiology applications of extremely hypersaline ecosystems

Dr. Gary Belovsky, Ph.D., Professor, Gillen Chair and Director of UNDERC, University of Notre Dame

Dr. Belovsky's research examines long term Great Salt Lake ecosystem dynamics, especially the population dynamics of brine shrimp. This 18 year involvement has been part of the Utah Division of Wildlife Resources' Great Salt Lake Ecosystem Project that has been the foundation for management of the brine shrimp harvest and has created the longest continuous database on the Great Salt Lake. This work led to Belovsky receiving the Governor of Utah's Medal for Science (2000).

Selected Great Salt Lake publications (93 total publications, 14 on Great Salt Lake):

Belovsky, G.E. and W.C. Perschon. A Management Case Study for a New Fishery: brine shrimp harvesting in Great Salt Lake. 27 pp. (submitted to Ecological Applications)

Belovsky, G.E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Van Leeuwen, and D.V. Allen. 2011. The Great Salt Lake Ecosystem (Utah, USA): long term data and a structural equation approach. *Ecosphere* 2: 1-40, art33. doi:10.1890/ES10-00091.1.

Belovsky, G.E. 1996 - 2003. Annual Reports: Brine shrimp population dynamics and sustainable harvesting in the Great Salt Lake: Utah Division of Wildlife Resources, Salt Lake City, Utah. 212 pp.

Belovsky, G.E., Mellison, C., Larson, C., and Van Zandt, P.A. 2002. How good are PVA models? Testing their predictions with experimental data on the brine shrimp. Pp. 257-283. *In*: S. R. Beissinger and D. R. McCullough (eds.), *Population Viability Analysis*. University of Chicago Press, Chicago, IL.

Belovsky, G.E., C. Mellison, C. Larson, and P.A. Van Zandt. 1999. Experimental studies of extinction dynamics. *Science* 286:1175-1177.

Education	**Areas of Expertise**
B.B.A., Management, University of Notre Dame M.F.S., Forest Science, Yale University Ph.D., Organismic Biology, Harvard University	• Foraging theory • Population dynamics (including predator-prey, inter-specific competition) • Nutrient cycling in ecosystems • Population viability for conservation • Hypersaline lake and grassland ecology

John F. Cavitt, Ph.D., Distinguished Professor of Zoology, and Director, Office of Undergraduate Research, Weber State University

Dr. John Cavitt's research is examining foraging behavior, diet, and population dynamics of aquatic birds using Great Salt Lake. Great Salt Lake is one of the most important breeding and staging areas for millions of aquatic birds, yet critical information is lacking on many aspects of their ecology and behavior. Cavitt focuses his research within four areas: 1) Life History Strategies and Population Dynamics, 2) Species Coexistence, 3) Habitat and Nest Site Selection, and 4) Foraging Behavior and Diet. These topics include examination of responses of birds and their habitat to contaminants, anthropogenic disturbance, and land management.

Selected Great Salt Lake publications:

Thomas, S.M. J. Lyons, B. Andres, E. Elliot-Smith, E. Palacios, J. Cavitt, J. Royle, S. Fellows, K. Maty, W. Howe, E. Mellink, S. Melvin, and T. Zimmerman. 2011. Population size of Snowy Plovers breeding in North America. Waterbirds 34 (4).

Hall, Lucas, J. Mull, and J.F. Cavitt. 2009. Relationship between cheatgrass coverage and the relative abundance of snakes on Antelope Island, Utah. Western North American Naturalist 69:88-95. PDF Reprint

Cavitt, J.F. and K. Stone. 2007. Selenium and mercury concentrations in breeding female American Avocets at Ogden Bay, Great Salt Lake, Utah. In: *Development of a Selenium Standard for the Open Waters of the Great Salt Lake*, 15pp. State of Utah Department of Environmental Quality, Division of Water Quality, Salt Lake City, UT.

Cavitt, J.F. 2007. Concentration and effects of selenium on breeding shorebirds at Great Salt Lake. In: *Development of a Selenium Standard for the Open Waters of the Great Salt Lake*, 30pp. State of Utah Department of Environmental Quality, Division of Water Quality, Salt Lake City, UT.

