CHAPTER 4 WETLANDS

2014 Integrated Report

UTAH DIVISION OF WATER QUALITY

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INTEGRATED REPORT

UTAH'S WETLAND PROGRAM

Introduction

DWQ initiated its Wetlands Program in 2004 with a focus on evaluating whether wetlands associated with Great Salt Lake (GSL) are fully supporting their broadly defined beneficial use: habitat support for waterfowl and shorebirds, and the necessary aquatic life in their food chain. Early efforts focused on shallow ponded areas, or impounded wetlands (IWs), where dikes, berms and ditches have been constructed to control water flow. DWQ's interest began in response to stakeholder concerns that nutrient loads from water treatment facilities adjacent to Great Salt Lake may have deleterious impacts on these productive and highly valued ecosystems. Initial work focused on IWs adjacent to Farmington Bay, where wetland managers and conservation groups observed the occasional dominance of Cyanobacterial mats, a common indicator of phosphorus-induced eutrophication (Reddy and DeLaune, 2008). One of the principle concerns was that these mats could negatively impact the health and vigor of extensive swards of submerged aquatic vegetation (SAV) (e.g. sago pondweed, Stuckenia sp.) or[D1] alter the species composition and abundance of aquatic macroinvertebrate communities. Both SAV and benthic macroinvertebrates are key food resources for migrant waterfowl species (Miller and Hoven, 2007) and important ecological components of shallow ponds (Keddy, 2010).

In 2009, DWQ finalized a draft Assessment Framework for GSL impounded wetlands (DWQ, 2009). This work developed an assessment tool, a multi-metric index (MMI), that integrates physical, chemical, and biological characteristics of impounded wetlands into an evaluation of the relative health (i.e. condition) of IW sites adjacent to the lake. Included within the draft framework report was an outline of next steps (see section 5.2 and Figure 1 in DWQ, 2009), which laid out a watershed-based approach for protecting Great Salt Lake wetlands. This chapter summarizes a validation of the draft assessment framework (MMI) for IWs based on data collected from a probabilistic survey of 50 impounded wetland sites (DWQ, 2009; CH2MHill, 2014). Current efforts to protect and conserve Utah's wetlands revolve around the development of water quality standards for wetlands and management of habitat for wetland-associated wildlife. The success of these efforts relies on a successful and scientifically valid wetland monitoring and assessment program. However, there is currently little monitoring and assessment data on the condition of Utah's wetlands (Sumner and others, 2010). DWQ is continuing a collaborative effort with Utah Geological Survey (UGS) (a Division of the Utah Department of Natural Resources) to address the lack of information on wetland condition. Our key goals in developing a wetland monitoring and assessment program, as exemplified in Utah's Wetland Program Plan (water.epa.gov/type/wetlands/upload/utah_wpp.pdf), are to: 1) inform decision-making for the derivation and implementation of statewide wetland water quality standards; 2) develop evidenced-based priorities for wetland conservation; 3) track progress of wetland management and conservation activities; and 4) assess the ecological condition of wetlands over time.

Utah's Wetlands

Utah is not only the second driest state in the union, it is also home to the Great Salt Lake ecosystem, a large inland basin that serves as a desert oasis for millions of migratory birds and other wildlife. Integrated with the GSL ecosystem are extensive wetlands that span the transition between the lake and a mosaic of cold desert, rugged mountains and rapidly growing urban areas. The updated National Wetlands Inventory (NWI, 2008) estimated approximately 427,000 acres of wetlands along Great Salt Lake. These wetlands provide essential ecosystem services, including: moderation of surface water and ground-water flows, and removal of nutrients and other pollutants. In addition, plant productivity in desert wetlands commonly exceeds that of adjacent uplands, which provides valuable forage for wildlife and cattle grazing (Schlesinger, 1997; Reddy and DeLaune, 2008). There continues to be an essential need to maintain the health and extent of these ecologically critical wetlands, especially in the face of severe and persistent threats from population growth (the majority of Utah's citizens reside within the GSL watershed), industrial and urban development, excessive surface-water and ground-water withdrawal, invasive species and [D2]relatively high rates of nutrient loading (Millennium Ecosystem Assessment, 2005; Dahl, 2006).

Wetlands Associated with Great Salt Lake

GSL wetlands are dominated by two main wetland classes: impounded wetlands and fringe wetlands. Figure 1 illustrates the areal extent of dominant wetland types associated with GSL. Impounded wetlands represent areas where dikes, berms, ditches and culverts have been constructed to control the inflow and outflow of water through wetlands. These wetlands are entirely human-made and occur as large, shallow ponds that range in size from 20 to over 500 acres (Miller and Hoven, 2007). Impounded[D3] wetlands associated with GSL encompass approximately 100,000 acres (40,000 ha) and are actively managed by both State and Federal agencies as well as private duck hunting clubs for waterfowl habitat.

Fringe wetlands are often associated with impounded wetlands, and occur where freshwater flows over very gently sloping portions of the exposed lakebed. Fringe wetlands are found below freshwater sources to Great Salt Lake, including: outlets from impounded wetlands, wastewater treatment facility discharges, and from other low-gradient surface channels or small streams. These wetlands are commonly vegetated by tall emergent marsh plant communities, however, shallow open water and hemi-marsh cover types also occur. Depending on the quantity of water flow, wetland geomorphic features and lake elevation, fringe wetlands can span from the border of impounded wetlands to the margin of Great Salt Lake itself. As such, these wetlands can be considered the last protective effort to immobilize, transform, or remove contaminants from surface waters prior to entering Great Salt Lake. Fringe wetlands adjacent to GSL encompass approximately 300,000 acres (121,000 ha) and are not typically managed by State and Federal agencies, or private hunting clubs for waterbird habitat.

