MONTANE ECOREGION WETLAND ASSESSMENT—SPATIAL DATA, FIELD STUDIES, AND MULTI-METRIC INDEX

by Diane Menuz, Elisabeth Stimmel, and Miles McCoy-Sulentic

UTAH DNR GEOLOGICAL SURVEY

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Cover photo (starting upper left): *A marsh in Bicknell Bottoms, a valley wet meadow south of Koosharem, wet meadows on the southern end of Fish Lake, a riverine wetland near Otter Creek, beaver pond wetlands near Hayden Fork, and a springfed subalpine meadow near Hayden Pass. Photos by Elisabeth Stimmel.*

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Wetland determinations done for this project should not be considered U.S. Army Corps jurisdictional delineations due to the limited time spent on each determination and the broader definition of wetland used in this study.

CONTENTS

FIGURES

TABLES

MONTANE ECOREGION WETLAND ASSESSMENT—SPATIAL DATA, FIELD STUDIES, AND MULTI-METRIC INDEX

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EXECUTIVE SUMMARY

Wetlands in Utah's mountainous regions are important resources that provide crucial ecological, economic, and social benefits. The montane ecoregion where these wetlands reside stretches across central Utah at elevations above 1830 m and includes foothills, mountain valleys, high plateaus, and alpine areas. The montane snowpack supplies most of Utah's water, and regional wetlands are critical for purifying and retaining this water, which recharges groundwater supplies that re-emerge and sustain late-season streamflow at lower elevations. Montane wetlands provide habitat for Utah's wildlife – including many state and federal sensitive species – and recreational opportunities that contribute to a high quality of life for Utahns. They also provide economic inputs through fees, licenses, and commercial expenditures. Montane wetlands face many threats, including damage from livestock and wild ungulates, invasive plant species, hydrological changes, impaired water quality, and encroachment from development. Despite the importance of Utah's montane wetlands, previous work to study them has focused on only a few watersheds. Efforts to responsibly manage and protect Utah's montane wetlands hinge on a solid understanding of their location and condition, which is currently lacking. The Utah Geological Survey (UGS) created a three-part study of montane wetlands to help fill data gaps.

Our first objective was to address the lack of reliable statewide wetland location data. We assessed seven existing spatial layers for accuracy and then combined data from each to create a final, more comprehensive wetland layer that includes location confidence levels and overstory vegetation classes. Accuracy assessment of this new layer, Utah Montane Wetlands dataset (UT-MOWET), revealed considerable variation, with datasets from digitized aerial imagery proving more accurate than modeled layers. The new dataset was also less accurate for lower-elevation wetlands, likely due to factors like irrigation influence, drought, and water management changes.

Due to the high variability of UT-MOWET accuracy, we recommend that users subset the data for their specific needs using the included confidence levels. Overall, we determined the best method for producing a highly accurate wetland dataset is creating a new dataset for a specific region and data use purpose, such as fine level NWI data for areas of interest. However, in some cases, modeled data may be more useful as a faster and cheaper alternative to digitizing aerial imagery, and modeled data may be more accurate than datasets examined in this study if they are created using high-resolution imagery for small areas.

For our second objective, we collected baseline information on montane wetlands by assessing 81 field sites using the Utah Rapid Assessment Procedure (URAP). Sites were selected using the UT-MOWET dataset and collected data included: wetland types, range of conditions, potential functions, common stressors, and plant community composition data. The study area combines the Wasatch/Uinta Mountains and Southern Rockies level III ecoregions (excluding the Jordan and Weber watersheds) and is divided into strata: Valleys, Foothills, Plateaus, Montane, and Subalpine. Every site assessed was assigned a weight proportional to the site's area relative to the total wetland area, which allows for accurate wetland parameter estimation across the entire study area.

Valleys and Foothills strata wetlands had more stressors, poorer conditions, and more introduced and disturbance-tolerant plant species than Montane and Subalpine wetlands. Potential drivers for decreased wetland condition in Valleys and Foothills include high population areas and higher densities of cropland and pasture. Plateaus had relatively intact native plant communities and no noxious weeds, but also had the most grazing-related stressors (i.e., soil disturbance by animals, hummocking, and excessive grazing). Additional research could look at whether land management decisions, human visitation rates, or other factors lead to reduced plant invasion in this stratum.

Across the study area, the most prevalent stressors are non-native and invasive plant species and stressors related to grazing. Despite widespread non-native plants, noxious weed species were not common at our sites. Livestock or excessive native grazing was particularly widespread, which can cause water contamination, hydroperiod changes, dewatering, decreased litter and shrub cover, and species composition shifts. However, grazing can benefit wetlands in certain cases, and positive or negative impacts are dependent on number and type of livestock, timing and duration of grazing, and context of the wetland system. Future research should look at how those factors affect measures of wetland condition.

The most commonly recorded hydrology stressor across the study area was agriculture runoff, manure, and excess irrigation water—a single stressor that captures both hydroperiod and water quality impacts from agriculture and grazing

activities. Most sites across all strata had water quality ratings of B or poorer, with the lowest ratings in the Valleys. Our water quality and hydroperiod ratings were based on inferences about stressors in the surrounding landscape due to our single-site-visit fieldwork model. To better understand site hydrology, future studies should include repeated water quality and water depth measurements, as well as remote sensing and groundwater trend analyses.

Horizontal interspersion—a metric which assesses the complexity of site vegetation—was one condition metric frequently rated poorly across our study. While this metric can be important for wildlife habitat, its connection to wetland health is less clear. Further research could determine if a relationship exists between wetland condition and horizontal interspersion in wetland systems in Utah, and, if not, interspersion should be used primarily for wetland functional assessments in Utah in the future.

We found several important relationships between wetland function and characteristics. First, wetlands in poorer condition can still provide important functions and are worth conserving. The low-elevation Valleys and Foothills wetlands receive, and therefore have the opportunity to remove, more pollutants than higher elevation wetlands, even though they may be in poorer condition. Second, beaver-influenced wetlands excel at many functions in Utah including moderating extreme flood events and purifying water, which can be worth millions to hundreds of millions of dollars in ecosystem services annually. Third, riverine and shrubland wetlands often provide high levels of function for both hydrology and habitat due to their location along floodplains, woody vegetation communities, and permanent surface water. Future montane wetland functional assessments should include additional functions such as carbon sequestration and groundwater recharge.

In objective 3 we developed a multi-metric index (MMI) to quantitatively estimate wetland condition for a subset of montane wetlands, combining data from this study with data from previous work in the Weber and Jordan watersheds. We focused on meadow wetlands in the Valleys and Foothills strata due to greatest need and these strata's similarity in vegetation composition and stress levels. This third objective had two major components. First, we used ordination and classification to understand how Valleys meadow wetlands compared to other meadow wetlands and to one another. We also used ordination to determine whether meadows from other strata could be grouped with the Valleys meadows for the MMI development. We then grouped meadow wetlands into distinct subtypes based on multiple factors to ensure the MMI's relevance to the full range of meadow wetlands. For the second component, we selected the least and most disturbed sites based on URAP stressor data and screened vegetation metrics for strong discrimination between least and most disturbed sites to develop the MMI. We then used the MMI to estimate the percentage of Valleys and Foothills meadows in good, fair, and poor condition.

The MMI was successful at differentiating between least and most disturbed sites with relatively high sensitivity, though the percentage of sites classified as least disturbed was relatively small. Few headwater, alluvial aquifer or irrigation wetlands were designated as least disturbed sites. Four metrics were included in the final MMI: weighted mean C, cover of introduced perennial species, the richness of FACW and OBL species, and relative richness of introduced annual species. Salinity tolerance metrics were also important in several top models; least disturbed sites had fewer species with high salinity tolerance. Assigning salinity tolerance values to additional plant species could improve our ability to understand the relationship between wetland salinity and disturbance.

Using the MMI to estimate the percent of Valleys and Foothills meadows in good, fair, and poor condition, we found 70% of the meadows are in poor condition. In contrast, URAP scores indicated that wetlands were in better condition. We found a moderate correlation between URAP condition scores and MMI scores, suggesting both methods capture some overlapping aspects of wetland condition while each may also highlight different factors of wetland health. We hypothesize that the MMI result showing that most Valleys and Foothills sites are in poor condition is likely more accurate than the URAP results for several reasons including: the MMI results match more closely with the results of a recent national study; the quantitative vegetation data and checklist approach of the stressor data are more straightforward than the qualitative URAP metrics; and the low range of values in the URAP categorical and overall scores indicates that scoring methods may need to be refined to improve discriminatory power. Regardless, these condition classes do not have official regulatory meaning and are best used to facilitate conversation amongst the public and policymakers. Given method improvements over the years and a now larger pool of statewide montane wetland data, we recommend reevaluating and recalibrating the URAP protocol's scoring method.

This study provides important baseline information on the location and health of Utah's montane wetlands, which is a necessary first step for protecting these systems. Additionally, we developed the multi-metric index (MMI) tool that can be used to evaluate changes in wetland health. This research can help design more intensive field studies within a subset of wetlands in the region. Future work could focus on what protects vegetation communities in the Plateaus from non-native species or, more broadly, the primary factors that drive invasion across the region and how water quality stressors in Valleys wetlands impact their condition. Future research could also work on integrating the condition and functions assessment and MMI into uses such as determining proposed mitigation site value or measuring restoration success. Regulators could evaluate MMI or function or condition scores at both impacted and proposed mitigation sites or use the MMI to evaluate wetland health before and after restoration implementation. If specific wetland functions are the focus, researchers should ensure wetland health correlates with those functions before using condition tools for their work.

INTRODUCTION

Wetlands in Utah's mountains are important resources, providing crucial ecological functions and supporting recreational opportunities and economic and social well-being. The montane ecoregion that includes these wetlands stretches across central Utah from Idaho to almost the southern border with Arizona, spanning an elevation gradient of over 1800 m that includes foothills, mountain valleys, high plateaus, and alpine areas (Figure 1). A deep montane snowpack supplies much of Utah's water, and wetlands in these areas play a critical role in purifying and retaining this water as well as recharging groundwater supplies before end use at lower elevations (Utah Division of Water Quality, 2019). Montane wetlands provide food and shelter for much of Utah's wildlife and provide important habitat for state sensitive species, such as Boreal Toad (*Anaxyrus boreas*), Columbia Spotted Frog (*Rana luteiventris*), and Autumn buttercup (*Ranunculus aestivalis*). Recreational activities, including hunting, fishing, birdwatching, and canoeing, in and around montane wetlands contribute to a high quality of life for Utahns and provide economic inputs through fees, licenses, and commercial expenditures (Bernales et al., 2023; Smith and Lamborn, 2023).

Utah's montane wetlands also face many threats, including damage from livestock and wild ungulates, invasive and encroaching plant species, hydrological changes due to groundwater and surface water alterations, impaired water quality, and encroachment from development (Menuz et al. 2016a, 2016b; Smith et al., 2018; Menuz and Sempler, 2018). Climate change could exacerbate some of these impacts as warmer temperatures and more frequent droughts stress wetland systems hydrologically (Lee et al., 2015). Despite the importance of Utah's montane wetlands, limited work has been done to evaluate their condition. Previous work has focused on only a few watersheds (Menuz et al., 2016a, 2016b; Menuz and Sempler, 2018) or on U.S. Forest Service land (Smith et al., 2018), rather than the ecoregion as a whole.

Any state-wide effort to assess montane wetlands is complicated by a lack of reliable data on wetland location. The U.S. Fish and Wildlife Service's National Wetland Inventory (NWI) data provide information on wetland locations nationwide, but the data are 20 to 40 years out of date for about 65% of the state (U.S. Fish and Wildlife Service, 2021) and both omit some wetlands and include some upland areas. Menuz and Sempler (2018) estimated that one-fourth of wetlands mapped by NWI in the montane region of the Jordan watershed were not in fact wetlands. In contrast, Smith and Lemly (2018) found that 40% of features they identified as fens (groundwater-dependent wetlands with high organic soil) on the Dixie National Forest were not mapped by NWI at all. It is critical to understand *where* wetlands are before attempting to determine their condition.

Rapid assessments methods are often used to study wetlands in the field (Fennessy et al., 2007). With a rapid assessment, surveyors visit sites for about a half a day to record easily observable features, often relying on qualitative ranking categories rather than quantitative measures (U.S. Environmental Protection Agency, 2006). Rapid assessments maximize the number of field sites that can be surveyed and are useful for providing baseline information on the types of wetlands in an area, the stressors they face, and their condition. The Utah Geological Survey (UGS) developed the Utah Rapid Assessment Procedure (URAP) to evaluate wetland condition in Utah (Menuz and McCoy-Sulentic, 2019b). In more recent years, the UGS also added a method for evaluating wetland function, the ability of a wetland to provide specific ecosystem services like wildlife habitat and floodwater storage. The UGS has used URAP to assess montane wetlands in the Jordan and Weber watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018), though we surveyed these wetlands before adding the function method to the protocol. These watersheds differ from most of the montane region because they are closest to Utah's densest population centers and most land is privately (versus federally) owned (Figure 1; Utah School and Institutional Trust Lands Administration et al., undated). To obtain a baseline understanding of all of Utah's montane wetlands, including their functions, we need to apply URAP to the remaining montane area in Utah.

Although rapid assessment tools are useful for obtaining information on baseline conditions, more quantitative tools evaluate wetland condition with a higher level of certainty. Quantitative tools can be used to set restoration performance standards, support the development of wetland water quality standards, and calibrate rapid assessment survey results (U.S. Environmental Protection Agency, 2006). Multi-metric indices (MMIs) are one quantitative tool frequently used in aquatic ecosystems (Magee et al., 2019). An MMI combines several biologically-based metrics (such as native plant cover or diversity of macroinvertebrates) to develop a single index that can distinguish between least and most disturbed sites. MMIs can identify wetlands that are in good condition in spite of unnatural alterations, such as sites with high system resilience or effective management, because those wetlands have MMI scores similar to least disturbed sites. The UGS previously tested the use of vegetation metrics for estimating wetland condition in montane regions, but efforts were hampered by low sample sizes (Menuz et al., 2016b; Menuz and Sempler, 2018).

This study is composed of three objectives to better understand the location, condition, and potential function of Utah's montane region. For objective 1, we created a new

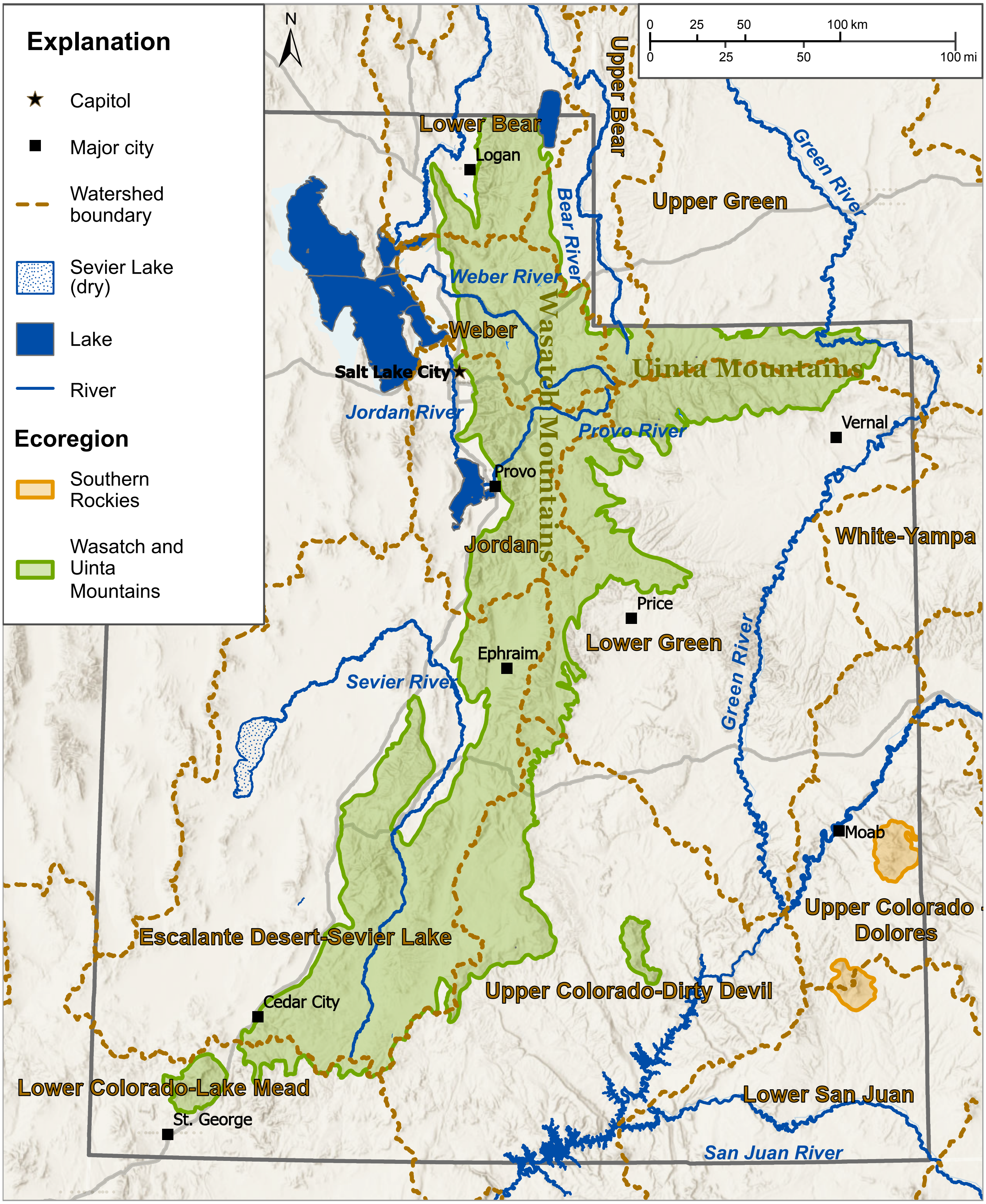

Figure 1. *The Montane ecoregion of Utah, composed of the Wasatch and Uinta Mountains and Southern Rockies level III ecoregions, and HUC6 watershed boundaries and major lakes and rivers.*

spatial layer to more accurately describe montane wetland types and distribution by combining several existing datasets together. For objective 2, we used URAP to collect wetland stressor, condition, and function data in previously unsurveyed parts of the montane regions to complete our broad understanding of montane wetlands in Utah. For objective 3, we developed an MMI for a subset of montane wetlands to more accurately identify wetlands in good, fair, and poor condition, combining data from this project with that from previous surveys.

STUDY AREA

We analyzed the entirety of Utah's montane region (Figure 1) to develop the new wetland spatial layer and create the MMI for objectives 1 and 3, respectively. For the field study in objective 2, our study area excluded the Jordan and Weber watersheds where the UGS had previously completed field studies (Menuz et al., 2016b; Menuz and Sempler, 2018). The Jordan and Weber watersheds were described in detail in those reports, so we describe the remaining part of the montane region in this report (see below).

Ecoregional and Geographic Setting

Utah has two mountainous level III ecoregions: the Wasatch and Uinta Mountains, and the Southern Rockies (Figure 1; Omernik, 1987). Ecoregions are "areas where ecosystems (and the type, quality, and quantity of environmental resources) are generally similar" (U.S. Environmental Protection Agency, 2013a). Ecoregions have four levels of hierarchy, from level I, which consists of general regions that cover large areas of the United States, to level IV, which is the smallest and most detailed level. The Wasatch and Uinta Mountains level III ecoregion comprises most of the study area. This ecoregion is a wide band that stretches from the northern Utah-Idaho border and northeastern Uinta Mountains through the middle of the state towards St. George (Figure 1). It is located almost entirely in Utah except for small parts in southern Idaho and southern Wyoming (U.S. Environmental Protection Agency, 2013a). The ecoregion ranges in elevation from 1830 m to 4125 m at Utah's highest point, Kings Peak, and contains a variety of terrain including glacial lakes, canyons, thin ridgelines, and mountain valleys. Distinct vegetation banding occurs at different elevations, with lower elevations consisting of grasses and shrubs, middle elevations consisting of aspen, pinyon-juniper, and scrub oak, and the highest elevations consisting of coniferous forests and sparsely vegetated alpine areas. The variation in elevation and terrain also creates variations in temperature and precipitation, which in turn creates a wide variety of microclimates and room for ecological diversity throughout the ecoregion. The ecoregion spans a large enough north-to-south distance that the southern part is typically 6° to 8°C warmer than the northern part (Brooks, 2012).

The Southern Rockies level III ecoregion makes up a much smaller part of the study area in comparison to the Wasatch and Uinta Mountains (Figure 1). Most of the ecoregion is found in Colorado, New Mexico, and Wyoming, and only isolated islands can be found in Utah in the La Sal and Abajo Mountains in the southeastern part of the state. The ecoregion ranges in elevation from 1830 m to 3660 m and is characterized by steep, rugged mountains with high elevations (Drummond, 2012). The Southern Rockies ecoregion is very similar to the Wasatch and Uinta Mountains, but has more coniferous vegetation at middle elevations rather than scrub oak, aspen, and pinyon-juniper (U.S. Environmental Protection Agency, 2013b).

Both level III ecoregions are further subdivided into level IV ecoregions. For our field assessment, we grouped the 11 level IV ecoregions from the Wasatch and Uinta Mountains and Southern Rockies into 5 strata based on similarities in patterns of elevation, vegetation, land ownership, and condition, as well as similarities found in past UGS studies. These strata are, from lowest to highest elevation, Valleys, Foothills, Plateaus, Montane, and Subalpine (Table 1).

The Valleys and Subalpine strata have the most wetland area found in the study area (26.1% and 40.6% of the wetlands, respectively), even though they are the two smallest area strata in our study area (Table 2). The Subalpine stratum also has the highest number of individual mapped wetlands, while the Valleys stratum has the fewest (Utah School and Institutional Trust Lands Administration et al., undated). The high elevation Subalpine wetlands are often isolated seeps or pools created by snowfall and cool temperatures, whereas the Valleys wetlands are usually river floodplains or large expanses of often irrigation-influenced groundwater discharge areas. This difference may explain why wetland area is high in both strata, but the number of individually mapped wetlands differ greatly. General wetland types found throughout the study area include wet meadows, isolated spring systems, emergent marshes, and woody wetlands along streams and rivers. There is abundant variation in plant species composition between wetland types and even within wetland types due to variation in hydrology, geographic location, elevation, and topography.

Table 1. *Level IV ecoregions that compose each stratum in our study area. The level IV ecoregions are found within one of two level III ecoregions, the Wasatch and Uinta Mountains (WUM) and the Southern Rockies (SR).*

Strata	Level IV Ecoregions
Valleys	Mountain Valleys (WUM)
Foothills	Semiarid Foothills (WUM)
Plateaus	High Plateaus (WUM)
Montane	Wasatch Montane Zone (WUM); Crystalline Mid-Elevation Forest (SR)
Subalpine	Alpine Zone (WUM); Alpine Zone (SR); Uinta Subalpine Forests (WUM); Mid-Elevation Uinta Mountains (WUM); Crystalline Subalpine Forests (SR)

Table 2. *Wetland extent and abundance, land ownership (Utah School and Institutional Trust Lands Administration et al., undated), and land cover (Multi-Resolution Land Characteristics Consortium, 2019) in study area by stratum. Wetland extent and abundance data is from the spatial layer (UT-MOWET) created for this study. The study area consists of the montane region of Utah excluding the Weber and Jordan watersheds and is based on strata from Table 1.*

Characteristic		Valleys	Foothills	Plateaus	Montane	Subalpine
Stratum Area (km^2)		2788	9729	7805	7221	6255
Number of Wetlands		8808	10,467	15,604	20,305	65,532
Wetland Area (km^2)		158	56	87	59	245
Land Ownership (% of total study area)	Federal	33.2%	70.3%	83.2%	71.4%	92.2%
	Private	55.7%	22.3%	11.1%	22.4%	5.4%
	State	10.9%	7.3%	5.7%	6.0%	0.7%
	Tribal	0.2%	0.1%	0.0%	0.2%	1.7%
Land Cover (% of total study area)	Developed	4.7%	1.5%	1.5%	1.5%	0.8%
	Agriculture	14.3%	0.6%	0.0%	0.0%	0.0%
	Barren Land	0.2%	0.1%	0.3%	0.0%	7.9%
	Open Water	2.6%	0.3%	0.4%	0.2%	0.6%
	Forest	11.3%	55.5%	63.7%	67.1%	67.8%
	Shrub/Scrub	62.1%	39.3%	30.0%	29.2%	12.8%
	Herbaceous	2.5%	2.5%	3.9%	1.6%	8.5%
	Emergent Herbaceous Wetlands	1.0%	0.1%	0.1%	0.1%	0.1%
	Woody Wetlands	1.3%	0.1%	0.2%	0.2%	1.5%

Hydrology

Our field study area spans nine level 6 hydrologic unit code areas (HUC6s) within the state of Utah (excluding the Jordan and Weber watersheds, not discussed here), some of which we discuss in combination based on their common terminal drainage (Figure 1). Hydrologic units represent the area of the landscape that drains to a single point in a stream network, and they are organized in a hierarchical system ranging from large HUC2 units to the smallest HUC12 units. The HUC6s in our study area include the Escalante Desert-Sevier Lake, Upper Bear River, Lower Bear River, Upper Green River, Lower Green River, Upper Colorado-Dirty Devil, Lower Colorado-Lake Mead, Upper Colorado-Dolores Watershed, and Lower San Juan Watershed.

Snowmelt is the main water source for all of Utah's watershed basins (Utah Division of Water Resources, 2020). Although most of Utah is semiarid and typically receives 40 cm or less of precipitation annually, the mountains receive on average 140 cm, and at very high elevations 1270 cm or more, with much of it as snow during winter months (Gillies et al., 2009). When snowmelt is captured on the landscape at high elevations by a combination of cool temperatures and shallow, low-permeability bedrock, it produces thousands of small catchments and their associated wetlands (Hansen, 1975; Sprinkel, 2006; Dover, 2007; Munroe 2009; Bryant, 2010). Excess snowmelt not held in these catchments runs off as mountain streams and rivers, which often support floodplain wetlands along their banks. The streams are sometimes dammed by beavers to form new and sometimes vast wetland complexes where otherwise there would be none. The runoff water may also infiltrate into the ground, recharging aquifers. This groundwater re-emerges under hydraulic pressure primarily in two types of places: along streambeds in low-lying areas, such as in mountain valleys, and where bedrock at or near the land surface blocks subterranean flow, forcing water to the surface. Such areas often have a high groundwater table, saturated soils, pooling, seeps, or springheads, or their water may discharge directly into streambeds or lakes (Robinson, 1971; Lambert et al., 1995; Snyder and Lowe, 1998; Somers and McKenzie, 2020).

Due to the snowmelt-driven hydrology of Utah's waters, above-ground runoff and water levels throughout the state naturally peak around May. Numerous dams and diversions throughout the state and within our study area serve to impound, release, and channel this water. Such controls can change flow timing either to earlier than usual, as reservoir levels are lowered to make room for the coming melt; or later than usual, as impounded water is released for summer irrigation (Utah Division of Water Resources, 2020). Groundwater extraction occurs in some of the more populated parts of our study area, most noticeably in Sanpete Valley.

Surface water quality impairments to various streams, rivers, reservoirs, and assessment units occur in every HUC6 watershed in our study area, with some watersheds more heavily impaired than others. Many surface waters are impaired for some combination of phosphorus, dissolved oxygen, temperature, pH, E. coli, benthic macroinvertebrates, harmful algal blooms, ammonia, total dissolved solids, and eutrophication. Some are also impaired for metals like aluminum, zinc, and copper (Utah Division of Water Quality, 2023). Elevated nitrate levels in groundwater is pervasive in southern Sanpete Valley and sporadic in other parts of the valley due to high ammonia in groundwater recharge from activities such as irrigation, grazing, and septic tanks (Janae Wallace, Utah Geological Survey, written communication, 2022).

Escalante Desert-Sevier Lake Watershed

The Escalante Desert-Sevier Lake watershed (HUC6: 160300) is an internally draining basin in which nearly all streams flow into the Sevier River to the terminal Sevier Lake (Figure 1). The watershed encompasses the Pahvant Range, Sevier Plateau, and Tushar Mountains. Notable regions with wetlands in these areas include Sanpete Valley, drained by the San Pitch River, Otter Creek (which leads into Otter Creek Reservoir), East Fork Sevier River, Piute Reservoir, Panguitch Lake, and the Sevier River.

The Sevier River and its tributaries are highly controlled, primarily for agricultural purposes, by several reservoirs and complex networks of irrigation canals. Combined diversion from the Sevier River complex and groundwater extraction is extensive enough that the average annual estimated systemic water use for agriculture alone is greater than the total estimated annual runoff from all rivers; each unit of water is used on average more than once, with about half of diverted water returning to streams as return flow downstream or as groundwater recharge (Utah Board of Water Resources, 1999).

Groundwater extraction has a prominent effect on the water table in Sanpete Valley, which has had an average drop of 6 m (and in some wells up to 12 m) in northern and central groundwater levels since the 1930s (U.S. Geological Survey, 2004; Smith et al., 2019). With this drop in the water table and the corresponding loss of hydraulic pressure, groundwater discharge to wetlands in southern Sanpete Valley is now significantly reduced. Southern Sanpete Valley was once reported to have wetlands extending 13 km above Gunnison Reservoir, which then dropped to only 3 km above the reservoir as reported in Robinson (1971). Today, groundwater discharge in southern Sanpete Valley is mostly confined to low streambeds and dispersed seeps and springs. Many areas that at one time reported free-flowing wells are now dry (Janae Wallace, Utah Geological Survey, written communication, 2022).

Upper and Lower Bear River Watersheds

Our study area includes parts of the Upper Bear (HUC6: 160101) and Lower Bear (HUC6: 160102) watersheds which encompass the northeastern part of Utah, and adjoining lands in southeastern Idaho and western Wyoming (Figure 1). These watersheds are defined by drainage to the Bear River, the largest tributary to Great Salt Lake. Two parts of our study area fall within these watershed boundaries. The first consists of the Bear River headwaters located in the northwestern part of the Uinta Mountains, where four small rivers from four mountain valley complexes merge to create the Bear River. The second part encompasses the northern Wasatch Range, including the Bear River Range, Mantua Reservoir, and Logan Canyon. Major rivers originating in this area include the Logan River, Blacksmith Fork, and the Little Bear River.

Water control infrastructure within our study area in these watersheds is generally minimal compared to nearby low-lying regions and other watersheds included in our study. Perhaps the largest water control project in the Upper and Lower Bear watersheds is associated with Bear Lake, which is fed by diversions from the Bear River for storage in the spring and then pumped back into the Bear River in the summer to meet irrigation needs (Pacificorp, 2016; Conder, et al., 2022).

Upper and Lower Green River Watersheds

The Green River watershed, typically divided into the Upper (HUC6: 140401) and Lower (HUC6: 140600) Green River, encompasses much of eastern Utah and western Wyoming (Figure 1). It is defined by drainage to the Green River, a direct tributary to the Colorado River. Our study area within this watershed includes much of the northern and most of the southern Uinta Mountains, as well as smaller parts of the Wasatch Range, the West Tavaputs Plateau, and the Wasatch Plateau. The Green River itself only enters our study area briefly through Flaming Gorge Reservoir. Otherwise, the study area is drained by direct and indirect tributaries of the Green River including the Strawberry River, Duchesne River, Price River, and headwater tributaries of the San Rafael River. Other noteworthy waterbodies in our study area include Strawberry Reservoir, Scofield Reservoir, and Joe's Valley Reservoir.

Water control infrastructure in these watersheds include two major transbasin water diversions: the Central Utah Project and the Duchesne Tunnel. The Central Utah Project diverts water from the Duchesne River through Strawberry Reservoir to the Spanish Fork River. Its primary purpose is to deliver water to farmers and municipalities in Utah County as well as to Utah Lake. Diversions average about 55,500 megaliters/yr since 2014 (Stewart, 2022). The Duchesne Tunnel diverts about 34,780 megaliters/yr of water from the Duchesne River to the Provo River near Kamas. Although both diversions run through the study area, their largest effects are located outside of it, impacting the lower Duchesne River and its associated wetlands. Other water control in this part of our study area primarily consists of impounded montane stream water used to form large reservoirs.

Upper and Lower Colorado River Watersheds

The vast Colorado River watershed covers a significant amount of the southeastern part of Utah. Our study area includes four HUC6s within the watershed: Upper Colorado-Dirty Devil (HUC6: 140700), Lower Colorado-Lake Mead (HUC6: 150100), Upper Colorado-Dolores (HUC6: 140300), and Lower San Juan (HUC6: 140802) (Figure 1). Several mountain ranges in our study area, including the La Sal, Abajo, Henry, and Pine Valley Mountains, and the Wasatch Plateau, have dozens of tributaries that all drain to the Colorado River, although the river itself never enters our study area. A few hydrologic features of note in the study area include Fish Lake, the floodplains in Fremont and Rabbit Valley (Loa), and the heavily spring-fed Bicknell Bottoms Wildlife Management Area (Ledbetter et al., undated).

Although the Colorado River watershed covers a large part of southern Utah, only a relatively small portion of our study area falls within it, and major water control infrastructure and other hydrologic impacts are primarily at lower elevations outside of the study area. The most notable water impacts within our study area are various reservoirs impounding mountain streams and significant groundwater development in the central Virgin River area near St. George (Burden, 2017).

Wildlife

Wetlands characteristically support greater amounts and types of wildlife than the surrounding landscape due to their dense, productive plant growth, and often consistent water supply. Amphibians, mammals, reptiles, fishes, invertebrates, migratory birds, and nesting birds all utilize wetlands for the crucial pockets of resources they hold, and these benefits are not limited to wetland-dwelling species alone. This use is evident in our study area where a multitude of common upland and game species can be found utilizing wetlands including mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*) and moose (*Alces americanus*). American beavers (*Castor canadensis*) also depend upon montane riverine areas for suitable locations to build dams and collect palatable aspen, cottonwood, or similar branches for food.