Cavitt, J.F., S. Jones, and T. Zimmerman. *In preparation*. Atlas of breeding colonial waterbirds in the Western United States. U.S. Fish and Wildlife Service Publication.

Education	Areas of Expertise
B.S., Biology, Illinois State University M.S., Biology, Illinois State University Ph.D., Biology, Kansas State University	• Foraging behavior and diet • Conservation of aquatic birds • Avian population dynamics

Dr. Wally Gwynn, Ph.D., Independent Consultant, formerly with Utah Geological Survey

Research focused on the brine chemistry of the lake extended into the industrial applications of salt/brine phase chemistry. Other research focused on the causes and consequences of bi-directional flow, or the lack thereof, through the breach and culvert openings in the railroad causeway. A brine chemistry database was developed and maintained, extending continuously from 1966 through the present. Products of the foregoing research included the collections of numerous lake-related books, articles, data, and photographs. Two major publications on the lake, published by the Utah Geological Survey, included chapters on the lake's history, geology, chemistry, industries, biology, hydrology, etc.

Selected Great Salt Lake publications:

Gwynn, J.W., editor, 1980, *Great Salt Lake, a scientific, historical and economic overview*. Utah Geological and Mineral Survey Bulletin 116, 400 p.

Gwynn, J.W., 1987, *Effects of breaching the Southern Pacific Railroad causeway, Great Salt Lake, Utah - physical and chemical changes*, August 1, 1984 - July, 1986. Utah Geological and Mineral Survey, Water Resources Bulletin 25, 25 p.

Gwynn, J.W., 1996, *Commonly asked questions about Utah's Great Salt Lake and ancient Lake Bonneville*. Utah Geological Survey Public Information Series 39, 22 p.

Gwynn, J.W., editor, 2002, *Great Salt Lake - an overview of change*. Utah Geological Survey, Department of Natural Resources Special Publication, 584 p.

Gwynn, J.W., 2006, *Saline minerals*, in Whitley, Colleen, editor, From the ground up–the history of mining in Utah. Logan, Utah State University Press, p. 101-125.

Education	Areas of Expertise
B.S., Mineralogy–Univ. of Utah - 1965 Ph.D., Mineralogy and Allied Fields–Univ. of Utah - 1970	• Saline Resources of Utah • Tar Sand Resources of Utah

Dr. Heidi Hoven, Ph.D., Director of The Institute for Watershed Sciences; Visiting Research Professor, Weber State University, Department of Botany

Dr. Heidi Hoven has been involved in Great Salt Lake wetlands research for the past eight years, primarily focusing on condition assessment of impounded and fringe wetlands as related to beneficial use support and has been investigating physiological and biological queues from submerged aquatic vegetation (SAV) as to why some impoundments fail to support sustained growth of SAV for the duration of the growing season. Dr. Hoven has recently developed a rapid wetland assessment method (Utah Wetlands Ambient Assessment Method, Version 1.2 or UWAAM; Hoven and Paul 2010) to provide a unified assessment strategy to be used by multiple agencies for §305(b), §404 regulation and for obtaining habitat management goals. UWAAM was developed specifically for wetlands of Great Salt Lake and its watersheds. Dr. Hoven also contributed to the development of the Avian Wetland Habitat Assessment Model for the eastern shore area of Great Salt Lake by The Cadmus Group, Watertown, Massachusetts. IWSciences has contributed to the development of a database to be used as a Great Salt Lake wetlands reference network that is built on existing data from various studies.

Selected Great Salt Lake Publications:

Hoven, H.M., D. Richards, W.P. Johnson, G.T. Carling. 2011. Plant Metric Refinement for Condition Assessment of Great Salt Lake Impounded Wetlands, Preliminary Report: June 7, 2011. IWSciences, Kamas, Utah.

Hoven, H.M. 2011. Evidence of Sustained Submerged Aquatic Vegetation (SAV) Growth in Bear River Bay, Great Salt Lake, Utah. IWSciences, Kamas, Utah.

Hoven, H.M. and D.S. Paul. 2010. Utah Wetlands Ambient Assessment Method Version 1.2. IWSciences, Kamas, Utah.

Hoven, H.M. 2010. Submerged Aquatic Vegetation of Impounded Wetlands of Farmington Bay, Great Salt Lake: Final Report to DWQ for the 2007 EPA Wetland Program Development Grant. IWSciences, Kamas, Utah.

