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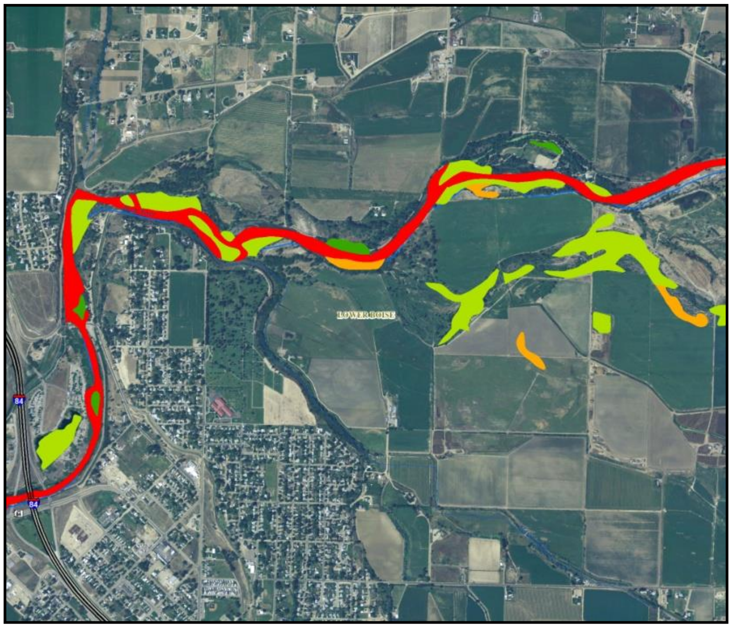
Development of a landscape-scale wetland condition assessment tool for Idaho



Wetland condition, Lower Boise River

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Abstract

Watershed-scale land uses and human activities affect the integrity and condition of wetlands across the landscape. The intensity of development, proportion of human land use, and environmental setting interact to determine wetland condition at finer spatial scales. Based on these premises, we used GIS to develop a landscape-scale model to predict wetland condition. The initial model focused on northern Idaho and southwestern Idaho. These regions both have extensive wetland impacts due to development and hydrologic alteration, but contrast greatly in environmental settings. The model was developed using existing spatial layers of stressors known to directly and indirectly affect wetland condition. These include land use (e.g., urban, agriculture, forestry, livestock grazing, etc.), development (e.g., density of population, roads, railroads, utilities, mining, industrial sites, dairies, recreation sites, etc.), and hydrologic alteration (e.g., density of canals, wells, reservoirs, etc.). We utilized an existing GIS tool, Analytical Tools Interface for Landscape Assessments, and conducted other spatial analysis to calculate stressor metrics for both subwatersheds (6^{th} level hydrologic unit) and individual wetlands mapped by the National Wetlands Inventory (NWI). Stressor metrics were then correlated with wetland condition determined from field data. Field rapid assessments of condition were conducted at randomly selected NWI wetlands (samples stratified by subbasin and Cowardin class). Existing data from wetland, riparian, and water quality monitoring were also used. Correlation and analysis of variance methods were used to determine which stressors best predicted wetland condition. The model created represents a prototype that will be refined as additional data and analysis are incorporated. The calculated metrics of landscape condition represent a relative baseline for the study area. With modification, this model will eventually be incorporated into a tool that can be used by land managers and planners to conduct GIS-based condition assessments of specific wetland sites across their landscape of interest. This type of landscape-scale wetland assessment can be applied to meet a variety of conservation, monitoring, and restoration planning needs.

Keywords

ATtILA, ecological condition, GIS, Idaho, landscape assessment, metrics, stressors, watershed assessment, wetlands, wetland assessment

Suggested Citation

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Introduction

Background: Landscape-scale analysis is commonly used for assessing the condition, extent, and distribution of watersheds and wetlands (Brooks et al. 2002a, Tiner 2002, Hychka et al. 2007, Mita et al. 2007, Troelstrup and Stueven 2007, Wardrop et al. 2007, Weller et al. 2007, Vance 2009). It is defined as the use of a geographic information system (GIS) and remote sensing to understand the characteristics of watersheds and wetlands across a landscape of interest. Typical assessment indicators include wetland coverage, land use, land cover, and human disturbance (US EPA 2006). These indicators are sometimes incorporated into a GIS model used to estimate condition. Indicators can be based on expert judgment or systematically evaluated based on analysis of on-the-ground condition data (Gergel et al. 2002, Brooks et al. 2004, Hychka et al. 2007, Mita et al. 2007, Troelstrup and Stueven 2007, Wardrop et al. 2007, Weller et al. 2007, NatureServe 2009, Vance 2009). Assessment models based on expert judgment alone are not as scientifically defensible. They lack the ability to objectively estimate accuracy or quantify (with confidence intervals) estimated condition. Regardless of methods used, landscape-scale assessment is a relatively low-effort method that maximizes the quantity, quality, and consistency of wetland data gathered over broad geographic areas (Hychka et al. 2007, Wardrop et al. 2007, Weller et al. 2007, Vance 2009). It can be a cost-effective way for all levels of government and non-governmental organizations to stretch limited assessment dollars.

Several landscape-scale GIS analyses of ecological condition have been conducted for Idaho (e.g., Quigley et al. 1999; Bdour et al. 2001; Oechsli and Frissell 2003; Idaho Conservation Data Center 2006 and 2007; Trout Unlimited 2009). These have focused on watershed integrity and aquatic habitats rather than wetland condition. Nationwide landscape assessments of wetlands have focused on wetland extent, not condition (Dahl 1990, 2000, and 2006). Prior to this project, the only broad-scale analysis of wetlands across large geographic areas of Idaho that integrates information on wetland ecological and recreation significance, threats, and condition is the “Idaho Wetland Conservation Prioritization Plan” (Hahn et al. 2005). Unlike Hahn et al. (2005), this project uses analytical methods to identify indicators of stressors, focuses solely on condition, and incorporates many more metrics of condition.

This project uses an objective, science-based approach to build a landscape-scale GIS assessment of wetland condition for Idaho. The long-term goal of this project is to design a “user-friendly,” reference-based decision-support tool. Objectives of this project are to:

- Develop a prototype landscape-scale GIS model that accurately predicts wetland condition. It will be the foundation for development of a GIS application for the tool, as well as expanded functionality related to predicting the potential of wetlands to provide specific functions.
- Train the model with field data in two ecological sections of Idaho that have high wetland impacts, the Owyhee Uplands (and immediately adjacent areas) of southwest Idaho and the Okanogan Highlands (and immediately adjacent areas).
- Collaboratively develop the assessment tool through Idaho Wetlands Working Group (IWWG) meetings to ensure goals identified in Idaho’s wetland conservation strategy are addressed.

Need for landscape-scale assessment**:** Wetlands provide functions and values greatly disproportionate to the small land area they occupy in the Intermountain West. From 1780 to 1980, approximately 56% (156,200 ha [386,000 ac]) of Idaho's wetlands were lost to drainage, dredging, filling, leveling, flooding, and other anthropogenic alterations (Dahl 1990). Areas of Idaho have experienced even greater wetland losses, mainly due to drainage for agriculture (Quigley et al. 1999). Due to conservation efforts, the rate of wetland loss has decreased during the last 20 years (Dahl 2000, 2006). Landscape-scale assessment is a useful approach for quantifying the condition of remaining wetlands.

Wetland functions and values are well recognized by ecologists and economists (Adamus et al. 1991, Brinson 1993, National Research Council 1995, Novitzki et al. 1996). Functions can be broadly grouped as hydrologic (e.g. surface and groundwater discharge, recharge, and storage), biogeochemical (e.g. food chain support; nutrient, toxicant, and sediment removal or transformation), and habitat. While wetlands with high ecological integrity and function still exist, many remaining wetlands in Idaho have been degraded by hydrologic alteration, pollution, land uses, and other impacts (Quigley et al. 1999). Values derived from wetland function, including those that can be assigned substantial monetary value, can be negatively affected by various impacts (National Research Council 1995, Novitzki et al. 1996). Values include: aesthetics; cultural, historical, and archeological; education and research; floodwater attenuation and storage; open space and recreation; sediment and shoreline stabilization; stream flow augmentation; wastewater treatment; water quality protection; and water supply. Wetland assessment strives, in part, to determine ecological integrity, or condition, as well as function, in context of human and natural disturbance (US EPA 2006).

Greater recognition of these benefits and functions of wetlands has led to strengthened wetland regulations, policies, and conservation (USFWS 1990, 1991). Disincentives for wetland drainage, agricultural conservation programs (e.g., the Wetland Reserve Program), land preservation and retirement programs, wetlands education, ecological research, governmental wetland management programs, impact mitigation, and community involvement have all contributed to slowing wetlands loss (Dahl 2006). Additionally, active wetland restoration, creation, and enhancement have increased acreage of certain wetland types in recent years (Dahl 2006). Wetland assessment, at multiple-spatial scales, feeds information to decision makers, land managers, and stakeholders that is necessary for implementing regulations, policies, and conservation programs.

Despite progress, losses and degradation of wetlands continue. Threats to wetland functions and values can be broadly grouped under hydrologic alteration, water quality impairment, habitat degradation, and alteration of watershed processes. Existing federal wetland protection laws and regulations are often limited in their ability to decrease these threats to specific wetland types. This has left isolated wetlands and other non-jurisdictional wetlands (including some riparian areas and ephemerally moist meadows) vulnerable. In addition, land use planning at state and local levels is often inadequate in preventing wetland loss and degradation. Landscape-scale assessment tools can be used by planners to address issues of wetland loss and disruption of watershed processes.

Certain land uses and improper management clearly cause direct and indirect effects on wetlands. These do not always result in wetland losses, but can cause shifts in wetland type and changes in function (sometimes increasing net wetland area for certain types, including open water ponds). Understanding the extent and distribution of these impacts, or stressors, across the landscape is a key to conservation and restoration of wetlands. Human-caused impacts to wetlands can be magnified by processes including mass earth movement, wildfire, extended drought, and climate change. The following are some documented stressors to wetlands in Idaho (Quigley et al. 1999):

- accidental or intentional introduction of introduced species
- agricultural activities
- beaver (*Castor canadensis*) removal
- dam, dike, levee, diversion construction and maintenance
- discharge of biologic and chemical pollutants
- disposal of dredge spoils or other solid waste
- fire suppression
- flood control and shoreline erosion protection
- groundwater pumping
- livestock grazing
- mining in or near wetlands
- nutrient loading in effluent and runoff
- recreation access improvements
- residential, commercial, industrial development
- road and highway construction and maintenance
- sediment accumulation
- timber harvest

Through public meetings held between 2005 and 2007, the IWWG, a statewide organization of stakeholders, identified the need for consistent and accurate data on wetland locations, quantity, types, condition, function, restorability, and trends. To address these and other issues, IWWG developed the draft “Idaho Wetland Conservation Strategy.” Methods for assessment, monitoring, and tracking wetlands at multiple spatial scales are an important part of the strategy. The landscape-scale wetland assessment tool developed for this project is an integral part of the state strategy.

The draft Idaho Wetland Conservation Strategy is guided, in part, by the U. S. Environmental Protection Agency’s (EPA) “Application of Elements of a State Water Monitoring and Assessment Program for Wetlands” (US EPA 2006). This document describes a three-tiered approach to assessment, with Level 1 focused on landscape-scale analysis. In 2007, Idaho Department of Fish and Game (IDFG) received a Wetland Program Development Grant from the EPA under Section 104 (b)(3) of the Clean Water Act to develop this Level 1 assessment tool. Consistent with IWWG and EPA priorities, this project is the next step in Idaho’s state wetland program.

This landscape-scale analysis can be used by land managers and planners to conduct GIS-based condition assessments of wetland sites and types across broad geographic areas. Many interested organizations have limited resources to conduct site-level assessments across the full range of wetlands in their regions. This integrated approach to assessment, ensures the best use of data and resources. As a result, wetland conservation, restoration, and mitigation activities can be conducted more efficiently and consistently across Idaho.

This project should not be considered a complete assessment of wetland condition or a functional assessment. It is preliminary landscape-scale assessment and has not been ground-truthed. The model will be refined as additional data becomes available. In addition, spatial layers for some important indicators of wetland condition (e.g., noxious weed distribution) were not available. This was not a wetland mapping project, nor a delineation of jurisdictional wetlands.

Study Area

Wetland stressors vary across the landscape in how they impact wetland condition. This is because the primary drivers of wetland formation, function, and condition (e.g., geomorphology, climate, soils, hydrology) change across the landscape (Johnson 2005, Hychka et al. 2007, Vance 2009). Therefore, the landscape context in which assessment occurs is important. Subbasins, or 8-digit 4th level hydrologic units (e.g., HUC8s) (Seaber et al. 1987) and Omernik ecoregions (McGrath et al. 2002) are good ways to synthesize the physical and climatic landscape and analyze wetland impacts.

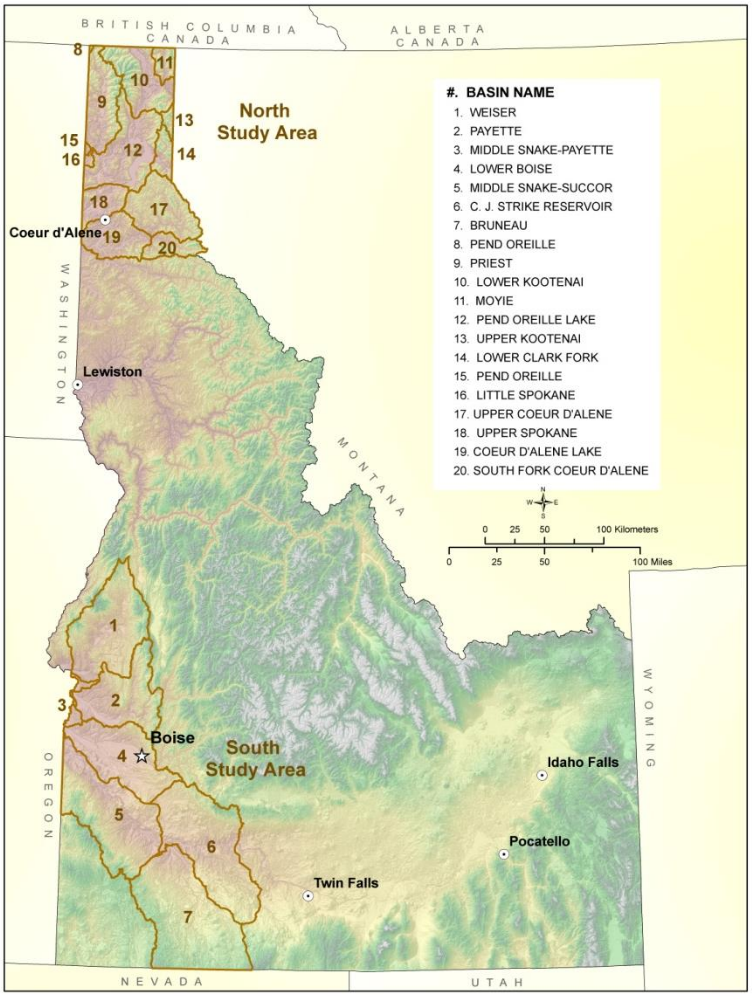


Figure 1.

The 2 study areas chosen for this project were in northern Idaho's "panhandle" and southwest Idaho (Figure 1). The north study area is characterized by mountainous terrain interspersed by broad intermountain river valleys and lake basins where the majority of towns, cities, and agricultural activities occur. The influence of continental glaciations, including moraines, outwash plains, and depressional features (e.g., kettles) are widespread. The climate is cool and temperate with maritime influence and localized rain shadow effects. There are extensive conifer-dominated forests with grassland and savannah ecosystems along the western edge (near Coeur D'Alene). Subbasins in the north Idaho study area include (Figure 1):

- Coeur D'Alene Lake
- Little Spokane
- Lower Clark Fork
- Lower Kootenai
- Moyie
- Pend Oreille
- Pend Oreille Lake
- Priest
- South Fork Coeur D'Alene
- Upper Coeur D'Alene
- Upper Kootenai
- Upper Spokane

Of these subbasins, Coeur D'Alene Lake, Pend Oreille Lake, and Priest encompass Idaho's 3 largest naturally occurring lakes (the level of each lake is now regulated by dams). Emergent wetlands, ranging from narrow fringes where bordered by steep terrain to extensive marshes in broad, shallow bays, are common (Jankovsky-Jones 1997 and 1999). Extensive floodplain, riverine wetlands, and broad valleys are defining features of the Lower Clark Fork, Lower Kootenai, Pend Oreille, Coeur D' Alene Lake, and South Fork Coeur D'Alene subbasins. The Priest and Moyie subbasins also include relatively large rivers with locally extensive riverine wetlands and wide floodplains, but these rivers are mostly higher gradient and flow through steeper walled valleys with narrower riparian zones. In contrast to the Priest and Coeur D'Alene River watersheds, the majority of the Clark Fork, Moyie, Kootenai, Spokane, and Pend Oreille River watersheds occur outside the state. The Clark Fork and Moyie Rivers terminate in Idaho, but the Pend Oreille and Spokane Rivers originate in the study area. The Little Spokane and Upper Spokane subbasins encompass foothill and lower mountains with scattered lakes and numerous small streams. The Upper Coeur D'Alene and Upper Kootenai subbasins are characterized by mountainous terrain that harbors the headwaters of many smaller streams. Subalpine wetlands occur in the Selkirk, Purcell, and Cabinet Mountains in the study area, primarily within the Priest, Lower Kootenai, Pend Oreille Lake, and Lower Clark Fork subbasins. Throughout the study area, but mostly at lower elevations, are numerous but scattered peatland wetlands (primarily fens). They occupy kettles and other depressions (e.g., abandoned river meanders) or occur as floating mats on the margins of lakes (Lichthardt 2004). The Priest subbasin contains the highest concentration of peatlands. Extensive fen and marsh complexes also occur along the lower Coeur D'Alene River.

The north Idaho study area occurs entirely within the Northern Rockies level III Omernik ecoregion. There are 9 level IV ecoregions within the study area (Figure 2):

- Coeur d'Alene Metasedimentary Zone
- Granitic Selkirk Mountains
- High Northern Rockies
- Inland Maritime Foothills and Valleys
- Kootenai Valley
- Northern Idaho Hills and Low Relief Mountains
- Purcell-Cabinet-North Bitterroot Mountains
- Spokane Valley Outwash Plains
- Western Selkirk Maritime Forest

Table 1 shows the proportion of level IV ecoregions comprising each subbasin in the north.

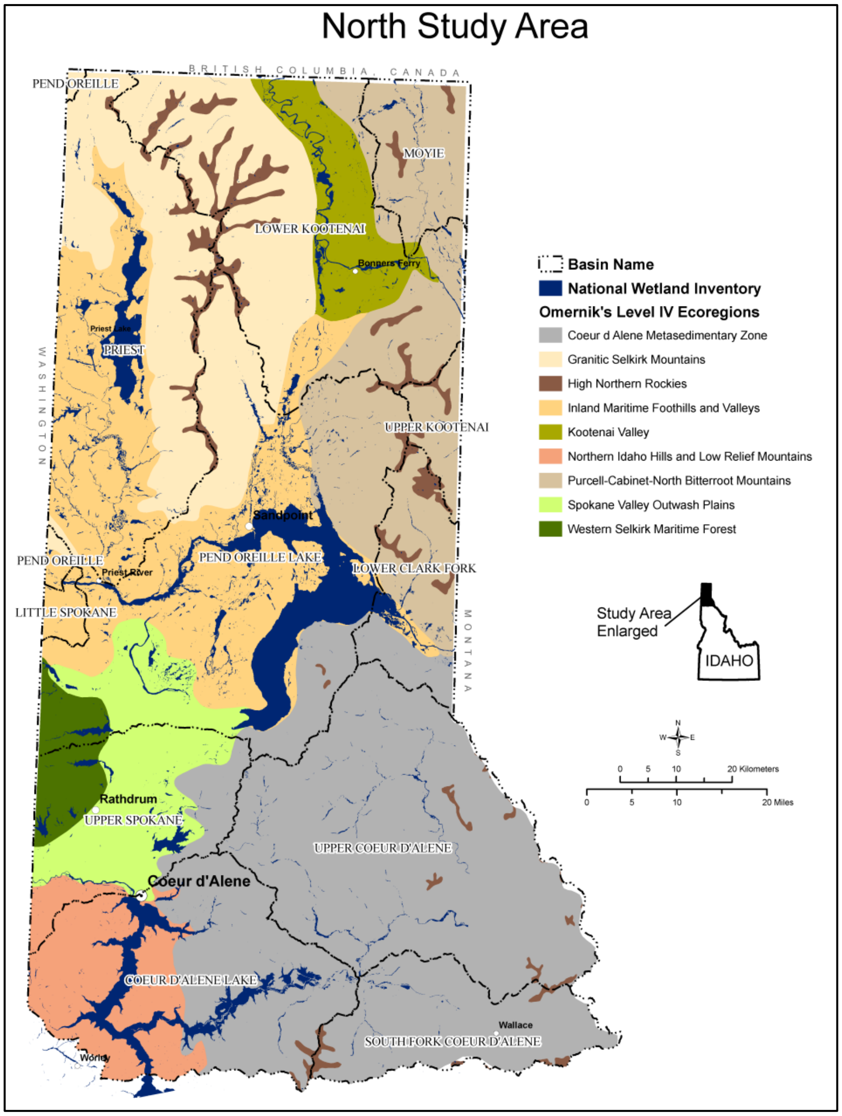


Figure 2.

Table 1.

Subbasin Name--North Study Area	Omernik IV Ecoregion	% of Subbasin
LITTLE SPOKANE	Inland Maritime Foothills and Valleys	97.8
LOWER CLARK FORK	Coeur d Alene Metasedimentary Zone	24.7
	High Northern Rockies	8.9
	Inland Maritime Foothills and Valleys	9.2
	Purcell-Cabinet-North Bitterroot Mountains	54.6
LOWER KOOTENAI	Granitic Selkirk Mountains	40.0
	High Northern Rockies	7.4
	Inland Maritime Foothills and Valleys	5.3
	Kootenai Valley	24.6
	Purcell-Cabinet-North Bitterroot Mountains	20.9
MOYIE	High Northern Rockies	3.7
	Kootenai Valley	1.3
	Purcell-Cabinet-North Bitterroot Mountains	87.7
PEND OREILLE	Granitic Selkirk Mountains	47.4
	Inland Maritime Foothills and Valleys	46.4
PEND OREILLE LAKE	Coeur d Alene Metasedimentary Zone	7.8
	Granitic Selkirk Mountains	12.1
	High Northern Rockies	1.5
	Inland Maritime Foothills and Valleys	48.3
	Purcell-Cabinet-North Bitterroot Mountains	14.5
	Spokane Valley Outwash Plains	11.3
	Western Selkirk Maritime Forest	4.2
PRIEST	Granitic Selkirk Mountains	43.1
	High Northern Rockies	3.9
	Inland Maritime Foothills and Valleys	52.4
UPPER KOOTENAI	High Northern Rockies	10.1
	Purcell-Cabinet-North Bitterroot Mountains	80.8
UPPER SPOKANE	Coeur d Alene Metasedimentary Zone	16.0
	Northern Idaho Hills and Low Relief Mountains	8.7
	Spokane Valley Outwash Plains	57.7
	Western Selkirk Maritime Forest	17.1
COEUR D'ALENE LAKE	Coeur d Alene Metasedimentary Zone	53.7
	High Northern Rockies	0.7
	Northern Idaho Hills and Low Relief Mountains	45.3
	Palouse Hills	0.0
	Spokane Valley Outwash Plains	0.3
SOUTH FORK COEUR D'ALENE	Coeur d Alene Metasedimentary Zone	95.3
	High Northern Rockies	3.4
	St. Joe Schist-Gneiss Zone	0.6
UPPER COEUR D'ALENE	Coeur d Alene Metasedimentary Zone	97.7
	High Northern Rockies	1.2

The south study area is characterized by a warm and dry climate with the majority of precipitation occurring in the winter months or at higher elevations. Extensive semi-arid basaltic and rhyolitic plains dominate, ringed by uplifted ridges and foothills. An arid area characterized by lacustrine deposits of ancient Lake Idaho occurs along the front of the Owyhee Mountains. Conifer-dominated mountainous terrain occurs at the northern and southwest margins in the Blue Mountains and Idaho Batholith. Broad river valleys leave foothills, supporting riverine wetlands and providing irrigation water for large areas of agriculture, as well as the many interspersed towns and urban areas. Large blocks of undeveloped shrub-steppe and annual-dominated grassland, primarily used for cattle grazing, occur at low elevations. Subbasins in the south Idaho study area are (Figure 1) Bruneau, C. J. Strike Reservoir, Lower Boise, Middle Snake-Payette, Middle Snake-Succor, Payette, and Weiser.