Montane wetlands are indispensable to many different sensitive wildlife species listed on Utah's list of Species of Greatest Concern (SGCN; Utah Wildlife Action Plan Joint Team, 2015). Utah's third-largest raptor, the Bald Eagle (*Haliaeetus leucocephalus*) utilizes wetlands with fish as a primary source of food. Columbia spotted frogs (*Rana luteiventris*) can be found in both riverine wetlands and high-altitude riparian zones in montane areas (Utah Wildlife Action Plan Joint Team, 2015). Boreal toads (*Anaxyrus boreas*) use high elevation wetland areas and especially pools created by beavers or springs for breeding (Utah Division of Wildlife Resources, 2019). Fish species on the SGCN list that are supported by the montane region's many Blue-Ribbon Fisheries include Bonneville cutthroat trout (*Oncorhynchus clarkii utah*) and Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*). There are also sensitive macroinvertebrate species such as the Bear Lake Springsnail (*Pyrgulopsis pilsbryana*), which can only be found in springs and streams near Bear Lake, and the Black Canyon Pyrg (*Pyrgulopsis plicata*), which is only known from rheocrene springs emerging on a hillside in Black Canyon, Garfield County, Utah (Utah Wildlife Action Plan Joint Team, 2015). Lastly, montane wetlands host several sensitive plant species which rely on this crucial habitat, including the Autumn buttercup (*Ranunculus aestivalis*) which only grows near the Sevier River, and Ute Lady's Tresses (*Spiranthes diluvialis*), which is an orchid found in moist areas such as wet meadows and riparian areas in northern Utah (Natural Resources Conservation Service, 2009).

Land Ownership and Land Use

Land ownership within our study area is 74.5% federal, 19.4% private, 5.7% state, and 0.4% tribal (Utah School and Institutional Trust Lands Administration et al., undated). Federal land is the predominant land ownership class in all strata except Valleys, where over half the land is privately owned (Table 2). Generally, federal land ownership increases and state and private land ownership decreases as elevation increases.

The Valleys stratum has the highest cover of agricultural land at 14.3%, and much of the agricultural lands are privately owned (Table 2; Utah School and Institutional Trust Lands Administration et al., undated). The agricultural areas are primarily cultivated crops, with slightly less hay/pasture areas (Multi-Resolution Land Characteristics Consortium, 2019). Even more land in the Valleys stratum is covered in shrub/scrub at 62%, which is the highest shrub/scrub cover of any of our strata. This stratum also holds the most highly populated municipalities fully within our study area: Ephraim, Mount Pleasant, and Manti (Utah Geospatial Resource Center, 2024).

The land in the Subalpine stratum, on the other hand, is almost entirely federally-owned with forest and shrub/scrub land cover (Table 2; Multi-Resolution Land Characteristics Consortium, 2019; Utah School and Institutional Trust Lands Administration et al., undated). The stratum also has the highest amount of tribally-owned land at 1.7%. This stratum holds the highest percentage of total wetlands – especially woody wetlands – of any of our strata. Common uses for land in this stratum include open range grazing allotments, timber, and various recreation activities such as hiking, fishing, mountain biking, and picnicking (U.S. Forest Service 2024a, 2024b).

The remaining three strata between Subalpine and Valleys (Foothills, Montane, Plateaus) share similar percentages of land cover and ownership that fall between values in the Valleys and Subalpine (Table 2). All are primarily forested with low to no cover of development and agriculture. These three strata also contain the lowest percentages of wetland cover of all our strata.

OBJECTIVE 1: WETLAND SPATIAL DATA

Background

The National Wetlands Inventory (NWI) dataset is the most complete and comprehensive data on wetland location available for Utah. These data are created by experienced mappers interpreting aerial imagery, capturing features as small as 400 m^2. However, NWI data for most of the study area is out of date, with over 95% of the area mapped in the 1980s or else derived from topographic maps and incomplete (U.S. Fish and Wildlife Service, 2021). For objective 1, we evaluated existing land cover datasets and then combined data to create a new dataset that more accurately describes the location of wetlands in the montane portion of Utah (Figure 1). We excluded minimally vegetated aquatic features in the final dataset, such as lakes, streams, and sparsely vegetated shores, even though those features are included in the NWI dataset.

Initial Data Evaluation

Datasets

We identified seven spatial layers depicting wetland or riparian areas to evaluate for this project (Table 3), including 1) NWI, 2) National Land Cover Dataset (NLCD), 3) LANDFIRE National Vegetation Classification (Landfire NVC), 4) Land Change Monitoring, Assessment, and Projection (LCMAP), 5) Water Related Land Use (WRLU), 6) Vegetation Classification, Mapping, and Quantitative Inventory (VCMQ), and 7) National Forest potential fen mapping (Fen). The NWI dataset is managed by the U.S. Fish and Wildlife Service (USFWS) and is the authoritative data on the location and types of wetlands across the United States. Data are created by trained mappers who use aerial imagery and supporting spatial layers to determine wetland, stream, and deepwater habitat boundaries (Dahl et al., 2020).

NLCD, Landfire NVC, and LCMAP are all raster datasets available at 30-m resolution nationwide. NLCD uses Landsat imagery to model 16 land cover classes. Ancillary data, including NWI and hydric soils data, are used to help train the models (Yang et al., 2018). Landfire NVC is a vegetation layer that depicts vegetation groups within the U.S. National Vegetation Classification (LANDFIRE, 2016). The groups are modeled using a combination of field reference data, Landsat imagery, elevation and topographic data, and biophysical gradient inputs. LCMAP uses a harmonic modeling process based on Landsat imagery to model land cover for eight cover classes (U.S. Geological Survey, 2021). LCMAP is the only one of the raster datasets available on an annual basis.

WRLU, VCMQ, and Fen are polygon datasets available for parts of the study area. The Utah Division of Water Resources updates WRLU on an annual basis to provide information on areas that consume or evaporate water (Utah Division of Water Resources, 2021b). WRLU data are focused on irrigated agricultural lands, but also includes many wetland and

Table 3. *Datasets and associated classes evaluated to create the combined montane wetland dataset and classes used to represent potential wetlands in each class. Dataset acronyms are explained in the text.*

Dataset	Data Type	Data Availability	Classes Used to Represent Potential Wetlands	Citation
NWI	Polygon	Statewide	Freshwater Emergent Wetland; Freshwater Forested/Shrub Wetland; Pond; Lake Edge[1]	U.S. Fish and Wildlife Service (2021)
NLCD	30-m raster	Statewide	Woody Wetland; Emergent Herbaceous Wetland	Multi-Resolution Land Characteristics Consortium (2019)
Landfire NVC	30-m raster	Statewide	Reclassified NVC classes to the following five classes: Emergent Wetland, Ruderal Emergent Wetland, Woody Wetland, Ruderal Woody Wetland, Riparian	LANDFIRE (2016)
LCMAP	30-m raster	Statewide	Wetland	U.S. Geological Survey (2021)
WRLU	Polygon	Primarily land within basins that influence water use; about 20% of the state	Riparian/Wetland (combined class)	Utah Division of Water Resources (2021a)
VCMQ	Polygon	U.S. Forest Service land	Riparian	U.S. Forest Service (2016, 2017, 2018, 2019a, 2019b)
Fen	Polygon	U.S. Forest Service land, excluding the Uinta-Wasatch-Cache National Forest	All classes	Smith and Lemly (2017a, 2017b, 2018)

[1]Derived from the NWI Lake class by subsetting out Lake features that had a mean value of less than 70% in the 10-year mean, August surface-water-extent layer.

riparian areas. The data were originally developed through aerial imagery interpretation, but more recently they have been updated using models that incorporate the Cropland Data Layer.

The U.S. Forest Service (USFS) produced the VCMQ data to provide information on existing vegetation types and canopy cover attributes on USFS land. For most National Forests in Utah, analysts used an image segmentation approach to separate imagery into distinct polygons and then used a variety of datasets, including moderate and high resolution imagery, topographic data, field and photo-interpreted reference data, and Landsat imagery, to model vegetation types (U.S. Forest Service, 2016, 2017, 2018, 2019b). However, the Ashley National Forest created VCMQ data by adding new attributes to an existing layer which contained much more detailed vegetation community information than required by the VCMQ format (U.S. Forest Service, 2019a).

The Colorado Natural Heritage Program has completed fen mapping projects on all National Forests in Utah except for the Uinta-Wasatch-Cache National Forest. These mapping projects use aerial imagery interpretation to depict the location of potential fens, which are groundwater-fed wetlands with organic soils (Smith and Lemly, 2017a, 2017b, 2018).

Preliminary Data Review and Stratification

We reviewed each dataset to identify which features could correspond to wetland features based on attributes in the data (Table 3). For some datasets, identifying wetland features was simple either because all features in the dataset were wetlands (Fen) or one or a few classes were clearly specified as wetland (LCMAP, NLCD). Two datasets (VCMQ, WRLU) grouped wetlands as part of a broader riparian or mixed riparian/wetland class that included non-wetland vegetation growing along streams and lakes as well as true wetlands growing in a variety of locations. Landfire NVC includes over 100 unique vegetation classes; we reclassified relevant classes into five broad wetland and riparian classes. NWI includes Pond and Lake classes in addition to vegetated wetland classes. We included Pond features as potential wetland features because past experience has shown that some areas mapped as water by NWI have become drier and are now vegetated. We also created a Lake Edge class by identifying Lake featureshaving surface water in August less than 70% of the years between 2011 and 2020, based on data from JRC Monthly Water History v1.3 (Pekel et al., 2016).

Once we identified potential wetland features in each dataset, we divided data into subgroups, or strata, to use in the accuracy assessment (Table 4). We expected subgroups within datasets to differ from one another in their accuracy based on characteristics such as location and wetland class and thus we used strata to obtain estimates for important subgroups. We stratified all datasets (with a few exceptions) by groupings of Omernik (1987) ecoregions (Table 1), combining the low elevation Semiarid Foothills and Mountain Valleys level IV ecoregions into a Lower Montane strata and all other ecoregions into an Upper Montane strata. We also stratified by dominant overstory vegetation whenever possible. Overstory vegetation classes were available for all datasets except LCMAP, Fen, and WRLU. For the WRLU data, we used lidar data from the Utah Geospatial Resource Center where available to classify sites as herbaceous, tree, or shrub. We used vegetation community information from the Ashley National Forest VCMQ dataset to classify features into three wetland likelihood classes based on the wetland indicator status of dominant species and presence of wet meadow or willows and used this as an additional stratification variable. We also stratified the Fen dataset by the confidence values assigned during mapping. During the accuracy assessment, we found that some NWI features were mapped as long linear vegetated wetlands within stream channels. These features were very rarely aquatic (based on this study's definition) and thus we identified these features in ArcPro, conducted an accuracy assessment on them, and included them as a new strata in the final analysis.

Dataset Accuracy Assessment Methods

We evaluated each dataset by strata to determine whether features corresponded with a set of aquatic classes that was broader than only vegetated wetlands to get a general sense of how well each dataset separated aquatic and non-aquatic land covers. For this evaluation, we defined aquatic features as lakes, shores, ponds, bars, and vegetated wetlands and classified channels and upland areas, including drier riparian areas, as non-aquatic (Table 5). After this initial evaluation, we simplified the strata by combining strata together within a dataset if they had similar accuracy. In addition to this aquatic analysis, we also looked more broadly at how accurately each layer classified the dominant overstory vegetation. In total, we evaluated 860 sites across 50 strata.

To evaluate dataset accuracy, we selected random sites using the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen, 2004), implemented in the spsurvey package (Dumelle et al., 2022) in R (R Core Development Team, 2021). The GRTS algorithm selects spatially balanced random samples and is frequently used for aquatic resource assessments. For each dataset, we first extracted the subset of features that represented potential wetlands to serve as the sample frame (Table 3). Next, we used the spsurvey package to select sites, stratified by ecoregional strata and dataset-specific stratification variables shown in Table 4. We typically selected 20 sites per stratum, but sometimes 10 or 30 sites depending on how much variability we expected in the stratum. For VCMQ and all raster data, we created assessment polygons by selecting random points, applying a 40-m buffer around the points, and then clipping the buffer polygons to the sample frame. For WRLU, NWI, and Fen data, we

Table 4. *Design methods used for evaluating dataset accuracy. Each dataset was divided into strata, typically representing all unique combinations of the two ecoregional classes (Lower Montane and Upper Montane) and dataset-specific stratification variables, except where otherwise noted. For example, for the NLCD layer, we evaluated 20 sites for each of the four strata, Lower Montane Herbaceous, Lower Montane Woody, Upper Montane Herbaceous, and Upper Montane Woody.*

Dataset	Selection Method	Dataset-Specific Stratification Variables	# Sites per Stratum
Fen	Divided sample frame and selected polygons	Low Confidence Fen	30
		Possible Fen[1]	10
		Likely Fen[1]	30
Landfire NVC	Buffer around points	Emergent Wetland	10
		Ruderal Emergent Wetland	10
		Woody Wetland	10
		Ruderal Woody Wetland	10
		Riparian	20
LCMAP	Buffer around points	Wetland	20
NLCD	Buffer around points	Herbaceous Wetland	20
		Woody Wetland	20
NWI	Divided sample frame and selected polygons	Emergent Wetland	20
		Forested Wetland	20
		Shrub Wetland	20
		Pond	20
		Lake Edge	20
		Long Linear	10
Ashley VCMQ[2]	Buffer around points	Unlikely Woody	10
		Uncertain Woody	20
		Likely Woody	10
		Unlikely Herbaceous	10
		Uncertain Herbaceous	20
		Likely Herbaceous	10
VCMQ	Buffer around points	Woody Riparian	20
		Herbaceous Riparian	20
WRLU[3]	Divided sample frame and selected polygons	Emergent Riparian/Wetland	20/30[4]
		Shrub Riparian/Wetland	20/10[4]
		Tree Riparian/Wetland	20/10[4]
		Unknown Riparian/Wetland	20/30[4]

[1]Possible and Likely fen classes combined into a single class with 10 sites for Lower Montane because of their rarity in that ecoregion.
[2]Data not stratified by ecoregion because of rarity of Lower Montane features.
[3]Lidar data used to assign canopy classes.
[4]Values represent the number of sites in the Lower and Upper Montane strata, respectively.

subdivided polygons into features approximately 4000 m^2 in size whenever possible, and up to no more than 6000 m^2, and then used spsurvey to select polygons.

We evaluated selected features in ArcPro to determine whether aquatic features were present within each assessment polygon. We defined aquatic features using the classes shown in Table 5. Stream channels and narrow bands of vegetation less than 10-m wide adjacent to channels were not considered aquatic for this evaluation. For each feature, we evaluated the percent area within the assessment polygon occupied by aquatic features as one of five cover classes: 0, >0 to 10, >10 to 30, >30 to 70, and >70 to 100. We also separately evaluated the dominant overstory vegetation class present in each polygon, using the following classes: Tree, Shrub, Herbaceous, Bare, Development, Shore, or Water. We did not consider whether features were aquatic or not when assigning the dominant overstory vegetation so that, for example, upland shrubs and wetland shrubs were grouped together into the Shrub class.

Two wetland ecologists experienced in identifying wetlands using aerial imagery conducted the accuracy assessment. We used multiple years of true color and color-infrared imagery along with supplemental data sources to assist with evaluation (Table 6). Both ecologists evaluated every assessment

Table 5. *Definition for features considered aquatic, wetland, and non-aquatic. We considered all aquatic features as target features for the evaluation of individual datasets and only those features in bold and italics for the evaluation of UT-MOWET.*

Class	Description
Classes Considered Aquatic	
Lake	Water present all year in most or all recent years of imagery (or always present after recent modification). NAIP imagery available for 2011, 2014, 2016, 2018, and 2021. Lakes are distinguished from Permanent Ponds in that they are at least 8 hectares (ha) in size.
Shore	Fluctuating edge of lake that is seasonally flooded about half the time or is typically flooded during normal water years. Typically will have water in the early season and then dry out by end of year in most years but may also be flooded most of the year in wetter years and dry most of the year in drier years. If a feature appears to be flooded in less than half the years and appears consistently vegetated with wetland vegetation, list under Emergent.
Permanent pond	Stable water present in all years or potentially some drying in 2018 and more recent imagery; features less than 8 ha.
Seasonal pond	***Water present in some but not all years of recent imagery and features are less than 8 ha. Features may appear to have fluctuating water levels across years of imagery.***
Bar	Sand or gravel bar along river with less than 30% cover of plants or alternatively bare and covered in pioneering species.
Emergent wetland	***Wetland composed of herbaceous vegetation as the tallest lifeform with at least 30% cover. Wetland can be created through irrigation in agricultural settings if there is strong evidence that the feature is irrigated frequently enough to create a consistent and distinct area with wetland indicators.***
Tree wetland	***Wetland composed of tree species with at least 30% cover. Trees are defined as woody species 6 m or greater in height.***
Shrub wetland	***Wetland composed of shrub species as the tallest lifeform with 30% cover. Shrubs are defined as woody species less than 6 m tall.***
Classes Considered Non-Aquatic	
Channel	Wet or dry stream channel or canal.
Urban	Development including houses, roads, and commercial buildings.
Urban grass	Non-wetland grass such as lawns and golf courses
Agriculture	Non-wetland area used for agriculture that appears to be crop, actively mowed, or has signs of active irrigation. Upland pasture without any of these indicators can be listed under "emergent upland."
Emergent upland	Upland composed of herbaceous vegetation as the tallest lifeform with at least 30% cover.
Shrub upland	Upland composed of shrub vegetation as the tallest lifeform with at least 30% cover.
Tree upland	Upland composed of tree vegetation as the tallest lifeform with at least 30% cover.
Other upland	Any other upland feature not meeting the definitions above. Make a note to describe the upland feature.

polygon for the LCMAP, NLCD, and VCMQ datasets and discussed any differences in their evaluation to improve consistency. For the remaining evaluations, one ecologist evaluated all polygons and a second ecologist examined several sites per strata and any polygons that the first ecologist marked as uncertain or needing additional review. If reviewers disagreed, a third reviewer evaluated the site to make the final determination. We developed a conventions document to outline the general workflow and provide guidance on how to evaluate challenging situations related to vegetation along channels, dense woody vegetation, and agricultural areas. Reviewers conducted ten days of field work across the study area between July 15 and September 22, 2023 to review sites with a high degree of uncertainty and learn about wetland signatures in different parts of the state.

To analyze the results, we first converted each aquatic cover class to the midpoint value of the class. We then estimated the percent aquatic area, standard deviation, and confidence intervals for each strata. We next combined strata together within a dataset if they had similar estimates for the percent aquatic area to simplify the strata and obtain more precise accuracy estimates. As an example, we combined the NLCD Upper Montane Emergent and NLCD Lower Montane Emergent strata together into a single NLCD Upper Montane strata. We then reran the statistical analysis on the new combined strata to produce final accuracy estimates, using sample weights from the initial site selection to correct for under and over sampling within strata.

We created a confusion matrix to compare the predominant overstory classes assigned by reviewers versus classes in the mapped data. A confusion matrix is used to compare modeled or mapped classes versus actual classes and helps to identify which classes are most often misclassified. Vegetation composed of grasses and forbs were mapped as Emergent in some datasets and Herbaceous in others, but were all considered Herbaceous for the confusion matrix. We calculated user accuracy for each class, which is the percent of time that a class shown on a map will actually be present on the ground. Though commonly included in confusion matrices, we did not calculate producer accuracy (the percent of time that a class on the ground is correctly classified on the map) because we evaluated more classes using imagery than were present in the datasets. We dropped the Development class from the analysis because it was very rare.

Table 6. *Datasets used to support accuracy assessments. Surface water and NDVI values were calculated in Google Earth Engine (Gorelick et al., 2017).*

Dataset	Source	Description
NAIP 2011, 2014, 2016, 2018, 2021	U.S. Department of Agriculture National Agriculture Imagery Program	1-meter resolution, 4-band aerial imagery collected during the summer of each year
NHD Spring points	U.S. Geological Survey	Point data of known springs and seeps identified in the National Hydrography Dataset
SSI spring points	Spring Stewardship Institute (SSI)	State-wide dataset depicting spring locations contained in the SSI database
Water Related Land Use	Utah Division of Water Resources, 2021a	Land use data showing the extent and type of irrigated crops, urban areas, and relatively natural landscapes.
Water Points of Diversion	Utah Division of Water Rights	Agricultural irrigation and other diversion points along water features identifying wells, stock ponds, and springs.
Soil hydric class	ESRI	Derived from Natural Resources Conservation Service Hydric Classification data in gSSURGO
Surface water extent	JRC Monthly Water History v1.3 (Pekel et al., 2016)	Percent of years between 2011 and 2020 with surface water present in May and August
NDVI	Sentinel-2 MSI: MultiSpectral Instrument, Level 2A	Two-month median NDVI values, for May/June and July/August, for two years, 2019 and 2020
1-m DEM derived from lidar	Utah Geographic Reference Center	Bare-earth data resampled to 1-m resolution
2-m canopy height derived from lidar	Utah Geographic Reference Center	Calculated by subtracting bare-earth data from first-return data and resampling to 2-m
1-m slope derived from lidar	Utah Geographic Reference Center	Derived from 1-m DEM using ArcPro Slope tool
10-m DEM	Utah Geographic Reference Center	Statewide 10-m DEM
10-m slope	Utah Geographic Reference Center	Derived from 10-m DEM using ArcPro Slope tool

Dataset Accuracy Assessment Results

Aquatic area estimates ranged from 4.8% (standard deviation (SD) = 12.0) for the VCMQ Lower Montane Woody Wetland class to 85.0% (SD = 0) for the Fen dataset Upper Montane Likely Fen class. The highest possible percent aquatic area is 85% since that is the highest midpoint in the cover classes. We combined the 50 initial strata into 18 final strata based on similarities in aquatic area estimates. We did not use any stratifying variables for LCMAP, Landfire NVC, and Fen (Table 7). The remaining datasets were divided and had between two and six strata. When we recalculated percent aquatic estimates for the combined strata, Fen and NWI Lake Edge strata had the highest estimated aquatic area and NWI Long Linear, VCMQ Lower Montane Woody, and Ashley VCMQ Unlikely had the lowest. Four datasets were stratified by ecoregion and, in each case, Lower Montane features were less accurate than Upper Montane features.

User accuracy for Herbaceous vegetation was generally good, ranging from 66.7% for Ashley VCMQ to 87.2% for NWI (Table 8). Woody accuracy was more mixed. Landfire NVC and NLCD user accuracy was only about 40%—features mapped as Woody were more often identified by reviewers as Herbaceous. In contrast, Woody accuracy was high for VCMQ and NWI data, and NWI data also accurately differentiated between Shrub- and Tree-dominated classes. NWI ponds were about equally likely to be Herbaceous, Shrub, or Water. NWI Lake Edge features were usually classified as Water, but were sometimes Bare or Emergent.

Final Wetland Data Creation

Dataset Creation

We created the final wetland dataset by 1) combining wetland and water features from each dataset into one dataset, 2) assigning a confidence value and overstory vegetation class to each of the resulting features, and 3) refining the dataset by removing small features, less accurate features, and non-wetland aquatic features (i.e., Water and Shore) (Appendix A). Although we wanted to include only vegetated wetland features and seasonal ponds in our final dataset, we initially included Water classes when they were mapped by a dataset because we knew from evaluation of the NWI data that some Water areas have dried up and are now vegetated. We expected accuracies for Water classes to be very high (e.g., Wickham et al., 2023) and thus did not conduct a separate Water assessment for other datasets.

For the first step, we combined data from all of the strata listed in Table 7 and Water classes, using the Union tool in

Table 7. Accuracy results for dataset assessment for final combined strata. Note that the maximum percent aquatic is 85% since we used midpoints of percentage classes for estimation.

Dataset	Final Stratum Name	# Features	Estimated % Aquatic (SE)	Confidence Class
NWI	Long Linear	10	4.6 (19.3)	Very low
VCMQ	Lower Montane Woody	20	4.8 (12.0)	Very low
Ashley VCMQ	Unlikely	20	7.5 (14.5)	Very low
NLCD	Lower Montane	40	25.2 (32.7)	Low
VCMQ	Upper Montane Woody	20	26.3 (35.8)	Low
NWI	Tree	35	27.5 (32.8)	Low
Ashley VCMQ	Likely and Uncertain	60	29.6 (30.7)	Low
Landfire NVC	None	120	31.7 (33.1)	Low
LCMAP	None	40	33.3 (36.6)	Low
NLCD	Upper Montane	40	42.8 (36.7)	Medium
NWI	Lower Montane Emergent & Pond	39	46.5 (40.7)	Medium
WRLU	Lower Montane	80	50.3 (36.1)	Medium
VMCQ	Emergent	40	53.9 (31.5)	Medium
NWI	Shrub	36	66.0 (32.3)	High
WRLU	Upper Montane	80	66.5 (28.7)	High
NWI	Upper Montane Emergent & Pond	40	68.0 (27.7)	High
NWI	Lake Edge	40	76.8 (22.9)	High
Fen	None	90	78.9 (20.2)	High

Table 8. Confusion matrix comparing mapped overstory classes versus the actual classes identified in the GIS-based accuracy assessment. Values represent the number of sites in each combination of mapped and actual class, except for user accuracy, which represents the percent of sites accurately mapped. The Riparian class is included for reference only, since Riparian does not crosswalk to any of the evaluated classes. NWI Lake Edge and Pond classes were classified as accurate if they were mapped as Water.

Dataset	Mapped Class	Actual Class							User Accuracy (%)
		Herbaceous	Woody (Tree + Shrub)	Shore	Shrub	Tree	Water	Bare	
Landfire NVC	Herbaceous	27	8	3	-	-	0	0	71.1
	Woody	16	13	3	-	-	1	0	39.4
	Riparian	14	20	0	-	-	1	0	-
NLCD	Herbaceous	24	13	0	-	-	0	0	64.9
	Woody	20	14	0	-	-	1	0	40.0
NWI	Herbaceous	34	-	0	4	1	0	0	87.2
	Lake Edge	11	-	0	0	1	17	11	42.5
	Pond	12	-	0	11	3	12	2	30.0
	Shrub	6	-	0	33	1	0	0	82.5
	Tree	1	-	0	12	23	1	1	60.5
VCMQ Ashley	Herbaceous	26	12	0	-	-	1	0	66.7
	Woody	11	26	0	-	-	1	0	68.4
VCMQ Other	Emergent	25	6	3	-	-	0	0	73.5
	Herbaceous	4	34	0	-	-	0	0	89.5

ArcPro. This tool maintains all feature attributes and creates new polygons for each unique set of overlapped features. Each resulting feature can be from a single dataset or can represent several datasets that all showed an aquatic resource at the same location.

For the second step, we assigned confidence values to features in the new combined layer using two factors (Appendix A; Fritz et al., 2011). First, we evaluated the accuracy of the most accurate dataset that mapped an aquatic feature at that location. We assigned the feature to a higher confidence value if, for example, the feature was mapped as Fen instead of Tree by NWI. Second, we looked at how many datasets mapped an aquatic resource at that location. We assigned the feature to a higher confidence class if, for example, four datasets mapped an aquatic resource at a location rather than two. We initially assigned features to overstory classes of Emergent, Woody, Water, or Unknown using either the most frequently assigned class or the class from the dataset with the highest overstory accuracy (Table 8). We later updated the classification of Water and Unknown features using lidar canopy height data.

Our last step involved cleaning up the dataset to remove unwanted features (Appendix A). We merged very small polygons into larger adjacent features and removed small (<0.1 ha) low confidence features that shared a boundary with higher confidence features. We also removed low confidence features that had low July/August 2020 NDVI values or were classified as Tree. We used NDVI and surface water extent data to classify some features as Water and Shore and removed these features from the final dataset.

Wetland Layer Accuracy Assessment Methods

We evaluated the accuracy of the final Utah Montane Wetlands dataset, or UT-MOWET, using two datasets, one composed of points stratified by confidence class (confidence assessment) and one composed of points stratified by ecoregions (field site assessment). We also evaluated the accuracy of the overstory vegetation classification as part of the confidence assessment. Points in both cases were selected using GRTS (Stevens and Olsen, 2004) in the spsurvey package (Dumelle et al., 2022). For both evaluations, we only considered Seasonal Ponds and Emergent, Shrub, and Tree wetlands as target wetlands since unvegetated aquatic features were removed from UT-MOWET (Table 5).

For the confidence assessment, we selected 50 points from each confidence class in the UT-MOWET layer. We evaluated UT-MOWET accuracy by using aerial imagery and supporting datasets (Table 6) to assess whether target wetlands were present at each point, allowing wetlands to be 10 m away from the point and still considered “at the point” to accommodate horizontal mapping standards (Federal Geographic Data Committee, 2009) and known issues with spatial data shifts (Zou et al., 2022). To evaluate cover class accuracy, we created a polygon assessment unit by applying a 40-m buffer around the points and clipping the buffer to the UT-MOWET polygon that contained the point. We recorded the most prevalent overstory class present in each polygon as Woody, Herbaceous, Bare, Development, Shore, or Water, grouping upland and wetland vegetation into a single class for evaluation.

We analyzed the overstory vegetation data in two ways. First, we compared the UT-MOWET overstory class to the overstory class assigned during the office assessment. We also conducted a comparison of the performance of the lidar canopy classification and the dataset-based classification, using the version of UT-MOWET (DRAFT-MOWET) before classes were updated with lidar data. In both analyses, we excluded points classified as Unknown in the UT-MOWET and DRAFT-MOWET datasets and one point classified as Bare in the office evaluation. We also excluded points without available lidar data in the lidar versus DRAFT-MOWET comparison. We calculated user, producer, and overall accuracy for each comparison.

The field site assessment relied on randomly selected points from the field-based wetland surveys, described in detail in objective 2. For the field study, we selected potential survey sites from a subset of the montane region. This subset excluded the Jordan and Weber watersheds, which had been the focus of earlier studies, and also excluded areas more than 3 km from roads due to accessibility issues (Figure 2). Within this narrower area, we selected points from UT-MOWET stratified by five ecoregional classes (Table 1). We selected a variable number of points per strata to meet our survey objectives and evaluated additional points in each strata as needed to replace sites dropped due to lack of wetlands or issues with landowner access. In total, we evaluated 116 points in the Valleys, 22 in the Foothills, 20 in the Plateaus and 11 each in the Montane and Subalpine. We evaluated each point initially using aerial imagery and supporting layers (Table 6). We considered wetlands to be present if they were located within 100 m of the point. If we determined that wetlands were present or were uncertain about wetland presence, we visited sites in the field if we could obtain landowner permission.

We used spsurvey to obtain estimates of UT-MOWET accuracy for both the confidence and field site assessments. Estimates for the confidence assessment represent how much of UT-MOWET is composed of target wetland features, whereas estimates for the field site assessment represent how much of UT-MOWET is close to (within 100-m of) wetlands.

UT-MOWET Layer Results

UT-MOWET includes 75,205 hectares of wetland features, of which 47.5% of the area is high confidence, 44.2% medium

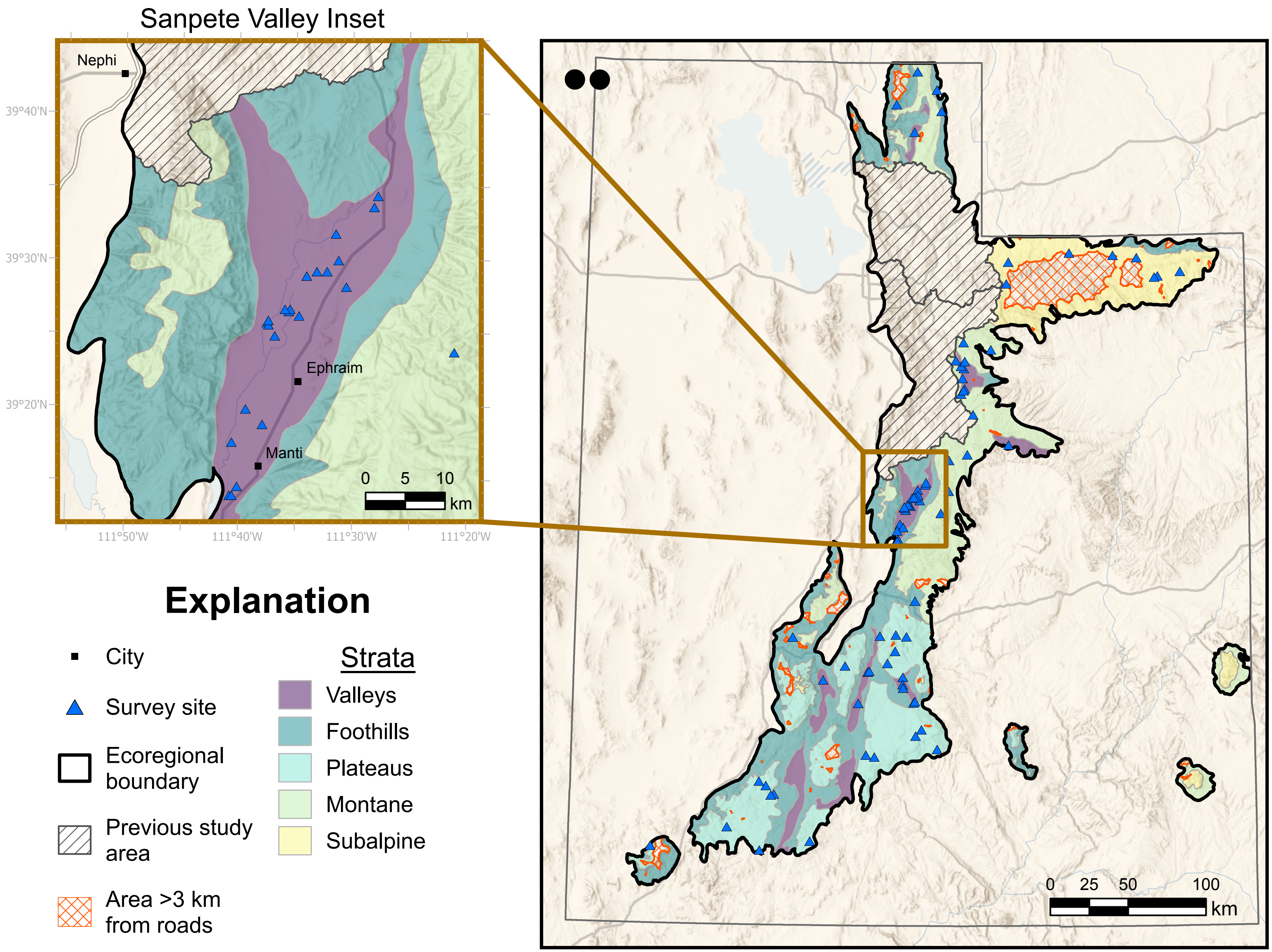

Figure 2. *Study area and ecoregional strata used for field survey and surveyed wetlands sites. Previous study areas and areas more than three kilometers from roads were excluded from the sample frame.*

confidence, and 8.4% low confidence (Table 9). Over one-half (60.3%) of the features are classified as Emergent, 16.6% Woody, 15.1% Unknown, and 8% Water; some of the Water features are likely Seasonal Ponds. NWI is the largest contributor to the final dataset, overlapping almost two-thirds of the data and contributing 20,211 hectares of mostly medium and high confidence features that were not identified in any of the other data sources. The other datasets were responsible for between 0.3% (for Ashley VCMQ) to 7.3% (for VCMQ) of unique features in the final layer.