Wetland Classification and Mapping

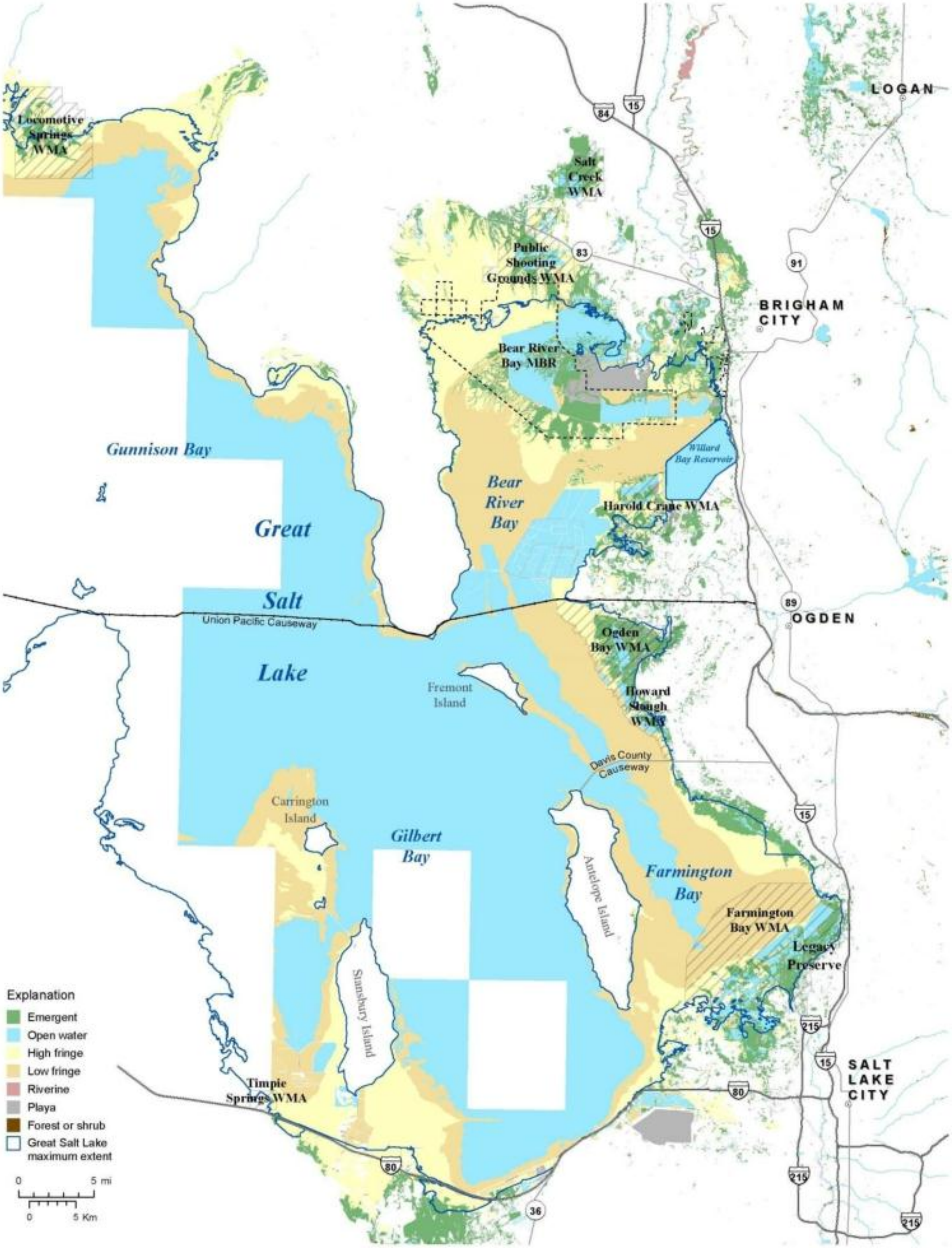
Two of the most important tasks of wetland monitoring and assessment are the classification and mapping of these ecosystems. These tasks are commonly the most challenging, since most wetlands occur as a complex mosaic on the landscape, with a wide variety of structural and functional characteristics. The principal goal of wetland classification, within a monitoring and assessment context, is to reduce the natural within-class variability of important structural or functional features, such that differences between high-quality and degraded ecosystems can reliably be detected.

There are two commonly used approaches to wetland classification: first, a biotic approach, where characteristics of plant community structure, especially those related to waterbird habitat, define wetland classes. This approach is represented by the Cowardin system (Cowardin et al., 1979), which is used extensively by the US Fish and Wildlife Service's National Wetlands Inventory (NWI) program (www.fws.gov/wetlands/) to detect changes in wetland area over time. A second approach also aims to detect temporal changes, but focuses on ecosystem processes (or functions) rather than measures of vegetation structure to evaluate functional changes over time. This approach is best represented by the Hydrogeomorphic (HGM) method developed by the US Army Corps of Engineers (USACoE) (Brinson, 1993; Smith et al., 1995). The HGM system combines three components to describe wetland classes: geomorphic setting, water source, and hydrodynamics.

The details of these classification methods are beyond the scope of this report, however, two main points are relevant to Utah's wetland monitoring and assessment efforts. First, the NWI system has been extensively used to map wetlands over the last 40 years, while the HGM system requires further development of regional wetland classes. Second, while both wetland classification systems (NWI and HGM) include a hierarchical structure, the HGM system was specifically designed for regional characterization of wetland subclasses. This is important because the structure and function of wetlands that develop in a semiarid environment can be quite different from wetlands that develop in, for example, a montane environment. As such, the HGM system is better suited for use as a sample frame for watershed-based wetland surveys.

Current efforts by UGS to enhance the usability of wetlands spatial data involve reclassifying NWI data into the HGM framework (Emerson and Hooker, 2011; Jones et al., 2013). NWI data are only available for approximately half of the state, and much of these data are at least 25 years old; however, recent coordination with US Fish and Wildlife Service personnel suggests that NWI data for the remaining portions of Utah is expected sometime in 2014. As such, we currently are unable to accurately quantify the extent of wetland resources in Utah, although it is quite clear that the wetlands associated with Great Salt Lake represent a truly valuable resource of state, national, and international importance (FFSL, 2013; via: www.ffsl.utah.gov/sovlands/gsl.php).

Figure 1. Dominant wetland classes associated with Great Salt Lake, Utah. (Source, R. Emerson, UGS, 2014)



DWQ uses wetland spatial data derived from work described in Emerson and Hooker (2011) for GSL wetland assessments. This dataset is based on the available NWI mapping, with a crosswalk to the HGM system that includes the following seven wetland types:

1) Open Water – Perennial water bodies
2) High Fringe – Largely non-vegetated wetlands near the historical lake margin, where water supply is primarily controlled by lake level. At lower lake levels, fringe wetlands represent large areas of mudflats adjacent to GSL.
3) Low Fringe – Fringe wetland from the perennial shoreline to the ephemeral high water level – for this study the seasonally flooded modifier from the NWI was used.
4) Emergent – Palustrine wetland with emergent vegetation. This wetland type is commonly associated with groundwater discharge (seeps and springs) or areas with shallow surface interflow over the land surface. *Note that emergent and low fringe types may coincide in areas near point-source discharges.*
5) Playa – Ephemeral ponds or depressional features with mineral soils, primary water sources include precipitation and ephemeral surface flow inputs.
6) Riverine – Perennial streams constrained to a channel (includes canals and ditches).
7) Forest/Shrub – Wetlands associated with woody plants, NWI codes FO (forest) or SS (scrub/shrub).

These data also retain some of the NWI modifiers that aid in further describing wetland types:

a) Impounded – NWI coded "h" wetlands, waterfowl ponds, stock ponds, and recreation ponds constructed with dams or barriers which purposefully or unintentionally obstruct the outflow of water.
b) Excavated – NWI coded "x" wetlands, these wetlands include canals and ponds excavated below the land surface with no dam or barrier.
c) Evaporation Pond – Appended auxiliary water-related land-use data from Utah Division of Water Rights. *This modifier was used to exclude industrial sites from the wetland sample frame.*

DWQ used these modifiers to generate an appropriate sample frame for the impounded wetland survey described below (see **Appendix 1**). It is anticipated that UGS will continue efforts to improve Utah's wetland classification and mapping dataset.