With some exceptions, wetlands are small in size and scattered, often associated with springs or created by reservoirs and irrigation, frequently ephemeral or temporary, or restricted to riparian zones of streams and rivers. Wetlands commonly occur on alkaline soil at the lowest elevations along major rivers or in alluvial valleys with high groundwater. Marsh-dominated wetlands created for wildlife habitat and water quality improvement (mainly fed by irrigation return water) are scattered throughout the study area. The Snake River is the defining feature of the C. J. Strike Reservoir, Middle Snake-Succor, and Middle Snake-Payette subbasins. Two large reservoirs occur on the Snake River, created by Swan Falls Dam and C. J. Strike Dam. While Swan Falls occurs in a canyon with limited wetland and riparian habitat associated along its shoreline, C. J. Strike Reservoir occurs in a broader canyon and supports extensive shoreline emergent marsh and scrub-shrub wetlands in the upper reaches where the Bruneau and Snake Rivers enter (Jankovsky-Jones 2001). Below Swan Falls, numerous islands in the Snake River support scrub-shrub and alkaline wetlands. Lake Lowell is another large reservoir in the study area (in the Lower Boise subbasin). It is relatively shallow and has large patches of emergent, forested, and scrub-shrub wetlands along its shoreline. Several large rivers terminate in the study area (Weiser, Payette, Boise, and Bruneau). These rivers formerly had wide floodplains that created broad alluvial valleys. Flood control and upstream dams have greatly curtailed flood flows and/or altered floodplain width on major rivers in the Lower Boise, Payette, and Weiser subbasins. Despite flood control, agricultural, and urban development, forested wetlands dominated by black cottonwood still characterize many riverine systems along the Boise, Payette, and Weiser Rivers (Bottum 2005). Unique, temporary playa wetlands are relatively common on the Snake River Plain south and west of Mountain Home.

The south study area is primarily comprised of the Snake River Plain level III ecoregion. It also includes a portion of the Blue Mountains ecoregion (to the northwest, in the Weiser subbasin) and the edge of the Idaho Batholith (to the northeast, primarily in the Weiser and Payette subbasins, but also along the northern edge of the Lower Boise and C. J. Strike Reservoir subbasins). The Northern Basin and Range ecoregion occurs along the southern part of the south study area, but was excluded because there were no digitally mapped wetlands available for analysis in this area. Eleven level IV ecoregions encompass nearly all the study area (Figure 3):

- Canyons and Dissected Highlands
- Continental Zone Foothills
- Foothill Shrublands-Grasslands

- High Glacial Drift-Filled Valleys
- High Idaho Batholith
- Hot Dry Canyons
- Melange
- Mountain Home Uplands
- Semiarid Foothills
- Southern Forested Mountains
- Treasure Valley
- Unwooded Alkaline Foothills

Table 2 shows the proportion of level IV ecoregions comprising each subbasin in the south.

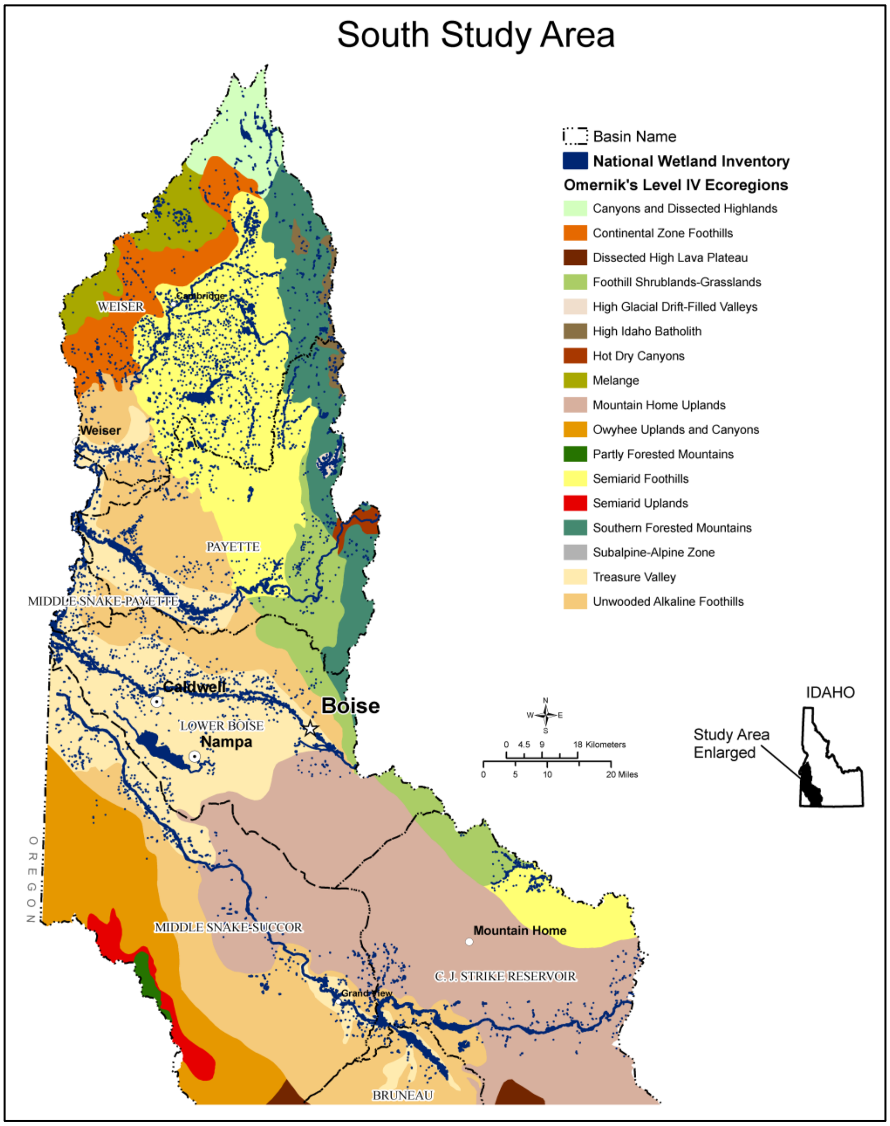


Figure 3.

Table 2.

Subbasin Name--South Study Area	Omernik IV Ecoregion	% of Subbasin
BRUNEAU	Dissected High Lava Plateau	82.8
	Mountain Home Uplands	1.0
	Semiarid Uplands	2.3
	Treasure Valley	1.6
	Unwooded Alkaline Foothills	12.4
C. J. STRIKE RESERVOIR	Dissected High Lava Plateau	25.1
	Foothill Shrublands-Grasslands	4.4
	Mountain Home Uplands	57.8
	Semiarid Foothills	7.7
	Treasure Valley	0.3
	Unwooded Alkaline Foothills	4.7
LOWER BOISE	Foothill Shrublands-Grasslands	9.1
	Mountain Home Uplands	27.0
	Southern Forested Mountains	0.9
	Treasure Valley	48.3
	Unwooded Alkaline Foothills	14.7
MIDDLE SNAKE-PAYETTE	Treasure Valley	50.9
	Unwooded Alkaline Foothills	45.7
MIDDLE SNAKE-SUCCOR	Dissected High Lava Plateau	2.5
	Mountain Home Uplands	22.7
	Owyhee Uplands and Canyons	30.0
	Partly Forested Mountains	1.0
	Semiarid Uplands	3.6
	Treasure Valley	13.5
	Unwooded Alkaline Foothills	26.3
PAYETTE	Foothill Shrublands-Grasslands	14.2
	High Glacial Drift-Filled Valleys	0.9
	High Idaho Batholith	1.3
	Hot Dry Canyons	1.8
	Semiarid Foothills	29.3
	Southern Forested Mountains	18.4
	Treasure Valley	12.3
	Unwooded Alkaline Foothills	21.8
WEISER	Canyons and Dissected Highlands	9.1
	Continental Zone Foothills	17.6
	High Idaho Batholith	1.5
	Melange	10.4
	Semiarid Foothills	40.2
	Southern Forested Mountains	11.4
	Subalpine-Alpine Zone	0.0
	Treasure Valley	2.8
	Unwooded Alkaline Foothills	7.1

Within these two study areas there are 20,878 digitally mapped National Wetland Inventory (NWI) polygons. All of the NWI maps for the north study area have been digitized. In the south study area, NWI digitizing focused on areas with ecologically significant wetlands or higher concentrations of wetlands. Most or all of the Weiser, Payette, and Middle Snake-Payette subbasins have been digitized, while slightly more than 50% of the Lower Boise subbasin (along the Lower Boise River) has been digitized. The basaltic plateaus of the Snake River Plain of the Lower Boise, C. J. Strike Reservoir, and Bruneau subbasin, as well as the arid Owyhee Mountain Front of the Middle Snake-Succor subbasin have not been digitized, but these areas lack significant areas of wetlands. Wetlands of the Snake River valley and canyon have been digitized.

Methods

Landscape-scale wetland assessment literature and models from other states and regions were reviewed for applicability in Idaho. These included national methods (NatureServe 2009), Delaware and Maryland (Tiner 2002a, 2002b, and 2005; Weller et al. 2007), Minnesota (Sands 2002), Montana (Daumiller 2003, Vance 2009), North Dakota (Mita et al. 2007), Ohio (Fennessy et al. 2007), Pennsylvania (Brooks et al. 2002 and 2004; Hychka et al. 2007; Wardrop et al. 2007;), and South Dakota (Troelstrup and Stueven 2007). Most of these landscape-scale analyses used a limited, but relatively similar list of spatial layer inputs to calculate metrics in their condition analyses. Many studies from other states focused on watershed-level analyses or specific focal areas. In general, we found no models suited for direct adoption or use without major modification in Idaho.

Spatial data sources: Based on literature review and availability of spatial data, we organized a list of potential spatial layers available for Idaho that included factors indicating wetland condition on the ground (Table 3). Because there were no prior studies in Idaho of which landscape-scale indicators might best predict wetland condition, we included as many spatial layers for potential indicators as possible. Spatial layers preferably had statewide coverage for inclusion in the analysis. With a few exceptions, all spatial layers were downloaded from the statewide geospatial data clearinghouse, the Interactive Numeric and Spatial Information Data Engine for Idaho (INSIDE Idaho; http://www.insideidaho.org). The wetland map used for this project was the digitized NWI layer for Idaho (http://www.fws.gov/wetlands/data/WebMapServices.html). We also calculated indicator metrics for 12-digit 6th level hydrologic units (HUC12s).

Statewide spatial layers were lacking for some important potential indicators, such as beaver (*Castor canadensis*) presence, herbicide or pesticide use, non-native species abundance, nutrient loading, off-highway vehicle use, recreational and boating impacts, and sediment accumulation. Statewide spatial layers were also lacking for two presumably important potential indicators of wetland condition, recent timber harvest and livestock grazing. To rectify this, GIS models of potential recent timber harvest and livestock grazing were created. This was done via raster calculations (30 m^2 pixels).

Table 3. Spatial layers used to calculate metrics for factors potentially affecting wetland condition.

Land Uses, Activities, or Other Factors Affecting Wetland Condition and Function	Relevant Spatial Layers	Spatial Data Type	Data Sources	Metric Calculated by ATtILA	Supplemental Metric	Reason Metric Not Used
agriculture	National Land Cover Data 2001	grid	US Geological Survey (http://www.mrlc.gov/nlcd_multizone_map.php)	yes		
beaver removal	no statewide coverage	n/a	n/a	no	no	
canals	canals	line	National Hydrography Dataset		yes	
dairies	dairies	point	ID Dept. of Water Resources		yes	
dams and reservoirs	dams; area covered by reservoirs	point	ID Dept. of Water Resources; National Hydrographic Dataset		yes	
diversions	points of diversion; points of use	point	ID Dept. of Water Resources		no	not actual water diversion
dredge spoils or other solid waste disposal	National Pollutant Discharge Elimination System permits	point	US Environmental Protection Agency		yes	
effluent discharge (from industrial or energy facility that alters thermal regime)	National Pollutant Discharge Elimination System permits	point	US Environmental Protection Agency		yes	
impervious surfaces (i.e., roofs, pavement; excessive runoff)	National Land Cover Data 2001	grid	US Geological Survey (http://www.mrlc.gov/nlcd_multizone_map.php)	yes		
flood control and shoreline erosion protection (i.e., rip-rap, dikes, levees)	no statewide coverage available	n/a	n/a	no	no	
groundwater pumping; ex-urban development	wells	point	ID Dept. of Water Resources		yes	
herbicide or pesticide spraying	no statewide coverage	n/a	n/a	no	no	
land subsidence due to extraction of oil, gas, materials	no statewide coverage	n/a	n/a	no	no	
livestock grazing	federal grazing allotments; National Land Cover Data 2001	polygon	Bureau of Land Management; Interior Columbia Basin Ecosystem Management Project; US Geological Survey (http://www.mrlc.gov/nlcd_multizone_map.php)		yes	
mining	Geographic Names Information System; state mineral leases; Federal Mining Claims; Waste Remediation Sites	point	ID Dept. of Lands; US Geological Survey; ID Dept. of Environmental Quality		yes	
non-native species (accidental or intentional introduction)	no statewide coverage	n/a	n/a	no	no	
nutrient loading in effluent and runoff	no statewide coverage	n/a	n/a	yes*		

Table 3. continued.

Land Uses, Activities, or Other Factors Affecting Wetland Condition and Function	Relevant Spatial Layers	Spatial Data Type	Data Sources	Metric Calculated by ATtiLA	Supplemental Metric	Reason Metric Not Used
off-highway vehicle use	no statewide coverage	n/a	n/a	no	no	
oil and gas drilling	oil and gas wells	point	US Geological Survey		no	not significant in ID; some in SE ID
other pollutant discharge	National Pollutant Discharge Elimination System permits; Resource Conservation and Recovery Act	point	US Environmental Protection Agency; Interior Columbia Basin Ecosystem Management Project		yes	
railroads	railroads	line	TIGER 2000 (1:100,000) (www.census.gov/geo/www.tiger/)		yes	
recreation access and navigation improvements	boating access points	point	Bureau of Land Management; ID Parks and Recreation		yes	
recreational and boating impacts to shorelines	no statewide coverage	n/a	n/a	no	no	
residential, commercial, industrial development	National Land Cover Data 2001; population	grid	US Geological Survey (http://www.mrlc.gov/nlcd_multizone_map.php)	yes		
roads and highways (construction and maintenance)	roads	line	TIGER 2000 (1:100,000) (www.census.gov/geo/www.tiger/)	yes		
sediment accumulation	no statewide coverage	n/a	n/a	no	no	
storm water detention pond construction and maintenance	no statewide coverage	n/a	n/a	no	no	
recent timber harvest	National Land Cover Data 2001; NW ReGAP Land Cover Map; Idaho Ecological Systems Map	grid; polygon	US Geological Survey; NW ReGAP; NatureServe		yes	
topographic position of wetland	land position	grid	NatureServe		no	not used; used metrics calculated by ATtILA
toxic element concentration (i.e., lead, selenium, etc.)	Comprehensive Environmental Response, Compensation, and Liability Act; Toxics Release Inventory	point	US Environmental Protection Agency; Interior Columbia Basin Ecosystem Management Project		yes	
utility corridors (powerlines, pipelines, etc.)	powerlines; pipelines	line	Interior Columbia Basin Ecosystem Management Project		yes	
* estimated by ATtILA based on land cover						

Areas of high livestock grazing likelihood were estimated using the following spatial layers:

- For public lands, livestock grazing was most likely to occur on areas equal to:

  National Land Cover Data (NLCD) 2001 layer, codes 71 herbaceous grassland and 81 pasture, hay (these land uses were most highly correlated with livestock grazing, based on field observations), intersected with **Bureau of Land Management non-vacant grazing allotments** and/or **Interior Columbia Basin Ecosystem Management Project (Quigley et al. 1999) active grazing allotments**

- For private and state-managed lands, livestock grazing was most likely to occur where equal to:

  NLCD 2001, codes 71 (herbaceous grassland) and 81 (pasture, hay) (these land uses were most highly correlated with livestock grazing, based on field observations)

Areas of high likelihood of recent timber harvest were estimated to be where:

> **NLCD 2001, codes 41 (Deciduous Forest), 42 (Evergreen Forest), 43 (Mixed Forest), or 90 (Woody Wetlands)** intersect with Northwest Gap Analysis Program's draft land cover layer, codes 155, 156, 157 (harvest regeneration) (available at http://gap.uidaho.edu/index.php/gap-home/Northwest-GAP/landcover/) and Idaho Ecological Systems land cover layer (IDFG 2008), pixels labeled clearcut

***Calculation of landscape and disturbance metrics*:** We examined the feasibility of developing our own GIS model from scratch, or enhancing an existing wetland analysis tool to fit Idaho's needs. Based on advice from Dr. Linda Vance (Montana Natural Heritage Program Wetland Ecologist) and literature review, we chose to use an existing tool to perform the intensive task of calculating metrics. The results would then be modified and added to for development of the Idaho specific landscape-scale assessment tool. Analytical Tools Interface for Landscape Assessments (ATtILA), developed by the US Environmental Protection Agency, Landscape Ecology Branch (Ebert and Wade 2000; available at http://www.epa.gov/nerlesd1/land-sci/attila/index.htm), was utilized to calculate metrics from most indicators (as in Hychka et al. 2007, Troelstrup and Stueven 2007, Vance 2009).

ATtILA is an ArcView 3.x extension in GIS that utilizes various spatial layers commonly used for landscape-scale assessment. ATtILA uses input layers (Table 3) to calculate metrics for landscape, riparian, human stressors, and physical characteristics within specified buffer distances of watersheds, wetland polygons, sample points, or any other land area of interest (i.e., the "reporting unit" (Table 4). It is a powerful computing tool that outputs spatially-linked data tables, eliminating the need for sorting through complex and time-consuming GIS calculations. Outputs can be exported and manipulated into any database software (e.g., MS Access, utilized for this project). We chose NWI polygons (classified by Cowardin et al. 1979) and HUC12s as reporting units. ATtILA calculates metrics within the reporting unit and for riparian zones (i.e., in variable width buffers adjacent to streams running through the reporting unit; 30 m and 120 m buffers were used for this project).

Several technical issues arose with use of ATtILA. One challenge was that many NWI polygons are irregularly shaped or smaller than a 30 m^2 pixel (the resolution of most data inputs used by ATtILA) making ATtILA calculations prone to errors for some polygons. Another complication was that ArcView 3.x Spatial Analyst, required to run ATtILA, is an old program with limited ability to process a large number of reporting units at one time, such as is found in our NWI layer. This prompted us to calculate metrics by 8-digit 4th level hydrologic units (HUC8s). This complicated the process further because many NWI polygons were split between HUC8s. Fundamentally, ATtILA operates most efficiently at the watershed scale, rather than at the wetland-scale. As a result, ATtILA was unable to process about 3.5% of the polygons. In total, 20,158 NWI polygons were processed by ATtILA. The condition of polygons without ATtILA data would later be extrapolated based on the estimated condition of their nearest neighbors. It was also unable to calculate patch metrics (e.g., patch size, density, edge, connectivity, diversity, etc.) without crashing the software (Table 4). These are all potentially important indicators of wetland condition. This may also have been due to the large number of small, irregularly shaped polygons.

Spatial layers needed for calculating landscape-scale assessment metrics with ATtILA were organized. ATtILA inputs were:

- **Reporting Units:**
  - ✓ NWI (http://www.fws.gov/wetlands/data/WebMapServices.html)
  - ✓ Hydrologic Units (Idaho Dept. of Water Resources, 1990, 1:100,000)
- **Land Cover:** NLCD, 2001 (http://www.mrlc.gov/nlcd_multizone_map.php)
- **Elevation and Slope:** National Elevation Dataset (30 m^2 pixels)
- **Streams:** Streamnet (IDFG 2008, 1:100,000; National Hydrography Dataset was too dense with streams to process with ATtILA)
- **Roads:** TIGER/Line files, 2000 (1:100,000, www.census.gov/geo/www.tiger/)
- **Population:** Tele Atlas North America, Inc., ESRI, 2006 (1:100,000)
- **Precipitation:** 18-year mean, total precipitation, 1980-1997, 1 km^2 pixel (University of Montana, Numerical Terradynamic Simulation Group, www.daymet.org/default.jsp)

The need for analysis of additional factors that influence wetland condition was identified. For example, we have numerous layers of point data for factors that have localized and/or downstream impacts on wetlands (e.g., boating access areas, dairies, dams, mines, points of water diversion, pollutant discharge, groundwater wells, etc.). ATtilLA is not a useful tool for calculating metrics for these layers. Spatial analytical tools were used in GIS to calculate metrics for these and other supplemental disturbance indicators (Table 3).

Table 4. Metrics for wetland stressors calculated by ATtILA.

