Wetland Monitoring and Assessment in Wyoming:

Addressing the Challenges of Wetlands in Highly-Managed Basins

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WYNDD
Wyoming Natural Diversity Database

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Abstract

The Wyoming Natural Diversity Database (WYNDD) at the University of Wyoming, in partnership with The Nature Conservancy in Wyoming (TNC), received funding from the U.S. Environmental Protection Agency's (USEPA) Wetland Program Development Grant program to improve the effectiveness of assessment methods to support state priorities for wetland monitoring in highly managed basins.

This project complements and builds upon the statewide wetland overview completed in 2010 (Copeland et al. 2010), and utilizes information available from five previous basin-wide wetland condition assessment projects completed in Wyoming thus far (Tibbets et al. 2015, 2016a, 2016b; Washkoviak et al. 2018a, 2018b).

This report summarizes our effort to determine the current data priorities for wetland assessments and to evaluate some tools and methods that can support Wyoming's monitoring, conservation, and restoration priorities into the future. We describe the results of a survey of wetland practitioners in Wyoming that ranks the importance of assessment goals in relation to their management needs. We then describe wetland assessment methods and data currently available in relation to the needs identified by wetland practitioners. We focus specifically on challenges with current methods and data gaps relevant to identifying at risk and vulnerable wetlands in highly managed river basins. We then provide an overview of the Wyoming wetland program and address its successes, shortcomings, and future needs. Lastly, we present the results of the development of a novel macroinvertebrate index of wetland condition for wetlands. Our work on that index fills gaps in data for wetland macroinvertebrates and a provides a potential rapid assessment method for condition relevant to the needs of wetland managers.

In review, the stakeholder survey repeated what we had already heard from many managers and wetland practitioners in the state: there is a need for assessment methods that are rapid, regionally standardized, and that evaluate function, condition, and/or wildlife habitat. These methods should ideally provide data for mapping, targeting areas for conservation and restoration, and the ability to assess change in habitat. Based on our review of current methods versus needs identified as important, most methods fall short in directly estimating the quality of wildlife habitat and the ability to use information to target areas for conservation or restoration.

1.0 Introduction

Wyoming is host to a wide variety of freshwater wetland ecosystems, including emergent marshes, wet meadows, playas, riparian forests, and fens. These wetlands exist at the interface, or ecotone, of aquatic and terrestrial ecosystems that create uniquely diverse and productive habitats in an otherwise semi-arid landscape. While only occupying 1.5% of the total land area of Wyoming, wetlands support a disproportionately high number of plant and wildlife species (Knight et al., 2014). For instance, approximately 90% of the wildlife species in Wyoming use wetland and riparian habitats daily or seasonally during their life cycle, and about 70% of Wyoming bird species are wetland or riparian obligates (Nicholoff, 2003). In addition to maintenance of biodiversity, wetlands provide a suite of ecosystem services including flood attenuation, stream flow maintenance, aquifer recharge, sediment retention, water quality improvement, and the production of food, goods, and recreational area for human use.

Despite their importance, recent studies identify wetlands in Wyoming as one of the most vulnerable ecosystems to future development and changes in climate (Copeland et al., 2010; Pocewicz et al., 2014). Specifically, studies led by multi-agency working groups have identified the need for baseline information about the quantity and quality of wetland complexes in Wyoming, especially wetlands associated with lower elevation, agricultural river basins (Copeland et al 2010; WJVSC 2010; Pocewicz et al. 2014). These “working wetlands” are interspersed within the floodplain mosaic of river basins, and overlap with multiple land-uses, including recreational, agricultural, natural resource extraction, residential, and urban areas. Given the historical loss of wetland area (Dahl, 1990), and the potential for future loss and degradation (Copeland et al. 2010, Pocewicz et al. 2014), there is an urgent need to better understand existing wetlands in Wyoming to inform the conservation and management of this vital natural resource.

Ecosystem monitoring and assessment programs are critical for wetland resource management, conservation, and restoration activities. Assessment programs are ideally designed to address specific freshwater information needs, policies, or regulations questions to have the greatest impact (Kuehne et al., 2017). Much of the work described in this report began with a call-to-action in 2010 from the Wyoming Bird Conservation Partnership (now the Wyoming State Conservation Partnership, SCP), an interagency working group organized to facilitate wetland habitat conservation planning and projects to help achieve priority state, regional, and continental objectives. The Wyoming SCP identified 9 priority basins in Wyoming that lacked critical baseline data needed to answer management questions (WJVSC, 2010). In answer to that call, WYNDD, TTNC, and the Wyoming Game and Fish Department (WGFD) have spent the last 10 years developing Wyoming’s wetland program and completing wetland profiles and ecological condition assessments to collect critical baseline information in these basins (Tibbets et al., 2015, 2016a, 2016b; Washkoviak et al., 2018a, 2018b).

This report summarizes our effort, in partnership with TNC in Wyoming, to determine the current data priorities for wetland assessments and to evaluate some of the tools and methods that can support Wyoming's specific monitoring, conservation, and restoration priorities into the future. We met this objective by utilizing a variety of methods to identify the needs of wetland practitioners, challenges with current methods, and data gaps relevant to at-risk and vulnerable wetlands in highly managed river basins. In addition, we provide an overview of the Wyoming wetland program and address its successes, shortcomings, and future needs in the context of wetland assessment. Lastly, we present the results of the development of a novel macroinvertebrate index of wetland condition for wetlands. This wetland macroinvertebrate study fills gaps in data for wetland macroinvertebrate taxa and provides an example of a rapid assessment method relevant to the needs of wetland managers.

2.0 Current Wetland Assessment Needs in Wyoming

2.1 Report from Wyoming's Wetland Stakeholder Survey

To identify the current needs and priorities for wetland monitoring and assessment, we surveyed wetland stakeholders working in Wyoming. In January 2018, we sent a standardized Google survey to 60 wetland professionals from non-profit, academic, state, tribal, and federal institutions. These individuals were identified based on an email list for the Wyoming SCP, the most active wetland management group in the state, and other individuals who were identified to have an interest or need for wetland assessment data. (The survey may be viewed in the accompanying PDF file, *CD96825501_FinalReport2022Feb_Appendix A*). We received responses from 33 individuals from 18 different organizations (Table 1). We presented the results of the full survey to over 30 key wetland personnel at the Wyoming State Bird Conservation Partnership meeting February 7-8, 2018 at the WGFD office in Casper, WY. We provide a summary of key findings in the sections to follow.

In response to the survey question, "*Are you or your organization currently using specific wetland monitoring or assessment methods?",* 52% of respondents use one or more wetland monitoring or assessment method, 30% do not, but want to learn more about monitoring, and 18% responded "not applicable". Of those utilizing a monitoring or assessment method, 11 different methods were listed (see accompanying PDF file, *CD96825501_FinalReport2022Feb_Appendix B*), and 33% of those were required for use within their organization. Many respondents cited use of general aquatic and riparian health assessment methods that include wetlands, but are not wetland-specific.

Based on the survey results, federal land managers are generally required to use the methodologies dictated by their agencies, while state and regional land managers face the challenge of deciding which methods are appropriate to use to meet their specific management and assessment needs. About half (52%) of respondents reported that their current monitoring and assessment methods do not meet the needs of their organization. When asked to specify the shortcomings of these methods, 39% of respondents noted that methods are too training- or resource-intensive, 31% noted the lack of quantification of wetland function or wildlife value, 23% stated that methods do not adequately address artificial or irrigated wetlands, and 8% listed the lack of a central data repository.

Table 1. Summary of the number of wetland professionals from each organization in Wyoming that responded to our survey in January 2018.

Organization	# Responded
Federal	
Bureau of Land Management	2
National Park Service - Yellowstone	2
US Army Corps of Engineers	2
US Dept. of Agriculture-NRCS	1
US Fish and Wildlife Service	4
Seedskadee & Cokeville Meadows Natl Wildlife Refuge	1
State / Regional	
Wyoming Department of Environmental Quality	1
Wyoming Game and Fish Department	5
Little Snake River Conservation District	1
Meeteetse Conservation District	1
Popo Agie Conservation District	1
Teton Conservation District	1
University	
Wyoming Natural Diversity Database	3
Non-profit	
Ducks Unlimited	2
Jackson Hole Land Trust	1
The Nature Conservancy	3
Wyoming Outdoor Council	1
Private (consultant)	
Alder Environmental, LLC	1

To find out what type of monitoring and assessment data is useful to stakeholders, we asked respondents to select from several options of different data categories. The top five types of data identified as “useful” were: information to identify targets for conservation (76%), updated wetland mapping (70%), documenting changes to habitat (64%), documenting results of restoration projects (57%), and information to identify targets for restoration (54%). These results were not surprising given that over half of stakeholders responded that they participate in work on wildlife (55%), restoration (58%), and monitoring and assessment (58%), and 46% work directly on land management.

We then asked participants to rate wetland assessment characteristics and/or endpoints based on importance of each for their wetland work. Based on the proportion of survey respondents who replied "Important" or "Very Important", the top characteristics selected were: evaluates wildlife habitat (87%), evaluates function (71%), evaluates ecological condition (68%) and is standardized for Wyoming/region (68%) (Figure 1). Lastly, 2/3 of participants answered that "maybe" they would use a statewide or regional standardized wetland assessment method, however, 80% answered they would have interest in the data.

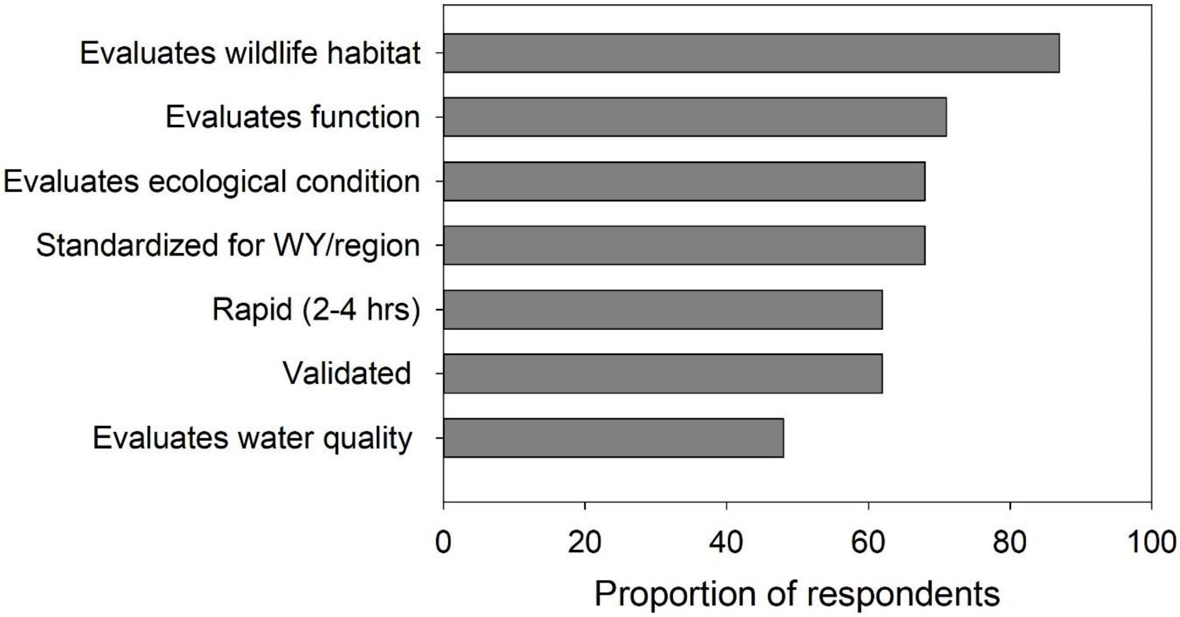


Figure 1. Proportion of survey respondents who replied "Important" or "Very Important" with respect to their need for specific assessment method characteristics.

2.2 Current Wyoming Assessment Methods

We compiled a list of wetland-specific assessment methods based on information from the survey and personal communication with wetland professionals working in Wyoming. We then reviewed each of these methods in relationship to the characteristics identified as important to wetland practitioners (Table 2). We found that wetland assessments in Wyoming are conducted for a variety of reasons by multiple organizations, and consequently, a variety of methods are used. Six of these methods were used at the federal level, while four were developed for use in the region or state. The methods used by USFS (Groundwater Dependent Ecosystems) and BLM (Proper Functioning for Lentic Areas Method) are specific to groundwater-dependent or other specific wetland types.