Water Quality Regulatory Protections for GSL Wetlands

Water quality regulations for Utah's waters have been developed iteratively over the past four decades, resulting in three distinct use classes, with different regulatory protections. Many wetlands, such as marshes and springs, are not explicitly identified, but are included in Utah's definition of "waters of the state" (waterquality.utah.gov/lawsrules.htm) and are protected by narrative standards that protect aquatic wildlife through designated uses (see: R317-2-6, rules.utah.gov/publicat/code/r317/r317-002.htm; ELI, 2008). Wetlands associated with Great Salt Lake have distinct use classes based on ownership and geographic location (i.e. relative to the historically-defined high lake level elevation, 4208 feet asl). For example, wetlands associated with the federal Bear River Migratory Bird Refuge (operated by the US Fish and Wildlife Service) as well as state Waterfowl management Areas (WMAs; operated by the Utah Division of Wildlife Resources) are provided specific beneficial use classes that include both narrative and numeric criteria to protect aquatic life uses (Classes 3B and 3D). Utah's water quality standards also define transitional wetlands (Class 5E), as those from the historically-defined high lake level elevation (4208 feet asl) to the current edge of the open waters of Great Salt Lake. Similarly situated wetlands around Great Salt Lake, with similar ecological characteristics, can fall within different wetland classes. Clearly, if criteria are intended to protect the biological and recreational uses of these waters, they should be based on their ecological characteristics, as opposed to management boundaries.

Current efforts by DWQ's *Wetlands Program* include identification and characterization of appropriate biological and ecological characteristics that can be used to refine - or establish - numeric criteria and assessment methods for narrative standards that are appropriately protective to people and wetland biota. Once established, DWQ can evaluate the chemical and physical conditions that are most strongly associated with healthy or degraded wetlands , which ultimately can be used to define water quality goals that are specific to these ecosystems.

Wetland Health and Assessment Methods

To assess IWs associated with Great Salt Lake, DWQ developed a Multimetric Index (MMI) assessment tool that integrates measures of physical, chemical and biological aspects of wetland condition. Several specific biological responses are expected to reflect the health of these waters, including a focus on submerged aquatic vegetation (SAV), aquatic benthic macroinvertebrates, and floating surface mats as potential biological indicators (DWQ, 2009). We used a probabilistic survey of[D4] impounded wetlands within the GSL project area so that our results could be generalized to all IWs within the GSL basin. To evaluate sensitivity to human-caused stress, we also obtained data for a wide range of physical and chemical stressors within both the water column as well as surface soils/sediments (**Table 1**). Additional details describing wetland measurements and the probabilistic sampling design can be found in the Impounded Wetlands Sampling and Analysis Plan (**Appendix 1**).

Table 1. Partial List of Important Stressor Metrics

	Cultural Eutrophication metri	
DO concentration	Dissolved and Total Nutrients:	Sediment Nutrients:
pH (field measure)	Ammonium	Ammonium
Chlorophyll A	Nitrite + Nitrate	Nitrite + Nitrate
Dissolved Organic Carbon	Phosphorus	Phosphorus
Total Suspended Solids	Fraction of ammonium as NH3	Sediment Organic Matter
Total Volatile Solids	Total Dissolved Solutes	Sediment Total N
TVS : TSS ratio		
	Physical Habitat Degradation metric	
Wetland Area	Max/Min Water Depth (summer)	Presence of fish (carp)
% Emergent Marsh	Max/Min Water Depth (early-autumn)	Specific Conductivity (field)
		Water Temperature ˚C

Toxic Constituent metrics

Dissolved (water column) Metals:	Sediment Metals (cold acid leachate)
Aluminum	Aluminum
Arsenic	Arsenic
Barium	Barium
Cadmium	Cadmium
Copper	Copper
Manganese	Manganese
Nickel	Nickel
Lead	Lead
Zinc	Zinc
Undissociated H_2S	Undissociated NH_3

Biological assessments of aquatic resources, including wetlands, primarily rely on three key components. The first component entails development of integrated measures of biological integrity, most commonly derived from the taxonomic composition of aquatic assemblages, such as algae, amphibians, macroinvertebrates or plants. The second component most commonly involves the identification and characterization of a collection of *Reference Standard Sites* (i.e., unaltered or least disturbed sites) that can be used as the baseline for all site comparisons within a given ecosystem type. The third component consists of appropriate probabilistic survey design that allows for generalization of wetland health at the watershed scale (Stevens and Jensen, 2007).

However, given that all impounded wetlands associated with Great Salt Lake are man-made, and most of these systems are actively managed for waterfowl and other water birds, we currently have no clear, *a priori* set of Reference Standard Sites to use for comparison. Instead, we used data from our probabilistic survey to validate the previously developed MMI (CH2MHill, 2014), and then evaluated the full dataset after a simple preliminary classification of stressor and response metrics based on upper and lower quartiles of the data.

The Impounded Wetland target population consists of ponded wetlands associated with Bear River, Farmington, and Gilbert Bays of Great Salt Lake that are primarily managed for production of a variety of habitats supporting waterfowl and shorebird populations (FWS, 2009). Industrial ponds (i.e. evaporation ponds) and ponds managed for non-waterfowl/water bird wildlife were excluded from the target population. The minimum size of IWs was five acres (approximately 2.0 ha). Field reconnaissance was performed to confirm that sites fit target criteria, including optimal water depths for SAV growth (25 to 100 cm) and waterfowl habitat. Measurements were collected over two index periods (IP): IP-1, June through July (summer); and IP-2, late-August through September (early-autumn).

Development of Impounded Wetland Assessments

The condition of IWs was characterized by three main indicators of ecological health: persistent cover of SAV between index periods, (lack of) occurrence of surface mats, and composition of benthic macroinvertebrate communities[D5]. These indicators are linked to both wetland management goals and beneficial use classes. High quality IWs (i.e. best ecological condition) are assumed to provide excellent habitat for waterfowl and the necessary food chain[D6] by supporting extensive beds of SAV, low incidence of surface mats, and[D7] diverse macroinvertebrate communities. By contrast, poor conditions may include a combination of sparse cover or early senescence of SAV, extensive surface mats, or simple macroinvertebrate communities.

Because we currently lack relatively unaltered IWs that can be used as *Reference Standard Sites*, we benchmarked our estimates of undegraded conditions on sites against the Best Attainable Condition (BAC) ecological reference standard (Stoddard et al. (2006). BAC represents the expected ecological condition of sites receiving best management practices and having the least amount of impact from adjacent land use. For this study, BAC sites were determined empirically, based on the upper 75th percentiles of biological response metrics from submerged aquatic vegetation (SAV), surface mat, and benthic macroinvertebrate community indicators. Upper (75th percentile) and lower (25th percentile) quartiles were used to score response and stressor metrics as 'GOOD' and 'POOR' assessment classes, respectively (see also Box1 p.10).