ATtILA field code	Metric Description	Kept in metric dataset	Kept for analysis	Removed from dataset	Reason for removal
Landscape metrics					
Land_area	Total terrestrial area in map units (total area minus water)	x	x		
LC_overlap	Percent overlap between reporting unit and land cover themes	x			used for data quality check
SL_LndArea	Total terrestrial area (total area minus water) in map units for the land cover/slope composite grid			x	not pertinent
SL_Overlap	Percent overlap between reporting unit and land cover/slope composite grid	x			used for data quality check
Pagc	Percentage of reporting unit that is crop land	x	x		
Pagp	Percentage of reporting unit that is pasture	x	x		
Pagt	Percentage of reporting unit that is all agricultural use	x	x		
Pfor	Percentage of reporting unit that is forest	x	x		
Pmbar	Percentage of reporting unit that is man made barren	x	x		
Pnbar	Percentage of reporting unit that is natural barren	x	x		
Png	Percentage of reporting unit that is natural grassland	x	x		
Pshrb	Percentage of reporting unit that is shrubland	x	x		
Purb	Percentage of reporting unit that is urban	x	x		
Pusr	Percentage of reporting unit that is user defined class	x	x		
Pwetl	Percentage of reporting unit that is wetland	x	x		
N_index	Percentage of reporting unit that is all natural land use	x	x		
U_index	Percentage of reporting unit that is all human land use	x	x		
Pxxxx_A	Each of the above (P) will also have a field with _A appended (e.g. Pfor_A) representing total area in map units.			x	not pertinent
AgcSL{n}	Percentage of reporting unit that has agricultural crop land on slopes >= {n} where {n} is the slope threshold; slope threshold = 10 for this study	x	x		
AgpSL{n}	Percentage of reporting unit that has agricultural pasture on slopes >= {n}	x	x		
AgtSL{n}	Percentage of reporting unit that has any agricultural land use on slopes >= {n}	x	x		
UserSL{n}	Percentage of reporting unit that has user defined class on slopes >= {n}			x	not calculated
AgxSL{n}_A	Each of the above (Ag) will also have a field with _A appended (e.g. AgtSL_A) representing total area in map units.			x	not pertinent
{F or U}Number	Number of patches within the reporting unit; Patch metrics will be prefixed by an F if forest was used or U if the user defined class was used to define patches.			x	not calculated; data processing difficulty
{F or U}AvgSize	Average size of patches within the reporting unit			x	not calculated; data processing difficulty
{F or U}PatDens	Patch density within the reporting unit (number of patches/km2)			x	not calculated; data processing difficulty
{F or U}Largest	Size of largest patch within the reporting unit			x	not calculated; data processing difficulty
{F or U}_PLGP	Proportion of largest patch to total area of forest or user class within the reporting unit			x	not calculated; data processing difficulty

Table 4. continued

ATtILA field code	Metric Description	Kept in metric dataset	Kept for analysis	Removed from dataset	Reason for removal
{F or U}_MDCP	Mean distance (in map units) to closest patch within the reporting unit			x	not calculated; data processing difficulty
PWN	Number of patches with neighbors within the reporting unit and search radius			x	not calculated; data processing difficulty
PWON	Number of patches without neighbors within the reporting unit and search radius			x	not calculated; data processing difficulty
{F or U}Edge{n}	Percentage of reporting unit that is defined as edge; based on user defined edge width ({n} in grid cells)			x	not calculated; data processing difficulty
{F or U}Core{n}	Percentage of reporting unit that is defined as core			x	not calculated; data processing difficulty
{F or U}_E2a{n}	Ratio of edge to area			x	not calculated; data processing difficulty
Pff{n}	Average forest connectivity within the reporting unit for user defined scale; for each of the below metrics (Pff), uu will be substituted for ff when the user defined class is used instead of forest to define patches; user defined scale is a {n} by {n} window of grid cells.			x	not calculated; data processing difficulty
PffPtch{n}	Percentage of reporting unit that is patch forest class for user defined scale			x	not calculated; data processing difficulty
PffTran{n}	Percentage of reporting unit that is transitional forest class for user defined scale			x	not calculated; data processing difficulty
PffEdge{n}	Percentage of reporting unit that is edge forest class for user defined scale			x	not calculated; data processing difficulty
PffPerf{n}	Percentage of reporting unit that is perforated forest class for user defined scale			x	not calculated; data processing difficulty
PffIntr{n}	Percentage of reporting unit that is interior forest class for user defined scale			x	not calculated; data processing difficulty
S	Simple diversity			x	not calculated; data processing difficulty
H	Shannon-Weiner diversity			x	not calculated; data processing difficulty
H_Prime	Standardized Shannon-Weiner diversity			x	not calculated; data processing difficulty
C	Simpson index			x	not calculated; data processing difficulty
Riparian Metrics					
RLA{n}	Land area within {n} map units of a stream			x	not pertinent
SLA{n}	Land area within {n} map units of a sample point			x	not pertinent
RO	Percent overlap of riparian zones and land cover	x			used for data quality check
SO	Percent overlap of sample point buffers and land cover			x	not calculated
Ragc0	Percentage of stream length adjacent to cropland	x	x		
Ragp0	Percentage of stream length adjacent to pasture	x	x		

Table 4. continued

ATtILA field code	Metric Description	Kept in metric dataset	Kept for analysis	Removed from dataset	Reason for removal
Ragt0	Percentage of stream length adjacent to all agricultural use	x	x		
Rfor0	Percentage of stream length adjacent to forest	x	x		
Rhum0	Percentage of stream length adjacent to all human land use	x	x		
Rmbar0	Percentage of stream length adjacent to man made barren	x	x		
Rnbar0	Percentage of stream length adjacent to natural barren	x	x		
Rnat0	Percentage of stream length adjacent to all natural land use	x	x		
Rng0	Percentage of stream length adjacent to natural grassland	x	x		
Rshrb0	Percentage of stream length adjacent to shrubland	x	x		
Rurb0	Percentage of stream length adjacent to urban	x	x		
Ruser0	Percentage of stream length adjacent to user defined class	x	x		
Rwetl0	Percentage of stream length adjacent to wetland	x	x		
Rxxxx30	Each of the riparian metrics may have a number greater than 0 following the code to represent a buffer distance. For example, Rfor30 is the percentage of forest in a 30 (map units) stream buffer area. If the buffer distance was a real number, it is rounded to the nearest integer.	x	x		
Rxxxx120	Each of the riparian metrics may have a number greater than 0 following the code to represent a buffer distance. For example, Rfor120 is the percentage of forest in a 120 (map units) stream buffer area. If the buffer distance was a real number, it is rounded to the nearest integer.	x	x		
Sagc{n}	Percentage of cropland within {n} map units of a sample point			x	points not analyzed
Sagp{n}	Percentage of pasture within {n} map units of a sample point			x	points not analyzed
Sagt{n}	Percentage of all agricultural use within {n} map units of a sample point			x	points not analyzed
Snbar{n}	Percentage of man made barren within {n} map units of a sample point			x	points not analyzed
Snbar{n}	Percentage of natural barren within {n} map units of a sample point			x	points not analyzed
Sfor{n}	Percentage of forest within {n} map units of a sample point			x	points not analyzed
Shum{n}	Percentage of all human land use within {n} map units of a sample point			x	points not analyzed
Snat{n}	Percentage of all natural land use within {n} map units of a sample point			x	points not analyzed
Sng{n}	Percentage of natural grassland within {n} map units of a sample point			x	points not analyzed
Sshrb{n}	Percentage of shrubland within {n} map units of a sample point			x	points not analyzed
Surb{n}	Percentage of urban within {n} map units of a sample point			x	points not analyzed
Suser{n}	Percentage of user defined class within {n} map units of a sample point			x	points not analyzed
Swetl{n}	Percentage of wetland within {n} map units of a sample point			x	points not analyzed
Human Stressors Metrics					
Land_area	Total terrestrial area in map units (total area minus water)			x	not pertinent
LC_overlap	Percent overlap between reporting unit and land cover themes	x			used for data quality check
P_Load	Phosphorus loading (kg/ha/yr)	x	x		
N_Load	Nitrogen loading (kg/ha/yr)	x	x		
POPDENS	Population density reported as population count/area of reporting unit in km2	x	x		

Table 4. continued

ATtILA field code	Metric Description	Kept in metric dataset	Kept for analysis	Removed from dataset	Reason for removal
POPFld	Population count via area-weighted redistribution; field name in ATtILA output is same as field name in input; field name alias is: "{input field name} - {input population theme name}"			x	not calculated
POPCHG	Percent change in total population	x	x		
PCTIA_LC	Percentage of reporting unit composed of impervious cover, based on land use	x	x		
RDDENS*	Road density reported as km of roads/area of reporting unit in km2*; if a road class is used in the metric computation, the output field name will have "C[CLASS]" appended; for example, for road class 1, the density name will be RDDENSC1; road classes = 1 - 6 in this study	x	x		
RDLEN*	Total road length in map units			x	not pertinent
STXRD*	Number of road/stream crossings per kilometer of stream in the reporting unit	x	x		
STXRD_cnt	Total number of road/stream crossings in the reporting unit			x	not pertinent
XCNT_*	Number of road/stream crossings within reporting unit by road class	x	x		
PCTIA_RD	Percentage of reporting unit composed of impervious cover, based on road density	x	x		
RNS{n}*	Length of roads near streams (user defined distance = 30 m in this study) divided by length of streams in reporting unit	x	x		
Physical Characteristic Metrics					
ELEVOVRLP	Percent overlap between {grid} and reporting unit themes	x			used for data quality check
ELEVMIN	Minimum grid cell value within reporting unit	x	x		
ELEVMAX	Maximum grid cell value within reporting unit	x	x		
ELEVRNG	Range of grid cell value within reporting unit	x	x		
ELEVMEAN	Average grid cell value within reporting unit	x	x		
ELEVSTD	Standard deviation of grid cell value within reporting unit	x	x		
PRCPOVRLP	Percent overlap between {grid} and reporting unit themes	x			used for data quality check
PRCPMIN	Minimum grid cell value within reporting unit	x	x		
PRCPMAX	Maximum grid cell value within reporting unit	x	x		
PRCPRNG	Range of grid cell value within reporting unit	x	x		
PRCPMEAN	Average grid cell value within reporting unit	x	x		
PRCPSTD	Standard deviation of grid cell value within reporting unit	x	x		
SLPOVRLP	Percent overlap between {grid} and reporting unit themes	x			used for data quality check
SLPMIN	Minimum grid cell value within reporting unit	x	x		
SLPMAX	Maximum grid cell value within reporting unit	x	x		
SLPRNG	Range of grid cell value within reporting unit	x	x		
SLPMEAN	Average grid cell value within reporting unit	x	x		
SLPSTD	Standard deviation of grid cell value within reporting unit	x	x		
STRMDENS	Stream density reported as km of streams / area of reporting unit in km2	x	x		
STRMLEN	Total stream length in map units			x	not pertinent

Preliminary wetland condition ranking: To better understand the condition of wetlands in the study area and help design a sampling scheme, we used ATtILA outputs to organize 20,158 NWI polygons into preliminary condition classes. Because it was not yet known which metrics were the best indicators of condition, we used professional judgment and peer-reviewed literature to decide which ATtILA outputs were relevant. Landscape-scale wetland assessment literature was consulted (Brooks et al. 2002a, Tiner 2002, Hychka et al. 2007, Mita et al. 2007, Troelstrup and Stueven 2007, Wardrop et al. 2007, Weller et al. 2007). ATtILA metrics used to determine preliminary condition rank were:

- % of polygon that is cropland
- % of polygon that is pasture
- % of polygon that is natural grassland*
- % of polygon that is urban
- % of polygon that is impervious surface based on land cover
- Population density
- Road density
- Number of road crossings of streams per km of stream
- % of stream length adjacent to agricultural use
- % of stream length adjacent to human land use
- % of stream length adjacent to natural grassland
- % of stream length adjacent to urban land use

*we used % natural grassland as a surrogate indicator of potential livestock grazing in areas of non-agricultural land use—the vast majority of natural grassland in wetland settings of Idaho is used for grazing.

Preliminary condition ranking categories were determined analogous to methods used by Stoddard et al. (2005), Fennessy et al. (2007), Mita et al. (2007), and Troelstrup and Stueven (2007). We used 5 condition categories:

1 = *minimally disturbed* (wetland present in the absence of human disturbances; zero to few stressors are present; land use is almost completely not human-created; equivalent to reference condition)

2 = *least disturbed* (wetland deviates the least from that in minimally disturbed conditions based on existing landscape disturbances; few stressors are present; majority of land use is not human-created; these are the best wetlands in areas where human influences are present; ecosystem processes and functions within natural ranges of variation found in the reference condition)

3 = *moderately disturbed* (several stressors are present; land use is roughly split between human-created and non-human land use; ecosystem processes and functions are altered and somewhat outside the range of variation found in the reference condition; ecosystem processes are restorable)

4 = *severely disturbed* (numerous stressors are present; land use is majority human-created; ecosystem processes and functions are severely altered or disrupted and outside the range of variation found in the reference condition; ecosystem processes are restorable, but may require large investment of energy and financial resources for successful restoration)

5 = *completely disturbed* (many stressors are present; land use is nearly completely human-created; ecosystem processes and functions are disrupted and outside the range of variation found in the reference condition; ecosystem processes are not feasibly restorable)

For each ATtILA metric (Table 3), the range of outputs for each of NWI polygon were organized into quintiles. Polygons within the top 20% (0-19) of the range, in terms of least human impact, were ranked a 1; polygons in the 20-39% ranked a 2, etc. The sum of ranks for each polygon was then calculated. If the sum was 12 (meaning the rank was 1 for each of the 12 metrics), then the preliminary condition rank was 1. For other polygons (sums ranging from 13-32), the lowest quartile (sums 13-17) was ranked 2, the next quartile (sums 18-22) ranked 3, the next quartile (sums 23-27) ranked 4, etc. Results of the preliminary condition ranking were entered into a blind database for later use.

***Reference wetland approach*:** To determine how metrics produced by ATtilLA and additional GIS analysis translate to wetland condition, we used a reference wetland approach (Hychka et al. 2007, Mita et al. 2007, Troelstrup and Stueven 2007, Wardrop et al. 2007, Weller et al. 2007, Vance 2009). This method defines the ecological condition of wetlands by the degree of departure from reference standard (for this project, the best condition wetlands known at the time of survey) (Troelstrup and Stueven 2007, Wardrop et al. 2007). This requires that wetlands of known condition (based on existing and/or field-generated rapid or intensively collected biologic data) are placed along a human disturbance gradient with the best available condition wetlands anchoring the top end. The calculated landscape and disturbance metrics are then tested for correlation and ability to predict condition of these reference wetlands.

To accomplish this we first obtained existing site-level wetland assessment and inventory data from various IWWG partner databases. Datasets used included:

- Idaho Department of Environmental Quality (IDEQ) for aquatic integrity and beneficial use monitoring data for rivers, streams, and lakes
- PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program for aquatic integrity and riparian condition data
- IDFG wetland site and plant community databases (IDFG 2008)

The Idaho Department of Environmental Quality (IDEQ) has adopted bioassessment methodology for aquatic ecosystems (i.e., streams, large rivers, lakes, and reservoirs) (Grafe 2002a, 2002b). The methodology is used for developing Idaho's 303(d) list, 305 (b) report, and water quality standards. Called the Beneficial Use Reconnaissance Program (BURP), this program includes a monitoring and assessment database that contains information on aquatic insects, fish, water chemistry, and aquatic and riparian habitat conditions from over 5,000 stream, river, and lake sites across Idaho. Time spent by IDEQ staff assisting us with our data request represented in-kind match and was used to meet grant requirements.

The PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program (PIBO) database stores extensive bioassessment information on aquatic and riparian habitat in the upper Columbia River Basin (which includes all of Idaho except the Bear River Basin) (Kershner et al. 2004). Data on a large number of biological and physical attributes, processes, and functions of riparian and aquatic habitats measured at reference stream reaches are available.

We queried IDFG Idaho Conservation Data Center (IDFG 2008) databases for wetland site and plant community data occurring in the study areas. This included information on ecological condition indicators. Descriptions of reference sites and plant communities are in found in Jankovsky-Jones (1997 and 1999) and Lichthardt (2004) for the north study area and Jankovsky-Jones (2001) and Bottum (2005) for the south.

We also obtained wetland site assessment data from partner Idaho Transportation Department (ITD). It was hoped that rapid functional assessment data from wetlands impacted by ITD projects would also be useful. However, data was generally lacking for the study area. Only a few sites with complete assessment data existed. This data was not used because ecological condition was difficult to determine from data provided (mostly wetland delineation and potential function assessment). Nevertheless, the time spent by ITD staff assisting us with this data request represented in-kind match used to meet grant requirements.

In GIS, all assessment points (BURP, PIBO, IDFG) were intersected with NWI wetland polygons (buffered by 100 m) and data organized into a project geodatabase. Numerous NWI wetland polygons intersected with multiple assessment points. In total, 365 NWI polygons in the north and 95 in the south intersected with one or more assessment points. For those polygons with more than one assessment point, the condition estimated for each point was averaged to represent the whole polygon. Ecological condition was estimated for these 460 NWI polygons according to the types of data available (Appendix 1).

Five wetland condition classes (described above in preliminary condition ranking section) were used. Ecological condition was estimated by first taking values for each category of data indicative of condition for each polygon NWI polygon (Table 4). Sums of each category were then organized into quintiles. Polygons within the top 20% (0-19) of the category, in terms of least human impact, were ranked a 1; polygons in the 20-39% ranked a 2, etc. The final condition rank for each polygon was calculated as the mean rank for all categories present. For BURP data, categories used for ranking were streambank stability, stream macroinvertebrate index, stream fish index, and stream habitat index (Grafe 2002a, 2002b). For PIBO data, categories used for ranking were total importance values of non-native plant species, total number of non-native plant species, dominance weighted community tolerance quotient for macroinvertebrates, River Invertebrate Prediction and Classification System score for macroinvertebrates, and streambank stability (Kershner et al. 2004). For IDFG reference wetland plant community data, total number of noxious and highly invasive non-native plant species, total cover of noxious and highly invasive non-native plant species, streambank stability (available for a small number of points), and element occurrence rank (a qualitative estimate incorporating observed condition; IDFG 2008) were used.

***Rapid wetland assessment*:** A probabilistic sampling scheme was developed to collect additional wetland condition data. Wetlands respond in different ways to landscape-level impacts according to geomorphology, landscape position, vegetation, hydrology, climate, soils, and other watershed characteristics (Johnson 2005, Hychka et al. 2007, Vance 2009). Large watersheds, as represented by HUC8s, are useful for expressing the diversity of different wetland environments and impacts as they change across the landscape. We used a probabilistic double stratified sampling scheme that ensured representation of these different wetland environments and condition classes across the landscape. The first stratification was by HUC8, the second by the abundance of NWI polygons in each preliminary wetland condition class. To carry out this sampling scheme, we determined the number of NWI polygons in each preliminary condition class in each HUC8. An amount of NWI polygons proportionate to their representation in each HUC8 were chosen. At least one NWI polygon in each condition class present was randomly chosen in each HUC8. In the north study area, 81 polygons were selected. In the south, 74 polygons were selected for potential sampling.

To assess on-the-ground wetland condition, we needed a rapid assessment method. Idaho lacks a state-specific rapid assessment method. Our plan was to use Montana Transportation Department's Wetland Assessment Method (Bergland and McEldowney 2008) because it is commonly used in Idaho. However, the primary purpose of this method is to assess potential wetland function, not condition. Although some indicators of condition are included, there weren't enough to capture all observations. We decided to develop a first draft rapid assessment method for Idaho based on literature review (Fennessy et al. 2004). The method had to be rapid and relatively simple, focused on condition, and relevant to Idaho and land use (as in Brown and Vivas 2005). The Penn State land use and stressor checklist method (Brooks et al. 2004) was a good model of a rapid and simple method. Other rapid assessment methods borrowed from to develop our method were Apfelbeck and Farris (2005), Faber-Langendoen et al. (2006), Collins et al. (2007), and Idaho Department of Fish and Game (2007). Functional assessment methodologies were also borrowed from (Smith et al. 1995; Jankovsky-Jones et al. 1999a and 1999b; Hauer et al. 2002; Keate 2005). The resulting forms used in the field are in Appendix 2.

Due to time and access constraints, about 50% of the randomly wetland polygons selected could be sampled. Care was taken to ensure that about 50% of the possible selected polygons in each subbasin and preliminary condition class were sampled. We rapidly assessed condition on 40 polygons in the north study area and 35 in the south (Appendix 3). Wetlands on private lands were assessed only if the majority of the polygon could be viewed (using binoculars) from the property boundary (e.g., a road, fenceline, etc.). Budget and time constraints prevented contacting landowners. Due to poor visibility, we could not complete stressor checklists for some private land wetlands. Condition was estimated using observed land use only. Aerial imagery was used to confirm land use. Two sampled wetlands coincided with prior known wetland reference sites (Clark Fork Delta and Freeman Lake, both in the north study area; Jankovsky-Jones 1997). Field assessment data was entered into the project geodatabase and polygons ranked for condition. Five wetland condition classes (described above in preliminary condition ranking section) were used. Ecological condition was estimated by first summing categories of human land use and stressors for each NWI polygon (Table 4). Sums of each category were then organized into quintiles. Polygons within the top 20% (0-19) of the category, in terms of least human impact, were ranked a 1; polygons in the 20-39% ranked a 2, etc. The final condition rank for each polygon was calculated as the mean rank of the two categories (Appendix 3). To test whether the rapid assessment method was capturing information necessary to predict wetland condition, linear regression (sum of least squares method) was used to examine the relationship between stressor and land use checklists and wetland condition.

Model development: The goal of this step was to create a simple, but statistically robust, predictive model of wetland condition. The objective was to determine which metrics (calculated by ATtILA and supplemental GIS analysis) were significantly correlated and/or predictive of wetland condition. We used a screening approach similar to Mita et al. (2007), Troelstrup and Stueven (2007), and Weller et al. (2007) to identify the best metrics for the model. We used statistical analyses analogous to those used by Hychka et al. (2007), Mita et al. (2007), Troelstrup and Stueven (2007), Weller et al. (2007), and Vance (2009) to accomplish this task. Each metric had to pass screens 1, 2, and 5, and either 3 or 4, in order to be considered for use in the predictive final model:

- **Screen 1:** Is metric ecologically relevant?
  - ✓ **Test:** professional judgment, literature review
- **Screen 2:** What is the range of metric data?
  - ✓ **Tests:** summary statistics; test for normality (D'Agostino & Pearson omnibus normality test, alpha = 0.05); must have broad range of data, not all zeros or unvarying
- **Screen 3:** Is metric significantly correlated with on-site condition measurements?
  - ✓ **Test:** Spearman correlation ($p < 0.05$) (used because metric data had non-Gaussian distribution); $r > 0.5$ = strong; $r = 0.4$ -0.5 = moderate; $r < 0.4$ = weak correlation
- **Screen 4:** Is metric a predictor of general wetland condition estimated from field observations? Does metric significantly differ among wetland condition classes?
  - ✓ **Test:** one-way analysis of variance (ANOVA) with Kruskal-Wallis and Dunn's Multiple Comparison tests (used because metric data had non-Gaussian distribution) (alpha = 0.05)
- **Screen 5:** Do metrics provide new and logical information?
  - ✓ **Test:** Redundancy and logic test—are metrics too closely related to each other or providing illogical results?

Within these two study areas there were 20,878 NWI polygons, of which 20,158 had ATtILA output results. Metrics that passed screens were used to estimate the ecological condition of 20,158 NWI polygons with calculated data. With a few exceptions (described below), they were not assigned weights for this preliminary model. Calculated metric data was highly variable range of values. Most ATtILA data outputs were percentage values expressed on a 0 to 100 scale. Other metric data varied. In order to have equal weighting in the model, all non-percentage metric data was normalized to a 0 to 100 scale. Metrics were separated into 2 categories—those negatively correlated with decreasing ecological condition (typically environmental data, such as elevation, slope, and precipitation; shown in results) and those positively correlated with decreasing condition. While environmental metrics were significantly correlated, we did not feel they should be equally weighted with all other metrics. For environmental metrics, we calculated the mean value for each polygon to calculate an *index of environmental vulnerability* (e.g., wetlands at lower elevations, slopes, and precipitation zones were more likely to have lower ecological condition). Data for all other metrics was summed and then adjusted by adding the index of environmental vulnerability value. The polygons were then ranked and placed in 4 condition classes:

1 = *minimally disturbed*; few stressors present; reference standard; conservation priority
2 = *moderately disturbed*; several stressors present; some processes and functions altered; processes and functions are restorable
3 = *severely disturbed*; numerous stressors present (or several high impact stressors); many processes and functions disrupted; processes and functions are restorable, but may require large investment of energy and financial resources for successful restoration
4 = *completely disturbed*; many stressors present, most high impact; most processes and functions are disrupted; restoration very difficult or impossible

The breakpoints between condition classes were based on the proportions of reference and rapidly assessed wetlands falling in each class. In the north study area, minimally disturbed wetlands were in the top 5% of all wetlands; moderately disturbed in the top 6 - 35%; severely disturbed 36 - 85%; and completely disturbed in the bottom 86 - 100%. In the south, the breakpoints were the same except for severely disturbed (36 - 90%) and completely disturbed (91 - 100%). The ecological condition of polygons without data was equated with that of the nearest neighboring polygon (typically immediately adjacent).

To put the NWI polygons into a watershed context, we also ranked HUC12s. Because we did not have reference watershed data, no analysis of metrics was done. Instead, all relevant metrics (based on literature review and professional judgment) were used. As with NWI polygons, non-percentage data was normalized on a 0 to 100 scale to maintain equal weighting among metrics. All HUC12s statewide were then ranked and placed in 6 condition classes, the breakpoints between which were similar to Troelstrup and Stueven (2007).

1 = *minimally disturbed*; watershed processes intact (top 5%)
2 = *lightly disturbed*; most watershed processes intact (6 - 10%)
3 = *moderately disturbed*; some watershed processes likely impaired (11 - 25%)
4 = *moderately disturbed*; some watershed processes likely disrupted (25 - 50%)
5 = *severely disturbed*; most watershed processes likely disrupted (51 - 75%)
6 = *completely disturbed*; watershed processes disrupted (bottom 76 -100%)

Results

***Reference wetlands*:** Across the both study areas, 641 reference wetland assessment data points were within or adjacent to NWI polygons (Figures 4 and 5). There were 389 BURP monitoring points, 118 PIBO monitoring points, and 134 plant community plots from 38 reference wetland sites (Figures 4 and 5). These 641 points were used to rank the condition of 460 NWI polygons. These 460 polygons represented about 3% of NWI polygons in the north study area and 1% of polygons in the south. Although locations of reference wetlands were not randomly selected, the distribution of assessment points was broad and representative of both study areas.