Hoven, H.M. & T.G. Miller. 2009. Developing vegetation metrics for the assessment of beneficial uses of impounded wetlands surrounding Great Salt Lake, Utah, U.S.A. In: Saline lakes around the world: unique systems with unique values. Oren, A., Naftz, D.L., and Wurtsbaugh, W.A. (eds.); The S.J. and Jessie E. Quinney Natural Resources Research Library, published in conjunction with the Utah State University College of Natural Resources.

Education	Areas of Expertise
B.S., Natural Resources, University of Rhode Island M.S., Plant Biology, University of New Hampshire Ph.D., Natural Resources Program, University of New Hampshire	• Aquatic plant ecophysiology and ecotoxicology • Wetland ecology and assessment methods • Biology and physiology of submerged aquatic vegetation • Land use planning and conservation of wetland and aquatic ecosystem services

Craig Miller, P.E., Utah Division of Water Resources

Craig Miller has worked in the Hydrology and Computer Applications Section within Water Resources for nearly thirty years focusing on river system modeling and hydrology. He was involved in studying how to manage a flooding Great Salt Lake in the early 1980s and more recently has been modeling how population growth along the Wasatch Front could affect Great Salt Lake inflows and levels.

Selected Great Salt Lake publications:

Loving, B.L., Waddell, K.M., and Miller, C.W., 2000, Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement through the Causeway, 1987-98: U.S. Geological Survey Water-Resources Investigations Report 00-4221, 101 p.

Loving, B.L., Waddell, K.M., and Miller, C.W., 2002, Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement Through the Causeway, 1963-98: Great Salt Lake an Overview of Change edited by J. Wallace Gwynn, Ph. D., p 143-166.

Education	Areas of Expertise
B.S., Civil Engineering, Brigham Young University M.S., Agricultural and Irrigation Engineering, Utah State University	• Hydrology • Future demands affecting Great Salt Lake levels.

Dr. Theron Miller, Ph.D., Research Scientist, Jordan River/Farmington Bay Water Quality Council	
For the last nine years, Dr. Miller's work has been mainly dedicated to studying and understanding the ecological processes associated with the sheet flow and impounded wetlands around Great Salt Lake. Water. Initial objectives were to identify potential linkages between water column nutrient concentrations and various indicators of ecological health and 303(d) beneficial use assessments. Specifically, research focused on relationships between nutrients and various measures of plant, macroinvertebrate and avian community health. Linkages between water column nutrients and biological metrics have not been strongly demonstrated, In continued cooperation with several academic and NGO subcontractors, Dr. Miller refocused the investigation on the relationship between sediment biogeochemical processes including whole sediment and pore water concentrations of toxic metals, ammonia phosphate and sulfides and plant and macroinvertebrate health and the relationship between habitat (SAV) structure and macroinvertebrate community health in Great Salt Lake impounded wetlands. For the last three years, Dr. Miller has also been working on water and sediment quality issues concerning the Jordan River. Selected Great Salt Lake publications: Miller, T.G., D. Richards, H.M. Hoven, W.P. Johnson, M. Hogset and G.T. Carling. 2011. Macroinvertebrate communities in Great Salt Lake impounded wetlands, their relationship to water and sediment chemistry and to plant communities and proposed modifications to the MMI. Report to the Jordan River/Farmington Bay Water Quality Council and Utah Division of Water Quality. 146 p. Hoven, H.M. & T.G. Miller. 2009. Developing vegetation metrics for the assessment of beneficial uses of impounded wetlands surrounding Great Salt Lake, Utah, U.S.A. In: Saline lakes around the world: unique systems with unique values. Oren, A., Naftz, D.L., and Wurtsbaugh, W.A. (eds.); The S.J. and Jessie E. Quinney Natural Resources Research Library, published in conjunction with the Utah State University College of Natural Resources. Miller, T.G. and H.M. Hoven. 2007. Ecological and beneficial use assessment of Farmington Bay wetlands: Assessment methods development. Phase I. Report to US EPA, Region 8. 51. Pages.	
Education	**Areas of Expertise**
B.S., Institution Fisheries Management, Utah State University Institution M.S., Aquatic Toxicology /, University of Alberta Ph.D., Environmental Biology and Ecology, University of Alberta	• Fisheries Biology and Limnology • Aquatic toxicology • Ecological toxicology • Sediment Limnology and sediment biogeochemistry