Exploratory Data Analysis

In the following section, results are summarized for three main response variables that represent a preliminary effort to characterize the health (i.e. condition) of GSL-IWs. These efforts build on previous and concurrent projects, including development of water quality standards for Willard Spur (see: www.willardspur.utah.gov/research/sciencedocs.htm) and other GSL wetlands(see: www.deq.utah.gov/Issues/gslwetlands/assessment.htm). Ultimately, our assessment framework will be used to evaluate the extent to which the designated uses of IWs are currently being supported; i.e. by protecting and maintaining surface waters for waterfowl, shorebirds and other water-oriented wildlife, including the necessary aquatic organisms in their food chain (see U.A.C. R317-2-6.3). Our approach to exploratory data analysis consists of three steps:

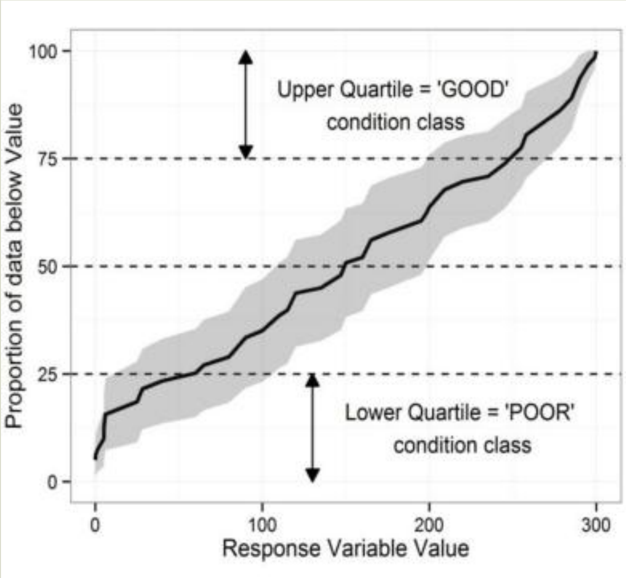
Step 1: *Evaluate the distribution of response metrics among wetlands associated with Bear River, Jordan River and Weber River watersheds*. To[D8] do this we generated cumulative distribution functions (CDFs) of response variables, using the R-package SPSurvey (Kincaid and Olsen, 2013).

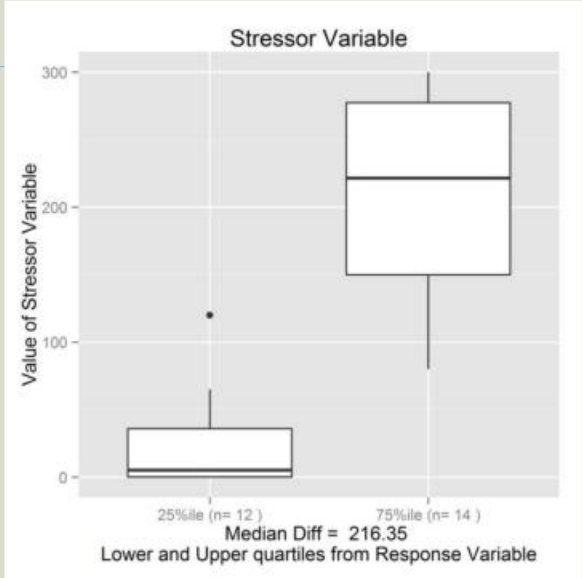
Step 2: *Evaluate the extent to which various stressors are able to differentiate IWs in Good vs. Poor conditions classes.* Comparisons were made by generating side-by-side boxplots that display the distribution of each stressor for the subset of sites that were in either good or poor biological condition (see **Appendix 2**).

Step 3: Develop an integrated measure of wetland condition, or ecosystem health, based on the response metrics, and then display the results as an MMI.

BOX 1 – How to interpret a Cumulative Distribution Function (CDF) plot

Empirical Cumulative Distribution Functions (CDFs) (Left Figure) are presented to illustrate how data for *Response Variables* are distributed among subwatersheds. Box plots (Right Figure) are used to compare the values of a *Stressor Variable* between GOOD versus POOR condition classes of a *Response Variable*.





<u>CDF Figure</u>

In the left figure, the x-axis represents the range of observed values for the *Response Variable*, and the y-axis represents the proportion of values that lie below that value. Horizontal dashed lines represent the 25_{th}, 50_{th} (median), and 75_{th} percentiles of the data. In this case, 25% of data have values less than 70, and 75% of data have values less than 250. Note that for *Response Variables* that increase with biological integrity (such as SAV Index or PMI scores), the lower quartile (25_{th} percentile) identifies the 'POOR' condition class and the upper quartile (75_{th} percentile) identifies the 'GOOD' condition class. The shaded region represents 95% confidence limits. Additional lines are drawn that include CDFs for the three subwatersheds .

<u>Box Plot Figure</u>

In the right figure, the x-axis is comprised of two groups, the lower quartile (25th percentile) and upper quartile (75th percentile) defined as representing 'POOR' and 'GOOD' sites, respectively. Data for these two groups are summarized for a Stressor Variable (y-axis), where the 'box' represents the 75th (upper) and 25th (lower) percentiles of the group data, and the horizontal line within the box represents of median. The 'whiskers' of the plot represent values within 1.5 times the interquartile range (difference of 25th and 75th percentiles), and individual points are outliers. This figure also includes information on the size of groups being compared (see x-axis labels, n = 12 and 14, respectively), as well as the difference in group-medians ('Median Diff = 216.35').

As a rough estimate, if the upper/lower limits of two boxes do not overlap, it is likely that the medians differ among groups. In this example, we could reasonably conclude that the *Response Variable* is sensitive to variations in the *Stressor Variable*. These figures are provided in **Appendix 2**

Surface Mats

Extensive cover of surface mats have been reported to occur in some GSL wetlands and may degrade recreation or biological designated uses (Miller and Hoven, 2007). Results from a recent econometric survey of Utah duck hunters suggest that hunters are concerned about the occurrence and potential impact of several environmental conditions on waterfowl habitat and hunting, including algal mats, *Phragmites* encroachment, and water reallocation away from wetlands (Duffield et al., 2011). The surface mat metric represents the relative cover of algae or floating aquatic vegetation (e.g. *Lemna*) on the pond surface during the early-autumn index period.

Benthic Macroinvertebrates

Common macroinvertebrates found in IWs associated with GSL are similar to taxa observed in other western wetlands (Apfelbeck, 1999; DWQ, 2009). Aquatic benthic macroinvertebrate metrics are derived from community composition data, and include: (1) relative abundance of invertebrates observed to be strongly associated with SAV as *plant-associated macroinvertebrates* (PMI[D9][D10]); and (2) Simpson's Index (SI). PMI includes the relative abundance of invertebrates among the following taxonomic groups: ephemeroptera (mayflies), odonata (dragonflies and damselflies, excluding the genus *Aeshna*), *Hesperocorixa* spp., *Ylodes* sp., and *Gyraulus*[D11], based on work by Larry Gray (see: 2007-2009 reports to DWQ; and pers. comm. January 2014), and is structurally similar to metrics designed to detect the effects of urbanization on freshwater wetlands in California (Lunde and Resh, 2012).