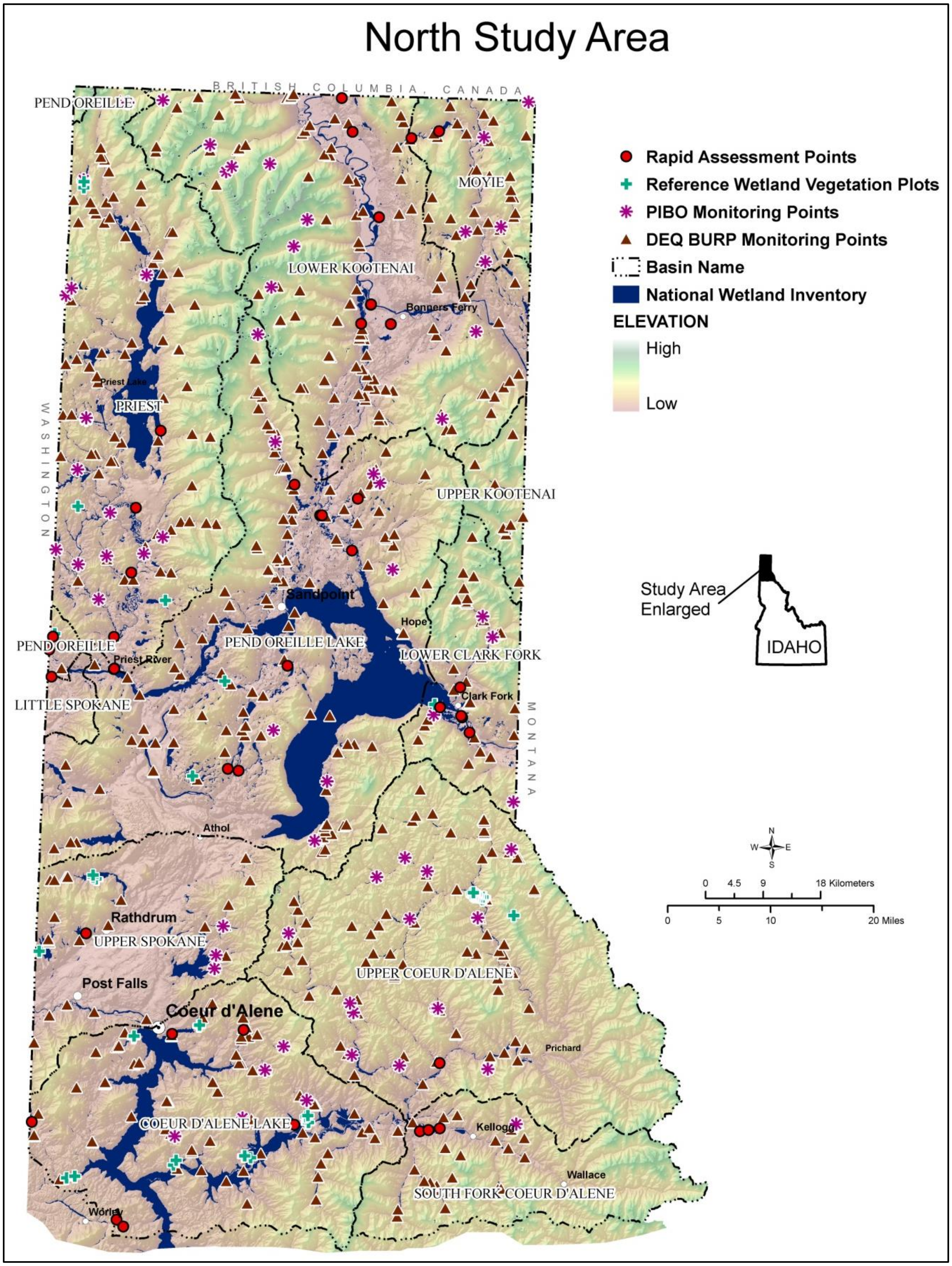

North Study Area
BRITISH COLUMBIA, CANADA
WASHINGTON
MONTANA
PEND OREILLE
MOYIE
LOWER KOOTENAI
Bonners Ferry
Priest Lake
PRIEST
UPPER KOOTENAI
Sandpoint
Hope
PEND OREILLE
PEND OREILLE LAKE
LOWER CLARK FORK
Priest River
Clark Fork
LITTLE SPOKANE
Athol
Rathdrum
UPPER SPOKANE
Post Falls
Coeur d'Alene
UPPER COEUR D'ALENE
Prichard
COEUR D'ALENE LAKE
Kellogg
Wallace
SOUTH FORK COEUR D'ALENE
Worley
Rapid Assessment Points
Reference Wetland Vegetation Plots
PIBO Monitoring Points
DEQ BURP Monitoring Points
Basin Name
National Wetland Inventory
ELEVATION
High
Low
Study Area Enlarged
IDAHO
N
W
E
S
0
4.5
9
18 Kilometers
0
5
10
20 Miles

Figure 4.

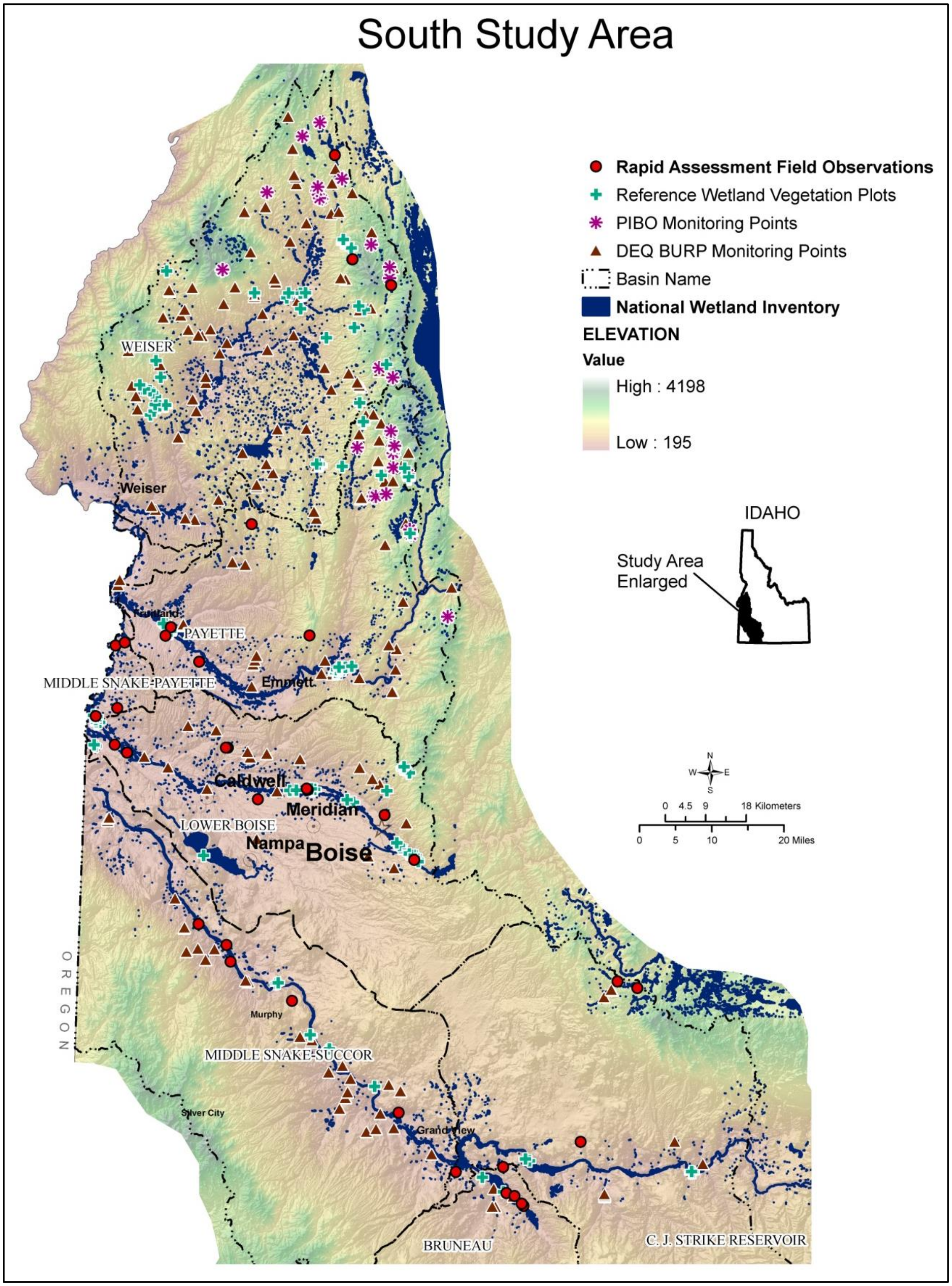

South Study Area
Rapid Assessment Field Observations
Reference Wetland Vegetation Plots
PIBO Monitoring Points
DEQ BURP Monitoring Points
Basin Name
National Wetland Inventory
ELEVATION
Value
High : 4198
Low : 195
IDAHO
Study Area Enlarged
WEISER
Weiser
Fruitland
PAYETTE
Emmett
MIDDLE SNAKE-PAYETTE
Caldwell
Meridian
LOWER BOISE
Nampa
Boise
OREGON
Murphy
MIDDLE SNAKE-SUCCOR
Silver City
Grand View
BRUNEAU
C. J. STRIKE RESERVOIR
0 4.5 9 18 Kilometers
0 5 10 20 Miles

Figure 5.

Condition of reference wetland polygons in the north study area were skewed toward the least disturbed and moderately disturbed classes (Figure 6). Over two-thirds fell in those classes compared to only 3% in the minimally disturbed class. Over 60% of the reference wetland polygons in the south study area were also in those condition classes, but the rest were more evenly distributed among remaining classes (Figure 7).

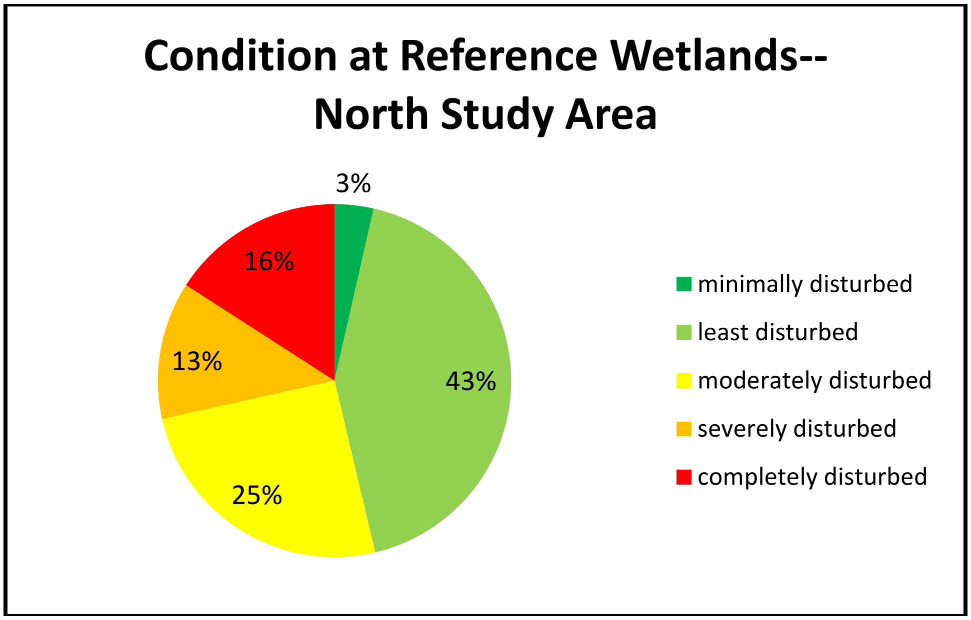


Figure 6.

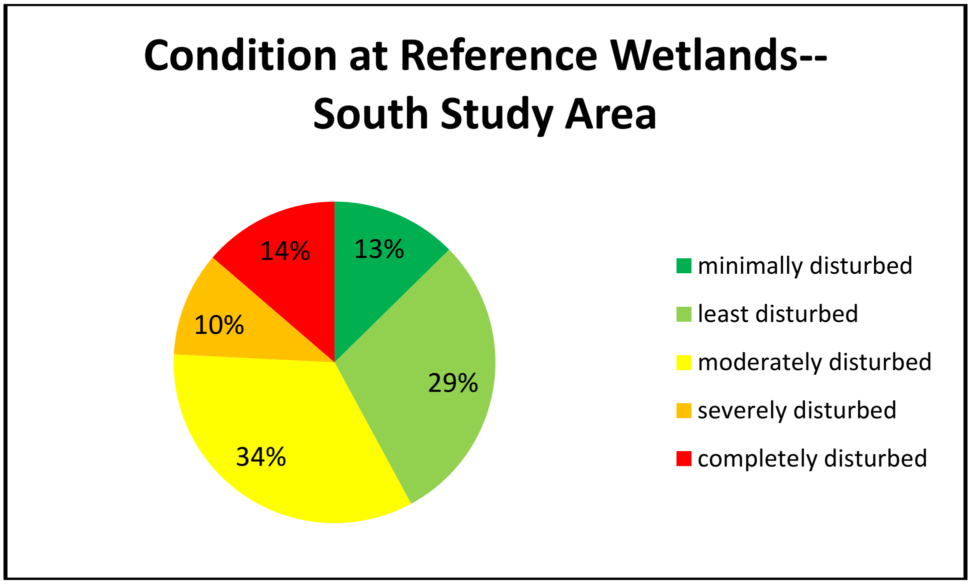


Figure 7.

***Rapid wetland assessment*:** Based on time budgeted for surveys, we attempted to access 90 wetlands for rapid assessment. Of these 90, we were able to access 29 on the ground for assessment; 46 had no ground access, but we were able to assess land use and/or stressors from roadsides or fence lines; and 15 were not accessible and not visible (data presented in Appendix 3). In total, we rapidly assessed both stressors and land use at 50 wetlands. At an additional 25 wetlands, land use within and surrounding the wetlands was documented (using field observations and aerial imagery), but stressors were not assessed because we could not observe the wetland. All 75 were assigned condition ranks. This exceeded our goals in the original work plan. When combined with reference wetlands with prior known data, about 3.6% of NWI polygons in the north study area and 1.4% in the south were used to develop the GIS model of wetland condition.

Across both study areas, 12% of the rapidly assessed wetlands were classified as minimally disturbed; 29% least disturbed; 21% moderately disturbed; 28% severely disturbed; and 10% completely disturbed. Figures 8 and 9 show wetland condition for each study area. In the north study area, our sampling scheme adequately spread samples across the disturbance gradient. In the south, wetlands in the minimally disturbed and completely disturbed condition classes were less frequently sampled relative to other wetlands. In both study areas, the least disturbed and severely disturbed classes were the most frequently assessed wetlands. Photos of wetlands in each condition class are found in Appendix 4.

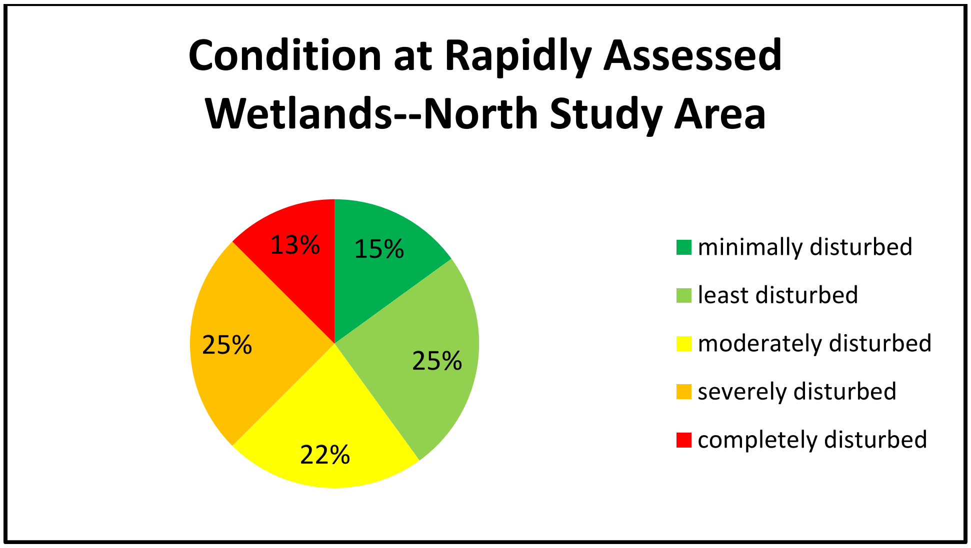


Figure 8.

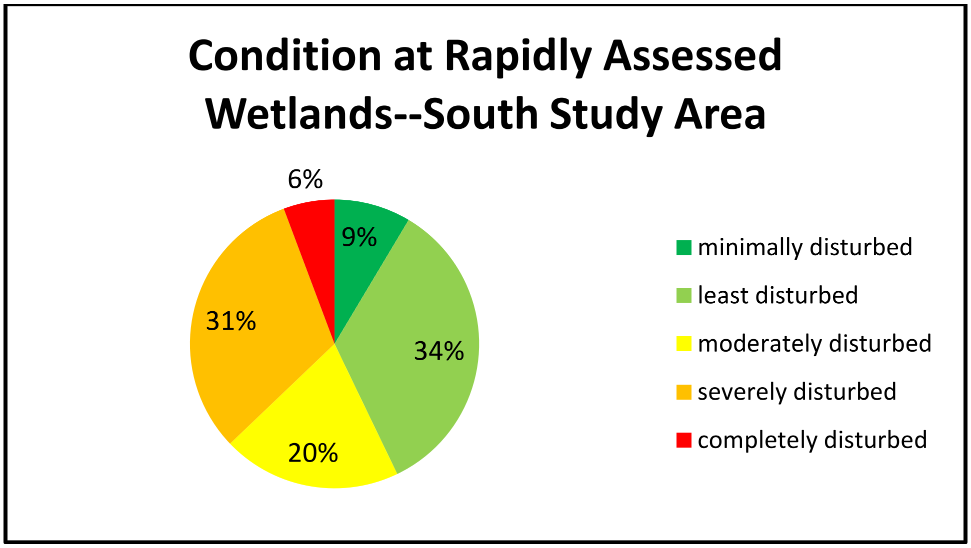


Figure 9.

In both study areas, palustrine emergent (PEM) wetlands were the most frequently assessed Cowardin subsystem type (Figures 10 and 11). In the north, palustrine scrub-shrub (PSS) and palustrine forested (PFO) were the next most commonly assessed subsystems. Palustrine unconsolidated bottom (PUB) and PSS were also frequently assessed in the south. The condition of PUB (and PUBH [permanently flooded]) in both study areas was consistently skewed toward the severely disturbed class. In the south, PUB often occurred in high impact areas such as farm ponds and small reservoirs. Several PFO wetlands were in the completely disturbed class due to haying and livestock pasturing that had converted some of the forested wetland to agricultural uses.

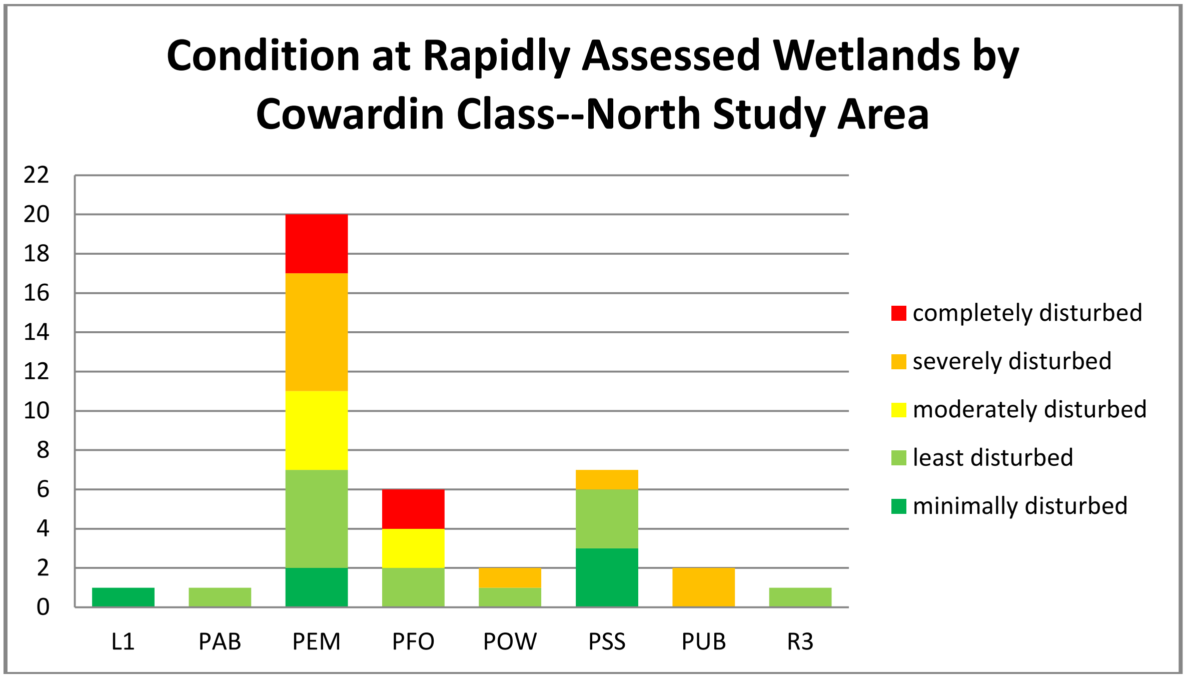


Figure 10.

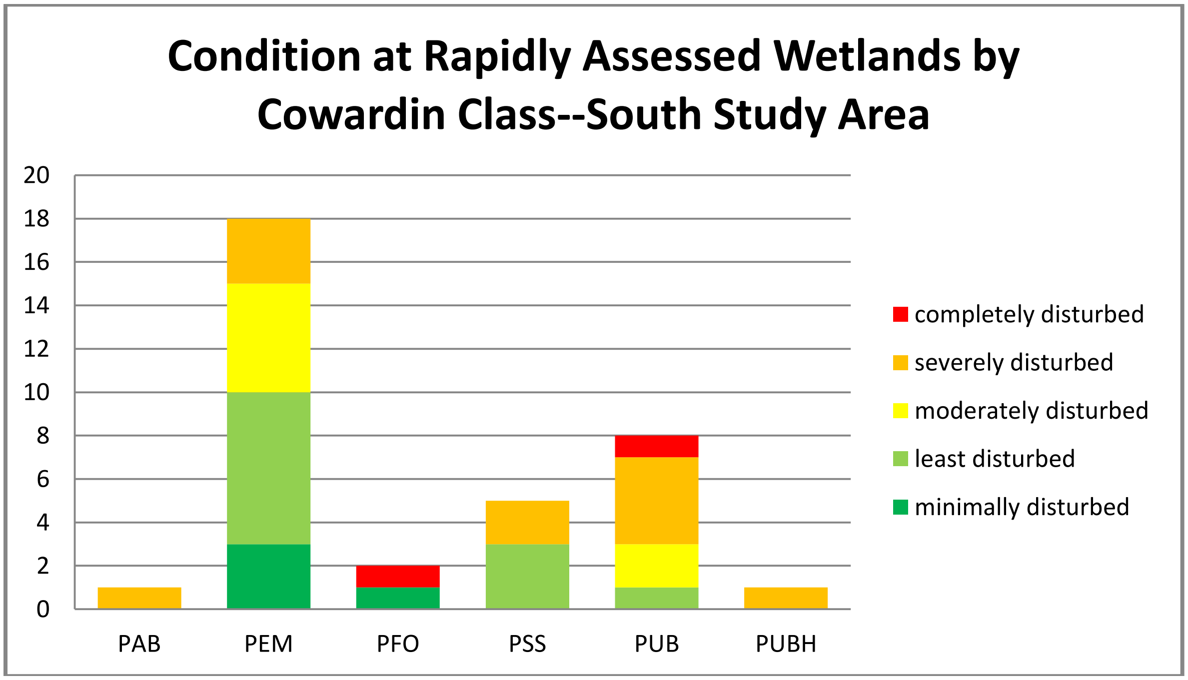


Figure 11.

***Performance of rapid assessment method*:** Further data exploration gave us clues about the nature of our wetland assessment data. There was only a 28% match between the preliminary rank of wetland polygons based on the ATtILA metrics chosen and the rank of wetlands based on field rapid assessment (Figure 12). However, accuracy increased to about 74% if the number of condition categories was reduced from 5 to 3.