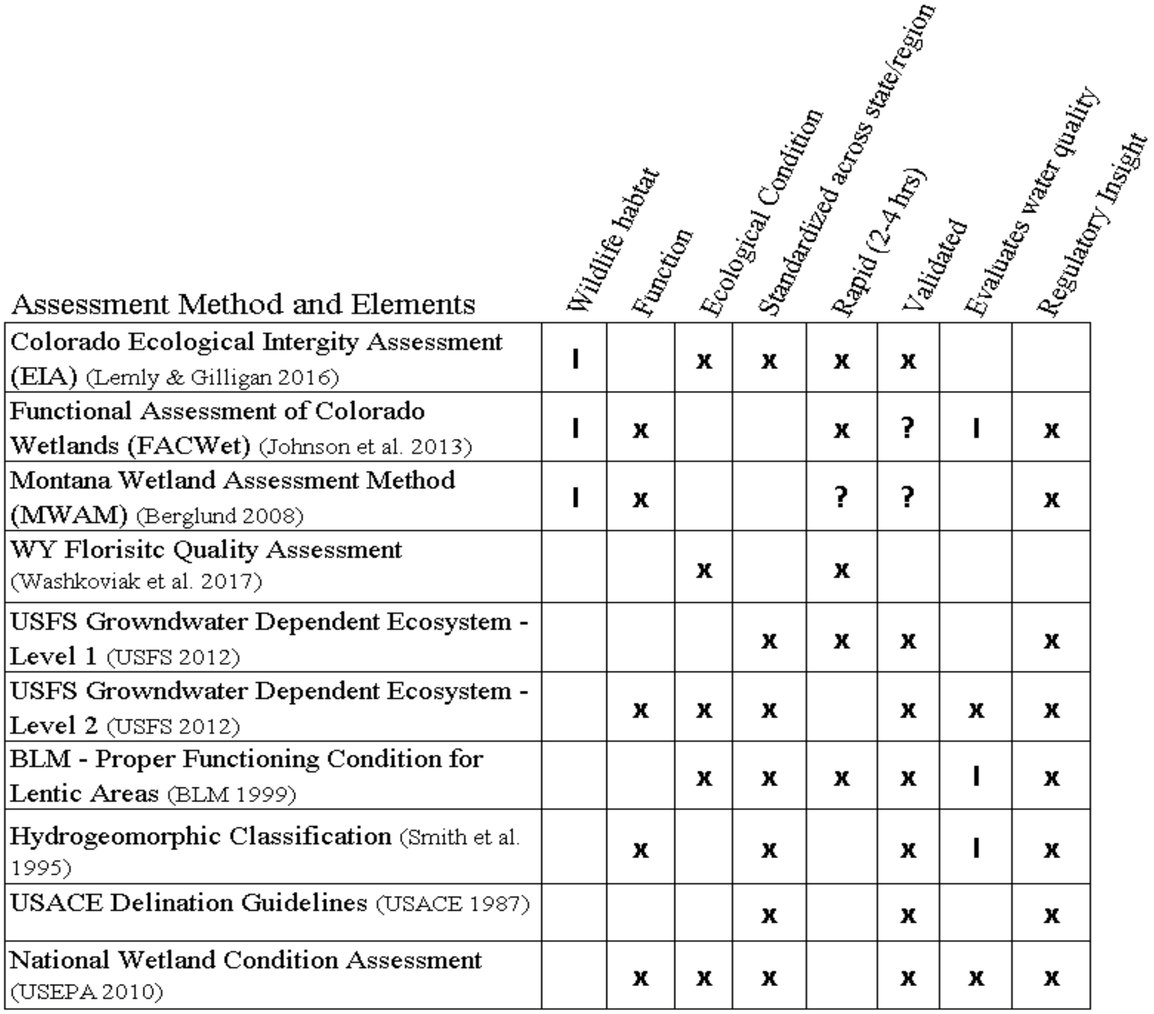
The crosswalk in Table 2 shows how assessment methods relate to sampling elements that survey respondents identified as important. We were not able to determine if FACWet or the MWAM have been validated. EIA, FACWet, and WMAW methods include qualitative metrics or physical or biological data that could be used to indirectly evaluate wildlife habitat potential. EIA methods typically include supplementary intensive measurements of vegetation composition and structure that can be analyzed to answer specific habitat questions, but this data is not included in the overall roll-up of wetland condition scores. The USACE Delineation Guidelines are not specifically a wetland assessment method, but are the standard methods used to establish the existence (location) and physical limits (size) of a wetland for purposes of federal, state, and local regulations.

2.3 What did we learn from the survey?

In review, the stakeholder survey repeated what we had already heard from many managers and wetland practitioners in the state: there is a need for assessment methods that are rapid, regionally standardized, and that evaluate function, condition, and/or wildlife habitat. These methods should ideally provide data for mapping, targeting areas for conservation and restoration, and the ability to assess change in habitat. Based on our review of current methods versus needs identified as important, most methods fall short in directly estimating the quality of wildlife habitat and the ability to use information to target areas for conservation or restoration. We did not include questions that asked about *where* assessment work should be focused, however, meetings with partners throughout the state indicated that the previously identified low elevation wetland complexes remain a priority (WJVSC 2010).

While there is an expressed need for methods that are Wyoming-specific, we found that federal agencies are institutionally mandated to use their own methods and are less likely to adopt a Wyoming-specific assessment method. Federal employees did, however, indicate interest in utilizing the data generated by other sampling methods. Employees from state, non-profit, and local conservation groups identified that they use some of the methods identified in Table 2, but that they have difficulty knowing what method to use based on different objectives/scenarios. For instance, the WGFD does not have standard methods for wetland and riparian assessments, and they are currently searching to find methods that assess wetland condition, wildlife habitat potential, potential impacts from land use, monitor restoration success, or impacts from changes in land management.

Table 2. Summary of the wetland assessment methods used to measure condition and/or function in Wyoming in relationship to desired characteristics based on the survey.



Assessment Method and Elements	Wildlife habitat	Function	Ecological Condition	Standardized across state/region	Rapid (2-4 hrs)	Validated	Evaluates water quality	Regulatory Insight
Colorado Ecological Intergity Assessment (EIA) (Lemly & Gilligan 2016)	I		x	x	x	x		
Functional Assessment of Colorado Wetlands (FACWet) (Johnson et al. 2013)	I	x			x	?	I	x
Montana Wetland Assessment Method (MWAM) (Berglund 2008)	I	x			?	?		x
WY Florisitc Quality Assessment (Washkoviak et al. 2017)			x		x			
USFS Growndwater Dependent Ecosystem - Level 1 (USFS 2012)				x	x	x		x
USFS Growndwater Dependent Ecosystem - Level 2 (USFS 2012)		x	x	x		x	x	x
BLM - Proper Functioning Condition for Lentic Areas (BLM 1999)			x	x	x	x	I	x
Hydrogeomorphic Classification (Smith et al. 1995)		x		x		x	I	x
USACE Delination Guidelines (USACE 1987)				x		x		x
National Wetland Condition Assessment (USEPA 2010)		x	x	x		x	x	x

2.4 Developing a Wyoming Wetland Assessment Method

When this project began, part of our original objective was to develop a Wyoming-specific assessment program to quantify the condition and value of wetlands in highly managed landscapes. As we navigated this process, we concluded that developing an entirely new assessment program was not a priority of wetland stakeholders in Wyoming. Without stable funding resources for testing and validation, method development would be an inefficient use of resources without a commitment to adopt these methods from land managers and other users in the state. We did, however, continue our efforts to successfully develop the Wyoming Wetland Invertebrate Metric (WWIM) (see Section 7 for details) since we were well underway with development before the project began.

WYNDD is often asked for guidance about the different types of methods available and how to choose the appropriate one based on management objectives and institutional limitations. Instead of developing a new condition assessment program, we seek to strengthen understanding of the resources that are already in place by developing content to help land managers better understand the methods that are currently available, the types of data that are produced, and how to adapt these methods into their own assessment programs. We hope that understanding the ecological underpinnings of these methods will allow practitioners to better utilize the data produced from these assessments for management.

3.0 Understanding Wetland Assessment Options

3.1 Choosing a Sampling Method

The first step in designing or choosing a wetland assessment program is to determine the management question driving the assessment, the information required to answer that question, and the time, funding, and expertise available to obtain the information. As Stein et al. (2009) stated, "Rather than focusing on details of one specific method or debating the merits of one method over another, discussion should focus on the institutional structure and goals for which the methods are developed, tested, and ultimately implemented. It is critical that management needs drive the selection of an assessment approach and not the other way around." Asking the right questions from the beginning and designing assessments around specific policies and regulations are key to narrowing the knowledge-to-action gap in freshwater management (Kuehne et al., 2017). The objectives of the survey design must be stated precisely, and quantitatively, to guide the selection of the best survey design.

Generally, most methods focus on the assessment of the ecological integrity of wetlands, largely driven by a component of the 1972 US Federal Water Pollution Control Act (the "Clean Water Act" or CWA) to restore and maintain "the chemical, physical, and biological integrity of the Nation's waters". There is general acceptance of ecological integrity as a conservation goal, and over the past three decades, many methods have been developed to evaluate the complex ecological condition of freshwater ecosystems using observable field indicators that produce cumulative condition scores that inform ecosystem management (Kuehne et al., 2017).

However, it is important to point out the difference between methods that assess "function" versus those that assess "condition". Functional assessments generally focus on the capacity of a wetland to perform specific functions, for example, biogeochemical cycling or hydrologic storage, whereas condition assessments provide an integrated score for overall "ecosystem integrity" in which the functional capacity is inferred. The intended application of the data and endpoint should inform which method is appropriate.

3.2 Understanding Scale

The geographic scope of an assessment project can range from site to continent, and directly influences the potential outcomes and applications of the data collected. A number of sampling methodologies have been developed in the past twenty years to monitor wetland condition at a variety of spatial scales (Adamus, 1993; DeKeyser et al., 2003; Lemly and Gilligan, 2013; Olsen et al., 2019; U.S. Environmental Protection Agency, 2011; Vance et al., 2012). If you want to make inferences at the basin or state scale, spatially-explicit random sampling methods are required to scale-up results, however, communicating information on specific locations is lost during the roll-up summary of results. This is especially true for sites on private land that can only be identified at the township level. If management questions are about specific locations, sites can be targeted to answer the site-specific questions, but results cannot be projected onto other locations. Overall, it is important to understand the implications of the sampling scale, and how selecting points vs. polygons and sampling bias influences the results (see Olsen et al., 2012; Olsen and Kincaid, 2009; Stevens and Olsen, 2004).

3.3 Wetland Classification

The overall framework for an assessment survey design is defined by the classification of wetland types, or target population, included in the study and the geographic scope, or site selection, needed to answer management questions (Sutula et al., 2006). The primary goal of classification is to reduce the effect of within-class variability on the assessment scores to better discern differences in condition among wetlands. Ideally, the target population is precisely defined to meet the objectives of the study. Most wetland studies in the region combine classification categories that best describe wetlands of interest. For example, the current classification system used in Wyoming (see Washkoviak et al. 2018a) includes a combination of Hydrogeomorphic (HGM; Brinson, 1993), and vegetation-based classifications such as National Wetland Inventory (NWI; Cowardin et al., 1979) and Ecological Systems (Comer et al., 2003).

3.4 Setting expectations – defining reference condition

Assessments estimate ecological condition or function by integrating landscape and field metrics that focus primarily on the landscape setting and the physio-biological structure of a wetland in relation to reference sites for each wetland type. Reference sites ideally represent the natural variability of an “expected” reference condition. The scores for reference sites are used to provide benchmarks in setting qualitative condition category boundaries (e.g., Good, Fair, Poor) and to identify departures from an expected ecological condition.

The selection of criteria for defining reference condition has a direct effect on the thresholds set for the condition or function category boundaries. Therefore, selection criteria for reference condition must be explicit and specific for each study. Ideally, reference sites are those in minimally disturbed condition (MDC), representing the best approximation of “naturalness” or “biological integrity” on the landscape (Stoddard et al., 2006). Reference condition in most of

Wyoming's agricultural basins is best defined as least disturbed condition (LDC), "in the best available physical, chemical and biological habitat conditions given today's state of the landscape" (Stoddard et al. 2006). Because LDC can be different from MDC, reference sites may represent a condition that does not reflect the full potential for biological integrity.