Indicators of Wetland Stress

We measured well over 100 candidate physical, chemical and biological metrics as potential stressors to GSL impounded wetlands, including chemical constituents of surface water and wetland soils/sediments. Metrics were grouped into three stressor classes representing *Cultural Eutrophication*, *Physical Habitat*, and *Toxic Compounds*. A partial list of important stressor metrics is presented in **TABLE 5-1**. Analytes and metrics representing stress from *Cultural Eutrophication* includes both dissolved and total nutrients, sediment extractable nutrients, field measures of water column DO concentration and pH, as well as chemical-based MMIs (see **Appendix 1**). Initial metrics for *Physical Habitat* include wetland area, proportion of wetland area occupied by emergent marsh (or other wetland type), water depths and water salinity, and the observed presence of benthivorous fish (i.e. carp). Subsequent work will incorporate Level 2-based assessment metrics from UGS-led efforts to assess condition of emergent wetlands. Metrics indicating stress from *Toxic Constituents* include dissolved (water column) and sediment (cold-acid leachate) concentrations of trace elements, and water column concentrations of undissociated H_2S and NH_3. These stressor metrics will continue to be evaluated for their ability to help characterize the magnitude, duration, and extent of human disturbance-related stress, and ultimately incorporated into a disturbance gradient for GSL wetlands.

Biological responses to stress

The following section describes characteristics of the three main response indicators considered important to GSL impounded wetlands (Submerged Aquatic Vegetation, Surface Mats, and Macroinvertebrates), including the distribution of values among subwatersheds and breakpoint values for GOOD vs. POOR condition classes. Differences among GOOD / POOR condition classes for a suite of stressor metrics are presented in **Appendix 2**. A description of CDF and boxplot figures is included in **Box 1**.

RESPONSE: SUBMERGED AQUATIC VEGETATION

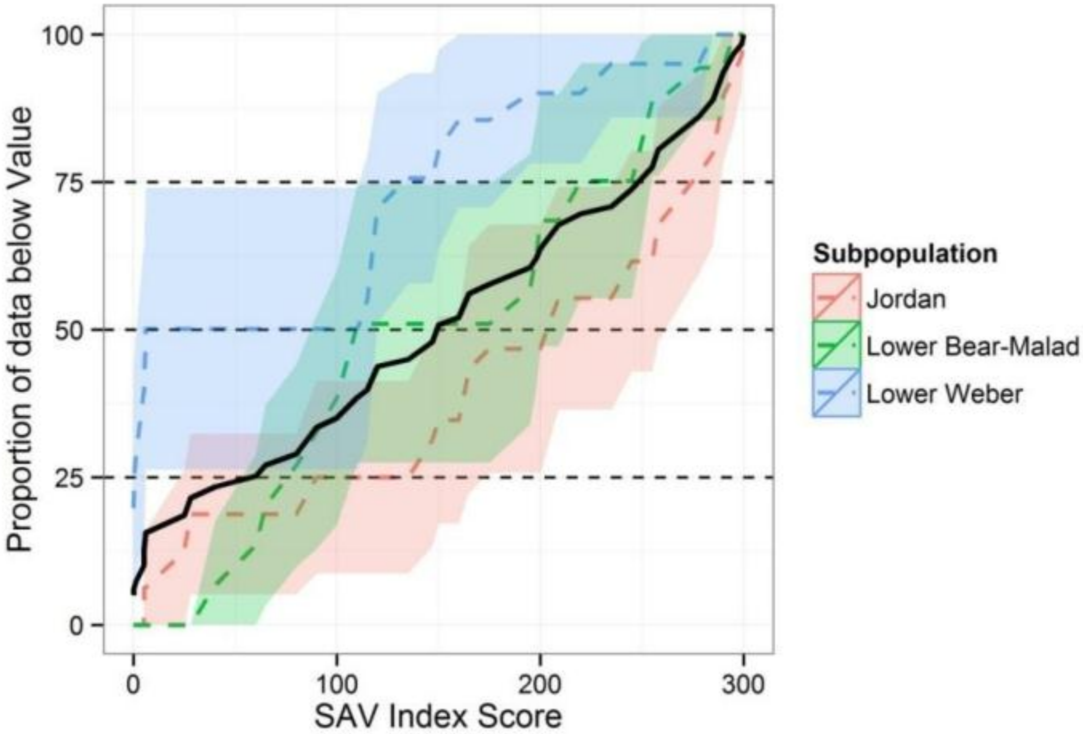


Figure 2. Cumulative distribution functions of Submerged Aquatic Vegetation index scores. CDFs for each subwatershed (subpopulation) are shown as colored dashed lines, with shaded areas as 95% confidence intervals. Weighted CDF for all sites is shown as the black solid line. Horizontal dashed lines highlight the 25th, 50th (median), and 75th percentiles of data.

Figure 5-2 illustrates the range of SAV Index Scores observed for the three subwatersheds and for the GSL study area as a whole. SAV Index Scores were based on total SAV cover[D12] and condition class, where SAV cover for the second index period was given twice the weight of the first index period, as long as the SAV condition score was 2 or greater (i.e. not senescent), to highlight the greater importance of healthy SAV in early-autumn for waterfowl beneficial use support.

Impounded wetlands in the Lower Weber river subwatershed had lower SAV Index Scores than IWs in the Jordan or Lower Bear river subwatersheds. As a starting point for evaluating the relative health (i.e. condition) of these wetlands on the basis of persistent SAV, breakpoints for ‘GOOD’ and ‘POOR’ condition classes of the SAV Index, calculated from 75th and 25th percentiles, are 248.75 and 68.75, respectively.

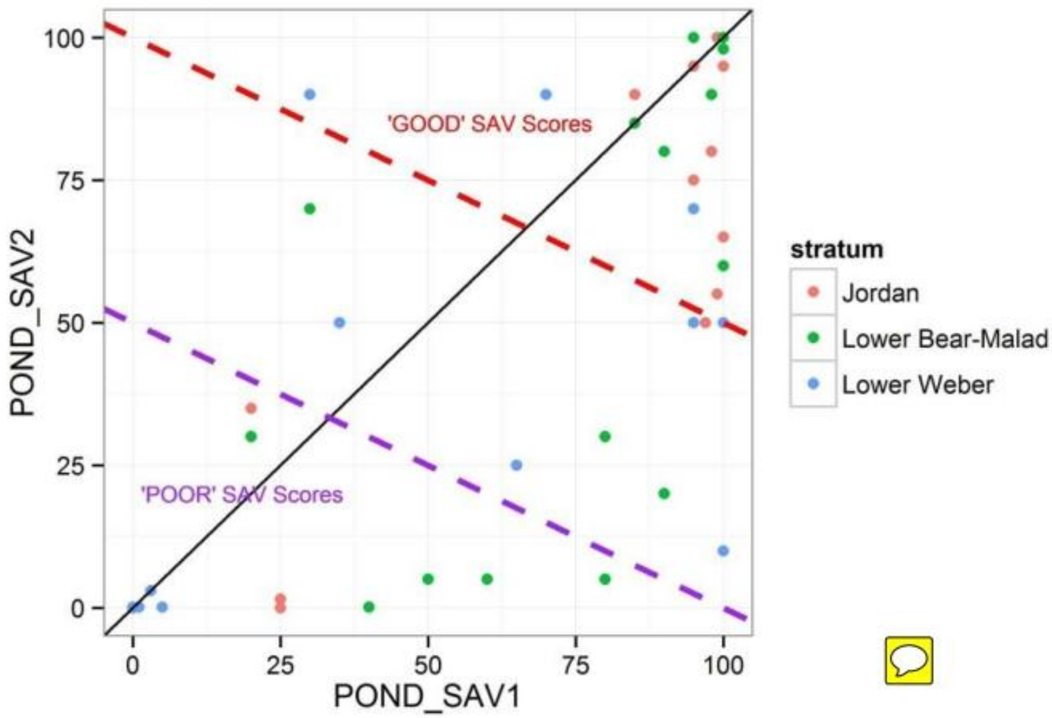


Figure 3. Total SAV cover from summer (x-axis; SAV1) versus early-autumn (y-axis; SAV2) in wetland ponds. Black diagonal line represents the 1:1 line, where summer SAV cover equals early-autumn cover, while the upper (red) and lower (purple) dashed lines indicate breakpoints for the GOOD and POOR classes of the SAV Index. Data points in the lower right portion of the figure have higher SAV cover in summer than early-autumn, while the converse is true for points in the upper left portion of the figure.