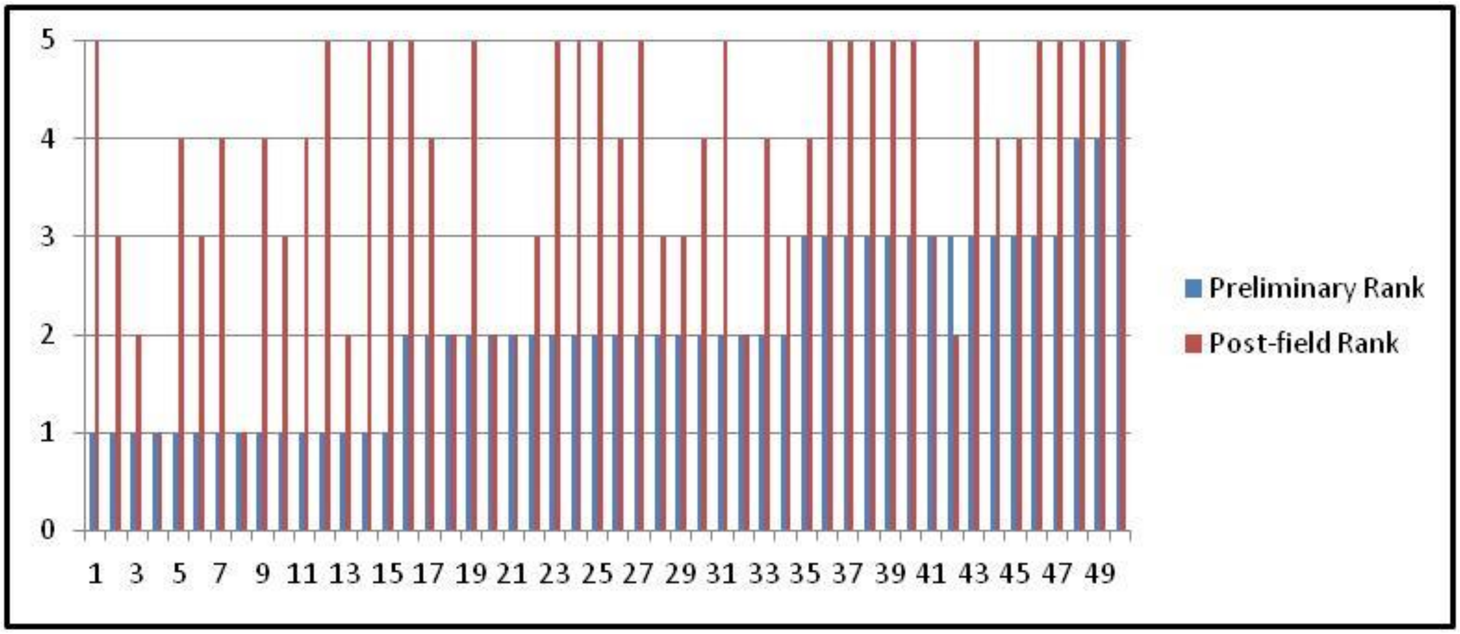


Figure 12. Preliminary and post-field condition rank (y-axis) for each wetland assessed (x-axis). Only wetlands with both stressor and land use assessment scores were included.

Based on these results, several questions were developed for further data exploration:

1) What were the relationships between stressors and land use detected using our rapid assessment method in the field? Did the methodology detect differences between wetlands based on stressors and land use?

- What was the relationship between human land uses and stressors observed in wetlands using our rapid assessment method (Figure 13)?

The number of observed stressors in a wetland polygon significantly increased as the number of human land uses observed in the wetland increased. The relationship fit an increasing exponential line slightly better than a linear regression line. This provided evidence supporting the assumption of all landscape-scale assessment—that human land use disturbances influence the amount of ecological stress placed on wetland ecosystems.

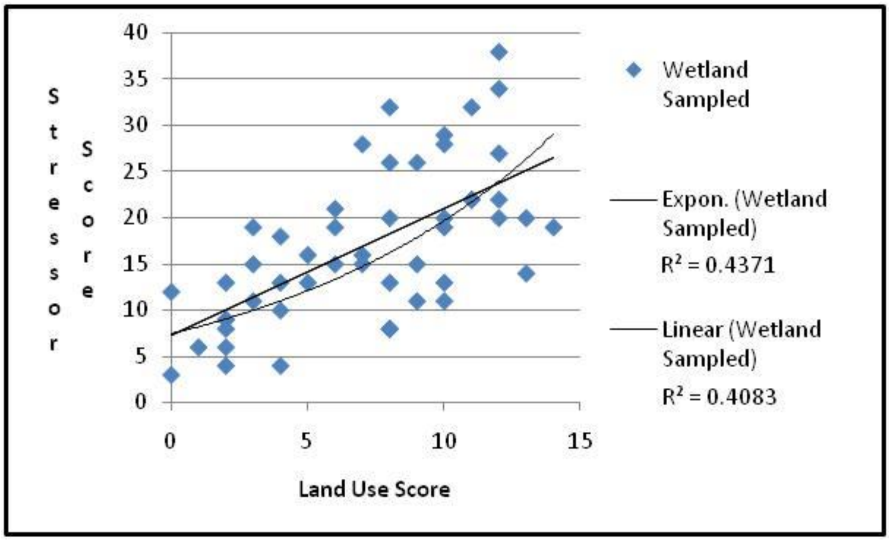


Figure 13. Relationship between observed stressor score in wetland and land use score using rapid assessment method developed for this project (significant for linear regression $P < 0.0001$).

- What was the relationship between the condition of the wetland polygon buffer and stressors observed in the wetland (Figure 14)?

As the number of stressors observed within the 50 m buffer increased, the number of stressors observed in the wetland polygon significantly increased. This is evidence supporting the assumption that disturbances within buffer zones influence ecological stress within a wetland.

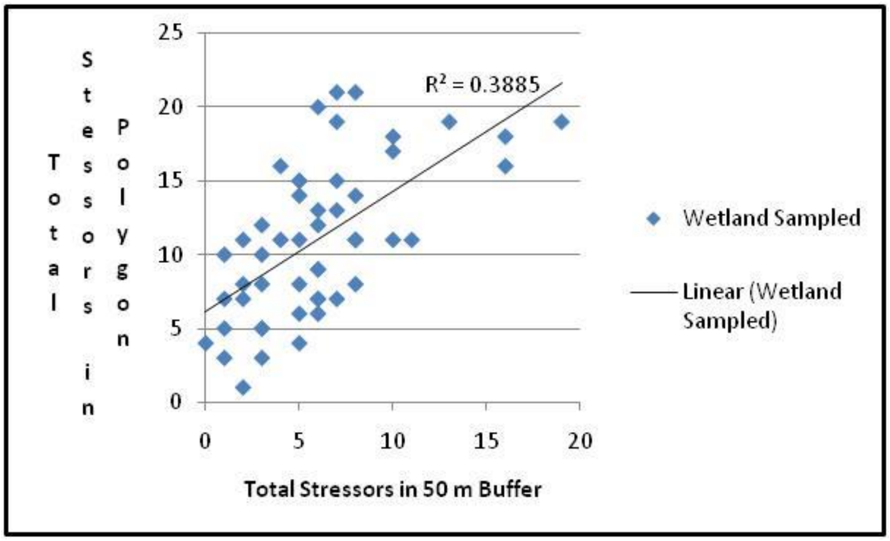


Figure 14. Relationship between total number of stressors observed in wetland and total number of stressors in 50 m wide buffer zone around wetland (significant for linear regression $P < 0.0001$).

2) Were there any relationships between ATtILA calculated metrics and the stressors and human land uses observed during field rapid assessment?

- What was the relationship between observed stressors (in the wetland and buffer) and ATtILA calculated metrics (Figures 15 and 16)?

There was a significant, but weak relationship (r^2 0.2 - 0.3) between stressors observed during rapid assessment and ATtILA calculated metrics. As the cumulative amount of GIS-derived stressors increased so did the number of stressors observed both within the wetland and buffer. This indicated that buffer condition may be an important determinant of polygon condition.

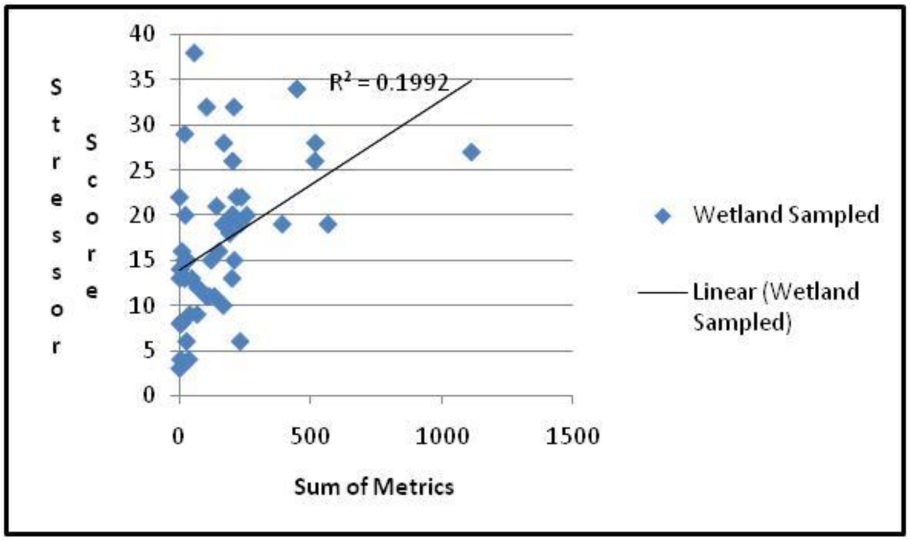


Figure 15. Relationship between stressor score and sum of all metrics calculated by ATtILA for the wetland (significant for linear regression *P* = 0.0012).

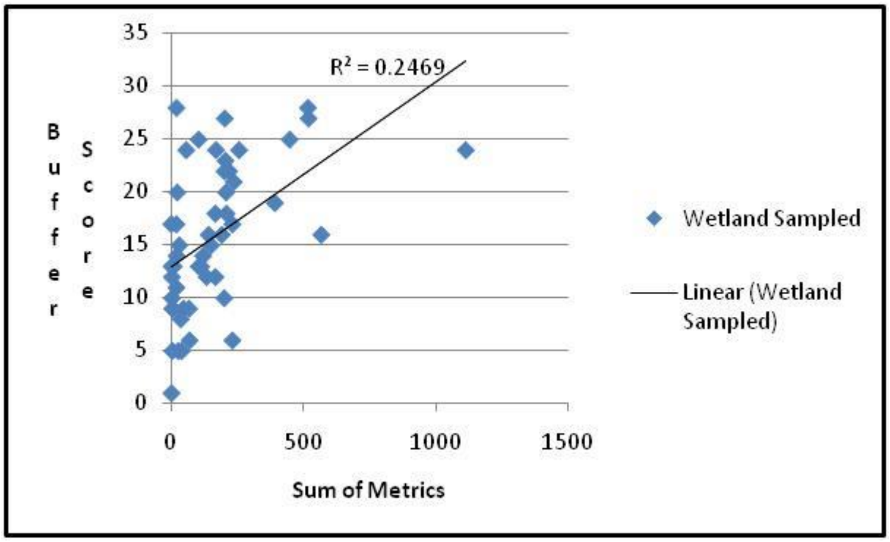


Figure 16. Relationship between the number of stressors in buffer ('buffer score') and sum of all metrics calculated by ATtILA for the wetland (significant for linear regression *P* = 0.0002).

- What was the relationship between observed stressors and land uses in the wetland and the sum of ATtILA metrics (Figures 17 and 18)?

There was a very weak, non-significant relationship between observed land uses and wetland condition determined from ATtILA metrics (Figure 17). These should have been more closely related because many ATtILA metrics are derived from land use (e.g., NLCD). This indicates potential inaccuracies in the NLCD due to land use changes since the layer was produced and/or map errors. There was a significant, but weak relationship ($r^2 < 0.2$) between the cumulative value of stressors in the polygon and the sum of ATtILA metrics (Figure 18).

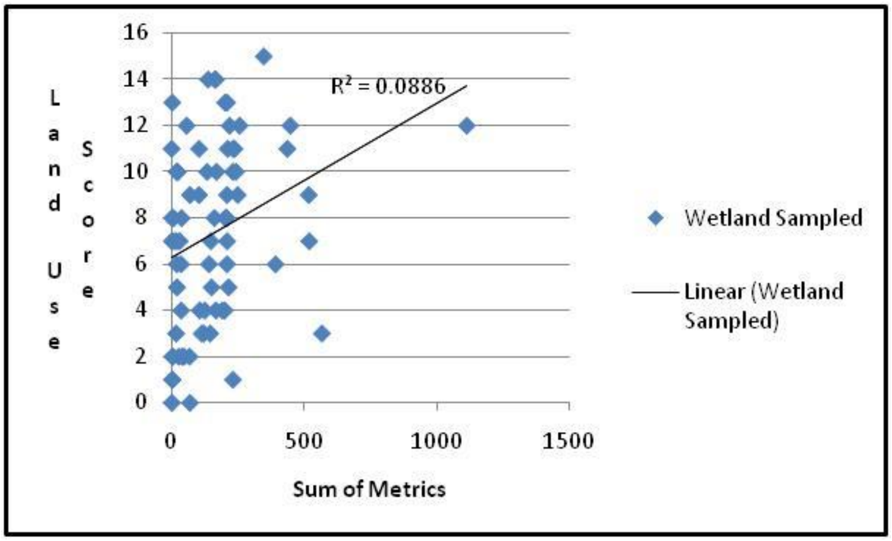


Figure 17. Relationship between the number of human land uses and sum of all metrics calculated by ATtILA for the wetland (not significant for linear regression *P* = 0.1066)

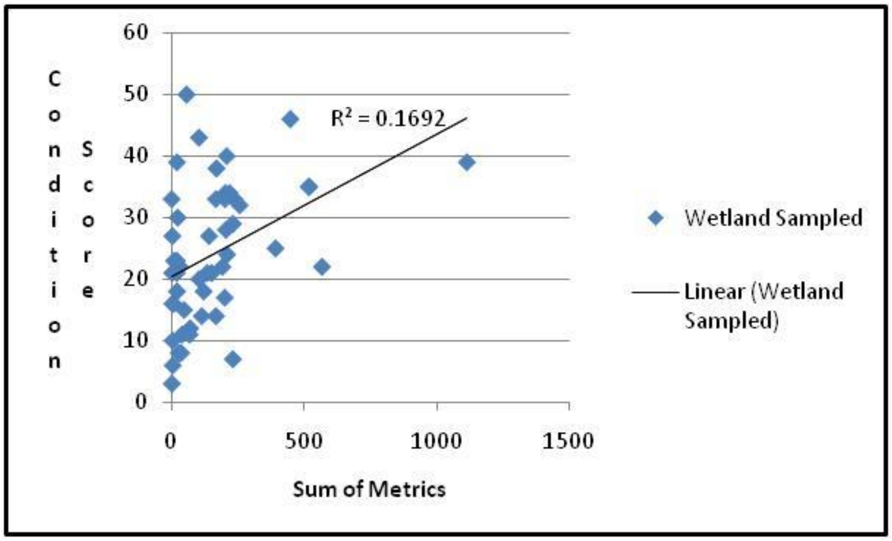


Figure 18. Relationship between the cumulative condition score and sum of all metrics calculated by ATtILA for the wetland (significant for linear regression *P* = 0.0030

This analysis shows that the rapid assessment methodology created for this project did have the ability to evaluate ecological condition of wetlands, but it does have some inherent inaccuracies and needs refinement. While there were relationships between observed stressors and GIS-derived metrics for indicators of stressors, indicators need to be further tested for their value in predicting condition.

***Model development*:** In the north study area, 21 metrics were positively correlated with increasing wetland degradation at reference and rapidly assessed wetlands. Seventeen metrics were negatively correlated with increasing wetland impacts. Although significant, all correlations were weak (r < 0.4). Not all of these metrics were used for the predictive model of wetland condition because some were illogical or redundant. For example, 3 metrics (percent likely recently harvested for timber, percent human-caused barren ground, and density of unpaved roads) were discarded because they were unexpectedly (based on literature review) negatively correlated. Density of railroads was discarded because calculated values were not correct. This metric will be reevaluated for future model iterations. To simplify the model and reduce redundancy, we decided to only use mean elevation, mean precipitation, and mean slope, and discarded the minimum, maximum, and standard deviation for these factors (all of which were also correlated). Three metrics differed significantly between wetland condition classes and were therefore good predictors of condition. For the model, 19 metrics were used to assess wetland condition (Table 5). The index of environmental vulnerability was based on the mean of 6 metrics negatively correlated with increasing wetland degradation (the last 2 below were predictive of wetland condition):

- mean elevation
- mean precipitation
- mean slope
- % forest
- % stream length adjacent to natural land
- % stream length within 30 m of natural land

In the south, 48 metrics were positively correlated with increasing wetland degradation and 6 negatively correlated. Data were lacking in reference and rapidly assessed wetlands for percent area of reservoir, density of boating access recreation sites, density of toxic element release sites, and density of dairies. Density of railroads was discarded because calculated values were not correct. These 5 metrics will be reevaluated for future model iterations. Other metrics (e.g., percent area of wetlands, natural land uses, shrubland, and naturally barren) were unexpectedly positively correlated with wetland degradation. To create a simpler model, these were also discarded. For the model, 33 positively correlated metrics were kept to assess wetland condition (Table 5). This list included 22 metrics that differed significantly between wetland condition classes (e.g., predictors of condition). Moderate correlations (r = 0.4 - 0.5) were found for:

- % agricultural land use
- % crop land
- % human land use
- phosphorus loading
- mean elevation

Five metrics were used to calculate the index of environmental vulnerability (Table 5). Wetland area and stream density were positively correlated with increasing wetland degradation:

- mean elevation
- mean precipitation
- mean slope
- area of wetland
- stream density

Data feeding the condition model for each study area is found in Appendix 5.

Table 5. Metrics chosen for predictive model of wetland condition.

Metric	North Study Area			South Study Area		
	Metrics positively correlated with increasing wetland degradation		Metrics that predict condition (significant difference between condition classes?)	Metrics positively correlated with increasing wetland degradation		Metrics that predict condition (significant difference between condition classes?)
	Spearman r	p	ANOVA	Spearman r	p	ANOVA
ATtILA landscape metrics						
% agricultural land use	0.2	0.0007		0.5	< 0.0001	* , ** , ***
% agricultural land on slopes ≥ 9%	0.1	0.0256				
% crop land	0.1	0.0378		0.5	< 0.0001	**
% pasture	0.1	0.0146		0.3	< 0.0001	*
% urban	0.1	0.0043		0.2	0.0150	
% human land use				0.5	< 0.0001	* , **
% natural grassland	0.2	0.0011				
ATtILA riparian metrics						
% stream length adjacent to agricultural land use				0.4	< 0.0001	* , **
% stream length within 30 m of agricultural land use				0.4	< 0.0001	* , **
% stream length within 120 m of agricultural land use				0.4	< 0.0001	* , **
% stream length adjacent to crop land				0.3	< 0.0001	*
% stream length within 30 m of crop land				0.4	< 0.0001	*
% stream length within 120 m of crop land				0.4	< 0.0001	*
% stream length adjacent to pasture				0.3	< 0.0001	
% stream length within 30 m of pasture				0.4	< 0.0001	
% stream length within 120 m of pasture				0.4	< 0.0001	
% stream length adjacent urban land use	0.1	0.0261		0.3	0.0032	
% stream length within 30 m of urban land use	0.1	0.0362		0.3	0.0015	
% stream length within 120 m of urban land use				0.3	0.0015	
% stream length adjacent to human land use				0.4	< 0.0001	* , **
% stream length within 30 m of human land use				0.4	< 0.0001	* , **
% stream length within 120 m of human land use				0.4	< 0.0001	* , **
% stream length adjacent to natural grassland				0.3	0.0001	*
% stream length within 30 m of natural grassland				0.3	0.0001	*
% stream length within 120 m of natural grassland				0.3	0.0004	
ATtILA human stressor metrics						
density of 4-lane highways	0.1	0.0221				
density of 2-lane highways	0.1	0.0165				
density of interstate freeways				0.2	0.0430	
length of roads within 30 m of streams				0.3	0.0052	** , ***
length of 4-lane highways within 30 m of streams	0.1	0.0145				

Table 5. continued

Metric	**North Study Area**			**South Study Area**		
	Metrics positively correlated with increasing wetland degradation		**Metrics that predict condition (significant difference between condition classes?)**	**Metrics positively correlated with increasing wetland degradation**		**Metrics that predict condition (significant difference between condition classes?)**
	Spearman r	**p**	**ANOVA**	**Spearman r**	**p**	**ANOVA**
length of 2-lane highways within 30 m of streams	0.1	0.0344				
length of county, city roads within 30 m of streams				0.2	0.0183	**
number of road/stream crossings				0.3	0.0059	** , ***
number of 4-lane highway/stream crossings	0.2	0.0008				
number of 2-lane highway/stream crossings	0.1	0.0344				
number of county, city road/stream crossings				0.2	0.0406	**
nitrogen loading	0.1	0.0423		0.4	< 0.0001	
phosphorus loading	0.1	0.0337		0.5	< 0.0001	
population density	0.1	0.0242				
ATtILA physical characteristic metrics						
area of wetland				0.2	0.0306	
stream density				0.4	< 0.0001	
Supplemental metrics						
density of canals, ditches (km/km^2)				0.3	0.0004	**
density of wells (#/km2)	0.2	0.0009	**	0.3	0.0002	* , **
% likely grazed by livestock	0.1	0.0407		0.2	0.0162	** , ***
Metric	**Metrics negatively correlated with increasing wetland degradation**		**Metrics that predict condition (significant difference between condition classes?)**	**Metrics negatively correlated with increasing wetland degradation**		**Metrics that predict condition (significant difference between condition classes?)**
mean elevation	-0.3	< 0.0001		-0.5	< 0.0001	
mean precipitation	-0.2	< 0.0001		-0.3	0.0002	
mean slope	-0.3	< 0.0001		-0.3	0.0006	
% forest	-0.2	0.0013				
% stream length adjacent to all natural land use	not significant		*			
% stream length within 30 m of all natural land use	not significant		*			

r > 0.5 = strong
r = 0.4 -0.5 = moderate
r < 0.4 = weak
* = relative significance

Prototype landscape-scale wetland assessment tool: The predictive model of wetland condition was used to estimate the ecological condition of 20,878 NWI polygons across both study areas. In both the north and south study areas, a large majority of wetlands fell in the moderately disturbed condition class. Relatively few polygons were minimally disturbed or completely disturbed.

In the north study area, the proportion of wetlands in different condition classes varied greatly by subbasin (Figures 19 and 20). In mountainous or heavily forested subbasins, such as the Moyie, Priest, Upper Coeur D'Alene, and Upper Kootenai, about 90% or greater of the wetlands were in minimally disturbed or moderately disturbed classes (Figure 20). The Priest subbasin had the most minimally disturbed wetlands, both by proportion and total number. Mountainous subbasins tended to have less total wetlands when compared to lower elevation and flatter subbasins such as Pend Oreille Lake or Priest (Figure 19). At least about 60% of the wetlands in the Little Spokane and Pend Oreille subbasins were in the severely disturbed or completely disturbed classes (Figure 20). These subbasins had the least wetlands in the study area (Figure 19). The Pend Oreille subbasin had the lowest proportion minimally disturbed wetlands in the north study area. Although the Priest subbasin had a small proportion of wetlands in severely or completely disturbed condition, these wetlands had very high scores for disturbance (Appendix 5).