Figure 3 shows examples of the UT-MOWET layer compared to field locations visited in 2023. In some cases, UT-MOWET either completely missed wetlands or captured wetlands but likely overmapped wetland presence (Figure 3 A and B). We also compared the new dataset (UT-MOWET) with the dataset commonly used for wetland identification (NWI). In many cases, UT-MOWET features were only slightly larger in area than NWI polygons, not adding much additional useful information. However, we also saw examples where UT-MOWET identified a wetland that appeared to be incorrectly shifted in the NWI polygon (Figure 3C) or located a feature that was only partially mapped by NWI (Figure 3D). UT-MOWET also mapped some wetlands that were entirely missing from the NWI dataset (Figure 3B and E).

UT-MOWET Layer Accuracy

Based on the confidence assessment, we estimated that 61% of UT-MOWET is target wetland (Table 10). As expected, high confidence features were most likely to be wetland and low confidence features were least likely to be wetland. Five points, four of which were in the high confidence category, were classified as non-wetland aquatic features including Permanent Pond, Shore, and Bar.

Overall accuracy of the UT-MOWET overstory classification was 78%. Producer and user accuracy for Emergent and Woody classes were between 79% and 84%, whereas accuracies for Water were much lower (Table 11). Most features mapped as Unknown were actually in the Woody class. Lidar canopy classification had higher user and producer accuracies than the classification in the DRAFT-MOWET dataset except for user accuracy for the emergent classes, which was only slightly lower (Table 12). The lidar data, which we did not use to assign a water class, classified five of six water points as emergent. User and producer accuracies for most comparisons were above 75%.

For the field site assessment, we found that 74% of UT-MOWET within the field study area is within 100 m of target wetlands (Table 13). Similar to the confidence assessment, accuracy increased as data confidence levels increased. Accuracy estimates for Upper Montane sites were higher than estimates for Lower Montane sites, but differences were not significant (i.e., confidence intervals overlapped).

Discussion

Wetland mapping accuracy varied considerably between datasets and amongst classes within datasets. Dataset accuracy was generally highest in data created through aerial imagery digitization compared to modeled datasets. Fen data was the most accurate, likely because it was created recently using aerial imagery digitization and because fens have more distinct signatures than wetlands with drier water regimes. NWI was also highly accurate, though some classes and regions were more accurate than others (Table 7). Inaccuracies in NWI data are likely due to a combination of factors, including the age of the data, changing mapping standards, and misalignment of some wetland polygons with aerial imagery (Zou et al., 2022). Also, non-wetland riparian areas were often mapped as forested wetlands in older NWI data (Goodwin and Stimmel, 2023). Similarly, features in datasets with a riparian class (i.e., Landfire NVC, VCMQ, and WRLU) may have had higher accuracy if we evaluated

Table 9. *Summary statistics for UT-MOWET. This table shows the hectares of aquatic features contributed by each dataset to UT-MOWET, broken down by confidence class. "Overlap" indicates the percentage of UT-MOWET area covered by each dataset (e.g., 7.4% of UT-MOWET contained polygons from Ashley VCMQ). "Area of Unique Features" refers to the area in UT-MOWET contributed by only one dataset, while "Unique Contribution" shows the percentage of UT-MOWET's total area contributed by a single dataset.*

Dataset	Area by Confidence Class (ha)			Overlap	Area of Unique Features (ha)			Unique Contribution
	High	Medium	Low		High	Medium	Low	
UT-MOWET	35,708	33,212	6285		9385	18,175	5414	43.8%
Datasets								
Ashley VCMQ	4474	861	235	7.4%	0	0	194	0.3%
Fen	8912	0	0	11.9%	892	0	0	1.2%
Landfire NVC	15,526	8656	3676	37.0%	0	0	3081	4.1%
LCMAP	4960	3542	439	11.9%	0	0	204	0.3%
NLCD	13,817	9358	408	31.4%	19	528	93	0.9%
NWI	30,636	18,101	368	65.3%	7855	10,961	253	25.4%
VCMQ	9244	7604	2088	25.2%	10	3895	1590	7.3%
WRLU	9487	6734	0	21.6%	610	2793	0	4.5%

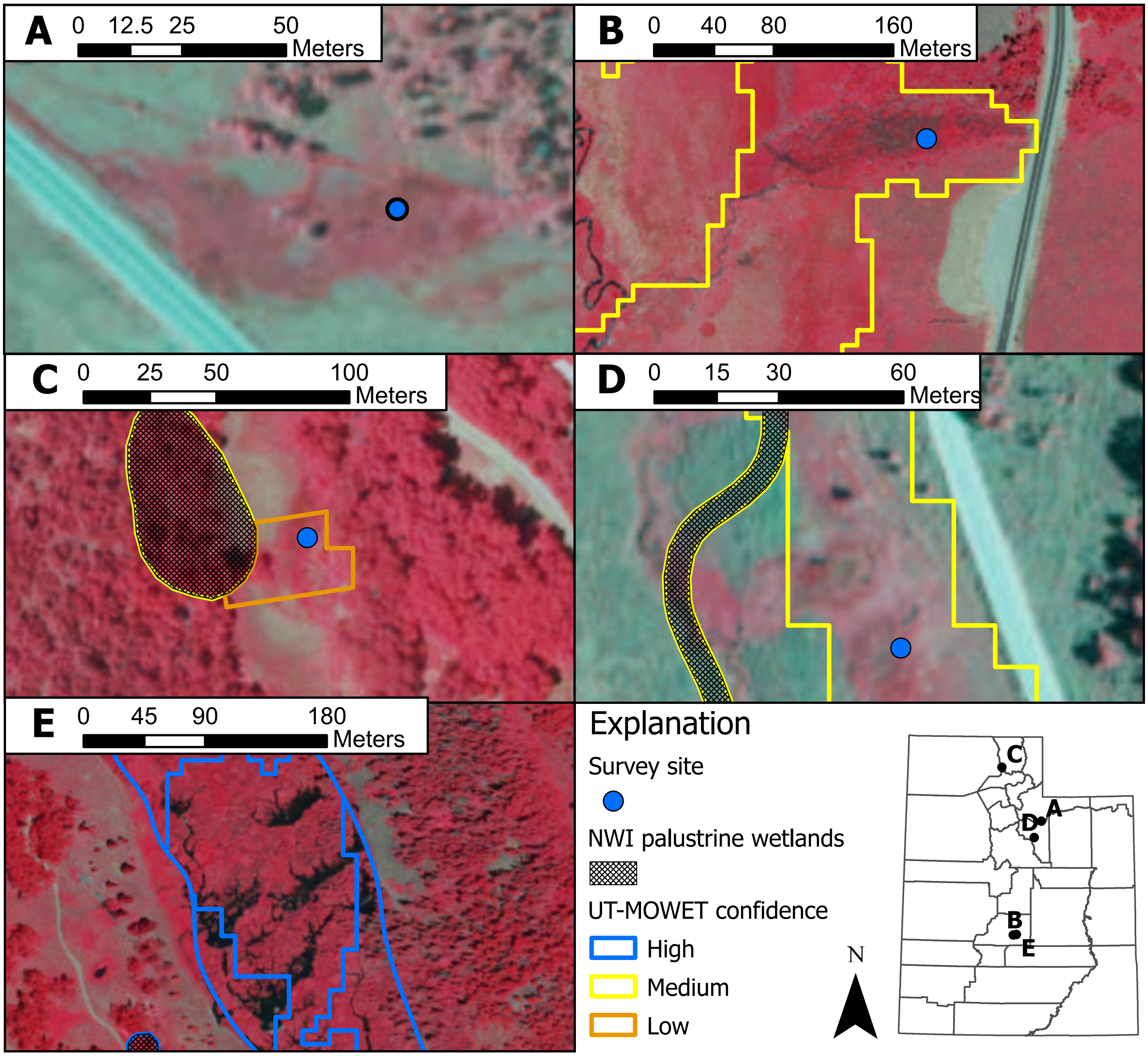

__Figure 3.__ Examples of UT-MOWET compared with NWI vegetated and pond features. High, medium, and low confidence features are represented by blue, yellow, and orange lines, respectively. All wetlands were verified in the field at the indicated survey site, except for the site in E. Some wetlands were missed by both UT-MOWET and NWI (A), whereas other UT-MOWET wetlands may include some non-wetland area (B). UT-MOWET sometimes correctly identified a wetland location that was adjacent to a NWI polygon that appears incorrectly spatially shifted (C). UT-MOWET also sometimes expanded on wetland area mapped by NWI (D) or accurately captured wetland missed by NWI (E).

__Table 10.__ Accuracy of the UT-MOWET dataset overall and by confidence class, from the confidence assessment. Values indicate the estimated percent of mapped area that is target wetland, standard error, and 95% confidence intervals.

Class	% Wetland (SE)	95% CI
Low	16.0 (4.5)	7.2–24.8
Medium	46.0 (5.9)	34.4–57.6
High	82.0 (5.0)	72.2–91.8
UT-MOWET	60.6 (3.5)	53.6–67.5

Table 11. *Confusion matrix for UT-MOWET overstory accuracy based on the confidence assessment. Numbers represent the number of sites in each combination of mapped and actual class, except for user and producer accuracies, which are percentages. Bare and Unknown classes are shown for reference but are not included in the user and producer accuracy calculations since they were not recorded in both the mapped and actual classes.*

Mapped Class	Actual Class				User Accuracy (%)
	Emergent	Water	Woody	Bare	
Emergent	57	5	10	1	79.2
Water	1	3	1	0	60.0
Woody	10	1	40	0	78.4
Unknown	3	0	18	0	-
Producer Accuracy (%)	83.8	33.3	78.4	-	

Table 12. *Confusion matrix for DRAFT-MOWET and lidar canopy class accuracy. Numbers represent the number of sites in each combination of classes, except for user and producer accuracies, which are percentages. Note that the Water class was not included as a class option in the lidar canopy classification.*

Comparison	Overall Accuracy	Mapped	Actual Class			User Accuracy (%)
			Emergent	Water	Woody	
DRAFT-MOWET Class	78.3	Emergent	32	1	4	86.5
		Water	0	4	0	100.0
		Woody	7	1	11	57.9
		Producer Accuracy (%)	82.1	66.7	73.3	
Lidar Canopy Class	81.7	Emergent	36	5	2	83.7
		Water	-	-	-	-
		Woody	3	1	13	76.5
		Producer Accuracy (%)	92.3	-	86.7	

Table 13. *Accuracy of the UT-MOWET dataset from the field site assessment for the study area shown in Figure 2, by confidence class and ecoregional group. Values indicate the estimated percent of mapped area that is target wetland, standard error, and 95% confidence intervals.*

Subpopulation	# Sites	% Wetland (SE)	95% CI
UT-MOWET subset	180	74.0 (3.9)	66.3-81.7
Confidence Class			
Low	12	37.0 (9.1)	19.1-54.8
Medium	132	65.9 (5.6)	55.0-76.9
High	36	91.6 (2.7)	86.3-96.9
Ecoregional Group			
Lower Montane	138	64.4 (3.4)	57.8-71.0
Upper Montane	42	80.9 (6.3)	68.5-93.4

features broadly for presence of riparian vegetation, rather than based on our narrower aquatic classes.

The four spatial layers created through modeling did not perform as well as the data created through aerial imagery interpretation. Wetlands may be particularly difficult to model—the wetland class for the nationwide NLCD dataset had user accuracy of only 54%, amongst the lowest for any modeled class (Wickham et al., 2023; note that our accuracy values cannot be directly compared to these values because we estimated area of accuracy rather than presence or absence of the correct value). Challenges to modeling wetlands include heterogeneous signatures (e..g., can have forested, shrub, or emergent overstories), fuzzy boundaries, changing signatures within and between years, and, often, small or narrow size (Mahdavi et al., 2018; Abdelmajeed et al., 2023). Some large-scale wetland models have reported high accuracies, such as a model of arctic wetlands with an overall accuracy of 89% based on evaluation with digitized polygons (Merchant et al., 2023). However, ten models of French wetlands evaluated with high-quality field data had overall accuracies between 42% and 66% (Rapinel et al., 2023), similar to the UT-MOWET accuracy of 61%. Accuracies in different modeling projects may differ substantially based on what data are used for evaluation.

Lower Montane features in each dataset were less likely to be aquatic than Upper Montane features. We also saw a trend towards this pattern in the field-based assessment of the UT-MOWET layer. Lower Montane regions are hotter and drier than upper regions and, particularly in the Mountain Valleys, subject to more irrigation and more intensive land use (Omernik, 1987). These wetlands are harder to identify consistently because they are often dry most of the summer and because irrigation signatures can look similar to wetland signatures in imagery. Furthermore, Lower Montane wetlands may be more susceptible to drying out due to groundwater pumping, water diversion and the recent megadrought in Utah (Williams et al., 2022). NWI, the primary dataset contributing to UW-MOWET, has not been updated recently enough to capture all of these changes in land use and hydrology.

The overall accuracy for UT-MOWET was impacted by issues with the input datasets—old data, imprecise data, and overly generalized data. Users could exclude certain confidence classes depending on their data needs. For example, practitioners conducting regulatory reviews may want to screen all possible wetlands to ensure thoroughness. For other applications, such as modeling wildlife habitat or selecting field assessment sites, users may want to exclude low confidence sites. Users could select from only high confidence sites if they want to have a very high chance of success, for example, for visiting a wetland to take photographs or collect plant specimens.

The accuracy of UT-MOWET could be improved with additional refinement. Improving accuracies of individual datasets before combining could increase accuracy of the final dataset. Additional input datasets such as topographic wetness indices, slope, canopy height, and NDVI could be used to better differentiate between wetlands and the more narrowly-defined riparian areas in the VCMQ and WRLU datasets or to identify NWI features that have been permanently eliminated. The three raster datasets (NLCD, Landfire NVC, and LCMAP) provided little unique wetland area or had low accuracy or both and could be excluded from future datasets. The dataset combination and classification algorithms could also be adjusted to further increase accuracy by, for example, more accurately identifying water or incorporating new lidar data. However, any refinement would need to consider the tradeoff between false positives and false negatives, which may vary by data use.

The best method for creating a highly accurate wetland dataset is through creation of a new dataset explicit to a region of interest and data use purpose. For the best accuracy with the finest level of detail, we recommend producing updated NWI data for areas of interest. NWI data outperformed most other data sources, despite being very out of date, and is widely used across the United States. The WRLU dataset, because it was fairly accurate and is updated regularly, could also be a useful layer with additional refinement to distinguish between wetlands and riparian areas. Modeled data, though not as accurate as other data sources, can be a useful tool since it is much faster and cheaper than aerial imagery interpretation (Mahdavi et al., 2018). Wetlands models may be more accurate when they are built on higher-resolution imagery and developed for smaller regions of interest (rather than nationwide). However, some wetland types, such as smaller, forested, and irrigation wetlands, may remain challenging to model accurately (State of Washington Department of Ecology, undated).

OBJECTIVE 2: FIELD SURVEY

Background

The goal of this objective was to collect baseline field data on Utah's montane wetlands to fill in existing knowledge gaps, understand threats to these systems, and provide data for future studies. The UGS previously used the Utah Rapid Assessment Procedure (URAP) to collect data on wetland health in the Weber and Jordan watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). These studies found that montane wetlands were generally in good condition based on certain measures, such as vegetation structure and soil disturbance, but have widespread cover of non-native plant species and, at lower elevations, altered water quality and quantity and encroachment from development. The current field study focused on the remaining montane regions of Utah (Figure 2), areas which are distinct from previously studied areas because they are farther from Utah's population centers and have less privately owned land. This study looked only at wetlands within 3 km of mapped roads to facilitate access.

Rapid assessments are good tools for collecting data with a moderate level of detail at a large number of field sites (U.S. Environmental Protection Agency, 2006; Fennessy et al., 2007). URAP collects data using a stressor checklist and condition metrics that evaluate different aspects of wetland condition, including the landscape setting, hydrology, vegetation structure, vegetation composition, and physical structure. In recent years, the UGS added a functional component to evaluate a site's ability to provide wildlife habitat, water quality improvement, and flood and erosion control. This functional data was not collected in the previous Weber and Jordan studies. For this study, we used URAP to collect field data at 81 sites in the montane ecoregion.

Condition and function are sometimes used interchangeably though they measure different properties of an ecosystem. Ecological condition can be defined as "the ability of a wetland to support and maintain its complexity and capacity for self-organization with respect to species composition, physico-chemical characteristics, and functional processes as compared to wetlands of a similar type without human alterations" (Fennessy et al., 2007). Condition is often evaluated in terms of degree of deviation from what is known or expected to occur at sites without any anthropogenic alteration (i.e., reference sites). Condition assessments differ from functional assessments in that the latter specifically focus on the functional aspect of condition, such as the ability of a wetland to attenuate flood waters or provide wildlife habitat, without regard to the overall naturalness of a site.

Site Selection

Study Area, Sample Frame, and Target Population

The study area for the field survey was a portion of the montane region of Utah that excludes previously surveyed areas and difficult to access locations based on two modifications. First, we excluded the previously surveyed Weber and Jordan HUC6 watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). Second, we removed areas that were not within 3 km of the nearest road to facilitate site access. This latter step reduced the size of the study area by about 7.7%, with most of the reduction occurring in the Uinta Mountains (Figure 2, Table 14). We used UT-MOWET, the dataset created in objective 1, as the sample frame for the project.

Table 14. *Strata used in field assessment. Target area is the area included in the study after areas more than 3 km from road were removed. Strata definitions can be found in Table 1.*

Stratum	Target Area (km^2)	% Area Removed by Road Buffer
Valleys	2790	0
Foothills	9460	2.8
Plateaus	7640	2.1
Montane	7070	2.1
Subalpine	4240	32.2

The target population for the field study was wetlands at least 0.1 ha in size and at least 10 m wide. We defined wetlands as sites with at least 30% cover of erect, rooted, persistent herbaceous or woody vegetation (Cowardin et al., 1979) and with at least two of three wetland indicators defined by the U.S. Army Corps of Engineers (USACE) for use in permitting: wetland hydrology indicators, hydric soil indicators, and dominance of hydrophytic plant species (U.S. Army Corps of Engineers, 2008). We only required two of three indicators for several reasons. First, we had a broader definition of wetland that included some mesic areas that receive more moisture than upland areas but not enough to maintain true wetland hydrology. We assumed that these marginal wetlands areas were likely to provide similar functions as many wetlands. Second, we conducted surveys in 2022 at a time when the majority of Utah was experiencing extreme drought (National Oceanic and Atmospheric Administration and National Drought Mitigation Center, 2024) as well as a 22-year megadrought (Williams et al., 2022). We thus expected that we would be less likely to observe hydrology indicators at many sites.

Strata and Selection of Study Sites

We divided the study area into separate ecoregional zones, or strata, to ensure that we captured the full range of wetland types and land uses found in the study area. We based the strata on Omernik (1987) level IV ecoregions, combining some ecoregions together based on ecoregional similarity and expected similarity of condition. The final strata include Valleys, Foothills, Plateaus, Montane, and Subalpine (Table 1, Figure 2). We excluded a large part of the Subalpine strata, and only minor parts of other strata, by limiting the study area to areas within 3 km of roads (Table 14).

We used the spsurvey package (Dunelle et al., 2022) in R (R Core Development Team, 2021) to select survey sites using a Generalized Random Tessellation Stratified (GRTS) survey design. We selected sample points instead of wetland polygons because URAP evaluates fixed area plots rather than whole wetlands. We used a stratified equal weight selection design, meaning that all wetland areas within each stratum had equal probability of selection.

We selected different numbers of sample sites and oversample sites in each strata based on 1) the amount of wetland area in each strata, 2) the expected degree of variability in condition within the strata, and 3) (for oversample sites) the likelihood of obtaining landowner access. We selected 75 sample sites, including 8 each in the Foothills, Montane, and Subalpine strata, 15 in the Plateaus, and 35 in the Valleys. We selected 50 oversample sites in the Foothills, 16 in the Montane and Subalpine, 30 in the Plateaus, and 140 in the Valleys. Oversample sites were used to replace primary sample points that could not be surveyed due to lack of permission from landowners or absence of target wetland. We surveyed 1 and 6 additional sites in the

Foothills and Valleys, respectively, for a total of 81 survey sites, due to the order in which we received permission to conduct surveys.

Site Office Evaluation and Landowner Permission

Sample points were evaluated in the office to determine whether they were located near target wetlands based on true color and infrared aerial imagery, normalized difference vegetation index, digital elevation data, land use and irrigation data, and hydric soils data (Table 6). Survey points were moved up to 100 m from the original location to account for spatial inaccuracies in the data. For sites that were potential wetlands, we contacted landowners and land managers through phone calls and a mailer to request permission to conduct surveys.

We conducted an office evaluation for each site before field surveys to gather useful landscape data to support field efforts. In the office evaluation, we evaluated sites using a variety of spatial layers to determine likely sources of hydrology for the wetland. We also evaluated sites for the presence of potential hydrology stressors because many originate at the landscape scale and are easier to see in aerial imagery than in the field. We used aerial imagery to look for stressors such as ditches, impoundments, water quality stressors, and adjacent impervious surfaces and filled out the Hydrology component of the stressor checklist. We also obtained information to aid field evaluation of the functional metrics, including information about water quality impairments, harmful algal blooms, and history of flooding near the site.

Field Methods

We used the latest version of URAP (Appendices B and C), dated January 2021, to conduct field surveys. URAP was developed in 2014 by the UGS to evaluate wetland condition after field testing three wetland rapid assessment methods (Menuz et al., 2014). The protocol was largely based on methods used by the Colorado Natural Heritage Program (Lemly and Gilligan, 2013), which was modeled on the Ecological Integrity Assessment developed by NatureServe (Faber-Langendoen et al., 2008). We first tested our method in the Weber River watershed in 2014 (Menuz et al., 2016b). The protocol underwent extensive changes in 2017 following a validation study (Menuz and McCoy-Sulentic, 2019b) and additional major changes to the stressor data collection method in 2019 (McCoy-Sulentic et al., 2021). We began collecting wetland function data in 2018 in wetlands in the Central Basin and Range ecoregion (Menuz and McCoy-Sulentic, 2019a; McCoy-Sulentic et al., 2021) using Washington State's wetland rating system (Hruby, 2014). Our discussion of the URAP methods focuses primarily on the components used in this analysis, including data on site classification, stressors, condition, function, wildlife observations, and vegetation.

UGS surveyors visited each site and verified the presence of target wetlands by looking for at least two of the three USACE wetland indicators (U.S. Army Corps of Engineers, 2008, 2010). If wetlands were present, we set up a survey as a 0.5-ha circular plot centered on the initial sample point when possible, shifting plot location and changing plot shape as needed to avoid upland inclusions and water deeper than 1 m. Each plot is referred to as a site. Surveyors used a handheld auger to dig one or more soil pits at each site, characterized the pits, and identified hydric soil indicators using standard methods (Appendix B; U.S. Army Corps of Engineers, 2008, 2010).

Survey Site Characterization

Surveyors classified sites by general wetland type (e.g., marsh, meadow, or shrubland) and hydrogeomorphic (HGM) class in the field. However, we refined the HGM key at the end of the field season and added four HGM subclasses, and thus, we reviewed each site using field data, aerial imagery, and elevation data to create final HGM assignments (Appendix D). The subclasses in the revised key include irrigation (applied to depressional and slope wetlands), beaver (applied to riverine and depressional wetlands), headwater (applied to riverine and slope wetlands), and impoundment (applied to depressional and fringe wetlands). Sites not falling into one of those subclasses were not assigned a subclass.

Surveyors also classified wetlands based on origin and grazing status. For wetland origin, we classified wetlands as natural, natural but altered, or created based on the wetland's hydrology; the latter two values were combined for analysis due to the paucity of non-natural wetlands. Wetlands were considered altered if the hydropattern or the extent of inundation was likely to be moderately to severely affected by the alterations and created if the wetland was built in a location that likely did not support a wetland previously. For grazing status, surveyors determined whether the site had a history of livestock grazing based on freshness of dung and tracks, presence of livestock, fencing, and signs of browsing on vegetation. Options for the grazing status include never regularly grazed, historically or rarely grazed, routinely grazed but not in current year, and grazed in the current year prior to survey. For analysis, these options were grouped into two categories, "not grazed" for the first two and "routinely grazed" for the latter two options.

Surveyors recorded all wildlife they observed at each survey site and in similar habitat directly adjacent to the survey site. Surveyors were not trained in wildlife identification and recorded wildlife species to the level of known taxonomic specificity. Some observations were recorded very generally as "songbird" or "frog" and other observations were recorded with more specificity as "northern leopard frog" or "cedar waxwing."

Stressors

Surveyors recorded data on stressors observed in the field and updated Hydrology stressors initially recorded as part of the site office evaluation. Stressors were grouped into four categories of impact: Buffer stressors within 100 m surrounding the site, Vegetation stressors within the site, Soil stressors within the site, and Hydrology stressors (Tables 15, 16). For each stressor, we determined the degree of degradation by categorizing the extent of the site affected by the stressor and the severity of the stress. Extent values ranged from 1 (small—affecting 1%–10% of the site or landscape) to 4 (pervasive—affecting 71%–100% of the site or landscape). Severity values also ranged from 1 to 4, from likely to slightly degrade/reduce to likely to extremely degraded/destroy or eliminate.

Wetland Condition

We collected wetland condition data using a series of predominantly qualitative metrics (Appendices B and C). Each metric rates wetland condition ranging from A, pristine or reference condition, to D, severely altered wetlands that may have little conservation value and be extremely difficult to restore. Some metrics have more than four states to account for a greater diversity of recognized states, and the best condition state at some sites is assigned a value of AB because of the difficulty in distinguishing between the two. Metrics are divided into five categories: Landscape Context, Hydrologic Condition, Physical Structure, Vegetation Structure, and Vegetation Composition (Table 17). Observers used office evaluation data, maps, and information obtained from walking around sites and the surrounding area to score the metrics.

Wetland Function

We collected data on wetland potential for three functions: 1) Water Quality improvement, 2) Hydrologic functions (flood and erosion reduction), and 3) Habitat for wildlife, using Washington State's wetland rating system (Hruby, 2014). The wetland rating system requires surveyors to evaluate metrics related to three components for each function: 1) site potential to provide the function, 2) landscape potential to support the function, and 3) societal value. Site potential metrics evaluate whether the site has characteristics that would enable it to support the function, such as storage depth for the Hydrologic function or vegetation structural diversity for the Habitat function. Landscape potential metrics for the Water Quality and Hydrologic functions evaluate whether surrounding land use is likely to result in the site receiving water quality stressors, erosive forces, or floodwaters. For the Habitat function, the landscape potential metrics evaluate whether the surrounding landscape has disturbances that may interfere with wildlife use. The societal value metrics evaluate whether the functions provided by a site are likely to benefit society by, for example, protecting flood-prone areas downstream or protecting water quality for streams and lakes with impairments. Surveyors evaluate a different set of metrics for the Water Quality and Hydrologic functions depending on a site's HGM classes and the same set of metrics for all sites for the Habitat function.

We identified several challenges with using Washington State's rating system as part of the URAP montane assessment. First, some aspects of the rating system rely on data or documents specific to Washington. Second, the Washington system is designed and calibrated to be used on whole wetlands rather than the smaller plots used by URAP. Third, the protocol is not calibrated for montane wetlands. To address the first issue, we used modifications made by McCoy-Sulentic et al. (2021) and made additional modifications to the societal value component of the habitat function to account for data unavailable in Utah. To help address the last two issues, we asked surveyors to subjectively rate sites in the field with an overall rating of "low," "medium," or "high" for each function and record their reasoning for either agreeing or disagreeing with the rating provided by the method. These subjective ratings were used to help evaluate the effectiveness of the method and highlight any novel situations where the protocol might not be adequately capturing site function. We also used wildlife observation data recorded during our field surveys to evaluate and calibrate scoring for the Habitat function (see the Data Analysis section). In addition to these changes, we added clarifying text to some of the metrics to make it easier for observers to rate sites consistently.

Wetland Vegetation

We recorded all plant species within the site after searching the area using a progressive, timed meander method adapted from the Minnesota Pollution Control Agency's Rapid Floristic Quality Assessment (Minnesota Pollution Control Agency, 2014). In this method, a base time of 30 minutes is set for each site, with 20 minutes added for each additional vegetation community. Communities were identified as distinct groupings of plant species having similar physiognomy (e.g., wet meadow or shrub complex). If three or more species were found in the last 10 minutes of the survey, we added an additional 10 minutes of survey time. We added additional 10-minute increments as needed until less than three new species were encountered in the final 10 minutes. For each species found, we recorded height class, percent cover within the site, and phenology. Plant species not identified in the field were pressed in newspaper and brought to the office for later identification. We used a dissecting microscope, standard set of plant dissection tools, and several plant identification guides to aid with identification, including *A Utah Flora* (Welsh et al., 2003), all volumes of the *Intermountain Flora* series (see introductory volume, Cronquist et al., 1972), *Grasses of the Intermountain West* (Anderton and Barkworth, 2000), *Field Guide to Intermountain Sedges* (Hurd et al., 1998), and *Flora of North America* (http://floranorthamerica.org).

Table 15. Stressors evaluated in the Buffer category and the corresponding MMI screening categories.

Field Assessment Category	MMI Screening Category	Stressor Name
Buffer	Buffer Development	Agricultural field
Buffer	Buffer Development	Development and pavement
Buffer	Buffer Development	Oil and gas infrastructure
Buffer	Buffer Development	Other development
Buffer	Buffer Development	Roads or railroads
Buffer	Buffer Development	Utilities
Buffer	Buffer Soil	Excess salinity
Buffer	Buffer Soil	Excessive erosion
Buffer	Buffer Soil	Excessive sedimentation
Buffer	Buffer Soil	Hiking trails or vehicle ruts
Buffer	Buffer Soil	Hummocking
Buffer	Buffer Soil	Other soil disturbance
Buffer	Buffer Soil	Physical resource extraction
Buffer	Buffer Soil	Soil disturbance by animals
Buffer	Buffer Soil	Substrate removal
Buffer	Buffer Soil	Trash or dumping
Buffer	Buffer Vegetation	Direct herbicide or fertilizer application
Buffer	Buffer Vegetation	Evidence of recent fire
Buffer	Buffer Vegetation	Livestock or excessive native grazing
Buffer	Buffer Vegetation	Non-native or invasive plants
Buffer	Buffer Vegetation	Other natural stressors
Buffer	Buffer Vegetation	Other vegetation stressors
Buffer	Buffer Vegetation	Pest insect damage
Buffer	Buffer Vegetation	Recent beaver dam blowout
Buffer	Buffer Vegetation	Timber extraction
Buffer	Buffer Vegetation	Vegetation mowing
Buffer	Not Included	Motorized recreation
Buffer	Not Included	Non-motorized recreation
Buffer	Not Included	Other recreation stressors

Data Analysis

Statistical Methods

Each site was assigned a weight proportional to the amount of area represented by the site relative to the total wetland area in the study area. This weighting allows for accurate estimation of wetland parameters across the entire study area. After the survey effort, we adjusted weights twice based on the total number of sites evaluated in each stratum. First, we adjusted weights using the "adjwgt" function in the spsurvey package in R to obtain weights for all evaluated sites (i.e., sites that were not part of the oversample). We used these weights to obtain estimates for the sample frame, including the percent of area not in the target population, the percent in the target population but not surveyed, and the percent target that were surveyed. We adjusted the weights a second time using the "adjwgtNR" function in spsurvey to make inference to all wetlands in the study area. To make this adjustment, we had to assume that the unsurveyed target sites are missing at random, meaning that the reason some data is missing is unrelated to the actual missing data itself (T. Olsen, U.S. EPA, written communication, February 12, 2024). We used this second set of weights for analysis of the stressor, condition, function, and vegetation data.

We used the "cat_analysis" and "cont_analysis" functions in the spsurvey package to estimate parameters for categorical and continuous variables. To compare continuous variables between strata, we used analysis of variance (ANOVA) with the post-hoc Tukey's honest significance difference test, or, when data did not meet assumptions of equal variance or normal distribution, the Kruskal-Wallis rank sum test with the post-hoc Dunn test with Benjamini-Hochberg corrections for multiple comparison. To compare categorical variables with other categorical variables (such as wetland types versus wetland strata), we considered classes to be significantly different when the 95% confidence interval in the cat_analysis

Table 16. *Stressors evaluated in the Soil, Vegetation, and Hydrology categories and the corresponding MMI screening categories.*

Field Assessment Category	MMI Screening Category	Stressor Name
Hydrology	Hydroperiod	Canals, ditches
Hydrology	Hydroperiod	Control of flow and energy
Hydrology	Hydroperiod	Culverts or paved stream crossings
Hydrology	Hydroperiod	Dams or reservoirs
Hydrology	Hydroperiod	Diking or impoundments
Hydrology	Hydroperiod	Engineered channels
Hydrology	Hydroperiod	Excavated ponds
Hydrology	Hydroperiod	Groundwater extraction
Hydrology	Water Quality	Agriculture runoff, manure, and excess irrigation water
Hydrology	Water Quality	Direct water source is impaired
Hydrology	Water Quality	Oil, gas, or mine runoff
Hydrology	Water Quality	Other hydrological stressors
Hydrology	Water Quality	Point source discharge
Hydrology	Water Quality	Stormwater runoff
Soil	Site Soil	Excess salinity
Soil	Site Soil	Excessive erosion
Soil	Site Soil	Excessive sedimentation
Soil	Site Soil	Hiking trails or vehicle ruts
Soil	Site Soil	Hummocking
Soil	Site Soil	Other soil disturbance
Soil	Site Soil	Physical resource extraction
Soil	Site Soil	Soil disturbance by animals
Soil	Site Soil	Substrate removal
Soil	Site Soil	Trash or dumping
Vegetation	Not Included	Motorized recreation
Vegetation	Not Included	Non-motorized recreation
Vegetation	Not Included	Other recreation stressors
Vegetation	Site Vegetation	Agricultural field
Vegetation	Site Vegetation	Direct herbicide or fertilizer application
Vegetation	Site Vegetation	Evidence of recent fire
Vegetation	Site Vegetation	Livestock or excessive native grazing
Vegetation	Site Vegetation	Non-native or invasive plants
Vegetation	Site Vegetation	Other development
Vegetation	Site Vegetation	Other natural stressors
Vegetation	Site Vegetation	Other vegetation stressors
Vegetation	Site Vegetation	Pest insect damage
Vegetation	Site Vegetation	Recent beaver dam blowout
Vegetation	Site Vegetation	Timber extraction
Vegetation	Site Vegetation	Utilities
Vegetation	Site Vegetation	Vegetation mowing

Table 17. *Condition metrics evaluated by the Utah Rapid Assessment Procedure, by metric category.*

Metric	Description
Landscape Context Category	
Percent Intact Landscape	Percentage of 500-m buffer surrounding site that is directly connected to site and composed of natural or semi-natural (buffer) land cover
Percent Buffer[1]	Percentage of site edge composed of buffer land cover
Buffer Width[1]	Mean width of buffer land cover (evaluated up to 100 m in width)
Buffer Condition: Soil and Substrate[1]	Soil and substrate condition within buffer (e.g., presence of unnatural bare patches, ruts, etc.)
Buffer Condition: Vegetation[1]	Vegetation condition within buffer (i.e., nativity of species in buffer)
Hydrologic Condition Category	
Hydroperiod[2]	Naturalness of wetland inundation frequency and duration
Turbidity and Pollutants[3]	Visual evidence of degraded water quality, based on evidence of turbidity or pollutants
Algae Growth[3]	Evidence of algal blooms within site (evaluated both in water and in areas with large patches of dried algae)
Water Quality	Evidence of water quality stressors reaching or within site
Connectivity	Hydrologic connection between site edge and surrounding landscape
Physical Structure Category	
Substrate and Soil Disturbance	Soil disturbance within site
Vegetation Structure Category	
Horizontal Interspersion	Number and degree of interspersion of distinctive vegetation patches within site
Litter Accumulation[4]	Naturalness of herbaceous litter accumulation within site
Woody Debris[4, 5]	Naturalness of woody debris within site
Woody Species Regeneration[4, 5]	Naturalness of woody species regeneration within site
Vegetation Composition Category	
Relative Native Cover	Relative cover of native species (native species cover / total cover)
Absolute Noxious Cover	Absolute cover of noxious weeds

[1]Buffer metrics are combined into an overall score using the following equation: Overall Buffer=(Percent Buffer*Buffer Width)$^{0.5}$*([Buffer Condition: Soil+Buffer Condition: Vegetation]/2)$^{0.5}$
[2]Evaluated with respect to similar wetlands within hydrogeomorphic class.
[3]Only evaluated when water or large patches of dry algae were present at sites.
[4]Evaluated with respect to similar wetlands within wetland type.
[5]Only evaluated when woody debris and woody species are expected at sites.

output for each class did not overlap. Weight adjustment and all statistical analysis were conducted in R (R Core Development Team, 2023).