The above figure illustrates how total SAV cover differs among subwatersheds and between summer (SAV1) and early-autumn (SAV2) index periods. Highest quality ponds occur in the upper right corner of the figure. Ponds of concern, particularly those that show a large reduction in SAV cover between index periods, lie along the lower portion of the figure. Few sites fall along the 1:1 line, illustrating the idea that total SAV cover in early summer is a poor predictor of cover in late-summer[D13].

PESPONSE: SURFACE MATS

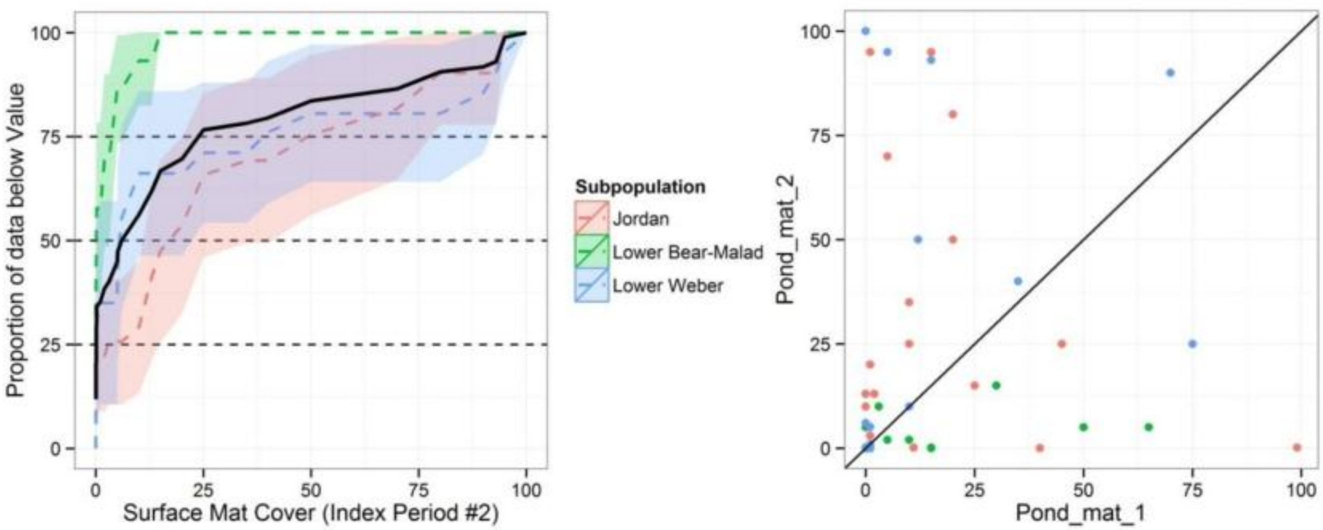


Figure 4. CDF for cover of Surface Mats during early-autumn sampling period (left), and scatterplot of Surface Mat cover (right) between summer (x-axis) and early-autumn (y-axis[D14]). Note that higher values of Surface Mat cover indicate a more degraded ecological state, while lower values of cover are preferred.

The CDFs for cover of surface mats (macroalgae and/or *Lemna* sp.) during the early autumn Index Period (Figure 4, left) show that few ponds had extensive cover of Surface Mats (75th percentile of all sites was approximately 25% cover), and these sites were primarily located within the Lower Weber and Jordan river subwatersheds. Lower Bear river subwatershed had the lowest extent of Surface Mat cover among ponds. Breakpoints for GOOD vs. POOR condition classes are calculated as less than 1% cover and greater than 25% cover, respectively. The scatterplot for Surface Mats (Figure 5-4, right) shows that extensive surface mats were generally uncommon in the ponds during both index periods, and that mat cover was poorly correlated between IPs among ponds.

RESPONSE: BENTHIC MACROINVERTEBRATES

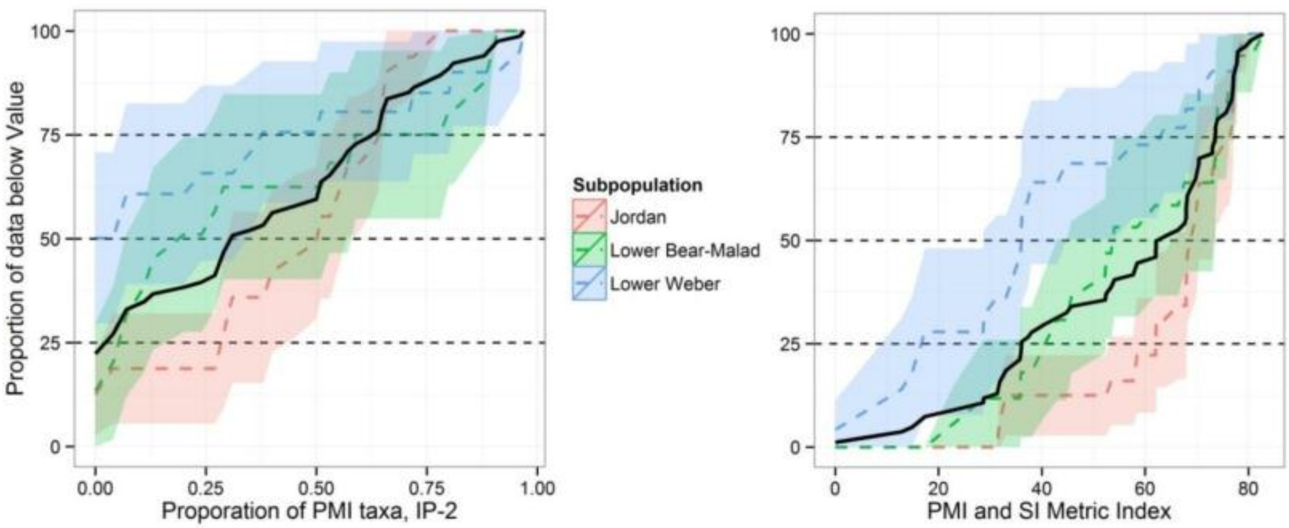


Figure 5. CDFs describing the distribution of two indices of macroinvertebrate community composition: Plant-associated Macroinvertebrate Index (PMI) (left) and a composite metric index of PMI and Simpson's diversity index (as 1-D) (right), based on early-autumn data and calculated as an MMI (see Appendix 2).