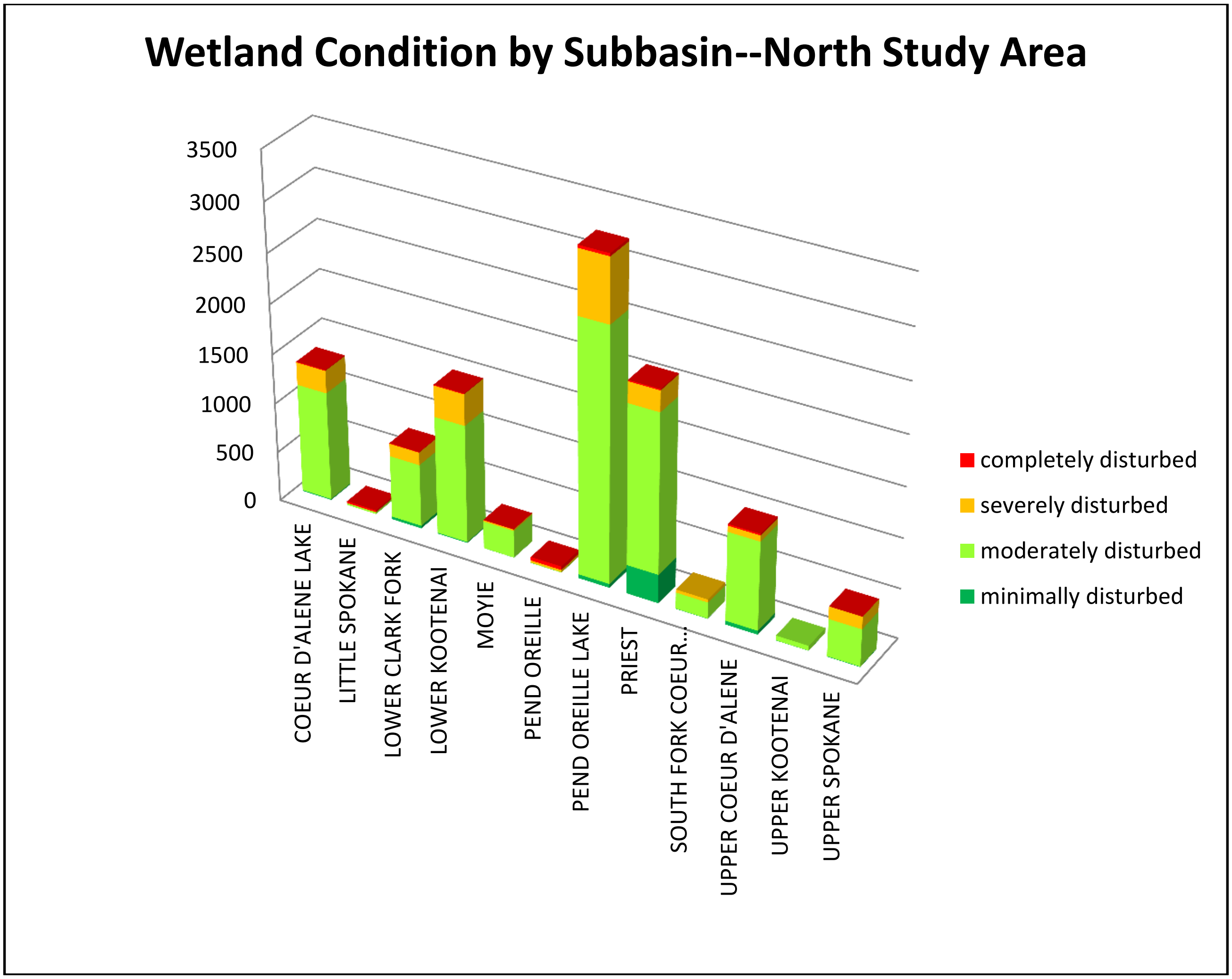


Figure 19.

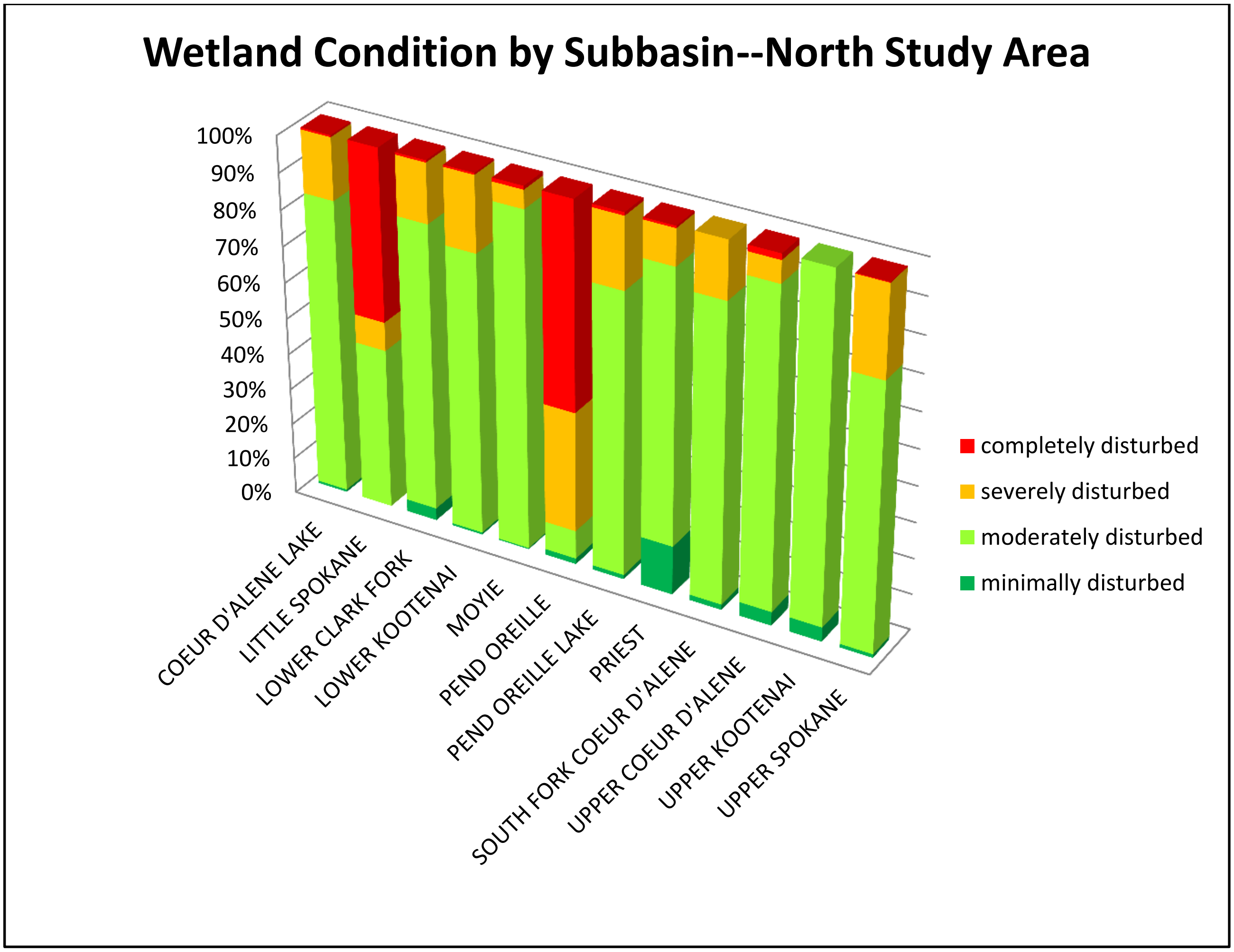


Figure 20.

In the north, palustrine emergent (PEM) was the most common wetland type, followed by palustrine scrub-shrub (PSS) and palustrine forested (PFO) (Figure 21). At least 30% of PEM, palustrine open water (POW), palustrine unconsolidated bottom (PUB), and palustrine unconsolidated shore (PUS) wetlands were severely or completely disturbed (Figure 22). The wetland classes with the highest proportion of minimally or moderately disturbed wetlands were lacustrine (L2 littoral), palustrine aquatic bed (PAB) and PSS, and riverine (R2 lower perennial, R3 upper perennial, and R4 intermittent). However, the lacustrine (L1 limnetic and L2), PAB, and riverine classes were much less frequently occurring than PEM, PSS, and PFO classes (Figure 21).

Figure 23 shows the distribution of wetlands by condition class for the entire north study area. Maps of wetlands by condition class for each subbasin are found in Appendix 6. Clusters of severely and completely disturbed wetlands tend to be associated with the U. S. Highway 95 corridor between Athol and Bonners Ferry. Large clusters of wetland degradation are also noticeable in the lower Priest subbasin, along the Pend Oreille River, and throughout the Upper Spokane subbasin. Large patches of severely disturbed wetlands also occur along the lower Clark Fork and Coeur D'Alene Rivers. Minimally disturbed wetlands tended to be widely scattered in mountainous areas of the Priest, Lower Clark Fork, Upper Kootenai, and Upper Coeur D'Alene subbasins. These wetlands tend to be relatively small in area and discontinuously distributed.

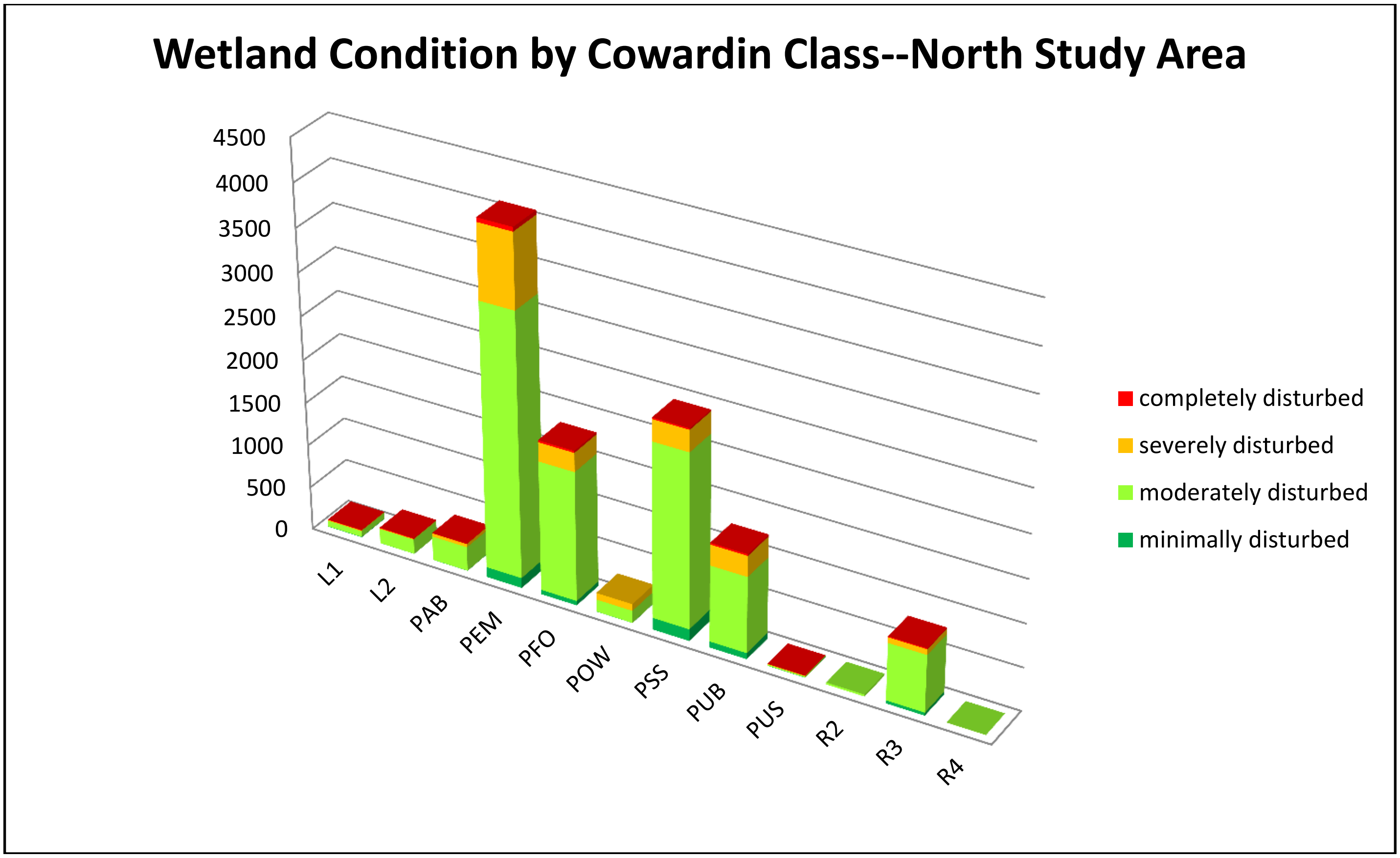


Figure 21.

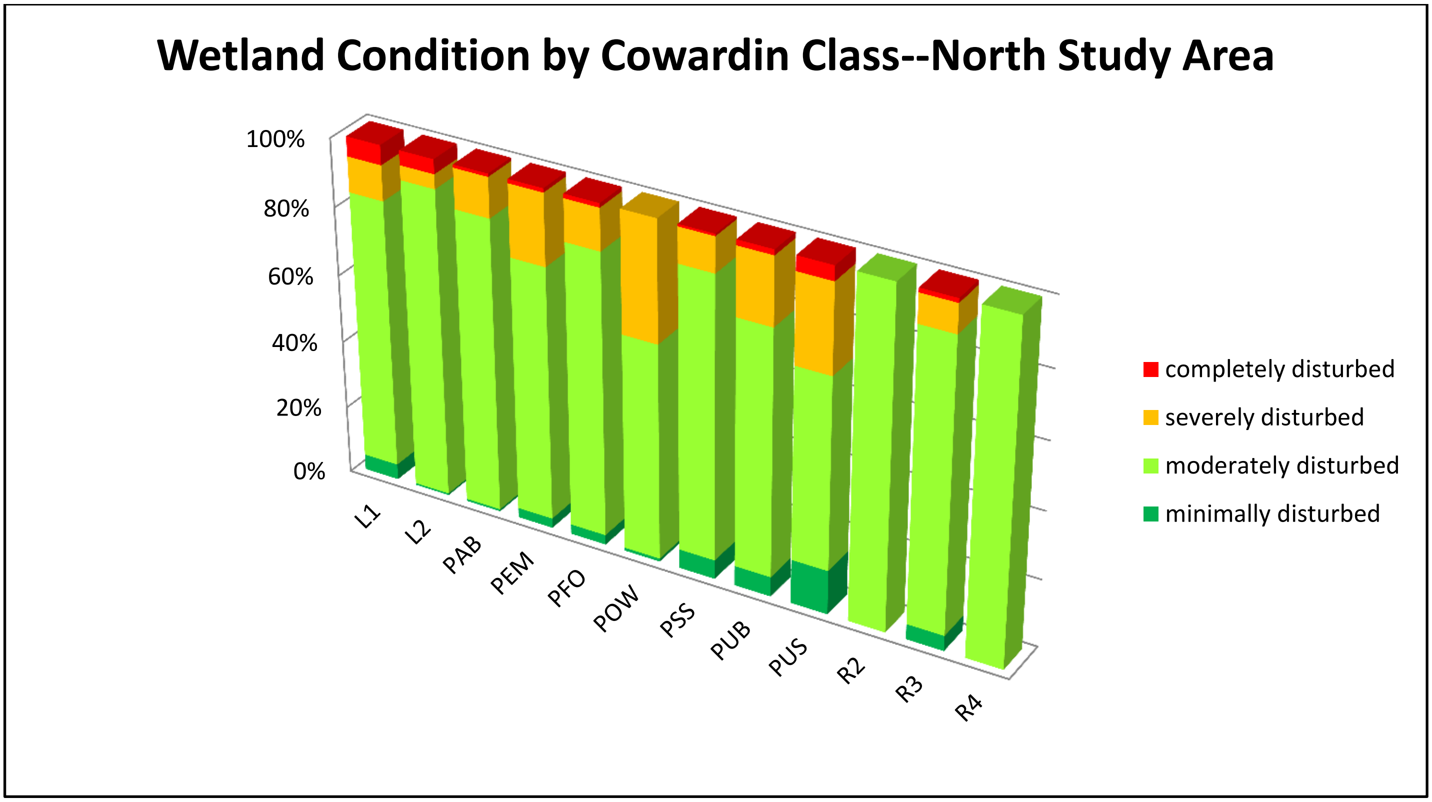
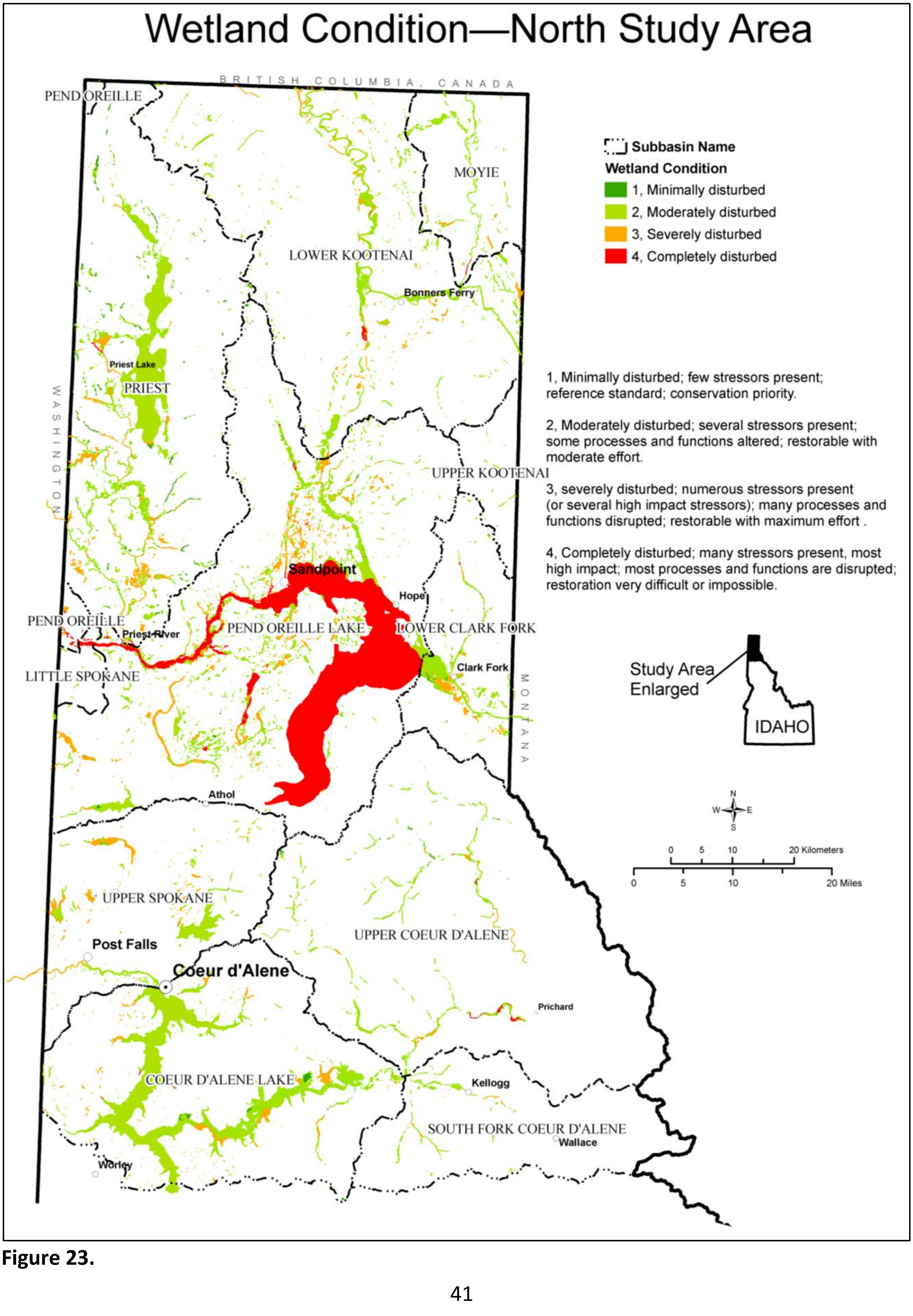


Figure 22.



Wetland Condition—North Study Area

Subbasin Name

Wetland Condition

- 🟩 1, Minimally disturbed
- 🟩 2, Moderately disturbed
- 🟧 3, Severely disturbed
- 🟥 4, Completely disturbed

1, Minimally disturbed; few stressors present; reference standard; conservation priority.

2, Moderately disturbed; several stressors present; some processes and functions altered; restorable with moderate effort.

3, severely disturbed; numerous stressors present (or several high impact stressors); many processes and functions disrupted; restorable with maximum effort .

4, Completely disturbed; many stressors present, most high impact; most processes and functions are disrupted; restoration very difficult or impossible.

Figure 23.

In the south study area, wetlands are most abundant in the Weiser, Payette, and Lower Boise subbasins (Figures 24). Of these subbasins, the Weiser had the largest number of wetlands in the minimally and moderately disturbed classes (Figure 25). Compared to the north, the model for the south resulted in a much larger proportion of wetlands in the minimally disturbed condition class (Figure 25). The Bruneau, C. J. Strike Reservoir, and Weiser subbasins had the highest proportion of wetlands in the minimally disturbed class. The Lower Boise subbasin had the least proportion in the minimally disturbed class, followed by the Middle Snake-Payette. In contrast to the Lower Boise, the Middle Snake-Payette subbasin had the second least number of wetlands in the study area (Figure 24), but it had a relatively low amount of severely and completely disturbed wetlands. The Middle Snake-Succor had the largest proportion of wetlands in the severely and completely disturbed classes.

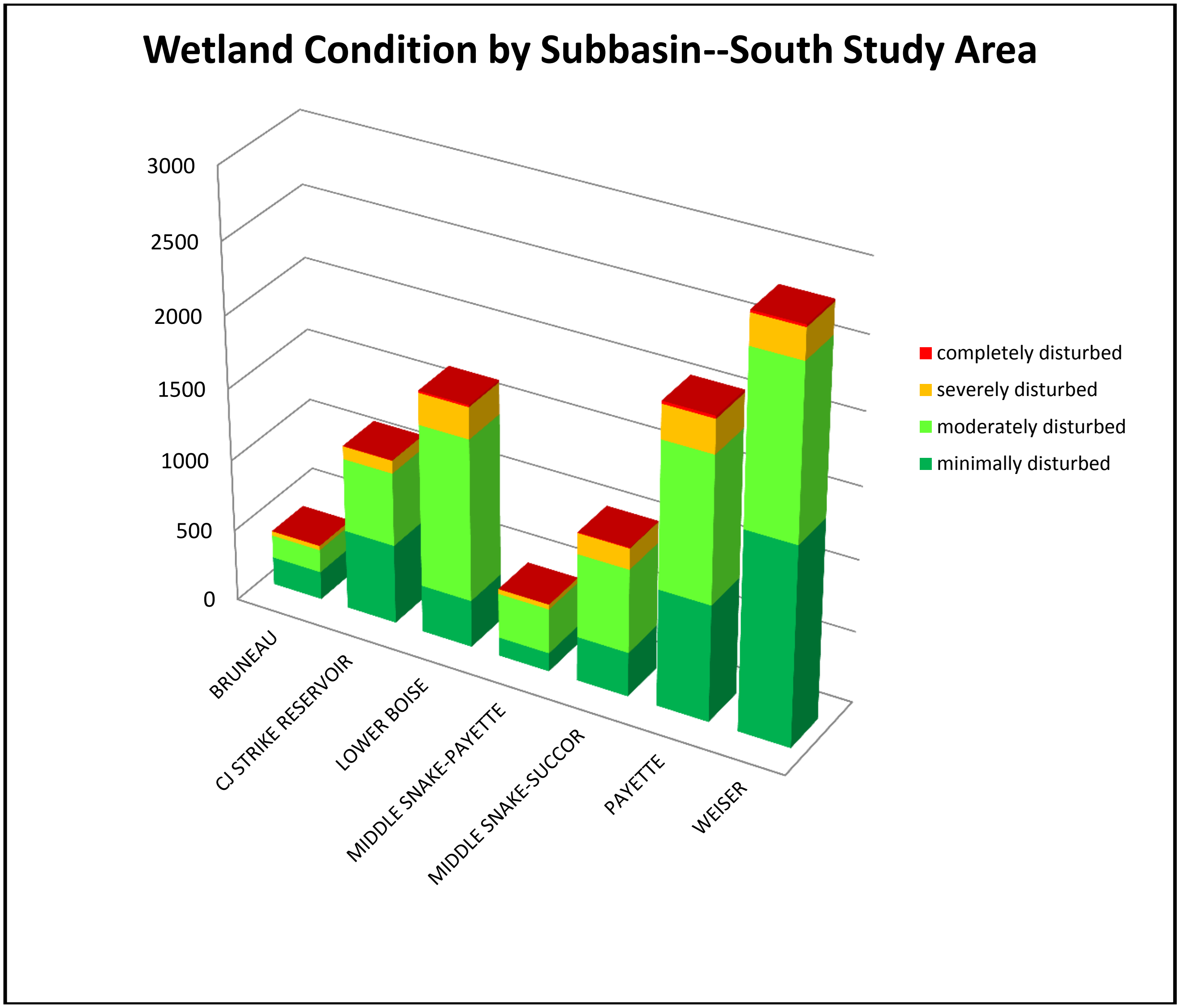


Figure 24.