Stressors

Severity and extent ratings for each stressor were translated into impact scores following methods from Lemly et al. (2017). Impact scores ranged from 1 for stressors with slight severity and small extent to 10 for stressors with extreme severity and pervasive extent (Table 18). Impact scores were then summed within each stressor category (Landscape, Hydrology, Soil, and Vegetation) to obtain categorical impact scores. To obtain an Overall Impact score for each site, we took a weighted sum of the four categorical scores (multiplying each categorical score by 0.3, except for the Soil impact score which was multiplied by 0.1) and summed the scores together. We then classified the overall score and each categorical score into qualitative ratings ranging from absent to very high using thresholds outlined in Table 19. We analyzed the stressor data by looking at differences in the categorical and Overall Impact scores by strata and by examining common stressors.

Wetland Condition

To calculate categorical and overall condition scores, we first used vegetation data to assign ratings for the two Vegetation Composition metrics. We then converted individual metric ratings to numerical scores based on the following: A or AB = 5, A- = 4.5, B = 4, C = 3, C- = 2, D = 1. We combined individual scores for the percent buffer, buffer width, buffer soil condition, and buffer vegetation condition metrics into an overall buffer score (Table 17). We then calculated categorical scores by calculating the mean score for metrics in each category, using only the overall buffer score and percent intact landscape metrics in the Landscape Context category (Table 17). An overall condition score was calculated by taking the mean value of the categorical scores.

Table 18. *Conversion from stressor extent and severity rating to stressor impact score and rating.*

Stressor Impact Calculator		Extent			
		Pervasive = 4	Large = 3	Restricted = 2	Small = 1
Severity	Extreme = 4	Very High = 10	High = 7	Medium = 4	Low = 1
	Serious = 3	High = 7	High = 7	Medium = 4	Low = 1
	Moderate = 2	Medium = 4	Medium = 4	Low = 1	Low = 1
	Slight = 1	Low = 1	Low = 1	Low = 1	Low = 1

Table 19. *Conversion from categorical impact scores and overall weighted score to an overall impact rating.*

Score	Rating
10+	Very High
7–9.9	High
4–6.9	Medium
1–3.9	Low
0–0.9	Absent

Wetland Function

We followed methods from Hruby (2014) to obtain ratings for each function component, which involves summing scores for all metrics to obtain a component score and then converting the scores to a component rating of low, medium, or high using thresholds that are specific to each function and component (Table 20). We used wildlife observations data from our field surveys to evaluate thresholds for the Habitat function due to issues noted in the field methods section. We plotted Habitat component scores against the number of observed species and broad taxonomic groups (invertebrates, birds, mammals, fish, amphibians, and reptiles). We identified a positive relationship between the site potential component and both the number of species and number of taxonomic groups recorded at each site (Figure 4). The relationships between wildlife observations and the other two Habitat components were not as clear or consistent. After examining plots and looking at natural breaks in the data, we modified thresholds for site potential to better align with the patterns we saw in the data, which increased the number of sites scored as medium or high (Table 21).

To assign ratings to each function, we used a method developed by McCoy-Sulentic et al. (2021) since Hruby (2014) only has methods for obtaining function component ratings and an overall site rating, not ratings for the functions themselves. McCoy-Sulentic et al. (2021) converted the function component ratings to a component score (low = 1, medium = 2, high = 3), summed the component scores for each function to get an overall function score, and created thresholds to convert function scores to function ratings of low, medium, and high by comparing scores with surveyor's subjective ratings, establishing thresholds of 3–5: low, 6–7: medium, and 8–9: high (Table 20). When we analyzed our subjective function ratings versus function ratings using those thresholds, we found that ratings matched between 68% and 72% of the time, depending on the function. Notably, surveyors rarely applied the subjective high rating for any of the functions; it was only assigned to 2.5%, 3.7%, and 9.9% of sites for the Hydrologic, Water Quality, and Habitat functions, respectively.

Once we finalized the scoring method, we estimated the percent of wetland area across the study area that scored low, medium, or high for each function overall and by component. We also analyzed four wetland attributes to see whether they were associated with higher functioning wetlands. We looked at HGM class, HGM subclass, dominant overstory vegetation (emergent or shrubland), and strata. We combined the strata from Table 1 into two groups to obtain an adequate sample size: 1) Valleys and Foothills and 2) Plateaus, Montane, and Subalpine. For each attribute, we used cat_analysis in spsurvey to obtain 95% confidence intervals and considered classes that had non-overlapping confidence intervals to be significantly different from one another. We grouped medium and high functioning wetlands together for the attribute analysis to increase statistical power.

Wetland Vegetation

We summarized vegetation data to examine common and problematic (e.g., noxious or aggressive) species found in the study area and to make estimates about three vegetation metrics, two of which are also metrics used in the condition analysis. We use species' scientific names as listed in the Natural Resources Conservation Service (2024) PLANTS Database to reference plants throughout this report.

Noxious cover is the percent cover by noxious weed species found at each site. The commissioner of the Utah Department of Agriculture and Food designates plant species as noxious weeds if they are "especially injurious to public health, crops, livestock, land, or other property" (Utah Code §4-17-102, 2017). We used the Utah noxious weed list to determine noxious status for our calculations.

Relative native cover is a measure of the percent of all plant cover at a site that is composed of native species. We determined nativity primarily based on designations in the PLANTS Database. For species listed as both native and introduced in the PLANTS database, we assigned a final nativity status based on factors such as whether known sub-

Table 20. Process for obtaining function component and overall function scores, using the Habitat function and data from a hypothetical site. Metric scores within a component are added together, converted to component ratings based on thresholds for each component, and then converted to a component rating of low, medium, or high. The component rating is then converted to a component score of 1, 2, or 3, summed, and converted to an overall function rating.

	Landscape	Site Potential	Society
Actual Habitat Component Thresholds			
Low	-2 to 0	0 to 5	0
Medium	1 to 3	6 to 10	1
High	4 to 9	11 to 18	2
Hypothetical Site Data			
Sum of Metric Scores	-2	10	2
Component Rating	Low	Medium	High
Component Score	1	2	3
Function Score	6		
Function Rating	Medium		

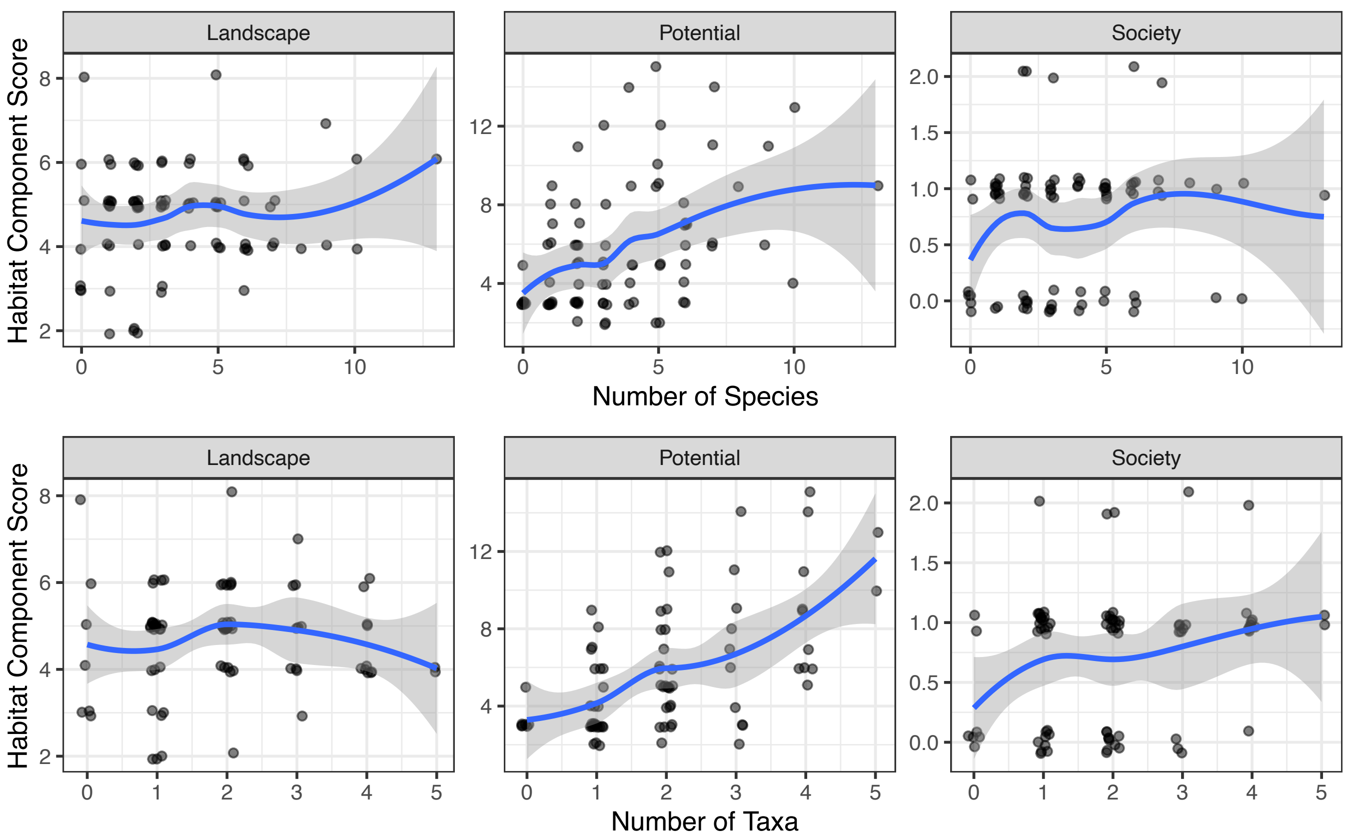

Figure 4. Scores for each component of the habitat function compared with the number of species and unique taxonomic groups observed at each site. Blue lines and grey shading represent the estimate and 95% confidence intervals from a loess smoothing function. Points are transparent and offset from exact values due to high overlap between points.

Table 21. Range of values used to rank sites for site potential to provide Habitat function. The original scoring method from Hruby (2014) was modified as shown in the table. More sites were ranked medium and high after the modification than with the original scoring method.

Rank	Original Range	Modified Range	Original # Sites	Modified # Sites
Low	0–6	0–5	56	46
Medium	7–14	6–10	24	26
High	15–18	11–18	1	9

species from Utah were all listed as native or non-native and information from Welsh et al. (2003) and the *Intermountain Flora* series (see introductory volume, Cronquist et al., 1972). Based on this evaluation, we classified smooth brome (*Bromus inermis*), lambsquarters (*Chenopodium album*), Kentucky bluegrass (*Poa pratensis*), weeping alkaligrass (*Puccinellia distans*), and common dandelion (*Taraxacum officinale*) as introduced, and we classified common yarrow (*Achillea millefolium*), stinging nettle (*Urtica dioica*), and thymeleaf speedwell (*Veronica serpyllifolia*) as native. Though listed as native in the PLANTS database, we treated reed canarygrass (*Phalaris arundinacea*) as introduced based on a recent genetic analysis (Kettenring et al., 2019).

The third vegetation metric we report on, mean C, is derived from coefficient of conservatism values (C-values). C-values are values assigned to species based on their association with disturbance through a combination of best professional judgment, literature review, and field observations. Low values indicate that species are usually found at disturbed sites, high values indicate that species are associated with pristine sites, and values in the middle indicate that species may be found equally at either type of site; values range from 0 to 10 (Rocchio and Crawford, 2013). All non-native species are assigned a C-value of 0. We used C-values developed and described in McCoy-Sulentic et al. (2021) and calculated mean C as the mean C-value for all species at a site, without adjusting for cover.

Results

Survey Site Characteristics

We evaluated 180 sites through aerial imagery examination and field visits to identify a final list of 81 surveyable sites (Table 22, Figure 2). The remainder of the sites were either non-target (i.e., not wetland) or were inaccessible. Lack of access was almost always due to inability to get permission from landowners, though one site was inaccessible due to road closure. In the Valleys and Foothills, over one-third of evaluated sites were non-target. Inaccessible sites were also more common in these two strata. In contrast, we surveyed at least 72% of evaluated sites in the other three strata. Across the entire study area, about one-quarter of the mapped wetland area is estimated to be non-target. We classified most non-target sites as non-wetland, though some were too small or narrow to be surveyed or were other aquatic features outside of our target population, such as deep water. We conducted all field surveys between June 6 and September 12, 2022.

We recorded hydrology indicators at all 81 sites, hydrophytic vegetation at all but one site, and hydric soils at only 40 sites. We found hydric soil indicators at 32% of Valleys, 44% of Foothills, 60% of Plateaus, 75% of Montane, and 100% of Subalpine sites. We occasionally evaluated wetland indicators using the USACE indicators for the Arid West rather than the Western Mountains, Valleys, and Coast when sites fit better into the Arid West classification (U.S. Army Corps of Engineers, 2010). These sites included those that were located in the Valleys or Foothills and received <50 cm of precipitation per year (based on 30-year PRISM climate normals; PRISM Climate Group, undated). This resulted in four of nine Foothills sites and 33 of 42 Valleys sites being classified as Arid West sites.

Wetland classification: Across the study area, the most common wetland type is meadow (77.7% of wetland area) followed by shrubland (21.0%) and then marsh (1.3%, Table 23). Meadow is also the most common wetland type in each strata, though confidence intervals for meadow and shrubland overlapped in the Montane and Subalpine stratum. Marsh wetlands were only found in the Valleys stratum.

We encountered four HGM classes and four HGM subclasses in the study area. Wetlands classified as slope are the most common in the study area (50.1%) and lacustrine fringe the least (0.7%; Table 23). Riverine (24.1%) and depressional wetlands (25.2%) were equally abundant. Only one site, in the Valleys, was classified as Lacustrine Fringe. Across the study area, wetland area is estimated to be 39.7% with no subclass, 29.9% headwater, 18.7% irrigation, 12.0% beaver, and 0.7% impoundment, though almost all confidence intervals overlapped (Table 23). The abundance of each subclass did not differ by strata for the subclasses found in those strata except in the Valleys, which had more irrigation and wetland without a subclass than other subclass types.

Most wetland area in the study area is natural (70.6%, 95% CI [62.1–79.1]) rather than altered or created (29.4%, 95% CI [20.9–37.9]). This also holds true in each of the strata except

Table 22. *Number of sites evaluated per stratum and percent of wetland area estimated to fall into each survey status, followed by standard error in parentheses.*

Stratum	Evaluated Sites (#)	% Surveyed (SE)	% Target Not Surveyed (SE)	% Non-Target (SE)
Study Area	180	58.0 (4.4)	16.0 (2.9)	26.0 (4.0)
Valleys	116	35.3 (3.3)	29.3 (3.3)	35.3 (3.1)
Foothills	22	40.9 (9.7)	22.7 (7.7)	36.4 (9.2)
Plateaus	20	75.0 (8.2)	10.0 (5.9)	15.0 (7.5)
Montane	11	72.7 (11.2)	0.0 (0.0)	27.3 (11.2)
Subalpine	11	72.7 (12.3)	9.1 (8.1)	18.2 (10.9)

Table 23. *Estimates of the percent of wetland area in each wetland class, following by 95% confidence interval in parentheses.*

Wetland Class	Study Area	Valleys	Foothills	Plateaus	Montane	Subalpine
Wetland Type						
Marsh	1.3 (0.0–3.0)	4.9 (0.0–10.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Meadow	77.7 (66.7–88.6)	90.2 (81.8–98.7)	77.8 (53.0–100.0)	73.3 (52.3–94.4)	62.5 (30.3–94.7)	75.0 (47.9–100.0)
Shrubland	21.0 (10.2–31.8)	4.9 (0.0–10.8)	22.2 (0.0–47.0)	26.7 (5.6–47.7)	37.5 (5.3–69.7)	25.0 (0.0–52.1)
HGM Class						
Depressional	25.2 (15.9–34.5)	39.0 (27.7–50.4)	11.1 (0.0–29.1)	26.7 (6.9–46.4)	37.5 (4.5–70.5)	12.5 (0.0–33.1)
Lacustrine Fringe	0.7 (0.0–1.8)	2.4 (0.0–6.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Riverine	24.1 (12.8–35.3)	22.0 (12.2–31.7)	33.3 (3.2–63.5)	13.3 (0.0–29.4)	37.5 (5.3–69.7)	25.0 (0.0–53.8)
Slope	50.1 (37.3–62.8)	36.6 (23.9–49.2)	55.6 (26.0–85.1)	60.0 (40.3–79.7)	25.0 (0.0–54.0)	62.5 (29.4–95.6)
HGM Subclass						
Beaver	12.0 (3.9–20.1)	9.8 (2.5–17.0)	11.1 (0.0–30.6)	0 (0.0)	37.5 (5.8–69.2)	12.5 (0.0–33.1)
Headwater	29.9 (17.8–42.1)	4.9 (0.0–10.6)	33.3 (4.9–61.7)	53.3 (31.0–75.6)	25.0 (0.0–54.0)	37.5 (5.7–69.3)
Impoundment	0.7 (0.0–1.8)	2.4 (0.0–6.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Irrigation	18.7 (10.9–26.6)	46.3 (36.6–56.1)	22.2 (2.5–42.0)	0 (0.0)	0 (0.0)	12.5 (0.0–34.5)
No subclass	38.7 (25.8–51.5)	36.6 (25.2–47.9)	33.3 (6.0–60.7)	46.7 (24.4–69.0)	37.5 (6.0–69.0)	37.5 (4.5–70.5)

Valleys and Foothills. The Foothills had no difference in wetland origin, and most of the wetland area in the Valleys is altered or created (68.3%, 95% CI [59.8–76.8]) rather than natural (31.7%, 95% CI [23.2–40.2]). Most of the wetland area across the study area is also routinely grazed (71.1%, 95% CI [62.3–80.0] versus not grazed (28.9%, 95% CI [20.0–37.7]). Wetlands with routine grazing are more common than ungrazed wetlands in the Valleys, Foothills, and Plateaus strata, whereas there was no difference in grazing status in the Montane and Subalpine strata.

Wildlife observations: Surveyors recorded at least one wildlife observation at each site and an average of 3.7 taxa per site (Table 24). Observations included both direct species observations and evidence such as nests, footprints, and scat. The most commonly recorded taxonomic groups included invertebrates (64 sites), birds (44), and mammals (29). The most commonly recorded invertebrates were butterflies, dragonflies or damselflies, bees, grasshoppers, mollusks, and unknown insects. The most common birds and mammals included unknown birds, deer, and beaver. Fish, amphibians, and reptiles were each recorded at fewer than 10 sites.

Stressors

Several stressors were prevalent in our study area and impacted over one-half of all wetland area in our study area (Table 25). Many of these stressors are frequently associated with livestock grazing, though they can also be caused by excessive wildlife use or runoff from nearby agricultural fields. The common grazing-related stressors are: soil disturbance by animals (site), soil disturbance by animals (buffer), excessive grazing (site), excessive grazing (buffer), and agricultural runoff or manure. An additional livestock-related stressor, hummocking, was not as widespread but was very impactful whenever it was found, especially at the site level (Figure 5). Non-native and invasive plants (site and buffer) are two additional stressors that were very widespread (Table 25). Throughout the study area, these stressors were typically recorded with low or medium impact ratings, but high impact ratings occurred occasionally in the lower elevation strata: Valleys, Foothills, and Plateaus (Figure 6). Non-native and invasive species, notably, only received low or medium impact ratings except for one instance, and had only low or no impact in the Plateaus stratum at the site level.

Although most of the stressor categories rarely had impact ratings above medium, several Hydrology category stressors had high or very high impacts at the site level (Figure 7). Canals/ditches and impaired water source were the two most widespread Hydrology stressors after agriculture runoff/manure and both were recorded with high or very high impact at sites in the Foothills and Valleys (Table 25; Figure 7). The remaining common Hydrology stressors (diking or impoundments, culverts and paved stream crossings, control of flow and energy, and groundwater extraction) were only rarely recorded with high impacts.

We found significant differences in impact scores between strata for all stressor categories except in the Soil stressor category (Table 26; Figure 8). For Overall Impact, Valleys and Foothills wetlands had higher impact scores than Montane and Subalpine wetlands in post-hoc testing ($p < 0.03$), whereas Plateaus did not differ significantly from any other strata. We observed a similar pattern in the Hydrology category, where Valleys and Foothills had significantly higher impact scores than Montane ($Z = -3.03$, $p = 0.004$ and $Z = 2.31$, $p = 0.02$) and Subalpine ($Z = -3.70$, $p = 0.001$ and $Z = 2.85$, $p = 0.01$) wetlands, along with higher impact scores than Plateaus as well ($Z = -3.41$, $p = 0.002$ and $Z = 2.32$, $p = 0.02$; Figure 8).

Table 24. *Wildlife observations recorded during field surveys.*

Taxonomic Group	List of Recorded Species
Amphibian	Unknown frog, northern leopard frog, tadpole
Bird	Avocet, cedar waxwing, chickadee, crow, duck, goldfinch, goose, gray jay, hummingbird, ibis, jay, killdeer, mallard, marsh bird, meadowlark, raptor, red-tailed hawk, red-winged blackbird, robin, sandhill crane, shorebird, songbird, sparrow, stilt, swallow, tern, unknown bird, woodcock, yellow-headed blackbird
Fish	Unknown fish
Invertebrate	Aquatic insect, bee, beetle, bivalve, butterfly, caddisfly, caterpillar, cricket, dragonfly/damselfly, fly, grasshopper, harvestman, hummingbird hawk moth, unknown insect, unknown invertebrate, ladybug, locust, mayfly, mollusk, mosquito, snail, spider, wasp, water boatman, yellowjacket
Mammal	Beaver, chipmunk, cow, coyote, deer, elk, fox, groundhog, unknown mammal, mole, unknown rodent
Reptile	Garter snake, unknown snake

Table 25. *Estimated percent of wetland area in each strata with each stressor (standard error in parenthesis), for those stressors found at over 20% of sites in at least one stratum. Estimates are ordered first by stressor category and then by frequency across the study area.*

Stressor Name	Category	Study Area	Valleys	Foothills	Plateaus	Montane	Subalpine
Soil disturbance by animals	Buffer	70.2 (4.8)	70.7 (5.6)	55.6 (14.2)	80.0 (8.9)	50.0 (15.9)	75.0 (11.0)
Livestock or excessive native grazing	Buffer	65.4 (4.6)	61.0 (6.4)	77.8 (10.0)	86.7 (8.1)	37.5 (15.5)	62.5 (10.3)
Non-native or invasive plants	Buffer	56.6 (5.9)	82.9 (4.6)	88.9 (9.9)	46.7 (12.5)	75.0 (14.8)	25.0 (14.9)
Roads or railroads	Buffer	33.1 (5.1)	26.8 (6.2)	44.4 (11.7)	40.0 (11.5)	50.0 (14.8)	25.0 (11.6)
Hiking trails or vehicle ruts	Buffer	10.1 (3.9)	9.8 (3.8)	22.2 (13.1)	6.7 (5.8)	0.0 (0.0)	12.5 (10.4)
Hummocking	Buffer	10.6 (2.3)	12.2 (4.0)	22.2 (11.6)	26.7 (9.0)	0.0 (0.0)	0.0 (0.0)
Other vegetation stressors	Buffer	9.5 (4.7)	0.0 (0.0)	0.0 (0.0)	6.7 (5.5)	0.0 (0.0)	25.0 (13.8)
Vegetation mowing	Buffer	3.4 (1.2)	4.9 (3.0)	22.2 (10.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Utilities	Buffer	2.1 (1.2)	0.0 (0.0)	22.2 (12.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Agriculture runoff, manure, and excess irrigation water	Hydrology	67.8 (4.5)	85.4 (3.4)	88.9 (9.3)	60.0 (10.1)	37.5 (15.5)	62.5 (10.3)
Direct water source is impaired	Hydrology	30.1 (5.3)	46.3 (6.4)	55.6 (11.1)	6.7 (5.8)	25.0 (13.8)	25.0 (13.7)
Canals, ditches	Hydrology	24.2 (4.3)	53.7 (5.3)	44.4 (13.3)	0.0 (0.0)	12.5 (11.3)	12.5 (11.2)
Stormwater runoff	Hydrology	16.0 (4.4)	12.2 (4.2)	33.3 (13.9)	6.7 (5.4)	37.5 (15.9)	12.5 (10.5)
Culverts or paved stream crossings	Hydrology	6.3 (2.1)	2.4 (2.1)	33.3 (13.9)	13.3 (8.0)	0.0 (0.0)	0.0 (0.0)
Soil disturbance by animals	Soil	64.1 (4.8)	53.7 (6.6)	55.6 (14.2)	80.0 (7.3)	37.5 (15.4)	75.0 (11.0)
Hummocking	Soil	16.5 (3.0)	24.4 (5.7)	22.2 (11.6)	40.0 (11.7)	0.0 (0.0)	0.0 (0.0)
Non-native or invasive plants	Vegetation	79.9 (5.7)	90.2 (4.1)	100.0 (0.0)	73.3 (9.3)	100.0 (0.0)	62.5 (16.3)
Livestock or excessive native grazing	Vegetation	61.0 (4.6)	48.8 (5.9)	66.7 (13.6)	86.7 (8.1)	37.5 (15.5)	62.5 (10.3)
Other vegetation stressors	Vegetation	9.5 (4.7)	0.0 (0.0)	0.0 (0.0)	6.7 (5.5)	0.0 (0.0)	25.0 (13.8)
Vegetation mowing	Vegetation	2.1 (0.9)	0.0 (0.0)	22.2 (10.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

In the Vegetation category, only the Foothills stratum had significantly higher impact scores than Valleys in post-hoc testing ($Z = 3.10$, $p = 0.01$) and no other strata pairs had significant differences (Figure 8). Several Vegetation stressors occurred only in the Foothills, including agricultural fields, utilities, and vegetation mowing. Foothills sites also had high or very high impacts in over 25% of surveyed sites for the Vegetation stressor "livestock or excessive native grazing," while Valleys had less than 10% of sites with a higher rating for this stressor (Figure 6). Post-hoc testing of the Buffer category found that only Foothills and Montane differed significantly from one another ($Z = 2.85$, $p = 0.02$), and all other strata were not significantly different. A final interesting note about strata differences is that Plateaus wetlands typically did not differ significantly from other strata in any category, except for having lower Hydrology stressor impacts than Valleys and Foothills wetlands (Figure 8).

Wetland Condition

Overall wetland condition scores were significantly higher in the two highest elevation strata, Montane and Subalpine, compared to the two lowest elevation strata, Valleys and Foothills ($p < 0.05$), while Plateaus did not differ significantly

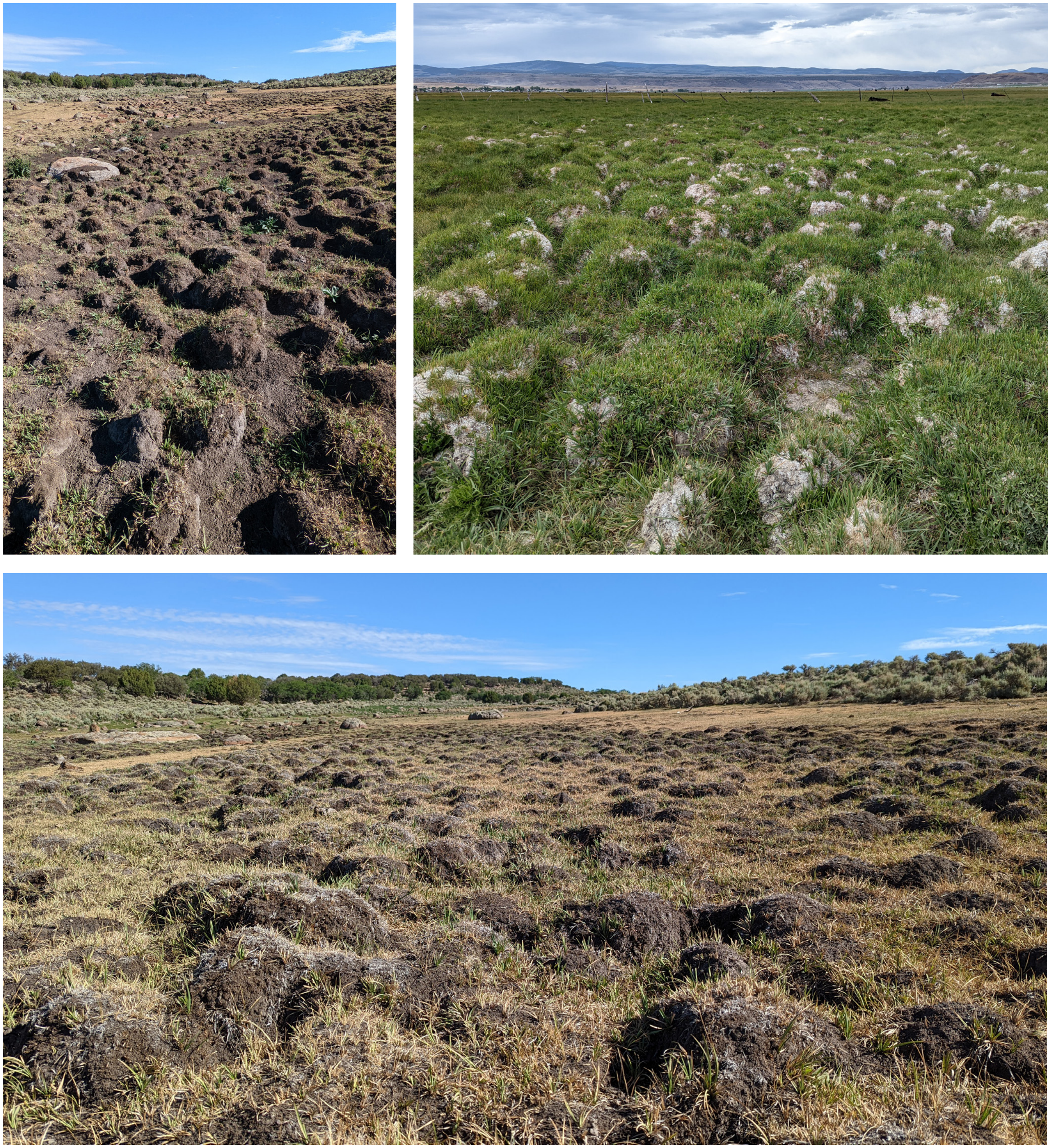

Figure 5. *Soil hummocking due to trampling is a stressor sometimes found in heavily grazed wetlands. This type of hummocking is formed by compaction, water channeling, and erosion of organic material. Hummocks created by trampling can affect how water moves through a wetland and the wetlands ability to store water (Booth et al., 2014). In our study, hummocking was generally uncommon but had high impacts wherever it was found.*

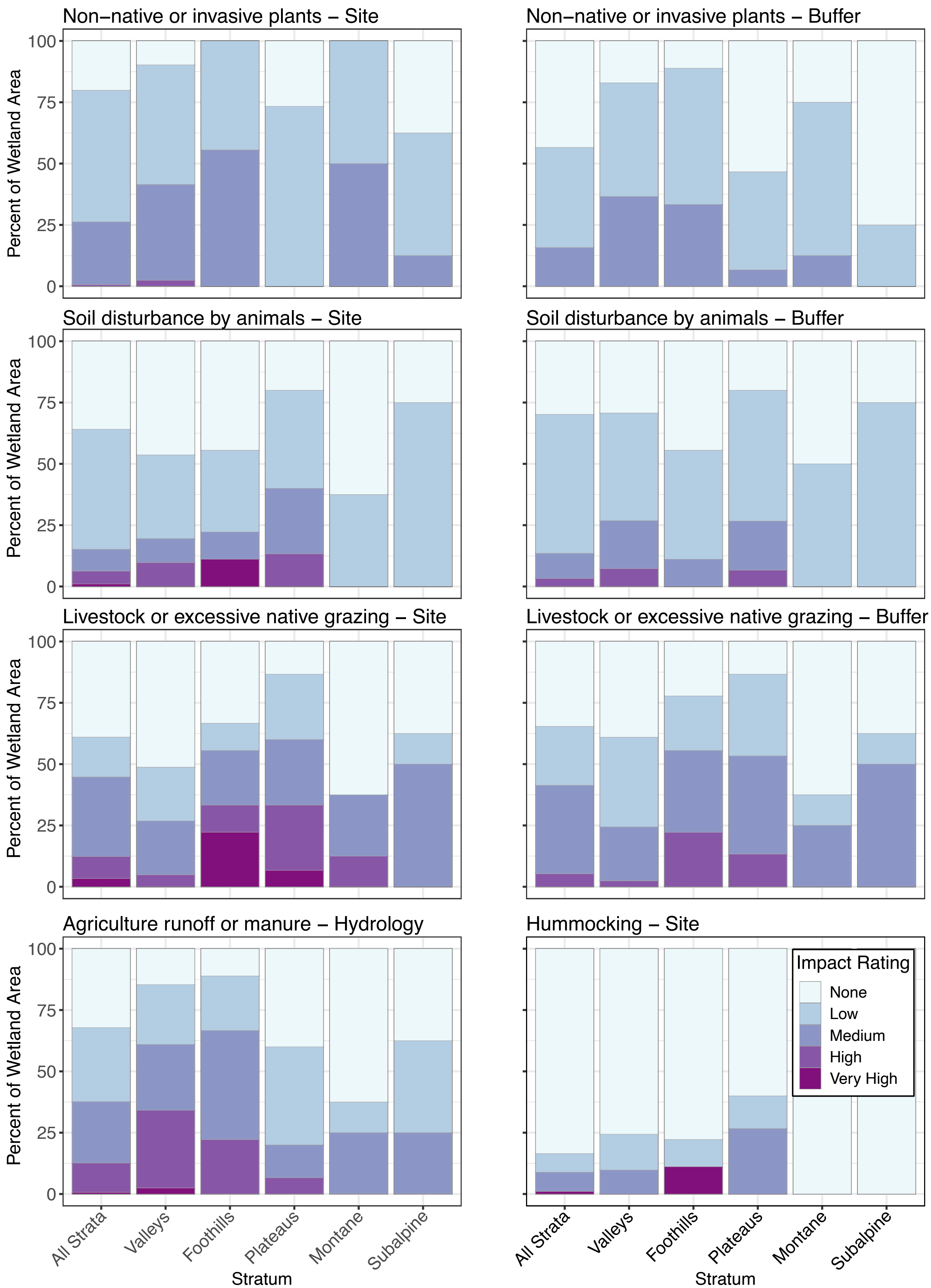

Figure 6. *Prevalence of stressors related to non-native plants and grazing. Plots show the percent of wetland area that received impact ratings of "none," "low," "medium," "high," or "very high" by strata.*