There are different approaches to identifying reference sites, but most studies select sites utilizing a combination of targeting wetlands based on best professional judgement from local practitioners and selection based on evaluation of ambient distributions from study sites. Recent work on defining reference and baseline condition in human-dominated systems (see Kopf et al., 2015 for review) are valuable for providing insight on one of the most challenging aspects of developing and implementing an assessment study in highly-managed river basins.

3.5 Assessment Frameworks and metrics

Many mechanisms to protect, manage, and restore freshwater systems depend on the accuracy, efficiency, and defensibility of assessment data. Currently, a three-tiered approach to wetland assessments is recommended by the U.S. EPA, with each tier increasing in degree of effort, cost, and scale:

- Level 1 assessments, or wetland profiles, are broad in geographic coverage and are used to characterize land use and the distribution of resources, such as wetland types, across the landscape. These assessments primarily utilize digital information or remote sensing data in a Geographic Information Systems to provide a "desktop analysis" of wetlands at the landscape scale.
- Level 2 assessments evaluate the condition of individual wetlands using field-based methods that focus on indicators, including anthropogenic disturbances, also known as stressors, which are rapid and easy to measure. Level 2 Rapid Assessment Methods (RAMs) are used throughout a number of regions in the USA because they provide an on-site assessment of wetland condition with relatively little effort (Fennessy et al., 2007). Common RAMs estimate the ecological condition of the wetland landscape, by integrating metrics that focus primarily on hydrology, and physical and biological structure (Table 3, in section 4.1 below, lists example metrics). RAM metrics focus on observable stressors and disturbances known to degrade the ecological integrity of wetlands. Metric scores and identification of stressors are incorporated into a wetland profile to provide information about the integrity of a basin's wetland resources. Field sampling generally takes 2 - 4 hours to complete.
- Lastly, Level 3 assessments utilize more intensive methods, such as measures of diversity, to collect quantitative field data using metrics of biological integrity. Types of level 3 data include plant and animal species lists, macroinvertebrate sampling, soil profile characterization, and water quality measurements. Field sampling generally takes 6 – 8 hours to complete.

Depending on the availability of resources and the scope of a study, assessments can combine approaches from different levels to produce data at the required level of detail. The overall goal of most of these approaches is to provide a rapid, repeatable, and scientifically-defensible evaluation of the overall ecological condition of a wetland. At each wetland, field metrics are evaluated using descriptive ratings. The metrics typically assess four wetland attributes: Buffer, Hydrology, Physical Structure, and Biological Structure. Each field metric is developed with the assumption that it reflects a readily observable aspect of the complex ecological structure and condition of a wetland ecosystem. Metrics currently used in the region focus heavily on identifying the severity of anthropogenic disturbance, or "stressors", associated with degradation of wetland ecosystems. Metric values are then "rolled-up" or combined into a score that is used to describe wetlands along a condition gradient in relation to reference condition.

Assessment methods are based on the use of observable field indicators as surrogate for direct measures of condition. Therefore, field metrics must be calibrated and validated with independent data (see Karr and Chu, 1997; Stein et al., 2009; Sutula et al., 2006). It is vital to spend time understanding the assumptions and premises behind each wetland assessment method before applying a study design and condition metrics in a new study area.

4.0 Review of Wyoming's Wetland Program 2010-2020

This section describes the variety of projects the program has supported from 2010-2020. Final reports describing the results and methods used for individual basin assessments can be found on the WYNDD website (www.uwyo.edu/wyndd). Data is available at the site-level in GIS and Access databases stored at WYNDD. Please note that all data collected on private lands is sensitive and is not shared to exact location unless the landowner agreed to in a signed waiver.

4.1 Wetland Condition Assessment Studies

In 2010, several studies identified the need for more detailed basin-level assessments in Wyoming : the Wyoming Wetlands Conservation Strategy (WJVSC, 2010), the State Wildlife Action Plan (Wyoming Game and Fish Department, 2010) and a Level 1 wetlands assessment (Copeland et al. 2010). The study by Copeland et al. (2010) was pivotal in providing a landscape-scale geospatial assessment of wetlands to prioritize the next stages of wetland assessment work in Wyoming. In addition to mapping, wetland complexes were quantified as a function of their biological diversity, protection status, susceptibility to climate change, and proximity to sources of impairment. The study identified lower elevation wetland complexes as the least protected, in the poorest condition, and the most vulnerable to future land use change.

The Wyoming Joint Ventures Steering Committee utilized this information to inform the identification of nine priority wetland complexes to concentrate conservation project and assessment work. The priority complexes are: Bear River, Goshen Hole, Laramie Plains, Little

Snake River / Muddy Creek, NE Wyoming (Little Missouri River / Belle Fourche River / Beaver Creek), Red Desert / Great Divide Basin, Upper Green River, Snake River Valley (Jackson), and Wind River Basin (Figure 2). These priority basins were selected based on diversity, high project interest and opportunity, and unique ecological value.

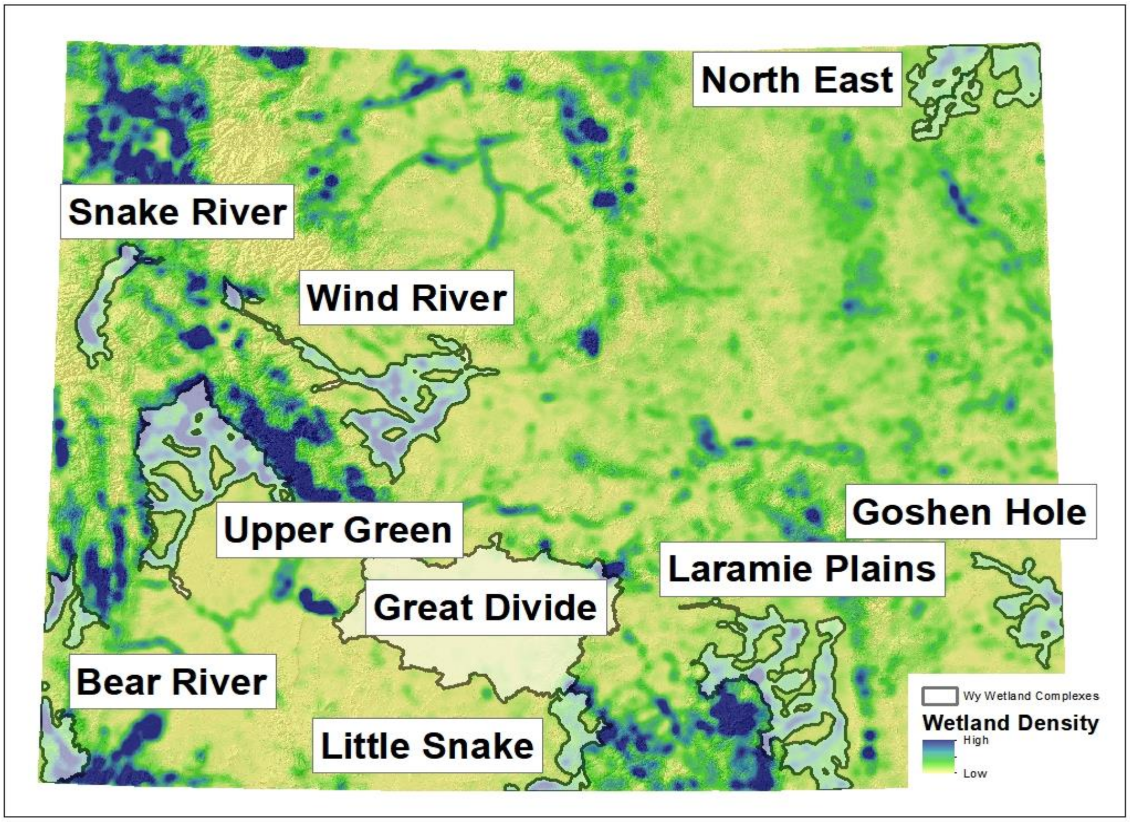


Figure 2. Thirty-one wetland complexes identified as having high concentrations of wetlands. From Copeland et al. (2010). Priority complexes are shown in dark blue.

To date, landscape profiles and wetland condition assessments are completed for five of the nine priority wetland complexes, led by partnerships between TNC, WGFD, and WYNDD. Most of the funding for these assessment projects came from the U.S. Environmental Protection Agency's Regional Wetlands Program Development Grants, supplemented by matching funds from Ducks Unlimited, WYDEQ, WGFD, WYNDD, and TNC.

The first wetland assessment project in the Upper Green River (Tibbets et al. 2015) used the USA RAM method (U.S. Environmental Protection Agency, 2002), that was later evaluated and adapted for use in Wyoming (WYRAM). Wetlands in the Goshen Hole (Tibbets et al. 2016a), Laramie Plains (Tibbets et al. 2016b), Little Snake River Basin (Washkoviak et al. 2081a), and Great Divide Basin (Washkoviak et al. 2081b) were all sampled and analyzed by adapting methods from the Colorado Natural Heritage Program's Ecological Integrity Assessment (EIA) (Lemly and Gilligan 2012).

Both WYRAM and EIA methods are based on the concept of ecological integrity as an assessment of the structure, composition, function, and connectivity of an ecosystem as compared to reference ecosystems. The overarching goal of the EIA framework is to provide a rapid, repeatable, scientifically defensible evaluation of the ecological condition of a wetland. EIA methods were developed by NatureServe to assess the condition of wetlands across broad landscapes (Faber-Langendoen et al., 2011) and have been refined by several regional wetland programs to specifically address wetland conditions in the Intermountain West (Lemly and Gilligan, 2013; Rocchio, 2007; Vance et al., 2012).

In the assessments of the Goshen Hole, Laramie Plains, Little Snake, and Great Divide wetlands, we applied Level 1 landscape profile and Level 2 field metrics based largely on the EIA methods developed by Lemly and Gilligan. (2012, 2013). Field indicators or metrics were evaluated at each wetland based on narrative ratings of four attributes: Landscape Context, Hydrologic Condition, Physicochemical Condition, and Biotic Condition (Table 3 and Table 4). The field metrics were assumed to represent a visible quality of a wetland ecosystem's complex ecological structure and function. Separate "stressor" metrics focused heavily on identifying the severity of anthropogenic disturbance associated with degradation of wetland ecosystems. Metric scores for each of the four attributes were combined into an overall EIA score that can be used to describe wetlands in relation to a reference condition.

Additional level 3 data on plant species composition and structure, soil profile characterization, and water quality measurements were collected in all four projects. Bird surveys were conducted at wetland sites in the Laramie Plains and Goshen Hole and macroinvertebrate sampling occurred in the Little Snake and Great Divide Basin (see results in Section 3 of this report).

Table 3. Ecological Integrity Assessment attributes and indicators.

Attributes	Indicators and Metrics
Landscape Context	• Landscape Fragmentation • Buffer Extent • Buffer Width • Buffer Condition
Hydrologic Condition*	• Water Source • Hydrologic Connectivity • Alteration of Hydroperiod
Physicochemical Condition	• Water Quality • Algal Growth • Substrate/Soil Disturbance
Biological Condition	• Relative Cover of Native Plant Species • Absolute Cover of Noxious Weeds • Absolute Cover of Aggressive Native Species • Mean C • Structural Complexity

Table 4. Summary of the year, level, site attributes, and surveys completed during wetland condition assessments for priority basins/wetland complexes in Wyoming.