Dr. David Naftz, Ph.D., Research hydrologist, U.S. Geological Survey, Utah Water Science Center	
Dr. Naftz has done research on a variety of water quality and climate-related issues in the western United States and began his research on Great Salt Lake in 2001. His research interests on Great Salt Lake have included mercury and selenium geochemistry, nutrient cycling, historical reconstruction of anthropogenic pollutants, submarine groundwater discharge, and hydrodynamic modeling of pollutant inputs. Selected Great Salt Lake publications: Naftz, D.L., Angeroth, C., Kenney, T., Waddell, B., Darnall, N., Silva, S., Perschon, C., and Whitehead, J., 2008, Anthropogenic influences on the input and biogeochemical cycling of nutrients and mercury in Great Salt Lake, Utah, USA: Applied Geochemistry, vol. 23, p. 1731-1744. Naftz, D., Fuller, C., Cederberg, J. Krabbenhoft, D., Whitehead, J., Garberg, J., and Beisner, K., 2009, Mercury inputs to Great Salt Lake, Utah: Reconnaissance-phase results, in Saline lakes around the world: Unique systems with unique values (A. Oren, D.L. Naftz and W.A. Wurtsbaugh, eds.), Utah State University Press, Logan, Utah. Naftz, D.L., Johnson, W.P., Freeman, M.L., Beisner, Kimberly, Diaz, Ximena, and Cross, V.A., 2009, Estimation of selenium loads entering the south arm of Great Salt Lake, Utah, from May 2006 through March 2008: U.S. Geological Survey Scientific Investigations Report 2008–5069, 40 p. Naftz, D.L., Cederberg, J.R., Krabbenhoft, D.P., Beisner, K.R., Whitehead, J., and Gardberg, J., 2011, Diurnal trends in methylmercury concentration in a wetland adjacent to Great Salt Lake, Utah, USA: Chemical Geology, vol. 283, p. 78-86. Naftz, D.L., Millero, F.J., Jones, B.F., and Green, W.R., 2011, An equation of state for hypersaline water in Great Salt Lake, Utah, USA: Aquatic Geochemistry, vol. 17, no. 6, p. 809-820.	
Education	**Areas of Expertise**
B.S., Geology, University of Southern Colorado M.S., Geochemistry, Colorado School of Mines Ph.D., Geochemistry, Colorado School of Mines	• Biogeochemistry of mercury and selenium • Hydrology

Dr. Wayne Wurtsbaugh, Ph.D., Professor, Utah State University, College of Natural Resources

Dr. Wurtsbaugh has worked on the plankton dynamics of the Great Salt Lake since 1985, including studies of eutrophication in Farmington Bay, comparative analyses of three bays of the lake, and factors controlling brine shrimp production. He has also conducted selenium and mercury studies on the stromatolite (biostromes) community in the lake, and assessed mercury transport between the deep brine layer and the brine shrimp.

Selected Great Salt Lake publications

Wurtsbaugh, W.A. 1992. Food-web modification by an invertebrate predator in the Great Salt Lake (USA). Oecologia 89:168-175.

Wurtsbaugh, W.A. and Z. M. Gliwicz. 2001. Limnological control of brine shrimp population dynamics and cyst production in the Great Salt Lake, Utah. Hydrobiologia. 466: 119-132.

Marcarelli, A.M., W.A. Wurtsbaugh and O. Griset. 2006. Salinity controls phytoplankton response to nutrient enrichment in the Great Salt Lake, Utah, USA. Can. J. Fish. Aquat. Sci. 63:2236-2248.

Wurtsbaugh, W.A. and A. M. Marcarelli. 2006. Eutrophication in Farmington Bay, Great Salt Lake, Utah 2005 Annual Report. Report to the Central Davis Sewer Improvement District, Kaysville, UT. 91 p.

Wurtsbaugh, W.A., J. Gardberg and C. Izdepski. 2011. Biostrome communities and mercury and selenium bioaccumulation in the Great Salt Lake (Utah, USA). Science of the Total Environment 409: 4425–4434.