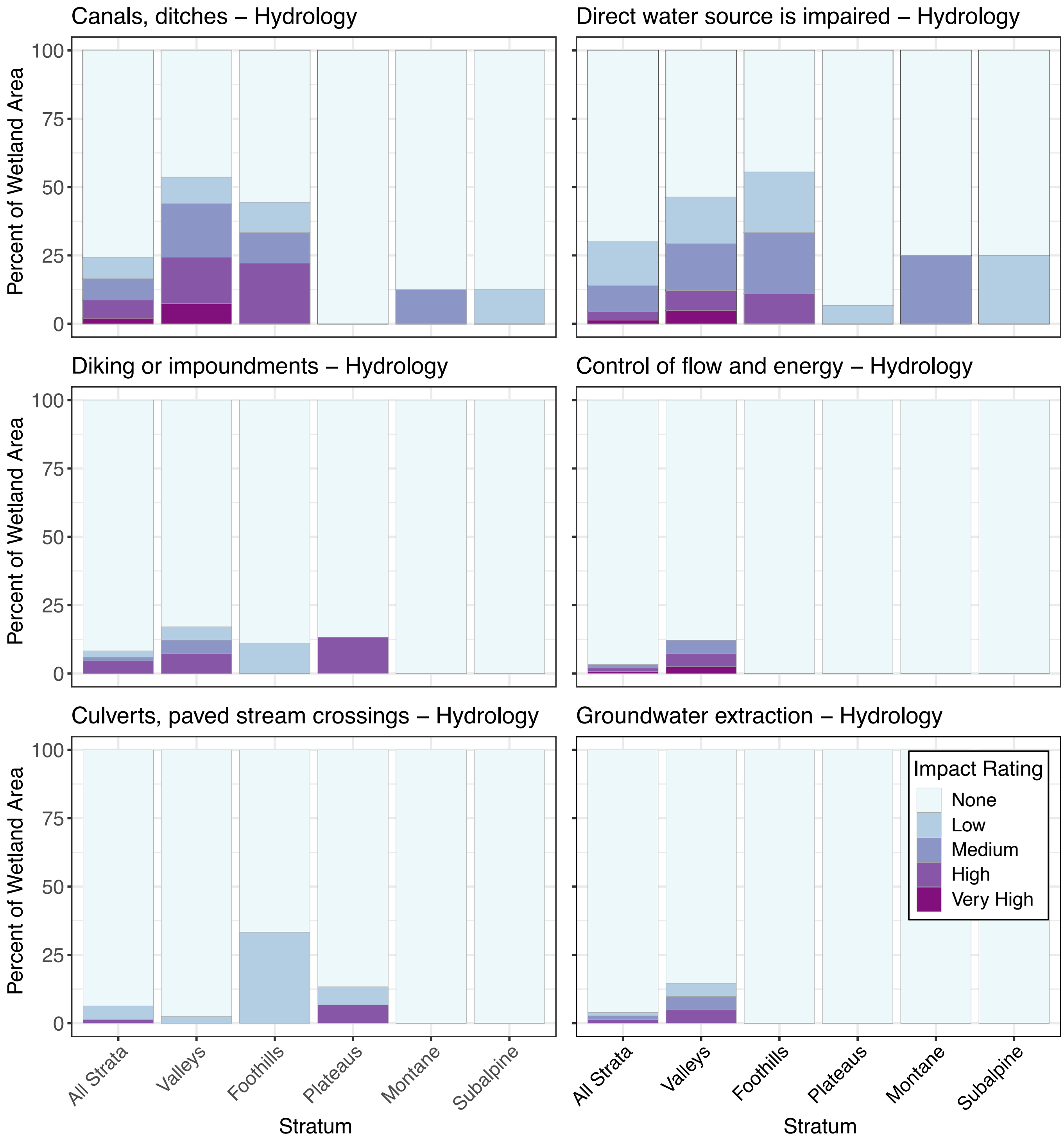

Figure 7. *Prevalence of common hydrology stressors. Plots show the percent of wetland area that received impact ratings of "none," "low," "medium," "high," or "very high" by strata.*

Table 26. *Statistical analysis results for comparisons of stressor, condition, and vegetation metric scores by strata.*

Stressor Category	Test Used	df	Test Statistic	*p*-value
Overall Impact	ANOVA	4	5.32	0.001
Hydrology	Kruskal-Wallis	4	26.63	< 0.001
Vegetation	Kruskal-Wallis	4	10.15	0.038
Soil	Kruskal-Wallis	4	8.57	0.073
Buffer	Kruskal-Wallis	4	10.67	0.031
Condition Metric Category	**Test used**	**df**	**Test Statistic**	***p*-value**
Overall URAP Score	ANOVA	4	6.30	0.002
Physical Structure	Kruskal-Wallis	4	9.22	0.056
Landscape Context	Kruskal-Wallis	4	9.24	0.055
Hydrologic Condition	Kruskal-Wallis	4	21.73	0.000
Vegetation Composition	Kruskal-Wallis	4	16.50	0.002
Vegetation Structure	Kruskal-Wallis	4	12.76	0.013
Vegetation Metric	**Test used**	**df**	**Test Statistic**	***p*-value**
Relative Native Cover	Kruskal-Wallis	4	17.33	0.001
Mean C	ANOVA	4	30.26	<0.001

from any other strata ($p < 0.05$; Table 26; Figure 9). This difference is reflected in the percentage of sites which had a condition score over 4.5 (close to the highest possible score of 5) in each stratum: 62.5% of Subalpine sites, 50% of Montane sites, then 20%, 4.8%, and 0% for Plateaus, Valleys, and Foothills sites, respectively.

Several other condition categories showed significant differences between strata as well. Three of the five categories (Hydrologic Condition, Vegetation Composition, and Vegetation Structure) had significant differences between strata based on Kruskal-Wallis tests followed by post hoc Dunn tests (Table 26; Figure 9). Subalpine sites had significantly higher Hydrologic Condition scores than Valleys ($Z = 3.84$, $p < 0.001$) and Foothills wetlands ($Z = -2.71$, $p = 0.01$). Plateaus wetlands also had significantly higher Hydrologic Condition scores than Valleys wetlands ($Z = 3.04$, $p = 0.01$) (Figure 9). For the Vegetation Composition category, Plateaus and Subalpine wetlands had significantly higher scores than Valleys wetlands ($Z = 3.25$, $p = 0.01$, and $Z = 2.79$, $p = 0.01$, respectively), and in the Vegetation Structure category, Montane and Subalpine sites had significantly higher scores than Foothills sites ($Z = -2.92$, $p = 0.02$, and $Z = -2.69$, $p = 0.02$; Table 26, Figure 9).

Across the entire study area, most wetland area was estimated to be rated between A and B for most metrics. Nine metrics were estimated to have an A or AB rating in over 50% of all wetland area (Table 27). Three of these metrics were in the Landscape Context category: percent buffer, buffer width, and buffer vegetation condition. For percent buffer and buffer width, only the Valleys and Foothills strata contained sites that were rated B or lower. The buffer vegetation condition metric had a similar pattern with instances of ratings below B in the Montane strata as well (Figure 10). The Hydrologic Condition category also had three highly-rated metrics: hydroperiod, wetland edge connectivity, and turbidity and pollutants. The hydroperiod metric had the highest ratings in the Montane and Subalpine strata. At least 75% of wetland area in every strata was rated as A or AB for wetland edge connectivity. The only sites rated C for this metric were in the Valleys, Plateaus, and Montane strata, and only one site, in the Montane stratum, was rated D (Figure 11). Turbidity and pollutants had primarily A, AB, or B ratings, except for a few cases of D ratings in the Foothills and Montane strata. It should be noted that turbidity and pollutants were only rated at sites with water present, so many sites received a NA (not applicable) for rating. Another notable metric with high ratings is algae growth. Surveyors only rate the algae growth metric if surface water or a noticeable dried algal mat are present. Of the 50 sites that were rated for this metric, only a few sites in the Valleys and Montane strata received C ratings.

Wetland condition ratings of C or below were less common. Metrics where at least 20% of the wetland area was rated C or lower include percent intact landscape, hydroperiod, water quality, litter accumulation, horizontal interspersion, and relative native cover (Table 27). Surveyors rated 41.6% of sites D for horizontal interspersion, which is the highest amount of D ratings for any condition metric. It was also the only condition metric with D ratings in all strata. Otherwise, only three metrics had over 5% of wetland area with an estimated D rating, including hydroperiod, relative native cover, and water quality (Table 27). D-rated sites were found in all strata for horizontal interspersion, three of five strata for relative native cover and water quality, and only two strata for hydroperiod (Figures 11 and 12). The Foothills strata was the only strata where no sites received an A rating for water quality (Figure 11).

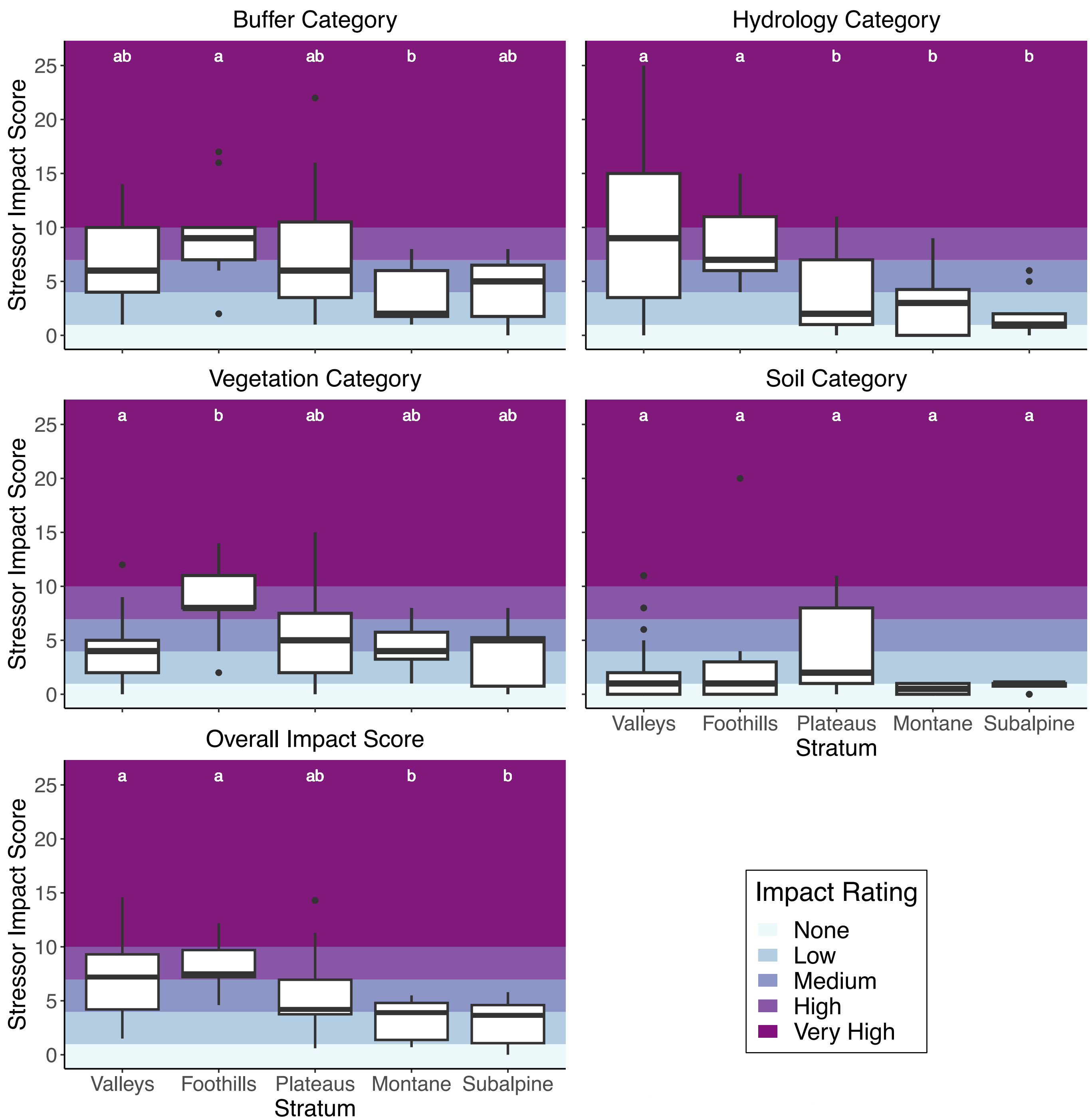

Figure 8. *Stressor impact scores by strata for each category (Buffer, Hydrology, Vegetation, Soil) and for overall combined impact. The whiskers of each boxplot show the 25th and 75th percentile for each stratum and the dots above and below are outliers. The horizontal line inside marks the median score. Boxplots with no shared letter above them are statistically significantly different. For example, for overall impact score, Valleys and Foothills have significantly higher stressor impact scores than Montane and Subalpine. Background plot colors indicate when a value falls into the qualitative impact rating categories of "none," "low," "medium," "high," or "very high."*

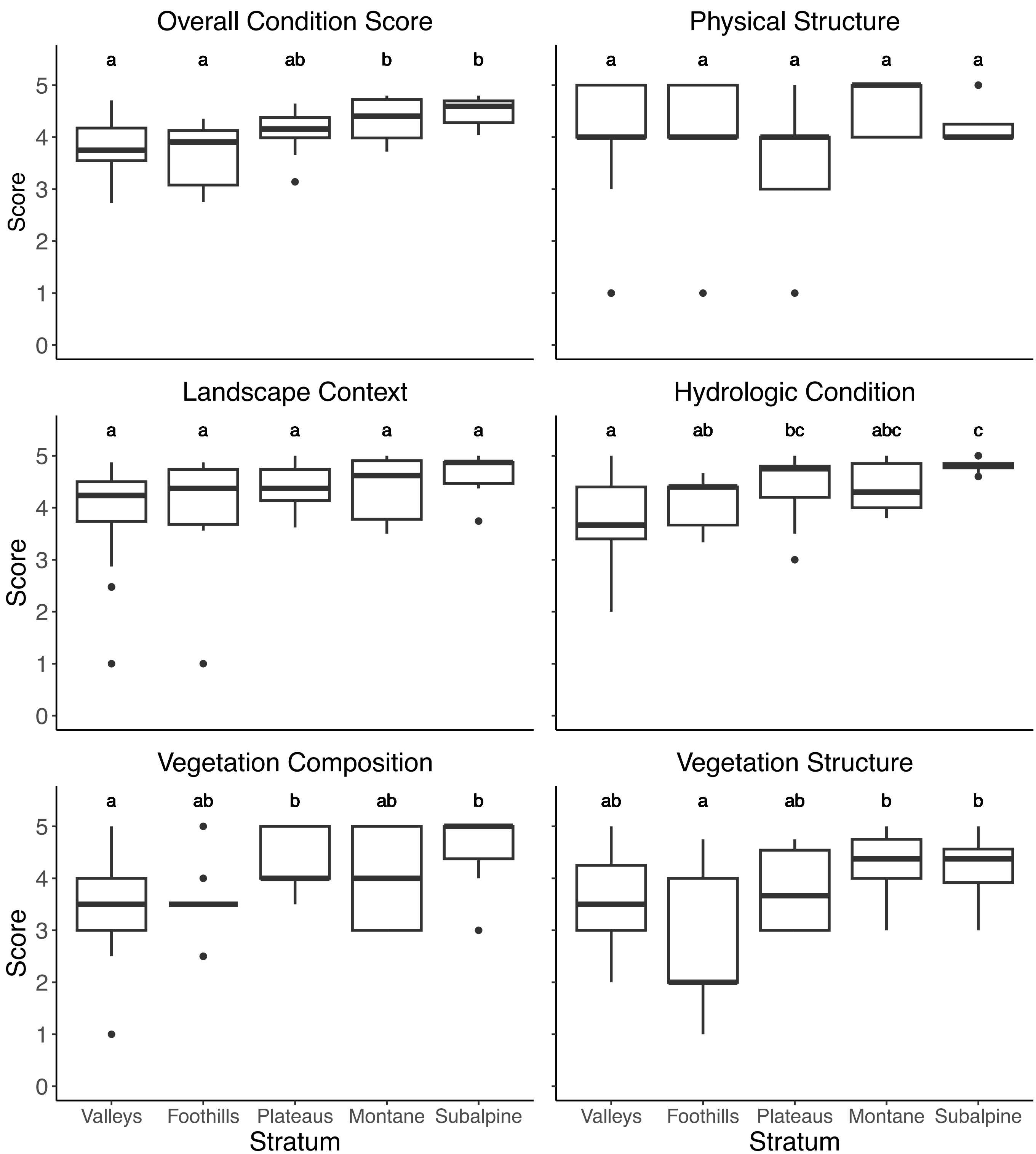

Figure 9. *Condition scores (translated from their field letter rating to a numerical score for analysis, seen on the y-axis) by strata for each category (Physical Structure, Landscape Context, Hydrologic Condition, Vegetation Composition, Vegetation Structure) and for overall condition. The whiskers of each boxplot show the 25th and 75th percentile for each stratum and the dots above and below are outliers. The horizontal line inside marks the median score. Boxplots with no shared letter above them are statistically significantly different. For example, for overall condition, Valleys and Foothills have significantly lower condition scores than Montane and Subalpine.*

Table 27. Condition metric results for the study area showing the estimated percent of wetland area with each rating and standard error in parentheses. Metrics are sorted by highest estimated percent of wetland area falling into the "A or AB" rank.

Metric	A or AB	A-	B	C	C-	D	NA
Percent Buffer	89.8 (2.4)	4.4 (2.0)	3.4 (1.6)	0.7 (0.6)	NA	1.7 (1.1)	NA
Wetland Edge Connectivity	87.2 (2.2)	NA	7.4 (1.5)	4.0 (1.8)	NA	1.4 (1.2)	NA
Buffer Width	76.1 (4.5)	7.7 (2.4)	12.5 (4.3)	2.0 (1.0)	NA	1.7 (1.1)	NA
Litter Accumulation	74.6 (4.7)	NA	NA	23.7 (4.6)	NA	1.7 (1.1)	NA
Absolute Noxious Cover	69.8 (4.2)	NA	24.0 (4.3)	5.5 (1.9)	NA	0.7 (0.6)	NA
Hydroperiod	65.6 (5.0)	NA	13.5 (4.4)	14.3 (2.6)	NA	6.6 (2.0)	NA
Buffer Condition: Vegetation	58.6 (4.8)	NA	29.6 (4.9)	6.8 (1.8)	NA	5.0 (1.6)	NA
Turbidity and Pollutants	52.1 (5.1)	NA	8.1 (2.2)	0.7 (0.6)	NA	2.4 (1.5)	36.7 (5.0)
Woody Debris	51.6 (5.9)	NA	NA	1.0 (0.9)	NA	0.0 (0.0)	47.4 (5.9)
Relative Native Cover	47.0 (5.9)	NA	NA	25.5 (4.9)	16.8 (2.7)	10.8 (4.1)	NA
Algae Growth	47.7 (5.9)	NA	20.5 (4.4)	2.1 (1.4)	NA	0.0 (0.0)	29.7 (4.9)
Woody Species Regeneration	43.3 (6.2)	NA	2.0 (1.3)	0.7 (0.6)	NA	0.7 (0.6)	53.4 (6.2)
Percent Intact Landscape	42.7 (5.6)	NA	33.4 (4.7)	20.9 (4.7)	NA	3.0 (1.2)	NA
Buffer Condition: Soil	36.4 (4.7)	NA	49.7 (4.8)	11.5 (2.5)	NA	2.4 (1.2)	NA
Soil Disturbance	34.6 (4.5)	NA	51.9 (4.7)	9.8 (2.4)	NA	3.7 (1.6)	NA
Water Quality	27.6 (4.7)	NA	47.4 (4.8)	15.7 (2.8)	NA	9.3 (2.3)	NA
Horizontal Interspersion	9.2 (3.8)	NA	27.4 (6.2)	21.8 (4.9)	NA	41.6 (6.3)	NA

Wetland Function

Across the study area, about two-thirds of wetland area was estimated to provide low Hydrologic function (Table 28). Low Hydrologic function was driven by two components, low site potential, which means that wetlands lacked characteristics that would make them effective for erosion and flood control, and low societal value because we did not identify flooding problems anywhere downstream from most wetlands. Hydrologic site potential was more frequently rated high than the other function components. Wetlands classified as the riverine HGM class, beaver-influenced HGM subclass, or shrubland overstory were more often rated medium or high for Hydrologic function than other wetland classes (Table 29). These three characteristics are interrelated; 78% of beaver-influenced and 62% of shrubland sites were also riverine. All 19 riverine sites were rated as medium or high for the Hydrologic function whereas shrubland sites classified as slope wetlands (n = 4) were always rated as low and one of the two beaver-influenced depressional sites was rated low as well.

Just over one-half of the wetland area in the study area was estimated to provide medium Water Quality function (Table 28) and most of the remaining wetland area provided low function. More than one-half of all wetland area was estimated to be medium for Water Quality landscape context, meaning that wetlands received a moderate amount of pollutants and contaminants from the surrounding landscape, and medium for Water Quality site potential, meaning that wetlands had some characteristics that promote water quality improvement. Ratings for societal value for the Water Quality function were more evenly spread across the rating options. Wetlands in the Valleys and Foothills provided higher Water Quality function compared to wetlands in other strata (Table 29). Irrigated wetlands provided higher Water Quality function than headwater wetlands and both irrigated and beaver wetlands provided higher function than those with no HGM subclass.

Across the study area, 28%, 60%, and 13% of the wetland area was estimated to provide low, medium, and high Habitat function, respectively (Table 28). Almost all wetland area was estimated to be high for Habitat landscape context, meaning that most wetlands were surrounded by minimally disturbed accessible habitat. Most wetland area was medium for societal benefit, which we defined as being surrounded by at least one key habitat found in the Utah Wildlife Action Plan (Utah Wildlife Action Plan Joint Team, 2015). However, about one-half of all wetland area was estimated to be low for Habitat site potential, meaning that these sites had few characteristics that make them of particular use to wildlife. Wetlands in the Valleys and Foothills provided lower Habitat function than wetlands in other strata (Table 29). Riverine wetlands provided higher Habitat function than depressional wetlands and all 9 beaver-influenced wetlands and all 13 shrubland wetlands were rated as medium or high for the Habitat function.

Wetland Vegetation

We recorded 355 unique plant species, including 293 native species, 61 introduced species, and 1 species with uncertain nativity status. Some native species that were common in all

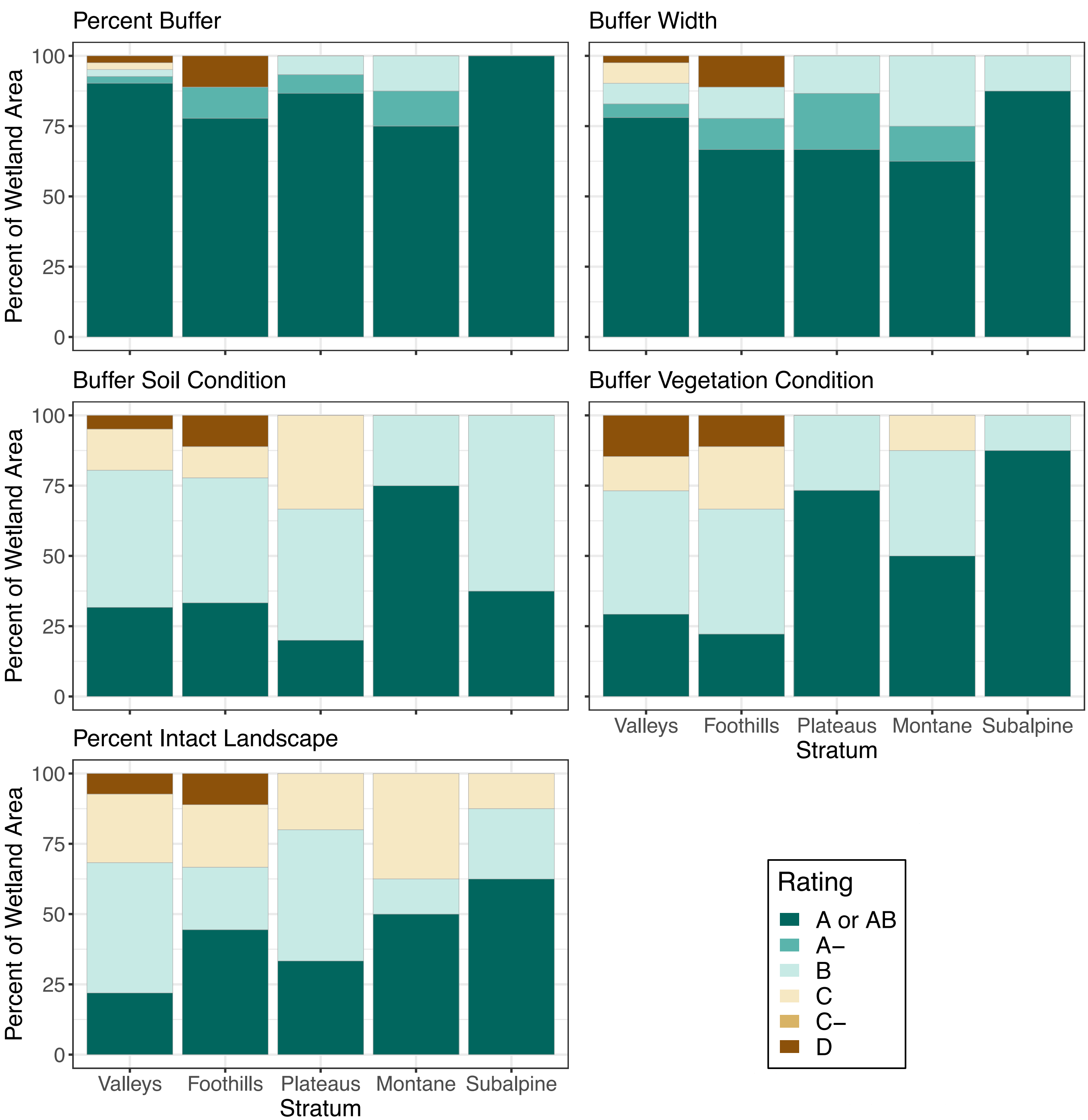

Figure 10. *Landscape condition metric ratings by stratum. Plots show the percent of wetland area that received impact ratings of "A or AB" through "D." Most metrics had four rating options—A, B, C, or D—but some had additional options such as A- or C- or a combined A and B category (AB). See Table 27 for ratings available for each metric.*

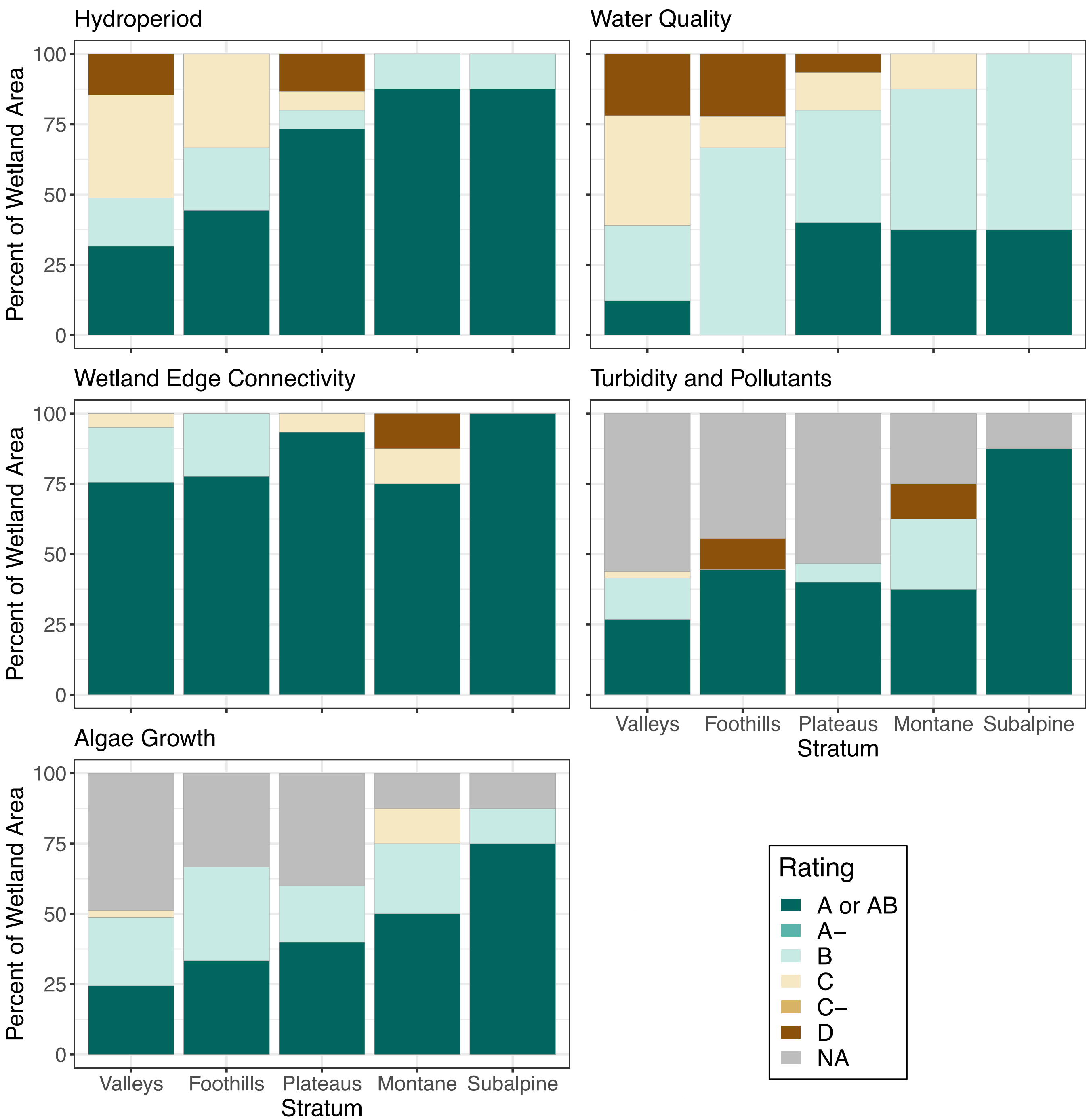

Figure 11. *Hydrology condition metric ratings by stratum. Plots show the percent of wetland area that received impact ratings of "A or AB" through "D." Most metrics had four rating options—A, B, C, or D—but some had additional options such as A- or C- or a combined A and B category (AB). See Table 27 for ratings available for each metric. Sites with "NA" rating had no surface water at the time of site visit and were therefore not evaluated for the algae growth or turbidity and pollutants metrics.*

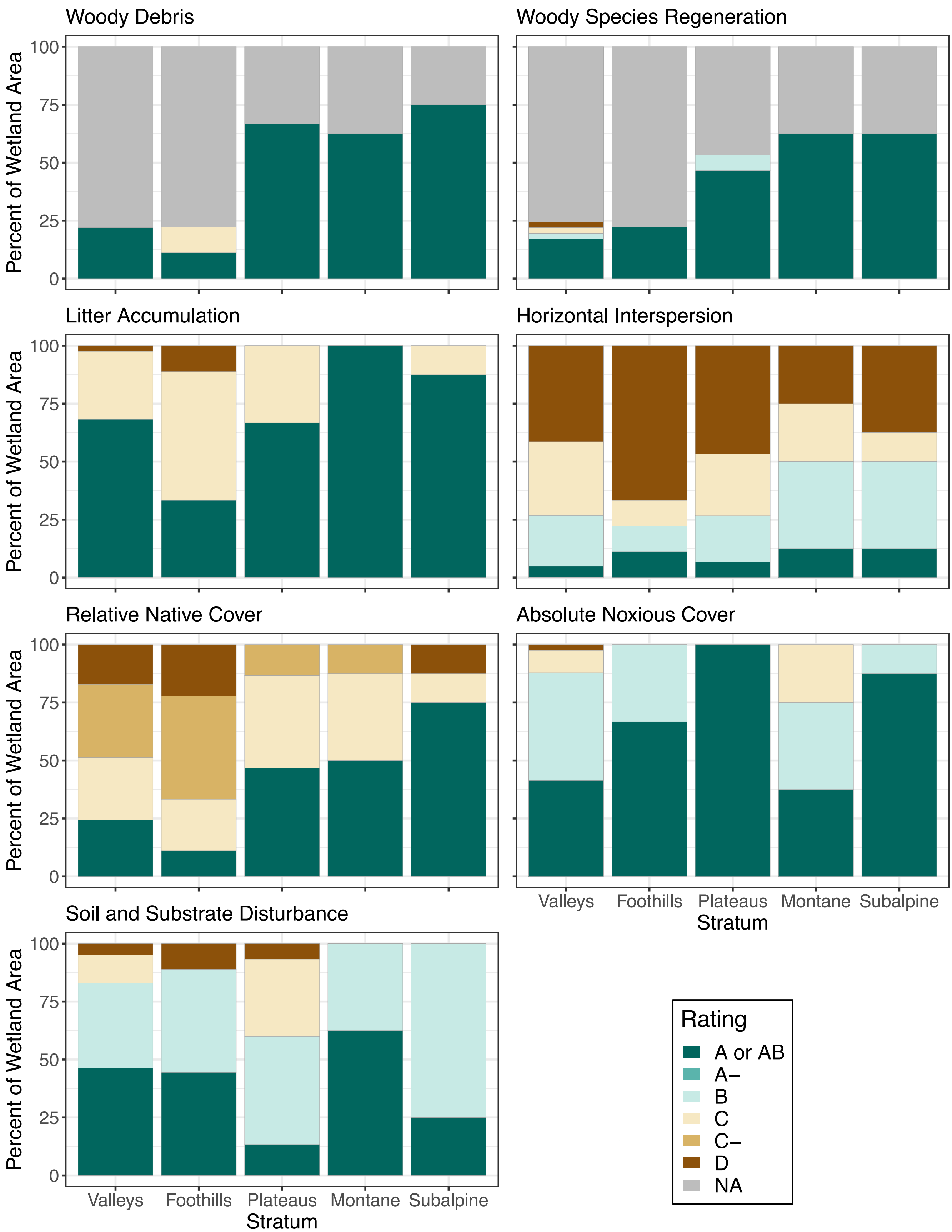

Figure 12. *Vegetation and soil condition metric ratings by stratum. Plots show the percent of wetland area that received impact ratings of "A or AB" through "D." Most metrics had four rating options—A, B, C, or D—but some had additional options such as A- or C- or a combined A and B category (AB). See Table 27 for ratings available for each metric. Sites with "NA" rating had no or minimal woody species at the time of site visit and were therefore not evaluated for woody-related metrics.*