		Level 1		Level 2 Attribute Metrics				Level 3 Biological Data			
Basin/Wetland Complex	Survey Year	Landscape Profile	NWI / LLWW (updated mapping)	Landscape Context	Physico-chemical Condition	Hydrologic Condition	Biotic Condition	Plant Species Survey	Bird Survey	Macro-invertebrate Survey	Data Repository
Upper Green River	2012	x		x	x	x	x	x			TNC/WYNDD
Laramie Plains Basin	2013	x		x	x	x	x	x	x		TNC/WYNDD
Goshen Hole	2014	x		x	x	x	x	x	x		TNC/WYNDD
Great Divide Basin	2015	x	x	x	x	x	x	x		x	WYNDD
Little Snake River / Muddy Creek	2016	x	x	x	x	x	x	x		x	WYNDD

4.2 Summary of Assessment Data

4.2.1 EIA Scores

Figure 3 shows the summary data for the 353 wetlands surveyed in the five basins in Wyoming listed above. “A” wetlands are at or near reference condition, are intact, and function within their natural range of variability. “A” wetlands typically exist in un-fragmented landscapes, with little to no surrounding land use stressors, invasive species are generally absent, and natural hydrologic functions are intact. As scores decrease, wetlands begin to deviate from their natural range of variability due to anthropogenic influences such as invasive species invasions, hydrologic modifications, and landscape fragmentation.

Surveys indicate 11% received an A condition score (Figure 3). Most wetlands sampled were ranked B (56%) or C (27%) indicating a slight or moderate deviation from reference condition.

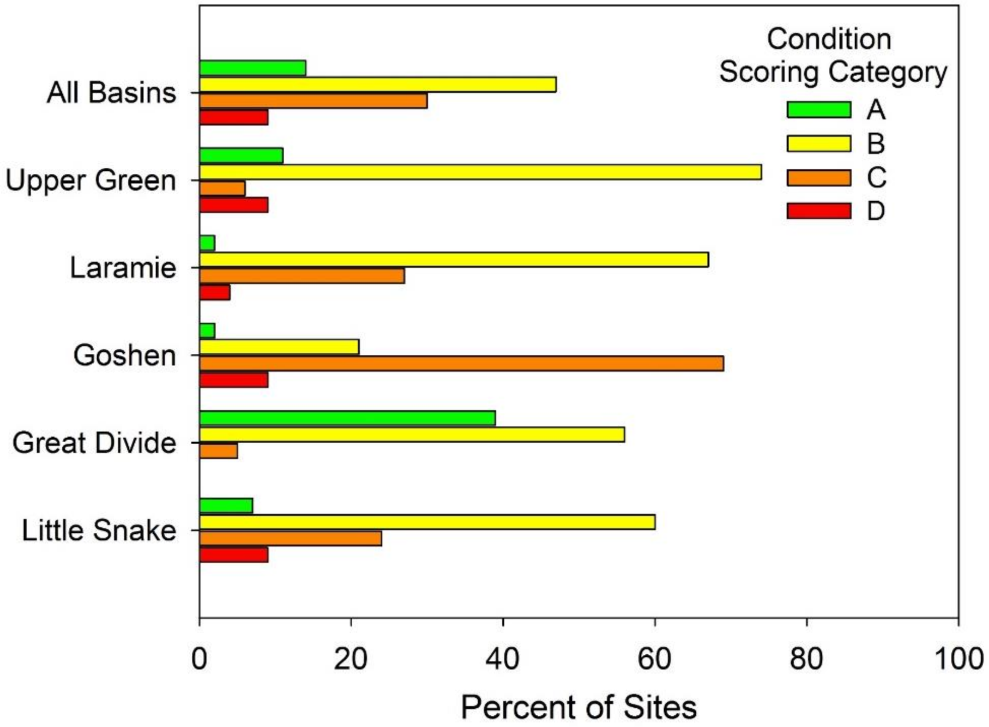


Figure 3. Ecological Integrity assessment condition scores for all sampled wetlands

Wetlands in the Laramie Plains, Upper Green and Little Snake basins occur in landscapes dominated by hay production and cattle grazing. Goshen Hole had the worst condition because much of the area is dominated by row crop agriculture which is scored more harshly because it typically results in more intensive landscape fragmentation, soil compaction, and hydrologic modifications compared to hay production and cattle grazing. Large dams and two major canals in Goshen Hole also negatively influenced scores based on basin-wide hydrologic alterations that affect wetland and riparian areas in the basin.

The Great Divide Basin is a significant landscape for conservation because it was, at the time of sampling, in the best condition with the highest proportion of A and B wetlands. The only available water comes from precipitation and snow melt which limits agriculture and development. The major threat to wetlands in the Great Divide basin come from natural resource extraction. We did not gain access to sample wetlands in existing in oil/gas fields we so we cannot report on the condition of wetlands in these locations. We did, however, sample the Chain Lakes Wildlife Habitat Management Area prior to the expansion of oil and gas extraction in the area. These data can be used as a baseline to understand how resource extraction is currently affecting wetland condition.

4.2.2 Indicators of Disturbance

We recorded indicators of disturbance or “stressors” within a 500-meter wide buffer around the sampled wetland and within the wetland assessment area boundary. Potential indicators of disturbance include natural phenomena or human-caused land management impacts that can negatively influence a wetland or reduce its ecological condition. These stressors can be used to identify the most prevalent impacts affecting wetland health in a given area and can help land mangers change and address disturbances that are under their control.

Figure 4 shows the top five stressors found across all sampled basins. The percent of sites with each stressor varies by basin, however results from the Great Divide basin skew results since so few stressors were affecting those wetlands. For example, 80% of sites sampled overall had invasive species present. Only 43% of wetlands in the Great Divide Basin had invasive species but 83 – 97% of sites sampled in other basins had invasive species present. Between 56 and 86% of wetlands were within 500 meters of a road or 2-track, 32-69% of wetlands were grazed, and 38 -35% had soil degradation due to pugging from livestock, wild horses, and native ungulates. Irrigation infrastructure affected 56% of all sampled wetlands but these results are also skewed by the Great Divide Basin. Only 10% of wetlands there (n = 7) were potentially affected by irrigation but 47 – 79% of sites sampled in other basins were affected.

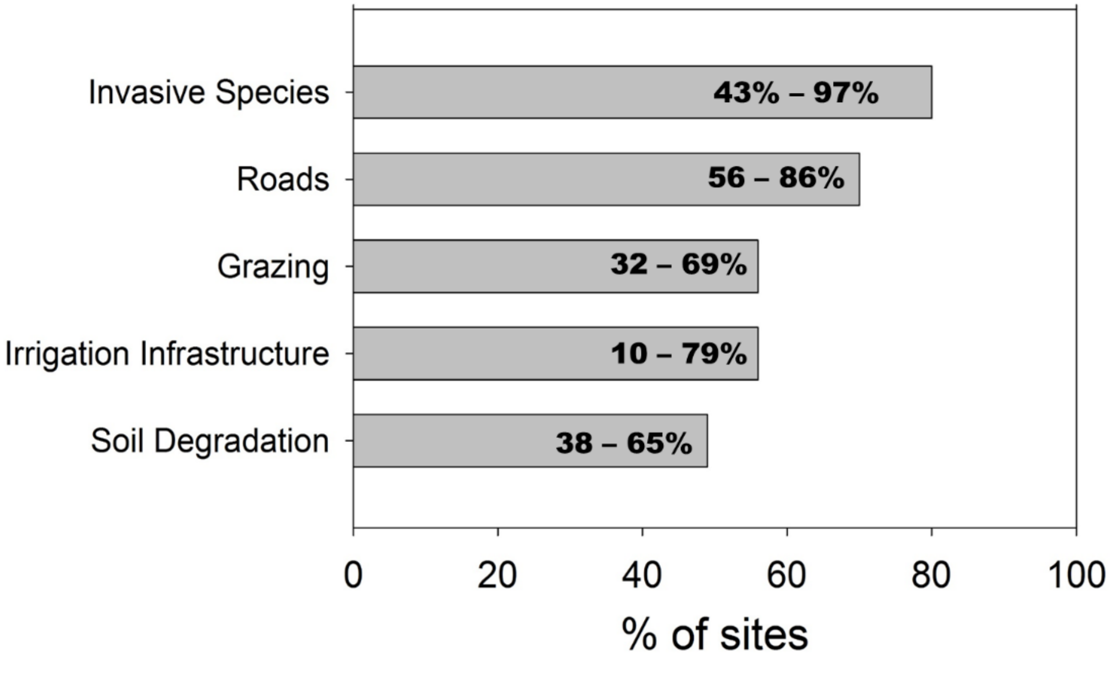


Figure 4. Percentage of sites with "stressors" present expressed as a range.

4.2.3 Hydrologic Modifications

Hydrology is the primary driver of the processes that establish and maintain wetlands, including ecological, physical, and chemical processes that sustain ecosystem functions and associated services and values to people (Mitch and Gosselink, 2000). Therefore, it is important to identify alterations to the natural hydrologic regime that may detrimentally affect the structure and function of a wetland. We used the Landscape Hydrology Metric (LHM) (Tibbets et al. 2015) to calculate the hydrologic condition metrics. LHM incorporates landscape-level data identifying alterations to hydroperiod and water source, along with field data characterizing wetland soils.

Historical wetlands with no visible hydrologic alterations represented 29% of wetlands sampled (Figure 5). Hydrologic modifications were observed at 71% of wetlands sampled, of these, 50% of sites were considered altered-hybrid which have both natural water sources and hydrological alterations affecting water availability, 15% were considered supported by irrigation infrastructure, and 6% were completely created by irrigation and occur in areas where no natural water source can be identified.

Assessment methods that equate human influence to a decline in condition can lead to misleading results for individual wetlands, and give an inaccurate profile of the wetlands in a basin. For example, if irrigation creates wetlands where they would not exist otherwise (see, for example, Peck and Lovvorn, 2001), or increases the size of already-existing wetlands, then the net effect of irrigation basin-wide may be to provide more wetland habitat. This created or augmented habitat may lack some of the integrity of natural wetlands, but it has more wetland habitat value than does non-wetland. Understanding the values of whole landscapes in this way, including a spectrum of natural, to historic, to hydrologically-altered, to created wetlands, is necessary for effective management of these systems.

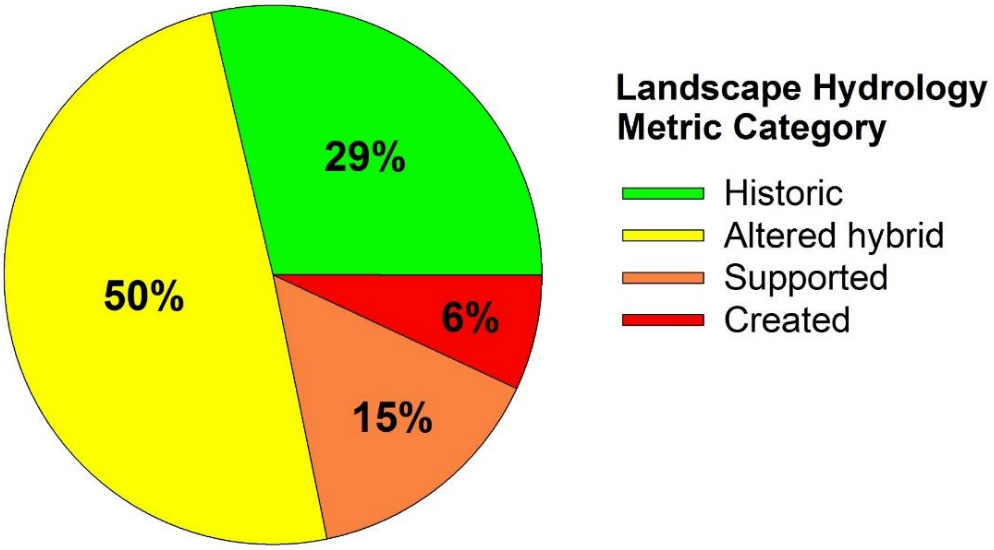


Figure 5. Percentage of sites by LHM category.

4.2.4 Sample bias considerations

In the assesement of the Upper Green River Basin wetlands (Tibbets et al. 2015), cumulative distribution function plots (CDF) were used to estimate the percentage (by area) of all the wetlands in the study area with a WYRAM score (indicating ecological integruty) equal to or less than a particular value. The CDF plots were constructed from the WYRAM scores from the sampled wetlands, which constituted 28% of the wetland acreas in the study area. The range in WYRAM scores was divided into disturbance classes, and the CDF plots allowed us to estimate the percentage (and the standard deviation) of the wetland acreage in the study area within each disturbance class. CDF estimates are useful for initial quantification of wetland condition within a basin, but one of their assumptions, that the data are obtained from a random sample, may be difficult to meet. For example, our data from the Upper Green River Basin assessment violate that assumption: we were denied permission to sample many wetlands on private lands, and so our data are biased toward public lands.