Education	**Areas of Expertise**
B.S., Fisheries and Wildlife, University of California at Davis M.S., Fisheries, Oregon State University Ph.D., Ecology, University of California at Davis	• Landscape limnology • Biogeochemical controls on aquatic productivity • Algal-nutrient relationships • Spatial-temporal relationships in fish foraging • Bioenergetics of fishes • Stable isotopes and food webs • Ecology of endemic and threatened fishes • Saline lake limnology

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Appendix D

Maps

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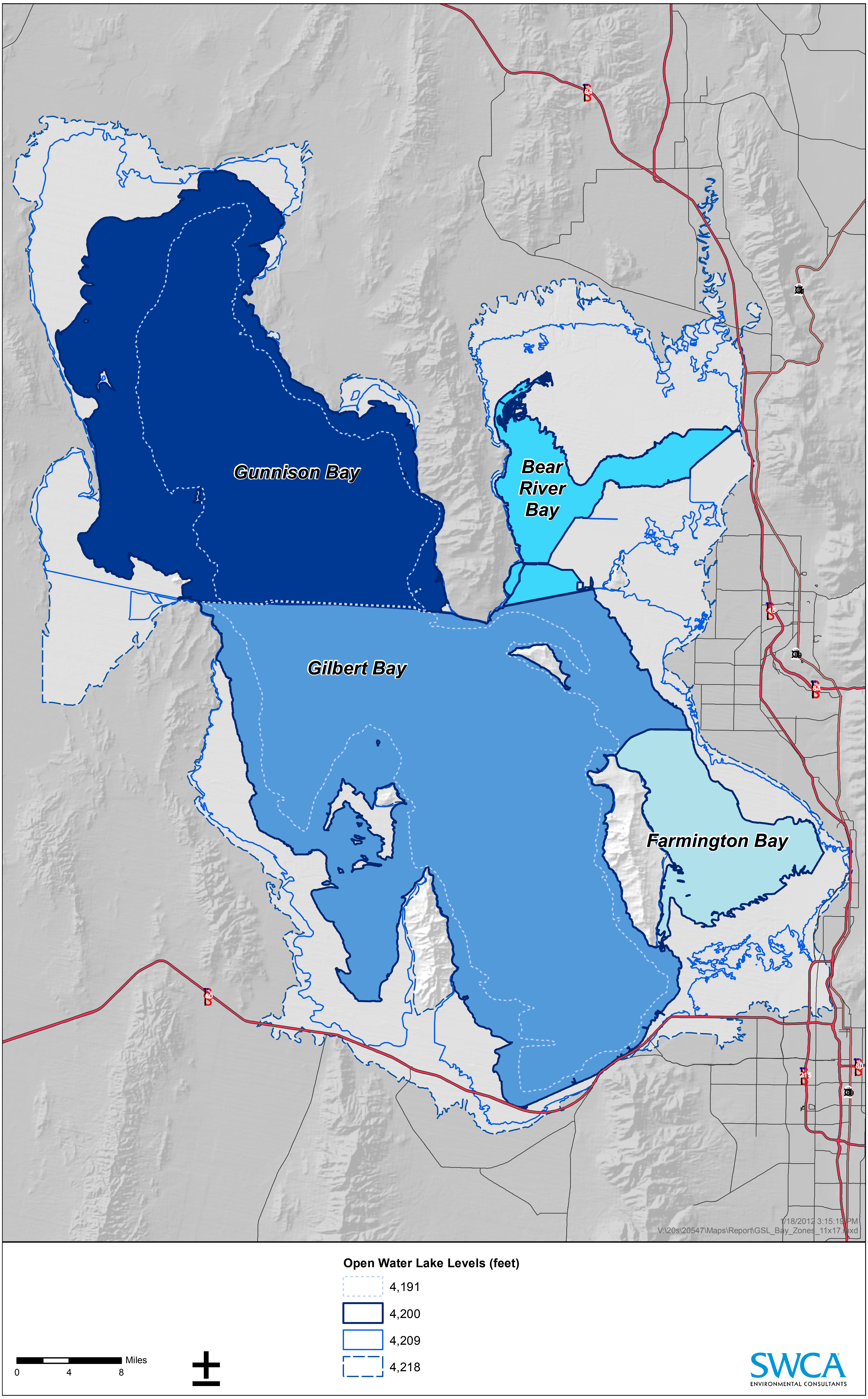

Map 1. Great Salt Lake elevation ranges and bays.