Table 28. *Wetland function estimates for the study area. Estimates include the percent of wetland area rated as low, moderate, or high for each function component and for the function overall, along with the standard error in parentheses.*

Function	% Low	% Medium	% High
Hydrologic	64.7 (6.5)	33.6 (6.5)	1.7 (1.1)
Hydrologic Landscape Context	13.5 (4.8)	85.8 (4.8)	0.7 (0.6)
Hydrologic Site Potential	40.1 (5.8)	32.4 (6.1)	27.5 (6.2)
Hydrologic Societal Value	76.3 (5.0)	19.6 (4.9)	4.0 (1.7)
Water Quality (WQ)	38.7 (6.4)	56.3 (6.4)	5.0 (1.5)
WQ Landscape Context	7.4 (3.6)	88.9 (3.9)	3.7 (1.5)
WQ Site Potential	21.5 (4.6)	60.6 (6.1)	17.9 (4.3)
WQ Societal Value	38.7 (5.9)	33.3 (5.9)	28.0 (3.0)
Habitat	27.5 (4.7)	59.5 (6.0)	13.1 (4.1)
Habitat Landscape Context	0	13.8 (4.3)	86.2 (4.3)
Habitat Site Potential	51.3 (5.8)	37.6 (6.4)	11.0 (4.0)
Habitat Societal Value	19.9 (2.3)	70.5 (4.3)	9.5 (3.8)

Table 29. *Estimated amount of wetland area rated as medium or high for each function, by wetland attribute. The HGM Lacustrine fringe class, represented by only one site, is excluded from the table.*

Attribute and Value (Number of Sites)	Hydrologic		Water Quality		Habitat	
	Estimated Area (%)	95% CI	Estimated Area (%)	95% CI	Estimated Area (%)	95% CI
Ecoregional Strata						
Plateaus, Montane, Subalpine (31)	36.5	17.7-55.3	51.2	32.6-69.8	85.2	72.6-97.8
Valleys, Foothills (50)	33.1	22.0-44.2	78.8	69.8-87.8	50.5	39.5-61.5
HGM Class						
Depressional (25)	18.9	0.0-41.3	73.6	59.0-88.3	51.0	31.6-70.3
Riverine (19)	100.0	100.0-100.0	45.4	26.4-64.3	93.0	84.7-100.0
Slope (36)	12.9	0.0-27.1	62.2	43.1-81.2	73.2	57.0-89.5
HGM Subclass						
Beaver (9)	88.2	66.8-100.0	89.0	73.0-100.0	100.0	100.0-100.0
Headwater (18)	18.0	0.0-40.6	56.9	30.8-83.0	76.3	53.2-99.5
Irrigation (22)	9.0	0.0-18.6	92.9	83.6-100.0	45.0	22.0-68.0
No subclass (32)	44.7	26.2-63.3	41.0	26.6-55.5	74.4	61.9-86.9
Dominant Overstory						
Emergent (68)	23.8	11.9-35.8	59.9	46.2-73.6	65.2	53.7-76.8
Shrubland (13)	78.3	62.7-93.9	66.3	35.9-96.7	100.0	100.0-100.0

strata include Booth's willow (*Salix boothii*), three different sedge species (Nebraska sedge [*Carex nebrascensis*], Northwest Territory sedge [*Carex utriculata*], and water sedge [*Carex aquatilis*]), tufted hairgrass (*Deschampsia cespitosa*), and arctic reed (*Juncus arcticus*). The introduced species common dandelion (*Taraxacum officinale*) was found at 61 sites and was the most common species recorded, but usually had low cover. Common introduced species that were often abundant at sites included the grasses meadow foxtail (*Alopecurus pratensis*), reed canarygrass, timothy (*Phleum pratense*), Kentucky bluegrass, and fescue (*Schedonorus* spp.). Species of introduced clover, particularly white clover (*Trifolium repens*), were also abundant at some sites.

Noxious weeds were found at more than one-half of the Valleys and Montane sites (58.5% and 62.5%, respectively), one-third (33.3%) of the Foothills sites, 12.5% of the Subalpine sites and none of the Plateaus sites (Figure 13). However, noxious weeds rarely dominated sites; only six sites had 5% or more cover by noxious weed species. Canada thistle (*Cirsium arvense*) was the most common noxious weed and was found in all strata except for Plateaus (Table 30). Three of the eight recorded noxious weeds—Canada thistle, Russian olive (*Elaeagnus angustifolia*), and broadleaved pepperweed (*Lepidium latifolium*)—are rated as facultative plants (meaning they are equally likely to be found in wetlands or uplands) and were recorded with 2% or more cover at one or more sites (Table 31). The remaining five noxious species are more associated with upland habitats or are not rated with a wetland indicator status and never exceeded 1% cover at any site.

Relative native cover ranged from 15.5% to 100% across our surveyed sites. Relative cover of native species differed significantly between strata based on a Kruskal-Wallis rank sum test (Tables 26 and 30; Figure 13). Valleys and Foothills wetlands had lower relative cover of native species compared to Plateaus and Subalpine wetlands based on post hoc pairwise comparisons ($p < 0.02$ for all comparisons; Z = -3.14 for Foothills-Subalpine, Z= -2.91 for Foothills-Plateaus, Z = 2.75 for Subalpine-Valleys, and Z = 2.53 for Plateaus-Valleys). Foothills also had lower relative cover of native species compared to Montane, whereas Montane wetlands did not differ from other strata ($p = 0.03$, Z = 2.19). Mean C ranged from 0.85 to 6.0 across sites. Mean C also differed significantly between strata (Tables 26 and 30; Figure 13). All pairwise comparisons were significant ($p < 0.045$) based on Tukey's HSD test for multiple comparisons except for Valleys versus Foothills and Montane versus Plateaus. Mean C was highest in the Subalpine and lowest in the Valleys and Foothills wetlands.

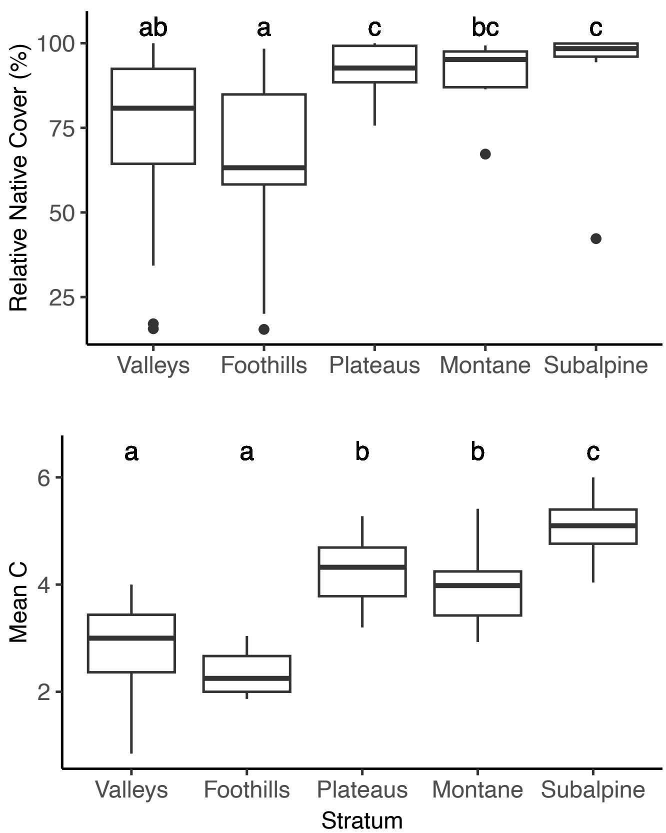

Figure 13. *Relative native plant cover and mean C for each strata. The whiskers of each boxplot show the 25th and 75th percentile for each stratum and the dots above and below are outliers. The horizontal line inside marks the median score. Boxplots with no shared letter above them are statistically significantly different. For example, for Relative Native Cover, Subalpine has a significantly higher percentage of Relative Native Cover than Valleys and Foothills.*

Discussion

Ecoregional Differences

Wetland stress and condition varied by strata. Lower elevation Valleys and Foothills wetlands had more stressors, poorer condition, and more introduced and disturbance-tolerant plant species than Montane and Subalpine wetlands. Plateaus wetlands had healthier plant communities and fewer hydrology stressors than lower elevation wetlands, but otherwise did not differ significantly from any strata. Plateaus had relatively intact native plant communities and no noxious weeds but also had the highest percent of sites with grazing-related stressors (i.e., soil disturbance by animals, hummocking, and excessive grazing) both within and surrounding sites.

Our results agree with previous studies that also found higher rates of disturbance in lower elevation montane wetlands (Menuz et al., 2016b; Menuz and Sempler, 2018). Drivers for poor conditions likely differ between the Valleys and Foothills. Valleys contain the population centers for the region and much of the land is irrigated cropland or pasture (Omernik, 1987; Utah Division of Water Resources, 2021a). Wetlands in this subregion are most impacted by altered hydrology from artificial irrigation, groundwater extraction, and surface water diversion. Foothills are impacted by many of the same stressors, but had high levels of grazing stressors and particularly low native species cover, which was also found in Foothills wetlands in the Weber and Jordan watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). The Foothills strata has the lowest density of wetlands and receives less precipitation on average than other strata (Omernik, 1987). These factors may concentrate wildlife and livestock in these wetlands, creating opportunities for non-native establishment due to increased seed dispersal and soil disturbance.

Table 30. *Vegetation metric estimates for the study area and strata, with standard error in parentheses.*

Plant Metric	Study Area	Valley	Foothill	Plateaus	Montane	Subalpine
Canada thistle cover (%)	0.6 (0.2)	1.2 (0.5)	0.1 (0.0)	0.0 (0.0)	1.9 (0.8)	0.1 (0.1)
Noxious cover (%)	0.8 (0.2)	1.5 (0.5)	0.2 (0.1)	0.0 (0.0)	2.5 (1.0)	0.1 (0.1)
Mean C	3.9 (0.1)	2.9 (0.1)	2.4 (0.1)	4.2 (0.1)	4.0 (0.2)	5.1 (0.2)
Relative native cover (%)	84.5 (2.3)	75.7 (2.9)	62.6 (6.9)	92.1 (1.7)	90.8 (3.2)	91.2 (6.3)

Table 31. *Estimated percent of wetland area impacted by each noxious weed species and standard error. These estimates indicate how widespread the species are rather than how much cover they occupy.*

Common Name (Scientific Name)	Noxious Class	Wetland Indicator Value	Max. Recorded Cover (%)	Study Area	Valleys	Foothills	Plateaus	Montane	Subalpine
Canada thistle (*Cirsium arvense*)	Class 3	FAC	25	22.5 (4.2)	34.1 (5.2)	22.2 (9.9)	0.0 (0.0)	62.5 (15.3)	12.5 (10.5)
Nodding plumeless thistle (*Carduus nutans*)	Class 3	UPL	0.1	10.9 (2.3)	24.4 (5.7)	0.0 (0.0)	0.0 (0.0)	37.5 (15.6)	0.0 (0.0)
Gypsyflower (*Cynoglossum officinale*)	Class 3	FACU	0.5	6.6 (2.2)	4.9 (2.9)	11.1 (9.3)	0.0 (0.0)	37.5 (15.9)	0.0 (0.0)
Field bindweed (*Convolvulus arvensis*)	Class 3	Not rated	1	3.3 (1.2)	12.2 (4.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Russian olive (*Elaeagnus angustifolia*)	Class 4	FAC	2	2.1 (1.3)	2.4 (2.1)	0.0 (0.0)	0.0 (0.0)	12.5 (10.2)	0.0 (0.0)
Whitetop (*Cardaria draba*)	Class 3	Not rated	0.1	2.0 (0.9)	7.3 (3.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Dyer's woad (*Isatis tinctoria*)	Class 2	Not rated	0.5	0.7 (0.5)	2.4 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Broadleaved pepperweed (*Lepidium latifolium*)	Class 3	FAC	2	0.7 (0.5)	2.4 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Horizontal Interspersion

The horizontal interspersion metric was noteworthy for how frequently it was rated D and for being the only metric with a D rating in every strata. We also rated an interspersion metric as part of the functional assessment and found similar results. The interspersion metric evaluates the number of distinct vegetation patches at a site and the degree to which they are intermixed, with higher numbers and intermixing receiving better ratings. Sites rated D for this metric are characterized by one dominant vegetation patch with little to no other zones. Interspersion can be important for wildlife habitat (Rehm and Baldassarre, 2007; Hruby, 2014; Melvin et al., 2024), but, despite being commonly found in wetland condition protocols (Mack, 2001; Stein et al., 2009; Lemly and Gilligan, 2013), its connection to wetland health is less clear. Stein et al. (2009) found a positive correlation between interspersion and benthic macroinvertebrate health in riverine wetlands in California. However, Vance et al. (2012) found that over 50% of minimally disturbed wet meadow and shrubland wetlands in the Rocky Mountains had low or no horizontal interspersion. Colorado Natural Heritage Program included an interspersion metric in older versions of their condition assessment (Lemly and Gillian, 2013), but now evaluates interspersion as part of a vegetation structure metric, explicitly stating that some systems, including meadows, may naturally have little structural complexity (Lemly et al., 2016). We recommend further research to determine if a relationship exists between wetland condition and horizontal interspersion in any wetland systems in Utah and, if not, removing the metric from the condition assessment but keeping it in the functional assessment.

Non-Native Species

Non-native and invasive plant species, the most widespread stressor recorded, impact an estimated 80% of wetland area in the study area. An estimated 15% of wetland plant cover in montane wetlands is non-native, less than estimates for montane wetlands in the Weber and Jordan watersheds (29% and 25%, respectively; Menuz et al., 2016b; Menuz and Sempler, 2018). Wetlands are more vulnerable to invasion by non-native species than upland areas, due partly from increased seed dispersal opportunities via water and wildlife transport and frequent natural and manmade disturbances (e.g., flooding, grazing) that open up bare ground and allow new species to establish (Zelder and Kercher, 2004). Interestingly, Plateaus wetlands had relatively intact vegetation despite high levels of soil disturbance. Additional research could look at whether land management decisions, human visitation rates, or other factors lead to reduced plant invasion in this strata. Non-native species can provide benefits, such as erosion control and livestock forage, and species such as Kentucky bluegrass, timothy, and white clover may be planted intentionally, displacing native species (California Invasive Plant Council, undated; Jensen et al., undated). However, non-native plants also have a broad range of documented negative effects, including decreasing native plant and invertebrates species diversity (Gerber et al., 2008), altering nutrient availability (Ehrenfeld, 2003), changing disturbance regimes (Mack and D'Antonio, 1998), and increasing water use (Gebauer et al., 2016).

Despite widespread non-native plants, noxious weed species were uncommon. Noxious weeds were estimated to be less widespread with lower cover in this study area than in montane wetlands in the Weber and Jordan watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). Similar to those watersheds, Canada thistle was the most widespread and abundant noxious weed species in this study. Canada thistle forms dense colonies through clonal spread, outcompeting native species, reducing wildlife diversity, and limiting recreation and livestock use (Zouhar, 2001). Noxious weeds may be uncommon in our study area for several reasons. First, much of the study area is managed by the U.S. Forest Service, which has well-developed management guidance for limiting noxious weed spread during activities such as livestock grazing and road work (U.S. Forest Service, 2003). Second, both public and private landowners are likely motivated to reduce noxious weed cover due to their management mandates or potential impacts to pasture and other lands. Last, many of the common noxious weeds in the montane region are upland or facultative upland species that are less likely to invade wetlands.

Though not a noxious weed, reed canarygrass is another species of concern in montane areas. The species is particularly common in the Foothills and Valleys (Menuz et al., 2016b; Menuz and Sempler, 2018) and has known negative impacts on wetland systems, including altering plant and invertebrate communities and changing sedimentation processes (Lavergne and Molofsky, 2004). The species has impacted cottonwood regeneration and amphibian habitat along the Provo River (P. Trater, Utah Reclamation Mitigation Conservation Commission, written communication, January 8, 2024). Gebauer et al. (2016) also suggested that reed canarygrass can decrease water availability along streams due to increased transpiration rates and a longer growing season.

Livestock Grazing

After non-native species, the most widespread stressors found at sites were related to livestock grazing. Wetland condition metrics were likely impacted by grazing as well; metrics related to soil disturbance and water quality had the lowest amount of estimated area rated as A after horizontal interspersion. Overall, livestock soil disturbance impacts were relatively light; most impacts were rated as low, hummocking was uncommon, and little wetland area was rated below B for soil disturbance. In contrast, about 34% of wetland areas had medium or higher impacts to vegetation from grazing. Evidence of grazing impacts were about twice as common in this study than in URAP studies in the montane parts of the Weber and Jordan watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). This difference could be due in part to the fact that less of the National Forest land in those watersheds have grazing allotments than in this project's study area. However, National Forest land also makes up a much smaller portion of those watersheds, and private ownership a larger portion, which means that other land management practices are also likely important for driving these differences.

Overgrazing can have a variety of effects on wetlands. Grazing can cause water quality contamination, hydroperiod changes, and dewatering (Morris and Reich, 2013; Booth et al., 2014; Cox et al., 2016). Grazing can also decrease litter and shrub cover and shift vegetation communities towards plant species that are less palatable and more disturbance-tolerant (Zhou et al., 2006; Morris and Reich, 2013). Some native and non-native species that can increase with grazing, including Kentucky bluegrass, Nebraska sedge, and arctic rush, were common in our study area (Hurd et al., 1992; Uchytil, 1993). However, grazing benefits have been documented as well. Managed grazing can sometimes reduce cover of problematic plant species such as reed canarygrass and can help provide disturbance regimes required by particular rare or significant plant species (Morris and Reich, 2013; Skopec et al., 2018; Duncan et al., 2019; Norland et al., 2022). Grazing effects and whether they are positive or negative are strongly controlled by number and type of livestock, timing and duration of grazing, and the particular context of the wetland system (Morris and Reich, 2013). Future work could look specifically at the relationship between degree of grazing stress and wetland condition measures.

Hydrology

The most commonly recorded hydrology stressor across the study area was agriculture runoff, manure, and excess irrigation water, a single stressor that captures both hydroperiod and water quality impacts from agriculture and grazing activities. Irrigation-dominated wetlands and hydroperiod impacts such as diversions, groundwater extraction, reservoirs, and flow channelization were common in the Valleys and Foothills and less common elsewhere. As studies in other areas of the western United States show (Peck and Lovvorn, 2001; Sueltenfuss et al., 2013; Berkowitz and Evans, 2014), irrigation water may play an important role in creating novel wetlands or supporting wetlands in regions like Sanpete Valley where groundwater withdrawal and diversion have impacted hydrology (Robinson, 1971; Smith et al., 2019). Reducing irrigation in these systems would likely eliminate some of these wetlands rather than allow them to return to a natural hydropattern unless the original water sources were also returned.

Our estimate of hydroperiod condition may underestimate true hydrologic threats for two reasons. First, in the most extreme cases, sites may no longer be wetland and thus were excluded from our surveys. Second, surveyors sometimes had a difficult time distinguishing between conditions caused by drought during the survey year versus longer-term hydrologic impacts. Remote sensing techniques and groundwater trend analysis could be good tools for evaluating change in hydrology over time (McCoy-Sulentic et al., 2021; Donnelly et al., 2022).

Most sites in all strata had water quality ratings of B or poorer, with the lowest ratings in the Valleys. Common water quality stressors included grazing, impaired water sources, and stormwater runoff from nearby roads. Water quality stress did not necessarily translate into obvious issues with algae or turbidity during site visits, though many sites could not be evaluated for those metrics due to lack of water at the time of site visit. Both water quality and hydroperiod are difficult to estimate during a single site visit and rely on assumptions about stressors in the surrounding landscape. Repeat water quality and water depth measurements at wetland sites could enhance our understanding of Hydrologic Condition.

Wetland Function

Although the function protocol used in this study is not fine-tuned for use with the URAP protocol or for montane wetlands, we found several important relationships between function and wetland characteristics. First, wetlands in poorer condition can still provide important functions and should not be regarded as unimportant or not worth conserving (McLaughlin and Cohen, 2013). In our study, Valleys and Foothills wetlands have more opportunity to remove greater volumes of pollutants than more pristine wetlands because they receive greater amounts of runoff and contaminants. Second, beaver-influenced wetlands provide high levels of a diverse set of functions in Utah, as has been documented more broadly (Marshal et al., 2018; Larsen et al., 2021). In fact, Thompson et al. (2021) estimated that the ecosystem services that beavers provide across the Northern Hemisphere, such as moderating extreme flood events and purifying water, are worth millions to hundreds of millions of dollars annually, depending on the service. Third, riverine and shrubland wetlands, which often co-occur, also provide high levels of Hydrologic and Habitat function. Riverine wetlands, also found to support high levels of Hydrologic function in the Central Basin (McCoy-Sulentic et al., 2021), are located in landscape positions that are more likely to receive floodwaters and are often composed of rigid-stemmed woody species that can help reduce flood velocity (Hruby, 2014). All of the shrublands in our study had permanent surface water and most were composed primarily of willows. This combination of habitat features can support a diversity of species such as beaver, moose, elk, birds, amphibians, and fish (Baker et al., 2005; Baril et al., 2011; Zeigenfuss and Abouelezz, 2018). Use of the function protocol in montane areas could be improved through literature review to better understand how montane wetlands affect downstream processes and to add new functions relevant to montane wetlands, such as carbon sequestration and groundwater recharge.

Study Limitations

Several limitations should be considered when interpreting the results of this study. First, our target population included a mixture of mesic and true wetland sites, meaning that our findings cannot be narrowly applied to only wetlands. Second, we assumed that wetlands not sampled were missing at random. Missing at random is a statistical term that means that missing data are due to an observed variable (in this case, lack of landowner permission), but not related to the data itself (e.g., condition and stressor information). Data would not be missing at random if landowners disproportionately refused access when sites were poorly managed or particularly pristine. However, lack of landowner permission may be due to factors other than wetland conditions, such as difficulty with obtaining a correct address or landowner distrust of state agencies.

The URAP method evaluates plots rather than entire wetlands, which has implications for metrics evaluated on the immediate plot edge. Metrics related to buffer width and expanse and edge connectivity had the best ratings of the condition metrics. Although this indicates that most wetland *area* is in good condition for these metrics, individual *wetlands* may have higher rates of adjacent landscape stress since we often surveyed sites embedded within larger wetland complexes. On the other hand, some metrics may be scored higher if the entire wetland was considered, especially metrics that depend on heterogeneity and complex features, such as horizontal interspersion and habitat function metrics related to structural diversity, plant species richness, and habitat features.

OBJECTIVE 3: MULTI-METRIC INDEX DEVELOPMENT

Background

Our goal for this part of the project was to develop a multimetric index (MMI) for a subset of montane wetlands using data from this study as well as similar studies in the Weber and Jordan watersheds (Menuz et al., 2016b; Menuz and Sempler, 2018). We initially focused on meadow wetlands in the Valleys (Table 1) because this strata contains a high proportion of wetlands and the greatest concentration of stressors (Menuz and other 2016b; Menuz and Sempler, 2018). Land ownership in the Valleys is also predominantly private, meaning that these wetlands are less likely to already be part of state and federal monitoring or management efforts. After conducting initial exploratory analysis, we expanded our focus to include meadow wetlands in both the Valleys and Foothills strata due to their high degree of similarity in vegetation composition and stress levels.

MMIs are quantitative tools frequently used to estimate biological condition of aquatic systems (Magee et al., 2019). An MMI is built by combining several metrics together into one robust indicator that can separate sites with high levels of disturbance from less impacted sites. The MMI can then be used to obtain quantitative estimates of wetland condition for a study area. MMIs can also be used to evaluate the condition of individual sites of interest to, for example, evaluate the success of a restoration project or identify which wetlands should be prioritized for protection.

We divided this objective into two major components. We first used ordination and classification to compare vegetation in Valleys meadow wetlands to those in other strata. We used ordination to visualize similarities and differences in plant community composition across sites and to determine whether meadow wetlands from other strata could be grouped with the Valleys meadows for the MMI development. We then assessed options for grouping Valleys meadows into distinct subtypes based on vegetation, water regime, landscape position, and other factors to make sure that the MMI would be relevant to the full range of Valleys sites. For the second component, we developed and applied the MMI. This involved selecting least and most disturbed sites based on URAP stressor data, screening vegetation metrics for strong discrimination between least and most disturbed sites to develop a final MMI, and using the MMI to estimate the percent of Valleys and Foothills meadow wetlands in good, fair, and poor condition.

Ordination and Classification

Ordination and Classification Methods

NMDS: We used ordination to evaluate whether other montane meadow wetlands could be grouped with Valleys meadows for the MMI development. Ordination is a statistical method that reduces complex multivariate data into a few simpler variables. We used the ordination method non-metric multidimensional scaling (NMDS) to reduce data on species presence and abundance to between two and three variables that capture most of the variation in plant community composition among sites. Sites that are closer together when the variables are plotted are more similar to one another in species composition. NMDS can also be used to identify covariates, such as climate or wetland class, that are correlated with plant community composition.

We first prepared the vegetation data by eliminating unknown species, dropping most records identified only to genus, and combining all subspecies and varieties into a single taxa at the species level. We also dropped species that were found at less than seven sites and sites where over 40% of the vegetation cover was composed of unidentified species or other records that were dropped. We used the R goeveg package (von Lampe and Schellenberg, 2024) to evaluate stress values, a measure of goodness-of-fit for NMDS, for different numbers of axes. Although stress values ≤ 0.20 are considered usable by McCune and Grace (2002), we used a maximum of three dimensions regardless of stress values for ease of visualization. We used the wrapper function “metaMDS” in the R vegan package (Oksanen et al., 2022) for the final NMDS and default values, except for setting the number of dimensions based on the stress values and the maximum number of random starts to 999.

We conducted a series of ordinations. We first included all montane and Central Basin (Menuz and McCoy-Sulentic, 2019; McCoy-Sulentic et al., 2021) meadow wetlands in one ordination because surveyors had observed similarities between Central Basin and montane meadows at some sites. We then conducted ordinations on the subset of ecoregions that had the most vegetative overlap with Valleys sites, including 1) Central Basin fresh meadows and Valleys and Foothills meadows and 2) Valleys and Foothills meadows.

Ordination covariates: We identified plant species and site covariates that were strongly correlated with each ordination axis using the “envfit” function and $p < 0.01$ as the threshold for significance due to the large number of comparisons. We fit four continuous variables—elevation, precipitation, salinity tolerance index, and prevalence index—to the two ordinations that included Central Basins sites (Table 32). Precipitation was obtained from 30-year climate normals (PRISM Climate Group, undated) and elevation from a 10-m digital elevation model from the Utah Geographic Reference Center. The two indices were calculated from site vegetation data. We calculated the prevalence index, which is a cover-weighted index based on the wetland indicator status ratings that describe an overall community's wetland affiliation (U.S. Army Corps of Engineers, 2010). Wetland indicator status describes a species affinity for wetlands and includes, in order of association with uplands to wetlands, upland (UPL), facultative upland (FACU), facultative (FAC), facultative wetland (FACW), and obligate (OBL). Prevalence ratings range from one to five with lower values indicating higher vegetation affinity for wetlands. We also calculated a salinity tolerance index. Salinity tolerances were taken from a combination of the PLANTS database (Natural Resources Conservation Service, 2024) and Palmquist et al. (2017). We converted salinity scores of none, low, medium, and high to values of 0, 1, 2, and 3 and then calculated a cover-weighted salinity index. Salinity tolerance ranged from 0 to 3 with higher values indicating more tolerance to saline conditions.

We evaluated an additional 11 continuous and 8 categorical variables in the final ordination of Valleys and Foothills meadow wetlands (Tables 32 and 33). The remaining continuous variables were all derived from site vegetation data. We calculated the relative cover of sedges, grasses, forbs, and native species, species richness (total number of species), and the relative cover of plants by wetland indicator status. We also calculated the mean coefficient of conservatism (C-value), a measure of species disturbance-tolerance described in detail in objective 2. We included two categorical variables describing sites’ location on the landscape, level IV ecoregion and watershed (Table 33). We included hydrogeomorphic (HGM) class and subclass, water regime, and water source, assigned to sites as described in objective 2. We also included covariates based on presence or absence of hydric soils and on plant wetland indicator status rating (modified from Natural Resources Conservation Service, 2024).

Classification and characterization: We used the NMDS plots of the Valleys and Foothills meadow wetlands ordination

Table 32. *Continuous variable association with axes for NMDS ordination of Valleys and Foothills meadow wetlands. Axis columns indicate the x and y coordinates on bivariate plots for each variable.*

Variable	Axes 1 and 2				Axes 1 and 3				Axes 2 and 3			
	Axis 1	Axis 2	R^2	p-value	Axis 1	Axis 3	R^2	p-value	Axis 2	Axis 3	R^2	p-value
Elevation	0.81	0.59	0.21	0.001	0.82	0.57	0.20	<0.001	0.73	0.68	0.11	0.024
Mean C	0.32	-0.95	0.02	0.438	0.67	-0.74	0.01	0.818	-0.94	-0.35	0.02	0.460
Precipitation	0.79	0.62	0.48	<0.001	0.91	0.41	0.38	<0.001	0.87	0.50	0.19	0.001
Prevalence index	-0.41	0.91	0.03	0.314	-0.13	0.99	0.28	<0.001	0.28	0.96	0.30	<0.001
Species richness	0.99	-0.13	0.42	<0.001	0.90	0.43	0.48	<0.001	-0.26	0.97	0.07	0.093
Relative Cyperaceae cover	1	0.02	0.02	0.461	0.24	-0.97	0.25	<0.001	0.01	-1	0.23	<0.001
Relative FAC cover	0.71	0.7	0.03	0.324	0.89	0.46	0.02	0.456	0.89	0.46	0.02	0.571
Relative FACU cover	-0.04	1	0.02	0.520	-0.02	1	0.12	0.013	0.37	0.93	0.14	0.006
Relative FACW cover	-0.93	-0.36	0.23	<0.001	-0.81	0.58	0.28	<0.001	-0.47	0.88	0.09	0.034
Relative forb cover	1	0.01	0.10	0.025	0.8	0.59	0.14	0.006	0.02	1	0.04	0.280
Relative grass (Poaceae) cover	-0.92	-0.39	0.04	0.288	-0.64	0.76	0.06	0.113	-0.34	0.94	0.03	0.322
Relative native cover	-0.75	-0.66	0.09	0.039	-0.81	-0.58	0.08	0.062	-0.78	-0.63	0.05	0.172
Relative OBL cover	0.99	-0.11	0.13	0.007	0.45	-0.89	0.46	<0.001	-0.06	-1	0.33	<0.001
Relative woody cover	0.99	0.14	0.12	0.014	0.61	0.79	0.24	<0.001	0.11	0.99	0.13	0.009
Salinity tolerance index	-0.91	-0.42	0.19	0.001	-0.99	-0.17	0.17	0.002	-0.94	-0.35	0.03	0.385

Table 33. *Categorical variable association with axes for NMDS ordination of Valleys and Foothills meadow wetlands.*

Variable	Values	Axis 1 and 2		Axis 1 and 3		Axis 2 and 3	
		R^2	p-value	R^2	p-value	R^2	p-value
Ecoregion	Valleys, Foothills	0.13	<0.001	0.07	0.006	0.08	0.003
HGM	Depressional, Riverine, Slope	0.07	0.055	0.07	0.033	0.10	0.006
HGM Subclass	Beaver, Headwater, Impoundment, Irrigation, None	0.25	<0.001	0.23	<0.001	0.15	0.003
Hydric Soils	Not Present, Present, Problematic Indicator	0.09	0.007	0.09	0.009	0.02	0.592
Hydrophytic Vegetation[1]	FAC, FACW, FACW+, OBL	0.04	0.410	0.12	0.009	0.14	0.001
Meadow Subtype	Arid, Stream, Mixed	0.34	<0.001	0.41	<0.001	0.16	<0.001
Water Regime[2]	Temporarily Flooded (A), Seasonally Saturated (B), Seasonally Flooded (C), Continuously Saturated (D), Seasonally Flooded-Saturated (E), Semipermanently Flooded (F)	0.19	0.001	0.17	0.004	0.10	0.126
Water Source	Alluvial Aquifer, Groundwater, Irrigation, Overbank Flooding, Precip. Acc., Stream-flow Acc.	0.20	0.001	0.31	<0.001	0.22	<0.001
Watershed	Colorado, GSL, Sevier	0.30	<0.001	0.30	<0.001	0.03	0.316

[1]Hydrophytic vegetation options are derived from the prevalence index. We used thresholds of <1.5, <2, <2.5, and <4 to classify sites as OBL, FACW+, FACW, and FAC, respectively. Thresholds were selected based on the distribution of values across sites.