4.3 The National Wetland Condition Assessment

Every 5 years the EPA samples and reports on trends of wetlands in the conterminous U.S as part of the National Wetland Condition Assessment (NWCA). In 2011 sampling in Wyoming was conducted by the Colorado Natural Heritage Program. In 2016 sampling was conducted by WYNDD. The next round of sampling will be completed in 2021. All NWCA methods and data are publicly available through the NWCA website.

4.4 Avian Richness Evaluation Method

A main objective of this project was to validate the "Avian Richness Evaluation Method" (AREM) habitat suitability tool for wetland birds using bird survey data for one ecoregion in Wyoming. Work began on this objective in January 2016, including a one-day meeting of the AREM working group in Jackson, Wyoming that included WGFD (Susan Patla), WYNDD (Lindsey Washkoviak), and TNC (Teresa Tibbets). During this meeting, the working group identified the use of bird surveys conducted in 2014 and 2015 in Goshen Hole (Tibbets et al. 2061a) and Laramie Plains (2016b) to focus further analyses. In addition, the group identified gaps in the AREM model that would require work beyond the scope and funding of this project.

Data from 113 wetland sites in the Goshen Hole and Laramie Plains were identified as appropriate for analyses. Each dataset was checked for quality, and transferred into a new database for analysis. The working group further focused the dataset to only include birds that breed in wetlands. This resulted in the production of a dataset of breeding birds from Goshen Hole and Laramie Plains that can be used to validate the AREM tool when the model parameters can be updated.

The major challenge in satisfying this objective was underestimation of the amount of time and resources required to adequately address unexpected data gaps in the AREM model. Before starting work, the working group was optimistic that the model was at a stage appropriate for validation. Further analyses indicated that gaps in the bird habitat data in the AREM model were resulting in incorrect habitat scores for certain birds. The working group addressed this challenge by deciding to continue to focus work on the bird survey datasets to better fill voids in the AREM habitat data for wetland birds. Because we have spent the time cleaning and organizing the bird survey data set, the quality of data used to update AREM in the future will be improved and applicable to habitat characters associated with the presence/absence of each species.

The expected outcome of this project is to provide wildlife managers with a user friendly, Wyoming-specific tool to quantitatively assess the potential species richness and habitat value, or suitability, of wetlands for birds. This valuable information can be used to identify areas of high conservation and restoration potential. At this point, we have produced a valuable dataset for breeding wetland birds that can be used as the next step in fine-tuning the AREM model.

4.5 Wetland Mapping

The most comprehensive wetland data set of wetland distribution is available from the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI). NWI is a nationally uniform system developed to describe and map that nation’s wetlands. Wetland polygons are attributed with Coward classifications that represent a wetlands vegetation composition and hydrologic regime (Cowardin et al 1979).

NWI is currently the best data set available for selecting potential wetland sampling sites and to complete level 1 analyses. Much of the mapping for our region was completed in the 1980’s by hand drawing wetland boundaries on acetate overlays of aerial photos that were then turned into paper maps and subsequently digitized. Digital data for all of Wyoming is publicly available at the USFWS NWI website.

There are efforts in Wyoming to update the NWI mapping. St. Mary's University of Minnesota has been updating NWI mapping with contracts from federal agencies and other entities across the U.S. Part of that work involves updated NWI mapping on Bureau of Land Management (BLM) lands in selected areas in Wyoming.

The updated mapping utilizes new methods to determine wetland boundaries and assigns the Landscape, Landform, Waterbody, Water flow path (LLWW) classification developed by USFWS (Tiner, 2003) to wetland polygons. LLWW coding allows managers to estimate wetland functional potential for wetlands. The updated NWI maps are submitted to USFWS to be incorporated into the nationally available dataset, but the USFWS does not accept the new LLWW codes at this time. These data should be made available to all wetland managers in Wyoming, but no organization is currently acting as the repository for this data (see Section 6.2).

As of 2019 there is updated mapping for the Chain Lakes Wildlife Habitat Management Areas, 6 USGS quadrangles in the Little Snake Watershed, areas of the Popo Aggie River watershed, and BLM and public lands in the Upper Green River watershed. In 2020, additional BLM and tribal lands in the Great Divide Basin and Wind River Basin will be mapped by St. Mary’s University.

The Montana Natural Heritage Program is also updating mapping in unknown portions of Wyoming.

4.6 Macroinvertebrate Index of Biotic Integrity

Statewide managers have emphasized the need for rapid assessment tools, and there is much interest in developing methods using macroinvertebrates as bioindicators for wetlands. One objective of this project is to determine if macroinvertebrates can be used as an integrative indicator of the ecological condition of wetlands in the intermountain basins of Wyoming. The goals are two-fold: 1) develop a list of aquatic macroinvertebrate taxa for wetlands that occur in Wyoming and 2) develop a macroinvertebrate-based indicator of biotic integrity (IBI) that is responsive to human disturbance gradients across a variety of wetland types. We provide a full report of the MMI study in section 7 of this report, below.

4.7 Identifying At-Risk and Vulnerable Wetlands in Wyoming

Land managers need tools to identify habitats that are vulnerable to changes in water management and development, and methods that allow them to answer different management questions. In response to this need, we worked with TNC and St Mary's University to develop criteria that allows us to identify at-risk or vulnerable wetland ecosystems due to climate change and other threats. The criteria are based on geo-spatial information that represent indicators of potential condition, function, biodiversity, ecosystem services, indicators of disturbance, landownership, and wildlife habitat value. The geo-spatial data were combined into the WyoWet decision support tool pilot project for the Little Snake River and Popo Agie watersheds in Wyoming.

The WyoWET decision support tool can be found at this link: http://smumn.maps.arcgis.com/apps/webappviewer/index.html?id=043c264a80f842b3a886b0c742ad06a3

4.7.1 WyoWet Data Descriptions

WyoWet combines a variety of publicly available geo-spatial data into one platform and allows users to view wetland polygons and interact with associated data about each polygon that: describes the biological and hydrologic functional potential; ranks its vulnerability to disturbances; displays hydrologic alterations to the landscape; and displays adjacent patterns. WyoWet gives land managers the tools to prioritize restoration, conservation, and protection efforts based on site specific data and ownership/management.

WyoWet relies heavily on updated wetland mapping. Wetland polygons were attributed with the Landscape, Landform, Waterbody, Water flow path (LLWW) classification developed by USFWS (Tiner, 2003) and the classification system of Cowardin et al. (1979).

The various sections of WyoWet are described below.

Biologic and Hydrologic Functions

LLWW and Cowardin codes were combined to estimate functional potential for all wetlands and riparian areas in the study areas (GeoSpatial Services Saint Mary's University of Minnesota, 2018). The final analysis of these combined coding systems resulted in the identification and classification of important wetland functions. A ranking process was devised based on whether or not a particular wetland provides a function. For each function a wetland provided, a value of "High", "Moderate" or "No function" (for that category) was given.

Hydrologic Alterations

NWI modifier codes (Cowardin et al., 1979) were used to identify wetlands that have been diked, impounded, and excavated. Additional geospatial data on points of diversion and irrigation could be incorporated to identify hydrologic alterations at different scales.

Sensitive Species

Wetlands that are important to Species of Greatest Conservation Need (SGCN) were identified by predictive habitat models generated by WYNDD. Predictive habitat models represent predictions of where a taxon might occur, based on the similarity in environmental characteristics of an area to those found at points of known occurrence for the taxon. The environmental gradients used to predict distribution generally include climate, land cover, topography, substrate, and hydrology. Total diversity as well as diversity by taxonomic groups are provided for each wetland polygon. Additional information about these models can be found on the Wyoming Species List of the WYNDD website (http://www.uwyo.edu/wyndd/).

Climate Resilience

Climate resilience represents the relative ability of habitats within a landscape to survive or recover from a change. Scores were calculated from models including topographic complexity, water availability, land protection, and landscape integrity generated by TNC, WYNDD, and WGFD. Additional information about the modeling approach can be found in the statewide vulnerability assessment (Pocewicz et al., 2014)

Development Vulnerability

Development vulnerability represents the likelihood of a wetland to experience future energy (wind and oil and gas) and residential development. Vulnerability scores were calculated from models generated by TNC, WYNDD, and WGFD. Additional information about the modeling approach can be found in the statewide vulnerability assessment (Pocewicz et al., 2014)

5.0 Wyoming Wetland Program Evaluation

The Wyoming wetland program, largely consisting of partnerships between WYNDD, TNC, and WGFD, was originally tasked in 2010 with completing wetland profiles and ecological condition assessments to collect critical baseline data for identified priority basins. Now we take a step back to review our assessment program to see if we are still asking the right questions, using the right methods, and presenting data in a way that is useful to land managers and easy to understand.

As described in the sections above, we provided the first landscape profiles and assessments of ecological condition for wetlands in five of the nine priority basins in Wyoming. In addition to basin-level condition scores, we also collected information on potential indicators of disturbance present on the landscape and completed comprehensive surveys of wetland plant communities and soil profiles. Together, this information provides wetland managers a baseline for better understanding that extent of wetlands resources, the status of ecological condition across the most common wetland types, and the extent of hydrologic alteration and human disturbance on the landscape. In addition, data collected from the intensive vegetation and soil surveys are being used by ecologists at WYNDD to write descriptions of wetland and riparian ecological systems in Wyoming, to appear in the Wyoming Field Guide on the WYNDD website (http://www.uwyo.edu/wyndd/).

While we did meet the original objectives of the program, we learned a lot about the applicability of our assessments for management questions and insight into how the needs of the state have evolved over time. Below are three questions we should be asking in the future.

1. Are there better methods to answer Wyoming's needs?

The Ecological Integrity Assessment methods were originally designed to identify historical wetlands that exist independently of human actions and are worthy of protection. While this is very important, EIA does not provide the information needed to quantify the functions and values that poor condition or human altered wetlands provide. Many of the low-scoring wetlands that are supported or created by irrigation infrastructure also harbor substantial biodiversity, host multiple species of concern, and are highly productive systems. We feel that if we focus only on condition, we are missing an opportunity to understand the role these systems play in our landscape. We need a new way to communicate the importance of wetlands in these highly managed systems so we can understand what will be gained or lost under changing water management scenarios.

2. Are we collecting data at appropriate scales?

Results from our surveys are rolled up and presented at the basin scale. This is partly because of how the original question to collect baseline data for the 9 basins was asked, and partly because we cannot present site-specific data collected on private lands without permission. Basin scale data is important for understanding overall trends, but many land managers want to be able to pinpoint specific locations for conservation or specific disturbance indicators to manage.

Our efforts also collected valuable level 3 data on vegetation structure, water quality, and soil profiles that was only minimally summarized in the basin reports. This raw data could be used to answer a multitude of specific management questions related to wetland characterization and wildlife habitat suitability; however, we currently lack the structure to effectively share this data (see below).

3. Can we better share collected data?

Wyoming currently lacks the infrastructure to easily share wetland data. Land managers need data digitally available so they can easily view, sort, and analyze it to meet their specific management questions at varying scale. WyoWET is a good first step at compiling publicly available geospatial data so that land managers can identify areas for protection, conservation, and preservation. But we do not currently have a way to make site specific data easily available while maintaining landowners' rights to privacy.

6.0 Wyoming Wetlands – Looking Forward

6.1 Threats from climate change

Climate change threatens the future of Wyoming's wetlands through changes in historical temperature and precipitation patterns. Temperatures in the western U.S. have already increased by over 1.5 °C and are projected to increase by 2 - 5 °C by the end of the century (Adhikari and Hansen, 2019; Deser et al., 2014; Dettinger et al., 2015; Johnson et al., 2005; Rice et al., 2012; Walsh et al., 2014). Precipitation projections are more variable, but studies generally predict more extreme precipitation events (larger rain or snow storms followed by prolonged periods of drought) with overall decreased precipitation in the southern U.S. and at lower altitudes and increased precipitation over the northern U.S. with increasing rainfall in higher altitudes (Dettinger et al., 2015; Erwin, 2009; Walsh et al., 2014). Longer and more severe droughts are also expected to increase in frequency for some regions. The Intergovernmental Panel on Climate Change in 2001 predicted a 66 -90% increase in mid-continent drought frequency over the next century.