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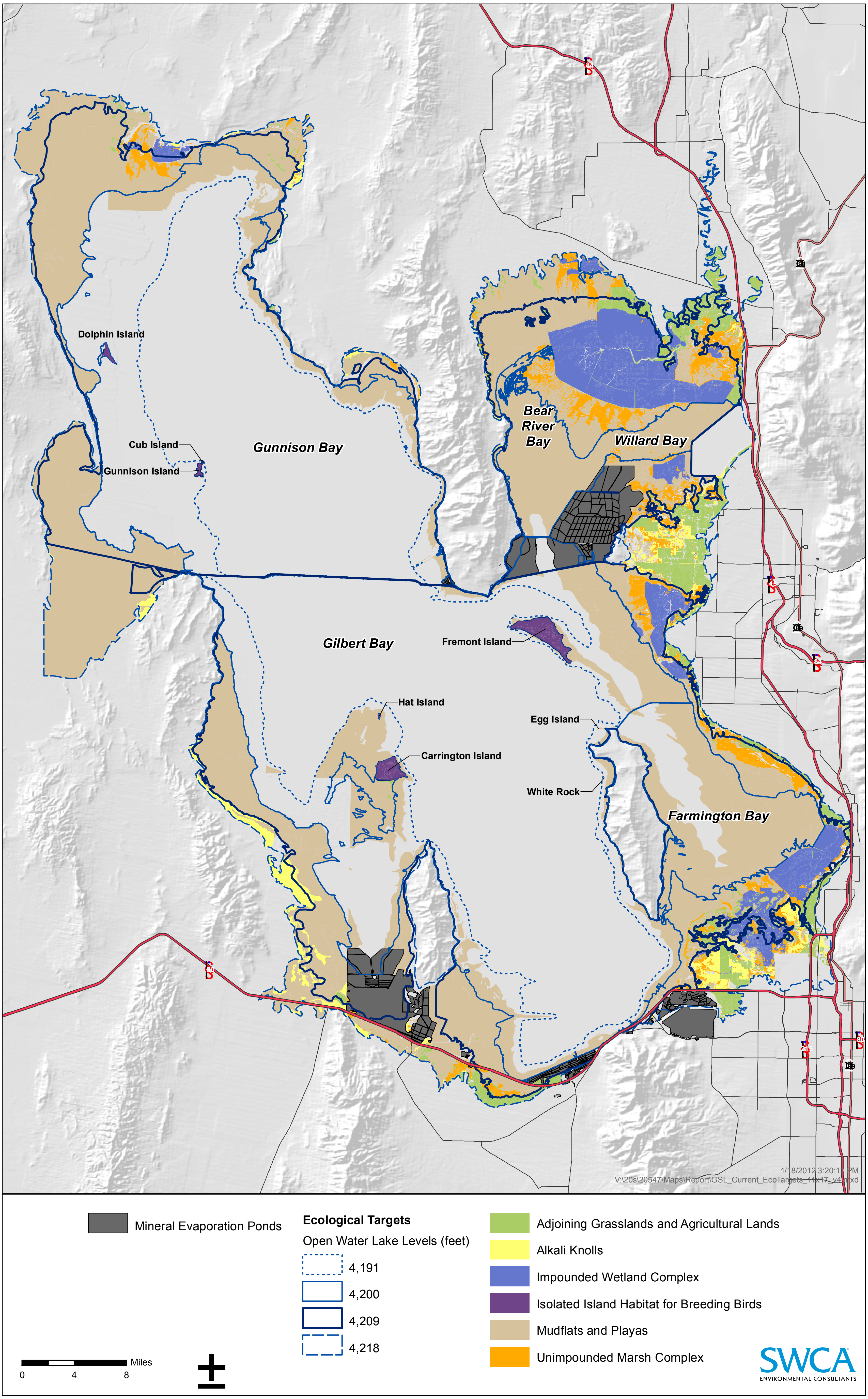

Map 2. Ecological targets.