CDFs for indices describing macroinvertebrate communities are shown in Figure 5[D15]. Both metrics are scaled to increase with increasing ecological condition (i.e. supportive of beneficial use). For PMI values (left), nearly all sites with POOR condition were located in the Lower Weber subwatershed, while sites with GOOD condition occurred in the Lower Bear-Malad and Lower Weber subwatersheds[D16]. Combining Simpson's diversity index and PMI into a macroinvertebrate MMI (right) increased the separation among subwatersheds, where the Lower Weber subwatershed was the main contributor to POOR condition classes, based on the PMI+SI multimetric index, while sites with GOOD condition classes were found mainly in the Jordan and Lower Bear-Malad subwatersheds. PMI and SI indices were poorly correlated ($r_2 = 0.32$), and most of the variation in SI was observed for PMI values < 0.30, suggesting that these two metrics are describing distinct aspects of the macroinvertebrate community. In addition, PMI increased with SAV Index (Figure 5-6), supporting the idea that biological assessments (and MMIs) should extend across multiple trophic levels (Karr and Chu, 1997[D17]).

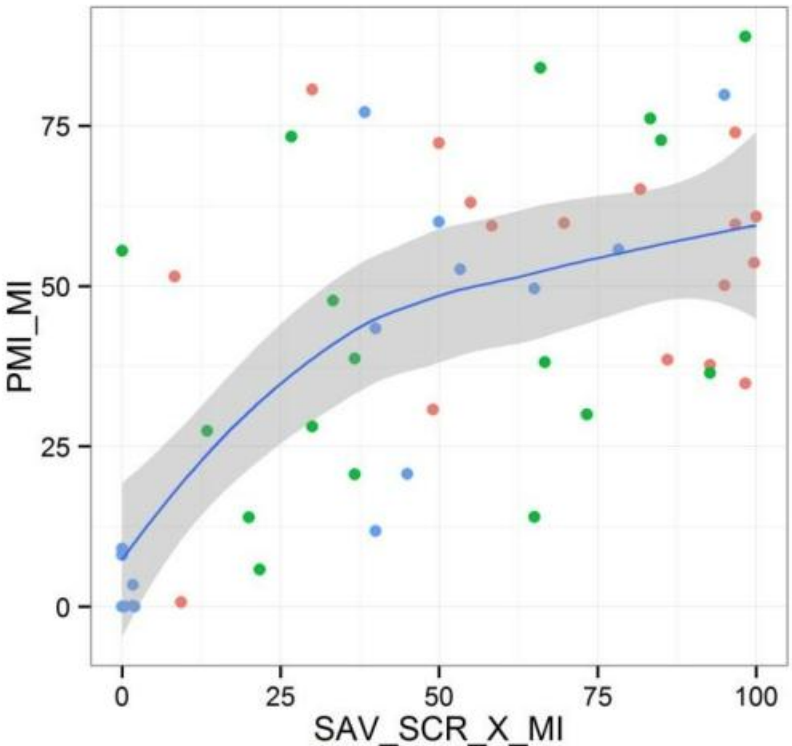


Figure 6. Scatterplot of PMI vs. SAV Index scores, with both indices scaled as MMIs.

Common patterns between Response and Stressor Metrics

The sensitivity of biological response metrics to specific stressor metrics was evaluated for GSL impounded wetlands by comparing the distribution of stressor-metric values between GOOD and POOR response metrics, as described above. A subset of stressor-response pairs is included for all three response metrics in **Appendix 2**. A brief description of notable stressor-response interactions is presented below.

RESPONSE: SUBMERGED AQUATIC VEGETATION

The SAV Index response metric was not sensitive to variations in summer or early-autumn water depth or salinity (**Figures A2-1** and **A2-2**), two potential covariates of IW health. GOOD sites had greater DO concentrations and pH than POOR sites, consistent with greater primary production, but SAV scores were insensitive to variation in total or dissolved nutrient concentrations (**Figures A2-3** to **A2-5**). Most striking among all of the stressors that we evaluated were the lower concentrations of total suspended solids (TSS) and higher percent organic matter of TSS in GOOD vs. POOR sites.

RESPONSE: SURFACE MATS

The cover of surface mats in early-autumn was not sensitive to variations in water depth, but was inversely associated with specific conductivity (**Figure A2-11**) such that sites with greater cover of surface mats had lower conductivity (or were less saline) than sites with low surface mat cover. The surface mat metric was insensitive to variations in DO, pH, and chlorophyll-a (**Figures A2-12** to **A2-13**), as well as nutrients; however sites with low surface mat cover had much lower DOC and DON concentrations than sites with extensive mats (**Figure A2-17**). Interestingly, while there was a good amount of overlap among classes, sites with greater surface mat cover also often had greater cover of SAV (**Figure A2-20**).

RESPONSE: BENTHIC MACROINVERTEBRATES

Finally, condition classes based on macroinvertebrate metrics were insensitive to water depth[D18] and salinity (**Figures A2-21** to **A2-22**), while GOOD sites had greater DO and pH than POOR sites, similar to the pattern for SAV metrics. Moreover, GOOD sites had greater SAV Index scores (**Figure A2-30**), higher cover of surface mats (**Figure A2-29**), and slightly greater total invertebrate biomass (**Figure A2-31**), suggesting that these biological responses may be useful indicators of wetland condition across multiple trophic levels.

Ecosystem Health – An Integrated measure of Impounded Wetland Condition

The SAV, surface mat, and macroinvertebrate metric indices were combined into an integrated metric of impounded wetland condition. This metric, termed the Ecosystem Health MMI, is a re-scaled linear combination of the response variable metrics described above. Ecosystem Health MMI values ranged from 14 to 100, representing a broad range of ecological response across the three sets of metrics. Breakpoints for GOOD vs. POOR condition classes were calculated as greater than 75 and less than 50, respectively. Ecosystem Health-MMI CDFs (Figure 7) show that few ponds had scores less than 40, and that ponds within the Lower Weber subwatershed had lower scores than ponds from the other two subwatersheds.

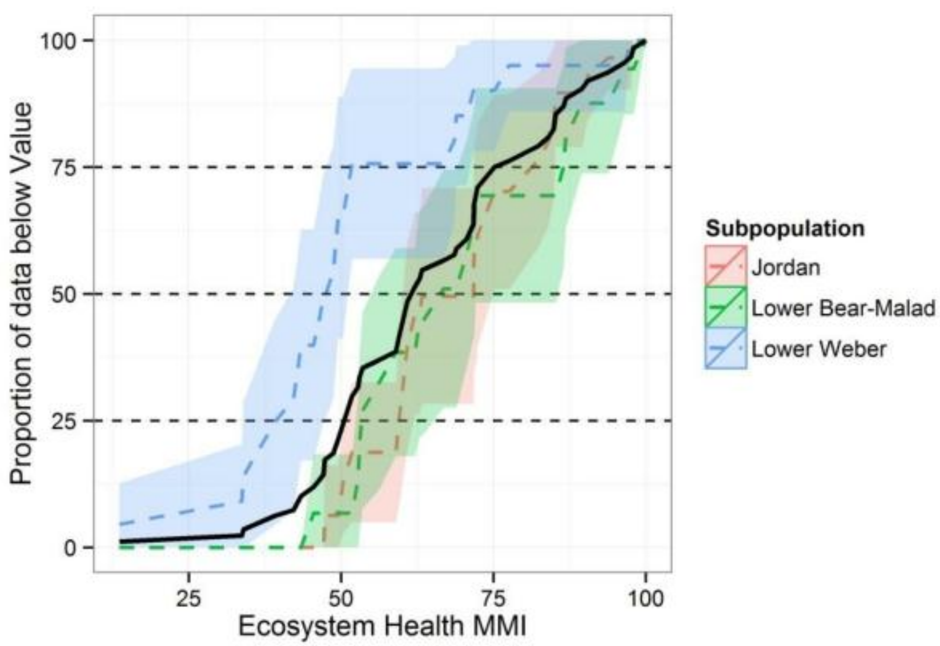


Figure 7. CDFs describing the distribution of the Ecosystem Health MMI, which is a composite of the SAV, macroinvertebrate, and Surface Mat indices.