Studies show that temperature increases are more extreme in winter months, resulting in more precipitation falling as rain and less as snow (Barnett et al., 2008; Polley et al., 2013; Walsh et al., 2014). Projections from Maurer et al. (2002) show 4% more precipitation will fall as rain instead of snow for every 1^0C of warming. This change results in less snowpack and earlier snowmelt in the western and northern U.S (Dettinger et al., 2015; Dwire et al., 2018). In 2014, the Intergovernmental Panel on Climate Change predicted a 25% decrease in spring snow cover for the Northern Hemisphere by the end of the century. Earlier snowmelt and more frequent and extreme rain events are leading to increased spring flooding resulting in less late-season water storage and lower instream flows for snowmelt-mediated systems (Dumanski et al., 2015; Johnson et al., 2012; Safeeq et al., 2013).

Wetland systems are extremely vulnerable to changes in hydrologic regimes (Erwin, 2009; Fu and Burgher, 2015). Wetland hydrologic regime (the patterns of water depth, duration, frequency, and timing) is the single most important factor dictating the distribution of wetland types and the establishment and maintenance of wetland structure, processes, and function (Mitch and Gosselink, 2000; van der Valk and Mushet, 2016). For some systems, more extreme precipitation events or more frequent flooding will increase water availability to wetlands which can create more stable water levels, shifting seasonal and temporary wetlands into more permanent states (Anteau et al., 2016). In other systems, more frequent drought conditions and increased evapotranspiration rates will decrease water availability, shifting wetlands to less stable hydrologic regimes and transition temporary wetlands into uplands (Dwire et al., 2018; Johnson et al., 2005; Middleton and Kleinebecker, 2012). Groundwater-dependent wetlands will likely see a decrease in water availability if groundwater levels decrease due to less recharge and increased groundwater use for human needs as more snow turns to rain (Dwire et al., 2018; Earman and Dettinger, 2011).

Changes to hydrologic regimes will also impact important wetland processes. The ability of a wetland to store and sequester carbon, release methane, and cycle nutrients, is inextricably linked to hydrology and disturbance patterns. Increased sedimentation, which reduces wetland depth and water storage, is expected from increased runoff from severe storms or higher-volume precipitation events (Gleason et al., 2011; Skagen et al., 2016). Increase runoff could also contribute additional nutrients and toxic substances (e.g., pesticides, heavy metals) to wetlands from adjacent land development which can negatively impact water quality and lead to eutrophication (Pitchford et al., 2012).

Water level fluctuations caused by seasonal droughts and periods of inundation are a normal part of many wetland wet/dry cycles and are required to maintain vegetation zone formation (Anteau, 2012; Anteau et al., 2016; Johnson et al., 2005; van der Valk and Mushet, 2016). Stable water levels reduce vegetation zone formation and result in a loss of plant species diversity (van der Valk and Mushet, 2016). Wetland function and condition will likely be diminished because of changes in plant species composition and habitat structure reducing available habitat for migrating waterbirds and other wetland-dependent wildlife species (Anteau, 2012; Forcey et al., 2011; Johnson et al., 2005; Steen et al., 2014).

Change in species composition occurs at both a local and regional scale as a result of climate change. Models estimate that species will react to climate change and habitat availability similarly to how they reacted to historical periods of drought or increased wetness (Woodward et al., 2010). Species ranges will either contract or expand. Habitat at the southern ends of species ranges will become less suitable. Entire biological communities will shift or be lost, rare species will likely see negative impacts, and there will be increased pressure from invasive species because of changes in hydrology and increased temperature (Association of State Wetland Managers, 2015; Mantyka-pringle et al., 2012; Steen et al., 2016). Wetlands and riparian areas will also act as refugia, providing habitat and migratory corridors as habitat suitability shifts (Fremier et al., 2015; Morelli et al., 2016; Seavy et al., 2009).

Climate change will also indirectly affect wetland function, condition, and distribution. Wetlands are already stressed from adjacent agricultural, industrial, and residential land that compete for available water and land area (Copeland et al., 2010). Drier conditions will increase the demand of water for human uses such as increased agriculture and irrigation (Davis et al., 2010). Wetter conditions will lead to more consolidation draining which can result in more stable water regimes for remaining wetlands and lead to increased overland flow and downstream flooding (Anteau, 2012; McCauley et al., 2015).

What does this mean for wetland managers and conservation? As illustrated above, climate change can disrupt a wetland’s hydrologic and disturbance regime, causing changes in wetland structure and function which will in turn affect species habitat availability and potential ecosystem services humans depend on. The nature of these changes depends on where the wetland sits in the landscape and how it gets its water. Wetland managers must consider current and future water availability at a landscape level for restoration and conservation efforts to be successful.

As indicated above, hydrologic modifications affect water availability to existing wetlands and have created new wetland area in many river basins throughout the state. When we overlay our sampled wetland data with GIS mapping data, we see that 22% of all wetland acres in Wyoming overlap with irrigation. In the sampled basins this number is much higher. Up to 70% of wetland acres in the basins overlap with irrigation. LHM analyses shows us that 71% of wetlands sampled have altered hydrology and 10 – 46% of wetlands are supported or created by irrigation.

This means that the future of Wyoming’s wetlands is strongly tied to our water management strategies. Water shortages due to climate change and predicted drought and increased human population may place pressure on water resource managers and agricultural producers to adopt water efficiency methods that would negatively impact wetland acreage created or supported by irrigation. Conservation and restoration strategies aimed at protecting wetland acreage will fall short of their intended purpose without an understanding of the role between hydrology, and wetland area, function, condition, and value in highly managed landscapes.

6.2 Future Needs of the State

We identified the following needs based on the results from survey respondents, information learned from in-person meetings, and from our professional opinions:

1. Finish Sampling 4 remaining basins: Bear River, northeastern Wyoming (Little Missouri River / Belle Fourche River / Beaver Creek), Snake River Valley (Jackson Hole), and Wind River Basin.

We think it is valuable to continue to use EIA to sample the remaining 4 basins, however it would be useful to incorporate new metrics that quantify wetland function and values in addition to condition.

2. Updated mapping that more accurately delineates wetland boundaries and is attributed with LLWW coding which can be used to estimate potential wetland functions.

Some updated wetland mapping is underway in Wyoming. We strongly recommend all new wetland projects in the state incorporate new wetland mapping with LLWW attribution. All NWI mapping should be submitted to the USFWS to be incorporated into their national program. There is no organization currently acting as the repository for updated mapping. We suggest WYNDD, TNC, or the Wyoming Geographic Information Sciences Center at the University of Wyoming should work with St. Mary's University of Minnesota, the Montana Natural Heritage Program, and other entities to maintain and share LLWW attribution data publicly.

3. Geo-spatial tools that compile publicly available data on wetland type, landownership, biological importance, functional potential, and vulnerability to help land managers target locations for restoration, conservation, and protection

Ideally, the WyoWet concept will be expanded upon through the WYNDD Data Explorer (http://www.uwyo.edu/wyndd/) as additional mapping efforts in Wyoming are completed. Additional data that could be added to the future WyoWet expansions include the extent of modified/irrigated wetlands (Wyoming Wildlife Consultants, 2007) and land management/ownership (Bureau of Land Management, 2010).

4. Create a publicly available toolbox that compares available methods and metrics that answer common assessment and monitoring questions with accompanying information about why the methods and metrics are important and how data are collected, analyzed, and interpreted.

Please see the Colorado Natural Heritage Program's Wetland Information Center, Watershed Planning Toolbox, and Wetland Mapper (all available at https://cnhp.colostate.edu/ourwork/wetlands/) for ideas on the types of information and geo-spatial data Wyoming could make available in the future.

5. Create and maintain a Wyoming wetland website and a data clearinghouse.

WYNDD received an EPA wetland program development grant that will allow them to incorporate information about Wyoming's wetlands into WYNDD's databases and create a new wetlands part of WYNDD's existing web site to make this information readily available. The new wetlands site will be linked to information on web sites of other organizations and thus will be a hub for information about the state's wetlands. The WDGF also maintains the Wyoming Wetland Website (https://wgfd.wyo.gov/Habitat/Wyoming-Wetlands) which provides a host of less technical information that is valuable for public outreach. All these tools must be maintained into the future to keep them relevant and up to date.

6.3 The Future of Wyoming's Wetland Program

Up to this point the Wyoming Wetland Program has consisted of a Wetland Ecologist and Freshwater Ecologist position housed under WYNDD or TNC and a Wetland Coordinator Position housed under Ducks Unlimited and WGFD. None of these positions have funding past January 2020 and the future of the Wyoming Wetland Program is uncertain. Currently there are no organizations planning to continue to develop and maintain Wyoming's wetland assessment and monitoring efforts.

The current strategy for maintaining wetland program projects and personnel on EPA wetland program development grants alone is not sustainable in the long term. To be an effective program there would be ideally a team including a program manager, database developer, GIS specialist, project manager, and seasonal employees. The program manager position must be a permanently funded position housed under a state organization or non-profit.

7. Macroinvertebrate Multi Metric Index

Freshwater wetland ecosystems are highly diverse and productive habitats that provide critical ecosystem services (including water quality improvement, water storage and flood abatement) and support biodiversity (Costanza et al. 1997). Monitoring and assessment methods have become increasingly vital for understanding human impacts to wetlands, and recent national and state programs focus on evaluating the ecological integrity, or condition, of wetlands. The use of indicator metrics is common for physical, chemical, and biological attributes of wetlands that are compared with values expected under reference conditions.

Many ecological integrity assessment (EIA) methods are designed to be completed within a day or less; however, in our experience, many agencies and organizations monitoring wetlands in Wyoming have limited time and resources to hire a 2-3 person field crew to complete a full assessment. For organizations with limited resources, focused biomonitoring on a taxonomic group could be a more time- and cost-effective way to assess ecological conditions.

Macroinvertebrates are the most common indicators of aquatic biomonitoring because they are abundant, diverse, sedentary, long-lived (weeks to years), easy to collect, and their response to perturbations differ, making them an excellent measure of ecosystem quality that may not be detected using standard assessment methods (Rosenberg and Resh 1993; Resh 2008; Barbour et al. 1999). Multi-metric indicators of condition, commonly referred to as an Indices of Biotic Integrity (IBI), have been successfully developed using aquatic insects, snails, annelids, and crustaceans for streams (Barbour et al. 1999; Carter et al. 2006; Karr and Chu 1997); however, development of IBIs for wetland assessment is more recent (Lunde & Resh 2012; Stein et al 2017; Lu et al. 2019) and IBIs have not been developed in the Rocky Mountain region of the U.S.

As part of this project, we used aquatic invertebrate collections and habitat measurements from wetlands in the Little Snake River Basin (Washkoviak et al. 2018a) and the Great Divide Basin (Washkoviak et al. 2018b) to develop a Wyoming Wetland Invertebrate Metric (WWIM), as an integrative indicator of the ecological condition of wetlands in the intermountain basins of Wyoming. The WWIM should be responsive to human disturbance gradients across a variety of wetland types.

7.1 Study Area

We sampled wetlands in the Great Divide and Little Snake River Basins located in Carbon and Sweetwater counties of southcentral Wyoming (Figure 6). This intermountain region is in the Wyoming Basin Level III Ecoregion and is characterized by a semi-arid climate that receives most of its precipitation in the spring (18 – 38 cm annually).

The Great Divide Basin (GDB) is an internally draining basin formed by a split in the Continental Divide. The study area included three large sub-basins that step down in elevation from west to east: the Red Desert, the Chain Lakes Flats, and Separation Flats (Heller et al. 2011). While there is an ~1100 m difference between the highest point in the Ferris Mountains (3050 m) and Separation Flats (1947 m), 80% of the basin falls within the 1947 – 2150 m elevation range (Heller et al. 2011). Drainage basins in the GDB often lack outlets, resulting in temporarily flooded depressions and playas that accumulate dissolved salts left behind by evaporation. Vegetation is characterized by vast expanses of sagebrush steppe intermixed with extensive greasewood flats, pockets of wetland playa, and meadow complexes.