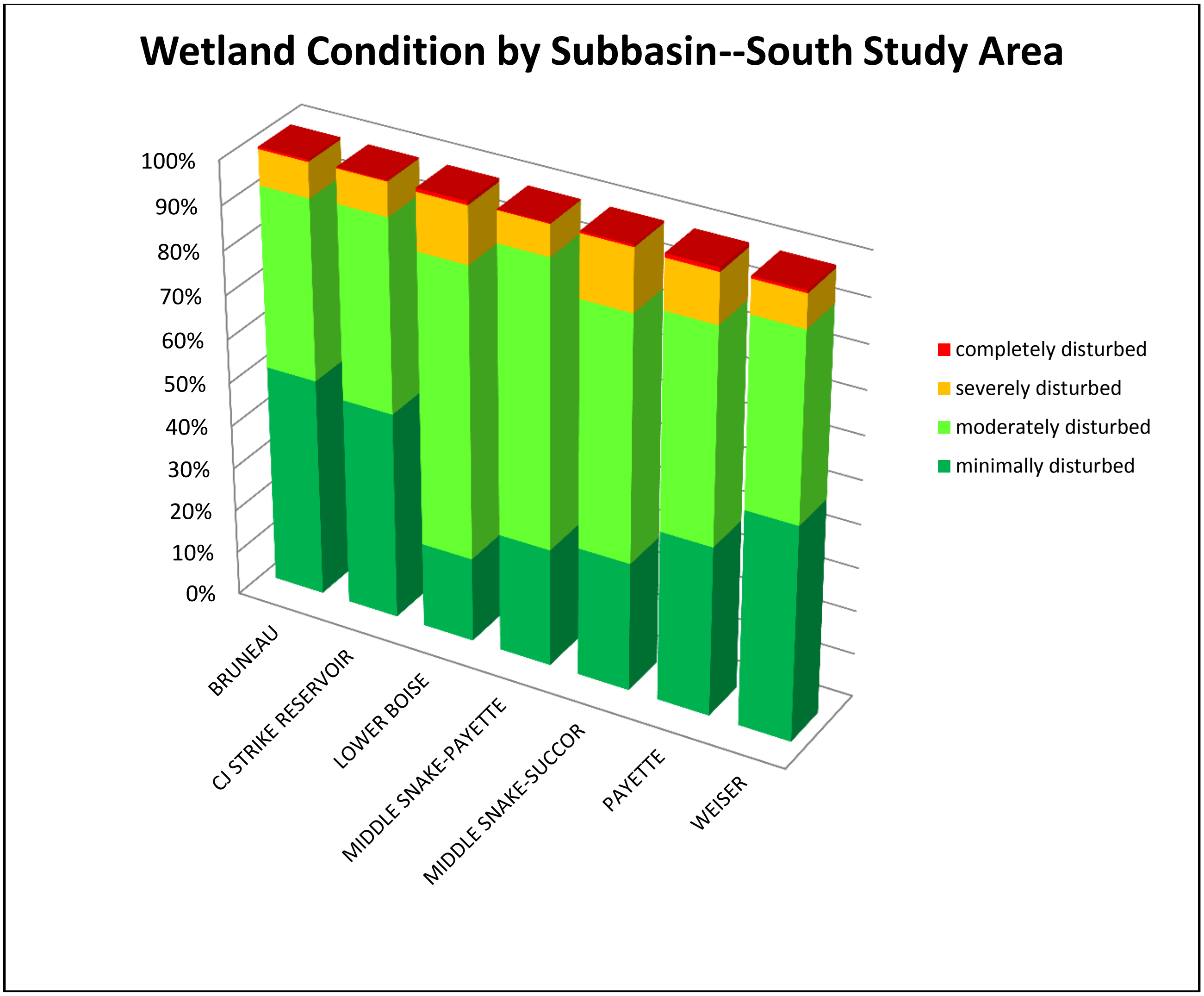


Figure 25.

Palustrine emergent (PEM) wetland is the most frequently mapped wetland class in the south study area, followed by palustrine unconsolidated bottom (PUB) (often in reservoirs) and palustrine scrub-shrub (PSS) (Figure 26). Lacustrine (L1 limnetic and L2 littoral) and riverine wetlands (R2 lower perennial and R4 intermittent) wetlands are uncommon in the study area. Although not abundant, riverine upper perennial (R3) wetlands had the highest proportion in the severely and completely disturbed classes (Figure 27). Other classes with over about 20% of wetlands in severely and completely disturbed classes were palustrine forested (PFO) and R4. Cowardin classes with over about 50% minimally disturbed wetlands were L2 and PSS.

The map of wetland condition in the south study area (Figure 28) shows severely and completely disturbed wetlands were widely distributed. Clusters of minimally disturbed wetlands occur throughout the Weiser subbasin, especially at higher elevations and in the Indian Valley area (southeast of Cambridge), as well as in the upper Payette subbasin (e.g., High Valley), the Danskin Mountains northeast of Mountain Home, and near Bruneau. In general, wetlands along the Snake River were moderately disturbed. Maps of wetlands by condition class for each subbasin are found in Appendix 6.

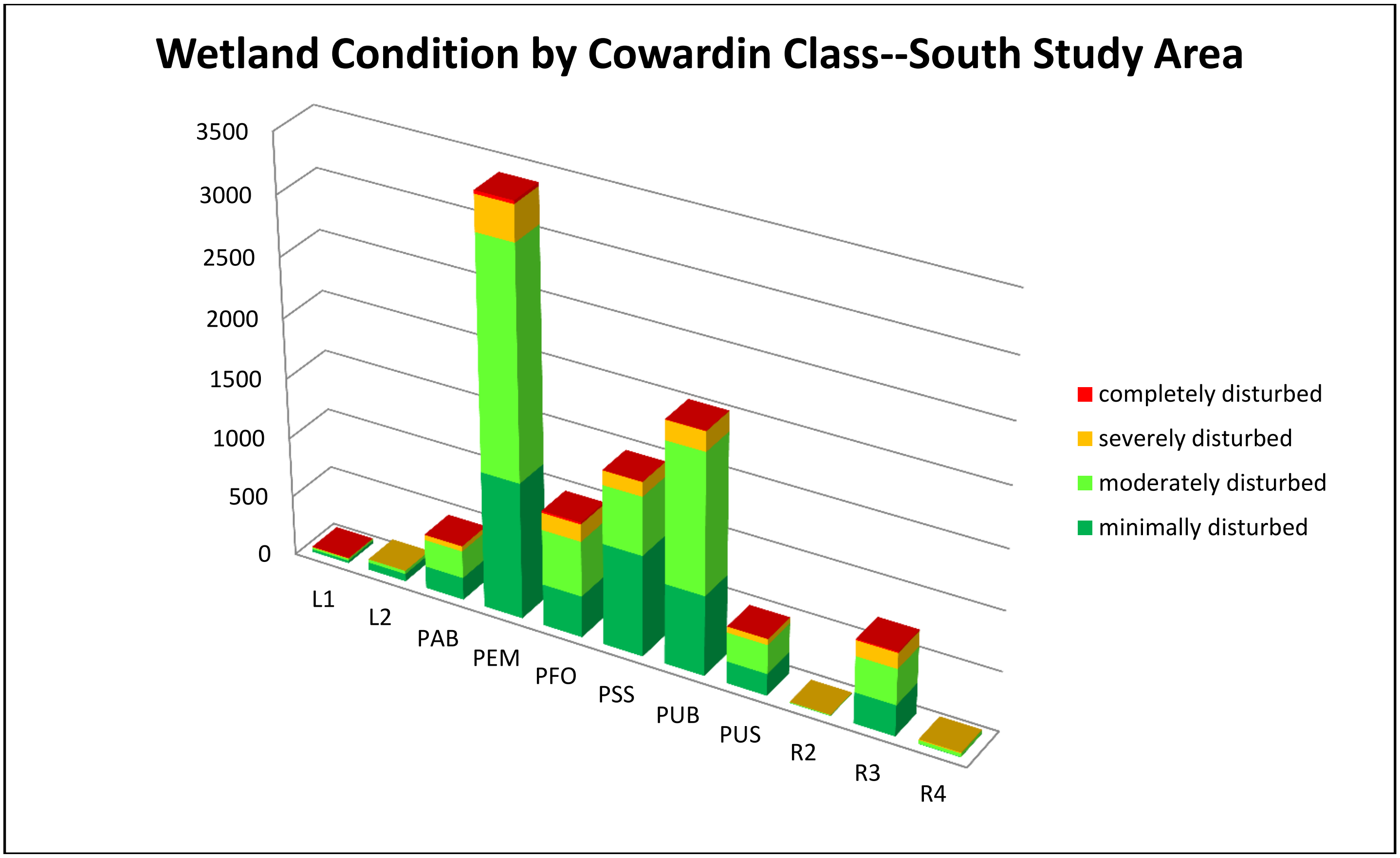


Figure 26.

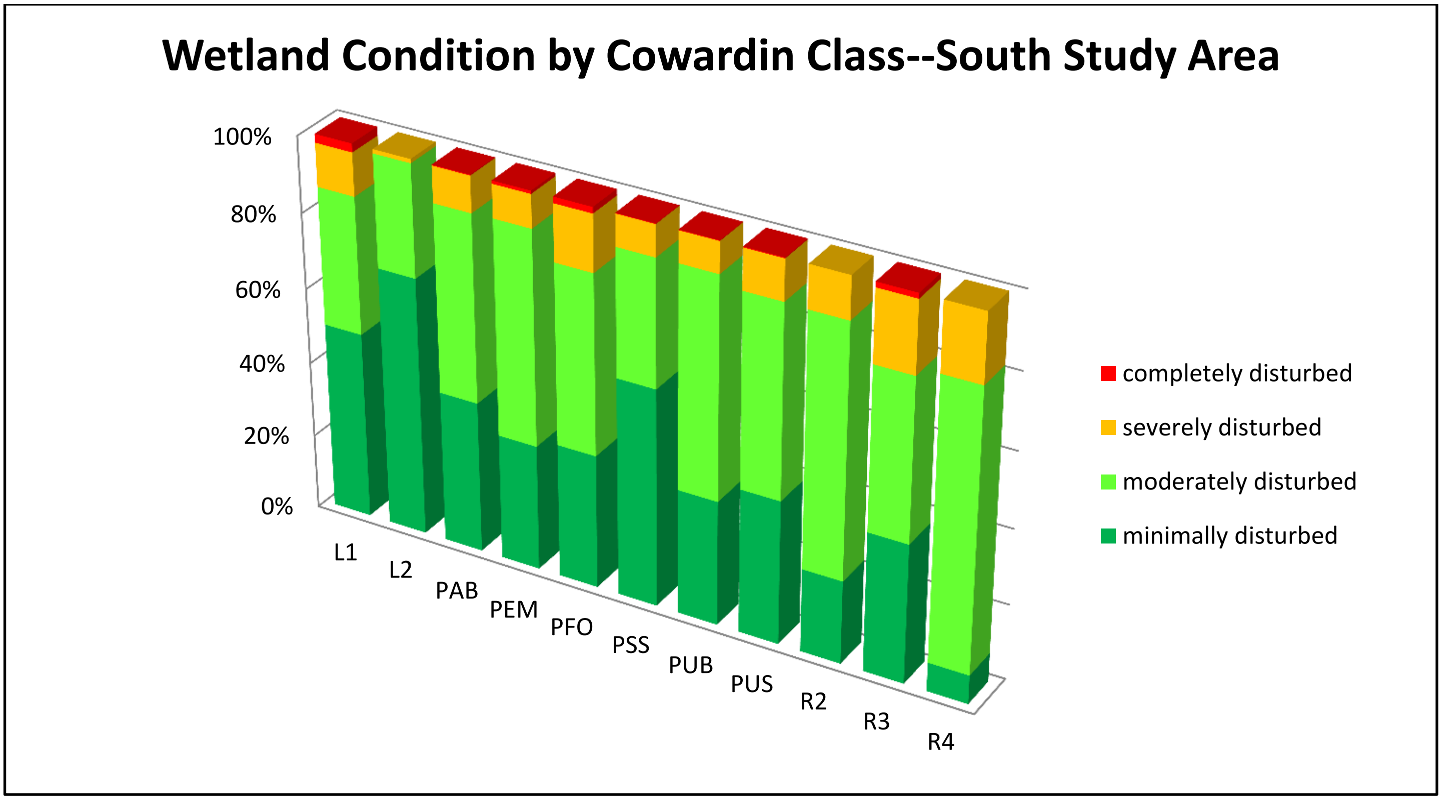


Figure 27.

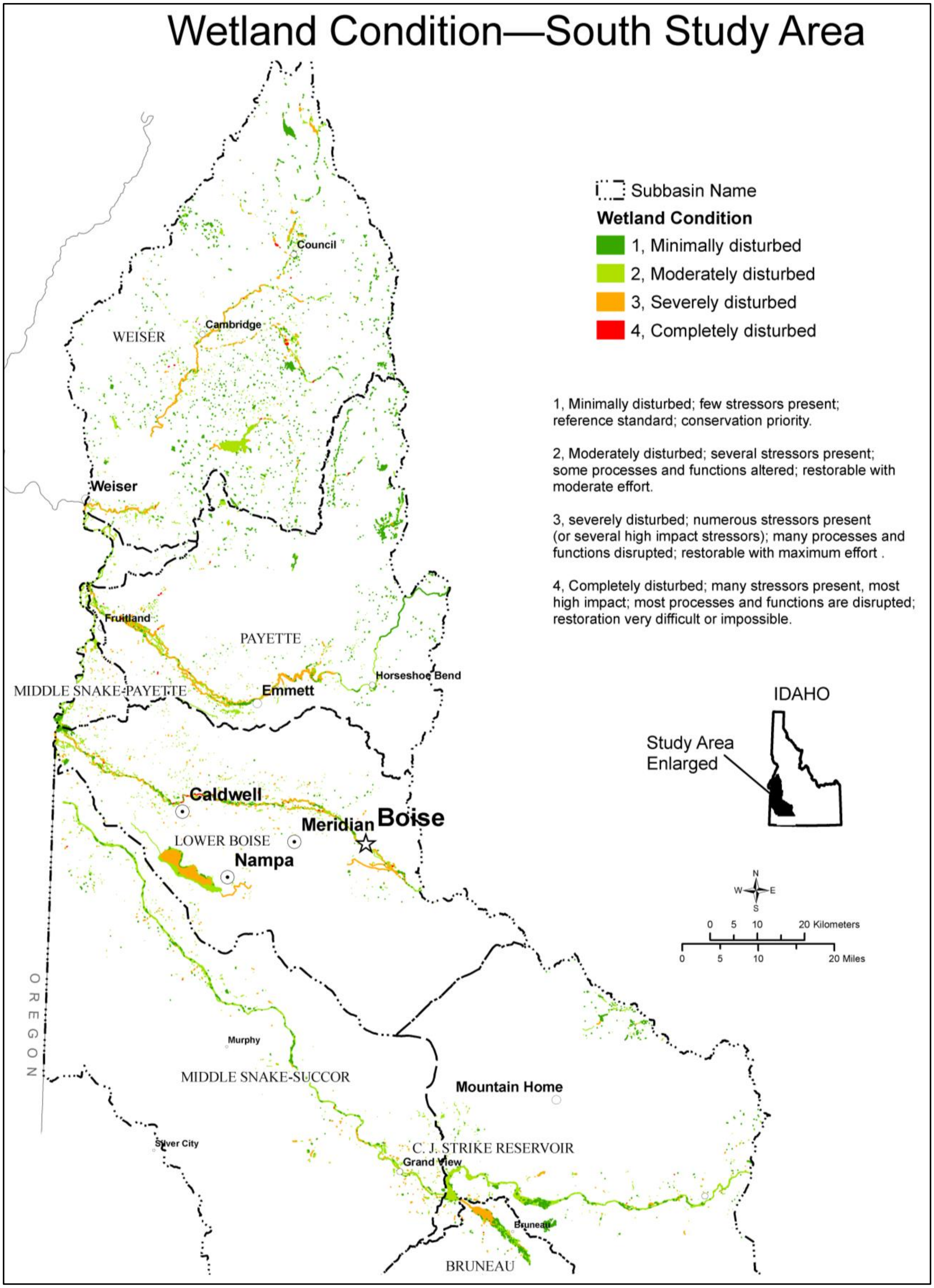

Wetland Condition—South Study Area
Subbasin Name
Wetland Condition
1, Minimally disturbed
2, Moderately disturbed
3, Severely disturbed
4, Completely disturbed
1, Minimally disturbed; few stressors present; reference standard; conservation priority.
2, Moderately disturbed; several stressors present; some processes and functions altered; restorable with moderate effort.
3, severely disturbed; numerous stressors present (or several high impact stressors); many processes and functions disrupted; restorable with maximum effort .
4, Completely disturbed; many stressors present, most high impact; most processes and functions are disrupted; restoration very difficult or impossible.
IDAHO
Study Area Enlarged
N
W
E
S
0
5
10
20 Kilometers
0
5
10
20 Miles
Council
Cambridge
WEISER
Weiser
Fruitland
PAYETTE
Horseshoe Bend
Emmett
MIDDLE SNAKE-PAYETTE
Caldwell
Meridian
Boise
LOWER BOISE
Nampa
OREGON
Murphy
MIDDLE SNAKE-SUCCOR
Mountain Home
Silver City
C. J. STRIKE RESERVOIR
Grand View
Bruneau
BRUNEAU

Figure 28.

Similar to results for wetlands, the ecological condition of HUC12s was also skewed toward the minimally disturbed and lightly disturbed classes (Figure 29). A similar proportion of the HUC12s were in the minimally disturbed and lightly disturbed condition classes in each study area. In both areas, about 40% of the HUC12s were lightly-moderately disturbed. The north had 10% HUC12s in the moderately-severely and severely disturbed classes, and zero in the completely disturbed class. The south had nearly twice as many HUC12s in these and the completely disturbed class. Data incorporated in the HUC12 condition model is found in Appendix 7.

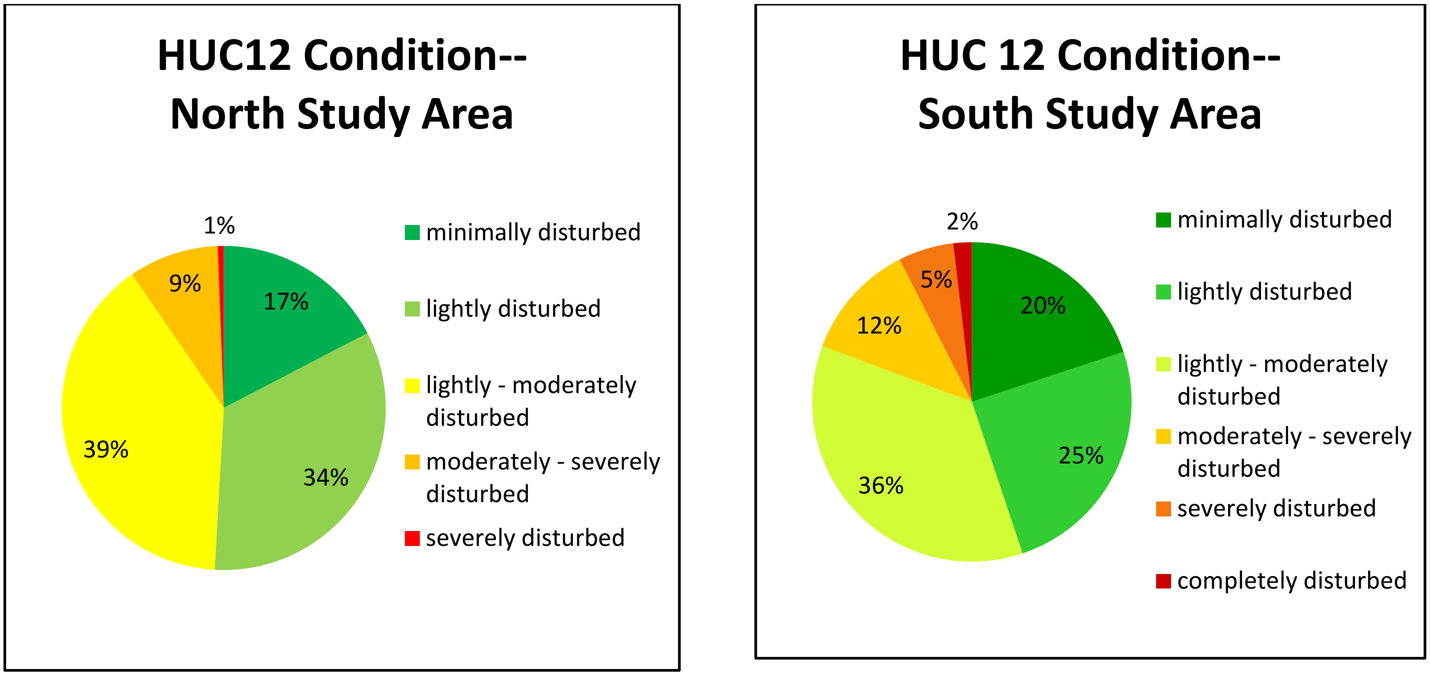


Figure 29.

Condition of HUC12 in the north varied greatly across subbasins (Figure 30). The Lower Clark Fork, Upper Kootenai, and Upper Coeur D'Alene subbasins had the highest proportion of HUC12s in the minimally disturbed class. Relatively few or no HUC12s were in the minimally and lightly disturbed classes in Coeur D'Alene Lake, Moyie, Pend Oreille, and Upper Spokane subbasins. The proportion of moderately-severely and severely disturbed HUC12s was highest in the Coeur D'Alene Lake, Pend Oreille Lake, South Fork Coeur D'Alene, and Upper Spokane subbasins (Figure 30).

HUC12 condition in the south study area was also highly variable across subbasins (Figure 31). The Lower Boise and Middle Snake-Payette subbasins lacked minimally disturbed HUC12s. Over about 40% of HUC12s in these subbasins were in the severely or completely disturbed condition classes. Severely disturbed HUC12s were also present in the Middle Snake-Succor, Payette, and Weiser subbasins. However, in these subbasins over 30% of the HUC12s were in the minimally or lightly disturbed classes. The Bruneau subbasin had the largest proportion of HUC12s in the minimally and lightly disturbed classes (over about 80%).

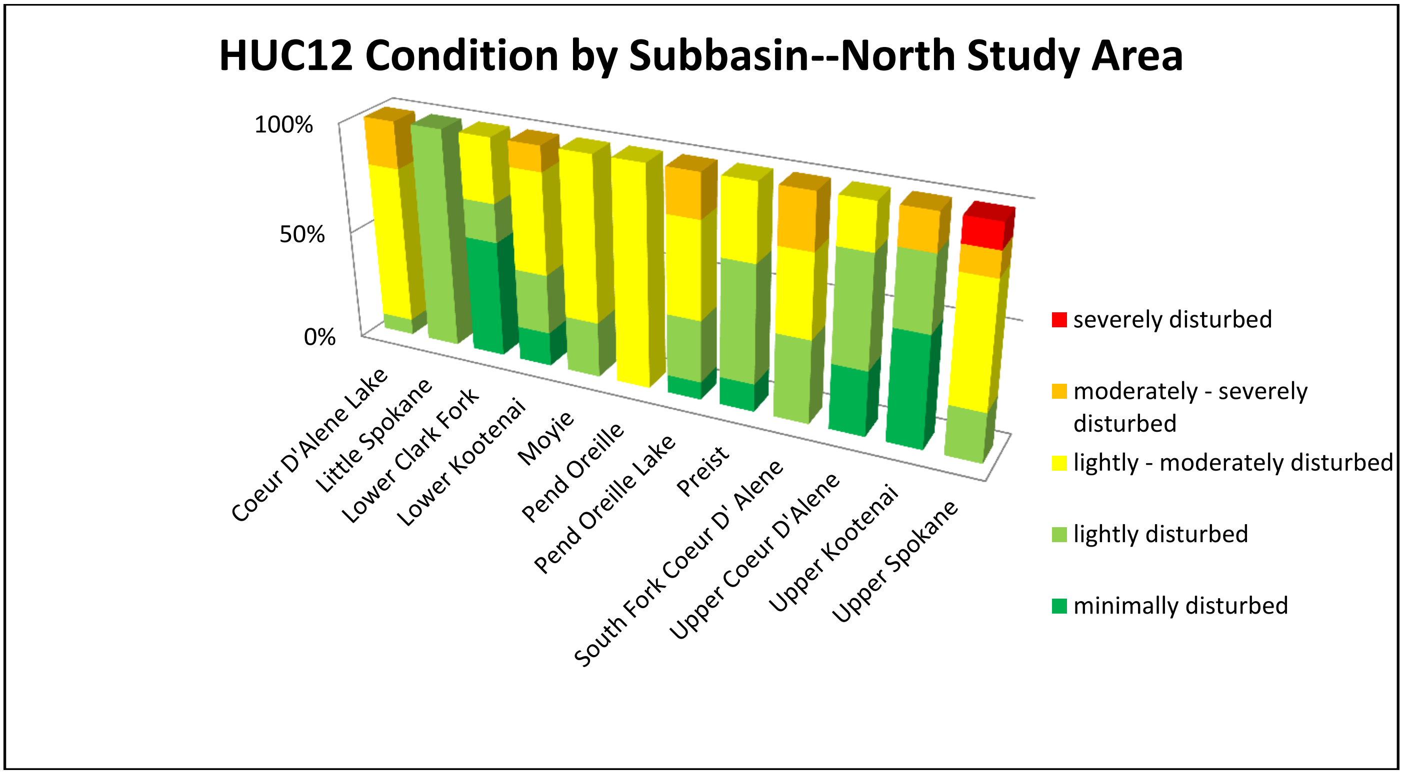


Figure 30.