CONCLUSIONS

Substantial progress has been made in Utah's *Wetland Program* over the last decade, particularly with regard to the development of field protocols and assessment tools that evaluate the health of wetlands associated with Great Salt Lake. Most recently, DWQ worked closely with Utah Geological Survey to develop a sample frame for GSL-IWs. This spatial information was used to develop a probabilistic survey of GSL-IWs, with technical assistance from EPA, and is a key component of watershed-based biological assessments of aquatic resources. Field data collection efforts resulted in updated field SOPs, and the data were used to validate a previously developed assessment framework for IWs, based on the MMI approach (CH2MHill, 2014). This assessment framework provides the basis for the results presented here.

Three key measures of the biological integrity of impounded wetlands were identified that span multiple trophic levels: seasonally-weighted SAV cover, early-autumn cover of surface mats, and a macroinvertebrate MMI based on community composition and plant-associated taxa. These metrics were evaluated based on statistical properties of the probabilistic survey, since all IWs associated with Great Salt Lake are man-made; as such, there is no currently available set of *Reference Standard Sites* to be used as a baseline. Instead, *Best Attainable Condition* (BAC) was defined for the survey results, based on the upper 75th and lower 25th percentiles. GOOD vs. POOR condition classes were then used to examine potential stressor-response relationships (Appendix 2).

This analysis revealed that desirable scores for SAV and macroinvertebrate metrics, indicating GOOD ecological condition, tended to be positively associated with higher DO concentrations and pH values, and greater organic matter (vs. mineral) contributions to total suspended solids. In addition, the development of surface mats (considered a negative biological response) was largely restricted to waters with low-salinity and higher TP concentrations.

Integration of these metrics into an Ecosystem Health MMI revealed important patterns of wetland condition among subwatersheds (Figure 8). Specifically, one subwatershed (Lower Weber River; bottom panel of Figure 8) contained most of the lowest-scoring (i.e. POOR) IW sites, while the GOOD sites were evenly distributed among both the Jordan and Lower Bear River subwatersheds.

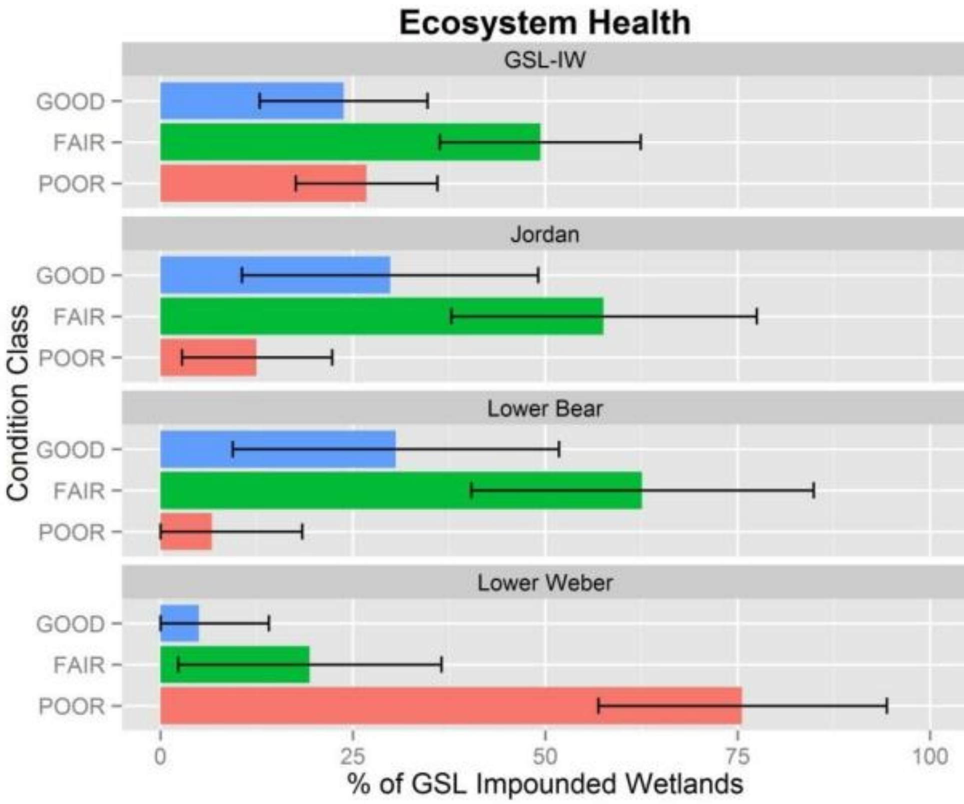


Figure 8. Relative abundance of IWs among condition classes for all GSL-IWs (top), and three subwatersheds (lower three figures), based on Ecosystem Health multimetric index. Error bars are 95% confidence intervals.

NEXT STEPS

DWQ is actively pursuing projects that continue to develop, test and refine wetland condition assessment frameworks for GSL wetlands. Two aspects of Utah's wetland assessment and reporting program have been identified for improvement over the short term: first, a concerted effort to identify and characterize the natural range of variation of Reference Standard Sites for both impounded and fringe (emergent marsh) wetlands. This effort will improve our ability to compare wetland condition metrics among sites as well as subwatersheds, by providing a clearly defined and quantifiable upper bound for measures of ecological integrity. The second aspect involves a closer examination of stressor metrics, particularly how they can be integrated among a wide suite of chemical, biological, and physical indicators. There is a clear need to scale site-specific wetland water- or sediment-based measurements with more spatially-integrated measures of stress; for example, identified from rapid assessment checklists. This effort would support development of a human disturbance index for the GSL area, following on other aquatic resource assessment efforts such as Utah's comprehensive assessment of stream ecosystems (UCASE) or the national Wadable Stream Assessment (WSA) programs.

DWQ's Wetland Program is currently working to broaden the scope of wetland assessments to a second wetland class associated with Great Salt Lake, fringe wetlands, and has identified a need for the development of appropriate sensitive, representative, and defensible tools that assess the health of these wetlands and their biota. DWQ is currently evaluating potential response metrics for fringe wetlands and anticipates having a draft assessment framework by 2016. All of these efforts are supported by funds to DWQ from competitive grants from EPA Wetland Program Development Grants.

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