[2]Water regimes based on usage in the National Wetlands Inventory data (Dahl et al., 2020).

to evaluate whether there were distinct subtypes that differed based on vegetation communities and covariate data. We wanted to evaluate how similar meadow wetlands were to one another and the extent to which environmental factors such as soil salinity and hydrology influence site groupings. We also wanted to ensure that we selected least disturbed sites that represented a broad range of wetlands when we developed the MMI. Our goal was to identify the most important factor(s) driving site differentiation without creating a large number of subtypes with few sites in each group.

Since the final NMDS for this group of sites included three dimensions, we visualized the ordination using both a 3D plot and three bivariate plots of all possible axes combinations. We added vectors to bivariate plots that showed the direction and strength of relationships for continuous variables that were significantly correlated with the axes. We color-coded sites using different combinations of categorical variables (e.g., by HGM class or by combination of water regime and watershed) and used the plotly package in R (Sievert, 2020) to create interactive plots that made it easier to review outliers and explore multiple categorical covariates at the same time.

Once we developed subtypes, we used the results of the NMDS and boxplots to visualize differences in plant metrics between subtypes. We also described the HGM classes, HGM subclasses, water regimes, and water sources associated with each subtype and determined whether subtypes had characteristic plant species.

Ordination and Classification Results

Ordination: The NMDS for all meadow wetlands was run on a matrix of 205 sites by 186 species. The stress for the two-dimensional NMDS was 0.198. All four covariates considered (elevation, precipitation, salinity tolerance index, and prevalence index) were significant ($p < 0.01$). Sites were generally clustered near other sites within the same ecoregional group (Figure 14). These groups were generally distinguished based on elevation and salinity, with higher salinity associated with lower elevations. However, some sites were outliers within their ecoregion, such as one Valleys site that plots in the middle on the Central Basin saline meadows (Basin Saline) and one Montane site that plots closer to the Foothills and Valleys.

Valleys sites overlapped substantially with sites in two other ecoregions (Figure 14). Some Valleys sites overlapped with some of the Central Basin fresh meadow (Basin Fresh) sites in the bottom-left quadrant of the plot, in a region of the NMDS associated with less precipitation, higher vegetation salinity, and lower prevalence index (indicating more wetland-associated vegetation). Valleys sites that fell into this region were primarily from the San Pitch watershed, but some were from the Fremont, Middle Sevier, and Provo watersheds as well. Almost all of the remaining Valleys sites overlapped substantially with Foothills meadow wetlands, occupying a space near the middle of the x-axis and spanning the length of the y-axis.

We next performed an ordination of Valleys sites with the two overlapping ecoregions, Foothills and Basin Fresh, which included 107 sites and 106 species. The three-axes ordination had a stress value of 0.213. Basin Fresh meadows formed a separate group from all other sites. Valleys sites in the Sevier watershed, particularly those in the San Pitch HUC8, also formed a distinct group. The remaining Valleys sites overlapped substantially with sites in the Foothills. Based on the separation in the NMDS, we moved forward with analysis of only the Foothills and Valleys sites.

The NMDS for Valleys and Foothills meadows was run on a matrix of 72 sites by 79 species. The three-dimensional NMDS for Valleys and Foothills meadows resulted in a stress value of 0.203. All covariates were significant in at least one axes combination except for mean C and relative cover of FAC, grass (Poaceae), and native species (Tables 32 and 33; Figure 15). The variables with the strongest relationships with the ordination included precipitation, relative OBL cover, species richness, prevalence index, watershed, and water source. These variables each had R^2 values of 0.30 or higher in at least one axes combination.

Classification and characterization: We separated meadow wetlands into three subtypes using a combination of water source and climate covariates (Figures 15 and 16; Appendix E). This new classification was significant in all three axes of the NMDS and was strongly correlated with the axes in two of the three axes combinations (Table 33). Each subtype had between 20 and 30 sites.

The stream meadow subtype was composed of wetlands hydrologically connected to streams. This subtype included meadows with direct surface connection to streams via overbank flooding or streamflow accumulation in ponds or impoundments along the channel. The subtype also included sites with subsurface connections to streams via an alluvial aquifer (a shallow unconsolidated aquifer adjacent to streams where groundwater can flow into or out of the stream). Stream meadow sites were associated with higher species richness, higher relative woody cover, and less relative cover from Cyperaceae and OBL species (Figures 15, 17, and 18).

We defined the arid meadow subtype as wetland meadows with annual precipitation less than 350 mm per year. Arid meadows were also at lower elevation than other subtypes, except for a few outlier sites with much higher elevation (Figure 19). This subtype includes sites in the San Pitch watershed and some sites in the East Fork Sevier, Fremont, and Middle Sevier watershed. One site in the Bear Lake watershed was grouped with these sites based on the precipitation

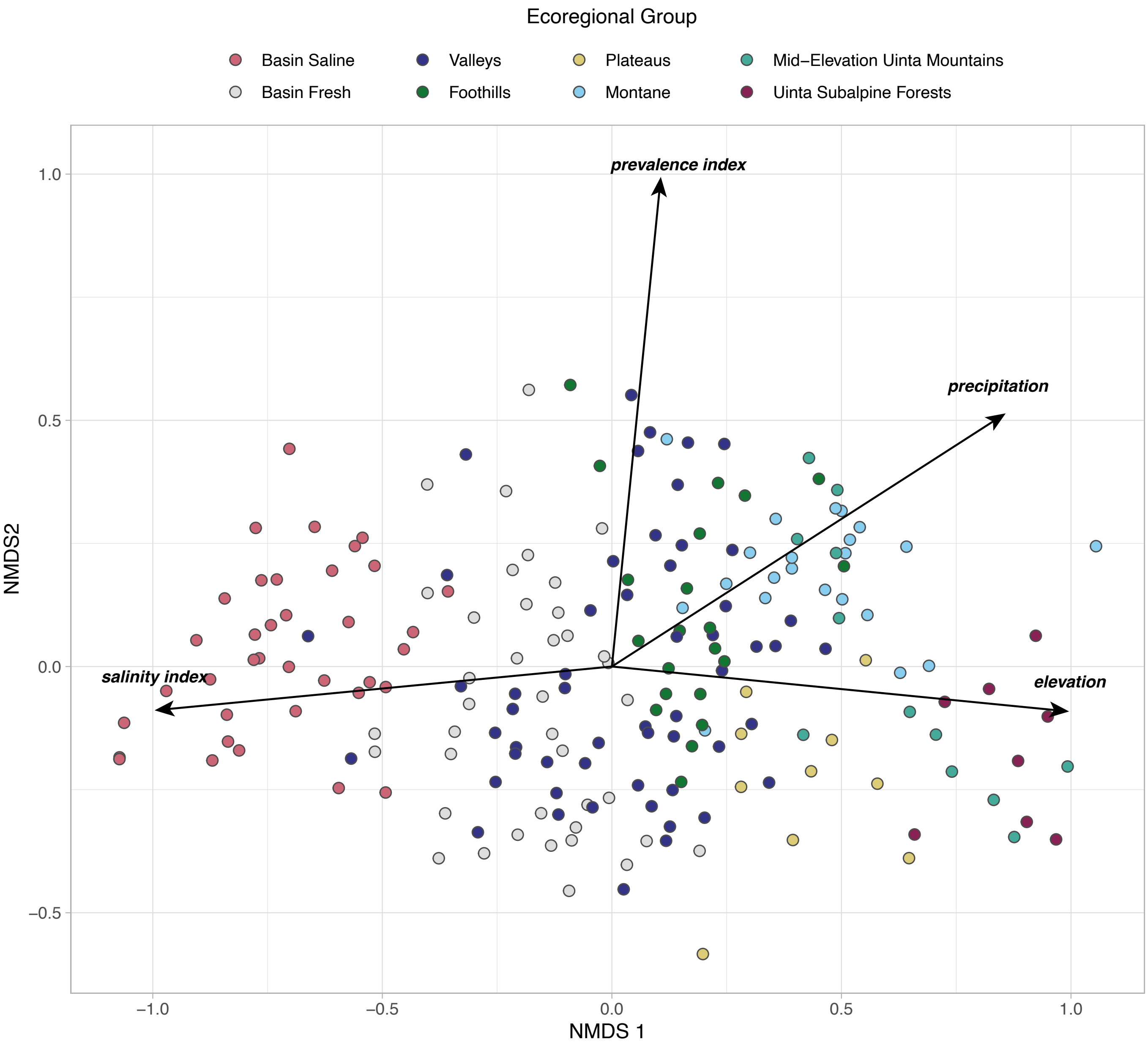

Figure 14. *Non-metric multidimensional scaling (NMDS) ordination plot of montane and Central Basin meadow plant communities. Sites that are closer together are more similar to one another in species composition. Arrows indicate the direction and strength of highly correlated covariates. Ecoregional groups include Central Basin saline and fresh meadows (Basin Saline and Basin Fresh) and a combination of strata and level IV ecoregions from Table 1.*

threshold, but was not as similar vegetatively. Arid meadows were associated with higher salinity, lower elevation, lower species richness, higher relative cover of FACW species, and lower relative forb and OBL cover (Figures 15, 17, and 18). Just over two-thirds of arid meadows had a temporarily flooded water regime and many arid meadows are irrigated.

The remaining sites were grouped into a mixed meadow subtype. These sites had moderate species richness, lower relative FACW cover, and higher relative OBL and Cyperaceae cover (Figures 15, 17, and 18). Both arid and mixed meadows were primarily depressional or slope wetlands with groundwater or irrigation water sources, but slope wetlands and groundwater water sources were more common in the mixed sites. Most mixed sites had water regimes that were wetter than the temporarily flooded water regime and one-third of mixed meadows were headwater wetlands.

Subtypes had many plant species in common, but also had species that were characteristic only of that subtype. Arctic rush (*Juncus arcticus*) and Nebraska sedge (*Carex nebrascensis*) were widespread with high cover across all meadow wetlands (Table 34). Saltgrass (*Distichlis spicata*) and annual saltbush (*Atriplex*) species were characteristic plants in the arid meadows. These two species are highly saline tolerant and are also very common in the Central Basin. The mixed

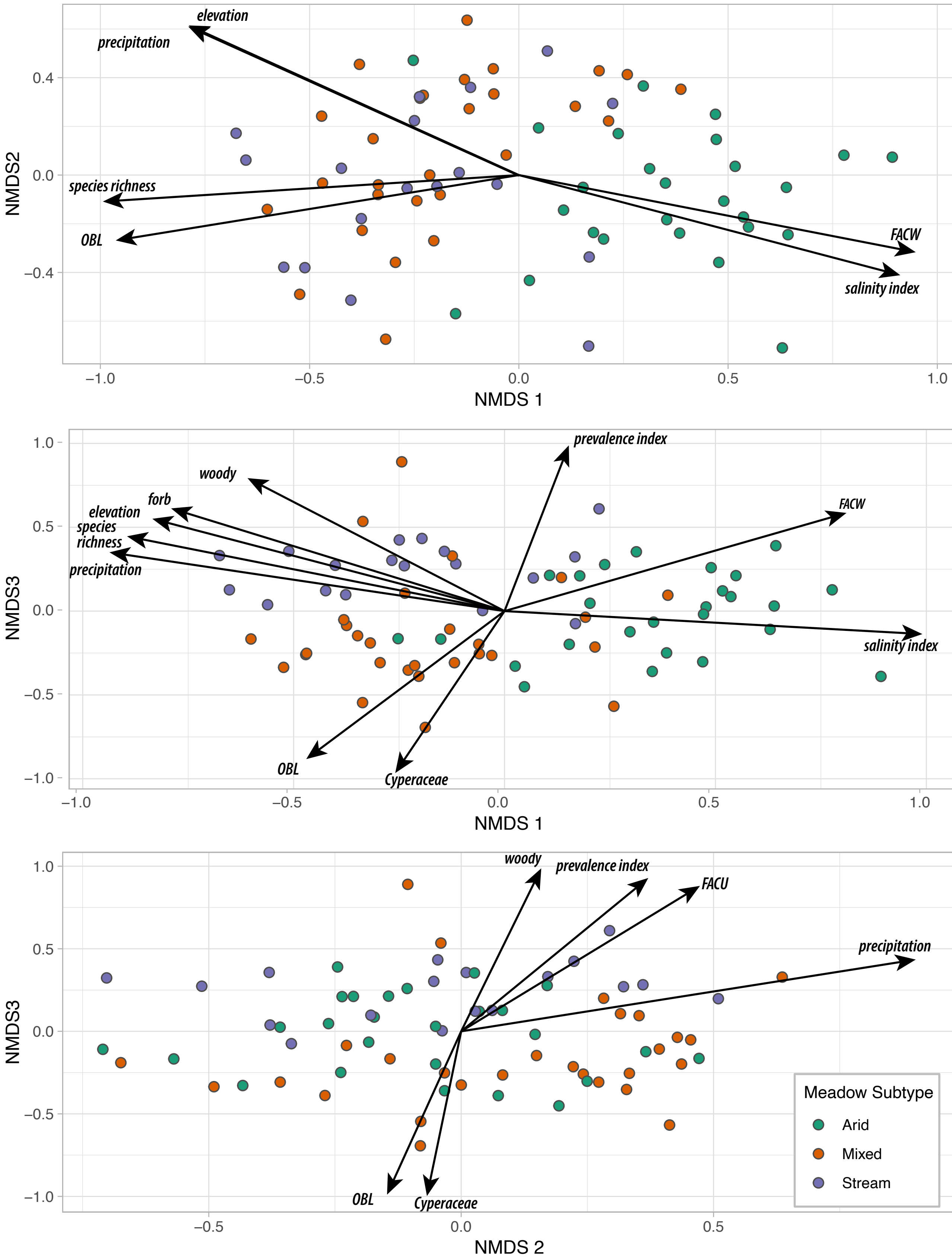

Figure 15. *Non-metric multidimensional scaling (NMDS) ordination plot of Valleys and Foothills meadow sites. Sites that are closer together are more similar to one another in species composition. Bivariate plots show each combination of axes in the 3-dimensional ordination. Arrows indicate the direction and strength of highly correlated covariates. Arrows labels for all but the indices, elevation, mean C, species richness, and precipitation indicate relative cover for the given class. Meadow subtypes are distinct groupings of sites based on vegetation community and covariate data, described in the classification results.*

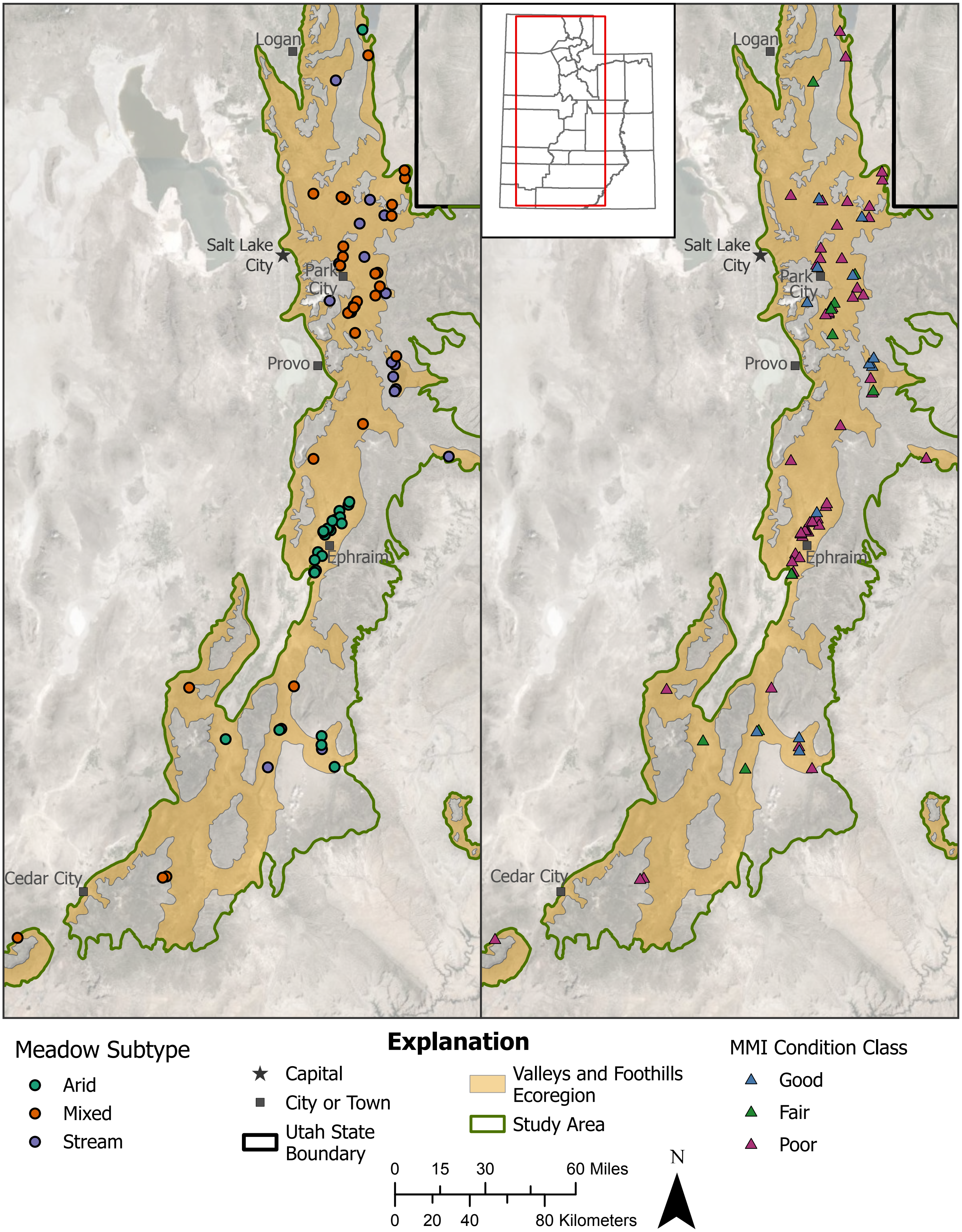

Figure 16. *Meadow subtypes (left) and multi-metric index condition classes (right) for meadows in the Valleys and Foothills. Note that the maps show the extent of relevant survey sites, but not the entire study area.*

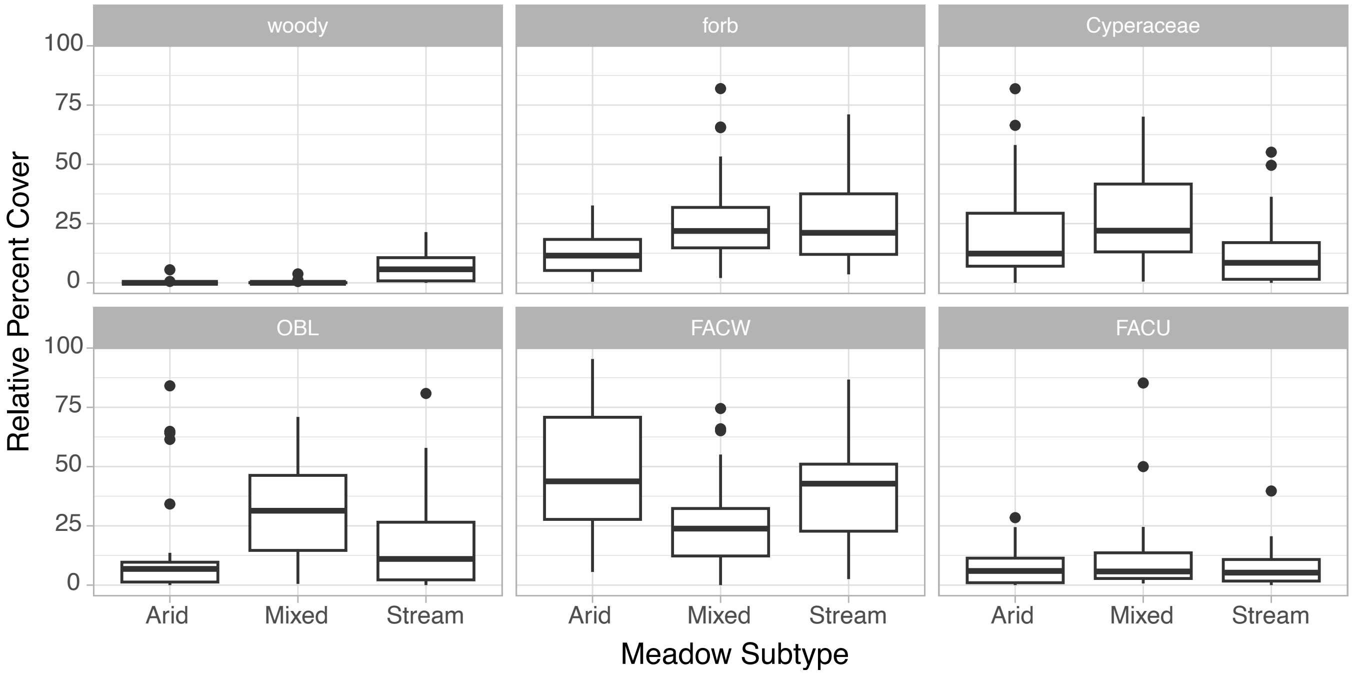

Figure 17. *Comparison of relative cover vegetation metrics by meadow subtypes. Metrics include the relative cover of all woody species, forb species, species in the Cyperaceae plant family, and species assigned the OBL, FACW, and FACU wetland indicators. The whiskers of each boxplot show the 25th and 75th percentile for each meadow subtype and the dots above and below are outliers. The horizontal line inside marks the median score.*

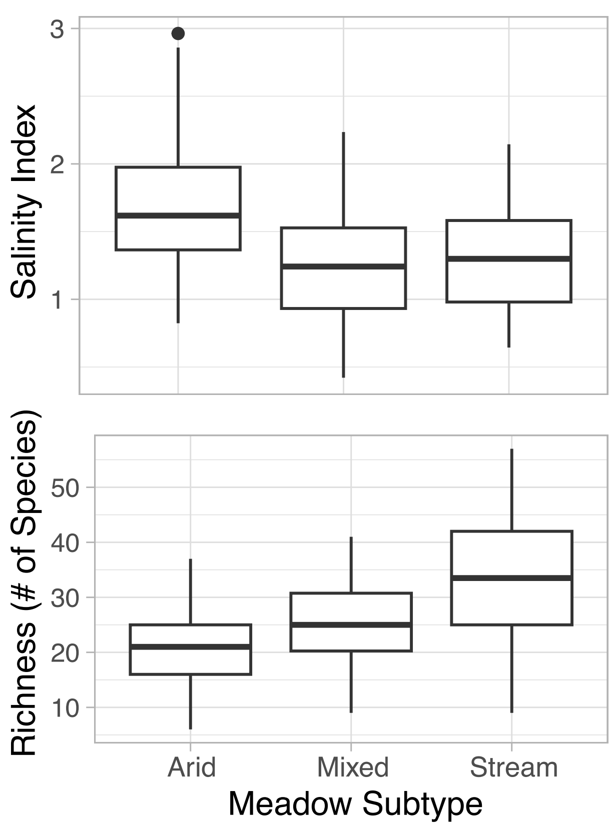

Figure 18. *Comparison of salinity tolerance and species richness by meadow subtypes. The whiskers of each boxplot show the 25th and 75th percentile for each meadow subtype and the dots above and below are outliers. The horizontal line inside marks the median score.*

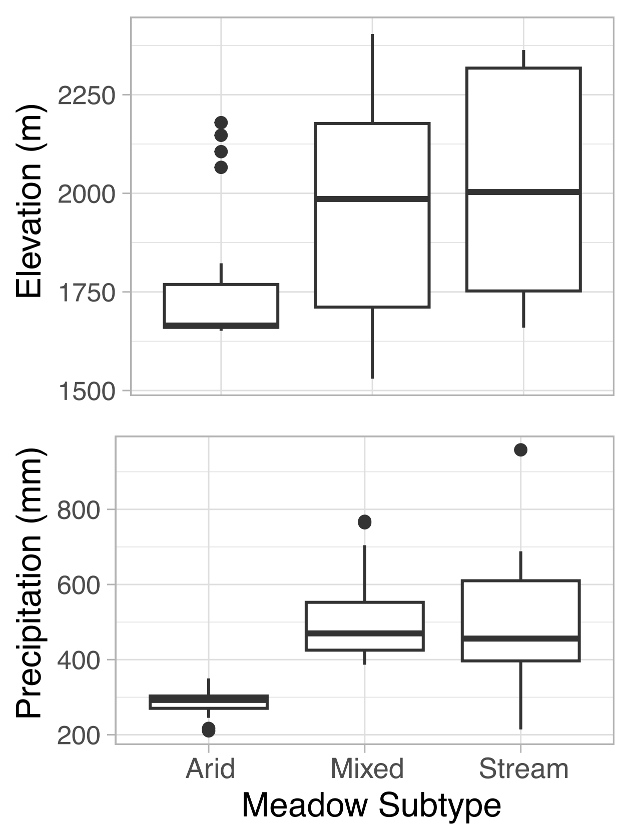

Figure 19. *Comparison of elevation and precipitation by meadow subtypes. The whiskers of each boxplot show the 25th and 75th percentile for each meadow subtype and the dots above and below are outliers. The horizontal line inside marks the median score.*

Table 34. *Plant species found in at least 50% of sites for at least one subtype, with species attribute data and both the percent of sites and median cover in the sites where species was found, by subtype.*

Scientific Name (common name)	Plant Layer	Nativity	Salinity Tolerance	Wetland Indicator	% of Sites			Median Cover (%)		
					Arid	Mixed	Stream	Arid	Mixed	Stream
Achillea millefolium (common yarrow)	Forb	Native	Low	FACU	3.8	40.0	60.0	0.1	0.5	0.5
Alopecurus pratensis (meadow foxtail)	Graminoid	Introduced	Low	FAC	61.5	20.0	45.0	11.0	2.0	2.0
Atriplex spp. (saltbush)	Forb	Unknown	NA	NA	50.0	0.0	5.0	0.1	0.0	1.0
Bromus inermis (smooth brome)	Graminoid	Introduced	Medium	UPL	3.8	3.3	50.0	0.1	1.0	1.0
Carex nebrascensis (Nebraska sedge)	Graminoid	Native	Low	OBL	61.5	66.7	40.0	4.0	9.0	6.0
Carex praegracilis (clustered field sedge)	Graminoid	Native	None	FACW	73.1	26.7	50.0	5.0	2.8	1.3
Cirsium arvense (Canada thistle)	Forb	Introduced	NA	FAC	19.2	36.7	70.0	0.5	0.5	1.0
Cirsium scariosum (meadow thistle)	Forb	Native	NA	FAC	50.0	23.3	25.0	0.5	0.1	0.5
Distichlis spicata (saltgrass)	Graminoid	Native	High	FACW	61.5	6.7	10.0	5.0	2.8	1.5
Eleocharis palustris (common spikerush)	Graminoid	Native	Low	OBL	19.2	23.3	55.0	2.0	1.0	0.5
Epilobium ciliatum (fringed willowherb)	Forb	Native	NA	FACW	11.5	53.3	45.0	0.1	0.5	0.5
Hordeum brachyantherum (meadow barley)	Graminoid	Native	Medium	FACW	50.0	40.0	50.0	0.5	1.0	0.8
Juncus arcticus (arctic rush)	Graminoid	Native	Medium	FACW	92.3	83.3	80.0	13.5	7.0	7.5
Phalaris arundinacea (reed canarygrass)	Graminoid	Introduced	Medium	FACW	23.1	13.3	55.0	4.0	1.0	10.0
Phleum pratense (timothy)	Graminoid	Introduced	Low	FAC	3.8	60.0	25.0	1.0	1.0	0.1
Poa pratensis (Kentucky bluegrass)	Graminoid	Introduced	Low	FAC	19.2	76.7	75.0	0.5	2.0	3.0
Potentilla gracilis (slender cinquefoil)	Forb	Native	None	FAC	26.9	10.0	50.0	0.5	0.5	0.5
Rumex crispus (curly dock)	Forb	Introduced	High	FAC	11.5	50.0	30.0	0.1	0.5	0.3
Taraxacum officinale (common dandelion)	Forb	Introduced	None	FACU	65.4	73.3	60.0	0.5	0.5	0.1
Thermopsis montana (mountain goldenbanner)	Forb	Native	NA	FAC	7.7	20.0	55.0	2.0	1.5	2.0
Trifolium repens (white clover)	Forb	Introduced	Low	FAC	11.5	56.7	40.0	0.1	2.0	1.0

meadows shared many widespread species in common with stream meadows and did not have any characteristic species that were particular to the subtype.

Stream meadows were distinctive for their cover and diversity of woody species. We recorded 26 different woody species across the stream meadow sites, compared to 10 species in the mixed meadows and only 1 in the arid meadows. Willows (*Salix* spp.) were particularly common and diverse. We recorded seven different willow species, and willows were found at 70% of stream sites, compared to 10% or fewer arid and mixed meadow sites. Sagebrush species, including big sagebrush (*Artemisia tridentata*) and silver sagebrush (*Artemisia cana*), were occasionally found in both mixed and stream meadows as well. Other distinctive plant species in stream meadows include the introduced plants Canada thistle (*Cirsium arvense*), reed canarygrass (*Phalaris arundinacea*), and smooth brome (*Bromus inermis*), and the native plants mountain goldenbanner (*Thermopsis montana*), slender cinquefoil (*Potentilla gracilis*), and common spikerush (*Eleocharis palustris*).

Ordination and Classification Discussion

We found that Valleys and Foothills meadow wetlands overlapped substantially in vegetation communities and could be combined together for analysis. Within these sites, we identified three distinct subtypes based on precipitation and stream adjacency. We did not find an obvious division based on water regime, even though variables related to species' wetland affinity, which relates to species' flooding tolerance, were amongst the most important in the ordination. Water regime may be an important factor driving species composition, but it is apparently secondary to the other factors we evaluated. Furthermore, many sites are likely heterogeneous in regards to water regime. A drier site may still have small wet patches and vice versa, helping homogenize vegetation at sites that differ based on predominant water regime.

Arid meadows in the montane region have a strong similarity to previously studied Central Basin meadows, something that surveyors also noticed in the field. Only one arid meadow was located in the northern half of the state and that site had vegetation more similar to the mixed meadow sites than the arid meadow sites, based on the ordination plots. The northern part of the state has cooler temperatures, which may offset the effect of lower precipitation. Future work in defining arid meadows should include targeted surveys across more of the state and investigation into whether climate variables that combine precipitation with temperature (such as the Standardized Precipitation Evapotranspiration Index) do a better job identifying arid meadows than precipitation alone.

Stream meadows are located alongside streams and rivers and have low cover of willows and other woody species. Shrubland wetlands with higher woody cover (usually over 25%) are also very common in these settings. Stream meadows may represent openings within patchy shrublands or may be part of the natural variation in woody cover along streams. Stream meadows could also be shrubland wetlands with reduced woody cover due to heavy grazing or other disturbances, but we found no evidence in our condition metric data that stream meadows were heavily impacted by grazing or had poor woody regeneration. Some, but not all, headwater sites were aligned with the stream meadows. Additional characterization of these headwater sites could help determine whether some headwaters sites should be assigned to the stream subtype.

Mixed meadows, as the name implies, were more united by their lack of affiliation with other meadows rather than a single joining factor. These sites also did not have any distinguishing plant species that separated them from other meadows. The most distinctive feature about the mixed meadows may be that almost all of them have a B seasonally saturated or wetter water regime, which is corroborated by the subtype's high cover of obligate wetland species. Further analysis could help characterize the main traits that unite the mixed meadows.

MMI Development

MMI Methods

Reference site selection: We used methods adapted from the Environmental Protection Agency's (EPA) National Wetland Condition Assessment (NWCA) to select least disturbed and most disturbed sites for Valleys and Foothills meadow wetlands (Herlihy et al., 2019). Researchers often use least disturbed sites to set reference conditions when pristine, undisturbed sites are not available in their dataset. The set of least and most disturbed sites were used to develop the MMI.

We used a set of metrics that measured different aspects of disturbance to screen sites and assign each to a least or most disturbed status. We used the field stressor data from the URAP surveys to create most of the screening metrics. We first separated the stressors into eight categories, derived from the four categories described in objective 2 (Tables 15 and 16). We dropped two stressors related to recreation due to inconsistency within and across projects in how these stressors were rated. We calculated stressor metric values as the sum of impact scores for all stressors within each category, following methods described in objective 2. We calculated the relative cover of introduced plant species to serve as the ninth and final screening metric (Table 35).

We initially set thresholds for selecting least disturbed sites to 1 for the stressor metrics and 5% for relative cover of introduced species. A site would therefore be considered least disturbed if it had values of 1 or less for each of the eight stressor metrics and 5% or less relative introduced cover. However, because no sites passed that screening threshold, we relaxed the thresholds for some metrics, with the goal of assigning between 15% and 25% of sites as least disturbed (Herlihy et al., 2019). We inspected the distribution of values for each stressor metric and changed threshold values iteratively to maintain an adequate sample size while minimizing threshold adjustments (Ode et al., 2015). Most disturbed sites were those that exceeded a highly disturbed threshold for any one of the nine stressor screening metrics. The threshold was initially set at 7 for stressors and 50% relative introduced cover and then adjusted so that approximately 20% to 30% of sites were classified as most disturbed, following Herlihy et al. (2019).

We evaluated the least disturbed sites to see how well they spanned a range of locations and site types for nine categorical variables (Table 36). These variables were the same as those evaluated for the NMDS of Valleys and Foothills sites, except that we used a finer-scale watershed boundary to evaluate spatial clustering in more detail. For each variable, we excluded values with less than five records and then used a Fisher's exact test to evaluate whether the proportion of sites classified as least disturbed differed across values. We used p-value ≤ 0.05 to indicate significance. For example, for the HGM variable, the test evaluated whether depressional, slope, and riverine wetlands differed in how often sites were considered least disturbed, and lacustrine fringe sites were excluded from analysis due to the rarity of this class.