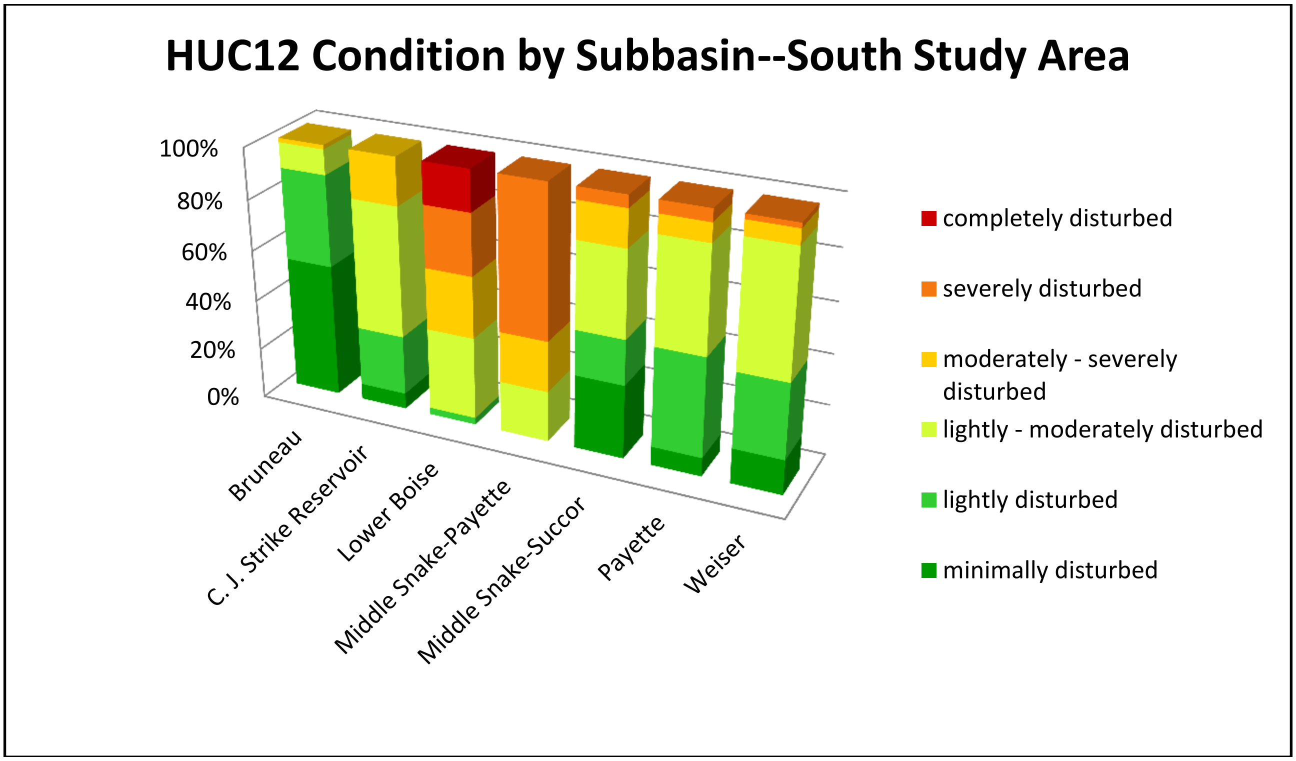


Figure 31.

In the north, minimally disturbed HUC12s occurred in the upper Priest and higher elevations of the Lower Kootenai and Pend Oreille Lake subbasins (e.g., Selkirk Mountains ecoregion) (Figures 32 and 33). The only severely disturbed HUC12 occurred at the city of Coeur D'Alene (e.g., Spokane Valley Outwash Plains ecoregion) (Figure 32). Lightly-moderately disturbed HUC12s (yellow) (Figure 33) were widespread where land use is a mosaic of forestry and rural farms and residences. Condition of HUC12s decreased around urban areas and along highway corridors. Condition improved in mountainous and roadless areas (Figure 32). Contiguous minimally and lightly disturbed HUC12s occur in the Selkirk, Purcell-Cabinet, and Coeur D'Alene Mountain ecoregions (Figure 2).

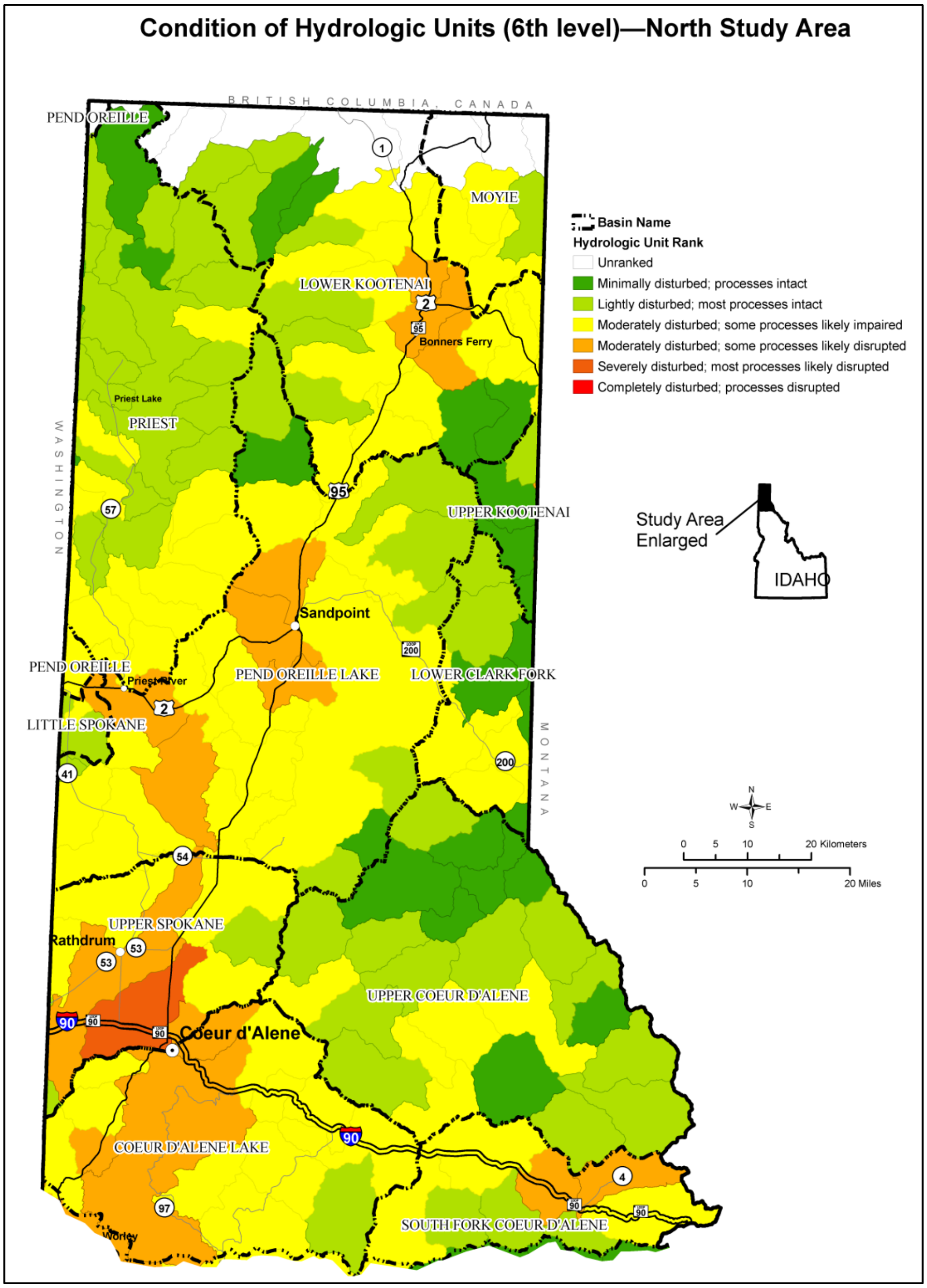
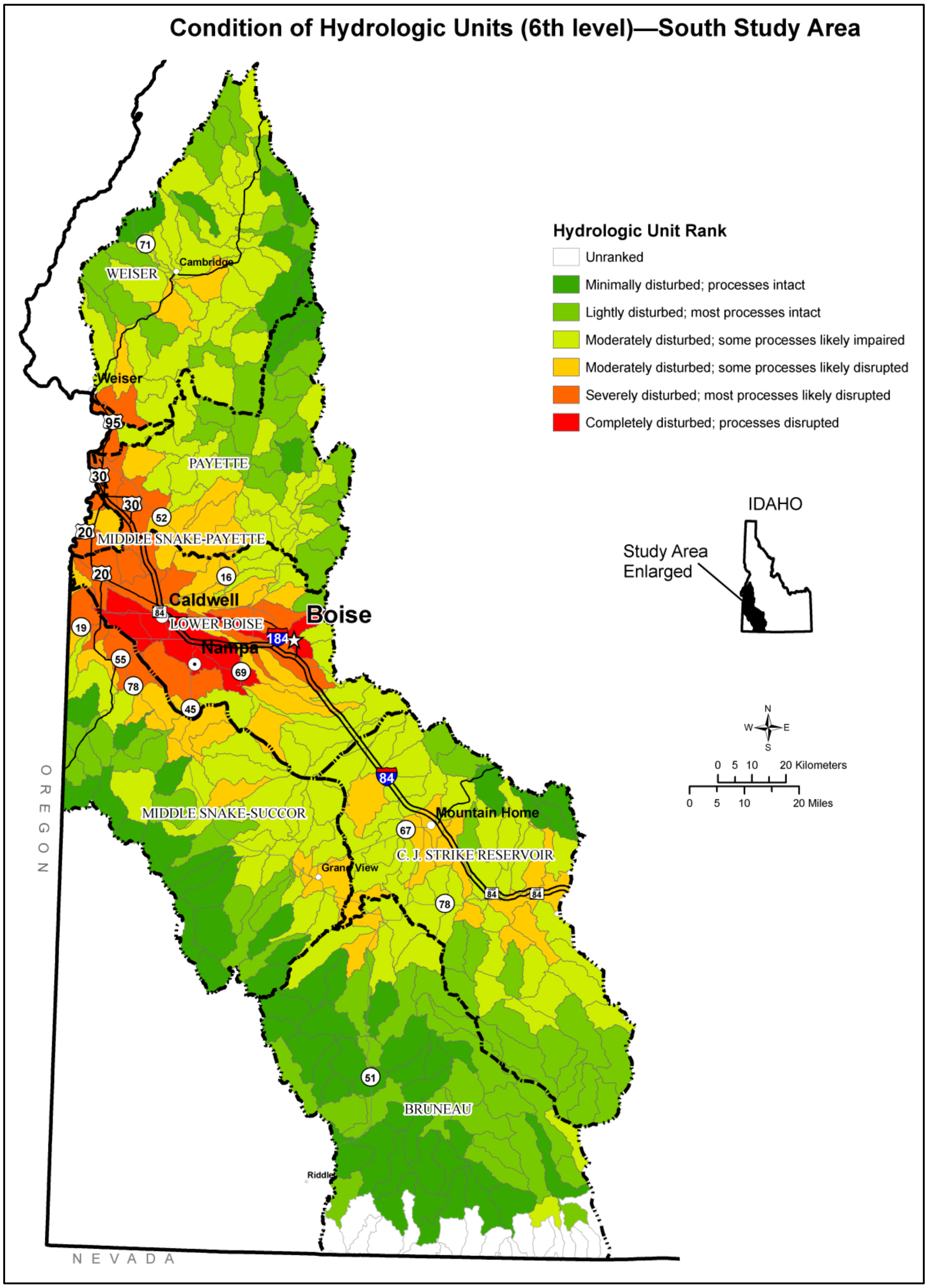


Figure 32.

Figure 33. Examples of HUC12 condition in the north study area. Brush Creek-Kootenai River HUC12, Lower Kootenai subbasin: lightly-moderately disturbed (top); Ruby Creek-Upper Priest River HUC12, Priest subbasin (bottom left and right): minimally disturbed

The south study area is characterized by a block of severely and completely disturbed HUC12s in the Lower Boise, Middle Snake-Payette, and lower portions of the Payette and Weiser subbasins (Figures 33 and 34), the area coinciding with the Treasure Valley ecoregion (Figure 3). Contiguous lightly and minimally disturbed HUC12s are found in mountainous areas of the Weiser (Cuddy Mountain, West Mountains), Payette (West Mountains), C. J. Strike Reservoir (Bennett Mountain), and Middle Snake-Succor (Owyhee Mountains) subbasins. Lightly-moderately disturbed HUC12s predominate in low to mid-elevation foothills of the Weiser and Payette subbasins (Figure 34). Blocks of minimally disturbed HUC12s also occur on the Owyhee Plateau in the Bruneau subbasin.



Condition of Hydrologic Units (6th level)—South Study Area

Figure 33.

Figure 34. Examples of HUC12 condition in the south study area. Yergenson-Squaw Creek HUC 12, Payette subbasin: lightly-moderately disturbed (top); Crane Creek-Boise River HUC12, Lower Boise subbasin: completely disturbed (bottom)

Discussion

***Prototype landscape-scale wetland assessment tool*:** The predictive model of wetland and HUC12 condition developed for this project is a prototype that needs further refinement. Based on inspection of results, condition ranking appears logical for most of the wetlands and HUC12s in the study area. For wetlands, results appeared to be influenced by polygon size, with the condition of large lakes and long riverine wetlands not as accurately assessed as small to mid-sized polygons. Results of condition ranking are a first-cut estimate and should not be used to make management decisions (Weller et al. 2007). Although a thorough accuracy assessment was not included as part of this project, it is unlikely that the prototype model meets the goal of 75% accuracy in predicting wetland condition. However, this landscape-scale assessment does succeed in objectively establishing a baseline of condition through its application of field observations of condition in development of a statistically based GIS model. The potential utility of this tool is enhanced because it includes both watershed and wetland-scale assessments. Synthesis of assessment data from multiple-spatial scales creates opportunities for additional conservation and restoration applications (Wardrop et al. 2007, Weller et al. 2007).

Landscape-scale assessments typically yield variable estimates of ecological condition at watershed and wetland scales (Hychka et al. 2007, Wardrop et al. 2007, Weller et al. 2007, Vance 2009). Because of this, they should not be used in lieu of on-the-ground assessments. Also, methods used in this project to develop the model of predictive condition (e.g., correlation) do not imply cause and effect between factors and condition (Hychka et al. 2007). In addition, we did not utilize a full range of possible tools that might strengthen the predictive model (e.g., Classification and Regression Tree (CART) as in Wardrop et al. 2007, Weller et al. 2007, and Vance 2009). Statistical methods, including CART and others, should be applied in future iterations of this assessment tool to examine covariance between metrics, better identify breaks in condition classes, and determine weighting for metrics. These analyses, combined with integration of buffer condition into the model, will likely strengthen the tool.

The strength of a landscape-scale assessment arises from their ability to calculate numerous metrics from large datasets for many wetlands at one time (Vance 2009). However, numerous sources of potential error can influence both model development and outputs. For example, NWI, NLCD, and other spatial layers contain accuracy errors and become out-of-date as land use and management activities change more rapidly than the layers (Weller et al. 2007, Vance 2009). Secondly, some site specific disturbances and indicators, such as livestock grazing and noxious weed or highly invasive plant species invasion, are not mapped well or at all (Vance 2009). Third, the rapid assessment method used for this project, while suitable for observing stressors and land uses that are related to landscape-scale metrics, has not been thoroughly tested. It is based on expert judgment and is an adaptation of other rapid assessment methods. A larger set of improved field data, derived from both rapid assessment and more intensive, site specific biologic assessment would likely strengthen the predictive model. Finally, we estimated condition at reference wetlands by using a subset of all data collected at assessment and monitoring sampling points. Potential errors in condition ranking could occur because we extrapolated condition determined from a point or several points to the whole wetland polygon (especially problematic at larger wetland polygons).

Our results support the assumption that land use and human disturbance across the landscape influence ecological condition at individual wetlands. As in Hychka et al. (2007), the metric screening approach was useful in identifying relationships between landscape-scale metrics and wetland condition. Although we found a large number of metrics significantly correlated with wetland condition, correlations were weak and may not provide enough information to create a robust and accurate model. Other metrics that were expected to be powerful indicators of wetland condition were not significantly correlated. This result was similar to Delaware and Maryland (Weller et al. 2007), Montana (Vance 2009), North Dakota (Mita et al. 2007), Pennsylvania (Hychka et al. 2007), and South Dakota (Troelstrup and Stueven 2007).

Like Weller et al. (2007) and Vance (2009), our results showed the importance of environmental variables (e.g., elevation, precipitation, slope, wetland size, stream density) as factors related to wetland condition, especially when the area of analysis spans multiple subbasins or ecoregions. In this project and these studies, the types and number of important metrics were highly variable, stressing the importance of using statistical tools to determine which metrics are important in a landscape-scale assessment. As in Vance (2009), we also documented regional differences, both in model development and resulting outputs. For example, the number of important metrics was greater in the south study area than the north, and the number of minimally disturbed wetlands was greater in the south. Whether this was due to differences between north and south versions of the model or actual differences in condition needs more evaluation. One way to compare wetlands across regions might be to assess all wetlands at one time with the same metrics, but to weigh the most important metrics for a region more heavily for wetlands in that region.

Overall, the initial process used and assessment results were similar to those in Montana (Vance 2009). Data processing challenges presented by using ATtILA (an outdated GIS extension), unsatisfactory results (e.g., poor accuracy in predicting wetland condition and weaker than expected correlations between landscape-scale metrics and condition), and incomplete statewide wetland mapping forced us to rethink the entire process and methodology used in this first phase. Vance (2009) solved these and other challenges by adopting a landscape integrity model approach (Faber-Langendoen et al. 2006). This method also calculates metrics for most of the land use and condition layers analyzed for this preliminary landscape-scale assessment. However, instead of calculating metrics for predetermined vector-based polygons (e.g., NWI polygons), metrics are calculated for every 30 m^2 pixel in the state and a single raster layer is produced. The power of this method stems from how distance from each human land use category, development type, or disturbance can be calculated for each pixel. This inverse weighted distance model is based on the assumption that ecological condition will be poorer in areas of the landscape with the most cumulative human activities and disturbances. Condition improves as you move toward least developed areas (Faber-Langendoen et al. 2006, Vance 2009). As before, weighting and condition thresholds can be estimated by using existing wetland condition assessment data. We have decided to use this landscape integrity model approach for Phase 2 of this project. Considerable data processing is necessary, but the resulting raster layer will have greater utility, incorporate wetland buffer characteristics, better estimate condition at a finer and consistent spatial scale, and bring us closer to our goal of creating a “user-friendly” and accurate decision-support tool for statewide landscape-scale wetland assessment.

***Project outcomes--partnerships*:** Development of the prototype landscape-scale wetland assessment tool has identified correlations between landscape-level metrics and wetland condition to help in planning conservation, mitigation, restoration, and creation projects. The prototype tool will enable stakeholders with limited resources to conduct a broad-scale assessment of wetland condition.

We organized an IWWG meeting on May 16, 2008, to introduce the project concept and methods. The meeting provided IWWG members with an opportunity for input on the prototype model. Fourteen people attended the 2-hour meeting. At least 8 members were utilizing non-federal dollars to attend and we applied the value of their time toward our match requirements. The project concept and potential uses of final products were well received. The main concerns were about the quality and timeliness of input spatial layers and how to incorporate ATtILA into a final user-friendly tool. It was decided that the landscape-scale assessment tool should be in the form of a suite of GIS layers rather than a complicated GIS extension program. The resulting GIS layers would be organized into a user-friendly interface that allows a user to choose which outputs are most relevant to their question. The output products would be periodically updated as spatial layers are updated. An IWWG meeting is planned to present results of this project. A poster presentation of this project was displayed at the Society of Wetland Scientists Pacific Northwest Chapter conference in Bellingham, Washington (April 28 - 30, 2010).

***Expected Applications*:** Phase 2 of this project includes refinement and testing of the prototype landscape-scale assessment tool. This will be accomplished by demonstrating its applicability in wetland planning. The tool will be applied in 5 case studies by working with partners, including prioritization of wetland protection and restoration in a rapidly urbanizing area; development of a wetland restoration plan; identification of wetland resources for land-use planning; working with a state agency to develop a plan for wetland management, mitigation, or conservation; and identification high value wetlands for at-risk species. Wetland-scale assessments will be used to field-test landscape-scale results for each case study. Results will be used to refine the tool. The main product will be a “user-friendly” GIS-based decision-support tool for statewide landscape-scale wetland assessment.

When finalized, the landscape-scale assessment tool will assist federal, state, tribal, and local organizations in the development and implementation of wetland protection programs. Such tools are useful for targeting assessment and monitoring efforts towards vulnerable wetland resources at broad spatial scales (Wardrop et al. 2007). This is especially true for organizations lacking funding for more intensive assessments and monitoring. Planners and managers will be able to analyze the distribution of wetland impacts across broad areas. For example, IDEQ has expressed interest in incorporating landscape-scale assessment methods into future revisions of their Surface Water Ambient Monitoring Plan required under the Clean Water Act. The landscape assessment tool could also be used to prioritize wetlands for acquisition in the Statewide Comprehensive Outdoor Recreation and Tourism and Conceptual Area Plans (as in Hahn et al. 2005). The condition of wetland habitats for at-risk species prioritized in the Idaho Comprehensive Wildlife Conservation Strategy (IDFG 2005) can also be assessed. In high priority regions, the condition of similar wetland types can be compared. Monitoring and conservation can then be tailored to meet specific objectives. When combined with hydrogeomorphic analysis or watershed profiles, condition information resulting from landscape-scale assessment can be combined with functional analysis and used for planning wetland protection, restoration, and mitigation in a watershed approach to help meet Clean Water Act requirements. Using historic wetland maps, the tool can also be used to compare past distribution, abundance, and condition of wetland types on the landscape with the present situation. Areas currently lacking wetlands where expected, based on past distribution, can be targeted for wetland restoration or creation. Specific types of wetlands to target can also be identified. The possibility of combining landscape assessment across political boundaries needs to be investigated for shared watersheds, such as the Kootenai and Clark Fork Rivers. Through these and other applications, this project will eventually aid in the design of projects that result in a net increase in wetland area and function.

Acknowledgements

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Appendices (files available on compact disc)

Appendix 1. Reference wetland data and condition ranks

Appendix 2. Rapid assessment method stressor and land use checklist datasheets

Appendix 3. Rapidly assessed wetland data and condition ranks

Appendix 4. Photos of rapidly assessed wetlands by condition class

Appendix 5. Data for metrics used in predictive model of wetland condition by study area

Appendix 6. Maps of wetlands in each subbasin and HUC12s by condition class

Appendix 7. Data for metrics used in HUC12 condition model