The Little Snake River Basin (LSRB) is located along the western side of the Sierra Madre and varies from 1853 – 2580 m in elevation. The area includes a wide diversity of plant communities, from aspen glades and mixed mountain shrubs at higher elevations, to sagebrush steppe and riparian galleries of cottonwood and willow intermixed with herbaceous wetlands and agricultural regions at lower elevations (Copeland et al. 2010). The study area also includes the Muddy Creek Wetlands Project, the largest constructed wetland complex in Wyoming (WBHCP 2014), which covers 5,000 acres of private and public lands, and includes over 2,500 acres of wetlands located along 6 miles of Muddy Creek near Dad, Wyoming.

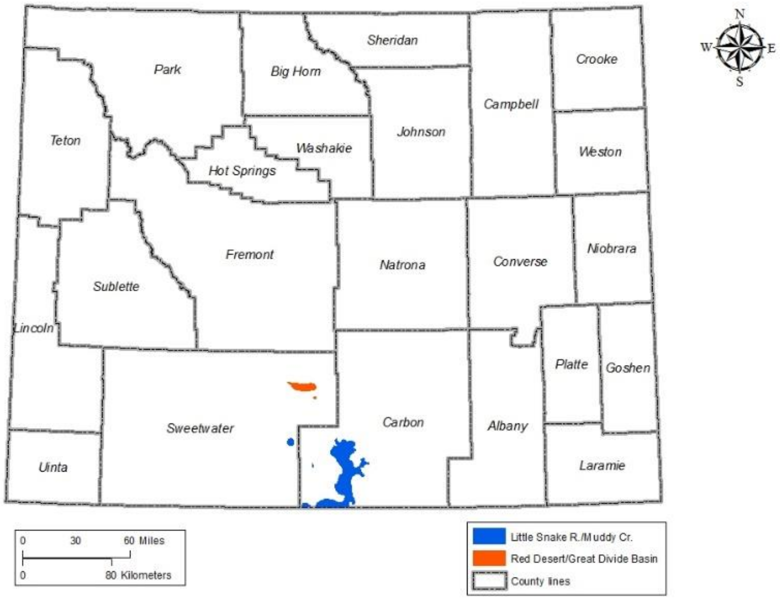


Figure 6. Map of the study area including the Little Snake River Basin (blue) and Great Divide Basin wetland complexes located in south-central Wyoming, USA.

7.2 Methods

7.2.1. Site Selection

We developed the Wyoming Wetland Invertebrate Metric (WWIM) from data collected at 55 wetlands sampled during the wetland condition assessments of the Little Snake River Basin (Washkoviak 2018a) and the Great Divide Basin (Washkoviak 2018b). Those wetlands were classified as alkaline wet meadows (n = 4), emergent marsh (n = 20), playa and saline depression (n = 10), riverine shrubland (n = 10), shrub flat (n = 1) and wet meadow (n = 10).

7.2.2. Environmental Integrity Assessment Scores

Each wetland sampling site was assigned an environmental integrity assessment (EIA) score, using methods developed by Lemly and Gilligan (2012, 2013). The EIA score was calculated from indicators and metrics assumed to represent one of four general attributes (Table 5). The indicators and metrics were measured and the EIA scores were calculated as part of the wetland condition assessments in each of the two study areas.

Table 5. Field attributes and indicators/metrics measured at each wetland using the Ecological Integrity Assessment method.

Attributes	Indicators and Metrics
Landscape Context	• Landscape Fragmentation • Buffer Extent • Buffer Width • Buffer Condition
Hydrologic Condition*	• Water Source • Hydrologic Connectivity • Alteration of Hydroperiod
Physicochemical Condition	• Water Quality • Algal Growth • Substrate/soil Disturbance
Biological Condition	• Relative Cover of Native Plant Species • Absolute Cover of Noxious Weeds • Absolute Cover of Aggressive Native Species • Mean Cover • Structural Complexity

7.2.3. Invertebrate Sampling Methods

We collected aquatic invertebrates using a D-frame dipnet (500-micron mesh). We collected invertebrates for 5 minutes and sampled habitats according to their proportional cover. Invertebrates were preserved in ~75% ethanol and returned to the laboratory for processing. We separated samples into a large fraction (2 mm sieve) and small fraction (500 µm sieve), and we processed the entire sample in separate fractions. We counted and identified individuals under a dissecting microscope using appropriate keys (Merritt et al. 2008, Thorp and Rogers 2014).

7.2.4. Data Analysis

We made the WWIM using standard methods to develop a macroinvertebrate multimetric index using the data collected at all sites. We did not remove a subset of samples because of our low sample size. A total of 44 potential metrics were tested for inclusion in the index. To select individual metrics, we subjected each metric to four filters: (1) discrimination between degraded and reference sites, (2) adequate range in values, (3) responsiveness to EIA scores, and (4) lack of redundancy with other significant metrics. We did not use a signal to noise filter because we do not have repeated samples through time. We used non-metric multi-dimensional scaling to assess the invertebrate communities in each wetland type. We removed invertebrates found only at one site or with total abundance <1%. We developed the metric with Program R (R Development Core Team 2013) using the *plyr* (Wickham 2011), *Matrix* (Bates and Maechler 2013), and *vegan* (Oksanen et al. 2013) packages.

For discrimination efficiency (the first filter), we used EIA scores to rank sites from least disturbed (EIA = 5) to most disturbed (EIA = 0). We selected the top and bottom 7% of sites as the most and least (reference) disturbed sites. For each metric, we made a boxplot showing the median, 25th percentile, 75th percentile, and minimum and maximum values (excluding outliers), and plotted the metrics for the sites on the boxes. Metrics that separated reference and degraded sites, with 60% of reference sites above the 75th percentile and 60% of degraded sites below the 75th percentile (or vice versa for indices with an inverse relationship to EIA score (Barbour et al. 1999), advanced to the second filter.

Adequate range in values (the second filter) removed indices that had a small difference between minimum and maximum scores. For example, richness metrics were removed if the range in richness values was <3, and proportional values were removed when the range was <0.1 (Stoddard et al. 2008).

Responsiveness to EIA scores (the third filter) used linear regression (lm) to test for a significant relationship between the metric and wetland condition (EIA score). Metrics that had a significant relationship ($\alpha \leq 0.05$) were retained. To ensure that metrics were responsive across all wetland types sampled, we used analysis of variance to test if any metric was related to a wetland type. We used Tukey Honest Significant Difference (HSD) to see which metrics differed among wetland types and we retained metrics if they did not have a significant ($p \leq 0.05$) relationship.

Finally, we checked for redundancy among metrics (the fourth filter) using Spearman's Rank correlation. If two metrics in a pair were highly correlated ($p < 0.8$), we retained only one. Metrics were scaled from 0 (degraded) to 100 (high quality) using the 5th or 95th percentiles depending on the direction of the relationship.

7.3 Results

We identified 145 unique taxa of wetland invertebrates belonging to 7 Phyla and 74 families (Table 6). The most common wetland macroinvertebrate taxa were insects (59%), followed by annelids (15%), mollusks (13%) and crustaceans (9%). Of the insects, Diptera were the most abundant order (86%) followed by Hemiptera (3.5%), Ephemeroptera (3.5%), Odonata (2.8%) and Coleoptera (2.6%). Of the non-insect invertebrates, leeches and worms (36%), snails (21%), ostracods (17%) and bivalves (12%) were most numerous. Invertebrate assemblages strongly overlapped among wetland types (Figure 7).

Table 6. Invertebrate counts by wetland type.

Taxa	**Alkaline Wet Meadow**	**Emergent Marsh**	**Playa & Saline Depression**	**Riverine Shrubland**	**Shrub Flat**	**Wet Meadow**
Annelida		**4696**	**3**	**822**	**6**	**817**
Arynchobdella		**44**		**5**		**7**
Erpobdellidae		39		4		7
Erpobdella		38		3		7
Haemopidae		2				
Haemopsis		2				
Macrobdellidae		1				
Oligochaeta		**4493**	**3**	**803**	**6**	**747**
Rhynchobdellida		**71**		**13**		**63**
Glossiphonidae		58		12		61
Actinobdella		3				
Glossiphonia		4				
Helobdella		42		11		61
Marvinmeyeria		7				
Piscicolidae		13		1		2
Myzobdella		13		1		
Arachnida		**70**	**4**	**14**		**24**
Trombidiformes		**70**	**4**	**14**		**24**
Crustacea	**17**	**2121**	**335**	**1108**	**28**	**416**
Amphipoda	**1**	**680**		**194**		**129**
Gammaridae		143		139		59
Gammarus		143		139		59
Hyalellidae	1	535		55		70
Hyalella	1	535		55		70
Anostraca			**47**			
Ostracoda	**16**	**1441**	**288**	**914**	**28**	**287**
Insecta	**12**	**15117**	**210**	**7523**	**77**	**6387**
Coleoptera	**1**	**430**	**15**	**159**		**128**
Curculionidae		1				
Dryopidae		1				
Dytiscidae	1	254	13	97		51
Acilius		9		1		1
Agabetes		1		1		
Agabinus		8		2		
Agabus		67		27		26
Celina		2				
Colymbetes		2				
Coptotomus				1		
Cybister		1		2		

Dytiscus		6		11		
Hydaticus		1				
Hydroporus		1		3		
Hydrovatus		1				
Hygrotus		3	2	1		4
Laccobius		5		2		5
Laccophilus		15		9		12
Laccornis		2				1
Neoporus		7		2		
Oreodytes	1	116	11	34		1
Gyrinidae		2				13
Gyrinus		2				13
Haliplidae		103		16		10
Haliplus		75		13		10
Peltodytes		25		2		
Helophoridae			1			
Helophorus			1			
Heteroceridae		1				
Hydrochidae		1				1
Hydrochus		1				1
Hydrophilidae		64		42		52
Ametor		6				6
Berosus		6		3		
Chaetarthria		1				
Cymbiodyta		2				
Enochrus		11		3		8
Helophorus		25		31		37
Hydrobius				4		
Tropisternus		12				
Scirtidae				1		
Cyphon				1		
Staphylinidae		3	1	2		1
Stenus			1			
Diptera	**4**	**12853**	**86**	**6281**	**28**	**6030**
Canacidae						6
Ceratopogonidae		5914	1	841		1301
Bezzia/Palpomyia		131		9		49
Culicoides		5719	1	816		1239
Dasyhelea		2		2		
Mallochohelea		24				6
Probezzia		31		11		5
Serromyia		5		3		2
Sphaeriomias		1				

Stilobezzia		1				
Chaoboridae		35		1		2
Chaoborus		19				
Chironomidae	3	6749	83	4987	28	4288
Non-Tanypodinae	2	5988	78	4665	26	3781
Tanypodinae		654		289	2	342
Dixidae		7		28		21
Dixa		6		28		17
Dixella		1				2
Dolichopodidae	1			1		
Empididae						1
Clinocera						1
Ephydridae		81	2	24		88
Ephydra		74	2	21		85
Hydrellia						3
Setacera				3		
Muscidae		1				
Psychodidae		16				2
Pericoma/Telmatoscopus		13				2
Psychoda		2				
Ptychopteridae		2		28		109
Ptychoptera				28		109
Scathophagidae		1				
Simulidae		20		359		129
Stratiomyidae		2		3		10
Nemotelus				1		
Odontomyia				2		9
Stratiomys						1
Syrphidae		5				7
Tabanidae		1		1		52
Chrysops		1				28
Silvius				1		
Tabanus						23
Tipulidae		19		8		13
Dicranota				1		1
Erioptera						1
Limnophila/Hexatoma						1
Limonia		1		2		7
Pilaria		1				
Tipula		14		5		3
Ephemeroptera	**4**	**631**	**0**	**298**	**1**	**86**
Baetidae	4	571	0	258	1	71
Baetis		229		83	1	32