Table 35. *Metrics used to screen for least and most disturbed sites with associated screening thresholds. Thresholds for least disturbed sites were initially set at 1 for stressor data and 5% for relative introduced cover, and thresholds for most disturbed sites were initially set at 7 for stressor metrics and 50% for relative introduced cover.*

Screening Metric	Least Disturbed Thresholds	Most Disturbed Thresholds
Buffer Development	1	7
Buffer Soil	2	7
Buffer Vegetation	5	14
Hydroperiod	7	13
Overall Stress	6	14
Site Soil	2	7
Site Vegetation	5	14
Water Quality	8	16
Relative Introduced Cover	30%	65%

Table 36. *Results of Fisher's exact test comparison of the proportion of sites associated with each value and assigned to each class. Comparisons include reference site assignment (least disturbed versus all other sites) and MMI condition class (poor versus good and fair). Note only values with at least 5 records were included in the analysis; the remaining values were excluded. P-values in bold indicate significance at* p < *0.05.*

Variable	Analyzed Values	Excluded Values	P-value Least Disturbed vs. Others	P-value Poor vs. Others
Ecoregion	Mountain Valleys, Semiarid Foothills	*NA*	0.27	0.10
HGM	Depressional, Riverine, Slope	Lacustrine Fringe	0.32	**0.01**
HGM Subclass	Beaver, Headwater, Irrigation, None	Impoundment	**0.03**	**0.02**
HUC8	Lower Weber, Provo, San Pitch, Strawberry, Upper Weber	Bear Lake, East Fork Sevier, Fremont, Little Bear-Logan, Middle Sevier, Price, Spanish Fork, Upper Bear, Upper Sevier, Upper Virgin, Utah Lake	**0.01**	0.06
Hydric Soils	Not present, Present	Problematic Indicator	1.00	0.61
Hydrophytic Vegetation	FAC, FACW, FACW+, OBL	*NA*	0.18	**<0.001**
Meadow Subtype	Arid, Mixed, Stream	*NA*	0.60	0.17
Water Regime	A, B, C	D, E, F	0.07	0.16
Water Source	Alluvial Aquifer, Groundwater, Irrigation, Overbank Flooding	Precipitation Accumulation, Streamflow Accumulation	**0.03**	**0.01**

Metric calculation and screening: We adapted methods used in the NWCA surveys to develop a vegetation MMI (Magee at al., 2019). We first obtained plant species attribute data for seven unique attributes for each plant species (Table 37). Some species could not be assigned values for some attributes due to incomplete data, but few sites had more than 50% missing data for any attribute. The attribute with the most missing data was salinity tolerance.

We calculated four different metrics for each plant attribute class (e.g., annual, UPL, Cyperaceae) listed in Table 37. These metrics included the total species richness and relative richness and the absolute cover and relative cover (Table 38). We also calculated several indices that integrated information from within an attribute. We converted salinity tolerance and wetland indicator status ratings to ordinal values and calculated mean and cover-weighted mean salinity and indicator values. We used C-values to calculate the mean C-value and the floristic quality assessment index (FQAI), separately for all species and native species only (Table 38). In total, we calculated 179 metrics for each site.

We next evaluated metrics based on the range of values present and responsiveness to disturbance. We followed methods from Magee et al. (2019) but could not evaluate metric repeatability because we lacked repeat visit sites in our dataset. We measured range by identifying metrics with highly skewed distributions, mostly zero values, or with very narrow ranges. We measured responsiveness by identifying metrics that did not distinguish between least and most disturbed sites based on a Kruskall-Wallis test. Metrics with p-value < 0.01 and chi-square statistic >5 passed the responsiveness screen. We standardized each metric that passed both the range and responsiveness tests to values between 0 and 10 on a continuous scale, with the floor (minimum) and ceiling (maximum) set at the 5th and 95 percentile of values for the metric (Magee et al., 2019). Each metric was scaled so that high values were associated with less disturbance and low values associated with more disturbance.

Multi-metric index selection: We tested all possible combinations of three, four, and five metric indices for the standardized metrics to determine which combinations would

Table 37. *Attributes used in the development of the MMI and associated attribute classes. We made minor modifications to some values for some of the attributes.*

Attribute	Classes	Data Source
Duration	Annual, biennial, perennial, plus annual+biennial combination	Natural Resources Conservation Service (2024)
Nativity	Introduced, native	Natural Resources Conservation Service (2024)
Wetland Indicator Status	UPL, FACU, FAC, FACW, OBL	Natural Resources Conservation Service (2024)
Family	Cyperaceae, Juncaceae, Poaceae	Natural Resources Conservation Service (2024)
Layer	Aquatic, forb, graminoid, shrub, tree	Natural Resources Conservation Service (2024)
Duration + Nativity	All combinations of nativity and duration	Natural Resources Conservation Service (2024)
Salinity Tolerance	None, low, medium, high	Palmquist et al. (2017); Natural Resources Conservation Service (2024)
Coefficient of Conservatism	Integers between 0 and 10	McCoy-Sulentic et al. (2021)
Disturbance Tolerance	Classified based on C-values, ranging from highly tolerant (C-value ≤ 2) to highly sensitive (C-value ≥ 9)	McCoy-Sulentic et al. (2021)

Table 38. *Metric types calculated from species attributes for the development of the MMI.*

Metric Type	Example
Species richness	Total number of annual species
Relative richness	Percent of all species that are annual
Absolute cover	Absolute cover of annual species
Relative cover	Percent of all plant cover that is composed of annual species
Mean salinity tolerance	Mean salinity tolerance value for all species, after converting ranks to ordinal values
Mean wetland indicator	Mean wetland indicator status for all species, after converting ranks to ordinal values
Mean C for all species and native species	Mean coefficient conservatism value for all species or native only
FQAI for all species and native species	Sum of coefficient of conservatism values divided by number of species for all species or native only
Cover-weighted values for salinity tolerance, wetland indicator, mean C, and FQAI	Values as above except relative to total cover of each species

yield the best MMI, following methods adapted from Magee et al. (2019). We first used Pearson correlation coefficients to screen out metric combinations with redundant variables. We took the absolute value of the correlation coefficient and only retained metric combinations with maximum and mean correlations less than 0.75 and 0.5, respectively.

We next evaluated the sensitivity and precision for each index that passed the correlation test. We first calculated MMI values for each survey site by summing the values for all metrics in an index, multiplying by ten, and dividing by the number of metrics in the index. We evaluated the sensitivity of each index by measuring the percent of most disturbed sites that were identified as most disturbed by the particular index using an interval test (Kilgour et al., 1998; Magee et al., 2019). Precision was measured as the standard deviation of index values amongst the least disturbed sites.

We selected the top performing indices within each combination category (3-, 4-, and 5-metric combinations). We used t-tests and boxplots to examine how well these indices discerned between least and most disturbed sites. We also considered whether indices included metrics that were impacted by missing data before we selected the final MMI.

Condition estimates: We classified wetland condition as good, fair, or poor using MMI percentile thresholds of >25, 5–25, and <5 respectively (Magee et al., 2019). Once sites were assigned to the three condition classes, we used the R package spsurvey to estimate the percent of wetland area in the Valleys and Foothills in good, fair, and poor condition. We created separate estimates for each of the three projects—this study and the Jordan (Menuz and Sempler, 2018) and Weber (Menuz et al., 2016b) watershed studies—since study weights were assigned differently in each project. To better understand factors associated with poor condition, we used the Fisher's exact test to evaluate the proportion of sites that were classified as poor versus fair or good for a variety of covariates (Table 36). We also used scatterplots and Pearson's correlation coefficients to examine the relationship between MMI scores and the overall and categorical wetland condition scores from URAP field surveys.

MMI Results

Reference site selection: Our initial selection of least and most disturbed sites using our default thresholds resulted in zero least disturbed sites and 84.2% of sites considered most disturbed. We adjusted thresholds for almost all of the stressor screening metrics to obtain an adequate sample size (Table 35). After these adjustments, 11 (14.5%) sites were categorized as least disturbed and 22 (28.9%) as most disturbed.

Based on the Fisher's exact test, the proportion of sites that were least disturbed differed based on HGM subclass, water source, and HUC8, but not for any other variables (Table 36). Only 3% and 9% of sites with irrigation and headwater HGM subclasses, respectively, were least disturbed, compared to 24% of sites with no subclass and 40% of beaver sites. Sites with alluvial aquifer and irrigation water sources were rarely least disturbed (<4% of sites) versus sites with groundwater (24%) or overbank flooding (30%). Amongst HUC8 watersheds, the Strawberry watershed had the highest percent of sites classified as least disturbed and the Provo watershed had the fewest. Between 8% and 20% of sites in the other three tested watersheds were least disturbed. In total, 10 of 16 watersheds did not have any least disturbed sites, though all but two of these watersheds had only one or two meadow wetland sites. Between 10% and 20% of sites in each subtype were classified as least disturbed and between 20% and 39% were classified as most disturbed (Table 39). The proportion of least and most disturbed sites in each subtype did not differ significantly (Table 36).

Multi-metric index: Twenty-four metrics passed the screening process (Table 40). Metrics related to the coefficient of conservation variable were most common, followed by metrics related to nativity and combined nativity and duration. None of the family, layer, or duration metrics passed the screening.

We tested 2024 3-metric, 10,626 4-metric, and 42,504 5-metric indices. The correlation test eliminated 54%, 75%, and 90% of indices, respectively. The remaining 7814 indices had sensitivity values between 0% and 68%. We conducted an initial evaluation of the 216 indices with sensitivity values of 50% or greater. Two metrics, cover-weighted mean C and cover of perennial introduced species, were found in 175 or more indices, whereas other metrics were in less than one-third of indices.

We next examined the indices with the highest sensitivity for each metric combination type (Table 41). Two 4-metric indices had sensitivity values of 68% and three 3-metric and one 5-metric combination had sensitivity values of 64%. All six of the top indices included the metrics cover-weighted mean C and cover of perennial introduced species. These

Table 39. *Site classification for the multi-index by meadow subtype, including least and most disturbed sites and sites classified by the MMI.*

Subtype	# of Sites	% Least Disturbed	% Most Disturbed	% Good Condition	% Fair Condition	% Poor Condition
Arid	26	15.4	38.5	11.5	7.7	80.8
Mixed	30	10.0	20.0	13.3	13.3	73.3
Stream	20	20.0	30.0	25.0	20.0	55.0

Table 40. *Vegetation metrics that passed the initial MMI screening, along with mean values for least and most disturbed sites and the direction of the relationship between the metric and disturbance. See Table 38 for variable definitions.*

Variable	Measure Type	Mean, Least Disturbed	Mean, Most Disturbed	Direction
Coefficient of Conservatism (C-value)				
FQAI all	Index	18.2	10.9	Positive
FQAI native	Index	20.5	14.0	Positive
Highly tolerant (C-value ≤2)	Cover	7.7%	36.4%	Negative
Highly tolerant (C-value ≤2)	Relative cover	10.0%	45.2%	Negative
Highly tolerant (C-value ≤2)	Relative richness	24.5%	44.6%	Negative
Intermediate tolerance (C-value 5 or 6)	Species richness	7.2	3.9	Positive
Mean C all	Index	3.4	2.4	Positive
Weighted Mean C all	Index	3.8	2.2	Positive
Nativity				
Introduced	Cover	7.3%	35.7%	Negative
Native	Cover	73.9%	44.8%	Positive
Native	Species richness	23.4	13.1	Positive
Native	Relative cover	90.6%	55.8%	Positive
Native	Relative richness	77.9%	60.3%	Positive
Nativity + Duration				
Introduced annual and biennial	Relative richness	4.8%	13.3%	Negative
Introduced annual	Relative richness	2.4%	8.8%	Negative
Introduced perennial	Cover	6.8%	31.9%	Negative
Introduced perennial	Relative cover	8.9%	39.8%	Negative
Native perennial	Cover	70.8%	43.3%	Positive
Native perennial	Relative richness	68.3%	53.4%	Positive
Salinity				
Mean salinity tolerance	Index	1.0	1.3	Negative
No salinity tolerance	Species richness	8.6	4.0	Positive
No salinity tolerance	Relative richness	41.7%	25.6%	Positive
Wetland Indicator				
FACW	Species richness	8.8	5.0	Positive
FACW and OBL	Species richness	14.3	9.2	Positive

Table 41. *Variables included in top MMIs for 3-, 4-, and 5- metric indices and MMI sensitivity, maximum and mean correlation between metrics, and precision (standard deviation). Final selected index is bolded and in italics.*

MMI Type	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Sensitivity	Max. Corr.	Mean Corr.	SD
Top 5 Variable	Introduced perennial cover	Weighted Mean C	Species richness FACW and OBL	Relative richness introduced annual	Relative richness no salinity tolerance	63.6	0.74	0.27	10.1
Top 4 Variable	***Introduced perennial cover***	***Weighted Mean C***	***Species richness FACW and OBL***	***Relative richness introduced annual***	NA	***68.2***	***0.74***	***0.30***	***8.7***
Top 4 Variable	Introduced perennial cover	Weighted Mean C	Relative richness introduced annual	Mean salinity tolerance	NA	68.2	0.74	0.25	8.8
Top 3 Variable	Introduced perennial cover	Weighted Mean C	Species richness FACW and OBL	NA	NA	63.6	0.74	0.39	7.1
Top 3 Variable	Introduced perennial cover	Weighted Mean C	Relative richness introduced annual	NA	NA	63.6	0.74	0.34	8.7
Top 3 Variable	Introduced perennial cover	Weighted Mean C	Relative richness no salinity tolerance	NA	NA	63.6	0.74	0.32	8.7

two metrics had a correlation of 0.74, just below the threshold used to screen out candidate indices. Other metrics in at least one of the top indices included: 1) richness of FACW and OBL species, 2) relative richness of annual introduced species, 3) relative richness of species with no salinity tolerance, and 4) mean salinity tolerance.

The six indices were all able to successfully distinguish between least and most disturbed sites based on a Welch two sample t-test ($p < 0.001$ for all comparisons) and boxplot evaluation. After this examination, we selected the 4-metric index composed of cover-weighted mean C, cover of perennial introduced species, richness of FACW and OBL species, and relative richness of introduced annual species as the final MMI for several reasons (Figure 20; Table 41). First, this index did not have salinity tolerance metrics, the attribute with the most missing data. Second, this index, along with one other index, had the highest precision value. Third, this index had amongst the lower mean correlation amongst metrics and precision similar to the other indices.

Condition estimates: We estimated MMI-based condition for 18, 14, and 44 meadow wetland sites in the Weber, Jordan, and present study, respectively. Most wetland area in each project was in poor condition and differences between the amount of good and fair wetland area were not significant (Figure 21). Wetland condition was poor for 72.8% (SE 5.5) of wetland area in the montane project, 72.0% (SE 11.6) in the Jordan project, and 69.2% (SE 10.9) in the Weber project. To be rated in good condition if each metric contributed equally to a site's MMI, a site would need to have approximately 11% or less introduced perennial cover, 4% or less of all species that were introduced annuals, weighted mean C-value of 3.6 or higher, and at least 16 FACW and OBL species (Table 42; Appendix F). Fewer sites met or exceeded those values for richness of FACW and OBL species and weighted mean C than for the other two metrics.

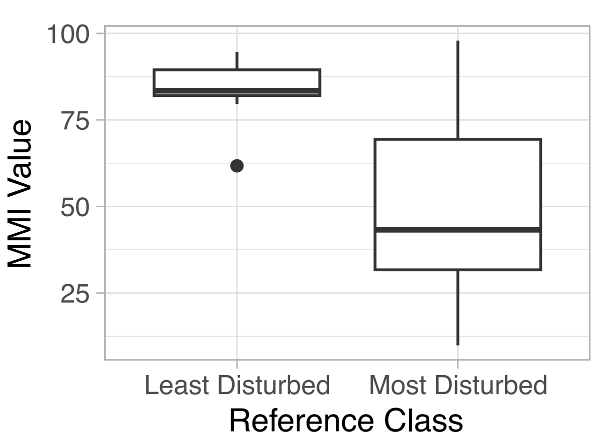

Figure 20. *Multi-metric index values for least and most disturbed sites. The whiskers of each boxplot show the 25th and 75th percentile for each reference class and the dots above and below are outliers. The horizontal line inside marks the median score.*

Though good sites were found across the study area, the majority were clustered in the northern half of the state (Figure 16). Only sites classified as least disturbed in the reference screening were assigned to the good MMI class, with the exception of four meadow sites that were in good condition despite higher disturbance. Several attributes differed between sites classified as poor condition versus those classified as fair or good (Table 36). Sites were less frequently assigned to the poor class if they were riverine, had beaver or no HGM subclass, or received water from overbank flooding. Sites with vegetation that was more strongly affiliated with wetlands were also less often in poor condition and more often in good condition. Between 12% and 25% of sites in each subtype were classified as good condition and between 55% and 81% were classified as poor condition, and differences in condition classes between subtypes were not significant (Tables 36 and 39).

MMI scores were significantly positively correlated with overall URAP score and with scores in the Landscape Context, Vegetation Structure, and Vegetation Composition categories, having R^2 values between 0.26 and 0.51 (Table 43). Scatterplots between the MMI and URAP scores showed that the URAP scores had a fairly narrow range of values compared to the MMI and that values in the Physical Structure, Vegetation Structure, and Vegetation Composition categories are essentially discrete rather than continuous (Figure 22).

MMI Discussion

Reference sites: We had to substantially loosen stressor values from our initial thresholds to select a group of least disturbed meadow sites. Herlihy et al. (2019) also found that stressor thresholds for NWCA surveys had to be adjusted substantially for herbaceous wetlands in the West, which had the largest adjustments of any reporting unit. In our study, the two stressor screening metrics related to hydrology (hydroperiod and water quality) required the largest adjustments. Since we evaluated our hydrology stressors at both the site and landscape scale, we captured information about all of the stressors accumulating across a watershed, which likely led to few sites with unaltered hydrology in our Valleys and Foothills wetlands.

Our set of least disturbed wetlands included a somewhat limited spatial distribution and broad range of wetland characteristics. Although we did have some sites from each of the major drainages (i.e., the Colorado, Great Salt Lake, and Sevier watersheds) represented in the least disturbed sites, some regions of the state lacked any least disturbed sites, particularly in northern Utah and the Provo watershed. Handpicked sites with good spatial representation would help expand the distribution of least disturbed sites and ensure that the MMI works well in Valleys and Foothills meadows across the state and could also help identify more sites with very low disturbance values (Herlihy et al., 2019).

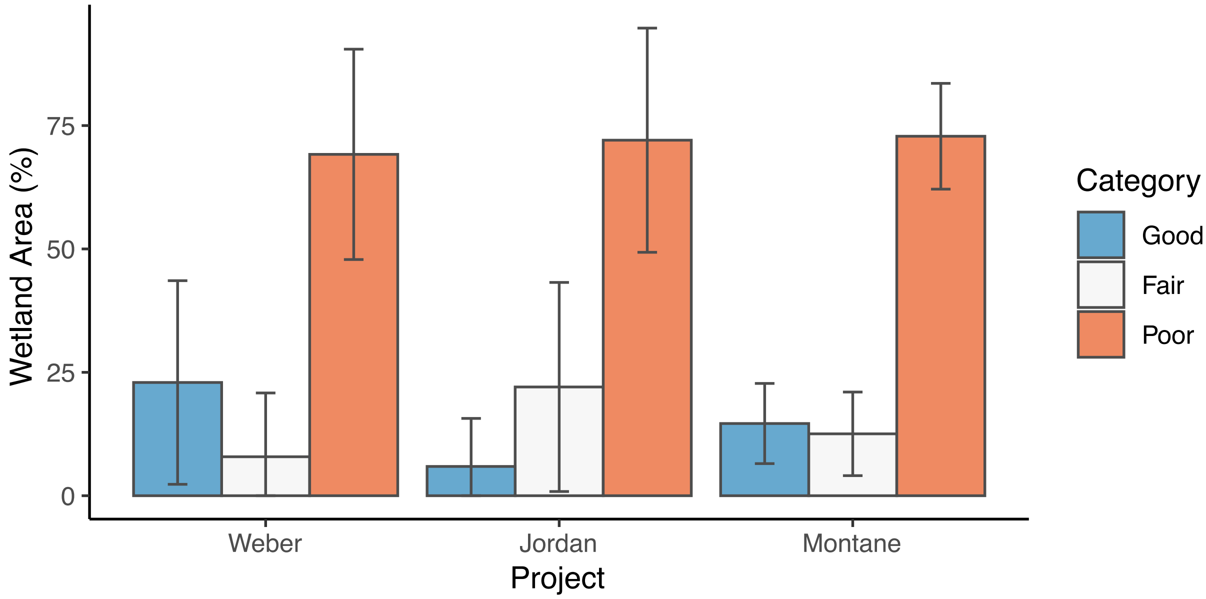

Figure 21. *Multi-metric condition class estimates for Valleys and Foothills meadow wetlands by survey project, shown as the percent of wetland area in each condition class. Bars indicate the upper and lower bounds of the 95% confidence interval. "Montane" project refers to the present study.*

Few headwater wetlands and wetlands with alluvial aquifer or irrigation water sources were designated as least disturbed sites, though sample sizes for most comparisons were small. Headwater wetlands had more vegetation and soil stressors within sites than other HGM subclasses, primarily due to non-native plants and grazing and soil disturbance from livestock. These wetlands are usually narrow bands of green vegetation surrounded by drier steep upland slopes, possibly making them targets for more intense grazing (Pinchak et al., 1991). Headwater wetlands surveyed in our study were usually seasonally saturated, with wet soils early in the summer that later dried out, making them accessible to grazers. Alluvial aquifer wetlands had high impact values for buffer and vegetation stressors due to a combination of non-native plants and livestock grazing. They also had relatively high impact values for most other stressors except those related to soils and hydroperiod. Irrigation-fed wetlands typically had hydrology stressors such as canals, ditches, berms, and agricultural or livestock runoff, leading to high impact values for the hydroperiod and water quality stressors.

Multi-metric index: The final MMI was very successful at differentiating between least and most disturbed meadow sites, with a sensitivity of 68.2% as compared to the NWCA's MMI sensitivity of 48.1% (Magee et al., 2019). We selected only a small percent of sites to represent the least disturbed wetlands, 14.5% compared to an average of 23% per reporting unit in the NWCA survey (Herlihy et al., 2019). If we had increased the number of least disturbed sites we selected, there may have been more overlap between least and most disturbed sites, reducing sensitivity. However, we sought to strike a balance between a reasonable sample size for least disturbed sites and not loosening stressor thresholds too much.

Table 42. *Floor and ceiling values used to standardize metrics in the final MMI. The good and fair examples show the approximate minimum values for mean C and FACW/OBL richness and maximum values for introduced species metrics needed for a site to score as good and fair, if each variable contributed approximately equally to the MMI.*

Variable	Floor	Ceiling	Fair Example	Good Example
Introduced perennial cover (%)	61.1	0.5	18	11
Weighted mean C	0.6	4.2	3.2	3.6
Species richness FACW and OBL	3.0	19.3	15	16
Relative richness introduced annual (%)	23.1	0.0	7	4

Table 43. *Pearson correlation coefficients and p-values for correlations between URAP condition scores (overall and by category) and the final MMI score.*

Condition Category	R^2	p-value
Overall condition score	0.44	<0.001
Landscape context	0.39	0.001
Hydrologic condition	0.18	0.131
Physical structure	-0.18	0.126
Vegetation structure	0.26	0.022
Vegetation composition	0.51	<0.001

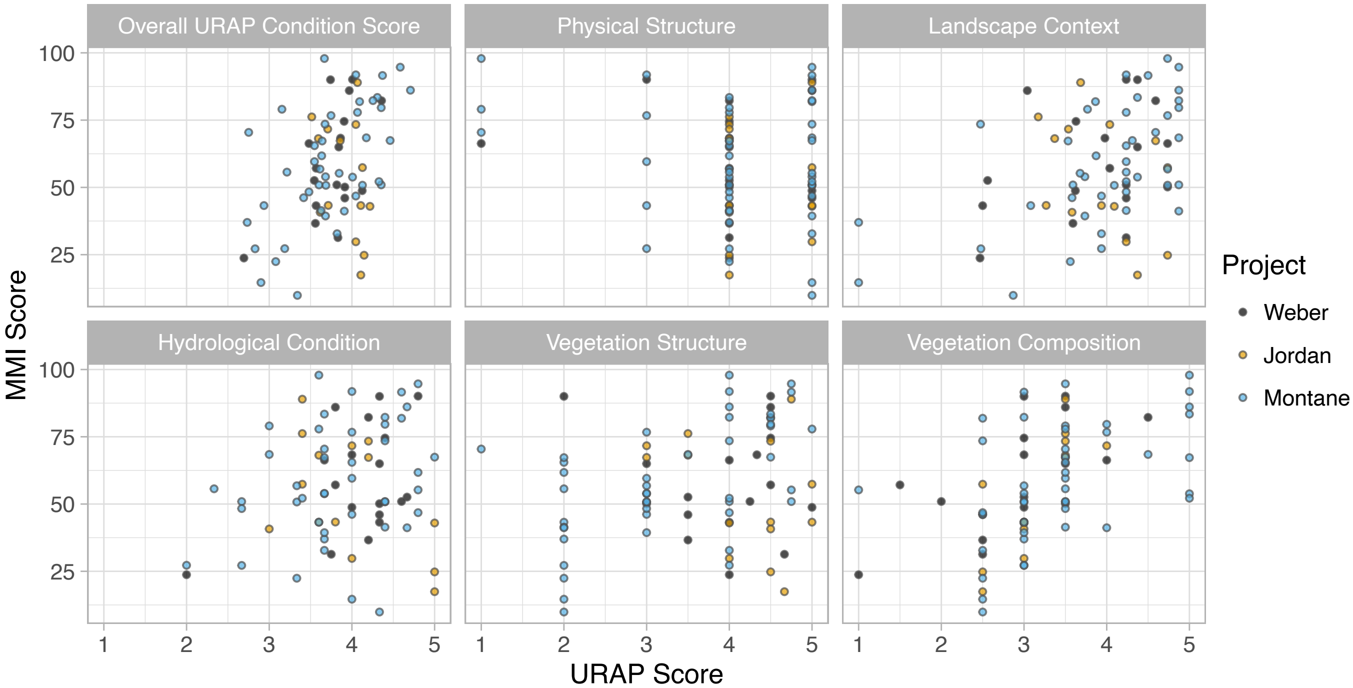

Figure 22. *Scatterplot between URAP condition scores (overall and by category) and the final MMI score, by project. "Montane" project refers to the present study.*

We included four metrics in the final MMI—cover-weighted mean C, cover of perennial introduced species, richness of FACW and OBL species, and relative richness of introduced annual species. Metrics related to species nativity are common in wetland MMIs (Magee et al., 2019; Bolding et al., 2020; Downard, 2021). Disturbances such as grazing, hydrologic impairment, and human activity can lead to higher diversity and abundance of introduced species (Ervin et al., 2006; Menuz and Kettenring, 2012; Jauni et al., 2014). Weighted mean C captures some of the same information as introduced cover since all introduced species have C-values of zero, but also provides additional information about disturbance tolerance of native species. The third metric in the MMI was the richness of FACW and OBL species, which was also included in a previous MMI for wetlands around Great Salt Lake in Utah (Downard, 2021). Water stress in wetlands is common in the West, both from drought and water diversion (Brinson and Malvárez, 2002; Green et al., 2017). Least disturbed wetlands may be less impacted by or more resilient to these hydrologic stressors and thus able to support a greater diversity of wetland-affiliated species. The last metric was the relative richness of introduced annual species; a similar metric was included in an MMI for marshes in Canada (Bolding et al., 2020). Annual species are able to spread rapidly into open habitat because they produce seeds in just one year and tend to be bisexual and self-compatible, meaning a single plant can fertilize its own flowers and produce seeds (Sutherland, 2004). Disturbances that create bare soil, such as grazing and mowing, and hydrologic changes like drought and drawdowns can create opportunities for annual species to invade wetlands (Bolding et al., 2020).

Metrics related to salinity tolerance (mean salinity tolerance and relative richness of species with no salinity tolerance) were important in several top models. Least disturbed sites had fewer species that could tolerate saline conditions. Increased wetland salinity can be caused by human disturbances, including water diversions, vegetation removal, deicing salts, and intensive irrigation (Jolly et al., 2008; Herbert et al., 2015). Furthermore, warm and dry climate conditions can increase wetland salinity by increasing evapotranspiration and decreasing salt-flushing storm events (Jolly et al., 2008). Salinity is also affected by natural environment conditions such as geology. For example, higher salinity in wells in Sanpete County have been attributed to weathering from particular geological formations in addition to return irrigation flows (Wallace et al., 2017). Our ability to evaluate the relationship between wetland salinity and disturbance could be improved by assigning salinity tolerance values to additional plant species.

Condition: Most wetland meadows in the Valleys and Foothills are in poor condition based on the MMI. The 2016 NWCA surveys found similar results for herbaceous wetlands (i.e., marshes and meadows) in the western United States (U.S. Environmental Protection Agency, 2023). Our estimate of about 70% of wetland area in poor condition falls in between the NWCA estimate of 61.8% poor condition in the Western Mountains and 87.2% poor condition in the Xeric region, based on the MMI developed for that project.

We found a moderate correlation between URAP condition scores and MMI scores, suggesting that both methods capture some overlapping aspects of wetland condition while each may also highlight distinct factors that are important for understanding wetland health. The lack of correspondence between MMI scores and the Physical Structure and Hydrologic Condition categories could indicate that these aspects are not well captured by vegetation data in the MMI or that our methods for measuring each using URAP are insufficient. Menuz et al. (2016b) and Faber-Langendoen et al. (2019) also found that Physical Structure was not a strong measure of wetland health when compared to other measures (MMI values and stressor data, respectively), though both studies found stronger relationships with Hydrologic Condition than found in the present study.

We converted only the MMI scores, and not the URAP scores, to condition classes. For the MMI, we used percentiles of the least disturbed sites' MMI scores to define the good, fair, and poor classes, following methods used in other aquatic surveys (Herlihy et al., 2008; Paulsen et al., 2008; Magee et al., 2019). However, other methods can be used to set thresholds, including looking for breakpoints in plots of index values and setting equidistant classes, which would have changed our estimates of wetland condition (Johnson et al., 2013). URAP does not have a method for turning URAP scores into condition classes and is more useful for identifying individual wetland characteristics that are problematic rather than estimating overall condition. However, most overall URAP scores fell between 3.5 and 4.5, which is equivalent to a range of about A- to C+ if applying the thresholds used for individual URAP metrics. If overall URAP scores were converted to classes based on these thresholds, most sites would be in fair to good condition, in marked contrast to the MMI where most sites were rated as poor.

We hypothesize that the MMI result showing that most Valleys and Foothills sites are in poor condition is likely more accurate for several reasons. First, these results match closely with the results of the NWCA study. Second, the quantitative vegetation data and checklist approach of the stressor data are more straightforward to evaluate than the qualitative URAP metrics. Last, the low range of values in the URAP categorical and overall scores indicates that scoring methods may need to be refined to improve discriminatory power. Applying a similar MMI to wetlands in other regions may be useful to evaluate whether findings correspond with expected condition in those regions (e.g., most subalpine wetlands are expected to be in fair to good condition). Regardless, Herlihy et al. (2008) provide valuable context when they state that condition classes have no regulatory meaning and are instead meant to facilitate conversation amongst the public and policymakers.

Given our disparate findings between URAP and MMI condition estimates, we recommend revisiting the URAP protocol to reevaluate the scoring method. The current method of combining URAP metric values into an overall score was developed by Menuz et al. (2016b), who tested several methods for combining metrics together against vegetation and stressor data and found that each produced similar results. However, methods for collecting URAP condition and stressor data have changed in the intervening years and it may be necessary to conduct additional testing and calibration of the scoring methods. NatureServe's Ecological Integrity Assessment (EIA), the model for URAP, has itself changed over the years (Faber-Langendoen et al., 2019), and the latest EIA protocol could be a useful guide for additional modifications to URAP. Notably, EIA weights each category before combining methods together, with the highest weight for the vegetation category and the lowest for the soils. We now have a large sample of montane wetland data across the state that could be used for a more intense validation and calibration effort for the URAP protocol.

CONCLUSIONS

According to Utah's Coordinated Action Plan for Water, "Utah is committed to maintaining and improving the health of our waters and watersheds throughout the state to support their function, importance, and uses" (State of Utah, 2022). Montane wetlands play an important role in meeting this statewide commitment by providing wildlife habitat, livestock forage, and recreational use. They are also crucial for supporting water quality and quantity for populations living downstream. This study provides important baseline information on the location and health of Utah's montane wetlands, which is a necessary first step for protecting these systems. In addition to this baseline information, we also developed a tool, the multi-metric index (MMI), that can be used to evaluate changes in wetland health.

To create more reliable wetland spatial data, we produced a dataset, UT-MOWET, that provides more comprehensive information on the location of montane wetlands, albeit with significant overmapping. We used these spatial data to select sites to conduct a rapid condition assessment on previously unstudied parts of the montane region. We found many similarities between our results and those from our previous studies in the Weber and Jordan watersheds, including more stressors and poorer condition in the Valleys and Foothills, widespread hydrology impacts at lower elevations, and the ubiquitous presence of livestock grazing and non-native vegetation throughout the montane region. However, grazing was even more widespread and non-native vegetation less common in this study area compared to those other regions. We were able to incorporate data from all three studies to create an MMI to more robustly evaluate meadow condition in the Valleys and Foothills strata, which we found were mostly in poor condition.

This research can serve as a starting point to design more intensive field studies within a subset of wetlands in the region. We can identify many future research topics that arise from this work. For example, this study is the first to use URAP in the Plateaus ecoregion. Wetlands in the Plateaus had overall stressor levels that were not distinguishable from lower elevation sites, but intact vegetation communities more similar to those found at higher elevations, with more cover by native, disturbance-intolerant plant species. Future work could look at what protects vegetation communities in the Plateaus from non-native species or, more broadly, the primary factors that drive invasion across the region. As another example, Valleys wetlands are frequently surrounded by water quality stressors, but the extent to which these stressors impact condition is uncertain. Researchers could use a combination of water quality stressor data, MMI scores, and water chemistry data collected at sites to better understand how stressors at the landscape scale affect wetland condition.

Further research and evaluation can help determine the applicability of the function and condition assessments and the MMI tool for use in contexts such as determining the value of a proposed mitigation site or measuring restoration success. Regulators could evaluate MMI, function, or condition scores at both impacted sites and proposed mitigation sites to establish mitigation ratios or determine mitigation site suitability (U.S. Army Corps, 2015; Kihslinger et al., 2019). Similarly, restoration practitioners could use the MMI to evaluate wetland health before and after restoration implementation. If restoration or mitigation is focused on particular functions rather than overall health, researchers may need to further validate the function tool or make sure that measures of wetland health correlate with the functions of interest before adopting the condition tools for their work. Notably, three of the four metrics used in the MMI directly measure aspects of wetland health that are commonly evaluated in mitigation projects—introduced plant cover and hydrophytic vegetation (Mathews and Endress, 2008).

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APPENDICES

APPENDIX A:
UT-MOWET DATASET DEVELOPMENT PROCESS

Link to supplemental data download:

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APPENDIX B:
UTAH GEOLOGICAL SURVEY UTAH RAPID ASSESSMENT PROCEDURE USER'S MANUAL AND REFERENCE MATERIAL

Link to supplemental data download:

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APPENDIX C:
UTAH RAPID ASSESSMENT PROCEDURE FIELD FORM

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APPENDIX D:
UPDATED HYDROGEOMORPHIC (HGM) KEY

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APPENDIX E:
3-DIMENSIONAL NMDS PLOT BY MEADOW SUBTYPE

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APPENDIX F:
METHOD FOR CALCULATING MULTI-METRIC INDEX CONDITION SCORES

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