Caenis		5				
Cloeon	4	31		6		
Caenidae		59				
Caenis		59				
Heptagenidae				22		15
Heptagenia				20		15
Leptophlebiidae				16		
Leptophlebia				4		
Paraleptophlebia				12		
Siphlonuridae				2		
Siphlonurus				2		
Hemiptera	**3**	**448**	**109**	**302**	**47**	**41**
Corixidae	3	332	24	279	6	30
Hesperocorixa		36	13	153	1	3
Palmacorixa		8	1			6
Gerridae		10		11		7
Limnoporus		10		11		7
Notonectidae		73				
Notonecta		4				
Lepidoptera				**2**		**1**
Noctuidae				1		
Megaloptera				**1**		**11**
Sialidae				1		11
Sialis				1		11
Odonata		**723**		**52**		**43**
Aeshnidae		6		3		
Aeshna		2		1		
Anax				2		
Rhionaeshna		3				
Calopterygidae		4		1		1
Calopteryx		4		1		1
Coenagrionidae		370		47		4
Amphiagrion		23		43		1
Argia		8				
Coenagrion/Enallagma		292		4		1
Gomphidae		3				
Progomphus		3				
Lestidae		256		1		20
Archilestes		62		1		3
Lestes		173				17
Libellulidae		77				18
Erythemis		1				
Sympetrum		76				18

Plecoptera			**308**		**41**
Nemouridae			308		41
Amphinemura			308		41
Trichoptera	**32**		**120**	**1**	**6**
Apataniidae	1				
Apatania	1				
Brachycentidae	16				
Amiocentrus	16				
Brachycentridae	2		6		
Brachycentrus			6		
Micrasema	2				
Glossosomatidae			1		
Hydropsychidae			7		1
Arctopsyche					1
Chematopsyche			1		
Hydropsyche			1		
Psychoglypha			5		
Hydroptilidae	1				
Ithytrichia	1				
Lepidostomatidae			22		
Lepidostoma			22		
Leptoceridae	1				
Limnephilidae	9		79		4
Amphicosmoecus			3		
Ecclisomyia			64		
Eocosmoecus	2				
Glyphopsyche					3
Hydatophylax			2		
Limnephilus	2				1
Nemotaulius	5				
Onocosmoecus			6		
Psychoglypha			4		
Polycentropodidae	1				
Psychomyidae			1		
Psychomyia			1		
Molluska	**4304**	**3**	**1414**	**8**	**680**
Basommatophora	**3274**	**3**	**338**	**8**	**409**
Ancylidae		2		8	
Lymnaeidae	838		103		160
Physidae	1711	1	182		97
Planorbidae	703		52		93
Veneroida	**1000**		**1075**		**271**
Sphaeriidae	1000		1075		271

Nematoda	**783**	**193**		**319**
Mermithida	**7**	**1**		
Nemata	**776**	**192**		**319**
Platyhelminthes	**23**	**100**	**11**	**32**
Tricladida	**23**	**100**	**11**	**32**

Out of the 44 metrics tested, ten separated degraded and reference sites based on EIA scores and passed the first filter of discrimination efficiency (Table 7). All ten of those metrics had large enough ranges between minimum and maximum values to pass the range test (second filter). Six of the ten had a statistically significant relationship ($\alpha \leq 0.05$) with EIA scores and passed the third filter (Table 7).

Of the six metrics that passed the first three filters, four were related to wetland type (ANOVA, $p< 0.05$; Tukey's HSD, $p < 0.05$). Proportion insects in the sample and proportion non-insect invertebrates in the sample were not significantly related to wetland type (ANOVA, $F = 0.85$, $p = 0.52$) and passed the fourth filter. Those two metrics were highly correlated because they add to 100%. Either could be used to assess wetlands, but we choose proportion of insects.

The WWIM score for a site, then, is simply the proportion of invertebtrates in a sample that are insects divided by the total number of invertebrates collected. Higher WWIM scores (those closer to 1) indicate higher-integrity wetlands, and lower scores indicate lower-integrity wetlands.

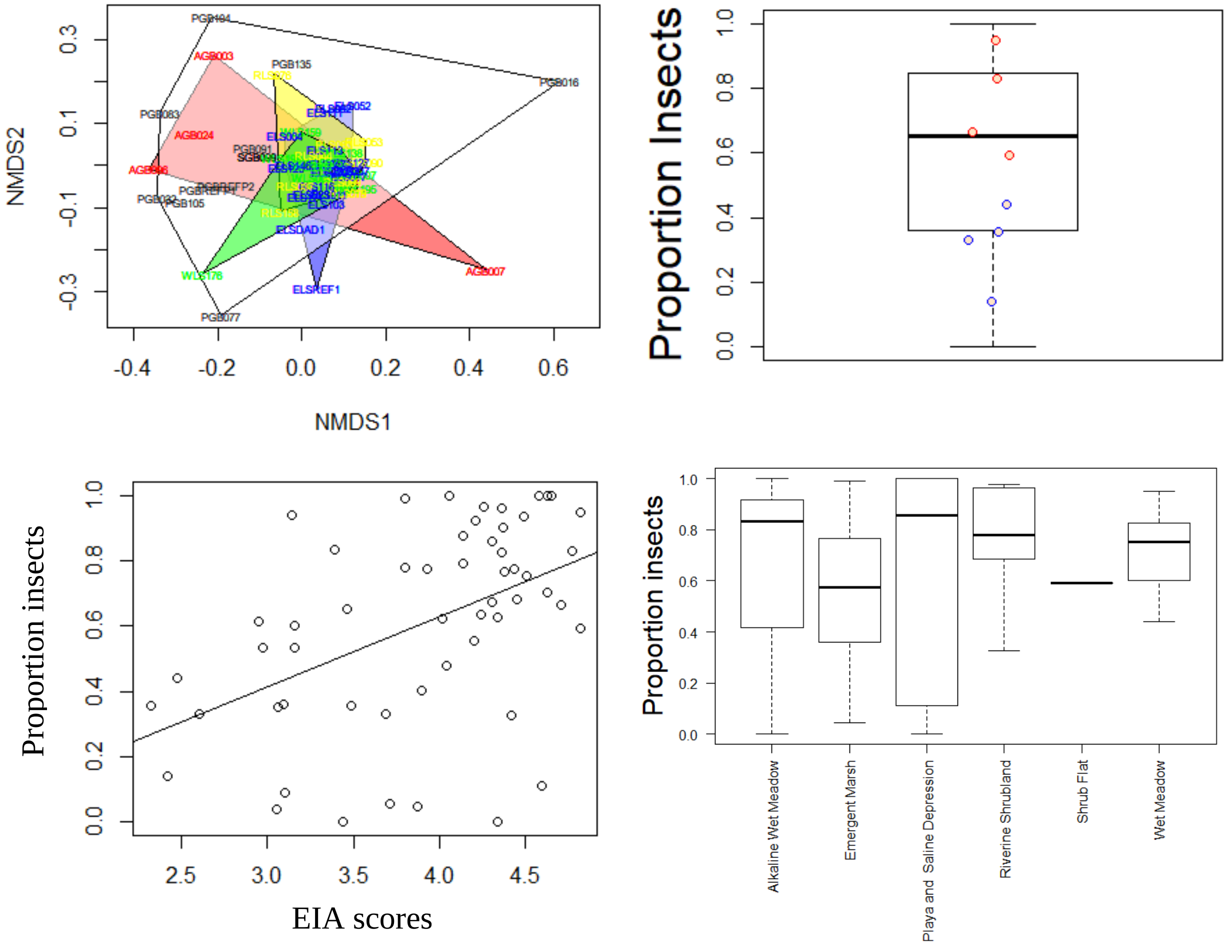


Figure 7. Results of statistical analyses of invertebrate data.
a.) Non-metric multidimensional scaling suggested that invertebrate assemblages in different wetland types largely overlapped. b.) The proportion of insects in the sample differentiated reference (red) from degraded (blue) wetlands. c.) The proportion of insects was positively related to Ecological Integrity Assessment (EIA) scores, where higher values indicated less-disturbed wetlands. d.) The proportion of insects did not vary with wetland type so this metric can be used in all wetland types tested.

Table 7. The 44 invertebrate metrics tested with four filters.
Metrics that passed the discrimination, range, and wetland type filters are marked with "Y" and those that failed are marked with "n". Only metrics that passed a filter were considered in subsequent filters, and an empty cell indicated that a metric failed to pass a previous filter. For the responsiveness filter, "++" indicates a positive relationship and "—" a negative relationship between the metric and the EIS score, and an asterisk indicates a statistically significant relationship ($\alpha \leq 0.05$).

Metric	Discrimination Efficiency	Range Test	Responsive-ness	Wetland Type
Richness	n			
Diversity	n			
Evenness	n			
EPT richness	n			
ETO richness	n			
Proportion EPT	n			
Proportion ETO	n			
Proportion EPT richness	n			
Hilsenhoff's Biotic Index (HBI)	n			
Proportion insects	**Y**	**Y**	++*	**Y**
Proportion non-insects	**Y**	**Y**	—	**Y**
Proportion Crustacea	n			
Proportion Mollusca	n			
Proportion Annelida	n			
Proportion Coleoptera	n			
Proportion Diptera	n			
Proportion Odonata	n			
Proportion Ephemeroptera	n			
Scraper richness	**Y**	**Y**	—*	n
Predator richness	**Y**	**Y**	—*	n
Proportion scrapers	n			
Proportion predators	n			
Shredder richness	**Y**	**Y**	—	
Proportion shredders	**Y**	**Y**	—	
Gatherer richness	n			
Proportion gatherers	n			
Swimmer richness	n			
Proportion swimmers	n			
Climber richness	n			
Proportion climbers	n			
Sprawler richness	n			
Proportion sprawler	n			
Clinger richness	**Y**	**Y**	—*	n
Proportion clinger	**Y**	**Y**	—*	n
Burrower richness	**Y**	**Y**	—*	n

Proportion burrower	n			
Metric	Discrimination Efficiency	Range Test	Responsive-ness	Wetland Type
Proportion Oligochaeta	n			
Proportion Leeches	n			
Proportion Tanypodinae/Chironomidae	n			
Proportion Chironomidae/EPT	n			
Proportion Chironomidae/ETO	n			
Proportion tolerant taxa (>7)	n			
Proportion super tolerant taxa (>8)	n			
Proportion sensitive taxa (<6)	**Y**	**Y**	—	n

7.4 Conclusions

In Wyoming, wetland ecosystem monitoring and assessment programs are critical given the historical loss of 38% of wetland area (Dahl 1990), and the vulnerability of these ecosystems to future development and climate change (Copeland et al. 2010, Pocewicz et al. 2014). This is the first multi-basin study of wetland macroinvertebrates, and our results provide information on the identity and diversity of taxa that inhabit a suite of different wetland types. Except for a handful of published studies on saline playas in the Laramie Basin (Hart & Lovvorn 2000, 2003, 2005) and constructed emergent marshes in Jackson Hole (Cooper & Anderson 1996), this is the first comprehensive survey of invertebrates in different wetland types within Wyoming.

The proportion of insects in wetlands is a simple metric that may be used to assess ecosystem quality. The assessment may be done in the field by an individual with general knowledge of invertebrates. For example, most insects can be differentiated from non-insect invertebrates by having 6 legs. Using the proportion of insects to assess wetland condition can be done rapidly and easily incorporated into protocols. The proportion of insects is related to better ecosystem quality in streams, and we found the same relationship here. Insects vary in their tolerance to degradation (Barbour et al. 1999), but class Insecta is generally more abundant in less disturbed aquatic habitats. Non-insect invertebrates are generally thought to be more tolerant of disturbance and include taxa such as scuds (amphipods), worms, and leeches; however, mean tolerance value of an assemblage (HBI) did not discriminate among reference and degraded sites. Therefore, the proportion of insects in a wetland measured more than tolerance value.

Interestingly, all final metrics except the proportion of insects differed among wetland types and these metrics may be useful in future studies to discriminate among types. For example, some invertebrates can survive drying and the invertebrates in these types of wetlands likely have strategies to survive such events. We found fairy shrimp in some wetlands and these crustaceans are adapted to living in temporary habitats by rapidly developing into adults, and their eggs are dispersed by wind.

Ecological Integrity Assessments (EIA) (Tibbets et al. 2015, 2016a, 2016b; Washkoviak 2018a, 2018b) provide a holistic assessment of wetland condition, but require a lot of resources (e.g., time in the field). The Wyoming Wetland Invertebrate Metric (WWIM) is potentially useful because it can be completed in <1 hour per site and is so simple that it may be used by citizen science programs. For example, many multi-metric macroinvertebrate IBIs are more resource intensive than the WWIM because they require picking, sorting, and identifying taxa in addition to field sampling.

Further intensive wetland macroinvertebrate sampling is needed to validate the use of the WWIM across wetland types in Wyoming and other states.

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